ARIZONA DEPARTMENT OF ENVIRONMENTAL QUALITY

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Janice K. Brewer
Governor

Henry R. Darwin
Director

SUBMITTED VIA EMAIL AND FEDEX

MAY 13 2014

Mr. Jared Blumenfeld
Regional Administrator
U.S. Environmental Protection Agency, Region IX
Mail Code: ORA-1
75 Hawthorne Street
San Francisco, CA 94105

RE: Proposed Revision to the Arizona State Implementation Plan for Regional Haze

Dear ~~Mr. Blumenfeld~~ Jared,

Consistent with the provisions of Arizona Revised Statutes §§ 49-104, 49-106, 49-404, and 49-425 (Enclosure 1), and the Code of Federal Regulations (CFR) Title 40, §§ 51.102 through 51.104, the Arizona Department of Environmental Quality (ADEQ) hereby adopts and submits to the U.S. Environmental Protection Agency (EPA) the *"Arizona State Implementation Plan Revision to the Arizona Regional Haze Plan for Arizona Electric Power Cooperative, Incorporated – Apache Generating Station, April 2014"* as a revision to the Arizona State Implementation Plan (SIP).

On February 28, 2011, ADEQ adopted and submitted to EPA, *Arizona's State Implementation Plan for Regional Haze under Section 308 of the Federal Regional Haze Rule*. On December 5, 2012, EPA acted on elements of Arizona's Regional Haze SIP approving its SO_2 and PM_{10} Best Available Retrofit Technology (BART) determinations, disapproving its NO_X BART determination, and establishing a NO_X BART FIP for the three EGUs (77 FR 72511; effective January 4, 2013). This action disapproved a portion of the SIP for Arizona Electric Power Cooperative, Inc. (AEPCO) coal-fired BART units (Units 2 and 3) and promulgated a corresponding Federal Implementation Plan establishing control technology and emission limits for NO_X at AEPCO's Steam Units 2 and 3. This SIP revision proposes changes in the BART limits established for Units 1, 2 and 3 at the Apache Generating Station.

The SIP revision consists of copies of the authorizing statutes cited above (Enclosure 1). ADEQ is submitting the authorizing statutes in Enclosure 1 as supporting information. Enclosure 2 contains the SIP Completeness Checklist demonstrating that this submission satisfies the requirements of 40 C.F.R. Part 51 Appendix V. Enclosure 3 contains the SIP revisions as described in the table above (Enclosure 3). Two paper copies and an electronic exact duplicate of the hard copy on CD are included with this letter. If you have any questions, please contact me at (602) 771-2288.

Sincerely,

Eric C. Massey, Director
Air Quality Division

cc. Colleen McKaughan, EPA
Tom Webb, EPA

ENCLOSURE 1

Arizona Revised Statutes
§§ 49-104, 49-106, 49-404, and 49-425

(Submitted for informational purposes only.)

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49-104. Powers and duties of the department and director

A. The department shall:

1. Formulate policies, plans and programs to implement this title to protect the environment.

2. Stimulate and encourage all local, state, regional and federal governmental agencies and all private persons and enterprises that have similar and related objectives and purposes, cooperate with those agencies, persons and enterprises and correlate department plans, programs and operations with those of the agencies, persons and enterprises.

3. Conduct research on its own initiative or at the request of the governor, the legislature or state or local agencies pertaining to any department objectives.

4. Provide information and advice on request of any local, state or federal agencies and private persons and business enterprises on matters within the scope of the department.

5. Consult with and make recommendations to the governor and the legislature on all matters concerning department objectives.

6. Promote and coordinate the management of air resources to assure their protection, enhancement and balanced utilization consistent with the environmental policy of this state.

7. Promote and coordinate the protection and enhancement of the quality of water resources consistent with the environmental policy of this state.

8. Encourage industrial, commercial, residential and community development that maximizes environmental benefits and minimizes the effects of less desirable environmental conditions.

9. Assure the preservation and enhancement of natural beauty and man-made scenic qualities.

10. Provide for the prevention and abatement of all water and air pollution including that related to particulates, gases, dust, vapors, noise, radiation, odor, nutrients and heated liquids in accordance with article 3 of this chapter and chapters 2 and 3 of this title.

11. Promote and recommend methods for the recovery, recycling and reuse or, if recycling is not possible, the disposal of solid wastes consistent with sound health, scenic and environmental quality policies. Beginning in 2014, the department shall report annually on its revenues and expenditures relating to the solid and hazardous waste programs overseen or administered by the department.

12. Prevent pollution through the regulation of the storage, handling and transportation of solids, liquids and gases that may cause or contribute to pollution.

13. Promote the restoration and reclamation of degraded or despoiled areas and natural resources.

14. Assist the department of health services in recruiting and training state, local and district health department personnel.

15. Participate in the state civil defense program and develop the necessary organization and facilities to meet wartime or other disasters.

16. Cooperate with the Arizona-Mexico commission in the governor's office and with researchers at universities in this state to collect data and conduct projects in the United States and Mexico on issues that are within the scope of the department's duties and that relate to quality of life, trade and economic development in this state in a manner that will help the Arizona-Mexico commission to assess and enhance the economic competitiveness of this state and of the Arizona-Mexico region.

17. Unless specifically authorized by the legislature, ensure that state laws, rules, standards, permits, variances and orders are adopted and construed to be consistent with and no more stringent than the corresponding federal law that addresses the same subject matter. This provision shall not be construed to adversely affect standards adopted by an Indian tribe under federal law.

B. The department, through the director, shall:
1. Contract for the services of outside advisers, consultants and aides reasonably necessary or desirable to enable the department to adequately perform its duties.
2. Contract and incur obligations reasonably necessary or desirable within the general scope of department activities and operations to enable the department to adequately perform its duties.
3. Utilize any medium of communication, publication and exhibition when disseminating information, advertising and publicity in any field of its purposes, objectives or duties.
4. Adopt procedural rules that are necessary to implement the authority granted under this title, but that are not inconsistent with other provisions of this title.
5. Contract with other agencies, including laboratories, in furthering any department program.
6. Use monies, facilities or services to provide matching contributions under federal or other programs that further the objectives and programs of the department.
7. Accept gifts, grants, matching monies or direct payments from public or private agencies or private persons and enterprises for department services and publications and to conduct programs that are consistent with the general purposes and objectives of this chapter. Monies received pursuant to this paragraph shall be deposited in the department fund corresponding to the service, publication or program provided.
8. Provide for the examination of any premises if the director has reasonable cause to believe that a violation of any environmental law or rule exists or is being committed on the premises. The director shall give the owner or operator the opportunity for its representative to accompany the director on an examination of those premises. Within forty-five days after the date of the examination, the department shall provide to the owner or operator a copy of any report produced as a result of any examination of the premises.
9. Supervise sanitary engineering facilities and projects in this state, authority for which is vested in the department, and own or lease land on which sanitary engineering facilities are located, and operate the facilities, if the director determines that owning, leasing or operating is necessary for the public health, safety or welfare.
10. Adopt and enforce rules relating to approving design documents for constructing, improving and operating sanitary engineering and other facilities for disposing of solid, liquid or gaseous deleterious matter.
11. Define and prescribe reasonably necessary rules regarding the water supply, sewage disposal and garbage collection and disposal for subdivisions. The rules shall:
(a) Provide for minimum sanitary facilities to be installed in the subdivision and may require that water systems plan for future needs and be of adequate size and capacity to deliver specified minimum quantities of drinking water and to treat all sewage.
(b) Provide that the design documents showing or describing the water supply, sewage disposal and garbage collection facilities be submitted with a fee to the department for review and that no lots in any subdivision be offered for sale before compliance with the standards and rules has been demonstrated by approval of the design documents by the department.
12. Prescribe reasonably necessary measures to prevent pollution of water used in public or semipublic swimming pools and bathing places and to prevent deleterious conditions at such places. The rules shall prescribe minimum standards for the design of and for sanitary conditions at any public or semipublic swimming pool or bathing place and provide for abatement as public nuisances of premises and facilities that do not comply with the minimum standards. The rules shall be developed in cooperation with the director of the department of health services and shall be consistent with the rules adopted by the director of the department of health services pursuant to section 36-136, subsection H, paragraph 10.
13. Prescribe reasonable rules regarding sewage collection, treatment, disposal and reclamation systems to prevent the transmission of sewage borne or insect borne diseases. The rules shall:
(a) Prescribe minimum standards for the design of sewage collection systems and treatment, disposal and reclamation systems and for operating the systems.
(b) Provide for inspecting the premises, systems and installations and for abating as a public nuisance any collection system, process, treatment plant, disposal system or reclamation system that does not comply with the minimum standards.
(c) Require that design documents for all sewage collection systems, sewage collection system extensions, treatment plants, processes, devices, equipment, disposal systems, on-site wastewater treatment facilities and reclamation systems be submitted with a fee for review to the department and may require that the design documents anticipate and provide for future sewage treatment needs.
(d) Require that construction, reconstruction, installation or initiation of any sewage collection system, sewage collection system extension, treatment plant, process, device, equipment, disposal system, on-site wastewater treatment facility or reclamation system conform with applicable requirements.
14. Prescribe reasonably necessary rules regarding excreta storage, handling, treatment, transportation and disposal. The rules shall:
(a) Prescribe minimum standards for human excreta storage, handling, treatment, transportation and disposal and shall provide for inspection of premises, processes and vehicles and for abating as public nuisances any premises, processes or vehicles

that do not comply with the minimum standards.
(b) Provide that vehicles transporting human excreta from privies, septic tanks, cesspools and other treatment processes shall be licensed by the department subject to compliance with the rules. The department may require payment of a fee as a condition of licensure. After the effective date of this amendment to this section, the department shall establish by rule a fee as a condition of licensure, including a maximum fee. As part of the rule making process, there must be public notice and comment and a review of the rule by the joint legislative budget committee. After September 30, 2013, the department shall not increase that fee by rule without specific statutory authority for the increase. The fees shall be deposited, pursuant to sections 35-146 and 35-147, in the solid waste fee fund established by section 49-881.
15. Perform the responsibilities of implementing and maintaining a data automation management system to support the reporting requirements of title III of the superfund amendments and reauthorization act of 1986 (P.L. 99-499) and title 26, chapter 2, article 3.
16. Approve remediation levels pursuant to article 4 of this chapter.
17. Establish or revise fees by rule pursuant to the authority granted under title 44, chapter 9, article 8 and chapters 4 and 5 of this title for the department to adequately perform its duties. All fees shall be fairly assessed and impose the least burden and cost to the parties subject to the fees. In establishing or revising fees, the department shall base the fees on:
(a) The direct and indirect costs of the department's relevant duties, including employees salaries and benefits, professional and outside services, equipment, in-state travel and other necessary operational expenses directly related to issuing licenses as defined in title 41, chapter 6 and enforcing the requirements of the applicable regulatory program.
(b) The availability of other funds for the duties performed.
(c) The impact of the fees on the parties subject to the fees.
(d) The fees charged for similar duties performed by the department, other agencies and the private sector.
C. The department may:
1. Charge fees to cover the costs of all permits and inspections it performs to ensure compliance with rules adopted under section 49-203, except that state agencies are exempt from paying the fees. Monies collected pursuant to this subsection shall be deposited, pursuant to sections 35-146 and 35-147, in the water quality fee fund established by section 49-210.
2. Contract with private consultants for the purposes of assisting the department in reviewing applications for licenses, permits or other authorizations to determine whether an applicant meets the criteria for issuance of the license, permit or other authorization. If the department contracts with a consultant under this paragraph, an applicant may request that the department expedite the application review by requesting that the department use the services of the consultant and by agreeing to pay the department the costs of the consultant's services. Notwithstanding any other law, monies paid by applicants for expedited reviews pursuant to this paragraph are appropriated to the department for use in paying consultants for services.
D. The director may:
1. If the director has reasonable cause to believe that a violation of any environmental law or rule exists or is being committed, inspect any person or property in transit through this state and any vehicle in which the person or property is being transported and detain or disinfect the person, property or vehicle as reasonably necessary to protect the environment if a violation exists.
2. Authorize in writing any qualified officer or employee in the department to perform any act that the director is authorized or required to do by law.

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49-106. Statewide application of rules

The rules adopted by the department apply and shall be observed throughout this state, or as provided by their terms, and the appropriate local officer, council or board shall enforce them. This section does not limit the authority of local governing bodies to adopt ordinances and rules within their respective jurisdictions if those ordinances and rules do not conflict with state law and are equal to or more restrictive than the rules of the department, but this section does not grant local governing bodies any authority not otherwise provided by separate state law.

49-404. State implementation plan

A. The director shall maintain a state implementation plan that provides for implementation, maintenance and enforcement of national ambient air quality standards and protection of visibility as required by the clean air act.

B. The director may adopt rules that describe procedures for adoption of revisions to the state implementation plan.

C. The state implementation plan and all revisions adopted before September 30, 1992 remain in effect according to their terms, except to the extent otherwise provided by the clean air act, inconsistent with any provision of the clean air act, or revised by the administrator. No control requirement in effect, or required to be adopted by an order, settlement agreement or plan in effect, before the enactment of the clean air act in any area which is a nonattainment or maintenance area for any air pollutant may be modified after enactment in any manner unless the modification insures equivalent or greater emission reductions of the air pollutant. The director shall evaluate and adopt revisions to the plan in conformity with federal regulations and guidelines promulgated by the administrator for those purposes until the rules required by subsection B are effective.

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49-425. Rules; hearing

A. The director shall adopt such rules as he determines are necessary and feasible to reduce the release into the atmosphere of air contaminants originating within the territorial limits of the state or any portion thereof and shall adopt, modify, and amend reasonable standards for the quality of, and emissions into, the ambient air of the state for the prevention, control and abatement of air pollution. Additional standards shall be established for particulate matter emissions, sulfur dioxide emissions, and other air contaminant emissions determined to be necessary and feasible for the prevention, control and abatement of air pollution. In fixing such ambient air quality standards, emission standards or standards of performance, the director shall give consideration but shall not be limited to the relevant factors prescribed by the clean air act.

B. No rule may be enacted or amended except after the director first holds a public hearing after twenty days' notice of such hearing. The proposed rule, or any proposed amendment of a rule, shall be made available to the public at the time of notice of such hearing.

C. The department shall enforce the rules adopted by the director.

D. All rules enacted pursuant to this section shall be made available to the public at a reasonable charge upon request.

ENCLOSURE 2

State Implementation Plan Completeness Checklist

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STATE IMPLEMENTATION PLAN COMPLETENESS CHECKLIST

Submittal of

Arizona State Implementation Plan Revision to the Arizona Regional Haze Plan for Arizona Electric Power Cooperative, Incorporated – Apache Generating Station, April 2014

40 CFR Part 51, Appendix V, *Criteria for Determining the Completeness of Plan Submissions*, contains the "minimum criteria for determining whether a State Implementation Plan submitted for consideration by EPA is an official submission for purposes of review under §51.103," *Submission of plans, preliminary review of plans*. Appendix V requires the following to be included in plan submissions for review by EPA:

1. **"A formal letter of submittal from the Governor or his designee, requesting EPA approval of the plan or revision thereof (hereafter ''the plan'')."** [Appendix V, 2.1(a)]

   See cover letter.

2. **"Evidence that the State has adopted the plan in the State code or body of regulations; or issued the permit, order, consent agreement (hereafter ''document'') in final form. That evidence shall include the date of adoption or final issuance as well as the effective date of the plan, if different from the adoption/issuance date."** [Appendix V, 2.1(b)]

   See cover letter.

3. **"Evidence that the State has the necessary legal authority under State law to adopt and implement the plan."** [Appendix V, 2.1(c)]

   See Enclosure 1.

4. **"A copy of the actual regulation, or document submitted for approval and incorporation by reference into the plan, including indication of the changes made (such as, redline/strikethrough) to the existing approved plan, where applicable ..."** [Appendix V, 2.1(d)]

   See Enclosure 3.

5. **"Evidence that the State followed all of the procedural requirements of the State's laws and constitution in conducting and completing the adoption/issuance of the plan."** [Appendix V, 2.1(e)]

   See cover letter and Enclosure 3, Appendix C – Public Process Documentation for the Arizona State Implementation Plan Revision to the Arizona Regional Haze Plan for Arizona Electric Power Cooperative, Incorporated – Apache Generating Station, April 2014.

6. **"Evidence that public notice was given of the proposed change consistent with procedures approved by EPA, including the date of publication of such notice."** [Appendix V, 2.1(f)]

   See Enclosure 3, Appendix C.

7. **"Certification that public hearing(s) were held in accordance with the information provided in the public notice and the State's laws and constitution, if applicable and consistent with the public hearing requirements in 40 CFR 51.102."** [Appendix V, 2.1(g)]

   See Enclosure 3, Appendix C.

8. **"Compilation of public comments and the State's response thereto."** [Appendix V, 2.1(h)]

   See Enclosure 3, Appendix C.

9. **"Identification of all regulated pollutants affected by the plan."** [Appendix V, 2.2(a)]

   Sulfur dioxide (SO_2), Oxides of Nitrogen (NO_X), Organic Carbon (OC), Elemental Carbon (EC), Fine Soil, Coarse Mass, and Sea Salt

10. **"Identification of the locations of affected sources including the EPA attainment/nonattainment designation of the locations and the status of the attainment plan for the affected areas(s)."** [Appendix V, 2.2 (b)]

    Not applicable for current submission (Arizona State Implementation Plan Revision to the Arizona Regional Haze Plan for Arizona Electric Power Cooperative, Incorporated – Apache Generating Station, April 2014). See Chapters 2, 4, and 6 of Arizona's Regional Haze SIP Submitted February 28, 2011.

11. **"Quantification of the changes in plan allowable emissions from the affected sources; estimates of changes in current actual emissions from affected sources or, where appropriate, quantification of changes in actual emissions from affected sources through calculations of the differences between certain baseline levels and allowable emissions anticipated as a result of the revision."** [Appendix V, 2.2(c)]

    Not applicable.

12. **"The State's demonstration that the national ambient air quality standards, prevention of significant deterioration increments, reasonable further progress demonstration, and visibility, as applicable, are protected if the plan is approved and implemented. For all requests to redesignate an area to attainment for a national primary ambient air quality standard, under section 107 of the Act, a revision must be submitted to provide for the maintenance of the national primary ambient air quality standards for at least 10 years as required by section 175A of the Act."** [Appendix V, 2.2(d)]

    See Enclosure 3, Arizona State Implementation Plan Revision to the Arizona Regional Haze Plan for Arizona Electric Power Cooperative, Incorporated – Apache Generating Station, April 2014. See Chapters 12 of Arizona's Regional Haze SIP submitted on February 28, 2011, and Chapter 11 of Arizona's Regional Haze SIP submitted on May 2013.

13. **"Modeling information required to support the proposed revision, including input data, output data, models used, justification of model selections, ambient monitoring data used, meteorological data used, justification for use of offsite data (where used), modes of models used, assumptions, and other information relevant to the determination of adequacy of the modeling analysis."** [Appendix V, 2.2(e)]

    See Enclosure 3, Arizona State Implementation Plan Revision to the Arizona Regional Haze Plan for Arizona Electric Power Cooperative, Incorporated – Apache Generating Station, April 2014.

14. **"Evidence, where necessary, that emission limitations are based on continuous emission reduction technology."** [Appendix V, 2.2(f)]

    Not applicable.

15. **"Evidence that the plan contains emission limitations, work practice standards and recordkeeping/reporting requirements, where necessary, to ensure emission levels."** [Appendix V, 2.2(g)]

    Not applicable.

16. **"Compliance/enforcement strategies, including how compliance will be determined in practice."** [Appendix V, 2.2(h)]

    See Enclosure 3, Arizona State Implementation Plan Revision to the Arizona Regional Haze Plan for Arizona Electric Power Cooperative, Incorporated – Apache Generating Station, April 2014.

17. **"Special economic and technological justifications required by any applicable EPA policies, or an explanation of why such justifications are not necessary."** [Appendix V, 2.2(i)]

    No known deviation from U.S. EPA policy.

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ENCLOSURE 3

Arizona State Implementation Plan Revision

Arizona State Implementation Plan
Under Section 308 of the Federal Regional Haze Rule
May 2013

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ADEQ
Arizona Department of Environmental Quality

FINAL

Arizona State Implementation Plan

Revision to the Arizona Regional Haze Plan for Arizona Electric Power Cooperative, Incorporated Apache Generating Station

Air Quality Division
April 2014

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

1.0 INTRODUCTION AND BACKGROUND

1.1 Introduction

This revision to the Arizona State Implementation Plan (SIP) for Regional Haze incorporates recent analysis showing that the new control strategy proposed by the Arizona Electric Power Cooperative (AEPCO) Apache Generating Station is "better-than-BART." The revision is intended to replace the Federal Implementation Plan (FIP) promulgated by the U.S. Environmental Protection Agency (EPA) and revise elements of Arizona's Regional Haze SIP pertaining to AEPCO Apache Generating Station.

As required, this document includes a description of the revised components in EPA's FIP and Arizona's Regional Haze SIP and a demonstration that this revision will not interfere with the ability of the area to attain/maintain the National Ambient Air Quality Standards (NAAQS) or any other requirement of the Clean Air Act (CAA).

1.2 Regulatory Background

On February 28, 2011, the Arizona Department of Environmental Quality (ADEQ) submitted a Regional Haze SIP under 40 CFR § 41.308 to EPA, which became complete as a matter of law. Several parties, including the Sierra Club and Grand Canyon Trust, filed a complaint in August 2011, for declaratory and injunctive relief in the D.C. Circuit, seeking to compel EPA to perform a nondiscretionary duty by not approving Regional Haze SIPs, including Arizona, or promulgating a FIP.

On November 9, 2011, EPA announced its intention to enter into a Consent Decree with the plaintiffs, which was granted on March 30, 2012. The Decree included a court-ordered schedule to review and act on more than 40 State Regional Haze plans. The scheduled deadlines were administratively extended in May 2012, which allowed EPA to separate their actions on the electric generating units (EGUs) Best Available Retrofit Technology (BART) and the remaining components of the SIP.

EPA and the plaintiffs submitted a motion on June 14, 2012, to extend the deadlines for both actions as required by the Consent Decree. Even though Arizona opposed this motion, the D.C. Circuit Court upheld the revised consent decree and set dates for proposed action on the EGU BART portion of Arizona's SIP by July 12, 2012, and remaining portions of the SIP by December 8, 2012. Final action on the EGU BART portion of the SIP was required on or before November 15, 2012 and the remainder of the SIP on or before July 15, 2013.

On July 20, 2012, EPA published a notice of proposed rule making (NPRM) that proposed partial approval and partial disapproval of Arizona's EGU BART determinations and proposed an EPA FIP (77 FR 42834). This proposed rule was finalized on December 5, 2012, when EPA published a notice of final rule making (NFRM) approving Arizona's SO_2 and PM_{10} BART determination, disapproving its NO_X BART determination, and establishing a NO_X BART FIP for the three EGUs (77 FR 72511; effective January 4, 2013).

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2.0 REVISION TO ARIZONA'S REGIONAL HAZE PROGRAM – 2014

2.1 Summary of Control Strategy Changes at Arizona Electric Power Cooperative, Inc. – Apache Generating Station

Effective January 4, 2013, EPA approved a portion of Arizona's Regional Haze SIP for AEPCO's Apache Generating Station BART eligible units, establishing emissions limits for NO_X, PM_{10}, and SO_2 at Unit 1 and PM_{10} and SO_2 at Units 2 and 3. In the same action, EPA disapproved a portion of the SIP for AEPCO's coal-fired BART units (Units 2 and 3) and promulgated a corresponding FIP which establishes control technology and emission limits for NO_X at AEPCO's Steam Units 2 and 3. EPA also disapproved the compliance schedules and requirements for equipment maintenance and operation, including monitoring, record keeping, and reporting at all the BART units since these were not included in the SIP. On February 2, 2013, AEPCO petitioned the EPA for administrative reconsideration of the final rule and proposed alternatives to the FIP that would achieve "better than BART" levels of visibility improvement.

This SIP revision proposes changes, subject to EPA approval, in the "best available retrofit technology" (BART) limits established for Units 1, 2 and 3 at the Apache Generating Station. For Steam Unit 2 (ST2), the SIP revision replaces a numeric limit based upon coal combustion and selective catalytic reduction (SCR) with a limit based upon conversion to natural gas combustion. For Steam Unit 3, the SIP revision replaces a numeric limit based upon coal combustion and SCR with one based upon coal combustion and selective non-catalytic reduction (SNCR). Additionally, this SIP revision corrects an error in the emission limits for Steam Unit 1 (ST1) during combined cycle operation and clarifies when the BART emission limits apply to ST1 in stand alone operation and when it applies to ST1 and Gas Turbine 1 (GT1) in combined cycle mode.

The new control strategies and compliance methods are incorporated as "Attachment E" to the facility's Operating Permit (Significant Permit Revision No. 59195 to Operating Permit No. 55412). "Attachment E" of the amended permit is included as a component of the revised SIP and is included in Appendix B.

Sections 2.2 and 2.3 of this SIP revision discuss in greater detail the "better than BART" outcome and visibility improvement due to the new control strategies.

Control Strategy Description

Steam Unit 1

This SIP revision amends the emission limits in the 2011 SIP by incorporating a new NO_X emission limit of 0.10 lb/MMBtu for the combined cycle operation of ST1 with GT1. However, to ensure a "better than BART" outcome for the NO_X limit associated with ST1, a 1205 lb/day limit, based on a 30 calendar day average, is being established for ST1 operating in standalone mode or in combined cycle mode with GT1.

Steam Unit 2

As part of this revision, ST2 will be converted from a primarily coal-fired unit to a unit that combusts pipeline quality natural gas effective December 5, 2017. Converting ST2 to natural gas results in reduced emissions of SO_2 compared to the current limit in the SIP, from 0.15 lb/MMBtu to 0.00064 lb/MMBtu, based on a 30 boiler operating day average. The new control strategy also reduces PM_{10} emissions from 0.03 lb/MMBtu to 0.01 lb/MMBtu effective December 5, 2017, and then to 0.008 lb/MMBtu, on a 30 boiler operating day average effective December 5, 2018. NO_X emissions increase from 0.07 lb/MMBtu to 0.085 lb/MMBtu, on a 30 boiler operating day average. The revised

controls authorize AEPCO to use coal as a fuel in ST2 in the event of a natural gas disruption such as a pipeline freeze-up or break.

Steam Unit 3

This SIP revision changes the control technology for ST3 from SCR to SNCR with an effective date of December 5, 2017. Additionally, the NO_x emission limit will be revised from 0.07 lb/MMBtu to 0.23 lb/MMBtu, based on a 30 boiler operating day average.

Table 1.1 provides a comparison of emissions limits and compliance dates between the FIP and 2011 SIP with the current 2014 SIP revision.

Table 1.1 – Summary of Proposed Changes to Emissions Limits and Compliance Dates for AEPCO (lb/MMBtu)

Source	NO_X		PM_{10}		SO_2	
	2011 SIP/FIP	2014 SIP	2011 SIP	2014 SIP	2011 SIP	2014 SIP
ST1/GT1	0.056 (ST1 stand alone or ST1/GT1 combined cycle), 12/5/2017 [SIP limit][1]	0.056 (ST1 stand alone), 12/5/2017; 0.10 (ST1/GT1 combined cycle), 12/5/2017	0.0075, June 5, 2013	No change	0.00064, June 5, 2013	No change
ST2	0.070 (across two units), 12/5/2017 [FIP limit]	0.085*, 12/5/2017	0.03, 12/5/2016	0.01, 12/5/2017 then 0.008, 12/5/2018	0.15, 12/5/2016	0.00064, 12/5/2017
ST3		0.23*, 12/5/2017	0.03, 12/5/2016	No change	0.15, 12/5/2016	No change

*Units ST2 and ST3also have a combined average limit option for NO_X.

2.2 Technical Analysis of Arizona Electric Power Cooperative, Inc. – Apache Generating Station Proposed Alternative

EPA's NFRM published on December 5, 2012, disapproved Arizona's BART determination and promulgated a FIP for NO_X at three facilities, including AEPCO's Apache Generating Station Units 1, 2, and 3 (77 FR 72511). On February 2, 2013, AEPCO petitioned EPA for administrative reconsideration of the proposed FIP limits and subsequently met to discuss the petition where AEPCO presented an alternative to EPA's BART FIP. On May 29, 2013, AEPCO submitted supplementary information to EPA that provided additional technical information to its original petition for reconsideration. AEPCO also provided their alternative and technical information to ADEQ.

To provide evidence of the effectiveness of AEPCO's alternative, ADEQ conducted a technical analysis to estimate emissions under uncontrolled and controlled modeling scenarios in order to evaluate the

[1] A May 2013 SIP revision clarified that "…the proposed BART limit [of 0.056 lb/MMBtu] for ST1 will apply when ST1 operates alone or if ST1 and GT1 are operated as a combined cycle operation. The proposed BART limit does not apply to (a) GT1 in stand-alone simple cycle operation or (b) ST1/GT1 when ST1 burners are shut off and ST1 is not producing electricity." [78 FR 46142; July 30, 2013]

control technologies and the affect on nitrogen oxides (NO_X), sulfur dioxide (SO_2), and total particulate matter (PM) emissions. The detailed analysis is presented in ADEQ's Technical Support Document (TSD), which can be found in Appendix A. Table 1.2 shows the controlled facility-wide annual emissions.

Table 1.2 – Controlled Facility-Wide Annual Emissions (tons per year)

Control	Combined NO_X	Combined SO_2	Combined PM
ADEQ BART Determination (2011 Regional Haze SIP)	4,159	2,013	403
EPA FIP	939	2,013	403
AEPCO Alternative	2,122	1,056	262

Source: Arizona Department of Environmental Quality (2013). AEPCO Apache Generating Station BART Alternative Control Review Technical Support Document, December 17, 2013

Using the emission estimates, ADEQ performed several different comparisons of the modeling scenarios, which are described in greater detail in the TSD (Appendix A). The comparisons showing the effectiveness of the AEPCO alternative are provided in Table 1.3. The alternative was compared with ADEQ's original BART determination for AEPCO and EPA's FIP.

The modeling comparisons demonstrate that the AEPCO alternative provides for greater emissions reductions than ADEQ's BART determination (Table 1.3). The alternative control not only shows higher NO_X reductions in comparison to ADEQ BART, it also has higher reductions in both SO_2 and PM. EPA's FIP also shows greater NO_X reductions compared to ADEQ's BART determination. When compared to EPA's FIP, the AEPCO alternative is estimated to have higher NO_X emissions; however, it shows more reductions in SO_2 and PM (Table 1.3). This difference becomes relevant when looking at the overall impact of and estimated emissions for both control technologies, which is discussed in Section 2.4.

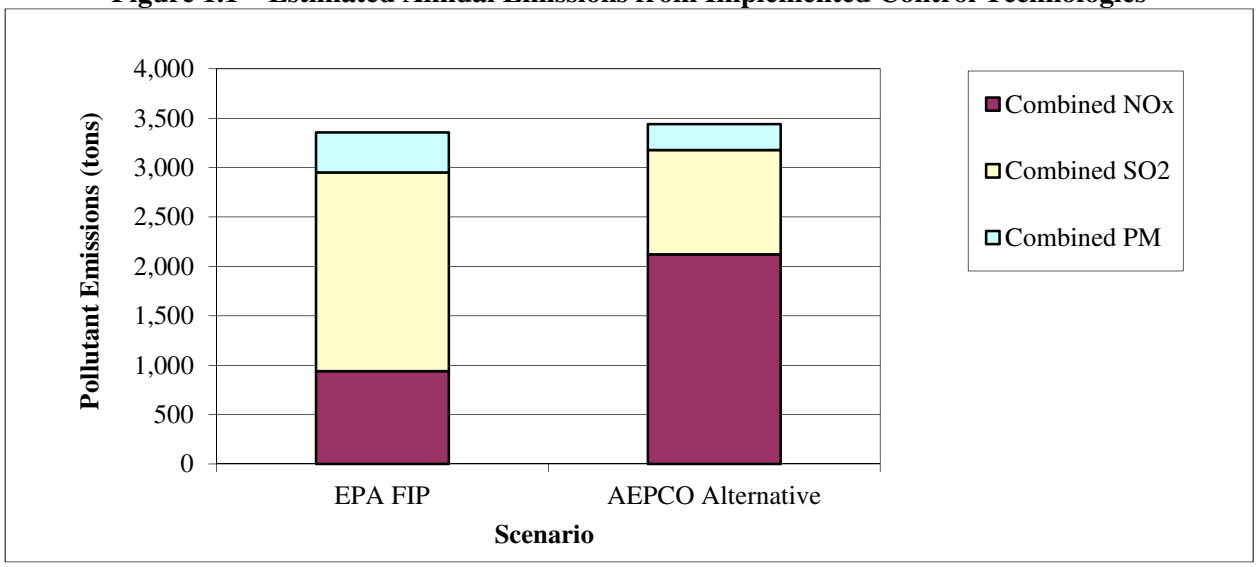
Table 1.3 – Comparison of Control Technologies and Annual Emission Reductions (tons per year)

Scenario Comparison	NO_X	SO_2	PM
EPA FIP to ADEQ BART	-3220	0	0
AEPCO Alt. to ADEQ BART	-2037	-957	-141
AEPCO Alt. to EPA FIP	1183	-957	-141

Source: Arizona Department of Environmental Quality (2013). AEPCO Apache Generating Station BART Alternative Control Review Technical Support Document, December 17, 2013

The data presented in Table 1.1 show that facility-wide estimated emissions vary by pollutant for each control scenario. The estimated emissions from ADEQ BART exceeds both EPA's FIP and AEPCO's alternative (Table 1.1). EPA's FIP and AEPCO's alternative show comparable reductions in total facility-wide emissions (Figure 1.1). Comparing the AEPCO alternative to the EPA FIP also shows that reductions from SCR are primarily from NO_X control; however, the alternative control has greater reductions in SO_2 and PM.

Figure 1.1 – Estimated Annual Emissions from Implemented Control Technologies



The overall contribution of individual pollutants is an important factor in determining if AEPCO's proposed controls are "Better-than-BART." Overall contribution coupled with an analysis of visibility impacts on Class I areas is also an important factor to determine if a control technology is "Better-than-BART."

In 2013, ADEQ submitted a Regional Haze SIP revision to EPA with an updated 2008 emissions inventory. State-wide emissions of SO_2 were 84,783 tons and NO_X emissions were 290,344 tons.[2] Of the SO_2 emissions, 93 percent were from point sources while only 21 percent of NO_X emissions were from point sources. In order to compare emissions to visibility, ADEQ reviewed IMPROVE monitoring data from Class I areas impacted by emissions from Apache Generating Station between 2000 and 2010. Although statewide NO_X emissions were over three and a-half times higher than SO_2 emissions, visibility impairment due to SO_2 was greater than NO_X.[3] On 20 percent best days, 20 percent worst days, and all days, visibility impairment due to SO_2 was 3.6, 3.6, and 3.9 times, respectively, greater than impairment from NO_X.[4]

AEPCO performed modeling runs for ADEQ's BART determination, EPA's FIP, and the proposed alternative. All of the runs used 2013 CALPUFF modeling.[5] ADEQ compared the modeling to estimate visibility impacts from the control scenarios at Arizona Class I areas. Table 1.4 shows the 98th percentile annual average in deciviews for 2001 to 2003. Visibility impacts vary among the Class I areas, likely due to proximity and spatial orientation to the facility; however, the AEPCO alternative modeled the best visibility at most of the Class I areas and overall visibility in comparison to ADEQ BART and EPA's FIP (Table 1.4).

[2] Arizona Department of Environmental Quality (2013). *Arizona State Implementation Plan Revision: Regional Haze Under Section 308 of the Federal Regional Haze Rule*.
[3] Arizona Department of Environmental Quality (2013). *AEPCO Apache Generating Station BART Alternative Control Review – Technical Support Document, December 17, 2013.*
[4] Ibid.
[5] Ibid.

Table 1.4 – AEPCO Modeled Facility-Wide Visibility Impacts on Class I Areas (in deciviews)			
Site	**ADEQ BART**	**EPA FIP**	**AEPCO Alternative**
	Avg 98th	**Avg 98th**	**Avg 98th**
Chiricahua NM	3.328	1.978	1.882
Chiricahua WA	3.418	1.886	1.851
Galiuro WA	2.178	1.208	1.111
Gila WA	0.642	0.262	0.287
Mazatzal WA	0.266	0.156	0.126
Mt. Baldy WA	0.269	0.109	0.112
Saguaro NP	2.502	1.421	1.346
Sierra Ancha WA	0.289	0.153	0.130
Superstition WA	0.596	0.313	0.275
Average	**1.499**	**0.832**	**0.791**
Source: Arizona Department of Environmental Quality (2013). AEPCO Apache Generating Station BART Alternative Control Review Technical Support Document, December 17, 2013			

2.3 Conclusion of ADEQ Technical Analysis

ADEQ's technical analysis of AEPCO's modeling that was submitted to EPA as an alternative control technology to EPA's FIP demonstrates that the proposed alternative is "better-than-BART." This assessment is based on total estimated emissions reductions, reductions in visibility impairing pollutants, IMPROVE monitoring data, and improvements in modeled facility-wide visibility impacts from Apache Generating Station at Arizona Class I areas.

The analysis of AEPCO's modeling shows that the proposed alternative provides for fewer annual emissions than ADEQ's BART determination. The alternative control has comparable annual emissions to EPA's FIP, with differences in the relative contribution of individual pollutants. AEPCO's alternative provides a 141 ton reduction in emissions of particulate matter (PM) when compared to EPA's FIP. Implementation of the control technologies also produce different estimated annual emissions for NO_X and SO_2. The analysis shows that EPA's FIP provides for greater reductions of NO_X, whereas the alternative provides for greater reductions in SO_2.

The impact of the difference in the relative contribution of NO_X and SO_2 is highlighted when compared with monitoring data. ADEQ's review of IMPROVE monitoring data points out that even though NO_X emissions exceed SO_2 emissions, visibility impairment due to SO_2 is much greater than impairment from NO_X. The difference in impairment points out that increased reductions in emissions of SO_2 will likely result in improved visibility.

AEPCO's analysis of modeled facility-wide impacts demonstrates that the alternative technology results in improved visibility at individual Class I areas. Of the control technologies, AEPCO's analysis shows the most improved visibility over the other technologies, including EPA's FIP.

Based on the reasoning outline above, ADEQ asserts that AEPCO's alternative technology is "better-than-BART" as well as better than EPA's FIP.

2.4 Federal Implementation Plan & State Implementation Plan Elements Supplanted/Replaced by Arizona Electric Power Cooperative, Inc. – Apache Generating Station Proposed Control Technology Alternative & Permit Revisions

This SIP revision replaces EPA's BART FIP for AEPCO Apache Generating Station and revises elements in Arizona's Regional Haze SIP pertaining to AEPCO. This SIP revision proposes changes in the BART limits established for Units 1, 2 and 3 at the Apache Generating Station. The changes, as contained in the revision to AEPCO's air quality permit (see Chapter 3 and Appendix B), also include appropriate compliance methods for all BART units.

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3.0 DEMONSTRATING NONINTERFERENCE UNDER CLEAN AIR ACT SECTION 110(l)

As described in Chapters 1 and 2 above, this revision to Arizona's Regional Haze program incorporates changes to the Best Available Retrofit Technology (BART) determination and control strategies for the Arizona Electric Power Cooperative, Inc., Apache Generating Station (AEPCO). The revised control strategies are intended to replace those contained in Arizona's February 28, 2011, Regional Haze State Implementation Plan (SIP) and the Environmental Protection Agency's (EPA's) January 4, 2013, Federal Implementation Plan (FIP) (77 FR 72512; December 5, 2012). Revisions to a submitted SIP must not interfere with the requirements of the Clean Air Act (CAA) as described in CAA Section 110(l):

> "(l) Plan Revisions—Each revision to an implementation plan submitted by a State under this Act shall be adopted by such State after reasonable notice and public hearing. The Administrator shall not approve a revision of a plan if the revision would interfere with any applicable requirement concerning attainment and reasonable further progress (as defined in section 171), or any other applicable requirement of this Act."

The information in Section 3.1 and 3.2 below evaluate emission changes due to the revised control strategies and demonstrates that the current SIP revision will not interfere with the ability of the program area to attain and maintain the National Ambient Air Quality Standards (NAAQS) or any other requirement of the Clean Air Act.

3.1 Demonstrating Noninterference with Attainment of the National Ambient Air Quality Standards under Clean Air Act Section 110(l)

Revisions to the SIP must not interfere with any applicable requirement concerning attainment of the air quality standards or reasonable further progress towards attaining those standards. An evaluation of the impact of the proposed control strategy for the AEPCO facility on air quality shows that the change will not interfere with attainment or maintenance of the NAAQS.

Title I of the CAA requires EPA to set National Ambient Air Quality Standards for those pollutants that are considered harmful to public health or the environment. Accordingly, the air quality standards are divided into two types: primary and secondary. Primary standards are designed for the protection of public health and secondary standards are intended to protect public welfare, such as decreased visibility and damage to animals, crops, vegetation, and buildings.[6] To date, EPA has established standards for six common air pollutants referred to as criteria pollutants: carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2), ground-level ozone O_3, particulate matter (PM), and sulfur dioxide (SO_2). EPA is also required to periodically evaluate those standards and revise them if scientific analyses indicate new standards would be more protective of public health and welfare.

Under Clean Air Act Section 107(d), states must make recommendations and EPA must designate areas that meet (attainment), cannot be classified, or do not meet (nonattainment) new or revised National Ambient Air Quality Standards. Based on air quality data and other factors, EPA designates areas as "nonattainment" if those areas are found to violate or contribute to violations of a NAAQS. Reasonable further progress is defined in Section 171 of the CAA as "… such annual incremental reductions in emissions of the relevant air pollutant … for the purpose of ensuring attainment of the applicable national ambient air quality standard ..."

The AEPCO facility is located in north central Cochise County. The area is designated as attainment or

[6] U.S. Environmental Protection Agency, http://www.epa.gov/air/criteria.html. Date Accessed: October 29, 2013.

unclassifiable for CO, Pb, NO_2, O_3, $PM_{2.5}$ (1997 and 2006 NAAQS), PM_{10}, and SO_2 (1971 NAAQS). Although designations have not yet been made for the 2012 $PM_{2.5}$ and 2010 SO_2 NAAQS, the area was recommended as attainment or unclassifiable for both pollutants under CAA Section 107(d)(1)(A).[7] Table 1.5 shows the current designation status of the area for each criteria pollutant listed in 40 CFR 81.303.[8]

Table 1.5 – Attainment Status for North Central Cochise County

Pollutant	Primary/Secondary	Averaging Time	Designation
Carbon Monoxide	Primary (1971)	8-hour	Nonclassifiable/Attainment
		1-hour	Nonclassifiable/Attainment
Lead	Primary and Secondary (2008)	Rolling 3 Month Average	Unclassifiable/Attainment
Nitrogen Dioxide	Primary (2010)	1-hour	Unclassifiable/Attainment
	Primary and Secondary (1971)	Annual	Cannot be classified or better than national standards
Ozone	Primary and Secondary (2008)	8-hour	Unclassifiable/Attainment
$PM_{2.5}$	Primary (2012)	Annual	Not yet designated
	Secondary (1997)	Annual	Unclassifiable/Attainment
	Primary and Secondary (2006)	24-hour	Unclassifiable/Attainment
PM_{10}	Primary and Secondary (1987)	24-hour	Unclassifiable
Sulfur Dioxide	Primary (2010)	1-hour	Not yet designated
	Primary (1971)	24-hour	Better than national standards
	Primary (1971)	Annual	Better than national standards
	Secondary (1971)	3-hour	Better than national standards

Source: 40 CFR 81.303

Table 1.6 contains a comparison of emissions changes due to the 2011 SIP, EPA FIP, and revised 2014 SIP (AEPCO proposal). Emissions (potential to emit) are provided for the BART eligible units ST2 and ST3 for all criteria pollutants including the ozone precursor volatile organic compounds (VOC).

Table 1.6 – Comparison of Emissions from EPA FIP and AEPCO Proposal (2014 SIP) (tons/year)

Control Strategy/ Emissions Unit	CO	Pb	NOx	VOC	$PM_{2.5}$	PM_{10}	SO_2
FIP ST2	710.5	4.4	603.6	46.5	165.6	258.7	1,293.4
FIP ST3	682.0	4.2	579.3	44.6	158.9	248.3	1,241.4

[7] See http://www.azdeq.gov/environ/air/plan/pm2.5.html and http://www.azdeq.gov/environ/air/plan/so2.html .
[8] 40 CFR 81.303, July 1, 2013, edition.

Table 1.6 – Comparison of Emissions from EPA FIP and AEPCO Proposal (2014 SIP) (tons/year)							
FIP Combined	1,392.5	8.6	1,182.9	91.1	324.5	507.0	2,534.8
2014 SIP ST2	710.5	0.0	732.9	46.5	69.0	69.0	5.5
2014 SIP ST3	682.0	4.2	1,862.2	44.6	158.9	248.3	1,241.4
2014 SIP Combined	1,392.5	4.2	2,595.1	91.1	227.9	317.3	1,247.0

Source: Data for all pollutants were obtained from the January 23, 2014, email and attached spreadsheet from Eric Hiser to Trevor Baggiore. Emissions in this Table differ from elsewhere in this document and represent emissions levels for the most polluting permissible fuel for each control regime. Estimates are based on maximum heat rates and conservative annual capacity factors. The data contained in ADEQ's December 17, 2013, *AEPCO Apache Generating Station BART Alternative Control Review Technical Support Document,* are an average annual emissions inventory based on 2008-2010 continuous emissions monitor (CEMs) heat rates and annual average days of operation.

Emissions for most pollutants are reduced under the AEPCO proposal. Because the area is designated attainment or unclassifiable for the criteria pollutants, no nonattainment or maintenance SIPs exist that might rely on emissions reductions at AEPCO to ensure continued attainment of the NAAQS. As noted, designations for the 2012 $PM_{2.5}$ and 2010 SO_2 NAAQS have not yet been completed in this area. Overall, emissions for these pollutants are lower with the AEPCO proposal when compared to the FIP and the change does not impact Arizona's designation recommendations for either standard.

The revised control strategy for ST1 adds a new NO_X emission limit for the combined cycle operation of ST1 with GT1 and provides for a slightly higher short term limit under this operating scenario. A daily emissions cap of 1,205 lb/day is also added for ST1 when operating in standalone mode or in combined cycle mode with GT1 to ensure there is no annual emissions increase due to this change.[9]

Although NOx emissions increase for the 2014 SIP revision when compared to the FIP, overall NOx emissions are reduced significantly from pre-control 2007 baseline levels. For ST2 and ST3 combined 2007 baseline emissions are 6,823.9 tons. Under the 2014 SIP strategy (conversion to natural gas at ST2 and use of SNCR at ST3), NOx emissions are estimated at 2,595.1 tons per year, providing a reduction of 4,228.8 tons per year from baseline. There is no annual emission change due to the change to the ST1/GT1 limit.

3.2 Demonstrating Noninterference with Other Applicable Requirements under Clean Air Act Section 110(l)

Other CAA requirements applicable to AEPCO are the visibility protection requirements for Federal Class I areas under Section 169A and air toxics under Section 112.

[9] The 1,205 lb/day cap for NOX (30 calendar day rolling average) is a proposed daily limit to ensure that the maximum impacts from ST1 and GT1 are always less than the original BART limit, and consequently raising the emission limit of ST1 and GT1 in combined cycle mode is not considered to be a relaxation of the SIP. The calculation is derived as follows using the existing emission limit of 0.056 lb/MMBtu (the original NOX emission limit required for ST1 and GT1 in combined cycle mode), and a conservative estimate of the heat rate (10,985 Btu/kWhr) over the primary operating range of ST1 and GT1 in combined cycle operation. The 82 MW in the equation below is taken from AEPCO's contract delivery obligation to its members:

0.056 lb/MMBtu * 1 MMBtu/1,000,000 Btu * 82 MW/hr * 1000 kW/1 MW * 10,985 Btu/kWh * 24 hrs/day = 1,210.6 lb/day

3.2.1 Regional Haze Program

In general, the visibility protection program requires a strategy for making reasonable progress toward meeting the national goal of restoring visibility at class I Federal areas to natural conditions. The AEPCO proposal shows an overall reduction in Regional Haze pollutants and the same or better improvement in visibility at Class I areas when compared to the FIP. A more detailed description of visibility impacts due to the AEPCO revision is included in Chapters 1 and 2.

The CAA requires that the installation and operation of BART be as expeditious as practicable but in no event later than five years after the date of approval of a SIP or promulgation of a FIP. The compliance dates for the emissions limits described in Section 2.1 of this document are within five years of the publication date of EPA's FIP, therefore, the revised control strategy for AEPCO will not interfere with the BART compliance requirement of the CAA.

Additionally, Arizona's Regional Haze SIP included a long-term strategy for making reasonable progress toward restoring visibility at Class I areas to natural conditions by 2064. The CAA defines long-term as 10 to 15 years and Arizona's long-term strategy, submitted to EPA in 2011, includes emission reductions and visibility improvements that are expected by 2018. Because the current SIP compliance dates occur within the period of the first long-term strategy, i.e., prior to 2018, the revised control strategy for AEPCO will not interfere with the long-term strategy requirement of the CAA.

3.2.2 Air Toxics

There are no ambient air quality standards for air toxics, therefore, compliance with applicable maximum achievable control technology (MACT) standards under CAA Section 112 demonstrate noninterference for air toxics in the program area. EPA developed standards for mercury and other air toxics for coal- and oil-fired electric generating units, effective April 2015. Facilities have three years from the effective date to implement the rule.

AEPCO proposes to convert ST2 from coal to pipeline natural gas. The reduction in air toxics by switching from coal to pipeline natural gas is significant, on the order of 1-2 magnitudes for toxic metals such as Mercury, Cadmium and Chromium. AEPCO's proposal of using SNCR rather than SCR for Steam Turbine 3 will result in reduced sulfuric acid gas formation which is common in SCR units due to the catalysts.

Arizona thus concludes that this SIP revision will not interfere with any applicable air toxics requirements of the CAA.

4.0 CONCLUSION

This SIP revision replaces EPA's BART FIP for AEPCO Apache Generating Station and revises elements in Arizona's Regional Haze SIP pertaining to AEPCO. It demonstrates that the proposed control technology will not interfere with attainment of the NAAQS or any other requirement under the CAA 110(l).

APPENDIX A

Arizona Electric Power Cooperative Inc.
Apache Generating Station
BART Alternative Control Review
Technical Support Document

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AEPCO Apache Generating Station BART Alternative Control Review Technical Support Document

April 15th, 2014

Arizona Department of Environmental Quality

TABLE OF CONTENT

TABLE OF FIGURES

TABLE OF TABLES

Demonstration that the Arizona Electric Power Cooperative Proposed Alternative Control Technology Satisfies the "Better-than-BART" Test as Proposed in the Guidelines for Making BART Determinations

I. Introduction

This document provides technical support for the revision and supplementation of the Regional Haze Rule section of the Arizona State Implementation Plan (SIP), originally submitted to the United States Environmental Protection Agency (EPA) on March 2nd, 2011[1]. On May 29th, 2013 the Arizona Electric Power Cooperative (AEPCO) petitioned the EPA for administrative reconsideration of proposed Best Available Retrofit Technology (BART) for the Apache Generating Station's (Apache) Steam Units 2 and 3, and for clarification on certain questions regarding the application of BART to Steam Unit 1 in EPA correspondence with the Arizona utilities. AEPCO presented EPA and the Arizona Department of Environmental Quality (ADEQ) with alternative pollution control technologies to address the visibility impacts of the two BART eligible units 2 and 3 on Class I areas near the facility in accordance with EPA's Regional Haze Rule 40 CFR § 308. These control technologies would incorporate additional emissions limits at Steam Unit 1 (ST1), a fuel switch at Steam Turbine 2 (ST2) from Coal to Pipeline Natural Gas (PNG), and the implementation of Selective Non-catalytic Reduction (SNCR) at Steam Unit 3 (ST3)[2]. Subsequently, on August 7th and 22nd, 2013 EPA provided ADEQ with modeling analyses of its own BART determination for the AEPCO Apache Steam Units 2 and 3. This technical support document analyzes the effectiveness of the AEPCO BART alternative pollution control methodologies for Class I area visibility enhancement in comparison to the State of Arizona's original BART determination and EPA's alternative modeling analysis. Furthermore, this document provides information necessary for the revision of the State of Arizona's Regional Haze SIP Chapter 10 to conform with 40 CFR § 51.308(e).

40 CFR § 51.308(e) outlines the requirements of BART for regional haze visibility impairment. Subsection 3 of the rule describes two scenarios by which a trading program or other alternative control measure is considered an acceptable alternative to BART. These two scenarios include:

1) Clear evidence that the distribution of emissions from the alternative control technology is not substantially different than under BART, and the alternative results in greater emissions reductions, or
2) Dispersion modeling to ensure visibility does not decline in any Class I area and overall average visibility improvement in all affected Class I areas exists when comparing the alternative approach to BART.

[1] Arizona Department of Environmental Quality (ADEQ). 2011. *Arizona State Implementation Plan: Regional Haze Under Section 308 of the Federal Regional Haze Rule*.
[2] Jorden Bischoff & Hiser, P.L.C. 2013. Supplement to Petition for Administrative Reconsideration of BART for Units 2 and 3, Apache Generating Station.

ADEQ finds that a significant change in the distribution of emissions occurs when comparing AEPCO's alternative control measure to EPA determined BART, precluding the applicability of scenario #1. Furthermore, while scenario #2 assesses whether visibility conditions at Class I areas would improve through the implementation of the alternative control measure, "the logical reference point is visibility conditions as they are expected to be at the time of program implementation but in the absence of the program"[3].

Predictive visibility modeling for future state conditions requires the use of a photochemical grid model. While appropriate for large-scale trading programs, photochemical modeling is not appropriate for single source modeling and thus scenario #2 is not applicable in the assessment of alternative control effectiveness for a single source against BART. Therefore, this document analyzes how the proposed alternative control measure implementation would affect the distribution of visibility impairing emissions from the Apache station and reviews CALPUFF modeling of control technologies in accordance with BART determination in order to satisfy 40 CFR § 51.308(e)(2)(i)(E). This rule states that when § 51.308(e)(3) does not apply, the determination should "otherwise [be] based on the clear weight of evidence".

Section II of this document outlines the annual emissions produced by the Apache facility assuming implementation of current controls, ADEQ's 2008 proposed BART controls of Low NO_x Burners (LNB) with Over-fire Air (OFA), EPA's determined BART of Selective Catalytic Reduction (SCR), and the 2013 AEPCO proposed alternative control technologies. While ADEQ presents a comparison of AEPCO's proposed alternative technology to SCR (EPA's BART), ADEQ considers SCR an economically infeasible control technology. Section III discusses the modeled visibility impacts on Class I areas of implementing each of the previously mentioned control technologies in order to validate the alternative control measure as a BART alternative and satisfy 40 CFR § 51.308(e)(2)(i)(E). Through the information and analyses presented in Sections II and III, ADEQ concludes that the installation and implementation of AEPCO's alternative control methodology results in "better-than-BART" visibility improvements at affected Class I areas as compared to ADEQ's BART (LNB & OFA) and EPA's BART (SCR) technologies.

[3] Environmental Protection Agency (EPA). 2005. *Regional Haze Regulations and Guidelines for Best Available Retrofit Technology (BART) Determinations*

II. Annual Emissions

Estimated controlled emissions for a BART alternative control methodology should be compared to BART controlled emissions in the evaluation of BART alternative control technology effectiveness. This section examines estimated emissions under uncontrolled and a variety of controlled scenarios to better understand how different proposed control technologies will affect NO_x, SO_2, and total PM emissions.

In January of 2008, AEPCO presented ADEQ with modeling results for the BART determination of three Steam Units at the Apache facility (Unit 1 – ST1, Unit 2 – ST2, and Unit 3 – ST3). ADEQ reviewed these modeling scenarios and determined BART for SO_2, NO_x, and PM for each of the three units and included these BART determinations in ADEQ's 2011 Regional Haze SIP. In 2012, EPA approved ADEQ's BART determinations of NO_x, SO_2, and PM for Apache ST1, and SO_2 and PM for ST2 and ST3. However, EPA disapproved ADEQ's NO_x BART determination for ST2 and ST3, asserting that Selective Catalytic Reduction (SCR) represents NO_x BART for these two units. ADEQ contends that SCR is economically infeasible and that BART for these two units is implementation of Low NO_x Burners (LNB) with Over-fire Air (OFA).

In 2013, AEPCO proposed a set of control technologies to ADEQ and EPA to act as a BART alternative. These control technologies would incorporate a fuel switch at ST2 from Coal to Pipeline Natural Gas (PNG) and the implementation of Selective Non-catalytic Reduction (SNCR) at ST3[4]. Within AEPCO's administration reconsideration documentation, CALPUFF modeling results were presented comparing the alternative control technology's impact on visibility at affected Class I areas against SCR installation and currently implemented controls at the facility. AEPCO also estimated emissions following the implementation of each control technology. Following this submittal, ADEQ received CALPUFF modeling results from EPA that examined visibility impacts of a baseline scenario (OFA only), LNB implementation, SNCR & LNB implementation, SCR & LNB implementation, and AEPCO's alternative technologies. For the purposes of this document, all modeling scenarios will include a descriptor of "2007" - referring to modeling runs from AEPCO's 2007 CALPUFF control measure modeling, "EPA" – referring to EPA's 2013 CALPUFF control measure modeling, or "2013" - referring to modeling runs from AEPCO's 2013 CALPUFF control measure modeling. Equipment information used for each of the modeling scenarios to estimate emissions from ST2 and ST3 for all analyzed control options are given below:

1. **2007 Baseline** – This scenario assumes 2008 operating conditions, including Electrostatic Precipitation (ESP) and wet scrubber upgrades.
2. **2013 Baseline** – This scenario assumes 2013 operating controls, which includes OFA, ESP, and wet scrubber upgrades.
3. **2007 LNB & OFA** - This scenario utilizes the emission factors from AEPCO's 2007 modeling of ST2 and ST3 controlled by LNB and OFA which assumed a

[4] Jorden Bischoff & Hiser, P.L.C. 2013. Supplement to Petition for Administrative Reconsideration of BART for Units 2 and 3, Apache Generating Station.

NO_x emission rate from each unit of 0.31lb/MMBTU. It also assumes ESP and wet scrubber upgrades were in place.

4. **EPA LNB & OFA** - This scenario assumes LNB and OFA implementation and ESP and wet scrubber upgrades. The addition of LNB is assumed by EPA in this modeling scenario to reduce 2013 Baseline NO_x emissions by 30%.
5. **2007 SCR** - This scenario utilizes the NO_x emission factors from AEPCO's 2007 modeling of ST2 and ST3 controlled by SCR (0.07 lb/MMBTU). It also assumes ESP and wet scrubber upgrades were in place.
6. **2013 SCR** - This scenario assumes control efficiency of NO_x on ST2 and ST3 of 81% and 84%, respectively. This scenario assumes SCR, LNB, and OFA implementation as well as ESP and wet scrubber upgrades.
7. **2013 9bv2 PNGt** - The 2013 9bv2 PNGt scenario reflects the implementation of the AEPCO alternative controls proposed in the ENVIRON International Modeling Report[5]. These alternative controls include a switch of ST2 from coal to PNG and the implementation of SNCR for ST3. Version 2 ("…v2…") applies a lower ST2 PM emission rate and ST3 NO_x emission rate, assumed to be more in line with rates which will occur when the control processes have reached a steady state of operation. For modeling purposes, this scenario assumes the PM emission factor is total PM.

Annual emissions were calculated in Tables 2 – 7 using the operating conditions listed in Table 1. For comparative purposes, all scenarios were assumed to have the same average heat rate and percentage of annual days of operation. The values of these operating conditions were calculated from CAMD data on days of operations for the individual units for the period of 2008 to 2010. 2007 Baseline emission factors listed in Table 1 were based on the modeling approaches adopted in 2007 modeling documentation which relied on the average emission factors measured from monitoring and testing data[6][7]. The 2013 Baseline emission factors listed in Table 1 for NO_x were calculated as the average emission factor from 2008 to 2010 CAMD data for the individual Units on days of operation, while SO_2 and PM utilized 2007 modeled emission factors. As AEPCO has already committed to using only natural gas as a fuel for ST1, emissions in Table 1 were not calculated for this unit as no additional controls will be applied; however, the CALPUFF modeling runs for these scenarios, reviewed later in this document, include facility-wide emissions (i.e. Unit 1, 2, and 3).

[5] Jorden Bischoff & Hiser, P.L.C. 2013. Supplement to Petition for Administrative Reconsideration of BART for Units 2 and 3, Apache Generating Station.
[6] CH2MHILL, 2007. BART Analysis for Apache Generating Station Steam Unit 2.
[7] CH2MHILL, 2007. BART Analysis for Apache Generating Station Steam Unit 3.

Table 1: Equipment factors utilized to calculate estimated annual emissions.

Control Option	Pollutant	Unit	Average Emission Factor, lb/MMBtu	Average Heat Rate, MMBtu/hr	Annual Days in Operation, %
2007 Baseline	NOx	ST2	0.471	1622	90.15%
2007 Baseline	SO2	ST2	0.15	1622	90.15%
2007 Baseline	PM	ST2	0.03	1622	90.15%
2007 Baseline	NOx	ST3	0.43	1707	93.80%
2007 Baseline	SO2	ST3	0.15	1707	93.80%
2007 Baseline	PM	ST3	0.03	1707	93.80%
2013 Baseline	NOx	ST2	0.371	1622	90.15%
2013 Baseline	SO2	ST2	0.15	1622	90.15%
2013 Baseline	PM	ST2	0.03	1622	90.15%
2013 Baseline	NOx	ST3	0.437	1707	93.80%
2013 Baseline	SO2	ST3	0.15	1707	93.80%
2013 Baseline	PM	ST3	0.03	1707	93.80%
2007 LNB & OFA	NOx	ST2	0.31	1622	90.15%
2007 LNB & OFA	SO2	ST2	0.15	1622	90.15%
2007 LNB & OFA	PM	ST2	0.03	1622	90.15%
2007 LNB & OFA	NOx	ST3	0.31	1707	93.80%
2007 LNB & OFA	SO2	ST3	0.15	1707	93.80%
2007 LNB & OFA	PM	ST3	0.03	1707	93.80%
EPA LNB	NOx	ST2	0.260	1622	90.15%
EPA LNB	SO2	ST2	0.15	1622	90.15%
EPA LNB	PM	ST2	0.03	1622	90.15%
EPA LNB	NOx	ST3	0.306	1707	93.80%
EPA LNB	SO2	ST3	0.15	1707	93.80%
EPA LNB	PM	ST3	0.03	1707	93.80%
2007 SCR	NOx	ST2	0.07	1622	90.15%
2007 SCR	SO2	ST2	0.15	1622	90.15%
2007 SCR	PM	ST2	0.03	1622	90.15%
2007 SCR	NOx	ST3	0.07	1707	93.80%
2007 SCR	SO2	ST3	0.15	1707	93.80%
2007 SCR	PM	ST3	0.03	1707	93.80%
2013 SCR	NOx	ST2	0.07	1622	90.15%
2013 SCR	SO2	ST2	0.15	1622	90.15%
2013 SCR	PM	ST2	0.03	1622	90.15%
2013 SCR	NOx	ST3	0.07	1707	93.80%
2013 SCR	SO2	ST3	0.15	1707	93.80%

Control Option	Pollutant	Unit	Average Emission Factor, lb/MMBtu	Average Heat Rate, MMBtu/hr	Annual Days in Operation, %
2013 SCR	PM	ST3	0.03	1707	93.80%
2013 9bv2 PNGt	NOx	ST2	0.085	1622	90.15%
2013 9bv2 PNGt	SO2	ST2	0.00064	1622	90.15%
2013 9bv2 PNGt	PM	ST2	0.008	1622	90.15%
2013 9bv2 PNGt	NOx	ST3	0.225	1707	93.80%
2013 9bv2 PNGt	SO2	ST3	0.15	1707	93.80%
2013 9bv2 PNGt	PM	ST3	0.03	1707	93.80%

II.A. Baseline Annual Emissions

This section presents a comparison the baseline scenarios to show how emission factor changes between the 2007 and 2013 modeling runs altered annually estimated total emissions for each pollutant.

Baseline emissions refer to those emissions estimated to occur from the ST2 and ST3 with currently installed control technologies and utilizing current practices. Two baseline scenarios are presented in this section. While ST1 emissions were not considered in this section, they were included in the facility-wide modeling runs reviewed later in this document. The 2007 and 2013 Baseline scenarios assume the facility has installed the ESP and wet scrubber upgrades mentioned in ADEQ's 2011 Regional Haze SIP. The emission factors reported in Table 1 for the 2007 Baseline scenario are derived directly from 2007 AEPCO modeling documentation[8,9]. 2013 Baseline NO_x emission factors differ from 2007 Baseline emission factors while SO_2 and PM emission factors are the same. 2013 NO_x emission factors were calculated from CAMD data as the average NO_x emission factor from each unit between the years of 2008 and 2010 on days of active operation. Heat rates and annual days of operation for both baseline scenarios were assumed equal to those calculated from CAMD data for the period of 2008-2010 on days of active operation, for comparative purposes. Differences occur between ST2 and ST3 NO_x emission factors for the 2007 and 2013 Baseline scenarios (Table 1) resulting in facility-wide annual average NO_x emissions which are 591 tons lower in the 2013 baseline than the 2007 baseline (Table 2).

[8] CH2MHILL, 2007. BART Analysis for Apache Generating Station Steam Unit 2.
[9] CH2MHILL, 2007. BART Analysis for Apache Generating Station Steam Unit 3.

Table 2: Estimated Baseline emissions from Apache ST2 and ST3.

Control Option	Pollutant	Unit	Emissions, tons/yr
2007 Baseline	NOx	ST2	3,016.55
2007 Baseline	SO2	ST2	960.69
2007 Baseline	PM	ST2	192.14
2007 Baseline	NOx	ST3	3,015.65
2007 Baseline	SO2	ST3	1,051.97
2007 Baseline	PM	ST3	210.39
Combined NOx			**6,032.21**
Combined SO2			**2,012.66**
Combined PM			**402.53**
2013 Baseline	NOx	ST2	2,376.10
2013 Baseline	SO2	ST2	960.69
2013 Baseline	PM	ST2	192.14
2013 Baseline	NOx	ST3	3,064.74
2013 Baseline	SO2	ST3	1,051.97
2013 Baseline	PM	ST3	210.39
Combined NOx			**5,440.84**
Combined SO2			**2,012.66**
Combined PM			**402.53**

* Annual emissions are calculated as the product of the average Emission Factor, the Average Heat Rate, the Percentage of Annual Days in Operation, and the conversion factor from lb/hr to tons/yr (4.38).

II.B. ADEQ BART Controlled Annual Emissions

This section presents a comparison of the LNB and OFA control scenarios to show how emission factor changes between the 2007 and 2013 modeling runs altered annually estimated total emissions for each pollutant.

ADEQ determined NO_x BART control of ST2 and ST3 to be LNB and OFA. While it produced greater emissions reductions, the economic infeasibility of SCR precluded its consideration by ADEQ as a viable option for BART. The emission factors used to estimate annual emissions for the 2007 LNB & OFA modeling scenario were taken from the 2007 AEPCO modeling documentation[10,11] and were based on manufacturer recommendations. In contrast, the EPA LNB & OFA scenario assumes a 30% control efficiency of 2013 Baseline emissions. Heat rates and annual days of operation for both scenarios were assumed equal to those calculated from CAMD data for the period of 2008-2010, in order to better compare ST2 and ST3 emissions between the two scenarios.

[10] CH2MHILL, 2007. BART Analysis for Apache Generating Station Steam Unit 2.
[11] CH2MHILL, 2007. BART Analysis for Apache Generating Station Steam Unit 3.

The EPA LNB & OFA scenario results in 322 fewer tons of NO_x emissions produced per annum when compared to the 2007 LNB & OFA scenario (Table 3).

Table 3: Emissions estimates for ADEQ determined BART control of ST2 and ST3.

Control Option	Pollutant	Unit	Emissions, tons/yr
2007 LNB & OFA	NOx	ST2	1,985.42
2007 LNB & OFA	SO2	ST2	960.69
2007 LNB & OFA	PM	ST2	192.14
2007 LNB & OFA	NOx	ST3	2,174.07
2007 LNB & OFA	SO2	ST3	1,051.97
2007 LNB & OFA	PM	ST3	210.39
Combined NOx			**4,159.49**
Combined SO2			**2,012.66**
Combined PM			**402.53**
EPA LNB & OFA	NOx	ST2	1,663.27
EPA LNB & OFA	SO2	ST2	960.69
EPA LNB & OFA	PM	ST2	192.14
EPA LNB & OFA	NOx	ST3	2,145.32
EPA LNB & OFA	SO2	ST3	1,051.97
EPA LNB & OFA	PM	ST3	210.39
Combined NOx			**3,808.59**
Combined SO2			**2,012.66**
Combined PM			**402.53**

* Annual emissions are calculated as the product of the average Emission Factor, the Average Heat Rate, the Percentage of Annual Days in Operation, and the conversion factor from lb/hr to tons/yr (4.38).

II.C. EPA BART Controlled Annual Emissions

This section presents the estimated calculated annual emissions following SCR control for the 2007 and 2013 modeling runs. This comparison illustrates how this control option was unaltered between the 2007 and 2013 modeling runs.

While ADEQ views SCR as an economically infeasible BART option, it was the control technology tested which produced the greatest emissions reductions in the 2007 Apache generating station modeling. An independent BART analysis was performed by the EPA which determined SCR as BART for NO_x emissions controls on ST2 and ST3 at the Apache generating Station and is thus recognized for the purposes of this document as EPA's BART.

For the purposes of annual emissions estimations, following BART implementation, ST2 and ST3 NO_x emission factors for 2007 and 2013 were assumed to be 0.07 lb/MMBtu.

These values are in line with Department of Energy (DOE) determined NO_x emission rates for SCR, ranging between 0.05 and 0.10 lb/ MMBtu[12]. The 2013 SCR scenario results in 81% and 84% control efficiency of 2013 Baseline emissions for ST2 and ST3 respectively. Heat rates and annual days of operation for both scenarios were assumed equal to those calculated from CAMD data for the period of 2008-2010, in order to better compare ST2 and ST3 emissions between scenarios. Pollutant specific emissions estimates are given in Table 4 for SCR control technology implementation on ST2 and ST3.

Table 4: Emissions estimates for SCR control of Units 2 and 3.

Control Option	Pollutant	Unit	Emissions, tons/yr
2007 SCR	NOx	ST2	448.32
2007 SCR	SO2	ST2	960.69
2007 SCR	PM	ST2	192.14
2007 SCR	NOx	ST3	490.92
2007 SCR	SO2	ST3	1,051.97
2007 SCR	PM	ST3	210.39
Combined NOx			**939.24**
Combined SO2			**2,012.66**
Combined PM			**402.53**
2013 SCR	NOx	ST2	448.32
2013 SCR	SO2	ST2	960.69
2013 SCR	PM	ST2	192.14
2013 SCR	NOx	ST3	490.92
2013 SCR	SO2	ST3	1,051.97
2013 SCR	PM	ST3	210.39
Combined NOx			**939.24**
Combined SO2			**2,012.66**
Combined PM			**402.53**

[*] Annual emissions are calculated as the product of the average Emission Factor, the Average Heat Rate, the Percentage of Annual Days in Operation, and the conversion factor from lb/hr to tons/yr (4.38).

[12] U.S. Department of Energy, 2005. A Review of DOE/NETL's Advanced NO_x Control Technology R&D Program for Coal-Fired Power Plants.

II.D. AEPCO Alternative Controlled Annual Emissions

This section presents information pertaining to AEPCO's alternative control technologies, including annually estimated emissions. Estimated annual emissions following the implementation of this control technology are presented for comparative purposes with the other control technologies discussed in this document.

AEPCO's most recent modeling submission, contained within the 2013 petition for administrative reconsideration, included a single alternative control technology approach for the two generating units; however, this single alternative approach was modeled for five different scenarios using the CALPUFF modeling platform. These five modeling scenarios took into account varying assumptions for the modeling inputs including differing emission rates. Of the variable PM emission factors tested by AEPCO, ADEQ determined the PNGt modeling scenarios are most in line with EPA's AP-42 emission factor for total PM emissions from a natural gas fired boiler of 0.0075 lb/MMBtu (0.0019 lb/MMBtu filterable PM and 0.0056 lb/MMBtu condensable PM)[13]. Therefore, ADEQ recognizes the PNGt modeling scenarios as more accurate emission estimates and modeling scenarios than PNGf. Additionally, AEPCO provided a scenario ("Updated PM EF") in which it utilized a PM emission factor value of 0.00042 lb/MMBtu for natural gas boiler emissions, as was used by EPA in the creation of the 2011 National Emission Inventory (NEI)[14]. While ADEQ recognizes the possible overestimation of PM emissions by use of a higher emission factor, ADEQ cites the following two criteria in its decision to not currently support the use of the 0.00042 lb/MMBtu emission factor presented by AEPCO:

1. Until EPA formally accepts the use of the new emission factors through the revision of AP-42 Chapter 1, ADEQ will assume the 1998 AP-42 emission factors are the most accurate available.
2. The use of emission factors that are in line with the 1998 AP-42 derived PM emission factors for natural gas fired boilers represents a conservative emission estimate and does not negate the ability of the modeling (discussed in Section III of this document) to show the AEPCO alternative approach as a reasonable BART alternative.

Finally, AEPCO presented two scenarios labeled as version 2 (i.e. v2) which introduced lower ST2 PM and ST3 NO_x emission rates. ADEQ accepts the lower limits for PM emission rates since they are more in line with AP-42 PM emission factor for natural gas fired boilers. Control technology process improvements are likely to occur at ST3 following initial SNCR implementation which will increase the overall NO_x control efficiency as this process reaches a steady operating state. Therefore, ADEQ recognizes the "2013 9bv2 PNGt" scenario as the most accurate scenario in estimating emissions and modeling visibility following control implementation. Unit and pollutant specific

[13] Environmental Protection Agency, 1998. AP 42, Fifth Edition, Volume I, Chapter1.4. http://www.epa.gov/ttnchie1/ap42/ch01/final/c01s04.pdf

[14] Environmental Protection Agency, 2013. PM EFs for Natural Gas Combustion. http://www.epa.gov/ttnchie1/net/2011inventory.html

emission estimates are given in Table 5 for this CALPUFF parameter modeling scenario for the proposed BART alternative control technology.

While ADEQ recognizes 2013 9bv2 PNGt as the most accurate modeling scenario, AEPCO has requested in their submitted administrative reconsideration documentation a 30-day rolling average NO_x emission limit of 0.23 lb/MMBtu for Unit 3 due to a perceived inability to achieve a rate of 0.225 lb/MMBtu at all times[15]. While this emission limit does not match the emission rate modeled in scenario 9bv2 PNGt, the modeled emission rate of 0.225 lb/MMBtu represents 97.8% of the NO_x emissions for this Unit. ADEQ does not expect remodeling of this scenario to show significantly altered visibility impairment for affected Class I areas.

Table 5: Emissions estimates for AEPCO alternative controls of Units 2 and 3.

Control Option	Pollutant	Unit	Emissions, tons/yr
2013 9bv2 PNGt	NOx	ST2	544.39
2013 9bv2 PNGt	SO2	ST2	4.10
2013 9bv2 PNGt	PM	ST2	51.24
2013 9bv2 PNGt	NOx	ST3	1,577.96
2013 9bv2 PNGt	SO2	ST3	1,051.97
2013 9bv2 PNGt	PM	ST3	210.39
Combined NOx			**2,122.35**
Combined SO2			**1,056.07**
Combined PM			**261.63**

* Annual emissions are calculated as the product of the average Emission Factor, the Average Heat Rate, the Percentage of Annual Days in Operation, and the conversion factor from lb/hr to tons/yr (4.38).

[15] The 0.23 lb/MMBtu, 30 BOD average rate must be met at all times. In general, under standard operating conditions, AEPCO believes Steam Unit 3 will achieve a maximum emission rate of 0.225 lb/MMBtu. However, should there be a number of startups and shutdowns within a single 30-day period, the unit may not be able to achieve the lower value. Because Steam Unit 3 is anticipated to serve in a load-following fashion, ADEQ concurs that the 0.225 lb/MMBtu rate is probably the most accurate for visibility modeling purposes.

II.E. Control Technology Annual Emissions Comparison

This section presents comparisons between previously reported annual emissions in order to: 1) understand how estimated annual emissions changed between the 2007 and 2013 modeling scenarios and 2) compare the magnitude and distribution of emissions reductions estimated with the implementation of the previously presented control technologies.

Table 6 provides a comparison of the total estimated emissions of each pollutant for each of the eleven scenarios outlined in Table 1. The 2013 Baseline scenario (Scenario 2 in Table 6) resulted in 591 (~10%) fewer tons of NO_x emissions than the 2007 Baseline scenario (Scenario 1 in Table 6) due to a lower average NO_x emission factor. Implementation of ADEQ BART, determined to be LNB and OFA, would result in a reduction of total NO_x emissions by 31.1% or 1,873 tpy and 30.0% or 1,632 tpy when examining 2007 and 2013 scenarios, respectively (Table 7). EPA's BART, implementation of SCR, would result in a total NO_x emission reduction below 2013 baseline emission rates of 82.7% or 4,502 tpy. AEPCO presented a range of modeling scenarios for their proposed alternative control strategy. As discussed in Section II.D., ADEQ considers "AEPCO 9bv2 PNGt" (Scenario 7 in Table 6) as the most appropriate scenario for comparative analyses. When comparing Scenario 7 to Scenario 2, a total NO_x emission reduction of 61.0% or 3,318 tpy is estimated. In addition, SO_2 emissions are estimated to be reduced by 47.5% or 957 tpy and PM emissions are estimated to be reduced by 35.0% or 141 tpy. While the Units 2 and 3 combined emissions reduced for NO_x, SO_2, and PM through the implementation of AEPCO's alternative control technologies exceeds ADEQ's BART emission reductions by 1,687 tpy, 957 tpy, and 141 tpy, respectively, these individual pollutant reductions varied significantly when comparing AEPCO's alternative control technologies to SCR. This is due to emissions reductions realized through SCR implementation being solely from NO_x control while AEPCO's alternative control technology realizes reductions in NO_x, SO_2, and PM. However, scenarios 5-7 show drastically reduced combined Units 2 and 3 emissions that are comparable amongst all scenarios (Figure 1). It is evident from Figure 1 that the AEPCO alternative control technology scenario (Scenarios 7) is drastically better than ADEQ's BART (Scenario 4) and comparable to EPA's BART (Scenario 6) in total emissions reductions. In which case, the relative contribution of individual pollutant visibility impairment should act as an important factor in determining if AEPCO's proposed controls are "Better-than-BART".

ADEQ submitted a revised 2008 emission inventory in its 2013 Regional Haze SIP revision[16]. Within this emission inventory, ADEQ calculated State-wide SO_2 emissions of 84,784 tons and NO_x emissions of 290,344 tons, with 93% (79,015 tons) of the SO_2 emissions originating from point sources while only 21% (60,759 tons) of the NO_x emissions came from point sources. Despite statewide NO_x emissions being ~3.5 times greater than statewide SO_2 emissions, SO_2 attributable ammonium sulfate visibility

[16] Arizona Department of Environmental Quality (ADEQ). 2013. *Arizona State Implementation Plan Revision: Regional Haze Under Section 308 of the Federal Regional Haze Rule*.

extinction (mM^{-1}) averaged 3.6, 3.6, and 3.9 times the magnitude of NO_x attributable ammonium nitrate visibility extinction for the 20% best days, 20% worst days, and all days, respectively, between 2000 and 2010 when analyzing IMPROVE monitoring data from Class I areas impacted by Apache Generating Station (Appendix A). The IMPROVE monitoring data, along with the point source emissions data indicate that, for the State of Arizona, it is likely more beneficial to reduce SO_2 emissions as compared to NO_x emissions when applying pollution controls to point sources to improve class I area visibility. Therefore, ADEQ believes AEPCO's proposed alternative control methodology would realize higher real-world visibility benefits than the other control methods tested.

Table 6: Controlled, combined Unit 2 and 3 annual emissions (tpy).

Scenario	Control	Combined NOx	Combined SO2	Combined PM
1	2007 Baseline	6,032	2,013	403
2	2013 Baseline	5,441	2,013	403
3	2007 LNB & OFA	4,159	2,013	403
4	EPA LNB & OFA	3,809	2,013	403
5	2007 SCR	939	2,013	403
6	2013 SCR	939	2,013	403
7	2013 9bv2 PNGt	2,122	1,056	262

Table 7: Control technology annual emission reductions as compared to 2007 and 2013 Baseline emissions.

Scenario Comparison	NOx TPY	SO2 TPY	PM TPY
"2013 Baseline" to "2007 Baseline"	-591	0	0
"2007 LNB & OFA" to "2007 Baseline"	-1,873	0	0
"EPA LNB & OFA" to "2013 Baseline"	-1,632	0	0
"2007 SCR" to "2007 Baseline"	-5,093	0	0
"2013 SCR" to "2013 Baseline"	-4,502	0	0
"2013 9bv2 PNGt" to "2013 Baseline"	-3,318	-957	-141
"2013 9bv2 PNGt" to "EPA LNB & OFA"	-1,686	-957	-141

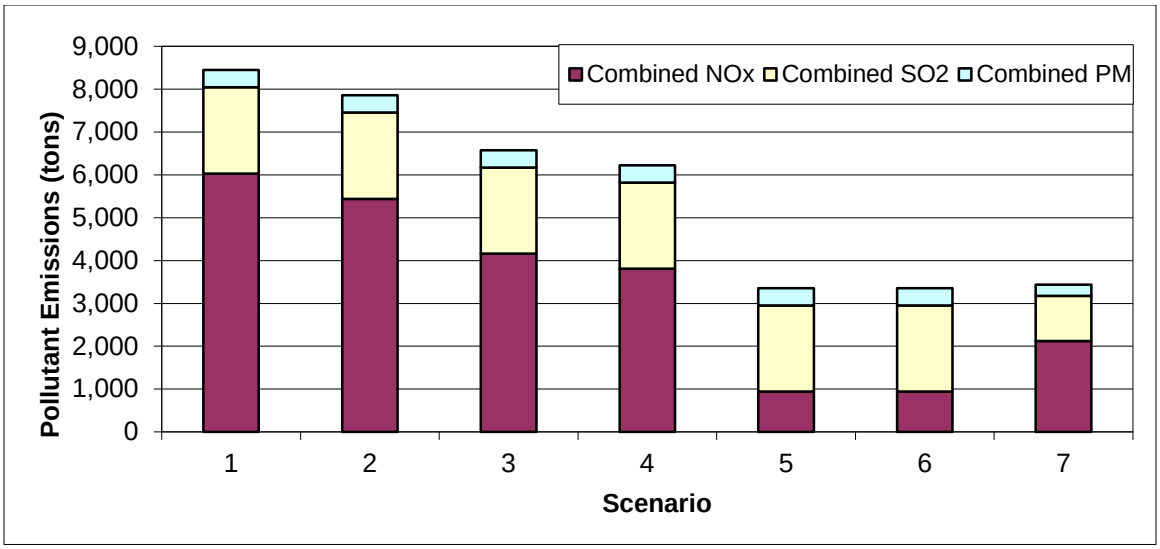

Figure 1: Pollutant annual emissions (tpy) estimated through the implementation of each control strategy.

III. Modeled Visibility Impacts

In addition to assessing the emissions reductions estimated through the implementation of AEPCO's alternative control measures, CALPUFF modeling was performed to quantify the visibility improvements on affected Class I areas following implementation of these measures. In this section, ADEQ reviews the results of the 2013 AEPCO modeling analysis and compares it to EPA modeling results in order to further confirm that the AEPCO alternative control technology implementation would result in visibility enhancements far exceeding ADEQ's BART and comparable to EPA's SCR, thus providing confirmation that it is a valid BART alternative. In this section, ADEQ compares results from the 2013 Baseline, EPA LNB & OFA, 2013 SCR, and 2013 9bv2 PNGt modeling scenarios in order to evaluate the visibility benefits of implementing AEPCO's alternative control technology. Due to modeling methodology changes, 2007 modeling results are not compared to 2013 modeling results in this section. However, to better understand modeling result variability not otherwise explained by emission rates, ADEQ discusses the inputs and parameters used in the 2013 EPA and 2013 AEPCO modeling scenarios and compares these runs to 2007 AEPCO modeling which was based on previous WRAP BART modeling.

Modeling of visibility impacts on affected Class I areas was performed using the EPA-approved CALPUFF modeling platform. CALPUFF is a multi-layer, multi-species non-steady-state puff dispersion model and is considered the state-of-the-science modeling application for predicting a single source's contribution to visibility impairment. The model includes a meteorological preprocessing program (CALMET) with algorithms for chemical transformation and deposition. It also includes a post processor (CALPOST) capable of calculating pollutant concentrations and visibility impacts.

The information provided in this section is based on review of the 2007 CALPUFF modeling documentation performed by AEPCO to update previous WRAP modeling; the documentation provided by AEPCO within their 2013 modeling administrative reconsideration request; review of EPA's 2013 Apache Generating Station BART modeling files; and review of the modeling files from AEPCO's 2013 CALPUFF modeling.

III.A. Modeling History

In this section, ADEQ reviews the CALPUFF modeling history of the Apache Generating Station.

AEPCO completed two different sets of modeling runs for the BART determination. In 2007, AEPCO contracted CH2MHILL to perform a BART determination for ST1, ST2, and ST3 of the Apache Generating Station through the utilization of the CALPUFF (v6.112) modeling platform. These modeling runs were performed to provide ADEQ with information for BART determination for the individual units as it related to NO_x,

SO_2, and PM pollution control. ADEQ's BART determination based on this modeling and additional analyses led to EPA approving ADEQ's proposed BART for ST1 and ADEQ's proposed BART for SO_2 and PM controls of ST2 and ST3, while disapproving ADEQ's NO_x BART determination for ST2 and ST3[17]. ADEQ and AEPCO are currently challenging this disapproval and EPA's imposition of a BART FIP in a petition for review before the Federal Court of Appeals for the Ninth Circuit. For these modeling runs, CH2MHILL estimated visibility impacts resulting from the implementation of a number of strategies for NO_x control of ST2 and ST3, including:

- LNB with OFA
- Rotating Opposed Fire Air (ROFA)
- ROFA with Rotamix
- LNB with OFA and SNCR
- LNB with OFA and SCR

In 2013, AEPCO proposed an alternative NO_x control technology for ST2 and ST3 which included the conversion of ST2 from coal fuel usage to natural gas fuel usage and LNB with OFA and SNCR control implementation for ST3. In order to assess the visibility improvements that would be achieved at impacted Class I areas with the implementation of this alternative control technology, AEPCO performed CALPUFF (v5.8) modeling. As opposed to CALPUFF version 6.112 utilized for 2007 modeling, all 2013 modeling relied upon version 5.8, an EPA approved version of the model. The more recent 2013 suite of modeling runs included visibility dispersion modeling of AEPCO's alternative control scenario as well as SCR implementation and compares the visibility improvements estimated using these two control techniques against the current visibility impact of ST2 and ST3 on Class I areas within 300 km of the Apache Generating Station. The AEPCO modeling was performed in consultation with EPA and through modeling file sharing, and as such, the 2013 EPA CALPUFF modeling and 2013 AEPCO modeling varied only slightly[18].

Despite the 2013 EPA and AEPCO modeling similarities, some modeling differences exist between the 2007 and 2013 runs. In this section ADEQ attempts to identify where these differences occurred in order to describe the variability in modeled results between the two years.

III.B. Modeling Methodologies

In this section, ADEQ presents an analysis of the methodologies and inputs utilized during the 2007 and 2013 CALPUFF modeling of the Apache Generating Station.

[17] Federal Register Volume 77, Number 234. pg. 72512.
[18] Jorden Bischoff & Hiser, P.L.C. 2013. Supplement to Petition for Administrative Reconsideration of BART for Units 2 and 3, Apache Generating Station.

Additionally, ADEQ attempts to identify any differences noted between the modeling runs and address any concerns these differences may raise for model suite comparisons.

All 2007 and 2013 modeling scenarios utilized a 300 km modeling domain surrounding the Apache Generating Station. Modeling was performed for three years of analysis: 2001, 2002, and 2003. BART visibility metrics were tested, consisting of the average of the 98th percentile (8th highest in a year) visibility metrics across the three years of the modeling and the 98th percentile using the three modeling years together (22nd highest over 3 years).

Both 2007 and 2013 modeling exercises ran CALMET, utilizing Mesoscale Meteorological Model (MM5) datasets, following the protocols outlined by the Western Regional Air Partnership – Regional Modeling Center (WRAP-RMC) methodologies (2006)[19], with only slight changes in the processing of CALMET data for the 2013 modeling scenario. In particular, the relative weighting of 1st guess field and observations in the surface layer (R1), the relative weighting of the 1st guess field and observations in the layers aloft (R2), the maximum radius of influence over land in the surface layer (RMAX1), and the maximum radius of influence over land aloft (RMAX2) varied between the 2007 and 2013 modeling runs as compared to WRAP modeling, to increase model performance. For the EPA and AEPCO 2013 modeling scenarios, R1 was reduced to a value of 18 km and R1MAX was reduced to a value of 30 km in order for surface air observations to better match MM5 observations. These changes were EPA recommended and followed the enhancements outlined in a revised BART analysis of the Navajo Generating Station[20].

The AEPCO 2013 modeling exercise also further enhanced 2007 modeling runs by altering background pollutant concentrations to match field observed values. 2007 CALPUFF modeling utilized a constant 1 part per billion (ppb) ammonia concentration as recommended by WRAP-RMC. For the AEPCO 2013 modeling, two sets of scenarios were run for which 1) a constant 1 ppb ammonia concentration was used during all months of the year and 2) the monthly ammonia concentration was varied to mimic the values developed during CALPUFF modeling of the Desert Rock Power Plant in Northwestern New Mexico PSD permit application. The 2007 CALPUFF modeling results were post-processed with CALPOST utilizing the annual average natural levels of aerosol components provided in EPA's Natural Visibility Guidance[21]. The 2013 modeling exercises used background concentrations of visibility impairing pollutants that matched the 20% best days visibility for the individually modeled years of 2001-2003. Utilization of the 20% best days visibility as background results in an accurate estimate

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[19] Western Regional Air Partnership (WRAP). 2006. *Draft Final Modeling Protocol, CALMET/CALPUFF Protocol for BART Exemption Screening Analysis for Class I Areas in the Western United States*. Western Regional Air Partnership, Air Quality Modeling Forum, Regional Modeling Center, August 15.

[20] ENSR Corporation. 2009. Revised BART Analysis for the Navajo Generating Station Units 1-3. Document No.: 05830-012-300. http://en3pro.com/wp-content/uploads/2011/02/BART-Analysis-by-ENSR-JAN-09.pdf

[21] Environmental Protection Agency, 2003. Guidance for Estimating Natural Visibility Conditions Under Regional Haze Rule. EPA-454/B-03-005.

of a single sources effect on any Class I area by incorporating conservative field measured pollutant concentrations.

Stack parameters (Table 8) and emission rates (Table 9) at ST2 and ST3 also varied for the 2013 modeling runs as compared to 2007 modeling runs. Variations in 2013 and 2007 emission rates are due to the use of 2008-2010 CAMD reported NO_x emissions and heat rate values in the calculation of 2013 emission rates[22]. ST1 emissions were in the CALPUFF modeling runs using the original SIP BART limit. The proposed AEPCO alternative limit for NO_x is slightly lower, but that change was not considered in the 2013 modeling analysis.

For the purposes of CALPUFF modeling compliance with EPA's Regional Haze Regulations and Guidelines for BART Determination, both the 2007 and 2013 modeling exercises used emissions estimates that reflected steady-state operating conditions during periods of high capacity utilization[23]. Light extinction calculations for 2007 modeling relied on Method 6 and were thus performed using CALPOST utilizing the following default extinction coefficients:

- Ammonium sulfate 3.0
- Ammonium nitrate 3.0
- PM coarse (PM_{10}) 0.6
- PM fine ($PM_{2.5}$) 1.0
- Organic Carbon 4.0
- Elemental Carbon 10.0

Monthly average relative humidity factors (*f*[RH]), as determined by WRAP modeling, were also utilized. However, 2013 light extinction relied upon method 8, which relies on the equation:

$$\begin{aligned} b_{ext} = {} & 2.2 f_s(RH)[NH_4(SO_4)_2]_{Small} + 4.8 f_L(RH)[NH_4(SO_4)_2]_{Large} \\ & + 2.4 f_s(RH)[NH_4NO_3]_{Small} + 5.1 f_L(RH)[NH_4NO_3]_{Large} \\ & + 2.8[OC]_{Small} + 6.1[OC]_{Large} + 10[EC] + 1[PMF] + 0.6[PMC] \\ & + 1.4 f_{SS}(RH)[Sea\ Salt] + b_{Site-specific\ Rayleigh\ Scattering} + 0.33[NO_2] \end{aligned}$$

[22] Emission rates reported in Table 9 are not directly comparable to emission factors reported in Table 1. 2008 – 2010 CAMD data was utilized, when available, for 2013 modeling, while Table 1 utilizes average emission factors and heat rates.

[23] Environmental Protection Agency, 2005. Regional Haze Regulations and Guidelines for BART Determinations. 70 Fed. Reg. 39104, 39129.

Table 8: Stack parameters used in 2007 and 2013 CALPUFF modeling.

Scenario	Source	Hs (m)	Elev (m)	Ds (m)	Vs (m/s)	Ts (K)
2007 Baseline	ST1	47.854	1278.03	2.438	27.61	409
	ST2	120.091	1280.16	5.05	17.68	330
	ST3	120.091	1280.16	5.05	17.68	330
2007 LNB with OFA	ST1	47.854	1278.03	2.438	27.61	409
	ST2	120.091	1280.16	5.05	17.68	330
	ST3	120.091	1280.16	5.05	17.68	330
2007 SCR	ST1	47.854	1278.03	2.438	27.61	409
	ST2	120.091	1280.16	5.05	17.68	330
	ST3	120.091	1280.16	5.05	17.68	330
2013 Baseline	ST1	47.85	1278.03	2.44	27.61	409.26
	ST2	120.090	1280.16	5.05	17.68	330.37
	ST3	120.090	1280.16	5.05	17.68	330.37
EPA LNB & OFA	ST1	47.85	1278.03	2.44	27.61	409.26
	ST2	120.09	1280.16	5.05	17.68	330.37
	ST3	120.09	1280.16	5.05	17.68	330.37
2013 SCR	ST1	47.85	1278.03	2.44	27.61	409.26
	ST2	120.09	1280.16	5.05	17.68	330.37
	ST3	120.09	1280.16	5.05	17.68	330.37
2013 9bv2 PNGt	ST1	47.85	1278.03	2.44	27.61	409.26
	ST2	120.090	1280.16	5.05	17.68	394.26
	ST3	120.090	1280.16	5.05	17.68	330.37

Table 9: 2013 EPA and AEPCO Modeled Emission Rates [g/s].

Scenario	Unit	SO_2	SO_4	NO_x	HNO_3	NO_3	PMF	PMC	EC	SOA
2013 Baseline	**ST1**	0.045	0.266	3.921	0	0	0.354	0.142	0.028	0.047
	ST2	41.439	2.588	161.001	0	0	3.547	4.604	0.136	0.647
	ST3	41.173	2.571	134.814	0	0	3.524	4.575	0.135	0.643
EPA LNB & OFA	**ST1**	0.045	0.266	3.921	0	0	0.354	0.142	0.028	0.047
	ST2	41.439	2.588	112.703	0	0	3.547	4.604	0.136	0.647
	ST3	41.173	2.571	94.372	0	0	3.524	4.575	0.135	0.643
2013 SCR	**ST1**	0.045	0.266	3.921	0	0	0.354	0.142	0.028	0.047
	ST2	41.439	3.311	30.59	0	0	3.547	4.604	0.136	0.647
	ST3	41.173	3.29	21.57	0	0	3.524	4.575	0.135	0.643
2013 9bv2 PNGt	**ST1**	0.045	0.266	3.921	0	0	0.354	0.142	0.028	0.047
	ST2	0.177	0.088	36.869	0	0	0	0	0.553	1.587
	ST3	41.173	2.571	69.492	0	0	3.524	4.575	0.135	0.643

III.C. Modeled Class I Area Visibility Impacts

ADEQ recognizes the differences that occurred between the 2007 and 2013 CALPUFF modeling runs. Due to these differences, ADEQ has chosen to focus on examining 2013 modeling scenarios in order to have directly comparable results from modeled control technologies. Specifically, in this section, ADEQ will compare the 2013 AEPCO modeling runs for the Baseline, SCR, and 9bv2 PNGt scenarios (for which EPA performed verification modeling to confirm all results) as well as the 2013 EPA LNB & OFA scenario.

Estimated visibility impacts on affected Class I areas are presented in this section for the 2013 AEPCO and EPA modeling results. 2013 CALPUFF modeled results for the EPA LNB & OFA scenarios are compared to AEPCO's 2013 modeled Baseline, SCR, and 9bv2 PNGt scenarios, assuming a constant ammonia background concentration of 1 ppb. While ADEQ supports the use of monthly varying background ammonia concentrations in order to most accurately model Apache Generating Station impacts on affected Class I areas, EPA did not present verification modeling results consistent with this method. However, all other 2013 AEPCO modeling scenarios analyzed in this section were verified by EPA modeling with a constant 1 ppb ammonia background. For this reason, ADEQ has decided to examine only the modeling results for those 2013 scenarios that assumed a constant background ammonia concentration of 1 ppb[24].

2013 AEPCO and EPA modeled runs assessed control technology visibility enhancements through the concurrent modeling of ST1, ST2, and ST3. Therefore, Table 10 presents the 98th percentile annual average and 22nd highest combined three year deciview (dv) facility-wide impacts from 2001 to 2003 for each control technology on affected Class I areas as determined through CALPUFF modeling. While modeled for 2007, visibility impacts at Pine Mountain Wilderness were not assessed in the 2013 modeling runs.

[24] While ADEQ does not examine the effect of monthly varying background ammonia concentrations for comparative purposes in this document, AEPCO modeling exhibited a greater visibility improvement at class I areas when modeling monthly varying background ammonia concentrations as compared to constant background concentrations of 1 ppb.

Table 10: Apache Generating Station modeled facility-wide visibility impacts on affected Class I areas. "Avg 98th" refers to the average of the annual 98th percentile visibility impacts in deciviews (dv) from 2001-2003. "22nd high" refers to the 22nd highest visibility impact in deciviews for combined 2001-2003 data. In all modeling scenarios, background ammonia concentrations are 1 ppb for Method 8 estimations using best 20% days visibility background.

	2013 Baseline		**EPA LNB & OFA**		**2013 SCR**		**2013 9bv2 PNGt**	
Site	**Avg 98th**	**22nd high**	**Avg 98th**	**22nd high**	**Avg 98th**	**22nd high**	**Avg 98th**	**22nd high**
Chiricahua NM	3.328	3.409	2.884	2.973	1.978	1.996	1.882	1.909
Chiricahua WA	3.418	3.464	2.907	2.932	1.886	1.979	1.851	1.852
Galiuro WA	2.178	2.219	1.809	1.826	1.208	1.205	1.111	1.135
Gila WA	0.642	0.629	0.489	0.493	0.262	0.279	0.287	0.295
Mazatzal WA	0.266	0.277	0.222	0.229	0.156	0.147	0.126	0.124
Mt. Baldy WA	0.269	0.282	0.209	0.217	0.109	0.114	0.112	0.116
Saguaro NP	2.502	2.493	2.151	2.117	1.421	1.463	1.346	1.317
Sierra Ancha WA	0.289	0.287	0.225	0.229	0.153	0.158	0.130	0.128
Superstition WA	0.596	0.612	0.482	0.512	0.313	0.315	0.275	0.283
Average	**1.499**	**1.519**	**1.264**	**1.281**	**0.832**	**0.851**	**0.791**	**0.795**

III.D. Control Technology Effectiveness Comparison

ADEQ recognizes the differences that occurred between the 2007 and 2013 CALPUFF modeling runs. Due to these differences, ADEQ has chosen to focus on examining 2013 modeling scenarios in order to have directly comparable results from modeled control technologies. Specifically, in this section, ADEQ presents the 2013 AEPCO modeled visibility percent improvements as referenced to the 2013 Baseline scenario following LNB & OFA, SCR, and 9bv2 PNGt controls implementation.

Facility-wide 2013 CALPUFF modeling results are presented for control technology implementation as compared to 2013 baseline visibility impacts in Table 11. In these scenarios, the average affected Class I area visibility enhancement was modeled to be approximately 18.2% or 17.7% when ADEQ's BART (LNB and OFA) is implemented at the facility. EPA's BART (SCR) implementation at the facility results in a 47.5% or 47.4% visibility enhancement from Baseline visibility impacts. The AEPCO alternative control methodology (9bv2 PNGt) resulted in slightly better modeled visibility enhancement as compared to SCR implementation. AEPCO modeling estimated that the implementation of this technology would result in an average visibility enhancement across affected Class I areas of approximately 51.1% or 51.4%. In addition to average statewide visibility improvements, Table 11 presents the visibility improvements at individual Class I areas, as compared to Baseline impacts, for the three control technology scenarios mentioned above. Seven of the nine Class I areas modeled showed greater visibility enhancement with the implementation of the AEPCO alternative control technology as compared to EPA's BART.

Table 11: Apache modeled facility-wide visibility enhancements in affected Class I areas with the implementation of LNB, SCR, and the AEPCO alternative control technology as compared to Baseline visibility impacts. "Avg 98th" refers to the average of the annual 98th percentile visibility impacts from 2001-2003. "22nd high" refers to the 22nd highest visibility impact for combined 2001-2003 data.

	EPA LNB & OFA		**2013 SCR**		**2013 9bv2 PNGt**	
Site	**Avg 98th**	**22nd high**	**Avg 98th**	**22nd high**	**Avg 98th**	**22nd high**
Chiricahua NM	13.4%	12.8%	40.6%	41.4%	43.4%	44.0%
Chiricahua WA	14.9%	15.4%	44.8%	42.9%	45.8%	46.5%
Galiuro WA	16.9%	17.7%	44.5%	45.7%	49.0%	48.9%
Gila WA	23.9%	21.6%	59.2%	55.6%	55.3%	53.1%
Mazatzal WA	16.7%	17.3%	41.4%	46.9%	52.6%	55.2%
Mt. Baldy WA	22.4%	23.0%	59.5%	59.6%	58.4%	58.9%
Saguaro NP	14.0%	15.1%	43.2%	41.3%	46.2%	47.2%
Sierra Ancha WA	22.0%	20.2%	47.1%	44.9%	55.0%	55.4%
Superstition WA	19.1%	16.3%	47.5%	48.5%	53.9%	53.8%
Average	**18.2%**	**17.7%**	**47.5%**	**47.4%**	**51.1%**	**51.4%**

IV. Conclusions

Installation of BART for certain large Electric Generating Units (EGUs) is required by EPA under the 1999 Regional Haze rule requirements (64 FR 35765) in an effort to abate anthropogenic visibility degradation in national Class I areas. In 2005, this rule was amended (70 FR 39156) to allow for the use of control techniques and technologies which, when implemented, would achieve greater reasonable progress towards the reduction of anthropogenic visibility degradation than would be achieved through the installation and operation of BART. On May 29th, 2013, AEPCO provided ADEQ and EPA with a proposed BART alternative for the Apache Generating Station to achieve visibility enhancement in Class I areas exceeding those which would be realized through the installation of ADEQ's and EPA's BART technologies. In this document, ADEQ has identified modeling parameter and input changes between the Apache CALPUFF runs of 2007 and 2013. Since AEPCO slightly altered modeling inputs between the 2007 and 2013 modeling runs, ADEQ chose to use AEPCO and EPA 2013 modeling runs for a comparison of AEPCO's proposed BART alternative with ADEQ's BART and EPA's BART. The modeling input changes between the 2007 and 2013 modeling runs are viewed by ADEQ as enhancements to modeling methodology which should increase the accuracy of the 2013 modeling runs as compared to the 2007 modeling runs. ADEQ therefore recognizes the modeling scenarios utilized in the above comparisons as the most accurate and reasonable for a direct BART alternative determination.

Section II of this document outlined the baseline emissions of NO_x, SO_2, and PM_{Total} and the emissions calculated with the implementation of LNB & OFA, SCR, and AEPCO's alternative control technology (9bv2 PNGt). 2013 modeling scenario total NO_x emissions from ST2 and ST3 from the above listed scenarios were 5,441 tpy; 3,809 tpy; 939 tpy; and 2,122 tpy, respectively. In addition, AEPCO's alternative control resulted in reductions of 957 tpy of SO_2 and 141 tpy of PM_{Total}, while LNB & OFA and SCR resulted in no significant additional emissions reductions for these pollutants as compared to Baseline emissions.

While AEPCO's alternative control technology resulted in drastically reduced emissions as compared to the Baseline emissions scenario (i.e. current state of operation) and resulted in reduced emissions as compared to LNB & OFA, the emissions distribution for this control technology varied greatly from SCR. Modeling analysis of these scenarios was performed to supplement the emissions calculation evaluation. The modeling of these scenarios support "Better-than-BART" determination by satisfying 40 CFR § 308(e)(2)(i)(E) by modeling the determination approach generally in accordance with § 308(e)(3). While § 308(e)(3) does not directly apply, the analysis presented above is in line with § 308(e)(3), which uses a two-pronged approach of insuring:

i. Visibility does not decline in any Class I area, and
ii. There is an overall improvement in visibility, determined by comparing the average differences between BART and the alternative over all affected Class I areas.

2013 CALPUFF modeling assessed the visibility impacts of ADEQ's BART (LNB and OFA), EPA's BART (SCR) installation, and AEPCO's alternative control methodology implementation to a baseline scenario. All three scenarios showed no decline in any Class I area visibility through implementation and an overall improvement in visibility in all affected Class I areas. SCR and the AEPCO proposed BART alternative exceeded the modeled visibility benefits of LNB and OFA implementation at all affected Class I areas. AEPCO's alternative control methodology (9bv2 PNGt) was found to be comparable to SCR and actually modeled an average visibility enhancement at Class I areas when compared to SCR. Therefore, ADEQ concludes that the installation and implementation of AEPCO's alternative control methodology results in "better-than-BART" visibility improvements at affected Class I areas as compared to ADEQ's BART and EPA's BART technologies. Furthermore, as the greatest visibility improvement of any of the control technologies tested for the Apache Generating Station was found to occur from the AEPCO alternative control methodology, ADEQ concludes that the implementation and installation of this technology will result in "greater reasonable progress" towards natural visibility conditions in affected Class I areas than would either previously determined BART technologies.

Finally, AEPCO has requested in their submitted administrative reconsideration documentation a 30-day rolling average NO_x emission limit of 0.23 lb/MMBtu for ST3 due to a perceived inability to achieve the modeled 0.225 lb/MMBtu emission rate at all times. While this emission limit does not match the emission rate modeled in scenario 9bv2 PNGt, the modeled emission rate of 0.225 lb/MMBtu represents 97.8% of the NO_x emissions modeled for this unit. ADEQ expects remodeling of this scenario to result in approximately equivalent visibility enhancement as compared to SCR.

Appendix A

Average annual ammonium sulfate and ammonium nitrate extinction (Mm^{-1}) measured at all affected class I areas between 2000 and 2010

Ammonium Sulfate Extinction (Mm^{-1})												
Best 20% Days												
Site	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Average
Chiricahua NM, Chiricahua WA, Galiuro WA (CHIR1)	2.5	2.2	2.5	2.2	2.1	2.4	2.3	2.0	1.7	2.3	2.0	2.2
Saguaro NP (SAGU1)	--	--	3.0	2.3	2.7	3.5	3.4	2.3	2.0	2.6	2.0	2.6
Gila WA, NM (GICL1)	--	2.3	1.8	1.4	1.9	2.0	1.9	1.6	1.3	1.8	1.6	1.8
Superstition WA (TONT1)	--	3.1	3.1	2.3	2.6	2.8	3.0	2.3	2.5	2.3	2.3	2.6
Mt. Baldy WA (BALD1)	--	2.1	1.4	1.4	1.7	1.7	1.7	1.4	1.2	1.9	1.7	1.6
Sierra Ancha WA (SIAN1)	--	2.3	2.3	1.8	2.3	2.0	2.3	1.8	1.6	1.7	2.2	2.0
Mazatzal WA, Pine Mt WA (IKBA1)	--	2.5	2.2	1.8	2.4	2.1	2.5	1.9	1.5	1.8	1.8	2.1
Site Average		**2.4**	**2.3**	**1.9**	**2.2**	**2.4**	**2.4**	**1.9**	**1.7**	**2.1**	**1.9**	**2.1**

Ammonium Sulfate Extinction (Mm^{-1})												
Worst 20% Days												
Site	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Average
Chiricahua NM, Chiricahua WA, Galiuro WA (CHIR1)	8.7	8.5	7.8	8.6	7.0	10.6	8.3	10.7	9.0	7.0	7.9	8.6
Saguaro NP (SAGU1)	--	--	8.3	7.8	6.1	10.6	6.6	7.9	6.1	5.7	7.0	7.3
Gila WA, NM (GICL1)	--	8.3	6.4	6.9	5.8	10.1	7.9	8.8	7.0	6.4	7.3	7.5
Superstition WA (TONT1)	--	7.0	7.5	6.9	7.3	11.0	8.1	9.0	7.9	6.5	7.2	7.8
Mt. Baldy WA (BALD1)	--	6.8	6.5	5.9	5.5	9.2	6.0	6.8	5.1	5.3	5.8	6.3
Sierra Ancha WA (SIAN1)	--	6.4	7.1	6.3	5.8	9.5	5.6	8.0	7.4	5.2	6.0	6.7
Mazatzal WA, Pine Mt WA (IKBA1)	--	6.3	7.4	6.2	6.1	9.1	6.9	8.1	7.6	5.7	5.7	6.9
Site Average		**7.2**	**7.3**	**6.9**	**6.2**	**10.0**	**7.1**	**8.5**	**7.2**	**6.0**	**6.7**	**7.3**

Ammonium Sulfate Extinction (Mm^{-1})												
All Days												
Site	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Average
Chiricahua NM, Chiricahua WA, Galiuro WA (CHIR1)	5.6	5.1	5.3	5.1	4.6	5.7	5.0	5.4	4.9	4.5	4.4	5.1
Saguaro NP (SAGU1)	--	--	5.2	5.2	4.5	6.1	5.1	5.1	4.4	4.1	4.3	4.9
Gila WA, NM (GICL1)	--	4.8	4.3	4.0	3.9	5.2	4.3	4.5	4.0	3.9	3.8	4.3
Superstition WA (TONT1)	--	5.0	5.1	4.7	4.8	6.4	5.5	5.5	5.4	4.5	4.6	5.2
Mt. Baldy WA (BALD1)	--	4.2	3.8	3.7	3.6	5.0	3.8	4.0	3.7	3.3	3.4	3.9
Sierra Ancha WA (SIAN1)	--	4.4	4.2	4.0	4.0	5.3	4.4	4.6	4.4	3.8	3.8	4.3
Mazatzal WA, Pine Mt WA (IKBA1)	--	4.7	4.3	4.1	4.5	5.1	4.7	4.9	4.6	3.9	3.8	4.5
Site Average		**4.7**	**4.6**	**4.4**	**4.3**	**5.5**	**4.7**	**4.9**	**4.5**	**4.0**	**4.0**	**4.6**

Ammonium Nitrate Extinction (Mm^{-1})												
Best 20% Days												
Site	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Average
Chiricahua NM, Chiricahua WA, Galiuro WA (CHIR1)	0.5	0.6	0.6	0.5	0.6	0.5	0.4	0.4	0.3	0.4	0.4	0.5
Saguaro NP (SAGU1)	--	--	0.8	1.2	0.9	1.0	0.8	0.8	0.7	0.6	0.7	0.8
Gila WA, NM (GICL1)	--	0.4	0.3	0.2	0.4	0.3	0.3	0.2	0.2	0.2	0.3	0.3
Superstition WA (TONT1)	--	1.2	0.9	1.1	0.6	0.7	0.5	0.8	1.0	0.5	0.9	0.8
Mt. Baldy WA (BALD1)	--	0.6	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.5	0.4
Sierra Ancha WA (SIAN1)	--	0.9	0.8	0.8	0.9	0.4	0.4	0.5	0.5	0.4	0.8	0.6
Mazatzal WA, Pine Mt WA (IKBA1)	--	1.1	0.9	0.8	0.6	0.8	1.0	0.8	0.6	0.4	0.5	0.8
Site Average		**0.8**	**0.7**	**0.7**	**0.6**	**0.6**	**0.5**	**0.5**	**0.5**	**0.4**	**0.6**	**0.6**

Ammonium Nitrate Extinction (Mm^{-1})												
Worst 20% Days												
Site	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Average
Chiricahua NM, Chiricahua WA, Galiuro WA (CHIR1)	1.1	0.9	1.9	1.5	1.4	1.0	1.7	1.1	1.1	1.4	1.2	1.3
Saguaro NP (SAGU1)	--	--	6.4	6.7	4.2	2.0	3.1	3.0	2.7	2.2	3.7	3.8
Gila WA, NM (GICL1)	--	0.6	1.0	1.1	0.9	0.6	0.7	0.9	0.8	0.9	0.7	0.8
Superstition WA (TONT1)	--	2.9	3.2	3.1	3.0	1.8	3.2	2.7	2.7	2.1	1.6	2.6
Mt. Baldy WA (BALD1)	--	0.9	1.2	1.4	1.0	0.7	0.9	1.3	0.8	1.2	0.8	1.0
Sierra Ancha WA (SIAN1)	--	1.9	2.3	2.2	2.2	1.5	1.9	2.2	1.6	1.9	1.4	1.9
Mazatzal WA, Pine Mt WA (IKBA1)	--	2.2	3.1	3.6	5.2	1.4	3.4	2.7	2.2	2.0	1.9	2.8
Site Average		**1.6**	**2.7**	**2.8**	**2.6**	**1.3**	**2.1**	**2.0**	**1.7**	**1.7**	**1.6**	**2.0**

Ammonium Nitrate Extinction (Mm^{-1})												
All Days												
Site	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Average
Chiricahua NM, Chiricahua WA, Galiuro WA (CHIR1)	0.9	0.7	1.2	0.9	0.9	0.8	0.9	0.9	0.6	0.7	0.7	0.8
Saguaro NP (SAGU1)	--	--	2.4	2.4	1.9	1.5	1.7	1.6	1.5	1.3	1.6	1.8
Gila WA, NM (GICL1)	--	0.6	0.7	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.5
Superstition WA (TONT1)	--	1.9	1.8	1.8	1.6	1.3	1.6	1.6	1.5	1.2	1.0	1.5
Mt. Baldy WA (BALD1)	--	0.8	0.9	0.9	0.7	0.7	0.6	0.7	0.7	0.7	0.6	0.7
Sierra Ancha WA (SIAN1)	--	1.4	1.6	1.5	1.4	1.0	1.1	1.2	1.1	1.0	0.9	1.2
Mazatzal WA, Pine Mt WA (IKBA1)	--	1.9	1.8	1.9	2.2	1.2	1.6	1.7	1.4	1.2	1.1	1.6
Site Average		**1.2**	**1.5**	**1.4**	**1.3**	**1.0**	**1.1**	**1.2**	**1.0**	**0.9**	**0.9**	**1.2**

APPENDIX B

Arizona Electric Power Cooperative Inc.
Apache Generating Station
Permit Revision

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ARIZONA DEPARTMENT
OF
ENVIRONMENTAL QUALITY

1110 West Washington Street • Phoenix, Arizona 85007
(602) 771-2300 • www.azdeq.gov

Janice K. Brewer
Governor

Henry R. Darwin
Director

CERTIFIED MAIL
RETURN RECEIPT REQUESTED

May 13, 2014

Michael D. Nelson
Arizona Electric Power Cooperative
P. O. Box 670
Benson, AZ 85602

Dear Mr. Nelson:

Subject: Significant Revision No. 59195 to Air Quality Control Permit No. 55412
Apache Generating Station - Place ID: 3532

The Arizona Department of Environmental Quality has received payment of the fee requested. Enclosed is a significant permit revision for the referenced facility. In accordance with Arizona Revised Statutes, §49-430, this significant permit revision should be readily available at all times on the premises.

This significant permit revision remains in effect until the expiration of Air Quality Control Permit No. 55412. Please continue to keep us informed of any changes that would affect your air pollution status during this period.

This decision is an appealable agency action under A.R.S. § 41-1092. You have a right to request a hearing and file an appeal under A.R.S. § 41-1092.03(B). You must file a written Request for Hearing or Notice of Appeal within **30 days** of your receipt of this Notice. A Request for Hearing or Notice of Appeal is filed when it is received by ADEQ's Hearing Administrator as follows:

Hearing Administrator
Office of Administrative Counsel
Arizona Department of Environmental Quality
1110 W. Washington Street
Phoenix, AZ 85007

The Request for Hearing or Notice of Appeal shall identify the party, the party's address, the agency and the action being appealed and shall contain a concise statement of the reasons for the appeal. Upon proper filing of a Request for Hearing or Notice of Appeal, ADEQ will serve a Notice of Hearing on all parties to the appeal. If you file a timely Request for Hearing or Notice of Appeal you have a right to request an informal settlement conference with ADEQ under A.R.S. § 41-1092.06. This request must be made in writing no later than **20 days** before a scheduled hearing and must be filed with the Hearing Administrator at the above address.

You are advised that a permit is a legally enforceable document. If your facility fails to comply with the provisions contained in its permit, you will be subject to enforcement action and could incur civil fines of

up to ten thousand dollars per day under A.R.S. §49-463 and/or be subject to criminal penalties in accordance with A.R.S. §49-464.

If you have any questions, contact Naveen Savarirayan in the Air Permits Section at (602) 771 - 2285.

Sincerely,

Eric C. Massey, Director
Air Quality Division

ECM: NS3

Enclosures (2): Significant Permit Revision No.: 59195
Technical Support Document (TSD)

ARIZONA DEPARTMENT OF ENVIRONMENTAL QUALITY
Air Quality Division
1110 W. Washington Street Phoenix, AZ 85007 Phone: (602) 771-2338

SIGNIFICANT PERMIT REVISION TO AIR QUALITY CONTROL PERMIT

(As required by Title 49, Chapter 3, Article 2, Section 49-426, Arizona Revised Statutes)

This air quality control permit does not relieve applicant of responsibility for meeting all air pollution regulations

1. PERMIT TO BE ISSUED TO (Business license name of organization that is to receive permit) **Arizona Electric Power Cooperative**

2. NAME (OR NAMES) OF OWNER OR PRINCIPALS DOING BUSINESS AS THE ABOVE ORGANIZATION

3. MAILING ADDRESS **P. O. Box 670**
Benson, AZ 85602

4. EQUIPMENT LOCATION/ADDRESS **3525 N. Highway 191 South**
Cochise, Cochise County, AZ 85606

5. FACILITIES OR EQUIPMENT DESCRIPTION **Electric Power Generating Facility**

6. THIS PERMIT ISSUED SUBJECT TO THE FOLLOWING ***Conditions as described in the attached revision***

7. ADEQ SIGNIFICANT REVISION NUMBER **59195 (Revision to Permit # 55412)** PERMIT CLASS **I**

SIGNIFICANT REVISION ISSUED THIS 13th DAY OF May, 2014

SIGNATURE

Eric C. Massey, Director, Air Quality Division
TITLE

SIGNIFICANT PERMIT REVISION DESCRIPTION

This Significant Permit Revision No. 59195 to Operating Permit No. 55412 is to be issued to the Arizona Electric Power Cooperative (AEPCO) for its Apache Generating Station to authorize a change for Steam Unit 2 (ST2) from coal to combusting pipeline natural gas, and to authorize a change in air pollution control for Steam Unit 3 (ST3) to selective non-catalytic reduction (SNCR) and the use of low NO_X burners. Additionally, this revision sets specific emission limits for Steam Unit 1 (ST1) in stand alone operation and for ST1 and Gas Turbine 1 (GT1) in combined Cycle mode. The proposed changes satisfy all requirements for a significant permit revision under Arizona Administrative Code, Title 18, Chapter 2, Section 320 (A.A.C. R18-2-320.A).

The following attachment has been added as follows:

ATTACHMENT "E"

SPECIFIC CONDITIONS

Addenda (Significant Revision #59195) to Operating Permit # 55412

For

Arizona Electric Power Cooperative, Inc. - Apache Generating Station

I. Best Available Retrofit Technology Applicability and Effective Date

Attachment "E" shall become effective on the effective date of the Administrator's action approving it as part of the state implementation plan.

Where multiple emission limits, standards or requirements apply to a unit, the most stringent limit, standard or requirement controls.

II. Best Available Retrofit Technology for Steam Unit 1

A. Applicability

1. The BART limit for Steam Unit 1 will apply when Steam Unit 1 operates in stand-alone operation or when Steam Unit 1 and Gas Turbine 1 operate in combined cycle operation.

2. The BART limit does not apply to:

   a. Gas Turbine 1 in stand-alone simple cycle operation; or

   b. Steam Unit 1 and Gas Turbine 1 in combined warming/drying operation when Steam Unit 1 burners are shut off and Steam Turbine 1 is not producing electricity.

B. Best Available Retrofit Technology Limits

1. Steam Unit 1 shall combust only pipeline natural gas.

2. Steam Unit 1 shall not emit more than 0.00064 lb SO_2/MMBtu heat input in stand-alone operation or in combined cycle operation with Gas Turbine 1,

averaged over 30 boiler operating days.

3. Steam Unit 1 shall not emit more than 0.0075 lb PM_{10}/MMBtu heat input in stand-alone operation or in combined cycle operation with Gas Turbine 1, averaged over 30 boiler operating days.

4. Effective December 5, 2017, Steam Unit 1 shall not emit NO_X in stand-alone operation in excess of 0.056 lb/MMBtu heat input, averaged over 30 boiler operating days.

5. Effective December 5, 2017, Steam Unit 1 and Gas Turbine 1 in combined cycle operation shall not emit NO_X in excess of 0.10 lb/MMBtu heat input, averaged over 30 boiler operating days.

6. Effective December 5, 2017, Steam Unit 1 in stand-alone operation and Steam Unit 1 and Gas Turbine 1 in combined cycle operation shall not emit NO_X in excess of 1205 lb/day, averaged over 30 calendar days.

7. The Permittee may comply with the limits in Section II through any combination of process adjustments or add-on controls, provided that such combination achieves the emission limit (on a 30-day rolling average basis), complies with applicable regulations and permits and the Permittee obtains any necessary preconstruction or operating approvals.

III. Best Available Retrofit Technology for Steam Units 2 and 3

A. Compliance with Best Available Retrofit Technology Limits on NO_X emissions from Steam Units 2 and 3

1. Compliance during a boiler operating day when both units are operating is demonstrated when either of the following conditions is met:

   a. The combined NO_X emissions of Steam Units 2 and 3 meet the combined limit in Condition III.D; or

   b. Each unit meets its individual NO_X limit in Conditions III.B and III.C.

2. Compliance during a boiler operating day when only one unit is operating is demonstrated when the operating unit meets its individual NO_X limit specified in Condition III.B or III.C.

3. Except as provided in Conditions III.B.2 and III.C.2, the Permittee may comply with the limits in Section III through any combination of process adjustments or add-on controls (or use of pipeline quality natural gas in lieu of coal in Steam Unit 3), provided that such combination achieves the emission limit (on a 30-day rolling average basis), complies with applicable regulations and permits, and the Permittee obtains any necessary preconstruction or operating approvals.

B. Best Available Retrofit Technology Limits for Steam Unit 2

1. Effective December 5, 2016, Steam Unit 2 shall not emit SO_2 in excess of 0.15 lb/MMBtu heat input, averaged over 30 boiler operating days and shall not emit PM_{10} in excess of 0.03 lb/MMBtu heat input (filterable only), averaged over 30 boiler operating days.

2. Effective December 5, 2017, Steam Unit 2 shall burn only pipeline quality natural gas except in the event of an emergency as defined in Section III.E.

3. Effective December 5, 2017, Steam Unit 2 shall not emit NO_X in excess of 0.085 lb/MMBtu heat input, averaged over 30 boiler operating days, SO_2 in excess of 0.00064 lb/MMBtu heat input, averaged over 30 boiler operating days, and PM_{10} in excess of 0.01 lb/MMBtu heat input (filterable + condensable), averaged over 30 boiler operating days.

4. Effective December 5, 2018, Steam Unit 2 shall not emit PM_{10} in excess of 0.008 lb/MMBtu heat input (filterable + condensable), averaged over 30 boiler operating days.

C. Best Available Retrofit Technology Limits for Steam Unit 3

1. Effective December 5, 2016, Steam Unit 3 shall not emit SO_2 in excess of 0.15 lb/MMBtu heat input, averaged over 30 boiler operating days and shall not emit PM_{10} in excess of 0.03 lb/MMBtu heat input (filterable only), averaged over 30 boiler operating days.

2. Effective no later than December 5, 2017, Steam Unit 3 shall install, operate and maintain low NO_X burners, overfire air, and selective non-catalytic reduction (SNCR) technology. The SNCR shall operate at all times that Steam Unit 3 is in operation and exhaust gas temperatures equal or exceed the manufacturer's recommended minimum temperature for operation of the SNCR technology.

3. Effective December 5, 2017, Steam Unit 3 shall not emit NO_X in excess of 0.23 lb/MMBtu heat input, averaged over 30 boiler operating days.

D. Best Available Retrofit Technology Limits for Combined Operation of Steam Units 2 and 3

Effective December 5, 2017, in lieu of the individual limits set forth for NO_X in Conditions III.B.3 and III.C.3, the combined NOx emissions of Steam Units 2 and 3, averaged over 30 boiler-operating days, shall not exceed the limit established in the following equation:

$$Limit = \frac{\left[\left(Unit\ 2\ MMBtu_{Gas} \times 0.085\ \frac{lb}{MMBtu_{Gas}}\right) + \left(Unit\ 2\ MMBtu_{Coal} \times 0.37\ \frac{lb}{MMBtu_{Coal}}\right) + \left(Unit\ 3\ MMBtu \times 0.23\ \frac{lb}{MMBtu}\right)\right]}{Unit\ 2\ MMBtu + Unit\ 3\ MMBtu}$$

E. Emergency Provision for Steam Unit 2

1. The Permittee will not operate Steam Unit 2 on coal after December 5, 2017 except in the event of a supply disruption caused by natural gas supplier or transporter pipeline failure, freeze-up or pipeline compression failure that reduces gas volume or gas pressure below that necessary for Apache Generating Station gas generation. The Permittee must discontinue coal firing as expeditiously as possible after restoration of natural gas service at levels supporting continuous firing of Steam Unit 2 and in no event more than 48 hours after restoration of such service.

2. During any such period of coal operation and for such period thereafter as provided in Section III.E.3, the Permittee shall comply with the emission limits set forth in Condition III.B.1 for PM_{10} and SO_2 and shall minimize NO_X emissions by use of good combustion practices and not to exceed 0.37

lb/MMBtu, averaged over 30 boiler-operating days.

3. Effective with the next boiler operating day after natural gas operation is restored for NO_X and SO_2, and within 90 boiler operating days after natural gas operation is restored for PM_{10}, the Permittee shall resume compliance with the applicable emissions limits set forth in Conditions III.B or III.D, as applicable.

IV. Compliance Determination

A. Continuous Emissions Monitoring System.

1. At all times, the Permittee shall maintain, calibrate, and operate a CEMS, in full compliance with the requirements found at 40 CFR Part 75, to accurately measure SO_2, NO_X, diluent, and stack gas volumetric flow rate from Steam Units 2 and 3. Steam Unit 2 is not subject to the requirements of this Condition IV.A for SO_2 upon its conversion to pipeline natural gas, but shall then comply with Condition IV.C.4.

2. At all times, the Permittee shall maintain, calibrate, and operate a CEMS, in full compliance with the requirements found at 40 CFR Part 75, to accurately measure NO_X, diluent, and stack gas volumetric flow rate from Steam Unit 1.

3. Except as provided herein, all valid CEMS hourly data shall be used to determine compliance with the emission limitations for NO_X and SO_2 (when applicable) in Sections II and III for each unit. When the CEMS is out-of-control as defined by Part 75, that CEMS data shall be treated as missing data and not used to calculate the emission average of the affected unit. Each required CEMS must obtain valid data for at least 90 percent of the unit operating hours, on an annual basis.

4. The Permittee shall comply with the quality assurance procedures for CEMS found in 40 CFR Part 75. In addition to these Part 75 requirements, relative accuracy test audits shall be calculated for both the NO_X and SO_2 pounds per hour measurement and the heat input measurement. The CEMs monitoring data shall not be bias adjusted.

5. Heat input for Steam Unit 1 and Gas Turbine 1 shall be measured in accordance with Part 75 fuel gas measurement procedures found in 40 CFR Part 75, Appendix D.

B. Compliance Determinations for NO_X.

1. Effective December 5, 2017, the 30-day rolling average NO_X emission rate for each of the following: stand-alone operation of Steam Unit 1, combined cycle operation of Steam Unit 1 and Gas Turbine 1, Steam Unit 2, Steam Unit 3, and combined Steam Units 2 and 3, shall be calculated for each calendar day that the unit operates in accordance with the following procedure:

   a. Step One: For each unit, sum the hourly pounds of NO_X emitted during the current boiler-operating day and the preceding twenty-nine (29) boiler operating days, to calculate the total pounds of NO_X emitted over the most recent thirty (30) boiler-operating day period for each unit, except that for Steam Unit 1 and Gas Turbine 1 during the combined warming/drying operation described in Condition II.A.2.b, all emissions are excluded;

b. Step Two: For each unit, sum the hourly heat input, in MMBtu, during the current boiler operating day and the preceding twenty nine (29) boiler-operating days, to calculate the total heat input, in MMBtu, over the most recent thirty (30) boiler-operating day period for each unit. For Steam Unit 1 and Gas Turbine 1 operating in combined cycle operation, MMBtu from both units shall be included in this calculation; but for Steam Unit 1 and Gas Turbine 1 operating in combined drying/warming operation, MMBtu from neither unit shall be included;

c. Step Three: For each unit, divide the total pounds of NO_X emitted by that unit from step one by the total heat input for that unit from step two to calculate each unit's 30-day rolling average NO_X emission rate, in pounds of NO_X per MMBtu, for each calendar day. This is the final step for determining whether Steam Unit 1 in stand-alone operation complies with the limits in Condition II.B.4, whether Steam Unit 1 and Gas Turbine 1 in combined cycle operation comply with the limits in Condition II.B.5, and whether Steam Units 2 and 3 comply with the limits in Conditions III.B or III.C;

d. Step Four: If demonstrating compliance for Steam Units 2 and 3 with the combined limit in Section III.D, sum together the total pounds of NO_X emitted from Steam Units 2 and 3 over each unit's most recent thirty (30) boiler-operating day period (the most recent 30 boiler operating day periods for different units may be different);

e. Step Five: Sum together the total heat input from Steam Units 2 and 3 over each unit's most recent thirty (30) boiler-operating day period;

f. Step Six: Divide the total pounds of NO_X emitted from step four for Steam Units 2 and 3 by the total heat input from step five for Steam Units 2 and 3, to calculate the combined 30-day rolling average NO_X emission rate for Steam Units 2 and 3, in pounds of NO_X per MMBtu, for each calendar day.

2. Effective December 5, 2017, for purposes of determining compliance with the limit in Condition II.B.6, the 30-day rolling average NO_X pound/day emission rate for stand-alone operation of Steam Unit 1 or combined cycle operation of Steam Unit 1 and Gas Turbine 1 shall be calculated for each calendar day in which either stand-alone or combined cycle operation occurs in accordance with the following procedure:

a. Sum the hourly pounds of NO_X emitted on that calendar day and the hourly pounds of NO_X emitted during the preceding twenty-nine (29) calendar days to calculate the total pounds of NOX emitted over the most recent thirty (30) calendar day period, except that for Steam Unit 1 and Gas Turbine 1 during the combined warming/drying operation described in Condition II.A.2.b, all emissions are excluded;

b. Divide the sum by 30 to calculate the 30-day rolling calendar day average pound/day emission rate for Steam Unit 1 in stand-alone operation and Steam Unit 1 and Gas Turbine 1 in combined cycle operation for comparison with the limit in Condition II.B.6.

3. For purposes of determining compliance with the limit in Condition II.B.4, only NO_X emissions generated and the heat input of fuel burned during periods when

Steam Unit 1 is operating in stand-alone operation shall be counted in the calculations required by Conditions IV.B.1.a through c.

4. For purposes of determining compliance with the limit in Condition II.B.5, only NO_X emissions generated and the heat input of fuel burned during periods when Steam Unit 1 and Gas Turbine 1 are operating in combined cycle operation shall be counted in the calculations required by Conditions IV.B.1.a through c.

5. Except as otherwise provided in this Condition IV.B, each 30-day rolling average NO_X emission rate shall include all emissions and all heat input that occur during all periods within any boiler-operating day, including emissions from startup, shutdown, and malfunction.

6. Compliance is demonstrated if:

   a. For Steam Unit 1:

      i. In stand-alone operation it meets its NO_X limit in Condition II.B.4 as calculated in Condition IV.B.1 step three; OR

      ii. In combined cycle operation with Gas Turbine 1 it meets the combined cycle NO_X lb/ton limit in Condition IV.B.5 as calculated in Condition IV.B.1 step three AND it meets the NO_X lb/day limit in Condition II.B.6 as calculated in Condition IV.B.2; OR

      iii. It is not operating during that calendar day.

   b. For Steam Units 2 and 3:

      i. Each operating unit meets its individual NO_X limit in Condition III.B or III.C respectively as calculated in step three; OR

      ii. The combined Steam Units 2 and 3 average meets its combined NO_X limit in Condition III.D as calculated in step six; OR

      iii. The unit is not operating during that calendar day.

7. If a valid NO_X pounds per hour or heat input is not available for any hour for a unit, that heat input and NO_X pounds per hour shall not be used in the calculation of the 30-day rolling average, except that if only NO_X pounds per hour data are available, it may be used to calculate compliance with the pound per day limit in Condition II.B.6, if applicable, in accordance with Condition IV.B.2.

C. Compliance Determinations for SO_2

1. Effective December 5, 2016, the 30-day rolling average SO_2 emission rate for Steam Units 2 and 3 shall be calculated for each calendar day on which the unit operates in accordance with the following procedure:

   a. Step One: Sum the total pounds of SO_2 emitted from the unit during the current boiler-operating day and the previous twenty-nine (29) boiler-operating days;

   b. Step Two: Sum the total heat input to the unit in MMBtu during the

current boiler-operating day and the previous twenty-nine (29) boiler-operating day;

c. Step Three: Divide the total number of pounds of SO_2 emitted during the thirty (30) boiler-operating days by the total heat input during the thirty (30) boiler-operating days. A new 30-day rolling average SO_2 emission rate shall be calculated for each new boiler-operating day.

2. Each 30-day rolling average SO_2 emission rate shall include all emissions and all heat input that occur during all periods within any boiler-operating day, including emissions from startup, shutdown, and malfunction.

3. If a valid SO_2 pounds per hour at the outlet of the FGD system or heat input is not available for any hour for a unit, that heat input and SO_2 pounds per hour shall not be used in the calculation of the 30-day rolling average.

4. Compliance is demonstrated if each operating unit meets its individual SO_2 limit in Condition III.B or III.C respectively as calculated in step three OR if the unit is not operating during that calendar day.

5. Steam Unit 1 and Steam Unit 2 (after conversion to pipeline natural gas) shall demonstrate compliance with the SO_2 limits through use of pipeline quality natural gas.

6. If Steam Unit 2 operates on coal pursuant to an emergency as defined in Condition III.E of this Attachment after its SO_2 CEMS is removed, the Permittee will demonstrate compliance with the SO_2 limits in Condition III.E.2 by calculating emissions based on the sulfur content of the coal on a lb/MMBtu basis multiplied by the number of MMBtu fired on coal multiplied by the overall sulfur removal efficiency of the Sulfur Dioxide Absorption System (SDAS) unit and converted to SO_2 and units of the standard.

D. Compliance Determinations for PM_{10}

1. Compliance with the particulate matter emission limitation for Steam Units 2 and 3 shall be determined from annual performance stack tests. Within one hundred eighty (180) days of the compliance deadline specified in Conditions III.B or III.C of this Attachment the Permittee shall conduct a stack test on Steam Unit 2 and 3 to measure PM_{10} using EPA Method 5, in 40 CFR part 60, Appendix A, or Method 201A/202 in 40 CFR Part 51, Appendix M.

2. Steam Unit 2, after conversion to pipeline natural gas, shall demonstrate compliance with its limits in Conditions III.B.1, III.B.3 and III.B.4 within 90 days of the effective dates specified in Conditions III.B.1, III.B.3 and III.B.4 respectively. Compliance for Steam Unit 2 shall be demonstrated using EPA Method 5, in 40 CFR part 60, Appendix A and Method 202, in 40 CFR Part 51, Appendix M, or EPA Method 201A/202 in 40 CFR Part 51, Appendix M.

3. After completion of the initial performance testing required in Conditions IV.D.1 and IV.D.2, compliance shall be determined in accordance to the following procedures:

a. For Steam Unit 1 and Steam Unit 2, the Permittee shall demonstrate compliance through use of pipeline quality natural gas.

b. For Steam Unit 3, the Permittee shall conduct a stack test on an annual basis to measure PM_{10} using EPA Method 5, in 40 CFR part 60, Appendix A, or Method 201A/202 in 40 CFR Part 51, Appendix M.

4. A test protocol shall be submitted to ADEQ a minimum of 30 days prior to the scheduled testing. The protocol shall identify which method(s) will be used to demonstrate compliance. Each test shall consist of three runs, with each run at least 120 minutes in duration and each run collecting a minimum sample of 60 dry standard cubic feet. Results shall be reported in lb/MMBtu using the calculation in 40 CFR Part 60 Appendix A Method 19.

5. In addition to required stack tests, the owner/operator shall monitor particulate emissions for compliance with the emission limitations in accordance with any applicable Compliance Assurance Monitoring (CAM) plan developed and approved in accordance with 40 CFR Part 64. The averaging time for any other demonstration of PM_{10} compliance or exceedance shall be based on a 6-hour average.

V. Recordkeeping, Reporting and Miscellaneous Provisions

A. Recordkeeping.

The Permittee shall maintain the following records for at least five (5) years:

1. All CEMS data, including the date, place, and time of sampling or measurement; parameters sampled or measured; and results.

2. Daily 30-day rolling emission rates for NO_X and SO_2, when applicable, for each unit, calculated in accordance with Section IV.

3. A log of each day when a unit does not operate.

4. Records of quality assurance and quality control activities for emissions measuring systems including, but not limited to, any records required by 40 CFR Part 75 and Section IV.

5. Records of all major maintenance activities conducted on Steam Units 1, 2 or 3, their associated air pollution control equipment, and CEMS.

6. Any other records required by 40 CFR Part 75.

7. A record of a current valid purchase contract, tariff sheet, transportation contract, or other acceptable documentation specifying the maximum total sulfur content of the pipeline natural gas. This record shall be updated annually.

B. Reporting

1. The Permittee shall notify the Director and EPA Region 9 within two weeks after completion of installation of combustion controls or Selective Non-Catalytic Reactors on any of the units subject to this Attachment.

2. Within 30 days after the applicable compliance date(s) in Conditions II.B, III.B, III.C and III.D, and within 30 days of every second calendar quarter thereafter (i.e., semi-annually), the Permittee shall submit a report that lists the daily 30-day rolling emission rates for NO_X and SO_2 for each unit, calculated in accordance

with Section IV of this Attachment. Included in this report shall be the results of any relative accuracy test audit performed during the two preceding calendar quarters. The Permittee may request, and the Department may authorize in writing, different semiannual reporting dates to harmonize with other semiannual reporting under the then-effective permit.

C. Equipment Operations.

At all times, including periods of startup, shutdown, and malfunction, the Permittee shall, to the extent practicable, maintain and operate the unit including associated air pollution control equipment in a manner consistent with good air pollution control practices for minimizing emissions. Pollution control equipment shall be designed and capable of operating properly to minimize emissions during all expected operating conditions. Determination of whether acceptable operating and maintenance procedures are being used will be based on information available to the Director, which may include, but is not limited to, monitoring results, review of operating and maintenance procedures, and inspection of the unit.

D. Affirmative Defense for Malfunctions

The following regulations are incorporated by reference and made part of this permit and state implementation plan:

1. R18–2–101, paragraph 65;

2. R18–2–310, sections (A), (B), (D) and (E) only; and

3. R18–2–310.01.

E. Definitions

Terms not defined below shall have the meaning given to them in the Clean Air Act or the Department's regulations implementing the Clean Air Act. For purposes of this Attachment:

Boiler-operating day:

Means a 24-hour period between 12 midnight and the following midnight during which any fuel is combusted at any time in the unit. For Steam Unit 1, boiler operating day does not include any day in which the only operation is the combined warming/drying operation with Gas Turbine 1 as defined in Condition II.A.2.b. For purposes of the limit in Condition II.B.4, "boiler operating days" shall include only those days during which Steam Unit 1 operates in stand-alone mode. For purposes of the limit in Condition II.B.5, "boiler operating days" shall include only those days during which Steam Unit 1 and Gas Turbine 1 operate in combined cycle mode.

Flue Gas Desulfurization System or FGD:

Means a pollution control device that employs flue gas desulfurization technology, including an absorber utilizing lime, fly ash, or limestone slurry, for the reduction of sulfur dioxide emissions.

Operating Hour:

Means any hour that fossil fuel is fired in the unit, except that for Steam Unit 1, operating hour does not include any hour in which the only operation is the combined warming/drying operation with Gas Turbine 1 as defined in Condition II.B.2.b.

Valid Data:

Means data recorded when the CEMS is not out-of-control as defined by Part 75.

TECHNICAL REVIEW AND EVALUATION OF APPLICATION FOR AIR QUALITY SIGNIFICANT PERMIT REVISION NO. 59195 TO OPERATING PERMIT NO. 55412

I. INTRODUCTION

This Significant Permit Revision No. 59195 to Operating Permit No. 55412 is to be issued to the Arizona Electric Power Cooperative (AEPCO) for its Apache Generating Station to authorize a change for Steam Unit 2 (ST2) from coal to combusting pipeline natural gas, and to authorize a change in air pollution control for Steam Unit 3 (ST3) to selective non-catalytic reduction (SNCR) and the use of low NO_X burners. Additionally, this revision sets specific emission limits for Steam Unit 1 (ST1) in stand alone operation and for ST1 and Gas Turbine 1 (GT1) in combined Cycle mode.

A. Company Information

Mailing Address: P.O. Box 670, Benson, AZ 85602

Facility Address: 3525 N. Hwy 191 South, Cochise, AZ 85606

B. Attainment Classification

This area is designated as attainment for all pollutants.

II. REVISION DESCRIPTION

A. Steam Unit 1

This revision sets emission rates for SO_2, PM_{10}, and NO_X. SO_2 and PM_{10} emission rates are set at 0.00064 and 0.0075 lb/MMBtu respectively. These emission rates are effective upon issuance of this revision. Effective December 5, 2017 this revision will set an emission rate for NO_X in stand alone operation to be 0.056 lb/MMBtu, and an emission rate for NO_X of 0.10 lb/MMBtu for operation in combined cycle mode with GT1. Additionally, effective December 5, 2017 a daily NO_X limit of 1,205 lbs averaged over 30 calendar days has been set for operation in both stand-alone mode and combined cycle mode with GT1.

B. Steam Unit 2

As part of this revision ST2 will be converted from coal to pipeline natural gas firing effective on December 5, 2017. Attachment "E" of this revision authorizes AEPCO the use of coal as a fuel in ST2 in the event of a natural gas disruption such as a pipeline freeze-up or break as further detailed in Attachment "E".

C. Steam Unit 3

This revision will authorize the facility to install and operate SNCR and low NO_X burners for the additional control of NO_x emissions from ST3 effective December 5, 2017. Additionally, the NO_x emission limit will be revised from 0.07 lb/MMBtu to 0.23 lb/MMBtu, based on a 30 boiler operating day average.

III. LIST OF ABBREVIATIONS

AEPCO	Arizona Electric Power Cooperative
GT1	Gas Turbine 1
Lb	Pound
Lb/MMBtu	Pound per Million Btu
NOx	Nitrogen Oxides
PM	Particulate Matter
SNCR	Selective Non-Catalytic Reduction
SO_2	Sulfur Dioxide
ST1	Steam Turbine 1
ST2	Steam Turbine 2
ST3	Steam Turbine 3

Appendix C

Public Process Documentation

Arizona State Implementation Plan Revision to the Arizona Regional Haze Plan for Arizona Electric Power Cooperative, Incorporated Apache Generating Station April 2014

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ADEQ Arizona Department of Environmental Quality
Janice K. Brewer, Governor
Henry R. Darwin, Director

PUBLIC NOTICE

PUBLIC NOTICE

YOU HAVE A VOICE IN AIR POLLUTION CONTROL IN ARIZONA

The Arizona Department of Environmental Quality (ADEQ) proposes two actions through this public notice; a revision to the Arizona State Regional Haze State Implementation Plan (SIP) and Significant Revision No. 59195 to Air Quality Control Permit No. 55412 for Arizona Electric Power Cooperative's (AEPCO) Apache Generating Station. AEPCO operates the Apache Generating Station located at 3525 N. Highway 191 South, Cochise, Cochise County, Arizona 85606. The mailing address for this facility is P. O. Box 670, Benson, AZ 85602. The Significant Revision to AEPCO's permit is intended as a component of the SIP revision in order to assist in satisfying the Arizona Regional Haze Best Available Retrofit Technology (BART) requirements. The Permit Revision changes AEPCO's Steam Unit 2, which normally burns coal, to only burn natural gas. Additionally, on Steam Unit 3, which burns coal, AEPCO will install selective non-catalytic reduction (SNCR), low NO_X burners and overfire air as additional air pollution control equipment. The facility emits the following air contaminants: particulate matter nominally less than 10 microns, particulate matter nominally less than 2.5 microns, volatile organic compounds, nitrogen oxides, sulfur dioxide, carbon monoxide, greenhouse gases, and hazardous air pollutants.

ADEQ will be holding a public hearing on Wednesday, March 26, 2014, at 6:00 PM at the City of Benson Council Chambers, 120 West 6th Street, Benson, AZ 85602. You have an opportunity to submit written comments on both the permit revision and the SIP revision or make oral comments at the public hearing. The written comment shall state the name and mailing address of the person, shall be signed by the person, their agent or attorney, and shall clearly set forth reasons why the permit revision should or should not be issued or why the SIP revision should not be finalized. Grounds for comment are limited to whether the permit revision and SIP revision meet the criteria for issuance spelled out in the state air pollution control laws or rules.

The draft permit, SIP revision and related documentation are available for review Monday through Friday between 8:30 a.m. and 4:30 p.m., at the ADEQ Records Center, at 1110 West Washington Street, Phoenix, Arizona. Please call (602) 771-4380 or email recordscenter@azdeq.gov 24 hours in advance to schedule an appointment to review the file. The documents are also available at the Benson City Clerks' Offices at 120 West 6th Street in Benson, AZ 85602. The draft permit revision and technical support document may be viewed online at http://azdeq.gov/cgi-bin/vertical.pl by accessing the notice on the Events and Notices Calendar for the date of this public notice. The proposed SIP revision can be viewed online at http://www.azdeq.gov/environ/air/plan/index.html by selecting Air Quality – Public Notices, Meetings, and Hearings.

The public notice period is in effect from February 19, 2014 to March 21, 2014. Comments may be submitted in writing to: Trevor Baggiore, Air Quality Division Deputy Director, ADEQ, 1110 West Washington Street, 3415A-1, Phoenix, AZ 85007 or via e-mail at Baggiore.Trevor@azdeq.gov. Persons wishing to submit written comments can also do so at the public hearing. Comments must be received by March 21, 2014.

ADEQ will consider all comments received in making a final decision on the proposed permit and SIP revisions. Everyone commenting will receive notification of the final decision. People who file comments on the permit revision will have the right to appeal the final decision as an appealable agency action to the Office of Administrative Hearing (OAH) pursuant to §41.1092.03, and the appeal must be filed within thirty (30) days after the issuance of the final decision. The OAH may sustain, modify, or reverse the final decision.

For questions or more information, or if you would like to receive copies of future public notices of air pollution control permits or air quality planning activities, please provide your name, address, and ZIP code, or e-mail address to Trevor Baggiore, (602) 771-2321, toll free (800) 234-5677, via e-mail Baggiore.Trevor@azdeq.gov or in writing to the ADEQ address above. In order to receive future public notices of air pollution control permits, your request should state that you wish your name to be placed on the air quality permit mailing list.

ADEQ
Arizona Department of Environmental Quality
Janice K. Brewer, Governor
Henry R. Darwin, Director

PUBLIC NOTICE

Persons with a disability may request a reasonable accommodation such as a sign language interpreter, by contacting Christina L. Weakland, (602) 771-4793, via email cw8@azdeq.gov. TDD line for hearing impaired individuals, (602) 771-4829. Requests should be made as early as possible to allow time to arrange the accommodation.

STATE OF ARIZONA)
:ss.
COUNTY OF COCHISE)

PUBLIC NOTICE

PUBLIC NOTICE
YOU HAVE A VOICE IN AIR POLLUTION CONTROL IN ARIZONA

The Arizona Department of Environmental Quality (ADEQ) proposes two actions through this public notice; a revision to the Arizona State Regional Haze State Implementation Plan (SIP) and Significant Revision No. 59195 to Air Quality Control Permit No. 55412 for Arizona Electric Power Cooperative's (AEPCO) Apache Generating Station. AEPCO operates the Apache Generating Station located at 3525 N. Highway 191 South, Cochise, Cochise County, Arizona 85606. The mailing address for this facility is P.O. Box 670, Benson, AZ 85602. The Significant Revision to AEPCO's permit is intended as a component of the SIP revision in order to assist in satisfying the Arizona Regional Haze Best Available Retrofit Technology (BART) requirements. The Permit Revision changes AEPCO's Steam Unit 2, which normally burns coal, to only burn natural gas. Additionally, on Steam Unit 3, which burns coal, AEPCO will install selective non-catalytic reduction (SNCR), low NOX burners and overfire air as additional air pollution control equipment. The facility emits the following air contaminants; particulate matter nominally less than 10 microns, particulate matter nominally less than 2.5 microns, volatile organic compounds, nitrogen oxides, sulfur dioxide, carbon monoxide, greenhouse gases, and hazardous air pollutants.

ADEQ will be holding a public hearing on Wednesday, March 26, 2014, at 6:00 PM at the City of Benson Council Chambers, 120 West 6th Street, Benson, AZ 85602. You have an opportunity to submit written comments on both the permit revision and the SIP revision or make oral comments at the public hearing. The written comment shall state the name and mailing address of the person, shall be signed by the person, their agent or attorney, and shall clearly set forth reasons why the permit revision should or should not be issued or, why the SIP revision should not be finalized. Grounds for comment are limited to whether the permit revision and SIP revision meet the criteria for issuance spelled out in the state air pollution control laws or rules.

The draft permit, SIP revision and related documentation are available for review Monday through Friday between 8:30 a.m. and 4:30 p.m. at the ADEQ Records Center, at 1110 West Washington Street, Phoenix, Arizona. Please call (602) 771-4380 or email recordscenter@azdeq.gov 24 hours in advance to schedule an appointment to review the file. The documents are also available at the Benson City Clerks' Offices at 120 West 6th Street in Benson, AZ 85602. The draft permit revision and technical support document may be viewed online at http://azdeq.gov/cgi-bin/vertical.pl by accessing the notice on the Events and Notices Calendar for the date of this public notice. The proposed SIP revision can be viewed online at http://www.azdeq.gov/environ/air/plan/index.html by selecting Air Quality – Public Notices, Meetings, and Hearings.

The public notice period is in effect from February 19, 2014 to March 21, 2014. Comments may be submitted in writing to: Trevor Bagglore, Air Quality Division Deputy Director, ADEQ, 1110 West Washington Street, 3415A-1, Phoenix, AZ 85007 or via e-mail at Bagglore.Trevor@azdeq.gov. Persons wishing to submit written comments can also do so at the pub-

like to receive copies of future public notices of air pollution control permits or air quality planning activities, please provide your name, address, and ZIP code, or e-mail address to Trevor Bagglore, (602) 771-2321, toll free (800) 234-5677, via e-mail Bagglore.Trevor@azdeq.gov or in writing to the ADEQ address above. In order to receive future public notices of air pollution control permits, your request should state that you wish your name to be placed on the air quality permit mailing list.

Persons with a disability may request a reasonable accommodation such as a sign language interpreter, by contacting Christina L. Weakland, (602) 771-4793, via email cw8@azdeq.gov. TDD line for hearing impaired individuals, (602) 771-4829. Requests should be made as early as possible to allow time to arrange the accommodation.

Publish: Feb. 19, 26, 2014
San Pedro Valley News-Sun

SARA BROWN **AFFIDAVIT OF PUBLICATION**

Sara Brown being first duly sworn, deposes and says: That (he) (she) is the Agent to the Publisher of the SAN PEDRO VALLEY NEWS-SUN and the ARIZONA RANGE NEWS newspapers printed and published weekly in the County of Cochise, State of Arizona, and of general circulation in the city of Benson, County of Cochise, State of Arizona and elsewhere, and hereto attached

ADEQ AIR POLLUTION
CONTROL IN ARIZONA
AEPCO

ADEQ AIR QUALITY DIVISION 14 FEB 27 AM 10:46

was printed and published correctly in the regular and entire issue of said SAN PEDRO VALLEY NEWS SUN and or ARIZONA RANGE NEWS for 2 issues, that the first was made on the 19th day of FEBRUARY 20 14

and the last publication thereof was made on the 26th day of FEBRUARY 20 14 that said publication was made on each of the following dates, to wit:

02/19/14
02/26/14

Request of
ADEQ-NEW SOURCE REVIEW/PE

San Pedro Valley News-Sun
Arizona Range News

By Sara Brown

Subscribed sworn to before me this 26th day of FEBRUARY 20 14

Jeff D McDole
Notary Public in and for the County of Cochise, State of Arizona

My Commission Expires: 9/25/15

JEFF D. MCDOLE
NOTARY PUBLIC - ARIZONA
Cochise County
My Commission Expires
September 25, 2015

ADEQ
Arizona Department of Environmental Quality

Air Quality Division
Sign-In Sheet

Please Sign In

SUBJECT: AEPCO Permit Revision/Regional Haze SIP Revision DATE: March 26, 2014

NAME	ORGANIZATION	PHONE	E-MAIL (Primary method of contact)
1. Walter J. Risch	Retired	686-0024	—
2. WENDY ERICA WEGRZYN	CONGRESSMAN BARBER	310-2755	WENDY.ERICA.WEGRZYN@MAIL.HOUSE.GOV
3. Ann English	Cochise County	432-9202	aenglish@cochise.az.gov
4. Heather Floyd	AZ G&T's	520 586-5431	hfloyd@sscw.coop
5. Geoff Oldfather	AZ G&Ts	520 444 8473	goldfather@sscw.coop
6. Alan & Pam Baker		(928) 310-4776	azgunsmith_14@yahoo.com
7. Dan Barrera	Self-employed	520-586-7021	ghrvpark@msn.com

Air Quality Division Sign-In Sheet – p __ of __

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8.	[illegible]	Benson Chamber of Commerce Grace Chapel	520 686-0490	charis@theriver.com
9.	Carol Kuipers	AZ G&T Cooperatives	520 4894134	ckuipers@ssw.coop
10.	Patrick Ledger	" "	520-586-5110	pledger@ssw.coop
11.	Barbara Stockwell	Trico Elec. Co-op.	520-398-9410	bstockwell@trico.coop
12.	Jim Andrew	AZ G&T COOPS	520 384 6517	JANDREW@AEPCO.COOP
13.	George Scott	SAEDC	265.6058	george@saedc.org
14.	John Shaver	AzGT	586-5332	jshaver@ssw.coop
15.	Kathleen Ortega	AZGT	520-586-5415	kortega@ssw.coop
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17.	Mike Nelson	AEPCO	520 384 4256	mnelson@aepco.coop
18.	WALTER BRAY	AEPCO	520 586 5201	wbray@ssw.coop
19.	HEWITT STUART	AEPCO	520 586 5331	hstuart@ssw.coop
20.	Rick Pocheber	Benson Hospital	520-891-1315	RPOCHEBER@BensonHosp.org
21.	Peter Scott	AZGT	520 6860919	pscott@ssw.coop

Air Quality Division Sign-In Sheet – p __ of __

	NAME	ORGANIZATION	PHONE	E-MAIL (Primary method of contact)
22.	Antonio Dias	Sierra Southwest	520-586-5316	ADIAS33 @ HOTMAIL.COM
23.	SHARI DIPESO	Sierra SW	520-909-0177	sldipeso @ gmail.com
24.	Emily Regis	AEPCO	520 586 5574	eregis@sswcoop
25.	JEFF Cook	BENSON City council	520-360-4856	JEFF.Cook@YAHOO.COM
26.	Susan Syfert	Candidate LD14 House	928.965.7242	susansyfert@gmail.com
27.	Jane Strain		520 249 4057	jstrain801@gmail.net
28.	Mark Grapp	Personal	520-720-9505	AZ Storage 411@gmail.com
29.	Karla Rothrock	Susan Syfert for LD14 House	520-559-2268	creativeinaz@gmail.com
30.	Stuart D. Kershner	self	520-720-9543	stuartdkershner@alumni.utexas.net
31.	Kathleen A Miller	Self	520-221-1337	miller296@yahoo.com
32.	Jim Burson	SWTC	520-586-5219	jburson@swtransco.coop
33.				
34.				
35.				
36.				

PROPOSED ARIZONA AIR QUALITY STATE IMPLEMENTATION PLAN (SIP) AND SIGNIFICANT PERMIT REVISION TO PERMIT NO. 55412

HEARING ON A PROPOSED ARIZONA STATE IMPLEMENTATION PLAN REVISION FOR THE REGIONAL HAZE SIP AND ASSOCIATED SIGNIFICANT REVISION NO. 55192 T AEPCO'S OPERATING PERMIT NO. 55412

Oral Proceeding

Hearing Officer Transcript

March 26, 2014

[Bruce Friedl]

Good evening and thank you for coming. I now open this hearing on the proposed Arizona State Implementation Plan revision for the West Central Pinal County 2006 24-hour Fine Particles (or $PM_{2.5}$) National Ambient Air Quality Standards also known as the NAAQS.

It is Wednesday, March 26, 2014; the time is 6:10 p.m. The location is the City of Benson Council Chambers at 120 West 6th Street, Benson, AZ 85602.

My name is Bruce Friedl, and I have been appointed by the Director of the Arizona Department of Environmental Quality (ADEQ) to preside at this proceeding.

The purposes of this proceeding are to provide the public an opportunity to:

(1) hear about the substance of the proposed SIP and significant permit revision; and
(2) present oral arguments, data, and views regarding the SIP and significant revision in the form of comments on the record.

Naveen

[Naveen Savarirayan]
Savarirayan

[Bruce Friedl]
is here representing ADEQ from the Air Quality Division, Air Quality Permits Section and Lisa Tomczak is here representing ADEQ from the Air Quality Division, State Implementation Plan Section.

The public notice appeared in the San Pedro News, Arizona Range News, and ADEQ's website beginning February 19, 2014. Copies of the proposed SIP revision and significant permit revision were made available at the ADEQ Records Center and ADEQ's website beginning February 19, 2014.

The procedure for making a public comment on the record is straightforward. If you wish to comment, you need to fill out a speaker slip, which is available at the sign-in table, and give it to

me. Using speaker slips allows everyone an opportunity to be heard and allows us to match the name on the official record with the comments. You may also submit written comments to me today.

Please note, the comment period for the proposed SIP revision significant permit revision ends today, March 26, 2014. All written comments whether they were sent via U.S. mail or via e-mail or via FAX must be postmarked or received by ADEQ by 5:00 p.m. today.

Comments made during the formal comment period are required by law to be considered by ADEQ when preparing the final SIP and significant permit revision. This is done through the preparation of a responsiveness summary in which the Department responds in writing to written and oral comments made during the formal comment period.

The agenda for this hearing is simple. First, we will present a brief overview of the proposed significant permit revision by Naveen of the Air Quality Permits Section, followed by an overview of the SIP revision by Lisa Tomczak. Secondly, I will conduct the oral comment period to call speakers in the order that I have received their speaker slips.

Please be aware that any comments at today's hearing that you want the Department to formally consider must be given either in writing or on the record at today’s hearing during the oral comment period of this proceeding.

At this time, Mr. Savarirayan will give a brief overview of the significant revision to the permit.

[Naveen Savarirayan]

This significant revision #59195 to Arizona Electric Power Cooperative hereby referred to as AEPCO for the Apache Generating Station Title 5 operating permit which is #55412 requires the facility to make the following changes to their permit. First, the facility will be required to change steam unit 2 which is currently a primarily a clifart unit to combust only natural gas. With the exception of an emergency such as National Gas curtailment or pipeline failures, in which case it may burn coal. Secondly, the facility will be required to install a Selective Non Catalytic Reduction system SNCR and incorporate the use of low NO_X burners on steam unit 3. Finally, the revision will set specific emission limits for steam unit 1 when it's operating in simple cycle mode and when operating in combined cycle mode with gas turbine one. All of these changes will become effective in the permit on December 5th 2017.

[Bruce Friedl]

Thank you Naveen. Now Mrs. Tomczak will give a brief overview of the proposed SIP revision

[Lisa Tomczak]

This revision to the Arizona State Implementation Plan for Regional Haze shows that the new control strategy purposed by AEPCO Apache Generating Station. Is better than, Best Available Retrofit Technology also called BART and is intended to replace the Federal Implementation Plan (FIP) promulgated by the Environmental Protection Agency. The plan includes a description of the revised components in EPA's FIP and Arizona Regional Haze SIP and a

demonstration that this revision will not interfere with the ability of the area to attain or maintain the National Ambient Air Quality Standards or any other requirement of the Clean Air Act.

On February 28, 2011, the Arizona Department of Environmental Quality or ADEQ submitted a Regional Haze, State Implementation Plan also called a SIP to EPA. Several parties including the Sierra Club and Grand Canyon Trust filed a complaint in August, 2011. They did this seeking to compel EPA to perform a non discretionary duty by not approving Regional Haze SIP including Arizona or promulgating a Federal Implementation Plan also called a FIP. On July 20, 2012 EPA published a notice of proposed rulemaking that proposed partial approval and partial disapproval of Arizona's BART determinations related to Electric Generating Units also called EGU and proposed a FIP. This proposal rule was finalized on December 5, 2012 and EPA published a notice of final rulemaking approving BARTs Arizona, the Arizona's BART determination for Sulfur Dioxide and Particulate Matter and disapproving its BARTs determination regarding Nitrogen Oxides and establishing a BART ship for Nitrogen Oxides. In their final rulemaking, EPA approved a portion of Arizona SIP for AEPCO's Apache Generating Station BART eligible units. Established emission limits for Nitrogen Oxides, Particulate Matter and Sulfur Dioxide at Unit 1, as well as, Particulate Matter and Sulfur Dioxide at Unit 2 and 3. EPA's disapproval and corresponding FIP established a control technology and Emissions limits for Nitrogen Oxide at steam units 2 and 3. EPA also disapproved the compliance schedules in requirements for equipment maintenance and operations, including monitoring, record keeping and recording at all BART units. Since these were not included in the original SIP submittal.

On February 2, 2013, a pro petition EPA for administrative reconsideration of the final rule and proposed alternatives to the FIP that would achieve better than BART levels of visibility improvement. A pro subsequently provided technical information regarding the proposed alternative to EPA and ADEQ. ADEQ estimated emissions under control and uncontrolled modeling scenarios in order to evaluate the control technology and proposed alternative and the effect on Nitrogen Oxide, Sulfur Dioxide and Particulate Matter emissions. The analysis shows that the proposed alternative is better than BART and ADEQ's assessment is based on total estimated emission reductions. Reductions in individual visibility, impairing pollutants, improved monitoring data and improvements, and modeled facility wide visibility impacts from Apache Generating Station at Class 1 areas.

The Clean Air Act stipulates that revisions to a submitted SIP must not interfere with requirements of Section 110L of the Clean Air Act and must demonstrate non interference with attainment of the National Ambient Air Quality Standards, as well as, other applicable requirements. Apache Generating Station is located in north central Cochise County. The area is designated as attainment or unclassifiable for Carbon Monoxide, Lead, Nitrogen Dioxide, Ozone, $PM_{2.5}$ (for both 1997 standard and 2006 standard), PM_{10} and Sulfur Dioxide (under the 1971 standard). Although, designations have not been made for the 2012 $PM_{2.5}$ and 2010 Sulfur Dioxide NAAQS. The area was recommended as attainment or unclassifiable for both of these pollutants.

ADEQ compared changes in dimension due to the Regional Haze SIP submitted in 2011, EPAs FIP and AEPCO proposed alternative. Because, the area is designated attainment or

unclassifiable for criteria pollutants. Nonattainment or maintenance plans exist, that might rely on emission reduction at the facility to ensure continued attainment of the standards. Overall emissions for these pollutants are lower with the AEPCO proposal when compared to the FIP and the change does not impact Arizona's designation recommendation for either the 2012 $PM_{2.5}$ standard and the 2010 Sulfur Dioxide standard. Because, the current SIP compliance states occur within the period for the first long term strategy. The revised control strategy for AEPCO will not interfere with the long term strategy requirement of the Clean Air Act. In addition to the criteria pollutants, the SIP revision must not interfere with compliance for air toxics and applicable maximum achievable control technology standards. The alternative proposal shows a reduction in air toxics by switching from coal to pipeline natural gas. There are reduction for toxic metals such as Mercury, Cadmium and Chromium. AEPCO's proposal of using SNCR Selective Non Catalytic Reduction rather than SCR Selective Catalytic Reduction for steam turbine 3 will result in reduced sulfuric gas formation. Based on this analysis ADEQ concludes that this alternative will not interfere with any applicable air toxics requirements of the Clean Air Act. This SIP revision replaces EPA's BART FIP for AEPCO Apache Generating Station and revises elements in Arizona's Regional Haze SIP pertaining to AEPCO. This SIP revision proposes changes in the BART limits established for units 1, 2 and 3 at the Apache Generating Station. The changes as contained in the revision to AEPCO's Air Quality Permit also include appropriate compliance methods for all BART units. In evaluation of the impact on Air Quality shows that the change will not interfere with attainment or maintenance of the NAAQS. ADEQ is requesting that EPA approve this plan for compliance with Clean Air Act requirements for visibility as well as non interference with applicable National Ambient Air Quality Standards under Section 110L.

[Bruce Friedl]

Thank you, Lisa. This concludes the explanation period of this proceeding on the proposed SIP and significant permit revision. I now open this proceeding for oral comments. And the first comment slip is Wendy Werden.

[Wendy Werden]

Yes, thanks, I'm Wendy Erika Werden I'm the outreach from Congressmen Ron Barber's Tucson office and the congressman would like to talk to you directly from the south so we have a message from him to talk about this issue.

[Bruce Friedl]

Thank you.

[Video: Congressman Ron Barber]

First of all I like to thank the Arizona Electric Power Cooperative and the Arizona Department of Environmental Quality (ADEQ) for allowing me to comment on todays hearing by this video tape recording. Unfortunately, I can't be with you today in person because Congress is in session and I'm in Washington DC. I do however have a senior member of my staff, in attendance at the meeting, so that she can report back to me on everything that is said about the plan and make sure I understand the full range of comments from the public.

Today's hearing is a long time in the making. Since 2012, I've worked with AEPCO and the EPA to ensure that the best possible outcome for our southern Arizona rate payers, the utilities, employees and our environment can be achieved.

The Apache Plant is a critical power supplier and employer in this region. It supports nearly 260 jobs and serves approximately 150,000 customers throughout rural Southeastern Arizona. The EPA's original proposal, in my view, threatened to eliminate these local jobs and raise electricity rates. This top down, one size fits all approach just doesn't work for Arizona and this is why I brought the EPA to the table. To show them that working with AEPCO we can find a much better plan. A plan that was unique to Arizona's needs and one that will actually lead to more emission reductions, less cost and will prevent a dramatic increase in electricity rates.

At my request the EPA met with AEPCO and after a series of meetings and the exchange of technical information, agreed that our local solution is better. In fact, EPA sent the Regional Administrator out to see AEPCO in action and actual understood, for the first time perhaps, what an incredible facility this is. The solution that we are talking about is really a win win out come for AEPCO and for EPA and the rate payers. And I am very please that EPA has agreed and has allowed the Apache facility to submit its revised plan. I want to thank the EPA for working in partnership with AEPCO, and with our community to find a solution that fits the local situation. I'm also please the Arizona Department of Environmental Quality is allowing the public to have comment on this plan; because, it's extremely important that all stakeholders are able to participate in the review process.

I look forward to a very productive hearing on AEPCO's revised implementation plan today. And I look forward to a positive outcome for AEPCO, its customers, its employees and the environment and of course for EPA. I think that's possible with this plan.

Thank you very much for listening to my comments and I hope you have a great hearing.

[Bruce Friedl]

Okay. Thank you very much. The next speaker is Patrick Ledger and if I can remind everyone to come as close to us as possible just to make sure we are recording for sure. Thank you.

[Patrick Ledger]

My name is Patrick Ledger, Chief Executive Officer of Arizona Electric Power Cooperative. We own and operate Apache Generating Station. On behalf of our rural Electric Cooperative members, as CEO of APECO I have my duties include establishing overall policy, administration, supervising operations, finances, environmental services, rate making and all other aspects of operation. On behalf of the Coops welcome to Benson and thank you for the opportunity to provide some comments today. AEPCO supports the Arizona Department of Environmental Quality's proposed revision to the Arizona Regional Haze plan for AEPCO's Apache Generating Station. ADEQ's significant permit revision #5959195 Operating Permit 55412 and believes they meet the criteria for issuance under both the Arizona and Federal rules. AEPCO is a rural member owned and not for profit generating, generation, transmission cooperative. Our members provide power to approximately 150,000 meters and close to about ½ million people throughout Arizona. AEPCO is relatively small entity with limited financial

means so it's imperative that AEPCO finds ways to meet environmental requirements without massive financial impacts. So that we can continue to provide our rural customers with reliable power and affordable power. The Environmental Protections Agency's Federal Implementation Plan would have imposed selected catalytic reduction technology on two of our major generating units. It would have cost at least 192 million dollars it would significantly threatened AEPCO's long term liability and our ability to provide our Coop members affordable power. ADEQ's proposed SIP and permit revisions on the other hand. Would reduce overall visibility impacts below what would have been obtained by the EPA FIP but at a fraction of the cost approximately 30 million dollars instead of 192 million dollars under the FIP. ADEQ's proposed Regional Haze SIP an operating permit revision should also be adopted because the plan will be better than BART. ADEQ's proposal includes transition of one batches station, primary coal fire generating units to a primary coal natural gas fire generating unit. And this transition combined with addition emission upgrades will substantially lower SO2 particulate matter emissions. This combined with additional investment of control technology on the remaining coal fire unit with less expensive selective non catalytic reduction technology achieves better visibility than EPA does. Finally AEPCO supports the significant permit modification proposed by ADEQ which sets forth necessary operative standards mandated by the SIP while still allowing reasonable flexibility for operation and ensuring reliable power for AEPCO's cooperative members. AEPCO commends ADEQ for your diligent work on the proposed SIP and the operating permit revisions and believes that the final approval for these revisions will benefit the State of Arizona and certainly AEPCO's customers, while also meeting the Regional Haze requirements. Thank you very much.

[Bruce Friedl]

Thank you. Okay, the next speaker is Lupe Diaz.

[Lupe Diaz]

Good evening, my name is Lupe Diaz I pastor a church, Grace Chapel here in town. Also, as Chamber President I represent the free market and free enterprise, on which our country thrived when entrepreneurs were allowed to be creative with meeting the needs of people and their communities by providing a quality service and a product. The Benson San Pedro Valley Chamber of Commerce has 114 members of which there are over 1,000 households represented by our member's employees.

In the case of the Apache Generating Station near Cochise, which is owned by the members of AEPCO; such as myself and business owners; we are in support of the alternative plan that Arizona G & T Cooperatives have provided to you, the Arizona Department of Environmental Quality. The plan supports reasonable requirements that show good stewardship of our environment by minimizing emissions and it is our opinion that it does not endanger our environment.

As member of AEPCO and Arizona's G & T Cooperatives we ask that you accept the plan as proposed. The alternative, requiring more than 200 million in capital investment, would result in consequences beyond our control and would harm our rural economy by raising the cost of wholesale power we all depend on. The AEPCO alternative plan at a cost of approximately 30 million achieves results that are better than what the EPA and your agency was seeking at a

much lower cost, one that will not have serious negative and long-term affects on our economy. Plus—it's better for our environment! We call that a win-win. Thank you for your support of the alternative plan. Thank you.

[Bruce Friedl]

Thank you. The next speaker is Ann English.

[Ann English]

Good Evening, I'm Ann English and I really appreciate the fact that the ADEQ is here to hear what the constituents and the people who take power from AEPCO have to say about the… about the program that has been put in place. The first thing I want to say is that I been aware of the EPA standards since they came out and we all kind of gasp as to what was going to be required of our Generating Power Plant. I am truly grateful that people have decided that they can sit down at to the table. Once you know what the problem is there can be more than one solution. In the beginning I think everybody just thought okay the EPA has a solution and we have to accept that but AEPCO didn't accept that. They said we got a better way perhaps. So, I think working with you and working with EPA we've come up as he said a win win. It doesn't often happen when we work with the federal government or government in any form. And I know since I'm part of government that we have bureaucracy established and it's hard for us to get around the regulations. And so I'm truly grateful that you have set the table and become a partner with us. I represent a lot of constituents the AEPCO power plant and Southern Springs Valley Electric is very important to rural Arizona. We depend on it and we depend on dependable and I won't say cheap power but as cheap as we can make it. That's why we created

the COOP and that's why we created AEPCO so that we have control over our destiny. And so I appreciate you working with them and that I would ask that you approve the significant permit revision. Because it is a hard won victory I think for us that we have finally gotten to the table and you have you have been willing to sit and listen to a better alternative then what was purposed to you by EPA. So, I appreciate you being here tonight and listening to what people have to say and I'm certainly hoping that you will approve this significant revision for AEPCO. Thank you.

[Bruce Friedl]

Okay. Thank you. The next speaker is Philip Bashaw.

[Philip Bashaw]

Thank you very much for the record my name is Philip Bashaw I'm the Director of the Government Relations for the Grand Canyon State Electric Cooperative Association. My association has submitted written comments. So I will keep my oral comments brief. The Grand Canyon State Electric Cooperative Association is a statewide association representing the six distribution Coops in the State of Arizona as well as one cooperative in California. We serve consumers in Arizona, California and New Mexico, the total a little more than 400,000 consumer electricity. AEPCO is also a member of our association. We are here today support the significant permit revisions to the AEPCO plan in the Apache Generating Station. AEPCO is the supplier of wholesale electricity for our electrical Coops throughout the State of Arizona the consumer that they provide electricity to. The EPA Federal Implementation Plan you heard a lot of the cost that would have been associated with that those would have been would have to been

born by our consumers day to day. We believe that the permit and SIP revisions create or balance between the cost an environmental benefits that we seek in those changes in those revision. And so, we would ask that you support and approve those changes to the SIP and the department as well. Thank you very much.

[Bruce Friedl]

Thank you. The next speaker is Walter Risch.

[Walter Risch]

Hello, I have a rather long dissertation and I really shorten it quite a bit. I appreciate this opportunity to come forward and say what I think about AEPCO. I came here in 1981 I'm an electrician by trade and worked for AEPCO for 27 years. I've come to the conclusion that AEPCO is and does what they say. As you can tell I'm 100 percent in support of Arizona Electric Power alternative plan and strongly recommend that they accept it and implement it. The ethical responsibility of AEPCO has demonstrated in their concern to come up with this alternative plan. Therefore, keeping cost down to it end users, the people and businesses and other Coops. That's all I have to say. Thank you.

[Bruce Friedl]

Thank you very much. The next speaker is Alan Baker.

[Alan Baker]

My name is Alan Baker I'm the Executive Director for the Wilcox Chamber of Commerce and Agriculture We have about 175 members that we have manufacturing and agriculture members. And we are in support of this revision and it really is a cost thing for our businesses they could not bare the cost of the EPA regulations should they come. Our businesses do manufacture food and so it would have consequences not just for us locally, but for people throughout the State and the country and even the world. Some of our agriculture businesses, like food, worldwide. So just want to thank ADEQ for working on this and we do support this revision. Thank you.

[Bruce Friedl]

Thank you. The next speaker is, sorry if I mispronounce your name Barrer, Barrern, Dan Barrera. We'll have to correct that.

[Dan Barrera]

For the record its Dan Barrera okay.. Born and raised here in Benson. A couple of things I just want to thank you for allowing us to speak today at the public comment session. I am in support of the proposed revision by ADEQ. I teach 8th grade mathematics. It's pretty simple, I had a couple liter bottles and I was saying to the kids. Okay, one cost $1.92 the other one cost 30 cents. Which one are you going to use, large sustains life and all of sudden they went with 30 cents. The water was clear, good visibility, and it tasted great. So, when I asked my students what they thought, it gave me a teaching opportunity to look at what EPA was proposing. And then what you were proposing along with AEPCO and I think this is just going to allow us to have the opportunity to support the revision. I also own a small motel and RV park. More and more people are living in RV units because that is all they can afford. If you have to implement the

192 million dollar retrofit people are going to afford to live in these RV units. So, I commend you for working with AEPCO in this revision. I just hope that it will pass through and we thank you for that opportunity. Thank you.

[Bruce Friedl]

Thank you very much. The next speaker is Barbara Stockwell.

[Barbara Stockwell]

Hello I'm sort of an outlander here because I live over in Pima County down on the Mexican border west of here. Quite a distance west of here, in fact, I happen to serve for the Board of Directors for Trico Electric Cooperative, which is one of the Arizona Electric, generation members. We were from the original founding Cooperatives; I think there were 3 of us. We remember how it was before we had generation before we had electric electricity in our homes. The power came to my little town; Arivaca, AZ,it's as the crow flies about 12 miles north of the border, but there is a range of hills. It doesn't keep out the illegal immigration but it is very close to the border, the range of hills and then we go 25 miles to the border. But, I lived there since I was a teenager. I love rural life, I love rural Arizona and we are so grateful to have the power that is provided by Arizona Electric. Our rates, we serve, my Coop serves all the away around Tucson. So, we have a big metropolitan area serve by the best your own utility. With maybe 45 or I don't know how many consumers per mile per line. Trico has better than many rural cooperatives we have, I think 11 consumers per mile per line. Its figure, the you know the finance on that one, I'm no mathematician like Mr. Barerra, you can tell. Our members pay more for their electricity. Since we are so close to Tucson, remember the Coops, there are 42 million

Coop members in the United States. The Cooperatives serve about 85% of the land mass of the United States. We are out where no one else would go. And yet our people count too. I have a one block main street in my town. The Fourth of July parade is very short, people say it's over already. We are small, but people out there have trouble paying their electricity bills already. I mean, I know because we have to, the board approves the write off list every month and it is pretty huge. And its people that are struggling and suffering because people don't want to have their electricity turned off and yet every month, there is quite a list of them. I think $40,000; $30,000; $25,000 worth of write offs every month. And we only have like 42,000 members. So, figure that one. Anyway, the cost, were so grateful to have this opportunity to try to do something else, from the original knock out blow. That our Cooperative rose up and decided to try to find something better and ADEQ did help us and we so appreciate that too. And we appreciate EPA listening to what its like out in rural areas, rural Arizona. It's tough out there. You know that the visibility, since this is a Regional Haze issue. Visibility down here in Southern Arizona is mostly because of dirt roads. I mean, there aren't that many paved roads. My road, to my town wasn't paved until maybe 20 or 30 years ago. Electricity came in 1975, I believe to my town, 75. Some of you, a lot of you weren't born then. So, like I say, we appreciate what we have from Arizona Electric. The rates are higher than Tucson Electric or Arizona Public Service, or Salt River Project and all the three huge electric utilities in the State. Our rates are higher than theirs, quite a lot higher I think, for each member. Trico, my Trico Electric Corp is higher than some of the other cost because we don't have any big commercials. We don't have big box stores, we have I think 2 grocery stores. I think they are both, are they Fry's, I think they are both Fry's, I believe. We don't have a WalMart we don't have a COSTCO, we don't have, even Benson has a COSTCO. NO they have a WalMart, they have a WalMart don't they. Sierra

Vista has two. Anyway I want to thank you for letting us talk. I want to remind you, that I found I just read this the night before last. I read a lot of this stuff. Executive Order 12866, which was promulgated in 1993. Requires that federal agency assess both the cost and benefits of a proposed regulation and adopt it under quote only upon a reasonable determination if the benefits justifies its cost. And more recently the office of management and budget said that the cost and benefits calculation should help determine whether a regulation is worth implementing at all. I'm just throwing that out. Anyway, thank you for being here and letting us have our say. I'm very, you can tell, I really am passionate of the people in my town most I've know all my adult life, since I was a teenager. I'm passionate about their needs and what we want need that's reliable and affordable electric energy. This can happen and it can help. Thank you.

[Bruce Friedl]

Thank you. The next speaker is George Scott.

[George Scott]

My name is George Scott, like Mr. Barrera I'm a life long resident here at Benson. I'm here representing the Southeast Arizona Economic Development Group a regional nonprofit organization that helps business. I'd like to read this statement. We liked to thank you for the opportunity to comment on the proposed revision to the Regional Haze, State Implementation Plan to modify and retrofit the requirements for the Apache Generating Station. On behalf of Southeast Arizona Economic Development Group its Board of Directors and Regional Business Membership that we represent we urge you to approve ADEQ proposed revision to the SIP and Arizona Electric Power Coops permit revision number 59195. Our region and rural economy

depend on reliable and affordable electric power. We need to know that not only will the electric rates remain as low as possible. We also need to know they will remain stable so we can plan for future needs and those of the community we represent. The revised plans will help AEPCO maintain those reliable rates. EPA's mandated plan on the other hand would have required AEPCO to invest around 200 million dollars at the Apache Generating Station. This would have resulted in the increase cost that would have been absorbed by our rural users in Arizona. AEPCO's proposal reduces the investment to around 32 million dollar and results in improvements to the air quality or probably better than what EPA was seeking. If the end results is the same or better visibility in the propose SIP cost around 170 million dollars less it seems to be a good balance of environmental benefit cost to AEPCO and to its members. We would like our Economic Development Group and our supporters would like to thank you for the opportunity to comment on this and to encourage the panel and ADEQ to support the plan. Thank you.

[Bruce Friedl]

Thank you. The next speaker is Dr. David Woodall.

[Dr. David Woodall]

Thank you very much for being in Benson tonight I represent Benson Unified School District. School District often gets criticize for all the acronyms and I got to tell you after listening to you read that statement. You kind of lost me right after published in the San Pedro news. It was hard to tell from that part on. I also want to speak in support of the ADEQ proposal I can't say a lot that hasn't already been said. However I am an avid outdoors man, I enjoy clean fresh air, I'm a

runner and a hiker. I certainly wouldn't be here supporting that plan because I have concerns about that, because I value that very much. To do to follow the EPA plan would be very detrimental to our community. Benson School District is also a number one school district in Arizona. Right now, I've done the research, about 60% free or reduce lunch students, many of our parents are at poverty level. To have increase rates would be very devastating. Also, electricity is the number two cost of our school district. We've been frozen, 6 of the last 8 years, as far as school funding. It would be very difficult for us to under go rate increase for our number 2 cost, which is electricity. I've heard everyone talk about a win win. The ADEQ proposal certainly sounds like a win win proposal, something that will benefit all of us and I do strongly support that. Thank you.

[Bruce Friedl]

Thank you very much. The next speaker is Kathleen Miller.

[Kathleen Miller]

My name is Kathleen Miller and I'm on the school board. But, I'm not here representing the board. I'm here representing myself. I've heard tonight, everybody saying we need to accept the this revised bid and I agree to a certain point. That, yes, it is way better than the EPA's choice to absolutely devastate rural Arizona. But I want to address the fact that the EPA doesn't need to be doing anything down here. The haze is not caused by the generating station, it's not caused by electricity being produce or caused by dust in the air. This will not change anything as far as our haze. I agree that this is a win win over the cost of what the EPA wants to do to us. But, the EPA needs to step back and not do this to any State especially to Arizona. Thank you.

[Bruce Friedl]

Thank you very much. I don't see any more speaker slips. Does anyone else wish to make a comment. Before we close the public comment period?

[Stuart D. Kershner]

I do.

[Bruce Friedl]

Yes.

[Stuart D. Kershner]

I'm been here the whole time.

[Bruce Friedl]

Yes.

[Stuart D. Kershner]

My name is Stuart Kershner and I live in St. David and I am speaking just on my behalf, my wife and I own a small farm over here. And we pay about $1,000 a year for electricity for our irrigation system. To have an increase in electricity of the amount that would have been required if the EPA regulations would have been promulgated and enforced. Would make our nonprofitable business, even more nonprofitable. Just to comment on the governmental thing.

The think and I agree with everybody and what everyone said so far. But, the idea that the federal government comes in and lays these regulations on it seems like the federal government in many aspects of it, not just EPA. It might be the Attorney General, whatever. Is having a fight with Arizona and the Arizona Government, and I think its wonderful, that at least in this case, Arizona fought back and it looks like we won. I think that's wonderful.

[Bruce Friedl]

You have a comment? Okay.

[Jeff Cook]

Thank you. My name is Jeff Cook, I represent myself. I would like to start by saying that having to do this 30 million dollar project is going to affect our rates. And my monthly income is just slightly over $1,000 a month and that every entity, city, schools, the WalMart, the gas stations. Everyone that has to suffer this rate increase is going to pass that on to the rest of us. And some of us are on fixed incomes. That does not mean that I'm opposed to this. I would like to echo what Ms. Miller said. Those were my thoughts at the EPA hearing. I think that the EPA has taken us hostage. Everyone in this room which includes ADEQ. I think they are forcing us to spend money that on our power generating plant up here, that probably that doesn't need to be spent. I think the benefits are minimal, probably even negligible.. The reason I say that are with the on going drought we've had here in Arizona. We have less vegetation and less ground cover, more particulates brought up by dust. We have prevailing winds that come from south of the border, going north or northeast. And south of the border they don't have any PA, they don't have the strict pollution standards requirements that we have here. Where they do not have the

requirements are on their mines, on their trucks, on their vehicles, on open burning, on their power plants. And all of those pollutants are blowing our way. My guess is if we shut down Apache Generating Station completely. We would probably see minimal or negligible benefit from that. And what EPA is forcing on us in the cost to upgrade this power plant I think to me is horrifying. I don't really think it needs to be done. I think there will be an incredibly slight benefit to the Haze to Particulates, as compared to what we have long across the border. At this point even though we are all held hostage I would like to thank AEPCO and all of their employees, all of their Coops for working to minimize the cost to all of, all of the members. I'm one of them. Since and your part as ADEQ to help negotiate the ransom that EPA is pushing on us. So and I would like to say I'm in support of AEPCO's proposal. Thank you.

[Bruce Friedl]

Thank you. Does anybody else wish to make a comment? Yes, sir.

[Jeff Wolf]

Thank you. My name is Jeff Wolf, the Communication Manager for Arizona's Communities I want to take the opportunity to not comment on the SIP. But, to thank publicly and for the record the people who always turn out and have supported not only this community but have helped us and given us advice and they are here tonight. I want to tell you all very much we do appreciate you. Thank you.

[Bruce Friedl]

We also want to thank everybody for coming and making comments. And if there are no others.

This concludes the oral comment period of this proceeding.

If you have not already submitted written comments, you may submit them to me at this time. Again, the comment period for this proposed SIP and significant permit revision ends today, March 26, 2014, at 5:00 p.m.

Thank you for attending.

The time is now 7.01 p.m. I now close this oral proceeding.

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Arizona's G&T Cooperatives
Touchstone Energy® Cooperatives

March 21, 2014

VIA FEDERAL EXPRESS
email: Baggiore.Trevor@azdeq.gov

Mr. Trevor Baggiore
Air Quality Division Deputy Director,
Arizona Department of Environmental Quality
1110 West Washington Street, 3415A-1
Phoenix, AZ 85007

RE: DRAFT Comments on the Proposed Revision to the Arizona Regional Haze Plan for Arizona Electric Power Cooperative, Inc. Apache Generating Station; and comments on Significant Permit Revision No. 59195 to Operating Permit No. 55412

Dear Mr. Baggiore,

Arizona Electric Power Cooperative, Inc. (AEPCO) appreciates the opportunity to comment in support of the Arizona Department of Environmental Quality's (ADEQ) proposed Arizona Regional Haze state implementation plan (SIP) revisions for AEPCO's Apache Station, and the significant permit revisions to AEPCO's operating permit. AEPCO is a rural, member-owned, not-for-profit cooperative whose members provide power to approximately 150,000 meters primarily for residential use. AEPCO is a relatively small entity with limited financial means, thus it is imperative that AEPCO be able to provide its rural customers with affordable and reliable power. The proposed SIP and permit revisions will reduce overall emissions of visibility impairing pollutants and visibility impacts to a level lower than those obtained by the Environmental Protection Agency (EPA) in its federal implementation plan (FIP), but at a fraction of the cost.

The proposed Regional Haze SIP revision and revised operating permit provides many advantages to the State of Arizona and AEPCO's rural customers, including:

- **Cost effective**. Under this proposal, AEPCO will convert one of its load-following coal units to natural gas. This in combination with additional emissions upgrades can achieve better visibility than contemplated by the FIP, but at a cost six times lower than EPA's proposal. AEPCO can ensure its long-term viability and commitment to its rural customers while simultaneously meeting its regional haze responsibilities.

www.azgt.coop
P.O. Box 2165 • 1000 S. Highway 80 • Benson, Arizona 85602 • (520) 586-5000 Phone
Arizona Electric Power Cooperative, Inc. • Southwest Transmission Cooperative, Inc. • Sierra Southwest Cooperative Services, Inc.

- **Better-than-BART**. The proposed revision achieves better visibility benefits than the best achievable retrofit technology (BART) that the EPA mandated in the FIP. By converting Steam Unit No. 2 (ST2) from a primary coal-fired unit to a primary natural gas-fired unit, AEPCO will substantially reduce emissions of sulfur dioxide (SO_2) and particulate matter with some increase in nitrogen oxides (NOx). These reductions allow AEPCO to convert ST3 from expensive selective catalytic reduction (SCR) technology to less expensive selective non-catalytic reduction (SNCR) technology, while still achieving a visibility improvement over the FIP. This change reduces the estimated cost of the regional haze program for Apache Station from approximately $192 million to $30 million, which is much more achievable for AEPCO rural electric cooperative members.

- **AEPCO supports the permit revision.** The proposed permit revision to AEPCO's operating permit provides the necessary requirements for AEPCO to meet the standards mandated by the SIP revision while still allowing reasonable flexibility for operation and ensuring reliable power supply for AEPCO's rural electric cooperative members.

The revised SIP is better-than-BART, and the changes can be achieved at a significant cost savings. The revisions allow AEPCO to remain a viable provider of power to rural meters, and meet its regional haze responsibilities.

AEPCO appreciates the opportunity to provide these comments. Please contact Ms. Michelle Freeark, AEPCO's Director of Safety and Environmental Services, at (520) 586-5122, or mfreeark@ssw.coop if you have any questions or concerns.

Sincerely,

Michelle R. Freeark

Michelle R. Freeark
Director of Safety and Environmental Services

CTS 321803

ANZA ELECTRIC COOPERATIVE, Inc.
A Touchstone Energy® Cooperative
Phone: (951) 763-4333
P.O. Box 391909 (58470 Highway 371) Anza, California 92539-1909
FAX: (951) 763-5297

ADEQ
AIR QUALITY DIVISION
14 FEB 24 AM 10: 48

February 19, 2014

Trevor Baggiore
Air Quality Division Deputy Director
ADEQ, 1110 West Washington Street, 3415A-1
Phoenix, AZ 85007

Dear Mr. Baggiore:

Thank you for the opportunity to review Arizona's proposed revision to the Regional Haze State Implementation Pan (SIP) to modify the Best Available Retrofit Technology (BART) requirements for Apache Generating Station.

I am writing to you to ask that you approve ADEQ's proposed revision to its Regional Haze State Implementation Plan (SIP) and Arizona Electric Power Cooperative, Inc.'s (AEPCO) significant permit revision no. 59195.

Anza Electric Cooperative, Inc. is a member/owner of AEPCO, and has been wholly dependent on the Apache Generating Station to provide affordable electric energy for our 5,000 members' services in California since 1979.

EPA's federally mandated plan would have required AEPCO to invest approximately $200 million at Apache Station, doubling the debt load on the plant. An investment of that magnitude could have resulted in a substantial rate increase on rural Californians served by our electric cooperative, as well as thousands of rural residents and businesses in Arizona.

AEPCO's proposal which is detailed in your SIP revision drastically reduces that investment to approximately $30 million dollars and results in "better than BART" visibility improvements through emission reductions. If the end result is approximately the same or better visibility and the proposed SIP costs approximately $170 million less, it would seem to be an appropriate balancing of cost and environmental benefit as required by the Clean Air Act.

ANZA ELECTRIC COOPERATIVE, Inc.
A Touchstone Energy® Cooperative
Phone: (951) 763-4333
P.O. Box 391909 (58470 Highway 371) Anza, California 92539-1909
FAX: (951) 763-5297

I thank you for your hard work and dedication to significant improvement in Arizona's air quality values and visibility, as well as considering our issues in California.

Sincerely yours,

Kevin Short
General Manager

Grand Canyon State Electric
Cooperative Association, Inc.
Your Touchstone Energy ® Cooperatives

March 19, 2014

Trevor Baggiore
Air Quality Division
Arizona Department of Environmental Quality
1110 West Washington Street
Phoenix, AZ 85007

Dear Mr. Baggiore:

Thank you for the opportunity to review Arizona's proposed revision to the Regional Haze State Implementation Pan (SIP) to modify the Best Available Retrofit Technology (BART) requirements for Apache Generating Station.

On behalf of the Grand Canyon State Electric Cooperative Association I urge you to approve ADEQ's proposed revision to its Regional Haze State Implementation Plan (SIP) and Arizona Electric Power Cooperative, Inc.'s (AEPCO) significant permit revision no. 59195.

The Grand Canyon Electric Cooperative Association is a membership organization consisting of the six electric distribution cooperatives and AEPCO in Arizona. We also count among our membership one cooperative in California. Our cooperatives serve more than 400,000 consumers of electricity in Arizona.

AEPCO is the supplier of wholesale energy to our cooperative members who distribute rural consumers throughout the Southwest. Co-op members depend on AEPCO to provide reliable, safe and affordable electricity.

EPA's federally mandated plan would have required AEPCO to invest approximately $200 million at Apache Station, doubling the debt load on the plant. An investment of that magnitude could have resulted in a substantial rate increase on rural Arizonans served by electric cooperatives across the state.

AEPCO's proposal which is detailed in your SIP revision drastically reduces that investment to approximately $30 million dollars and results in "better than BART" visibility improvements through emission reductions. If the end result is approximately the same or better visibility and the proposed SIP costs approximately $170 million less, it would seem to be an appropriate balancing of cost and environmental benefit, as required by the Clean Air Act.

2210 S. Priest Drive • Tempe, Arizona 85282-1109 • 602/286-6925 • Fax 602/286-6932 • www.gcseca.coop

I thank you for your hard work and dedication to significant improvement in our state's air quality values and visibility.

Sincerely yours,

John Wallace, CEO

March 21, 2014

Mr. Trevor Baggiore
Air Quality Division Deputy Director
1110 West Washington Street, 3415A-1
Phoenix, AZ 85007

Comments submitted via email to Baggiore.Trevor@azdeq.gov

Re: Arizona Department of Environmental Quality (ADEQ) proposal of two actions: revising the Arizona State Regional Haze State Implementation Plan (SIP) and Significant Revision No. 59195 to Air Quality Control Permit No. 55412 for Arizona Electric Power Cooperative's (AEPCO) Apache Generating Station.

Dear Mr. Baggiore:

The National Rural Electric Cooperative Association (NRECA) is providing these comments in support of your February 19, 2014 proposed revisions to the ADEQ Regional Haze SIP and the corresponding operating permit revision for AEPCO's Apache Generating Station.

NRECA is the national service organization for more than 900 not-for-profit rural electric utilities that provide electric energy to over 42 million people in 47 states or 12 percent of electric customers. Kilowatt-hour sales by rural electric cooperatives account for approximately 11 percent of all electric energy sold in the United States. NRECA members generate approximately 50 percent of the electric energy they sell and purchase the remaining 50 percent from non-NRECA members. The vast majority of NRECA members are not-for profit, consumer-owned cooperatives. NRECA's members also include 65 generation and transmission ("G&T") cooperatives, which generate and transmit power to 668 of the 838 distribution cooperatives. The G&Ts are owned by the distribution cooperatives they serve. Remaining distribution cooperatives receive power directly from other generation sources within the electric utility sector. Both distribution and G&T cooperatives were formed to provide reliable electric service to their owner-members at the lowest reasonable cost.

NRECA has closely followed, and commented on, the EPA's disapproval of the Arizona regional haze SIP and the EPA issuance of a Federal Implementation Plan (FIP). The EPA's FIP approach would have a significant adverse impact on AEPCO and their customers while providing limited visibility improvements. In particular, we believe that EPA did not take into account the flexibility that should be afforded to the state and AEPCO in determining BART for this facility. EPA acknowledged that AEPCO is a small entity under the Regulatory Flexibility Act, yet the state and AEPCO were not afforded flexibility to select an alternative BART limit to EPA's presumptive BART. NRECA intervened on behalf of AEPCO when they filed a petition for reconsideration of EPA's final action and we supported EPA's decision to grant administrative reconsideration on June 6, 2013.

AEPCO has spent considerable resources to conduct additional modeling and analysis of the Apache Generating Station. They determined that they could achieve a greater emission reduction in a way that significantly reduced the cost of compliance. This "AEPCO Alternative" was designed to replace the control strategies in the February 28, 2011 ADEQ Regional Haze SIP as well as the January 4, 2013 EPA FIP. AEPCOs approach would convert their Steam Unit 2 (ST2) from firing coal to firing natural gas. This would be coupled with adopting selective non-catalytic reductions as NOx controls for Steam Unit 3 (ST3) which would still fire coal. Combined, these changes will provide greater emission reductions than would have been adopted in the EPA's FIP. In addition, SO_2, hazardous air pollutants and greenhouse gases will also be reduced through this approach.

NRECA supports the February 19, 2014 AZDEQ proposal as it addresses the problems posed by EPA's FIP and instead, establishes a Best Available Retrofit Technology (BART) requirement in a way that both dramatically reduces the costs for AEPCO and their customers, and exceeds the visibility goals. This is a win-win for the environment, the states right to establish their implementation plan and AEPCO. ADEQ completed a technical analysis of AEPCOs BART analysis and determined that this alternative was "better than BART" as proposed by either the Arizona SIP, or the EPA FIP. The determination looked at total estimated emission reductions, reductions in visibility impairment and modeled facility-wide visibility impacts on Class I areas. The AZDEQs proposed SIP revisions will not interfere with attainment or maintenance of the National Ambient Air Quality Standards.

Significantly, AEPCO will be able to achieve these significant emission reductions in a cost effective manner and save at least $170 million dollars from what EPA would impose via the FIP. This will help keep AEPCOs debt load manageable and keep electricity rates affordable for its customers.

NRECA appreciates this opportunity to comment. NRECA and our members support the requirements to preserve and enhance visibility at our nation's Class I areas. That said, cooperatives also have a responsibility to their consumers who ultimately bear the cost of meeting various regulatory obligations. NRECA supports the AZDEQ proposed SIP and corresponding changes to the AEPCO permit as exceeding the visibility goals and saving AEPCO and their customers from significant costs. Please contact me if you have any questions at ted.cromwell@nreca.coop or (703) 907-5706.

T. Ted Cromwell
Sr. Principal, Environmental Policy
National Rural Electric Cooperative Association

321907

Sulphur Springs Valley Electric Cooperative, Inc.
A Touchstone Energy® Cooperative

Creden W. Huber
Chief Executive Officer
311 East Wilcox Drive
Sierra Vista, AZ 85635-2527

ADEQ
AIR QUALITY DIVISION
14 FEB 26 AM 10: 54

February 24, 2014

Mr. Trevor Baggiore
Air Quality Division Deputy Director
ADEQ, 1110 West Washington Street, 3415A-1
Phoenix, AZ 85007

Dear Mr. Baggiore:

Thank you for the opportunity to review Arizona's proposed revision to the Regional Haze State Implementation Pan (SIP) to modify the Best Available Retrofit Technology (BART) requirements for Apache Generating Station.

I am writing to you to ask that you approve ADEQ's proposed revision to its Regional Haze State Implementation Plan (SIP) and Arizona Electric Power Cooperative, Inc.'s (AEPCO) significant permit revision no. 59195.

AEPCO is our supplier of wholesale energy that we distribute to our members (end-use customers) throughout the Southwest. We depend on AEPCO to provide reliable, safe and affordable electricity.

EPA's federally mandated plan would have required AEPCO to invest approximately $200 million at Apache Station, doubling the debt load on the plant. An investment of that magnitude could have resulted in a substantial rate increase on rural Arizonans served by electric cooperatives across the state.

Sulphur Springs Valley Electric Cooperative (SSVEC) serves approximately 52,000 residential, businesses, small industrial and irrigation services. SSVEC purchases most of its electric power from AEPCO and the Apache generating station near Cochise, Arizona.

For over 75 years SSVEC's mission has been to provide safe, reliable and affordable electric service to our members. In the electric utility industry it is a constant challenge to improve the efficiencies of operation, cope with escalating prices of materials and electricity and its associated fuel costs.

For a measure not related to health issues, the original proposed FIP would place an undue hardship on SSVEC members. Unlike investor owned utilities, where investors seek to make a

profit, cooperatives, like SSVEC provide electric service at cost and any profits are eventually returned to the member/owners. The incentive at cooperatives is to keep prices as low as possible to benefit those members using the service.

AEPCO's population base is relatively economically disadvantaged and requiring the original FIP's costly controls at a cost estimated by AEPCO up to $200 million dollars would impose a disproportionate burden on these customers.

Nationally, the service territory average household income for electric coops falls almost 11 percent below the U.S. average household income. For Arizona's cooperative consumers, these economic conditions are more acute. Arizona cooperative customers average 16.4 percent lower household income than the rest of Arizona and 18.3 percent lower than the U.S. average.

The per capita income of AEPCO consumers is $29,183, a staggering 39 percent lower than the national average. These factors make affordable rates even more critical for AEPCO and their customers.

While an additional $58 million dollars, required by the FIP, that would be charged to SSVEC members, is a great deal of money in any context, the fact that we are in a rural area with a depressed economy makes it particularly burdensome on local citizens who will be required to pay it. Given the estimate of the increased cost of the proposed FIP I am asking for you to support the revised SIP.

AEPCO's proposal which is detailed in your SIP revision drastically reduces that investment to approximately $30 million dollars and results in "better than BART" visibility improvements through emission reductions. If the end result is approximately the same or better visibility and the proposed SIP costs approximately $170 million less, it would seem to be an appropriate balancing of cost and environmental benefit, as required by the Clean Air Act.

I thank you for your hard work and dedication to significant improvement in our state's air quality values and visibility.

Sincerely yours,

Creden W. Huber
Chief Executive Officer

321973

TRICO ELECTRIC COOPERATIVE, INC.

A Touchstone Energy® Cooperative

ADEQ AIR QUALITY DIVISION FEB 27 AM 10:48

February 26, 2014

Trevor Baggiore
Deputy Director, Air Quality Division
Arizona Department of Environmental Quality
1110 West Washington Street, 3415A-1
Phoenix, Arizona 85007

Dear Mr. Baggiore:

I would like to take this opportunity to formally thank you for the opportunity to review Arizona's proposed revision to the Regional Haze State Implementation Plan (SIP) and modification of the Best Available Retrofit Technology (BART) requirements for Apache Generating Station.

Trico Electric Cooperative, Inc., is a not-for-profit distribution cooperative serving roughly 42,000 residential and small commercial customers across the rural and suburban areas surrounding Tucson. Trico serves a large geographic area that includes: SaddleBrooke to the north in Pinal County; Dove Mountain, Marana and Avra Valley; Picture Rocks, Altar Valley, Robles Junction and Three Points; Arivaca and Sasabe; parts of Sahuarita and Green Valley; parts of Vail and Corona de Tucson, and, finally, Mt. Lemmon.

Trico is a Member-Owner of Arizona Electric Power Cooperative, Inc. (AEPCO), and Apache Generating Station, and purchases nearly 100 percent of the power it distributes to customers from AEPCO. As such, any issues affecting AEPCO in turn greatly affect Trico and its customers. Trico's customer base is predominantly residential, so cost and rate increases are acutely felt by our Members. Trico's rates are already higher than neighboring utilities and, though Trico staff is working diligently to maintain current rates while providing safe, reliable electric service, a large rate increase at AEPCO would be detrimental to Trico's customers.

With these concerns in mind, I urge you to approve Arizona Department of Environmental Quality's proposed revision to its SIP and AEPCO's significant permit revision no. 59195.

The Environmental Protection Agency's federally mandated plan would have required AEPCO to invest approximately $200 million at Apache Station, doubling the debt load on the plant. An investment of that magnitude could have resulted in a substantial rate increase not only for Trico and its customers, but for rural Arizonans served by electric cooperatives across the state.

P.O. Box 930 • Marana, AZ 85653 • Phone (520) 744-2944 • Toll Free (866) 337-2052 • www.trico.coop

AEPCO's proposal, which is detailed in your SIP revision, drastically reduces this investment to approximately $30 million dollars, and results in "better than BART" visibility improvements through emission reductions. This is truly a 'win-win' solution, one that balances cost and expense while providing comparable or better environmental benefit.

In closing, thank you for your hard work and dedication to the improvement of Arizona's air quality and visibility, and thank you, too, for your time and consideration of this matter.

Sincerely,

Vincent Nitido
CEO/General Manager

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March 21, 2014 (as revised March 24, 2014)

Mr. Trevor Baggiore
Air Quality Division Deputy Director
Arizona Department of Environmental Quality
1110 West Washington Street, 3415A-1
Phoenix, AZ 85007

Via e-mail to Baggiore.Trevor@azdeq.gov

Re: Proposed revisions to the Arizona State Regional Haze State Implementation Plan (SIP) and Significant Revision No. 59195 to Air Quality Control Permit No. 55412 for Arizona Electric Power Cooperative's (AEPCO) Apache Generating Station

Dear Mr. Baggiore,

Thank you for the opportunity to comment on the proposed revisions to the Arizona Regional Haze State Implementation Plan (SIP) and Permit No. 55412 for Arizona Electric Power Cooperative's (AEPCO) Apache Generating Station (Apache). Our organizations represent tens of thousands members and supports in Arizona, along with thousands more who value the national parks and wildernesses of Arizona and the broader desert Southwest.

Although we would like to support the proposed alternative to Best Available Retrofit Technology (BART) for Apache, we are unable to do so until it demonstrates that it provides a better visibility outcome than BART. ADEQ has not yet made such a showing for all affected Class I areas.

Americans have long valued our nation's diverse and stunning natural scenery.[1] In what has been lauded as "America's best idea," Congress first set aside national parks in the 19th century to preserve and celebrate some of the nation's most spectacular scenery. With the nation's rapid industrialization, however, these remarkable scenic views have become increasingly marred by air pollution. Today, air pollution is "perhaps the greatest threat to national parks," and pollution all too often degrades visibility in these iconic scenic areas.[2]

[1] John Copeland Nagle, *The Scenic Protections of the Clean Air Act*, 87 N.D. L. Rev. 571, 576 (2011).
[2] *See id.* at 573.

To reduce this threat to national parks and other treasured public lands, Congress amended the Clean Air Act in 1977.[3] Congress determined that national parks, wilderness areas, and other "Class I" federal areas should enjoy the highest level of air quality, and it set a national goal of eliminating all human-caused visibility impairment at these areas.[4] After concluding that EPA and the states had not made adequate progress toward reducing visibility impairment caused by numerous sources located across a large geographic area (i.e., regional haze), Congress again amended the Clean Air Act in 1990 to spur regional haze reductions.[5] The Act delegates implementation of the regional haze program to the United States Environmental Protection Agency (EPA).[6] EPA set a goal of achieving natural visibility conditions at every Class I area by 2064, and the agency directed states to make incremental, reasonable progress toward that goal.[7]

The 2064 natural visibility goal is to be achieved, in part, by installing Best Available Retrofit Technology (BART) controls as expeditiously as practicable at antiquated power plants and other sources built between 1962 and 1977.[8] BART is defined as "an emission limitation based on the degree of reduction achievable through the application of the best system of continuous emission reduction."[9] BART is an essential component of the regional haze program because Congress largely grandfathered the antiquated sources subject to BART into many of the Clean Air Act's requirements.[10] Consequently, many of these older sources have insufficient pollution controls. BART compels these disproportionately-polluting sources to install up-to-date and cost-effective pollution controls.

A BART alternative – as is proposed here – may be implemented in lieu of BART if it "achieve[s] greater reasonable progress than would be achieved through the installation and operation of BART."[11] This can be demonstrated in two ways, or "otherwise based on the clear weight evidence."[12]

1) First, if the "distribution of emissions" is the same under the alternative and under BART, the alternative need only have "greater emissions reductions."[13]
2) Second, if the distribution of emissions is dissimilar, visibility modeling is required.[14]

In this case, ADEQ has not demonstrated that the alternative achieves greater reasonable progress through any of these approaches. With regard to the first test, ADEQ determined that the distribution of emissions is not the same because the proportion of pollutants is dissimilar.[15]

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[3] 42 U.S.C. § 7491.
[4] *Id.* § 7491(a)(1).
[5] *Id.* § 7492.
[6] *Id.*
[7] 40 C.F.R. § 51.308(d)(1)(i)(B), (d)(1)(ii).
[8] 42 U.S.C. § 7491(b)(2)(A); 40 C.F.R. § 51.308(e).
[9] 40 C.F.R. § 51.301.
[10] *See* 70 Fed. Reg. 39,104, 39,111 (July 6, 2005).
[11] 40 C.F.R. § 51.308(e)(2).
[12] *Id.* § 51.308(e)(2)(i)(E).
[13] *Id.* § 51.308(e)(3).
[14] *Id.* § 51.308(e)(3).
[15] AEPCO Apache Generating Station BART Alternative Control Review Technical Support Document. December 17th, 2013. Arizona Department of Environmental Quality. p. 2.

The proposed alternative would emit more nitrogen oxides (NOx) and less sulfur dioxide (SO2) and particulate matter (PM).

We agree with ADEQ's determination that this method of demonstrating greater reasonable progress does not apply. In line with BART determinations that are pollutant specific, the test for "greater emissions reductions" clearly contemplates emissions reductions of the same pollutant, e.g., NOx emissions for NOx emissions. Indeed, if this were not the case, the result would be ludicrous – opening the door for trading non-equivalent pollutants without regard to their relative impact on visibility. A reduction of one ton of NOx does not necessarily have the same visibility impact as one ton of SO2, PM, or other pollutants, and moreover this relationship varies depending on site-specific circumstances. The impact of a trade-off in pollutants can only be accurately determined by visibility modeling.

However, EPA has elsewhere proposed finding that the "distribution of emissions" is the same if the emissions emanate from the same facility under both BART and the alternative. If this test of greater emissions reductions is applicable, ADEQ's proposed alternative appears to fail. The combined annual tons of NOx, SO2, and PM under the alternative are 85 tons higher than under BART.[16] It is unclear why this balance has changed from AEPCO's May 29, 2013 proposal, which showed, conversely, that the emissions under the alternative would be 65 tons per year less than under BART.[17, 18] With the information given, we can only conclude that the alternative does not provide greater emissions reductions, and thus would fail the first test if it were deemed applicable.

Even where it has proposed using the first test, however, EPA has admitted the necessity of visibility modeling – the second test. With regard to a proposed BART alternative for a facility in Tesoro, Washington, that would increase NOx while decreasing SO2 and PM, it acknowledged that visibility modeling was "appropriate" in light of concerns about the non-equivalence of pollutant impact.[19] Furthermore, with regard to the Sundt facility in Arizona, EPA prepared visibility modeling "to verify the visibility benefits of the proposed alternative" even though all three visibility-impairing pollutants – NOx, SO2, and PM – will decrease under the alternative.[20] Thus it is clear that even if the first test applies, visibility modeling should be considered, particularly when pollutant trade-offs are proposed, and must definitely show that the alternative provides greater reasonable progress than BART.

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[16] Proposed Arizona State Implementation Plan Revision to the Arizona Regional Haze Plan for Arizona Electric Power Cooperative, Incorporated, Apache Generating Station. ADEQ Air Quality Division, February 2014, p. 4, showing total emissions of 3,440 under the proposed alternative and 3,355 under BART. We note that the references on this page and in many other places to "facility-wide emissions" are incorrect; examination of the attached technical document clearly states that only emissions from Units 2 and 3 are included, as the emissions from Unit 1 are not expected to change from BART to the alternative. See AEPCO Apache Generating Station BART Alternative Control Review Technical Support Document. December 17th, 2013. Arizona Department of Environmental Quality. p. 4.

[17] May 29, 2013 letter from Eric Hiser to EPA, p. 5.

[18] We would also appreciate clarification as to whether the modeled results reflect the emissions scenarios in the May 29, 2013 proposal or the more recent emissions estimates.

[19] 78 Fed. Reg. 79355.

[20] 79 Fed. Reg. 9335.

In this case, ADEQ claims that the second test does not apply because the appropriate point of comparison is in the future and requires photochemical grid modeling. We disagree. The regulations state only that "dispersion modeling" is required. ADEQ cites the preamble to the final rule setting the tests in 51.308(e)(3), which notes "the logical reference point [for comparing a BART alternative] is visibility conditions as they are expected to be at the time of program implementation" (that is, in the future).[21] However, that same section notes "we did not specify the time period which should serve as the starting point for comparison."[22] The point of comparison is discretionary and not necessarily in the future.

Furthermore, in the case of single source modeling like CALPUFF, only the meteorological factors are influenced by the years modeled. Thus, while a more recent timeframe might arguably make more sense at this point than Arizona's BART baseline of 2001-2003, unless the meteorology has changed significantly in the last decade, it would make more of a difference under a multi-source photochemical grid model. CALPUFF modeling over the BART baseline years are sufficient to determine the relative benefit of different technologies applied at a single source; this is no different. Indeed, EPA has used CALPUFF in several similar situations.[23]

Thus we disagree with ADEQ, and believe that the second test applies. Nevertheless, as described by EPA, "the underlying purpose of both prongs of the test is to assess whether visibility conditions at Class I areas would be better with the alternative program in place than they would without it."[24] This is also the ultimate test that any "clear weight of evidence" must show.

ADEQ's proposal is incomplete in its demonstration in four significant ways. First, visibility is worse under the alternative than under BART at two of the modeled Class I areas, Mt. Baldy and Gila Wilderness Areas. ADEQ does not address this. We encourage ADEQ to achieve visibility improvements at all Class I areas, not seven out of nine. One possibility for this would be to convert Unit 3 to gas rather than Unit 2. The reasoning for this is that Unit 3's baseline NOx emissions are significantly higher than Unit 2's. Thus, more benefit (and lower NOx emissions) would accrue from converting Unit 3 and adding SNCR to Unit 2. We offer this as one suggestion out of many possible routes to close the gap and ensure improved visibility under the alternative at all affected Class I areas.

Second, the regulations require looking at both the best 20% and the worst 20% of days. We appreciate ADEQ's discussion of the 98th percentile values, but even under the "clear weight of evidence" standard, the analysis should include results from both less impacted and more heavily impacted days.

Third, we note that the modeled emission rate for Unit 3 (0.225 lbs/mmbtu) is lower than the permitted limit (0.23 lbs/mmbtu). Modeled results may thus be underestimates of the impacts, and we encourage conservative interpretation of the results as a margin of safety.

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[21] 70 Fed. Reg. 39138.
[22] *Id.*
[23] See, e.g., 78 Fed. Reg. 79355; 79 Fed. Reg. 9335.
[24] 70 Fed. Reg. 39138.

Finally, the regulations clearly contemplate the potential impacts at "any" and "all affected" Class I areas. ADEQ's results only discuss Class I areas within 300 km. There is no boundary at 300 km that limits the impact of pollutants; rather, it is a historical artifact based on perceived limits of the CALPUFF model. In fact, there are impacts well beyond 300 km that can be modeled by CALPUFF.[25] In this case, there are 14 more Class I areas between 300 and 600 km. The impacts to these and any other impacted Class I areas must be considered.

Thank you for the opportunity to submit comments on this matter.

Sincerely,

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[25] EPA previously has rejected long-range visibility modeling (greater than 300 kilometers) by referencing a now-discredited 1998 report regarding CALPUFF performance. See, e.g. 77 Fed. Reg. 57,864 (Sep. 18, 2012). The Interagency Workgroup on Air Quality Modeling (IWAQM) Phase 2 report (EPA, 1998) is outdated, and its results have been called into question by more recent studies. See discussion in October 25, 2012 letter to EPA (p. 6) and attached report (Long Range Transport Models Using Tracer Field Experiment Data (May 2012) (EPA Contract No: EP-D-07-102, Work Assignment No: 4-06).

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May 29, 2013

The Honorable Robert Perciasepe
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The Honorable Jared Blumenfeld
Regional Administrator
U.S. EPA, Region 9
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San Francisco, CA 94105

Re: Supplement to Petition for Administrative Reconsideration
BART for Units 2 and 3, Apache Generating Station
77 Fed. Reg. 72512 (Dec. 5, 2012)

Dear Messrs. Perciasepe and Blumenfeld:

On February 2, 2013, Arizona Electric Power Cooperative, Inc. ("AEPCO") filed a petition for administrative reconsideration of the U.S. Environmental Protection Agency ("EPA") final rule entitled "Approval, Disapproval and Promulgation of Air Quality Implementation Plans; Arizona; Regional Haze State and Federal Implementation Plans" in the *Federal Register* at volume 77, pages 72512 and following (the "Rule"). As part of the Rule, EPA promulgated a Federal Implementation Plan ("FIP") establishing "best available retrofit technology" or "BART" for Apache Generating Station Steam Units 2 and 3 operated by AEPCO. In its petition, AEPCO provided information demonstrating that the FIP is unaffordable, requested clarification of the application of the BART limits to Apache Generating Station Steam Unit 1, and expressed concern about unintended consequences of averaging provisions adopted as part of the compliance provisions of the BART FIP. AEPCO also stated that it believed that EPA's visibility objectives could be substantially met at less cost.

EPA graciously agreed to meet with AEPCO to discuss its petition on February 8, 2013, in Washington, DC, and then again in several subsequent conference calls. In these discussions, EPA and AEPCO have discussed, as AEPCO suggested on page 21 of its February 2, 2013 petition, alternatives to the BART determined in the FIP. EPA technical staff has indicated that they believe AEPCO's tentative recommendation at the February 8, 2013 meeting—a conversion of one of AEPCO's units from coal to pipeline natural gas and use of selective non-catalytic reduction ("SNCR") technology at the other—has sufficient merit to warrant a formal proposal for the Agency's consideration. Accordingly, consistent with EPA Region 9's request, AEPCO submits this supplement to its February 2, 2013 petition for administrative reconsideration setting forth its proposed alternative in more detail.

AEPCO's Proposal for BART

As discussed with EPA technical representatives, AEPCO is proposing that the following control technology be adopted as BART for Apache Generating Station Steam Units 2 ("ST2") and 3 ("ST3"). AEPCO believes that this proposal will achieve equivalent, or better, visibility results than that promulgated by EPA in the Final Rule.

BART for ST2

AEPCO proposes to permanently convert ST2 from coal to natural gas on December 5, 2017, with an exception for a limited emergency use in the event of disruption of the natural gas supply, which is discussed below. AEPCO proposes to establish BART as the following combination of technologies and pollutant limits:

Particulate Matter: Pipeline Natural Gas ("PNG"), 0.01 lb PM_{Total}/MMBtu 30-day rolling average, dropping to 0.008 lb PM_{Total}/MMBtu 30-day rolling average effective December 5, 2018.

Sulfur Dioxide: PNG, 0.00064 lb/MMBtu 30-day rolling average.

Nitrogen Oxides: PNG, 0.085 lb/MMBtu 30-day rolling average.

Emergency Provision: AEPCO will not operate ST2 on coal after the effective date of the BART determination except in the event of a supply disruption caused by natural gas supplier or transporter pipeline failure, freeze-up or pipeline compression failure that reduces gas volume or gas pressure below that necessary for Apache Generating Station gas generation. AEPCO must discontinue coal firing as expeditiously as possible after restoration of natural gas service at levels supporting continuous firing of ST2 and in no event more than 48 hours after restoration of such service.

Flexibility Provision: AEPCO may comply with the BART limits through any combination of process adjustments or add-on controls, provided that such combination achieves the BART numeric limit (on a 30-day rolling average basis) and complies with applicable regulations and permits and AEPCO obtains any necessary preconstruction or operating approvals.

BART for ST3

AEPCO proposes to retain coal as the principal fuel, with natural gas and co-firing of coal and natural gas as alternative operating scenarios, for ST3. AEPCO proposes to establish BART as the following combination of technologies and pollutant limits:

Particulate Matter:	Electrostatic precipitators (ESPs), 0.03 lb $PM_{Filterable}$/MMBtu 30-day rolling average.
Sulfur Dioxide:	SO_2 scrubbers, 0.15 lb/MMBtu, 30-day rolling average.
Nitrogen Oxides:	Low NOx Burners + Overfire Air + SNCR, 0.23 lb/MMBtu, 30-day rolling average.
Flexibility Provision:	AEPCO may comply with the BART controls through any combination of fuels, process adjustments, or add-on controls, provided that such combination achieves the BART numeric limit (on a 30-day rolling average basis) and complies with applicable regulations and permits and AEPCO obtains any necessary preconstruction or operating approvals.

EPA inquired whether AEPCO's SNCR installation might achieve a lower NOx rate over a longer average for modeling purposes. Based on input from FuelTech, AEPCO believes that overall NOx reductions would likely be on the order of 0.225 lb/MMBtu, but this cannot be achieved on a 30-day rolling average in all cases and AEPCO is not proposing the 0.225 lb/MMBtu as a limit because of the uncertainty. AEPCO has also proposed to reduce the particulate matter limit for the natural gas unit from 0.01 lb PM_{Total}/MMBtu to 0.008 lb PM_{Total}/MMBtu. This reduction would become effective on December 5, 2018.

<u>BART Timing</u>

AEPCO proposes to retain the current time line for implementation outlined in EPA's SIP approval (for PM and SO_2) and FIP (for NOx), except that specific deadlines are adjusted to accommodate the ST2 conversion to natural gas, as follows:

ST1:	Unchanged
ST2:	NOx effective December 5, 2017
	SO_2 0.15 lb/MMBtu effective December 5, 2016
	SO_2 0.00064 lb/MMBtu effective December 6, 2017
	$PM_{10\text{-}Filterable}$ 0.03 lb/MMBtu effective December 5, 2016
	$PM_{10\text{-}Total}$ 0.01 lb/MMBtu effective December 5, 2017
	$PM_{10\text{-}Total}$ 0.008 lb/MMBtu effective December 5, 2018
ST3:	NOx effective December 5, 2017
	SO_2 effective December 5, 2016
	$PM_{10\text{-}Filterable}$ effective December 5, 2016

Additionally, should final approval of this proposal be delayed by more than six months from the original SIP approval and FIP promulgation effective date, the implementation date would be tolled on a day-by-day basis to account for the delay. Final approval would be defined as the effective date of EPA's rule promulgating this proposal, unless stayed at the request of a third party, in which case final approval would be upon termination of the stay (assuming the

rule is upheld). If the proposal is invalidated, AEPCO must comply with the current BART FIP (and/or SIP, for non-NOx pollutants) within four and a half years.

Justification

AEPCO believes, based upon modeling, monitoring, and our general understanding of regional haze that the visibility benefits of its proposal will be better than those achieved by EPA's existing FIP—e.g., that AEPCO's proposal is "better than BART." Better than BART results are achieved both by the emissions reductions resulting from AEPCO's proposal and because the emissions results will better match Arizona's "Uniform Rate of Progress" goals to achieve the ultimate congressional goal.

Emissions Reductions Exceed Those Achieved Under EPA's SCR BART FIP

AEPCO has calculated the emissions reductions achieved from both EPA's SCR BART FIP and AEPCO's proposed alternative converting ST2 to pipeline natural gas and ST3 to SNCR using the same heat input rate as EPA did in the proposed and final rules and AEPCO's 85% utilization factor for all cases. Using this approach, the AEPCO alternative achieves additional aggregate emissions reductions for SO_2 and particulate matter that outweigh the increase in NOx emissions. This can be seen in the following table:

Control Option	Pollutant	Unit	Emissions Factor, lb/MMBtu	Heat Rate MMBtu/hr	Annual Capacity Factor	Emissions lb/hr	Emissions tpy
Baseline	NOx	ST2	0.371	2316	0.85	859.24	3198.94
Baseline	SO2	ST2	0.15	2316	0.85	347.40	1293.37
Baseline	PM	ST2	0.03	2316	0.85	69.48	258.67
Baseline	NOx	ST3	0.438	2223	0.85	973.67	3624.99
Baseline	SO2	ST3	0.15	2223	0.85	333.45	1241.43
Baseline	PM	ST3	0.03	2223	0.85	66.69	248.29
Combined NOx						1832.91	6823.92
Combined SO2						680.85	2534.80
Combined PM						136.17	506.96
EPA SCR	NOx	ST2	0.07	2316	0.85	162.12	603.57
EPA SCR	SO2	ST2	0.15	2316	0.85	347.40	1293.37
EPA SCR	PM	ST2	0.03	2316	0.85	69.48	258.67
EPA SCR	NOx	ST3	0.07	2223	0.85	155.61	579.34
EPA SCR	SO2	ST3	0.15	2223	0.85	333.45	1241.43
EPA SCR	PM	ST3	0.03	2223	0.85	66.69	248.29
Combined NOx						317.73	1182.91

Control Option	Pollutant	Unit	Emissions Factor, lb/MMBtu	Heat Rate MMBtu/hr	Annual Capacity Factor	Emissions lb/hr	Emissions tpy
Combined SO2						680.85	2534.80
Combined PM						136.17	506.96
AEPCO Proposal	NOx	ST2	0.085	2316	0.85	196.86	732.91
AEPCO Proposal	SO2	ST2	0.00064	2316	0.85	1.48	5.52
AEPCO Proposal	PM	ST2	0.008	2316	0.85	18.53	68.98
AEPCO Proposal	NOx	ST3	0.225	2223	0.85	500.18	1862.15
AEPCO Proposal	SO2	ST3	0.15	2223	0.85	333.45	1241.43
AEPCO Proposal	PM	ST3	0.03	2223	0.85	66.69	248.29
Combined NOx						697.04	2595.06
Combined SO2						334.93	1246.95
Combined PM						85.22	317.27
Comparison	**NOx TPY**	**SO2 TPY**	**PM TPY**	**Net Change**			
EPA to Baseline	-5641.02	0.00	0.00	-5641.02			
AEPCO to Baseline	-4228.86	-1287.85	-189.69	-5706.41			
AEPCO to EPA	1412.15	-1287.85	-189.69	-65.39			

As can be seen from the calculations, AEPCO's alternative will result in reducing an estimated 1288 tons of SO_2 and 190 tons of particulate matter compared to EPA's BART FIP, while increasing NOx emissions by approximately 1412 tons/year, resulting in an aggregate emissions reduction of an additional 65 tons/year. AEPCO's alternative thus achieves better than BART levels of reduction. As discussed below, AEPCO's alternative also achieves superior visibility benefits.

CALPUFF Modeling Shows "Better than Bart" Results

Both EPA Region 9 and AEPCO's consultant, ENVIRON (which assisted in the original Western Regional Air Partnership (WRAP) modeling effort), have conducted CALPUFF modeling of AEPCO's emissions. Both EPA and ENVIRON used a common CALMET meteorological database and a common version of the CALPUFF model to minimize unintended differences. Additionally, ENVIRON ran EPA's base case and SCR case and compared ENVIRON results to EPA, which showed good agreement, after adjusting a stack temperature correction from AEPCO. As noted in the ENVIRON report, AEPCO is using a direct comparison of the CALPUFF modeling results for both the average of the 98th percentile for the three years 2001-2003 or the 22nd high measurement over the 2001-2003 period for comparison with EPA's SCR scenario modeled results to determine whether AEPCO's proposed alternative results in better than BART results. Based on guidance provided by EPA, AEPCO is using NOx

values of 0.225 lb/MMBtu for its proposed SNCR alternative on ST3 rather than the 0.23 lb/MMBtu 30-day rolling limit. While AEPCO's vendor does not believe that AEPCO can achieve less than 0.23 lb/MMBtu during all 30-day periods, it does believe that, over time, AEPCO's emissions are likely to be 0.225 lb/MMBtu or less. The details of the modeling are set forth in the attached ENVIRON report "CALPUFF Visibility Modeling of the AEPCO BART Scenarios" dated May 10, 2013.

In the ENVIRON report, the AEPCO proposal is Version 2 of AEPCO Alternative Control 9b. In Attachment E5, ENVIRON report sets forth the CALPUFF model results as follows:

AEPCO CALPUFF Results	**Impact in Deciviews: 1 ppb Ammonia**				
EPA BART SCR	**98th Percentile**			**Avg 98th**	**22nd high**
Class I Area	**2001**	**2002**	**2003**	**2001 -2003**	**2001 -2003**
Chiricahua NM	1.790	2.147	1.996	1.978	1.996
Chiricahua Wild.	1.979	1.892	1.788	1.886	1.979
Galiuro Wild.	0.991	1.146	1.486	1.208	1.205
Gila Wild.	0.226	0.321	0.238	0.262	0.279
Mazatzal Wild.	0.167	0.172	0.130	0.156	0.147
Mount Baldy Wild.	0.102	0.132	0.092	0.109	0.114
Saguaro NP	1.308	1.460	1.495	1.421	1.463
Sierra Ancha Wild.	0.137	0.174	0.149	0.153	0.158
Superstition Wild.	0.317	0.307	0.314	0.313	0.315
Average	0.780	0.861	0.854	0.832	0.851
AEPCO CALPUFF Results	**Impact in Deciviews: 1 ppb Ammonia**				
AEPCO Alt Cntl 9bv2	**98th Percentile**			**Avg 98th**	**22nd high**
Class I Area	**2001**	**2002**	**2003**	**2001 -2003**	**2001 -2003**
Chiricahua NM	1.898	1.740	2.007	1.882	1.909
Chiricahua Wild.	1.852	1.837	1.863	1.851	1.852
Galiuro Wild.	0.959	0.952	1.421	1.111	1.135
Gila Wild.	0.292	0.342	0.226	0.287	0.295
Mazatzal Wild.	0.136	0.131	0.112	0.126	0.124
Mount Baldy Wild.	0.116	0.121	0.100	0.112	0.116
Saguaro NP	1.213	1.525	1.301	1.346	1.317
Sierra Ancha Wild.	0.132	0.139	0.118	0.130	0.128
Superstition Wild.	0.283	0.330	0.212	0.275	0.283
Average	0.765	0.791	0.818	0.791	0.795

Difference in dv between EPA BART SCR and AEPCO Alternative Cntl 9b (Alt – SCR)					
AEPCO CALPUFF Results	**98th Percentile**			**Avg 98th**	**22nd high**
Class I Area	**2001**	**2002**	**2003**	**2001 -2003**	**2001 -2003**
Chiricahua NM	0.108	-0.407	0.011	-0.096	-0.087
Chiricahua Wild.	-0.127	-0.055	0.075	-0.036	-0.127
Galiuro Wild.	-0.032	-0.194	-0.065	-0.097	-0.070
Gila Wild.	0.066	0.021	-0.012	0.025	0.016
Mazatzal Wild.	-0.031	-0.041	-0.018	-0.030	-0.023
Mount Baldy Wild.	0.014	-0.011	0.008	0.004	0.002
Saguaro NP	-0.095	0.065	-0.194	-0.075	-0.146
Sierra Ancha Wild.	-0.005	-0.035	-0.031	-0.024	-0.030
Superstition Wild.	-0.034	0.023	-0.102	-0.038	-0.032
Average	-0.015	-0.070	-0.036	-0.041	-0.055

In seven of the nine Class I Areas, AEPCO's proposal achieves additional visibility improvements beyond what EPA's BART FIP achieves. These improvements range from a low of -0.024 dv to a high of -0.097 dv. Only two areas show a marginal increase (of +0.004 and +0.025 dv) and these impacts are imperceptible and occur in areas where the Apache Station's total BART-eligible contribution to visibility impairment is less than 0.3 dv. Critically, using EPA's cumulative BART metric, AEPCO's proposal would achieve a -0.367 dv (on Average 98th percentile basis) or a -0.497 dv (on a 22nd high basis) improvement in visibility versus EPA's current BART FIP. AEPCO's proposal thus achieves "better than BART" results on even the most conservative basis.

As stated in the ENVIRON report, however, the use of the regulatory 1.0 ppb default ammonia concentration is not necessarily representative of visibility conditions in Arizona. Measured ammonia background values are available, as noted in the attached ENVIRON report and in prior comments by APS and SRP. If the variable, measured ammonia concentrations are used, improvements in visibility resulting from AEPCO's proposed alternative are greater, as set forth in the ENVIRON report in Attachment D2. This shows improvements ranging from a low of -0.015 to a high of -0.25 dv (average 98th percentile basis), or -0.005 to -0.275 dv (22nd high basis) in all nine areas and the cumulative impact is -1.059 dv (average 98th percentile basis) or --1.064 dv (22nd high basis). Using the more realistic, variable ammonia background suggests that visibility improvements will be considerably higher – approaching a full deciview, which is likely to be a perceptible improvement. AEPCO believes that a fully perceptible improvement is clearly better than BART.

Finally, as ENVIRON notes in its two attached reports, the natural gas particulate speciation data used in the existing Federal Land Manager (FLM) protocol substantially overstates the elemental carbon and organic carbon contributions from natural gas. As can be seen in Table 2b, the FLM protocol results in natural gas having higher carbon emissions than coal. EPA itself has changed these assumptions in the National Emissions Inventory (NEI)

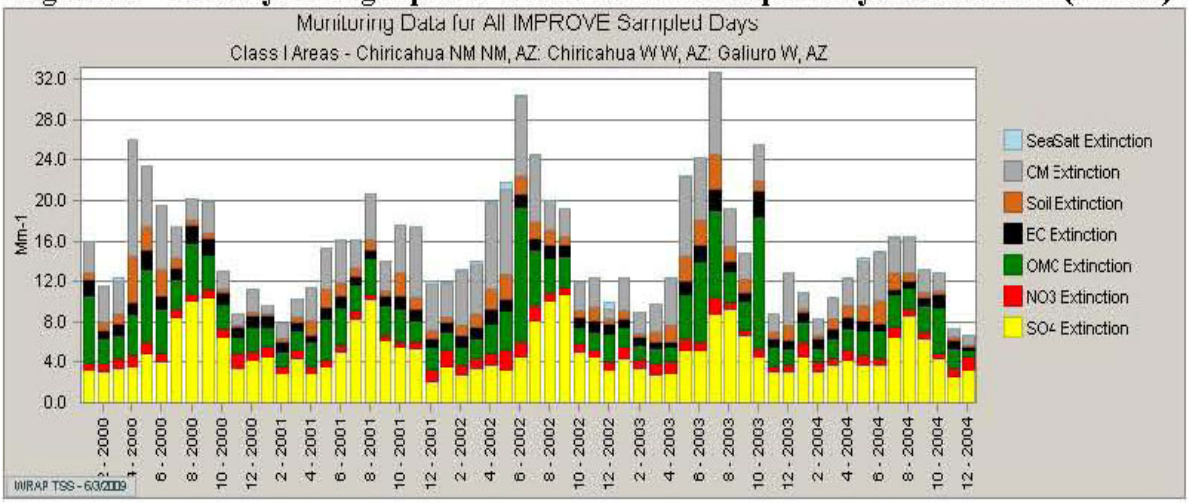
program. Using the NEI protocol results in far greater improvements, as seen in Attachment C of the ENVIRON report. While AEPCO cannot commit to the NEI values (because of testing and compliance demonstration issues with the Methods), use of the NEI values strongly suggests that actual visibility improvements will be greater than the conservative results shown in Attachments E5 and D2. Based on this extensive modeling work, and the sensitivity analysis inherent in the review of alternatives, AEPCO believes that the weight of the evidence demonstrates that its proposal will achieve better visibility improvements than EPA's current BART FIP. A discussion of the technical basis for the NEI is found in the attached ENVIRON memorandum entitled "Updated $PM_{2.5}$ Emissions Factors for Natural Gas-Fired Boilers," dated May 8, 2013. The modeling results are set forth in the aforementioned "CALPUFF Visibility Modeling of the AEPCO BART Scenarios" memorandum dated May 10, 2013.

As requested by EPA Region 9 staff, CALPUFF modeling results are submitted for AEPCO Control 9b version 2 only in the enclosed CD.

<u>AEPCO's Alternative Better Meets Uniform Rate of Progress Needs</u>

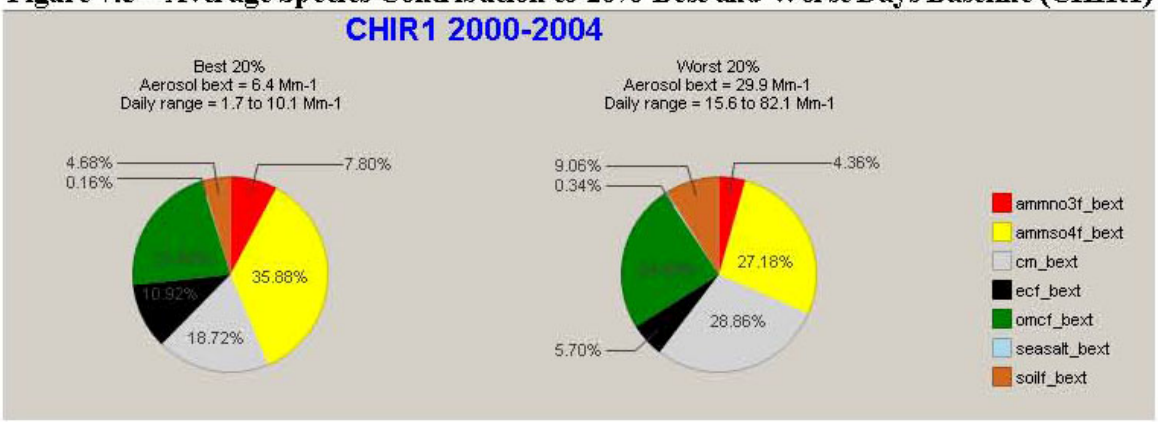
Visibility monitoring data at the Chiricahua monitor shows that both sulfate (derived in part from SO_2 emissions) and particulate (derived in part from direct $PM_{2.5}$ emissions) are, historically, more significant contributors to regional haze in the Chiricahua National Monument and Wilderness Area than is nitrate (derived in part from NOx emissions). The following chart, taken from Arizona's Regional Haze SIP, shows the relative contributions over time:

Figure 7.6 – Monthly Average Species Variation for All Sampled Days over Baseline (CHIR1)



As can be seen, both the yellow "SO_4 Extinction" and gray "CM (for coarse matter) Extinction" are generally much more significant than the red "NO_3 Extinction" factor, based on the IMPROVE dataset. Breaking this down into the regulatory division of the 20 percent "best" and "worst" days clearly shows the impact of SO_4 and CM versus NO_3:

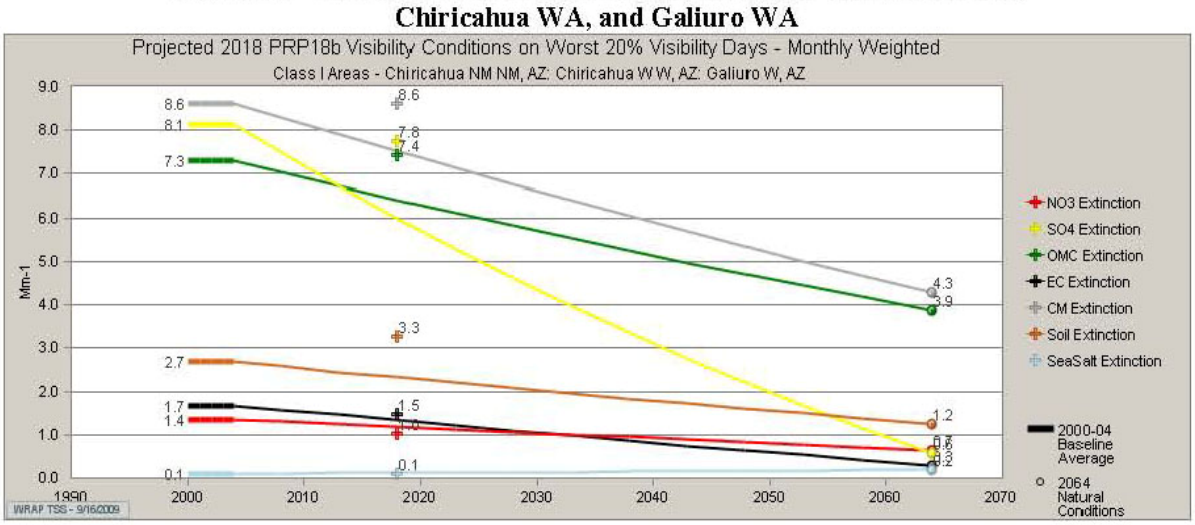
Figure 7.5 – Average Species Contribution to 20% Best and Worst Days Baseline (CHIR1)



Sulfate contributes 35.9% in best days and 27.2% in worst days, versus only 7.8 and 4.4% respectively for nitrate (nearly 5x and 6x the impact). CM contributes 18.7% in best days and 28.9% in worst days, or nearly 2x and 6x the impact of nitrate. Reductions in sulfate and coarse material thus should be anticipated to improve visibility by as much, or more than, equivalent reductions in nitrate.

Third, the Arizona Regional Haze SIP found, and EPA agreed, that the Uniform Rate of Progress (URP) demands significantly greater emissions reductions in sulfate and coarse material than nitrate, as seen in the following chart from the Arizona Regional Haze SIP:

Figure 9.1 – URP by Pollutant on 20% Worst Days for Chiricahua NM, Chiricahua WA, and Galiuro WA



The AEPCO proposal significantly advances progress toward the SO_4 Extinction and CM Extinction goals compared to the existing EPA FIP.

Based on the EPA and ENVIRON modeling, the monitoring data and general direction of emissions reduction needed to achieve the natural condition goal, and the general understanding of atmospheric chemistry and the limitations of the existing modeling tools, AEPCO believes that the weight of the evidence demonstrates that its proposal, which substantially reduces emissions of SO_2 and PM while increasing NOx emissions more modestly, will achieve "better than BART" visibility improvement.

AEPCO therefore formally requests that EPA reconsider its existing BART FIP limits and replace them with its proposal set forth in this letter for the reasons stated above.

Status of ST1/GT1

In its petition for administrative reconsideration, AEPCO noted that EPA's question and answer document for the Arizona BART program implied that Apache Generating Station gas turbine #1 (GT1) is subject to the ST1 BART limits. GT1 is a simple cycle turbine that can exhaust to the ST1 windbox; can be used to warm and dry the ST1 boiler, or can run in stand-alone mode. AEPCO believes that GT1, when operating in stand-alone mode or for boiler warming and drying, is a simple cycle unit not subject to BART. AEPCO, EPA and ADEQ held a conference call on February 22, 2013 to discuss the status of units ST1 and GT1. ADEQ has noticed a SIP revision addressing this issue.

ADEQ has proposed to clarify the ST1 BART determination as follows:

> After reviewing the company's BART analysis, and based upon the information above ADEQ has determined that, for Unit 1, BART for NOx is the installation of LNB with FGR (which will also burn No. 2 fuel oil with minor equipment change out) with a NOx emissions limit of 0.056 lb/MMBtu when burning PNG, and 0.06 lb/MMBtu when burning No. 2 fuel oil. It should be noted that the proposed BART limit for ST1 will apply when ST1 operates alone or if ST1 and GT1 are operated as a combined cycle operation. The proposed BART limit does not apply to (a) GT1 in stand-alone simple cycle operation or (b) ST1/GT1 when ST1 burners are shut off and ST1 is not producing electricity.

Arizona Regional Haze SIP, submitted to EPA on April 29, 2013, page 110 of 174. EPA's consent to ADEQ's proposed SIP revision (for which ADEQ has requested parallel processing) would resolve AEPCO's request for administrative reconsideration on this issue.

AEPCO appreciates EPA's statement in a recent proposal that it agrees with this proposed clarification. AEPCO requests that EPA repeat this consent to the ST1/GT1 clarification in the final rule so that AEPCO's compliance obligations with respect to ST1 and GT1 are clear.

Limit Achievability and Averaging

In its petition for administrative reconsideration, AEPCO expressed concern about the averaging limit and the potential impact on cycling units and the inequity of being held in violation of a limit when AEPCO has shutdown the unit causing the "average" limit to be

exceeded. As AEPCO noted, because the cross-unit average can only be brought back into compliance by restarting the unit not able to achieve the 0.07 lb/MMBtu limit, it creates tremendous pressure to shorten maintenance to bring the problem unit back up to restore compliance. Placing this pressure on unit maintenance is likely to cause increased problems, including trips, upon restart, potentially prolonging the period of noncompliance.

To resolve this problem, AEPCO proposes to revise the NOx determination along the following conceptual lines:

(1) The following NOx BART limits are established:
   a. ST2: 0.085 lb NOx/MMBtu, 30-BOD rolling average (BODRA)
   b. ST3: 0.23 lb NOx/MMBtu, 30-BOD rolling average
   c. ST2/ST3: Limit = ((ST2 MMBtu, 30BODRA * 0.085 lb/MMBtu) + (ST3 MMBtu, 30 BODRA * 0.23 lb/MMBtu))/(ST2 MMBtu, 30 BODRA + ST3 MMBtu, 30BODRA), where BODRA = 30 Boiler Operating Day rolling average for that unit
(2) Compliance during periods when both units are operating is demonstrated when either of the following conditions are met:
   a. The combined NOx emissions of both units meet the combined limit; or
   b. Each unit meets its individual NOx limit.
(3) Compliance during periods when only one unit is operating is met when the operating unit meets its individual NOx limits.

Proposed revisions to the existing FIP compliance language are attached for EPA's consideration for the Apache Generating Station. AEPCO does not know whether this approach is acceptable to the other utilities. AEPCO believes that averaging is valuable to provide operating flexibility when a unit is brought back on-line and that the proposed methodology may lessen the number of times that AEPCO might need to rely upon the malfunction provisions, which makes the averaging proposal set forth herein preferable.

AEPCO requests that EPA substitute the proposed compliance methodology for that set forth in the existing BART FIP.

AEPCO hopes that this proposal meets with EPA's approval. As can be seen, AEPCO believes that its proposal should achieve equivalent, and in fact likely superior, visibility gains to those that EPA would obtain under the NOx BART FIP. AEPCO can achieve these gains at considerably lower cost, lowering the burden on its members and rural Arizonans.

We look forward to EPA's consideration of this proposal. Please contact Michelle Freeark, AEPCO's Director of Environmental Services, at (520) 586-5122, or Eric Hiser, AEPCO's air counsel, at (480) 505-3927, if you have any further questions or concerns about this proposal. We look forward to EPA's consideration and continued discussion to see if EPA

and AEPCO, working together, can achieve "better than BART" results at an affordable cost to AEPCO, its cooperative members, and their ratepayers.

Sincerely,

Eric L. Hiser
Counsel for AEPCO

Attachments

- ENVIRON, "CALPUFF Visibility Modeling of the AEPCO BART Scenarios" (May 10, 2013)
- ENVIRON, "Updated $PM_{2.5}$ Emissions Factors for Natural Gas-Fired Boilers" (May 8, 2013)

PROPOSED FIP LANGUAGE

(3) *Federal emission limitations.*—(i) *NOX* emission limitations. **Except as provided in paragraph (iii), t**he owner/operator of each coal-fired unit subject to this paragraph (f) shall not emit or cause to be emitted NOX in excess of the following limitations, in pounds per million British thermal units (lb/MMBtu) from any group of coal-fired units. Each emission limit shall be based on a rolling 30-boiler-operating day average, unless otherwise indicated in specific paragraphs.

Group of coal-fired units Federal emission limitation
~~Apache Generating Station~~
~~Units 2 and 3 ..... 0.070~~
Cholla Power Plant Units 2,
3, and 4 ..... 0.055
Coronado Generating Station
Units 1and 2 ..... 0.065

(ii) [No change]
(iii) Apache Generating Station Units 2 and 3 shall not emit or cause to be emitted NOx, SO_2 or PM_{10} in excess of the following limitations, in pounds per million British thermal units (lb/MMBtu) from each unit, or emit or cause to be emitted NOx from the combination of Units 2 and 3 in excess of the following limit defined by equation. Each emission limit shall be based on a rolling 30-boiler-operating day average, determined as follows:

Apache Generating Station Limits, lb/MMBtu

Unit	**NOx**	**SO_2**	**PM_{10}**
Unit 2, Phase 1	**NA**	**0.15**	**0.03 Filterable**
Unit 2, Phase 2	**0.085**	**0.00064**	**0.01 Total**
Unit 2, Phase 3	**0.085**	**0.00064**	**0.008 Total**
Unit 3, Phase 1	**NA**	**0.15**	**0.03 Filterable**
Unit 3, Phase 2	**0.23**	**0.15**	**0.03 Filterable**
Combined Units 2/3	*****	**NA**	**NA**

***Combined Units 2/3 NOx Limit = ((Unit 2 MMBtu * 0.085 lb/MMBtu) + (Unit 3 MMBtu * 0.23 lb/MMBtu)/(Unit 2 MMBtu + Unit 3 MMBtu)**

Compliance during a boiler operating day when both units are operating is demonstrated when either of the following conditions are met: (A) the combined NOx emissions of Units 2 and 3 meet the combined limit; or (B) each unit meets its individual NOx limit. Compliance during a boiler operating day when only one unit is operating is demonstrated when the operating unit meets its individual NOx limit.

(4) *Compliance dates.* (i) The owners/operators of each unit subject to this paragraph (f) shall comply with the NOX emissions limitations and other NOX related requirements of this paragraph (f) no later than December 5, 2017.

(ii)**(A) Except as provided in paragraph (B), t**he owners/operators of each unit subject to this paragraph (f) shall comply with the applicable PM10 and SO2 emissions limits submitted to EPA as part of the Arizona Regional Haze SIP in a letter dated February 28, 2011, and approved into the Arizona State Implementation Plan on December 5, 2012, as well as the related compliance, recordkeeping and reporting of this paragraph (f) no later than the following dates:
Table [delete AEPCO Unit 2 and Unit 3]

(B) The owner/operator of the Apache Generating Station Units 2 and 3 subject to this paragraph (f) shall comply with the applicable PM_{10} and SO_2 emissions limits and the related compliance, recordkeeping and reporting requirements of this paragraph (f) no later than the following dates:

Apache Generating Station Compliance Time Line

Unit and Limits	Compliance Date
Unit 2, Phase 1	**December 5, 2016**
Unit 2, Phase 2	**December 5, 2017**
Unit 2, Phase 3	**December 5, 2018**
Unit 3, Phase 1	**December 5, 2016**
Unit 3, Phase 2	**December 5, 2017**
Combined Units 2/3	**December 5, 2017**

(iii) [No change]

(5) *Compliance determinations for NO_X and* ***SO_{24}***[1]—(i) *Continuous emission monitoring system.* (A) At all times after the compliance date specified in paragraph (f)(4) of this section, the owner/operator of each coal-fired unit shall maintain, calibrate, and operate a CEMS, in full compliance with the requirements found at 40 CFR Part 75, to accurately measure SO_2, NO_X, diluent, and stack gas volumetric flow rate from each unit. In addition, the owner/operator of Cholla Units 2, 3, and 4 shall calibrate, maintain, and operate a CEMS, in full compliance with the requirements found at 40 CFR Part 75, to accurately measure SO2 emissions and diluent at the inlet of the sulfur dioxide control device. Apache Unit 1 NO_X and diluent CEMs shall be operated to meet the requirements of Part 75. All valid CEMS hourly data shall be used to determine compliance with the emission limitations for NO_X and SO_2 in paragraph (f)(3) of this section for each unit. When the CEMS is out-of-control as defined by Part 75, that CEMs data shall be treated as missing data and not used to calculate the emission average. Each required CEMS must obtain valid data for at least 90 percent of the unit operating hours, on an annual basis. **Apache Unit 2 is not subject to the requirements of paragraph (f)(5)(i) for SO_2 upon its conversion to pipeline natural gas, but shall comply with paragraph (f)(5)(iii)(E).**
(B) The owner/operator of each unit **with a CEMS subject to paragraph (f)(5)(i)** shall comply with the quality assurance procedures for CEMS found in 40 CFR Part 75. In addition to these Part 75 requirements, relative accuracy test audits shall be calculated for both the NO_X and SO_2 pounds per hour measurement and the heat input measurement. The CEMs monitoring data shall not be bias adjusted. The inlet SO_2 and diluent monitors required by this rule shall also meet the Quality Assurance/Quality Control (QA/QC) requirements of Part 75. The testing and evaluation of the inlet monitors and the calculations of relative accuracy for lb/hr of NO_X, SO_2 and heat input shall be performed each time the Part 75 CEMS undergo relative accuracy testing. In addition, relative accuracy test audits shall be performed in the units of lb/MMBtu for the inlet and outlet SO_2 monitors at Cholla Units 2, 3, and 4. Heat input for Apache Unit 1 shall be measured in accordance with Part 75 fuel gas measurement procedures found in 40 CFR Part 75, Appendix D.

(ii) *Compliance determinations for NO_X*. (A) The 30-day rolling average NO_X emission rate for each coal-fired unit, or each group of coal-fired units, shall be calculated for each calendar day, even if a unit is not in operation on that calendar day, in accordance with the following procedure: step one, for each unit, sum the hourly pounds of NO_X emitted during the current boiler-operating day (or most recent boiler-operating day if the unit is not in operation), and the preceding twenty-nine (29) boiler operating days, to calculate the total pounds of NO_X emitted over the most recent thirty (30) boiler-operating day period for each coal-fired unit; step two, for each unit, sum the hourly heat input, in MMBtu, during the current boiler operating day (or most recent boiler operating day if the unit is not in operation), and the preceding twenty nine (29) boiler-operating days, to calculate the total heat input, in MMBtu, over the most recent thirty (30) boiler-operating day period for each coal-fired unit; **step three, for each unit, divide the total pounds of NO_X emitted by that unit from step 1 by the total heat input for that unit from step 2 to calculate each unit's 30-day rolling average NOx emission rate, in pounds of NOx per MMBtu, for each**

[1] The Federal Register version states SO_4, not SO_2.

calendar day; step **four**~~3~~, sum together the total pounds of NO_X emitted from the group of coal-fired units over each unit's most recent thirty (30) boiler-operating day period (the most recent 30 boiler operating day periods for different units may be different); step **five**~~four~~, sum together the total heat input from the group of coal-fired units over each unit's most recent thirty (30) boiler-operating day period; and step **six**~~five~~, divide the total pounds of NO_X emitted from step **four for each group of coal-fired units** ~~three~~ by the total heat input from step **five**~~four~~ for each group of coal-fired units, to calculate the 30-day rolling average NO_X emission rate for each group of coal-fired units, in pounds of NO_X per MMBtu, for each calendar day. Each 30-day rolling average NO_X emission rate shall include all emissions and all heat input that occur during all periods within any boiler-operating day, including emissions from startup, shutdown, and malfunction. **Compliance is demonstrated if either (I) each operating unit meets its individual NO_X limit as calculated in step three or (II) if the group of operating coal-fired units meets its combined NO_X limit as calculated in step six.**
(B) The 30-day rolling average NO_X emission rate for Apache Unit 1 shall be calculated in accordance with the following procedure: step one, sum the total pounds of NO_X emitted from the unit during the current boiler-operating day and the previous twenty-nine (29) boiler-operating days; step two, sum the total heat input to the unit in MMBtu during the current boiler-operating day and the previous twenty-nine (29) boiler-operating days; and step three, divide the total number of pounds of NO_X emitted during the thirty (30) boiler-operating days by the total heat input during the thirty (30) boiler operating days. A new 30-day rolling average NO_X emission rate shall be calculated for each new boiler-operating day. Each 30-day rolling average NO_X emission rate shall include all emissions and all heat input that occur during all periods within any boiler-operating day, including emissions from startup, shutdown, and malfunction.
(C) If a valid NO_X pounds per hour or heat input is not available for any hour for a unit, that heat input and NO_X pounds per hour shall not be used in the calculation of the 30-day rolling average.

(iii) *Compliance determinations for SO_2.*
(A) [no changes]
(B) [no changes]
(C) [no changes]
(D) [no changes]
(E) Apache Unit 1 and Apache Unit 2 (after conversion to pipeline natural gas) shall demonstrate compliance with the SO_2 limits through use of pipeline quality natural gas.

(6) Compliance determinations for particulate matter. Compliance with the particulate matter emission limitation for each coal-fired unit shall be determined from annual performance stack tests. Within sixty (60) days of the compliance deadline specified in paragraph (f)(4) of this section, and on at least an annual basis thereafter, the owner/operator of each unit shall conduct a stack test on each unit to measure PM10 using EPA Method 5, in 40 CFR part 60, Appendix A, or Method 201A/202 in 40 CFR Part 51, Appendix M. **Apache Unit 2, after conversion to pipeline natural gas, shall demonstrate compliance with its Phase 2 particulate matter emission limit within 90 days of conversion to natural gas, and shall thereafter demonstrate compliance with its Phase 3 particulate matter emission limit within 60 days of the compliance deadline specified in paragraph (f)(4) of this section. Compliance for Apache Unit 2 shall be demonstrated using EPA Method 5, in 40 CFR part 60, Appendix A and Method 202, in 40 CFR Part 51, Appendix M, or EPA Method 201A/202 in 40 CFR Part 51, Appendix M.** A test protocol shall be submitted to EPA and ADEQ a minimum of 30 days prior to the scheduled testing. The protocol shall identify which method(s) will be used to demonstrate compliance. Each test shall consist of three runs, with each run at least 120 minutes in duration and each run collecting a minimum sample of 60 dry standard cubic feet. Results shall be reported in lb/MMBtu using the calculation in 40 CFR Part 60 Appendix A Method 19. In addition to **required** ~~**annual**~~ stack tests, the owner/operator shall monitor particulate emissions for compliance with the emission limitations in accordance with ~~the~~**any** applicable Compliance Assurance Monitoring (CAM) plan developed and approved in accordance with 40 CFR Part 64. The averaging time for any other demonstration of the PM10 compliance or exceedance shall be based on a 6-hour average.

May 10, 2013

MEMORANDUM

To: Michelle Freeark, Arizona Electric Power Cooperative (AEPCO)
From: Ralph Morris and Lynsey Parker
Subject: CALPUFF Visibility Modeling of the AEPCO BART Scenarios

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SUMMARY

Arizona Electric Power Cooperative (AEPCO) is proposing an alternative to EPA's proposed Best Available Control technology (BART) NO_X emissions controls on their Apache ST2 and ST3 coal-fired electrical generating units (EGUs) located in southeast Arizona. EPA's BART Federal Implementation Plan (FIP) requires AEPCO to install selective catalytic reduction (SCR) control on both of Apache's coal-fired EGUs to achieve a NO_X emissions rate of 0.07 lb/MMBtu. The AEPCO Alternative would convert one of the EGUs to natural gas (ST2) and install selective non-catalytic reduction (SNCR) control on the other unit (ST3). AEPCO contracted with ENVIRON to perform CALPUFF visibility modeling for the EPA SCR BART and AEPCO Alternative control scenarios to estimate visibility impairment at Class I areas and demonstrate that the AEPCO Alternative control scenario achieves greater visibility benefits than EPA's SCR BART control scenario and therefore is "Better than BART."

EPA is performing similar CALPUFF modeling using the same CALPUFF modeling database as ENVIRON. The ENVIRON CALPUFF modeling was initially performed using all of the same assumptions as used by EPA, except in the AEPCO Alternative control scenarios the exit temperature in the natural gas-fired ST2 was higher; EPA used the same exit temperature in ST2 for both the coal and natural gas scenarios and one would expect natural gas effluent to be hotter than coal. For the EPA Base and EPA SCR BART scenarios, the ENVIRON CALPUFF modeling duplicated EPA's CALPUFF modeling results. For EPA's AEPCO Alternative Control 9 and 9b scenarios, there were slight differences in the visibility modeling results due to the different ST2 exit temperature assumptions. However, these differences were small, sometimes higher and sometimes lower, and on average across the Class I areas they were within ±5%.

ENVIRON then performed CALPUFF modeling using two technical enhancements to the CALPUFF modeling assumptions:

- Use of monthly varying background ammonia concentrations as used in the Desert Rock EGU PSD and Navajo Generating Station BART CALPUFF modeling that was agreed to by the Federal Land Managers (FLMs); and
- Use of a new PM emissions rate for natural gas-fired boilers based on more recent and accurate test measurements that is the same PM emissions factor EPA uses in their National Emissions Inventory (NEI).

The most accurate representation of the AEPCO Alternative available using CALPUFF V5.8 modeling system is using the monthly background ammonia and the updated natural gas PM emissions factor. Using this configuration and the BART visibility metrics that consist of the average of the 98th percentile (8th highest in a year) visibility metrics across the three years of modeling (2001-2003) and the 98th percentile using the three years of modeling together (22nd highest over 3 years), CALPUFF estimates that the AEPCO Alternative results in greater visibility improvement than the EPA BART SCR case at all of the Class I areas. The deciview visibility impairment impacts for the AEPCO Alternative are from 9% to 51% lower than the EPA BART SCR Case with the AEPCO Alternative producing visibility improvements averaged across the Class I areas of 31% and 33% better than the EPA BART SCR Case. Thus, the AEPCO Alternative is demonstrated to be Better than BART.

BACKGROUND

The Regional Haze Rule (RHR) goal is to achieve natural visibility conditions at Class I areas by 2064. One component of the RHR is the BART program that implements BART emission controls on specific existing point sources for emissions that have been shown to cause or contribute to visibility impairment at a Class I area. Such visibility precursor emissions include sulfur oxides (SO_X or SO_2), oxides of nitrogen (NO_X) and particulate matter (PM).

AEPCO Apache EGU

AEPCO operates the Apache Generating Station that consists of two ~175 Megawatt (MWe) EGUs (Steam Units 2 and 3 or ST2 and ST3). ST2 and ST3 are dual-fired boilers that are designed and permitted to operate on either coal or natural gas. The Arizona Department of Environmental Quality (ADEQ) has determined that the two Apache EGUs are BART-eligible[1]. The U.S. Environmental Protection Agency (EPA) has determined that BART for the NO_X emissions from the two Apache coal-fired EGUs is selective catalytic reduction (SCR) that achieves a 0.07 lb/MMBtu NO_X emissions rate on a 30-boiler operating day average over ST2 and ST3. AEPCO has proposed an alternative to EPA's proposed BART controls that would convert Apache ST2 to natural gas and install selective non-catalytic reduction (SNCR) on ST3. Thus, the differences in visibility impacts due to the EPA SCR BART and AEPCO Alternative control scenarios will hinge on the differences in visibility impacts associated with the different SO_2, NO_X and PM emissions of the two control scenario, with the EPA SCR BART scenario having lower NO_X and the AEPCO Alternative scenario having lower SO_2 emissions.

Better than BART

The Regional Haze Rule (RHR) has provisions for using visibility modeling to demonstrate that "an emission trading program or other alternative measures achieve[s] greater reasonable progress than would be achieved through installation and operation of BART" [40 CFR §51.308(e)(2)]. As stated in 40 CFR §51.308(e)(3), dispersion modeling should be used to demonstrate that the alternative to BART achieves "greater reasonable progress" by examining

1 http://www.azdeq.gov/environ/air/haze/

the changes in visibility impacts for the Worst and Best 20% days at each Class I area. A two pronged test is used to demonstrate that the Alternative is Better than BART:

1. Visibility does not decline in any Class I area; and

2. There is an overall improvement in visibility, determined by comparing the average difference between BART and the Alternative over all affected Class I areas.

Since the single-source BART visibility metric using CALPUFF V5.8 is the 98th percentile daily change in Haze index, commonly referred to as deciview (Δdv), rather than the RHR reasonable progress metric based on the Haze index averaged over the Worst and Best 20% visibility days at a Class I area, it is unclear how the 40 CFR §51.308(e)(3) "Better than BART" test should be applied for a single source. In fact, it is likely that a single source will not have any contributions to visibility impairment at a Class I area for many of the Worst and Best 20% days so that using the RHR reasonable progress visibility metric may not be appropriate. Thus, we are using the BART visibility metrics to evaluate whether the AEPCO Alternative achieves equivalent or greater visibility improvement at Class I areas than the EPA SCR BART scenario.

CALPUFF VISIBILILITY MODELING OF AEPCO APACHE EGUs

Both EPA Region 9 and ENVIRON are performing CALPUFF visibility modeling to estimate the visibility impacts due to the AEPCO Apache EGUs under the EPA SCR BART and AEPCO Alternative emission scenarios. EPA suggested, and AEPCO agreed, to use a common CALMET meteorological database as input to CALPUFF that was developed by ENSR/AECOM (2009) as part of the BART analysis for the Navajo Generation Station (NGS). ENSR/AECOM updated the original CALMET/CALPUFF BART modeling database[2] developed by the Western Regional Air Partnership (WRAP). Although EPA adopted the ENSR/AECOM (2009) CALMET database as the meteorological inputs for their AEPCO CALPUFF modeling, some other aspects of the ENSR/AECOM (2009) CALMET/CALPUFF were not adopted by EPA (e.g., monthly varying background ammonia concentrations).

ADEQ concluded that AEPCO Apache Units (ST1, ST2 and ST3) were subject to BART[3]. However, EPA also included ST1 in its CALPUFF visibility modeling analysis even though its BART limits are not an issue. Since the goal of the CALPUFF visibility modeling is to compare the visibility benefits of the EPA BART and the AEPCO Alternative emissions scenarios and the emissions for ST1 are held constant in all of the emission scenarios, then the inclusion of emissions from ST1 does not adversely affect the analysis. In fact, it may provide a more accurate representation of visibility impacts of emissions from ST2 and ST3 since the effects of emissions from ST1 will be accounted for in the aerosol equilibrium calculations and competition for ammonia among sulfate and nitrate due to all of the emissions from the Apache facility.

2 http://pah.cert.ucr.edu/aqm/308/bart.shtml

3 ST1 is a natural gas fired boiler. EPA promulgated ADEQ's proposed BART limits. The level of the limit for ST1 is not an issue.

Preliminary CALPUFF Visibility Modeling

Both EPA Region 9 and ENVIRON performed preliminary CALPUFF visibility modeling for an EPA Base, EPA SCR BART (NO_X control at 0.07 lb/MMBtu for both ST2 and ST3) and EPA's versions of the AEPCO Alternative case that corresponds to EPA's Control 9 and 9b scenarios (i.e., conversion of ST2 to natural gas and SNCR on ST3). ENVIRON also performed an AEPCO Alternative scenario with updated PM emissions factor that lowered the ST2 natural PM emissions factor from 0.010 to 0.00042 lb/MMBtu based on newer and more accurate test methods. ENVIRON then performed second versions (v2) of the EPA Control 9 and 9b scenarios that lowered slightly the ST2 PM emissions from 0.010 to 0.008 lb/MMBtu and the ST3 NO_X emissions from 0.230 to 0.225 lb/MMBtu. Table 1 summarizes the Apache ST2 and ST3 emission rates for the seven CALPUFF simulations performed by ENVIRON.

Table 1. Emission rates in lb/MMBtu for AEPCO stacks ST2 and ST3 for each of the CALPUFF modeling scenarios.

Scenario	Stack	SO_2	NO_X	PM
EPA Base OFA	ST2	0.150	0.371	0.030
	ST3	0.150	0.537	0.030
EPA SCR BART	ST2	0.150	0.070	0.030
	ST3	0.150	0.070	0.030
EPA AEPCO Alternative Control 9 PNGf	ST2	0.00064	0.085	0.010[a]
	ST3	0.150	0.230	0.030
EPA AEPCO Alternative Control 9b PNGt	ST2	0.00064	0.085	0.010[b]
	ST3	0.150	0.230	0.030
AEPCO Alternative with Updated PM Factor	ST2	0.00064	0.085	0.00042
	ST3	0.150	0.230	0.030
AEPCO Alternative Control 9v2 PNGf	ST2	0.00064	0.085	0.008[a]
	ST3	0.150	0.225	0.030
EPA AEPCO Alternative Control 9bv2 PNGt	ST2	0.00064	0.085	0.008[b]
	ST3	0.150	0.225	0.030

a. Control 9 and 9v2 assume the PM emissions rate is just the filterable PM and uses the NPS speciation spreadsheet to calculate the condensable portion of the PM emissions
b. Control 9b and 9bv2 assume the PM emissions rate is the total PM emissions (filterable plus condensable)

Table 2a displays the stack parameters and Table 2b displays the emission rates for the ENVIRON CALPUFF modeling runs. Table 2b contains emissions for five versions of the AEPCO Alternative. The first three versions of the AEPCO Alternative emission scenarios differ on how the PM emissions are treated from the natural gas-fired ST2 EGU. EPA Control 9 scenario assumes that the pipeline natural gas (PNG) fired ST2 0.01 lb/MMBtu PM emissions rate is just the filterable portion of the PM emissions (PNGf) and uses the NPS PM speciation spreadsheet for natural gas turbines[4] to estimate the condensable component of the PM resulting in a net total PM emissions rate of 0.04 lb/MMBtu. EPA Control 9b scenario assumes that the ST2 0.01

4 http://www.nature.nps.gov/air/permits/ect/ectGasFiredCT.cfm?CFID=5318051&CFTOKEN=bb591d8a00830488-94B1977A-F3F6-E4E3-099C6FEA63BA2179

lb/MMBtu emissions rate is the total PM emissions rate (PNGt). The third AEPCO Alternative presented in Table 2b uses an updated PM emissions rate for natural gas-fired boilers of 0.00042 lb/MMBtu for total PM emissions. This updated PM emissions rate for natural gas fired boilers is based on more recent and accurate test data and EPA believes it is more accurate and representative of PM emissions from natural gas combustion so it is used in EPA's National Emissions Inventory (NEI). Justification for the new PM emissions rate for natural gas fired boilers is provided below with more details provided in Morris and England (2013). As discussed above, the final two AEPCO Alternative are version 2 (v2) of the EPA Control 9 and 9b scenarios that slightly lowered the ST2 PM and ST3 NO_X emission rates.

Although AEPCO used the same emissions as EPA for the AEPCO Alternative EPA Control 9 and 9b scenarios, the exit temperature for ST2 was updated to reflect the hotter effluent from burning natural gas instead of coal. When EPA modeled the AEPCO Alternative in Control 9 and 9b they kept the exit temperature of ST2 at the same 330.4 degrees Kelvin (K) level as used when ST2 is burning coal. ENVIRON's CALPUFF modeling used a higher exit temperature of 394.3 K that reflects the higher temperatures when natural gas is used over coal. This results in slight differences in the CALPUFF estimated visibility impacts in EPA's and ENVIRON's modeling of the AEPCO Alternative for EPA Control 9 and 9b scenarios.

Table 2a. Stack parameters used in the AEPCO CALPUFF modeling.

Scenario	Source	X-Coord (km)	Y-Coord (km)	Hs (m)	Elev (m)	Ds (m)	Vs (m/s)	Ts (K)
EPA Base Case	ST1	-1213.03	-793.196	50.088	1278.03	2.438	27.61	352.59
	ST2	-1213.03	-793.196	120.09	1280.16	5.05	17.68	330.37
	ST3	-1213.03	-793.196	120.09	1280.16	5.05	17.68	330.37
EPA SCR BART Case (0.07 lb/MMBtu)	ST1	-1213.03	-793.196	50.088	1278.03	2.438	27.61	352.59
	ST2	-1213.03	-793.196	120.09	1280.16	5.05	17.68	330.37
	ST3	-1213.03	-793.196	120.09	1280.16	5.05	17.68	330.37
EPA AEPCO Alternative Control 9	ST1	-1213.03	-793.196	50.088	1278.03	2.438	27.61	352.59
	ST2	-1213.03	-793.196	120.09	1280.16	5.05	17.68	394.261[a]
	ST3	-1213.03	-793.196	120.09	1280.16	5.05	17.68	330.37
EPA AEPCO Alternative Control 9b	ST1	-1213.03	-793.196	50.088	1278.03	2.438	27.61	352.59
	ST2	-1213.03	-793.196	120.09	1280.16	5.05	17.68	394.261[a]
	ST3	-1213.03	-793.196	120.09	1280.16	5.05	17.68	330.37
AEPCO Alternative with Updated PM	ST1	-1213.03	-793.196	50.088	1278.03	2.438	27.61	352.59
	ST2	-1213.03	-793.196	120.09	1280.16	5.05	17.68	394.261[a]
	ST3	-1213.03	-793.196	120.09	1280.16	5.05	17.68	330.37

a. Note that EPA's CALPUFF modeling used a 330.37 K for ST2 on natural gas.

Table 2b. Emissions used in the AEPCO BART control scenarios (g/s).

Scenario	Source	SO_2	SO_4	NO_X	PMF	PMC	EC	OC	PMtot
EPA Base Case	ST1	0.045	0.266	3.921	0.354	0.142	0.028	0.047	0.837
	ST2	41.439	2.589	161.001	3.548	4.606	0.136	0.647	11.526
	ST3	41.173	2.571	134.814	3.524	4.575	0.135	0.643	11.448
	Total	82.657	5.426	299.736	7.426	9.323	0.299	1.337	23.811
EPA SCR BART (0.07 lb/MMBtu) Case	ST1	0.045	0.266	3.921	0.354	0.142	0.028	0.047	0.837
	ST2	41.439	2.589	30.59	3.548	4.606	0.136	0.647	11.526
	ST3	41.173	2.571	21.57	3.524	4.575	0.135	0.643	11.448
	Total	82.657	5.426	56.081	7.426	9.323	0.299	1.337	23.811
EPA AEPCO Alternative Control 9 (PNGf)	ST1	0.045	0.266	3.921	0.354	0.142	0.028	0.047	0.837
	ST2	0.177	0.088	36.869	0	0	2.763	8.199	11.05
	ST3	41.173	2.571	70.912	3.524	4.575	0.135	0.643	11.448
	Total	41.395	2.925	111.702	3.878	4.717	2.926	8.889	23.335
Diff w/ EPA SCR		-49.9%	-46.1%	99.2%	-47.8%	-49.4%	878.6%	564.8%	-2.0%
EPA AEPCO Alternative Control 9b (PNGt)	ST1	0.045	0.266	3.921	0.354	0.142	0.028	0.047	0.837
	ST2	0.177	0.088	36.869	0	0	0.691	1.984	2.763
	ST3	41.173	2.571	70.912	3.524	4.575	0.135	0.643	11.448
	Total	41.395	2.925	111.702	3.878	4.717	0.854	2.674	15.048
Diff w/ EPA SCR		-49.9%	-46.1%	99.2%	-47.8%	-49.4%	185.6%	100.0%	-36.8%
AEPCO Alternative with Updated PM emissions rate for ST2 (0.00042 lb/MMBtu)	ST1	0.045	0.266	3.921	0.354	0.142	0.028	0.047	0.837
	ST2	0.177	0.008	36.869	0.02216	0	0.01508	0.07096	0.1162
	ST3	41.173	2.571	70.912	3.524	4.575	0.135	0.643	11.448
	Total	41.395	2.845	111.702	3.90016	4.717	0.17808	0.76096	12.4012
Diff w/ EPA SCR		-49.9%	-47.6%	99.2%	-47.5%	-49.4%	-40.4%	-43.1%	-47.9%

Attachment A contains the CALPUFF modeling results at Class I areas for the EPA Base that assumes Low NO_X Burners (LNB) and Over-Fired Air (OFA), EPA SCR BART (0.07 lb/MMBtu) and two AEPCO Alternative EPA Control 9 and 9b emission control scenarios performed by EPA[5] and by ENVIRON. Figure 1 displays the location of the AEPCO Apache facility and the nearby Class I areas. The EPA and ENVIRON CALPUFF modeling results for the EPA Base and EPA SCR BART cases are almost identical, with just one minor difference in 2003 at one (Saguaro) Class I area (see Attachments A1 and A2). However, there are slight differences in the visibility (deciview) impacts at the Class I areas for the AEPCO Alternative Control 9 and 9b CALPUFF runs due to the different ST2 exit temperature assumptions used in the EPA (330.4 K) and ENVIRON (394.3 K) CALPUFF modeling. Attachments A3 and A4 displays the 98th percentile visibility metrics at

5 EPA CALPUFF modeling results were taken out of a spreadsheet "Apache_SCR_and_Alt_visx_130318.xlsx" and is identified as "draft, sjb 2013-03-18".

Class I areas in deciview and their differences for the EPA and ENVIRON CALPUFF modeling of Control 9 and 9b, respectively. The percent differences in the deciview impacts between the EPA and ENVIRON CALPUFF modeling for Control 9 and 9b are shown in, respectively, Tables 3a and 3b. The effects of the different ST2 exit temperature in the EPA and ENVIRON CALPUFF modeling of Control 9 and 9b results in deciview increases by as much as 13% and decreases by as much as -8%, with the average change across all Class I areas results in differences of less than ±5%.

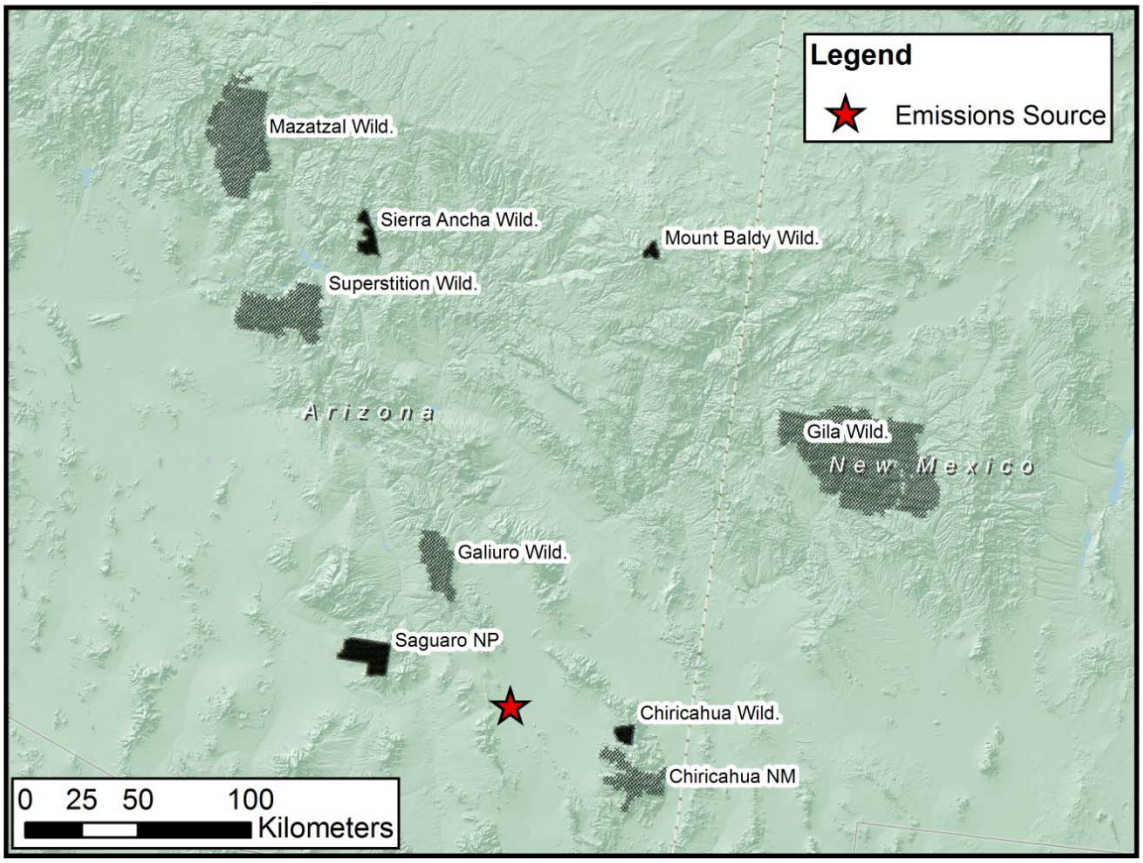

Figure 1. Location of the AEPCO Apache EGUs (red star) and nearby Class I areas.

Table 3a. Percent differences in visibility impacts at Class I areas between EPA's and AEPCO's CALPUFF modeling for AEPCO Alternative EPA Control 9 (PNGf) [see Attachment A3 for more details].

Percent Difference in EPA and AEPCO CALPUFF Results (AEPCO – EPA)					
AEPCO Alt Cntl 9 (PNGf)	**98th Percentile**			**Avg 98th**	**22nd high**
Class I Area	**2001**	**2002**	**2003**	**2001 -2003**	**2001 -2003**
Chiricahua NM	-3.5%	-10.3%	-7.1%	-7.1%	-7.1%
Chiricahua Wild.	-7.7%	-5.8%	-7.2%	-6.9%	-6.8%
Galiuro Wild.	6.7%	-0.7%	-7.4%	-0.9%	-4.3%
Gila Wild.	12.0%	3.4%	11.8%	8.5%	-3.1%
Mazatzal Wild.	-2.2%	-0.6%	2.7%	-0.2%	0.0%
Mount Baldy Wild.	-1.5%	-1.4%	10.0%	2.0%	0.0%
Saguaro NP	0.2%	0.0%	-4.5%	-1.4%	-2.0%
Sierra Ancha Wild.	4.6%	-6.6%	-4.6%	-2.2%	0.0%
Superstition Wild.	-8.0%	7.5%	-2.9%	-0.9%	-1.6%
Average	-1.8%	-3.9%	-5.5%	-3.7%	-4.9%

Table 3b. Percent differences in visibility impacts at Class I areas between EPA's and AEPCO's CALPUFF modeling for AEPCO Alternative EPA Control 9b (PNGt) [see Attachment A4 for more details].

Percent Difference in EPA and AEPCO CALPUFF Results (AEPCO – EPA)					
AEPCO Alt Cntl 9b (PNGt)	**98th Percentile**			**Avg 98th**	**22nd high**
Class I Area	**2001**	**2002**	**2003**	**2001 -2003**	**2001 -2003**
Chiricahua NM	-1.5%	-11.6%	-3.3%	-5.3%	-2.9%
Chiricahua Wild.	-1.7%	-3.0%	-4.0%	-2.9%	-4.0%
Galiuro Wild.	-0.8%	-6.5%	-6.6%	-4.9%	-3.4%
Gila Wild.	13.4%	5.4%	-1.7%	6.2%	0.3%
Mazatzal Wild.	0.0%	0.0%	-1.7%	-0.5%	-3.9%
Mount Baldy Wild.	2.5%	-3.3%	5.8%	1.5%	2.5%
Saguaro NP	-1.8%	-2.4%	-2.3%	-2.2%	-3.2%
Sierra Ancha Wild.	3.7%	1.4%	-3.3%	0.8%	0.0%
Superstition Wild.	-1.0%	5.9%	-8.3%	-0.1%	-1.0%
Average	-0.7%	-4.5%	-3.9%	-3.0%	-3.0%

Refined CALPUFF Visibility Modeling

More refined and accurate CALPUFF V5.8 modeling was conducted by making two sequential updates to the CALPUFF modeling approach used by EPA:

- Use of monthly varying background ammonia concentrations, as used in the ENSR/AECOM (2009) NGS BART modeling; and
- Use of updated natural gas combustion PM emissions factor as used by EPA in the National Emissions Inventory (NEI).

The rationale and justification for these two updates are given below, with more details given in ENSR/AECOM (2009) and Morris and England (2013).

Background Ammonia Concentration Update

The EPA regulatory version of CALPUFF (V5.8) has a known bias toward overestimating the impacts of nitrate and resultant visibility impairment. For example, Morris, Tana and Yarwood (2003) found that the CALPUFF MESOPUFF-II chemical transformation algorithm in CALPUFF V5.8 overestimates nitrate formation during the day by a factor of 2 to 3 on average when compared to a full-science chemistry mechanism. Morris and co-workers (2006) evaluated the CMAQ-LISBON model that uses the CALPUFF MESOPUFF-II chemical transformation module against ambient air quality measurements and found that it overestimated the observed nitrate concentrations by a factor of 2.8 on average; the standard CMAQ model with the full chemistry predicted the average of the observed nitrate values to within 10%. Scire, Wu and Strimaitis (2013) evaluated CALPUFF over southwestern Wyoming and found that CALPUFF V5.8 with the MESOPUFF-II chemistry and 1 ppb background ammonia over-predicted the observed nitrate concentrations by a factor of 4 to 6. They noted that "Substantially improved results were obtained with the use of seasonally varying observed ammonia concentrations that ranged from 0.43 ppb in the winter to 1.1 ppb in the summer."

Realizing that the use of monthly average background ammonia is more realistic and can partly mitigate the large CALPUFF nitrate overestimation bias, ENSR/AECOM developed monthly average background ammonia concentrations for their CALPUFF modeling of the proposed Desert Rock Power Plant that they also used in their NGS BART CALPUFF modeling. These monthly average background ammonia values were reviewed and accepted by the Federal Land Managers (FLMs). Figure 2 below reproduces the Section from the ENSR/AECOM NGS BART modeling report that explains and justifies the use of monthly background ammonia values. Consistent with Scire, Wu and Strimaitis (2006), ENSR/AECOM used lower monthly background ammonia values in the winter (0.2 ppb) than summer (1.0 ppb). This makes sense since a lot of the ammonia emissions occur due to volatilization of livestock waste that is expected to be greater in the warmer than cooler months.

Ambient Background Ammonia Values

The POSTUTIL utility program was used to repartition HNO_3 and NO_3 using appropriate ammonia background values that were approved by the Federal Land managers for the nearby Desert Rock Energy Facility (DREF) PSD permit application. For that project, located nearby in northwestern New Mexico, it was realized that the likely over-prediction by CALPUFF of nitrates in winter can be partially addressed by using a monthly variation of background ammonia concentrations. The default value of 1.0 ppb for arid lands as referenced in the IWAQM Phase 2 document is valid at 20 deg C, but the same document cites a strong dependence with ambient temperature, with variations of a factor of 3-4. This same dependence is seen at the CASTNET monitor at Bondville, Illinois (see page 5 at http://www.ladco.org/tech/monitoring/docs_gifs/NH3proposal-revised3.pdf). In addition, a study of light-affecting particles in SW Wyoming indicated that nitrates were over-predicted by a factor of 3 for a constant ammonia concentration of 1.0 ppb, and by a factor of 2 for an ammonia concentration of 0.5 ppb (see slide 57 at http://www.air.dnr.state.ga.us/airpermit/psd/dockets/longleaf/facilitydocs/050711_CALPUFF_eval.pdf). Since there are no large sources of ammonia due to agricultural activities near the Class I areas being analyzed (see Figure 1 in http://www.ladco.org/tech/monitoring/docs_gifs/ammonia_role_midwest_haze.pdf), it is appropriate to introduce a monthly varying ammonia background concentration to the CALPUFF modeling. Table A-2 lists the values that were used in CALPUFF and have been agreed to by the National Park Service for DREF and other PSD submittals. These proposed values are consistent with the CMAQ modeled values provided in Appendix A of www.vistas-sesarm.org/BART/CMAQ2002_evaluation_Dec31_2005.pdf.

Ammonia slip sensitivity analysis is discussed in Appendix B.

Table A-2 Ambient Ammonia Background Concentrations

Month	Ambient Ammonia Background Concentration (ppb)
January – February	0.2
March – April	0.5
May – September	1.0
October – November	0.5
December	0.2

Figure 2. Excerpt from ENSR/AECOM (2009) NGS BART CALPUFF modeling report justifying the use of monthly background ammonia values for CALPUFF V5.8 modeling in Arizona.

Updated Natural Gas Combustion PM Emissions Factor

EPA's modeling of PM emissions from the natural gas-fired ST2 in the AEPCO Alternative scenario assumed a 0.01 lb/MMBtu emissions rate. This is a conservative estimate that is consistent with EPA's AP-42 emissions factor report that assumes a 0.0075 lb/MMBtu PM emissions rate for natural gas-fired boilers that is 0.0019 lb/MMBtu filterable and 0.0056 lb/MMBtu condensable PM emissions[6]. However, the sampling method used to develop the AP-42 PM emissions rate for natural gas boilers (typically Method 201a for filterable and Method 202 for condensable) is known to have positive bias artifact that overstates actual PM emissions. More recent test data using more accurate measurement methods (e.g., dilution chambers) have measured much lower PM emissions rates from natural gas combustion. EPA has adopted these lower PM emission rates for natural gas combustion and uses them in their

6 http://www.epa.gov/ttnchie1/ap42/ch01/final/c01s04.pdf

National Emissions Inventory (NEI[7]). The updated natural gas-fired boiler PM emissions factor is 0.00042 lb/MMBtu, which is 23 to 95 times lower than the PM emissions assumed by EPA for ST2 in their modeling of the AEPCO Alternative assuming that the 0.01 lb/MMBtu PM emission factor represents the total (Scenario 9b) or just the filterable (Scenario 9) portion of the PM emissions. Details on the derivation and justification of the updated and more accurate PM emissions factor for natural gas combustion in boilers is given in Morris and England (2013).

Refined CALPUFF Modeling Results using Monthly Background Ammonia

Attachment B displays the CALPUFF visibility modeling results at Class I areas for the EPA Base, EPA SCR BART and the AEPCO Alternative Control 9 and 9b emission scenarios post-processed using the POSTUTIL processor with the monthly background ammonia concentrations (see Figure 2). Shown in these tables are the BART visibility metrics that include the 98th percentile (8th highest) daily visibility impacts due to the Apache ST1, ST2 and ST3 emissions for each of the three modeling years (2001-2003), the average of the 98th percentile across the three modeling years and the 98th percentile across all three years combined (i.e., the 22nd highest daily visibility impacts in the three year period). As discussed previously, the RHR has procedures for estimating whether an alternative control scenario is "Better than BART" using the RHR reasonable progress visibility metrics that are based on the Worst and Best 20% visibility days, but that approach appears to be more appropriate when looking at BART across all or many BART-eligible sources. When looking at a single source, the source may not even be contributing to visibility impairment at a Class I area during many of the Worst and Best 20% days. Thus, we are evaluating the EPA BART and AEPCO Alternative visibility impacts using the BART visibility metrics (i.e., 98th percentile daily visibility impacts in deciviews).

Tables 4a and 4b displays the percent differences in the CALPUFF BART visibility metrics at each Class I area between the EPA SCR BART and the, respectively, AEPCO Alternative EPA Control 9 and 9b emission scenarios post-processed using monthly background ammonia (AEPCO Alternative – SCR/BART). For the EPA Control 9 scenario that assumes the 0.01 lb/MMBtu PM emissions scenario for ST2 operating using pipeline natural gas is just the filterable portion (PNGf), the AEPCO Alternative (Control 9 PNGf) scenario estimates more visibility impairment than SCR/BART scenario most of the time with an average increase of approximately 35-37%. However, the AEPCO Alternative Control 9b that assumes the ST2 0.01 lb/MMBtu PM emissions rate is the total PM (PNGt) estimates more visibility improvements than SCR/BART with the AEPCO Alternative average visibility improvement over SCR/BART being 10-12%.

7 See "PM EFs for Natural Gas Combustion at 2011 NEI website: http://www.epa.gov/ttnchie1/net/2011inventory.html

Table 4a. Percent difference in 98th percentile deciview impacts at Class I areas between EPA BART SCR and AEPCO Alternative EPA Control 9 (PNGf) emissions scenario using AEPCO CALPUFF results processed with monthly average background ammonia concentrations.

Percent Difference EPA BART SCR and AEPCO Alternative Cntl 9 (Alt – SCR)					
AEPCO CALPUFF Results	**98th Percentile**			**Avg 98th**	**22nd high**
Class I Area	**2001**	**2002**	**2003**	**2001 -2003**	**2001 -2003**
Chiricahua NM	34.3%	21.8%	30.8%	28.8%	28.9%
Chiricahua Wild.	22.4%	32.5%	20.9%	25.2%	23.8%
Galiuro Wild.	26.0%	23.4%	31.7%	27.2%	20.3%
Gila Wild.	29.8%	41.7%	28.6%	34.0%	31.1%
Mazatzal Wild.	-8.0%	2.8%	-1.8%	-2.5%	0.7%
Mount Baldy Wild.	22.7%	2.3%	1.1%	8.2%	26.3%
Saguaro NP	35.8%	30.8%	33.4%	33.3%	31.6%
Sierra Ancha Wild.	10.7%	9.3%	-8.0%	3.9%	2.2%
Superstition Wild.	12.6%	10.0%	3.6%	8.7%	8.3%
Average	27.3%	25.6%	26.1%	26.4%	24.8%

Table 4b. Percent difference in 98th percentile deciview impacts at Class I areas between EPA BART SCR and AEPCO Alternative EPA Control 9b (PNGt) emissions scenario using AEPCO CALPUFF results processed with monthly average background ammonia concentrations.

Percent Difference EPA BART SCR and AEPCO Alternative Cntl 9b (Alt – SCR)					
AEPCO CALPUFF Results	**98th Percentile**			**Avg 98th**	**22nd high**
Class I Area	**2001**	**2002**	**2003**	**2001 -2003**	**2001 -2003**
Chiricahua NM	-8.5%	-14.9%	-3.7%	-9.0%	-8.0%
Chiricahua Wild.	-9.0%	-6.3%	-9.6%	-8.2%	-10.2%
Galiuro Wild.	-15.0%	-15.1%	-12.8%	-14.2%	-14.2%
Gila Wild.	3.9%	-0.5%	-12.0%	-2.7%	-3.6%
Mazatzal Wild.	-28.3%	-26.2%	-25.0%	-26.6%	-23.4%
Mount Baldy Wild.	6.7%	-26.7%	-13.3%	-11.6%	-2.4%
Saguaro NP	-10.6%	-10.1%	-8.0%	-9.5%	-7.9%
Sierra Ancha Wild.	-20.7%	-23.6%	-37.8%	-26.9%	-25.5%
Superstition Wild.	-14.1%	-17.6%	-27.1%	-19.4%	-20.0%
Average	-10.0%	-11.8%	-9.6%	-10.5%	-10.2%

Refined CALPUFF Modeling using Updated PM Emissions Factor for Natural Gas-Fired Boilers

CALPUFF modeling was conducted for the AEPCO Alternative using the updated PM emissions rate for the ST2 natural gas-fired boiler (0.00042 lb/MMBtu). Attachment C compares the CALPUFF visibility results at Class I areas for the EPA SCR BART and the AEPCO Alternative with updated PM emissions factor scenarios and their differences. The percent differences in the visibility results for the SCR/BART and AEPCO Alternative with updated PM emissions factor for ST2 are shown in Table 5. Using the average of the 98th percentile visibility metric across the three years of modeling, the AEPCO Alternative has from 18.7% (Mount Baldy) to 51.0% (Sierra Ancha) more visibility benefits than the EPA SCR BART case. On average across the Class I areas the AEPCO Alternative has 32.7% more visibility benefits than the SCR/BART case.

Similar results are seen using the 98th percentile across the three years of modeling (i.e., 22nd highest in 2001-2003) with the AEPCO Alternative having from 9.4% (Mount Baldy) to 50.0% (Sierra Ancha) more visibility benefits than SCR/BART with an average of 31.0% more visibility benefits than SCR/BART.

Table 5. Percent difference in 98th percentile deciview impacts at Class I areas between EPA BART SCR and AEPCO Alternative with Updated PM Emissions Factor (0.00042 lb/MMBtu) for ST2 emissions scenario using AEPCO CALPUFF results processed with monthly average background ammonia concentrations.

Percent Difference EPA BART SCR and AEPCO Alternative w/ PM (Alt – SCR)					
AEPCO CALPUFF Results	**98th Percentile**			**Avg 98th**	**22nd high**
Class I Area	**2001**	**2002**	**2003**	**2001 -2003**	**2001 -2003**
Chiricahua NM	-26.3%	-33.8%	-18.2%	-25.8%	-24.2%
Chiricahua Wild.	-26.8%	-20.6%	-25.5%	-24.3%	-28.3%
Galiuro Wild.	-39.9%	-40.3%	-29.9%	-36.2%	-39.4%
Gila Wild.	-15.7%	-16.7%	-28.6%	-19.7%	-18.4%
Mazatzal Wild.	-43.2%	-47.2%	-43.4%	-44.7%	-39.4%
Mount Baldy Wild.	1.9%	-40.6%	-19.5%	-18.7%	-9.4%
Saguaro NP	-37.2%	-30.7%	-27.1%	-31.3%	-29.6%
Sierra Ancha Wild.	-41.5%	-50.0%	-62.2%	-51.0%	-50.0%
Superstition Wild.	-36.1%	-36.4%	-56.0%	-42.3%	-40.1%
Average	-29.4%	-35.1%	-34.5%	-32.7%	-31.0%

Version 2 of AEPCO Alternative Control 9 and 9b

The AEPCO Alternative Control 9v2 and 9bv2 used slightly lower PM emissions for ST2 and NO_X emissions for ST3 than the EPA Control 9 and 9b scenarios. The Control 9v2 and 9bv2 CALPUFF modeling results are given in Attachment D and Tables 6a and 6b. AEPCO Alternative Control 9v2 has more visibility benefits than SCR BART at 2-3 Class I areas and less benefits 6-7 Class I areas; on average Control 9v2 has13-15% more visibility degradation than SCR BART (Table 6a). However, the AEPCO Alternative Control 9b has more visibility benefits than SCR BART at all of the Class I areas and on average has 14% more visibility benefits than SCR BART (Table 6b).

Table 6a. Percent difference in 98th percentile deciview impacts at Class I areas between EPA BART SCR and AEPCO Alternative Control 9v2 (PNGf) emissions scenario using AEPCO CALPUFF results processed with monthly average background ammonia concentrations.

Percent Difference EPA BART SCR and AEPCO Alternative Cntl 9v2 (Alt – SCR)					
AEPCO CALPUFF Results	**98th Percentile**			**Avg 98th**	**22nd high**
Class I Area	**2001**	**2002**	**2003**	**2001 -2003**	**2001 -2003**
Chiricahua NM	21.1%	10.6%	21.0%	17.4%	15.7%
Chiricahua Wild.	12.3%	21.9%	11.9%	15.3%	13.8%
Galiuro Wild.	14.4%	12.1%	18.3%	15.1%	7.7%
Gila Wild.	18.8%	32.4%	15.0%	22.8%	22.3%
Mazatzal Wild.	-14.0%	-5.5%	-8.2%	-9.4%	-5.1%
Mount Baldy Wild.	19.6%	-5.3%	-6.7%	1.9%	19.2%
Saguaro NP	23.0%	18.8%	20.5%	20.7%	20.1%
Sierra Ancha Wild.	2.5%	-0.7%	-18.8%	-5.8%	-5.1%
Superstition Wild.	4.7%	1.5%	-3.6%	0.8%	-1.4%
Average	16.0%	14.8%	15.4%	15.4%	13.5%

Table 6b. Percent difference in 98th percentile deciview impacts at Class I areas between EPA BART SCR and AEPCO Alternative Control 9bv2 (PNGt) emissions scenario using AEPCO CALPUFF results processed with monthly average background ammonia concentrations.

Percent Difference EPA BART SCR and AEPCO Alternative Cntl 9bv2 (Alt – SCR)					
AEPCO CALPUFF Results	**98th Percentile**			**Avg 98th**	**22nd high**
Class I Area	**2001**	**2002**	**2003**	**2001 -2003**	**2001 -2003**
Chiricahua NM	-11.7%	-18.8%	-6.4%	-12.2%	-11.2%
Chiricahua Wild.	-12.3%	-8.8%	-12.7%	-11.2%	-13.5%
Galiuro Wild.	-19.3%	-19.3%	-15.9%	-18.0%	-19.7%
Gila Wild.	0.0%	-2.7%	-14.9%	-5.5%	-5.9%
Mazatzal Wild.	-31.8%	-30.7%	-28.7%	-30.5%	-26.4%
Mount Baldy Wild.	5.2%	-29.6%	-15.7%	-13.6%	-4.2%
Saguaro NP	-14.8%	-13.7%	-11.1%	-13.1%	-11.1%
Sierra Ancha Wild.	-24.8%	-28.7%	-44.6%	-32.0%	-29.0%
Superstition Wild.	-17.9%	-21.6%	-31.7%	-23.6%	-24.5%
Average	-13.7%	-15.2%	-12.6%	-13.8%	-13.8%

Use of Constant 1 ppb Background Ammonia

Attachment E compares the CALPUFF visibility modeling results for the EPA SCR BART scenario with the five AEPCO Alternative emission scenarios only post-processed using a constant 1 ppb background ammonia concentration. The difference in the EPA SCR BART and the five AEPCO Alternative emission scenarios expressed as a percentage is given in Tables 7a-e below. When assuming that the 0.01 or 0.008 lb/MMBtu PM emission rate is just the filterable portion of the PM and using the NPS natural gas PM speciation profile (Control 9 and 9v2) the AEPCO Alternative has on average across the Class I areas approximately 30% (Control 9) and 20% (Control 9v2) more visibility impairment than EPA SCR BART scenario using a 1 ppb background ammonia concentration (Tables 7a and 7d). However, even when using a 1 ppb background ammonia when the 0.01/0.008 lb/MMBtu PM emissions rate is assumed to be the total PM then the AEPCO Alternative has 2-3% (Control 9b; Table 7b) and 4-5% (Control 9bv2; Table 7e) more visibility benefits than EPA SCR BART. The AEPCO Alternative with updated natural gas PM emissions factor provides on average 14-15% more visibility benefits than EPA SCR BART scenario using 1 ppb background ammonia concentration (Table 7c).

Table 7a. Percent difference in 98th percentile deciview impacts at Class I areas between EPA BART SCR and AEPCO Alternative Control 9 (PNGf) emissions scenario using AEPCO CALPUFF results processed with constant 1 ppb background ammonia concentration.

Percent Difference EPA BART SCR and AEPCO Alternative Cntl 9 (Alt – SCR)					
AEPCO CALPUFF Results	**98th Percentile**			**Avg 98th**	**22nd high**
Class I Area	**2001**	**2002**	**2003**	**2001 -2003**	**2001 -2003**
Chiricahua NM	38.2%	22.6%	32.0%	30.5%	32.0%
Chiricahua Wild.	31.7%	28.4%	40.4%	33.4%	29.1%
Galiuro Wild.	47.7%	35.1%	19.6%	32.2%	29.6%
Gila Wild.	66.4%	47.7%	42.0%	51.3%	40.5%
Mazatzal Wild.	11.4%	5.2%	14.6%	10.0%	9.5%
Mount Baldy Wild.	30.4%	11.4%	30.4%	22.7%	25.4%
Saguaro NP	40.4%	40.1%	26.9%	35.6%	31.0%
Sierra Ancha Wild.	26.3%	5.2%	2.0%	10.4%	5.1%
Superstition Wild.	21.8%	35.5%	8.9%	22.0%	22.5%
Average	37.3%	29.8%	29.0%	31.9%	29.5%

Table 7b. Percent difference in 98th percentile deciview impacts at Class I areas between EPA BART SCR and AEPCO Alternative Control 9b (PNGf) emissions scenario using AEPCO CALPUFF results processed with constant 1 ppb background ammonia concentration.

Percent Difference EPA BART SCR and AEPCO Alternative Cntl 9b (Alt – SCR)					
AEPCO CALPUFF Results	**98th Percentile**			**Avg 98th**	**22nd high**
Class I Area	**2001**	**2002**	**2003**	**2001 -2003**	**2001 -2003**
Chiricahua NM	6.0%	-13.8%	2.2%	-2.0%	-1.4%
Chiricahua Wild.	-2.5%	-0.1%	5.0%	0.8%	-2.6%
Galiuro Wild.	1.0%	-10.3%	-2.0%	-3.8%	-1.5%
Gila Wild.	19.1%	6.3%	-1.2%	8.2%	7.1%
Mazatzal Wild.	-14.0%	-20.4%	-10.1%	-15.1%	-12.4%
Mount Baldy Wild.	12.0%	-6.1%	9.2%	4.5%	2.8%
Saguaro NP	-2.9%	4.9%	-7.7%	-1.7%	-5.5%
Sierra Ancha Wild.	-0.6%	-17.5%	-19.1%	-12.2%	-16.3%
Superstition Wild.	-6.2%	7.5%	-28.7%	-8.0%	-5.7%
Average	0.9%	-4.4%	-1.3%	-1.7%	-2.7%

Table 7c. Percent difference in 98th percentile deciview impacts at Class I areas between EPA BART SCR and AEPCO Alternative with updated PM emissions factor emissions scenario using AEPCO CALPUFF results processed with constant 1 ppb background ammonia concentration.

Percent Difference EPA BART SCR and AEPCO Alternative PM Update (Alt – SCR)					
AEPCO CALPUFF Results	**98th Percentile**			**Avg 98th**	**22nd high**
Class I Area	**2001**	**2002**	**2003**	**2001 -2003**	**2001 -2003**
Chiricahua NM	-3.2%	-29.1%	-6.4%	-12.4%	-10.6%
Chiricahua Wild.	-16.6%	-12.0%	-3.9%	-10.8%	-15.4%
Galiuro Wild.	-17.9%	-28.5%	-11.6%	-18.3%	-15.8%
Gila Wild.	19.1%	0.3%	-14.1%	2.8%	-4.6%
Mazatzal Wild.	-32.6%	-38.5%	-23.5%	-32.0%	-22.8%
Mount Baldy Wild.	11.0%	-12.2%	4.9%	0.9%	0.8%
Saguaro NP	-11.0%	-1.0%	-23.9%	-11.4%	-20.4%
Sierra Ancha Wild.	-19.1%	-31.7%	-30.0%	-26.9%	-29.8%
Superstition Wild.	-22.9%	1.5%	-51.9%	-20.5%	-15.7%
Average	-10.4%	-16.8%	-17.8%	-14.3%	-14.9%

Table 7d. Percent difference in 98th percentile deciview impacts at Class I areas between EPA BART SCR and AEPCO Alternative Control 9v2 (PNGf) emissions scenario using AEPCO CALPUFF results processed with constant 1 ppb background ammonia concentration.

Percent Difference EPA BART SCR and AEPCO Alternative Cntl 9v2 (Alt – SCR)					
AEPCO CALPUFF Results	**98th Percentile**			**Avg 98th**	**22nd high**
Class I Area	**2001**	**2002**	**2003**	**2001 -2003**	**2001 -2003**
Chiricahua NM	29.5%	12.0%	23.4%	21.1%	21.3%
Chiricahua Wild.	22.6%	19.8%	31.1%	24.4%	19.8%
Galiuro Wild.	36.8%	21.9%	11.8%	21.8%	20.5%
Gila Wild.	48.7%	34.0%	29.8%	36.9%	31.2%
Mazatzal Wild.	6.6%	-2.9%	6.2%	3.0%	2.0%
Mount Baldy Wild.	24.5%	3.0%	23.9%	15.6%	18.4%
Saguaro NP	28.3%	32.0%	14.2%	24.6%	23.0%
Sierra Ancha Wild.	18.2%	-1.7%	-3.4%	3.7%	-3.2%
Superstition Wild.	15.1%	28.0%	-2.2%	13.5%	15.9%
Average	27.5%	19.9%	19.5%	22.1%	20.3%

Table 7e. Percent difference in 98th percentile deciview impacts at Class I areas between EPA BART SCR and AEPCO Alternative Control 9bv2 (PNGf) emissions scenario using AEPCO CALPUFF results processed with constant 1 ppb background ammonia concentration.

Percent Difference EPA BART SCR and AEPCO Alternative Cntl 9bv2 (Alt – SCR)					
AEPCO CALPUFF Results	**98th Percentile**			**Avg 98th**	**22nd high**
Class I Area	**2001**	**2002**	**2003**	**2001 -2003**	**2001 -2003**
Chiricahua NM	4.7%	-16.9%	0.4%	-4.0%	-3.6%
Chiricahua Wild.	-5.2%	-2.4%	3.2%	-1.5%	-5.4%
Galiuro Wild.	-2.4%	-13.9%	-3.9%	-6.6%	-4.8%
Gila Wild.	19.6%	4.9%	-3.9%	7.0%	4.4%
Mazatzal Wild.	-17.4%	-24.6%	-13.0%	-18.6%	-15.3%
Mount Baldy Wild.	11.0%	-8.1%	7.0%	2.9%	1.5%
Saguaro NP	-5.7%	3.4%	-11.4%	-4.2%	-8.1%
Sierra Ancha Wild.	-3.1%	-20.5%	-21.5%	-14.9%	-19.6%
Superstition Wild.	-9.3%	5.9%	-33.2%	-10.6%	-8.8%
Average	-1.5%	-6.8%	-3.6%	-4.0%	-5.4%

DISCUSSION OF RESULTS

Much of the discussion and CALPUFF modeling sensitivity analysis given above relates to PM emissions from the natural gas-fired ST2 in the AEPCO Alternative. This was because of the uncertainty and bias in these PM emissions estimates, not because of their importance in impairing visibility in the southwest. In fact, the WRAP Subject-to-BART CALPUFF visibility modeling of the AEPCO Apache EGU found that the maximum visibility impairment (98th percentile averaged across 2001-2003) at any Class I area (Chiricahua NM 45 km away) due to Apache's SO_2, NO_X and PM emissions were, respectively, 1.24, 1.12 and 0.02 deciviews. That is, the Apache PM emissions represent less than 2% of the visibility impairment of its SO_2 or NO_X emissions. Thus, the real question in evaluating whether the AEPCO Alternative has more visibility benefits than the EPA SCR BART scenario revolves around the trade-offs between the visibility impairment of the higher NO_X emissions in the AEPCO Alternative versus the higher SO_2 emissions in the EPA SCR BART emissions scenarios.

Table 8 lists the total SO_2 and NO_X emissions from Apache ST1, ST2 and ST3 for the EPA SCR BART and Apache Alternative emission scenarios and compares them with the total SO_2 and NO_X emissions for Arizona from the WRAP Plan02d (representing 2000-2004 baseline) and the Prp18b (2018) emissions scenarios that were downloaded from the WRAP TSS website[8]. For both Apache control scenarios, the Apache SO_2 and NO_X emissions represents less than 5% of the total 2018 emissions in Arizona (and even less for Plan02d).

Table 8. Comparison of the Apache EPA SCR BART and AEPCO Alternative SO_2 and NO_X emissions with total emissions in Arizona (tons per year).

Scenario	SO_2 (tpy)	NO_X (tpy)
EPA SCR BART	2,873.3	1,949.5
AEPCO Alternative	1,439.0	3,883.0
Arizona (Plan02d)	104,327.1	344,100.8
Arizona (Prp18b)	70,854.9	101,972.9

Figure 3 displays the daily visibility impairment at the Chiricahua Class I area for the three modeling years (2001-2003). The results for other Class I areas in the region are similar. The visibility impairment due to SO_2 emissions (yellow) is always much greater than that due to NO_X emissions (red). There is evidence of days with high visibility impairment due to dust (large soil and coarse mass identified by brown and grey colors) and fires (large organic and elemental carbon identified by green and black colors). The annual average visibility extinction at Chiricahua Class I area for the 2000-2011 12-year period is given in Figure 4. Visibility extinction due to SO_2 emissions (ammonium sulfate in yellow) is approximately a third of the total extinction ranging from a low of 26% in 2011, which appears to be a higher fire influenced year, to a high of 42% in 2005, with a 12-year average contribution of 35%. The contribution of NO_X emissions (ammonium nitrate in red) to total visibility extinction, on the other hand, is much smaller ranging from 4.9% (2008) to 7.2% (2004) of the total extinction with an average of 5.7%.

8 http://vista.cira.colostate.edu/TSS/Results/Emissions.aspx

In fact, despite NO_X emissions being 3.3 (Plan02d) to 1.4 (Prp18b) times higher than SO_2 emissions in Arizona (Table 8), visibility impairment due to SO_2 emissions is from 4.6 (2002) to 7.8 (2008) times greater than visibility impairment due to NO_X emissions at Chiricahua. This is due in part because SO_2 emissions are converted to particulate sulfate that impairs visibility, whereas NO_X emissions are converted to nitric acid that does not impair visibility, which in turn can be converted to particulate nitrate assuming ammonia is present and the right meteorological conditions occur. And the hot dry and low ammonia conditions of the desert southwest favor more of the converted NO_X emissions staying as nitric acid rather than converting to particulate nitrate.

Given that SO_2 emissions are more important than NO_X emissions in producing visibility impairment in the southwest U.S., then one would expect that the AEPCO Alternative would result in more visibility improvements than the SCR BART scenario. Thus, the conclusion that the AEPCO Alternative is "Better than BART" is consistent with our understanding of visibility impairment at Class I areas in the southwestern U.S.

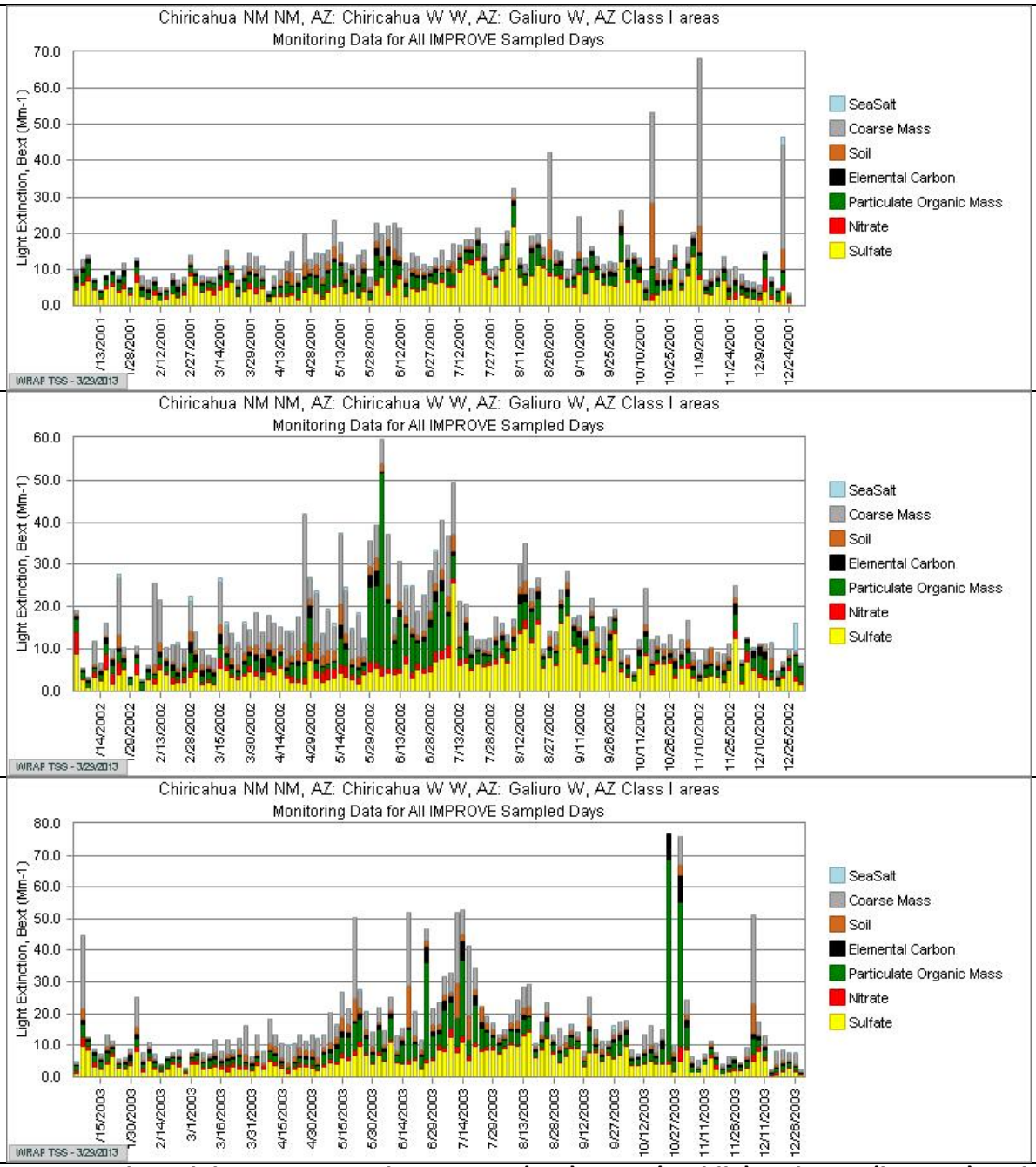

Figure 3. Daily visibility extinction during 2001 (top), 2002 (middle) and 2003 (bottom) at the Chiricahua Class I area.

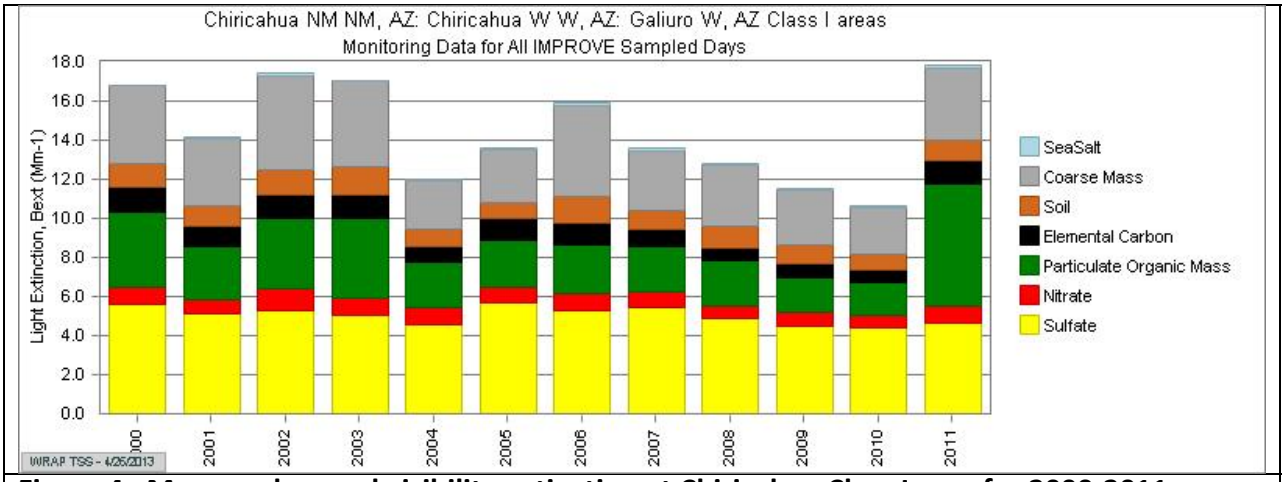

Figure 4. Measured annual visibility extinction at Chiricahua Class I area for 2000-2011.

REFERENCES

ENSR/AECOM. 2009. Revised BART Analysis for the Navajo Generating Station Units 1-3. ENSR Corporation, Document No. 05830-012-300. (http://en3pro.com/wp-content/uploads/2011/02/BART-Analysis-by-ENSR-JAN-09.pdf).

Morris, R., C. Tana and Greg Yarwood. 2003. Evaluation of the Sulfate and Nitrate Formation Mechanisms in the CALPUFF Modeling System. Presented at Guideline on Air Quality Models – An A&WMA Specialty Conference. Mystic, Connecticut. October 22-24, 2003.

Morris, R., S. Lau, B. Koo, A. Hoats and Greg Yarwood. 2006. Further Evaluation of the Chemistry Algorithms used in the CALPUFF Modeling System. Presented at Guideline on Air Quality Models: Application and FLAG Developments – An A&WNA Specialty Conference. Denver, Colorado. April 26-28, 2006.

Scire, J.S., Z.-X. Wu and D.G. Strimaitis. 2006. Implementation and Evaluation of ISORROPIA in CALPUFF. Presented at A&WMA Conference Guideline on Air Quality Models: The Path Forward, Raleigh, North Carolina. March 19-21, 2013.

USEPA. 2011. Regional Haze Rule (RHR). 40 CFR 51.308. July 1, 2011 edition. (http://www.gpo.gov/fdsys/pkg/CFR-2011-title40-vol2/pdf/CFR-2011-title40-vol2-sec51-308.pdf).

USEPA. 2005. Demonstration that CAIR Satisfies the "Better-than-BART" Test As Proposed in the Guidelines for Making BART Determinations. EPA Docket Number: OAR-2003-0053-YYYY. March. (http://www.epa.gov/cair/pdfs/finaltech04.pdf).

USEPA. 2011. Regional Haze: Revisions to Provisions Governing Alternatives to Source-Specific Best Available Retrofit Technology (BART) Determinations, Limited SIP Disapprovals, and Federal Implementation Plans. 40 CFR Parts 51 and 52. EPA-HQ-OAR-2011-0729; FRL-9614-7. Federal Register / Vol. 76, No. 251 / Friday, December 20, 2011 / Proposed Rules. (http://www.gpo.gov/fdsys/pkg/FR-2011-12-30/pdf/2011-33586.pdf).

Attachment A

Comparison of EPA and AEPCO CALPUFF Modeling Results

Visibility Method 8 using Best 20% Days Visibility Background

Constant 1 ppb Background Ammonia Concentrations

A1: EPA Base Case (OFA)

A2: EPA SCR (0.07 lb/MMBtu) Case

A3: EPA AEPCO Alternative Control 9 (ST2 PNGf and ST3 SNCR)

A4: EPA AEPCO Alternative Control 9b (ST2 PNGt and ST3 SNCR)

Attachment A1: EPA and AEPCO CALPUFF Results for EPA Base Case (OFA).

EPA CALPUFF Results	Impact in Deciviews: EPA Base with Ammonia = 1ppb				
EPA Base Case (OFA)	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	3.210	3.270	3.503	3.328	3.409
Chiricahua Wild.	3.404	3.387	3.464	3.418	3.464
Galiuro Wild.	1.805	2.113	2.615	2.178	2.219
Gila Wild.	0.673	0.753	0.500	0.642	0.629
Mazatzal Wild.	0.299	0.268	0.231	0.266	0.277
Mount Baldy Wild.	0.285	0.282	0.239	0.269	0.282
Saguaro NP	2.299	2.767	2.386	2.484	2.485
Sierra Ancha Wild.	0.287	0.304	0.275	0.289	0.287
Superstition Wild.	0.609	0.684	0.494	0.596	0.612

AEPCO CALPUFF Results	Impact in Deciviews: EPA Base with Ammonia = 1ppb				
EPA Base Case (OFA)	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	3.210	3.270	3.503	3.328	3.409
Chiricahua Wild.	3.404	3.387	3.464	3.418	3.464
Galiuro Wild.	1.805	2.113	2.615	2.178	2.219
Gila Wild.	0.673	0.753	0.500	0.642	0.629
Mazatzal Wild.	0.299	0.268	0.231	0.266	0.277
Mount Baldy Wild.	0.285	0.282	0.239	0.269	0.282
Saguaro NP	2.299	2.767	2.441	2.502	2.493
Sierra Ancha Wild.	0.287	0.304	0.275	0.289	0.287
Superstition Wild.	0.609	0.684	0.494	0.596	0.612

Difference in EPA and AEPCO CALPUFF Results (AEPCO – EPA)					
EPA Base Case (OFA)	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	0.000	0.000	0.000	0.000	0.000
Chiricahua Wild.	0.000	0.000	0.000	0.000	0.000
Galiuro Wild.	0.000	0.000	0.000	0.000	0.000
Gila Wild.	0.000	0.000	0.000	0.000	0.000
Mazatzal Wild.	0.000	0.000	0.000	0.000	0.000
Mount Baldy Wild.	0.000	0.000	0.000	0.000	0.000
Saguaro NP	0.000	0.000	0.055	0.018	0.008
Sierra Ancha Wild.	0.000	0.000	0.000	0.000	0.000
Superstition Wild.	0.000	0.000	0.000	0.000	0.000

Attachment A2: EPA and AEPCO CALPUFF Results for EPA SCR Case (0.07 lb/MMBtu)

EPA CALPUFF Results	Impact in Deciviews: EPA Base with Ammonia = 1ppb				
EPA SCR Case	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	1.790	2.147	1.996	1.978	1.996
Chiricahua Wild.	1.979	1.892	1.788	1.886	1.979
Galiuro Wild.	0.991	1.146	1.486	1.208	1.205
Gila Wild.	0.226	0.321	0.238	0.262	0.279
Mazatzal Wild.	0.167	0.172	0.130	0.156	0.147
Mount Baldy Wild.	0.102	0.132	0.092	0.109	0.114
Saguaro NP	1.308	1.460	1.495	1.421	1.463
Sierra Ancha Wild.	0.137	0.174	0.149	0.153	0.158
Superstition Wild.	0.317	0.307	0.314	0.313	0.315

AEPCO CALPUFF Results	Impact in Deciviews: EPA Base with Ammonia = 1ppb				
EPA SCR Case	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	1.790	2.147	1.996	1.978	1.996
Chiricahua Wild.	1.979	1.892	1.788	1.886	1.979
Galiuro Wild.	0.991	1.146	1.486	1.208	1.205
Gila Wild.	0.226	0.321	0.238	0.262	0.279
Mazatzal Wild.	0.167	0.172	0.130	0.156	0.147
Mount Baldy Wild.	0.102	0.132	0.092	0.109	0.114
Saguaro NP	1.308	1.460	1.495	1.421	1.463
Sierra Ancha Wild.	0.137	0.174	0.149	0.153	0.158
Superstition Wild.	0.317	0.307	0.314	0.313	0.315

Difference in EPA and AEPCO CALPUFF Results (AEPCO – EPA)					
EPA Base Case (OFA)	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	0.000	0.000	0.000	0.000	0.000
Chiricahua Wild.	0.000	0.000	0.000	0.000	0.000
Galiuro Wild.	0.000	0.000	0.000	0.000	0.000
Gila Wild.	0.000	0.000	0.000	0.000	0.000
Mazatzal Wild.	0.000	0.000	0.000	0.000	0.000
Mount Baldy Wild.	0.000	0.000	0.000	0.000	0.000
Saguaro NP	0.000	0.000	0.000	0.000	0.000
Sierra Ancha Wild.	0.000	0.000	0.000	0.000	0.000
Superstition Wild.	0.000	0.000	0.000	0.000	0.000

Attachment A3: EPA and AEPCO CALPUFF Results for AEPCO Alternative Control 9.

EPA CALPUFF Results	Impact in Deciviews: EPA Base with Ammonia = 1ppb				
AEPCO Alt Cntl 9 (PNGf)	98th Percentile			Avg 98th	22nd high
Class I Area	**2001**	**2002**	**2003**	**2001 -2003**	**2001 -2003**
Chiricahua NM	2.561	2.904	2.822	2.762	2.822
Chiricahua Wild.	2.807	2.571	2.692	2.690	2.727
Galiuro Wild.	1.366	1.559	1.909	1.611	1.629
Gila Wild.	0.331	0.458	0.298	0.362	0.404
Mazatzal Wild.	0.190	0.182	0.145	0.172	0.161
Mount Baldy Wild.	0.135	0.149	0.108	0.131	0.143
Saguaro NP	1.834	2.044	1.982	1.953	1.955
Sierra Ancha Wild.	0.165	0.195	0.159	0.173	0.166
Superstition Wild.	0.417	0.385	0.352	0.385	0.392

AEPCO CALPUFF Results	Impact in Deciviews: EPA Base with Ammonia = 1ppb				
AEPCO Alt Cntl 9 (PNGf)	98th Percentile			Avg 98th	22nd high
Class I Area	**2001**	**2002**	**2003**	**2001 -2003**	**2001 -2003**
Chiricahua NM	2.474	2.633	2.634	2.580	2.634
Chiricahua Wild.	2.606	2.430	2.511	2.516	2.554
Galiuro Wild.	1.464	1.548	1.777	1.596	1.562
Gila Wild.	0.376	0.474	0.338	0.396	0.392
Mazatzal Wild.	0.186	0.181	0.149	0.172	0.161
Mount Baldy Wild.	0.133	0.147	0.120	0.133	0.143
Saguaro NP	1.837	2.045	1.897	1.926	1.916
Sierra Ancha Wild.	0.173	0.183	0.152	0.169	0.166
Superstition Wild.	0.386	0.416	0.342	0.381	0.386

Difference in EPA and AEPCO CALPUFF Results (AEPCO – EPA)					
AEPCO Alt Cntl 9 (PNGf)	98th Percentile			Avg 98th	22nd high
Class I Area	**2001**	**2002**	**2003**	**2001 -2003**	**2001 -2003**
Chiricahua NM	-0.087	-0.271	-0.188	-0.182	-0.188
Chiricahua Wild.	-0.201	-0.141	-0.181	-0.174	-0.173
Galiuro Wild.	0.098	-0.011	-0.132	-0.015	-0.067
Gila Wild.	0.045	0.016	0.040	0.034	-0.012
Mazatzal Wild.	-0.004	-0.001	0.004	0.000	0.000
Mount Baldy Wild.	-0.002	-0.002	0.012	0.003	0.000
Saguaro NP	0.003	0.001	-0.085	-0.027	-0.039
Sierra Ancha Wild.	0.008	-0.012	-0.007	-0.004	0.000
Superstition Wild.	-0.031	0.031	-0.010	-0.003	-0.006

Attachment A4: EPA and AEPCO CALPUFF Results for AEPCO Alternative Control 9b.

EPA CALPUFF Results	Impact in Deciviews: EPA Base with Ammonia = 1ppb				
AEPCO Alt Cntl 9b (PNGt)	98th Percentile			Avg 98th	22nd high
Class I Area	**2001**	**2002**	**2003**	**2001 -2003**	**2001 -2003**
Chiricahua NM	1.968	1.991	2.122	2.027	2.016
Chiricahua Wild.	1.946	1.945	1.990	1.960	1.990
Galiuro Wild.	1.014	1.051	1.545	1.203	1.221
Gila Wild.	0.258	0.332	0.238	0.276	0.306
Mazatzal Wild.	0.141	0.135	0.117	0.131	0.132
Mount Baldy Wild.	0.115	0.127	0.097	0.113	0.115
Saguaro NP	1.278	1.598	1.380	1.419	1.401
Sierra Ancha Wild.	0.131	0.140	0.124	0.132	0.131
Superstition Wild.	0.296	0.318	0.234	0.283	0.296

AEPCO CALPUFF Results	Impact in Deciviews: EPA Base with Ammonia = 1ppb				
AEPCO Alt Cntl 9b (PNGt)	98th Percentile			Avg 98th	22nd high
Class I Area	**2001**	**2002**	**2003**	**2001 -2003**	**2001 -2003**
Chiricahua NM	1.939	1.784	2.054	1.926	1.960
Chiricahua Wild.	1.913	1.889	1.914	1.905	1.913
Galiuro Wild.	1.006	0.987	1.450	1.148	1.181
Gila Wild.	0.298	0.351	0.234	0.294	0.307
Mazatzal Wild.	0.141	0.135	0.115	0.130	0.127
Mount Baldy Wild.	0.118	0.123	0.103	0.115	0.118
Saguaro NP	1.255	1.560	1.349	1.388	1.357
Sierra Ancha Wild.	0.136	0.142	0.120	0.133	0.131
Superstition Wild.	0.293	0.338	0.216	0.282	0.293

Difference in EPA and AEPCO CALPUFF Results (AEPCO – EPA)					
AEPCO Alt Cntl 9b (PNGt)	98th Percentile			Avg 98th	22nd high
Class I Area	**2001**	**2002**	**2003**	**2001 -2003**	**2001 -2003**
Chiricahua NM	-0.029	-0.207	-0.068	-0.101	-0.056
Chiricahua Wild.	-0.033	-0.056	-0.076	-0.055	-0.077
Galiuro Wild.	-0.008	-0.064	-0.095	-0.056	-0.040
Gila Wild.	0.040	0.019	-0.004	0.018	0.001
Mazatzal Wild.	0.000	0.000	-0.002	-0.001	-0.005
Mount Baldy Wild.	0.003	-0.004	0.006	0.002	0.003
Saguaro NP	-0.023	-0.038	-0.031	-0.031	-0.044
Sierra Ancha Wild.	0.005	0.002	-0.004	0.001	0.000
Superstition Wild.	-0.003	0.020	-0.018	0.000	-0.003

Attachment B

Comparison of AEPCO's CALPUFF Visibility Results for EPA BART SCR (0.07 lb/MMBtu) and AEPCO Alternative Control 9 (PNGf) and 9b (PNGt)

Visibility Method 8 using Best 20% Days Visibility Background

Monthly Varying Background Ammonia Concentrations (ENSR/AECOM, 2009)

B1: EPA BART SCR vs. AEPCO Alternative Control 9 (PNGf))

B2: EPA BART SCR vs. AEPCO Alternative Control 9b (PNGt)

Attachment B1: EPA BART SCR vs. AEPCO Alternative Control 9 (PNGf) monthly ammonia.

AEPCO CALPUFF Results	Impact in Deciviews: Monthly Ammonia				
EPA BART SCR	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	1.657	1.820	1.747	1.741	1.747
Chiricahua Wild.	1.834	1.651	1.622	1.702	1.788
Galiuro Wild.	0.886	1.047	1.156	1.030	1.096
Gila Wild.	0.218	0.278	0.227	0.241	0.251
Mazatzal Wild.	0.150	0.145	0.110	0.135	0.136
Mount Baldy Wild.	0.097	0.132	0.089	0.106	0.099
Saguaro NP	1.185	1.263	1.349	1.266	1.263
Sierra Ancha Wild.	0.122	0.151	0.138	0.137	0.138
Superstition Wild.	0.277	0.269	0.278	0.275	0.277
Average	0.714	0.751	0.746	0.737	0.755
AEPCO CALPUFF Results	Impact in Deciviews: Monthly Ammonia				
EPA AEPCO Alt Cntl 9	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	2.225	2.217	2.285	2.242	2.252
Chiricahua Wild.	2.245	2.188	1.961	2.131	2.214
Galiuro Wild.	1.116	1.292	1.522	1.310	1.318
Gila Wild.	0.283	0.394	0.292	0.323	0.329
Mazatzal Wild.	0.138	0.149	0.108	0.132	0.137
Mount Baldy Wild.	0.119	0.135	0.090	0.115	0.125
Saguaro NP	1.609	1.652	1.799	1.687	1.662
Sierra Ancha Wild.	0.135	0.165	0.127	0.142	0.141
Superstition Wild.	0.312	0.296	0.288	0.299	0.300
Average	0.909	0.943	0.941	0.931	0.942
Difference in dv between EPA BART SCR and AEPCO Alternative Cntl 9 (Alt – SCR)					
	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	0.568	0.397	0.538	0.501	0.505
Chiricahua Wild.	0.411	0.537	0.339	0.429	0.426
Galiuro Wild.	0.230	0.245	0.366	0.280	0.222
Gila Wild.	0.065	0.116	0.065	0.082	0.078
Mazatzal Wild.	-0.012	0.004	-0.002	-0.003	0.001
Mount Baldy Wild.	0.022	0.003	0.001	0.009	0.026
Saguaro NP	0.424	0.389	0.450	0.421	0.399
Sierra Ancha Wild.	0.013	0.014	-0.011	0.005	0.003
Superstition Wild.	0.035	0.027	0.010	0.024	0.023
Average	0.195	0.192	0.195	0.194	0.187

Attachment B2: EPA BART SCR vs. AEPCO Alternative Control 9b (PNGt) monthly ammonia.

AEPCO CALPUFF Results	Impact in Deciviews: Monthly Ammonia				
EPA BART SCR	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	1.657	1.820	1.747	1.741	1.747
Chiricahua Wild.	1.834	1.651	1.622	1.702	1.788
Galiuro Wild.	0.886	1.047	1.156	1.030	1.096
Gila Wild.	0.218	0.278	0.227	0.241	0.251
Mazatzal Wild.	0.150	0.145	0.110	0.135	0.136
Mount Baldy Wild.	0.097	0.132	0.089	0.106	0.099
Saguaro NP	1.185	1.263	1.349	1.266	1.263
Sierra Ancha Wild.	0.122	0.151	0.138	0.137	0.138
Superstition Wild.	0.277	0.269	0.278	0.275	0.277
Average	0.714	0.751	0.746	0.737	0.755
AEPCO CALPUFF Results	Impact in Deciviews: Monthly Ammonia				
EPA AEPCO Alt Cntl 9b	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	1.467	1.489	1.662	1.539	1.567
Chiricahua Wild.	1.632	1.514	1.434	1.527	1.562
Galiuro Wild.	0.719	0.852	0.961	0.844	0.909
Gila Wild.	0.229	0.276	0.192	0.232	0.239
Mazatzal Wild.	0.111	0.106	0.083	0.100	0.104
Mount Baldy Wild.	0.105	0.096	0.077	0.093	0.096
Saguaro NP	1.014	1.096	1.205	1.105	1.132
Sierra Ancha Wild.	0.094	0.112	0.090	0.099	0.102
Superstition Wild.	0.233	0.217	0.200	0.217	0.217
Average	0.623	0.640	0.656	0.639	0.659
Difference in dv between EPA BART SCR and AEPCO Alternative Cntl 9b (Alt – SCR)					
	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	-0.190	-0.331	-0.085	-0.202	-0.180
Chiricahua Wild.	-0.202	-0.137	-0.188	-0.176	-0.226
Galiuro Wild.	-0.167	-0.195	-0.195	-0.186	-0.187
Gila Wild.	0.011	-0.002	-0.035	-0.009	-0.012
Mazatzal Wild.	-0.039	-0.039	-0.027	-0.035	-0.032
Mount Baldy Wild.	0.008	-0.036	-0.012	-0.013	-0.003
Saguaro NP	-0.171	-0.167	-0.144	-0.161	-0.131
Sierra Ancha Wild.	-0.028	-0.039	-0.048	-0.038	-0.036
Superstition Wild.	-0.044	-0.052	-0.078	-0.058	-0.060
Average	-0.091	-0.111	-0.090	-0.097	-0.096

Attachment C

Comparison of AEPCO's CALPUFF Visibility Results for EPA BART SCR (0.07 lb/MMBtu) and AEPCO Alternative with Updated PM Emissions Factor for ST2 (0.00042 lb/MMBtu)

Visibility Method 8 using Best 20% Days Visibility Background

Monthly Varying Background Ammonia Concentrations (ENSR/AECOM, 2009)

C1: EPA BART SCR vs. AEPCO Alternative with Updated PM Emissions Factor for ST2

Attachment C1: EPA BART SCR vs. AEPCO Alternative with Updated PM monthly ammonia.

AEPCO CALPUFF Results	Impact in Deciviews: Monthly Ammonia				
EPA BART SCR	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	1.657	1.820	1.747	1.741	1.747
Chiricahua Wild.	1.834	1.651	1.622	1.702	1.788
Galiuro Wild.	0.886	1.047	1.156	1.030	1.096
Gila Wild.	0.218	0.278	0.227	0.241	0.251
Mazatzal Wild.	0.150	0.145	0.110	0.135	0.136
Mount Baldy Wild.	0.097	0.132	0.089	0.106	0.099
Saguaro NP	1.185	1.263	1.349	1.266	1.263
Sierra Ancha Wild.	0.122	0.151	0.138	0.137	0.138
Superstition Wild.	0.277	0.269	0.278	0.275	0.277
Average	0.714	0.751	0.746	0.737	0.755
AEPCO CALPUFF Results	Impact in Deciviews: Monthly Ammonia				
AEPCO Alt w/ Updated PM	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001-03	2001 -2003
Chiricahua NM	1.27	1.32	1.44	1.34	1.37
Chiricahua Wild.	1.40	1.34	1.26	1.33	1.35
Galiuro Wild.	0.60	0.70	0.87	0.72	0.74
Gila Wild.	0.18	0.23	0.17	0.20	0.21
Mazatzal Wild.	0.10	0.10	0.07	0.09	0.10
Mount Baldy Wild.	0.10	0.09	0.07	0.09	0.09
Saguaro NP	0.81	0.93	1.02	0.92	0.93
Sierra Ancha Wild.	0.08	0.10	0.08	0.09	0.09
Superstition Wild.	0.19	0.19	0.17	0.18	0.19
Average	1.27	1.32	1.44	1.34	1.37
Difference in dv between EPA BART SCR and AEPCO Alternative w/ PM (Alt – SCR)					
AEPCO CALPUFF Results	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001-03	2001 -2003
Chiricahua NM	-0.39	-0.50	-0.30	-0.40	-0.38
Chiricahua Wild.	-0.44	-0.31	-0.37	-0.37	-0.44
Galiuro Wild.	-0.29	-0.34	-0.29	-0.31	-0.36
Gila Wild.	-0.04	-0.05	-0.06	-0.05	-0.04
Mazatzal Wild.	-0.05	-0.05	-0.04	-0.04	-0.04
Mount Baldy Wild.	0.00	-0.04	-0.02	-0.02	-0.01
Saguaro NP	-0.38	-0.34	-0.33	-0.35	-0.34
Sierra Ancha Wild.	-0.04	-0.06	-0.06	-0.05	-0.05
Superstition Wild.	-0.08	-0.08	-0.11	-0.09	-0.09
Average	-0.19	-0.20	-0.17	-0.19	-0.19

Attachment D

Comparison of AEPCO's CALPUFF Visibility Results for EPA BART SCR (0.07 lb/MMBtu) and AEPCO Alternative Control 9v2 (PNGf) and 9bv2 (PNGt)

Visibility Method 8 using Best 20% Days Visibility Background

Monthly Varying Background Ammonia Concentrations (ENSR/AECOM, 2009)

D1: EPA BART SCR vs. AEPCO Alternative Control 9v2 (PNGf))

D2: EPA BART SCR vs. AEPCO Alternative Control 9bv2 (PNGt)

Attachment D1: EPA BART SCR vs. AEPCO Alternative Control 9v2 (PNGf) monthly ammonia.

AEPCO CALPUFF Results	Impact in Deciviews: Monthly Ammonia				
EPA BART SCR	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	1.657	1.820	1.747	1.741	1.747
Chiricahua Wild.	1.834	1.651	1.622	1.702	1.788
Galiuro Wild.	0.886	1.047	1.156	1.030	1.096
Gila Wild.	0.218	0.278	0.227	0.241	0.251
Mazatzal Wild.	0.150	0.145	0.110	0.135	0.136
Mount Baldy Wild.	0.097	0.132	0.089	0.106	0.099
Saguaro NP	1.185	1.263	1.349	1.266	1.263
Sierra Ancha Wild.	0.122	0.151	0.138	0.137	0.138
Superstition Wild.	0.277	0.269	0.278	0.275	0.277
Average	0.714	0.751	0.746	0.737	0.755
AEPCO CALPUFF Results	Impact in Deciviews: Monthly Ammonia				
AEPCO Alt Cntl 9v2	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	2.318	2.006	2.013	2.114	2.044
Chiricahua Wild.	2.427	2.059	2.013	1.815	1.962
Galiuro Wild.	1.356	1.014	1.174	1.368	1.185
Gila Wild.	0.336	0.259	0.368	0.261	0.296
Mazatzal Wild.	0.178	0.129	0.137	0.101	0.122
Mount Baldy Wild.	0.127	0.116	0.125	0.083	0.108
Saguaro NP	1.678	1.457	1.501	1.626	1.528
Sierra Ancha Wild.	0.162	0.125	0.150	0.112	0.129
Superstition Wild.	0.365	0.290	0.273	0.268	0.277
Average	0.994	0.828	0.862	0.861	0.850
Difference in dv between EPA BART SCR and AEPCO Alternative Cntl 9v2 (Alt – SCR)					
	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	0.349	0.193	0.367	0.303	0.275
Chiricahua Wild.	0.225	0.362	0.193	0.260	0.247
Galiuro Wild.	0.128	0.127	0.212	0.156	0.084
Gila Wild.	0.041	0.090	0.034	0.055	0.056
Mazatzal Wild.	-0.021	-0.008	-0.009	-0.013	-0.007
Mount Baldy Wild.	0.019	-0.007	-0.006	0.002	0.019
Saguaro NP	0.272	0.238	0.277	0.262	0.254
Sierra Ancha Wild.	0.003	-0.001	-0.026	-0.008	-0.007
Superstition Wild.	0.013	0.004	-0.010	0.002	-0.004
Average	0.114	0.111	0.115	0.113	0.102

Attachment D2: EPA BART SCR vs. AEPCO Alternative Control 9bv2 (PNGt) monthly ammonia.

AEPCO CALPUFF Results	Impact in Deciviews: Monthly Ammonia				
EPA BART SCR	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	1.657	1.820	1.747	1.741	1.747
Chiricahua Wild.	1.834	1.651	1.622	1.702	1.788
Galiuro Wild.	0.886	1.047	1.156	1.030	1.096
Gila Wild.	0.218	0.278	0.227	0.241	0.251
Mazatzal Wild.	0.150	0.145	0.110	0.135	0.136
Mount Baldy Wild.	0.097	0.132	0.089	0.106	0.099
Saguaro NP	1.185	1.263	1.349	1.266	1.263
Sierra Ancha Wild.	0.122	0.151	0.138	0.137	0.138
Superstition Wild.	0.277	0.269	0.278	0.275	0.277
Average	0.714	0.751	0.746	0.737	0.755
AEPCO CALPUFF Results	Impact in Deciviews: Monthly Ammonia				
AEPCO Alt Cntl 9bv2	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	1.422	1.441	1.612	1.492	1.521
Chiricahua Wild.	1.581	1.474	1.392	1.482	1.513
Galiuro Wild.	0.690	0.820	0.938	0.816	0.864
Gila Wild.	0.218	0.268	0.188	0.225	0.233
Mazatzal Wild.	0.109	0.103	0.081	0.098	0.102
Mount Baldy Wild.	0.103	0.095	0.076	0.091	0.094
Saguaro NP	0.969	1.058	1.168	1.065	1.094
Sierra Ancha Wild.	0.091	0.108	0.088	0.096	0.100
Superstition Wild.	0.225	0.210	0.193	0.209	0.210
Average	0.601	0.620	0.637	0.619	0.637
Difference in dv between EPA BART SCR and AEPCO Alternative Cntl 9bv2 (Alt – SCR)					
	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	-0.235	-0.379	-0.135	-0.250	-0.226
Chiricahua Wild.	-0.253	-0.177	-0.230	-0.220	-0.275
Galiuro Wild.	-0.196	-0.227	-0.218	-0.214	-0.232
Gila Wild.	0.000	-0.010	-0.039	-0.016	-0.018
Mazatzal Wild.	-0.041	-0.042	-0.029	-0.037	-0.034
Mount Baldy Wild.	0.006	-0.037	-0.013	-0.015	-0.005
Saguaro NP	-0.216	-0.205	-0.181	-0.201	-0.169
Sierra Ancha Wild.	-0.031	-0.043	-0.050	-0.041	-0.038
Superstition Wild.	-0.052	-0.059	-0.085	-0.065	-0.067
Average	-0.113	-0.131	-0.109	-0.118	-0.118

Attachment E

Comparison of AEPCO's CALPUFF Visibility Results for EPA BART SCR (0.07 lb/MMBtu) and the Various AEPCO Alternative Scenarios using Constant 1 ppb Ammonia

Visibility Method 8 using Best 20% Days Visibility Background

Constant 1 ppb Background Ammonia Concentration

E1: EPA BART SCR vs. AEPCO Alternative Control 9 (PNGf))

E2: EPA BART SCR vs. AEPCO Alternative Control 9b (PNGt)

E3: EPA BART SCR vs. AEPCO Alternative w/ Updated PM Factor

E4: EPA BART SCR vs. AEP Alternative Control 9v2 (PNGf))

E5: EPA BART SCR vs. AEPCO Alternative Control 9bv2 (PNGt)

Attachment E1: EPA BART SCR vs. AEPCO Alternative Control 9 (PNGf) constant ammonia.

AEPCO CALPUFF Results	Impact in Deciviews: 1 ppb Ammonia				
EPA BART SCR	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	1.790	2.147	1.996	1.978	1.996
Chiricahua Wild.	1.979	1.892	1.788	1.886	1.979
Galiuro Wild.	0.991	1.146	1.486	1.208	1.205
Gila Wild.	0.226	0.321	0.238	0.262	0.279
Mazatzal Wild.	0.167	0.172	0.130	0.156	0.147
Mount Baldy Wild.	0.102	0.132	0.092	0.109	0.114
Saguaro NP	1.308	1.460	1.495	1.421	1.463
Sierra Ancha Wild.	0.137	0.174	0.149	0.153	0.158
Superstition Wild.	0.317	0.307	0.314	0.313	0.315
Average	0.780	0.861	0.854	0.832	0.851
AEPCO CALPUFF Results	Impact in Deciviews: 1 ppb Ammonia				
AEPCO Alt Cntl 9	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	2.474	2.633	2.634	2.580	2.634
Chiricahua Wild.	2.606	2.430	2.511	2.516	2.554
Galiuro Wild.	1.464	1.548	1.777	1.596	1.562
Gila Wild.	0.376	0.474	0.338	0.396	0.392
Mazatzal Wild.	0.186	0.181	0.149	0.172	0.161
Mount Baldy Wild.	0.133	0.147	0.120	0.133	0.143
Saguaro NP	1.837	2.045	1.897	1.926	1.916
Sierra Ancha Wild.	0.173	0.183	0.152	0.169	0.166
Superstition Wild.	0.386	0.416	0.342	0.381	0.386
Average	1.071	1.117	1.102	1.097	1.102
Difference in dv between EPA BART SCR and AEPCO Alternative Cntl 9 (Alt – SCR)					
AEPCO CALPUFF Results	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	0.684	0.486	0.638	0.603	0.638
Chiricahua Wild.	0.627	0.538	0.723	0.629	0.575
Galiuro Wild.	0.473	0.402	0.291	0.389	0.357
Gila Wild.	0.150	0.153	0.100	0.134	0.113
Mazatzal Wild.	0.019	0.009	0.019	0.016	0.014
Mount Baldy Wild.	0.031	0.015	0.028	0.025	0.029
Saguaro NP	0.529	0.585	0.402	0.505	0.453
Sierra Ancha Wild.	0.036	0.009	0.003	0.016	0.008
Superstition Wild.	0.069	0.109	0.028	0.069	0.071
Average	0.291	0.256	0.248	0.265	0.251

Attachment E2: EPA BART SCR vs. AEPCO Alternative Control 9b (PNGt) constant ammonia.

AEPCO CALPUFF Results	Impact in Deciviews: 1 ppb Ammonia				
EPA BART SCR	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	1.790	2.147	1.996	1.978	1.996
Chiricahua Wild.	1.979	1.892	1.788	1.886	1.979
Galiuro Wild.	0.991	1.146	1.486	1.208	1.205
Gila Wild.	0.226	0.321	0.238	0.262	0.279
Mazatzal Wild.	0.167	0.172	0.130	0.156	0.147
Mount Baldy Wild.	0.102	0.132	0.092	0.109	0.114
Saguaro NP	1.308	1.460	1.495	1.421	1.463
Sierra Ancha Wild.	0.137	0.174	0.149	0.153	0.158
Superstition Wild.	0.317	0.307	0.314	0.313	0.315
Average	0.780	0.861	0.854	0.832	0.851
AEPCO CALPUFF Results	Impact in Deciviews: 1 ppb Ammonia				
AEPCO Alt Cntl 9b	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	1.939	1.784	2.054	1.926	1.960
Chiricahua Wild.	1.913	1.889	1.914	1.905	1.913
Galiuro Wild.	1.006	0.987	1.450	1.148	1.181
Gila Wild.	0.298	0.351	0.234	0.294	0.307
Mazatzal Wild.	0.141	0.135	0.115	0.130	0.127
Mount Baldy Wild.	0.118	0.123	0.103	0.115	0.118
Saguaro NP	1.255	1.560	1.349	1.388	1.357
Sierra Ancha Wild.	0.136	0.142	0.120	0.133	0.131
Superstition Wild.	0.293	0.338	0.216	0.282	0.293
Average	0.789	0.812	0.839	0.813	0.821
Difference in dv between EPA BART SCR and AEPCO Alternative Cntl 9b (Alt – SCR)					
AEPCO CALPUFF Results	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	0.149	-0.363	0.058	-0.052	-0.036
Chiricahua Wild.	-0.066	-0.003	0.126	0.019	-0.066
Galiuro Wild.	0.015	-0.159	-0.036	-0.060	-0.024
Gila Wild.	0.072	0.030	-0.004	0.033	0.028
Mazatzal Wild.	-0.026	-0.037	-0.015	-0.026	-0.020
Mount Baldy Wild.	0.016	-0.009	0.011	0.006	0.004
Saguaro NP	-0.053	0.100	-0.146	-0.033	-0.106
Sierra Ancha Wild.	-0.001	-0.032	-0.029	-0.021	-0.027
Superstition Wild.	-0.024	0.031	-0.098	-0.030	-0.022
Average	0.009	-0.049	-0.015	-0.018	-0.030

Attachment E3: EPA BART SCR vs. AEPCO Alternative with Update PM Emissions.

AEPCO CALPUFF Results	Impact in Deciviews: 1 ppb Ammonia				
EPA BART SCR	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	1.790	2.147	1.996	1.978	1.996
Chiricahua Wild.	1.979	1.892	1.788	1.886	1.979
Galiuro Wild.	0.991	1.146	1.486	1.208	1.205
Gila Wild.	0.226	0.321	0.238	0.262	0.279
Mazatzal Wild.	0.167	0.172	0.130	0.156	0.147
Mount Baldy Wild.	0.102	0.132	0.092	0.109	0.114
Saguaro NP	1.308	1.460	1.495	1.421	1.463
Sierra Ancha Wild.	0.137	0.174	0.149	0.153	0.158
Superstition Wild.	0.317	0.307	0.314	0.313	0.315
Average	0.780	0.861	0.854	0.832	0.851
AEPCO CALPUFF Results	Impact in Deciviews: 1 ppb Ammonia				
AEPCO Alt PM Update	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	1.73	1.63	1.87	1.74	1.79
Chiricahua Wild.	1.66	1.67	1.71	1.68	1.68
Galiuro Wild.	0.81	0.87	1.32	1.00	1.02
Gila Wild.	0.28	0.32	0.21	0.27	0.27
Mazatzal Wild.	0.12	0.12	0.10	0.11	0.12
Mount Baldy Wild.	0.12	0.12	0.10	0.11	0.12
Saguaro NP	1.17	1.44	1.17	1.26	1.19
Sierra Ancha Wild.	0.11	0.13	0.11	0.12	0.12
Superstition Wild.	0.25	0.31	0.20	0.25	0.27
Average	1.73	1.63	1.87	1.74	1.79
Difference in dv between EPA BART SCR and AEPCO Alternative PM (Alt – SCR)					
AEPCO CALPUFF Results	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	-0.06	-0.52	-0.13	-0.24	-0.21
Chiricahua Wild.	-0.32	-0.23	-0.08	-0.21	-0.30
Galiuro Wild.	-0.18	-0.28	-0.17	-0.21	-0.19
Gila Wild.	0.06	0.00	-0.03	0.01	-0.01
Mazatzal Wild.	-0.05	-0.05	-0.03	-0.04	-0.03
Mount Baldy Wild.	0.01	-0.02	0.01	0.00	0.00
Saguaro NP	-0.14	-0.02	-0.32	-0.16	-0.28
Sierra Ancha Wild.	-0.03	-0.05	-0.04	-0.04	-0.04
Superstition Wild.	-0.07	0.01	-0.11	-0.06	-0.05
Average	-0.09	-0.13	-0.10	-0.10	-0.12

Attachment E4: EPA BART SCR vs. AEPCO Alternative Control 9v2 (PNGt) constant ammonia.

AEPCO CALPUFF Results	Impact in Deciviews: 1 ppb Ammonia				
EPA BART SCR	**98th Percentile**			**Avg 98th**	**22nd high**
Class I Area	**2001**	**2002**	**2003**	**2001 -2003**	**2001 -2003**
Chiricahua NM	1.790	2.147	1.996	1.978	1.996
Chiricahua Wild.	1.979	1.892	1.788	1.886	1.979
Galiuro Wild.	0.991	1.146	1.486	1.208	1.205
Gila Wild.	0.226	0.321	0.238	0.262	0.279
Mazatzal Wild.	0.167	0.172	0.130	0.156	0.147
Mount Baldy Wild.	0.102	0.132	0.092	0.109	0.114
Saguaro NP	1.308	1.460	1.495	1.421	1.463
Sierra Ancha Wild.	0.137	0.174	0.149	0.153	0.158
Superstition Wild.	0.317	0.307	0.314	0.313	0.315
Average	0.780	0.861	0.854	0.832	0.851
AEPCO CALPUFF Results	**Impact in Deciviews: 1 ppb Ammonia**				
AEPCO Alt Cntl 9v2	**98th Percentile**			**Avg 98th**	**22nd high**
Class I Area	**2001**	**2002**	**2003**	**2001 -2003**	**2001 -2003**
Chiricahua NM	2.318	2.405	2.464	2.396	2.421
Chiricahua Wild.	2.427	2.266	2.344	2.346	2.370
Galiuro Wild.	1.356	1.397	1.661	1.471	1.452
Gila Wild.	0.336	0.430	0.309	0.358	0.366
Mazatzal Wild.	0.178	0.167	0.138	0.161	0.150
Mount Baldy Wild.	0.127	0.136	0.114	0.126	0.135
Saguaro NP	1.678	1.927	1.708	1.771	1.799
Sierra Ancha Wild.	0.162	0.171	0.144	0.159	0.153
Superstition Wild.	0.365	0.393	0.307	0.355	0.365
Average	0.994	1.032	1.021	1.016	1.023
Difference in dv between EPA BART SCR and AEPCO Alternative Cntl 9v2 (Alt – SCR)					
AEPCO CALPUFF Results	**98th Percentile**			**Avg 98th**	**22nd high**
Class I Area	**2001**	**2002**	**2003**	**2001 -2003**	**2001 -2003**
Chiricahua NM	0.528	0.258	0.468	0.418	0.425
Chiricahua Wild.	0.448	0.374	0.556	0.459	0.391
Galiuro Wild.	0.365	0.251	0.175	0.264	0.247
Gila Wild.	0.110	0.109	0.071	0.097	0.087
Mazatzal Wild.	0.011	-0.005	0.008	0.005	0.003
Mount Baldy Wild.	0.025	0.004	0.022	0.017	0.021
Saguaro NP	0.370	0.467	0.213	0.350	0.336
Sierra Ancha Wild.	0.025	-0.003	-0.005	0.006	-0.005
Superstition Wild.	0.048	0.086	-0.007	0.042	0.050
Average	0.214	0.171	0.167	0.184	0.173

Attachment E5: EPA BART SCR vs. AEPCO Alternative Control 9bv2 (PNGt) constant ammonia.

AEPCO CALPUFF Results	Impact in Deciviews: 1 ppb Ammonia				
EPA BART SCR	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	1.790	2.147	1.996	1.978	1.996
Chiricahua Wild.	1.979	1.892	1.788	1.886	1.979
Galiuro Wild.	0.991	1.146	1.486	1.208	1.205
Gila Wild.	0.226	0.321	0.238	0.262	0.279
Mazatzal Wild.	0.167	0.172	0.130	0.156	0.147
Mount Baldy Wild.	0.102	0.132	0.092	0.109	0.114
Saguaro NP	1.308	1.460	1.495	1.421	1.463
Sierra Ancha Wild.	0.137	0.174	0.149	0.153	0.158
Superstition Wild.	0.317	0.307	0.314	0.313	0.315
Average	0.780	0.861	0.854	0.832	0.851
AEPCO CALPUFF Results	Impact in Deciviews: 1 ppb Ammonia				
AEPCO Alt Cntl 9bv2	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	1.898	1.740	2.007	1.882	1.909
Chiricahua Wild.	1.852	1.837	1.863	1.851	1.852
Galiuro Wild.	0.959	0.952	1.421	1.111	1.135
Gila Wild.	0.292	0.342	0.226	0.287	0.295
Mazatzal Wild.	0.136	0.131	0.112	0.126	0.124
Mount Baldy Wild.	0.116	0.121	0.100	0.112	0.116
Saguaro NP	1.213	1.525	1.301	1.346	1.317
Sierra Ancha Wild.	0.132	0.139	0.118	0.130	0.128
Superstition Wild.	0.283	0.330	0.212	0.275	0.283
Average	0.765	0.791	0.818	0.791	0.795
Difference in dv between EPA BART SCR and AEPCO Alternative Cntl 9bv2 (Alt – SCR)					
AEPCO CALPUFF Results	98th Percentile			Avg 98th	22nd high
Class I Area	2001	2002	2003	2001 -2003	2001 -2003
Chiricahua NM	0.108	-0.407	0.011	-0.096	-0.087
Chiricahua Wild.	-0.127	-0.055	0.075	-0.036	-0.127
Galiuro Wild.	-0.032	-0.194	-0.065	-0.097	-0.070
Gila Wild.	0.066	0.021	-0.012	0.025	0.016
Mazatzal Wild.	-0.031	-0.041	-0.018	-0.030	-0.023
Mount Baldy Wild.	0.014	-0.011	0.008	0.004	0.002
Saguaro NP	-0.095	0.065	-0.194	-0.075	-0.146
Sierra Ancha Wild.	-0.005	-0.035	-0.031	-0.024	-0.030
Superstition Wild.	-0.034	0.023	-0.102	-0.038	-0.032
Average	-0.015	-0.070	-0.036	-0.041	-0.055

May 8, 2013

MEMORANDUM

To: Michelle Freeark, Arizona Electric Power Cooperative (AEPCO)
From: Ralph Morris and Glenn England
Subject: Updated $PM_{2.5}$ Emissions Factors for Natural Gas-Fired Boilers

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SUMMARY

AEPCO is proposing an alternative to EPA's proposed Best Available Retrofit Technology (BART) NO_X emissions controls on their Apache ST2 and ST3 coal-fired electrical generating units (EGUs). EPA's proposed BART scenario would install selective catalytic reduction (SCR) on both of Apaches coal-fired EGUs, whereas the AEPCO Alternative would convert one of the units to natural gas (ST2) and install selective non-catalytic reduction (SNCR) on the other unit (ST3). AEPCO needs to demonstrate that their Alternative control scenario produces equivalent or better visibility improvements at Class I areas than the EPA SCR BART control scenario. This demonstration needs to account for the tradeoffs in visibility impacts associated with the AEPCO ST2 and ST3 SO_2, NO_X and PM emissions for the EPA SCR BART scenario (lower NO_X) versus AEPCO Alternative (lower SO_2). The CALPUFF dispersion model (V5.8) is used to calculate the visibility impacts at Class I areas for the EPA SCR BART and AEPCO Alternative emission scenarios.

One key assumption in comparing the visibility impacts of the EPA BART and AEPCO Alternative emission scenarios is the level of PM emissions from the natural gas fired ST2 EGU in the AEPCO Alternative. EPA's CALPUFF modeling of natural gas-fired ST2 in the AEPCO Alternative initially used a PM emissions factor of 0.01 lb/MMBtu that is based on EPA's AP-42 emissions factor report. EPA's CALPUFF modeling performed sensitivity tests assuming that the 0.01 lb/MMBtu emissions factor was just the filterable portion of the PM and was the total PM emissions (filterable plus condensable). When assuming that the 0.01 lb/MMBtu PM emissions factor is just the filterable portion of the PM, EPA used the NPS speciation profiles for natural gas that assumes the condensable PM emissions is three times the filterable component (i.e., 0.04 lb/MMBtu total emissions). It should be noted that the AP-42 PM emissions factors for total, filterable and condensable PM emissions are 0.0075, 0.0019 and 0.0056 lb/MMBtu, respectively[1].

The data used to develop the AP-42 natural gas combustion PM emissions factor are outdated, sparse and based on test data that are highly influenced by positive measurement bias. As part of the development of the National Emissions Inventory (NEI), EPA provided guidance for updated natural gas PM emissions factors based on newer measurement technology that is more sensitive and accurate and does not exhibit the positive measurement bias artifact. EPA's

1 http://www.epa.gov/ttnchie1/ap42/ch01/final/c01s04.pdf

new natural gas combustion total PM_{10} emissions factor is 0.00042 lb/MMBtu[2]. The use of the updated natural gas PM emissions factor will result in a more accurate assessment of the visibility benefits of the AEPCO Alternative emissions control for the Apache EGU.

BACKGROUND

The Regional Haze Rule (RHR) goal is to achieve natural visibility conditions at Class I areas by 2064. One component of the RHR is the Best Achievable Retrofit Technology (BART) program that implements BART emission controls on specific existing point sources for emissions that have been shown to cause or contribute to visibility impairment at a Class I area. Such visibility precursor emissions include sulfur oxides (SO_X or SO_2), oxides of nitrogen (NO_X) and particulate matter (PM).

Arizona Electric Power Cooperative (AEPCO) operates the Apache Electrical Generation Unit (EGU) that consists of two ~175 Megawatt (MWe) electrical generating boilers (Stacks 2 and 3; ST2 and ST3). The two Apache EGUs (ST2 and ST3) are duel-fired boilers that are designed to operate on either coal or natural gas, with coal being the primary fuel that they are permitted to use. The Arizona Department of Environmental Quality (ADEQ) has determined that the two Apache EGUs are BART-eligible. The U.S. Environmental Protection Agency (EPA) has determined that BART for the NO_X emissions from the two Apache coal-fired EGUs is selective catalytic reduction (SCR) that achieves a 0.07 lb/MMBtu NO_X emissions rate. AEPCO has proposed an alternative to EPA's proposed BART controls that would convert Apache ST2 to natural gas and install selective non-catalytic reduction (SNCR) on ST3. Thus, the differences in visibility impacts due to the EPA BART and AEPCO Alternative control scenarios will hinge on the differences in visibility impacts associated with the different SO_2, NO_X and PM emissions of the two control scenario, with the EPA BART scenario having lower NO_X and the AEPCO Alternative scenario having lower SO_2 emissions.

Both EPA Region 9 and ENVIRON for AEPCO are performing CALPUFF visibility modeling to estimate the visibility impacts due to the AEPCO Apache EGUs under the EPA BART and AEPCO Alternative emission scenarios. One important input is the amount PM emissions from natural gas-fired boilers associated with the AEPCO Alternative proposal to switch ST2 from coal to natural gas. AP-42 and most measurements using EPA methods show that condensable PM dominates total measured PM emissions from natural gas-fired sources (Corio and Sherwell, 2000). EPA has been using a PM emissions factor based on the old (1990) Method 202 which significantly overstates condensable PM emissions from natural gas-fired sources because of known SO_2/sulfate interference and sensitivity issues. The natural gas PM emissions factor has been updated and the latest emissions inventories developed by EPA (e.g., 2011 NEI) use a more accurate and much lower PM emissions factor for natural gas boilers. This Memorandum describes the new natural gas PM emissions factor and explains why it should be used to obtain a more accurate assessment of the visibility benefits of the AEPCO Alternative BART control.

2 See tab "Final table with NG Adjustments" of spreadsheet "natgas_procgas_lpg_pm_efs_not_ap42_032012_revisions.cls" under "PM EFs for Natural Gas Combustion" on 2011 NEI website (http://www.epa.gov/ttnchie1/net/2011inventory.html)

PRIMARY PM EMISSIONS FROM NATURAL GAS-FIRED BOILERS

Primary particulate matter (PM) emissions from gas-fired external combustion sources (such as the Apache ST2 and ST3 boilers when operated on natural gas) are extremely low over a wide range of normal operating conditions. EPA's *Compilation of Emission Factors* - commonly known by its EPA report number, AP-42 – provides emission factors for particulate matter (PM) emissions from natural gas-fired external combustion sources (USEPA, 1998a). The data used to generate these emission factors are outdated, sparse and based on test methods that are subject to uncontrolled, positive measurement bias. EPA derived an alternative, lower gas-fired boiler primary $PM_{2.5}$ emission factor for use in National Emissions Inventories (NEIs), based on newer test measurements using a more sensitive and accurate research method. ENVIRON recommends using the newer emission factor for the AEPCO Alternative scenario, which we consider to be more representative of actual PM_{10}/$PM_{2.5}$ emissions from gas-fired external combustion sources, for assessing air quality and visibility impacts associated with changes in source emissions.

For gaseous fuels, primary particles originate from sulfur in the fuel, a very small fraction of which may be converted to sulfuric acid aerosol, and from soot and certain semi-volatile organic compounds that may be both generated and consumed during the combustion process under some conditions. Mineral matter and ash that contribute to particulate emissions from coal- and oil-fired combustion sources are absent from natural gas fuels. Substantially all of the primary particles emitted from gas-fired external combustion sources are expected to be equal to or smaller than 2.5 micrometers aerodynamic diameter ($PM_{2.5}$) because they form via nucleation and condensation of vapors as the gases cool in the process and atmosphere.

At 40 CFR 51, §51.50, U.S. EPA defines primary particles as follows: "Particulate Matter (PM). Particulate matter is a criteria air pollutant. For the purpose of this subpart, the following definitions apply:

(1) Filterable $PM_{2.5}$ or Filterable PM_{10}: Particles that are directly emitted by a source as a solid or liquid at stack or release conditions and captured on the filter of a stack test train. Filterable $PM_{2.5}$ is particulate matter with an aerodynamic diameter equal to or less than 2.5 micrometers. Filterable PM_{10} is particulate matter with an aerodynamic diameter equal to or less than 10 micrometers.

(2) Condensable PM: Material that is vapor phase at stack conditions, but which condenses and/or reacts upon cooling and dilution in the ambient air to form solid or liquid PM immediately after discharge from the stack. Note that all condensable PM, if present from a source, is typically in the $PM_{2.5}$ size fraction, and therefore all of it is a component of both primary $PM_{2.5}$ and primary PM_{10}.

(3) Primary $PM_{2.5}$: The sum of filterable $PM_{2.5}$ and condensable PM.

(4) Primary PM_{10}: The sum of filterable PM_{10} and condensable PM."

PM EMISSIONS TEST METHODS

Because EPA defines primary particles in terms of material collected in a stack test train, it's important to consider the test methods upon which PM emission factors are based. Filterable PM and condensable PM are defined entirely by the test methods used to measure them. There are two types of test methods for particulate matter considered here:

- Hot filter/iced impinger methods; and
- Dilution methods.

Hot Filter/Iced Impinger Methods

These methods draw a stack gas sample through a heated filter and then through a series of iced impingers to cool the sample and collect condensed vapors. The material on the filter and upstream is termed filterable or "front half" PM and the material in the impingers is termed condensable or "back half" PM. The amount of material collected is determined by weighing (gravimetrically). EPA first promulgated Method 5 for measuring PM emissions from stationary sources in 1977 (USEPA, 1977; 40 CFR 60, Appendix A). EPA Method 5 determines total PM collected in a sampling probe and on a heated filter and, optionally, in iced impingers placed downstream of the filter. In the impingers, the filtered sample gas bubbles through chilled water to cool the gas to 20°C or lower, causing certain constituents with dew points above this temperature, such as sulfuric acid, to condense and become captured in the impinger liquid. The liquid solutions optionally may be evaporated and dried, and the mass of the dried residue determined gravimetrically to determine condensable PM. Prior to passage of PM_{10} ambient air quality standards in 1986, few states and regions required measurements of condensable PM because it was considered an insignificant part of total particulate emissions.

In 1991, with the advent of PM_{10} ambient air quality standards, EPA promulgated Method 202 for determining condensable particulate matter (USEPA, 1991), in part because it recognized that condensable PM would comprise a more significant fraction of PM_{10} than total PM. The method specified similar iced impinger equipment as used in Method 5, with the addition of an optional filter (seldom used), and specified a different procedure for analyzing the sample which defined organic and inorganic condensable PM fractions by first extracting the liquid impinger sample with a solvent. The method also allowed a variety of options intended to capture various state and local regulatory agency practices. During Method 202 development, EPA observed interferences from sulfur dioxide gas (SO_2) and volatile organic compounds, and the method specifies an optional post-test purge of the sampling train to minimize these interferences (DeWees et al., 1989, 1990). Others subsequently reported significant positive bias in Method 202 results from SO_2 when testing coal fired power plants (Filadelfia et al., 1996) and cement plants (Holder et al., 2001).

In 2010, EPA revised its test methods for PM_{10} to add filterable $PM_{2.5}$ capability to Method 201A and revise Method 202 substantially (USEPA, 2010; 40 CFR 51, Appendix M). The revised

Method 202 adds a condenser coil and a filter to the condensable sampling equipment, and the impingers are initially dry rather than charged with water. The modifications were made to minimize gas-liquid contacting thought to be a cause of positive measurement bias. Results with the revised Method 202 for gas-fired combined cycle plants have been varied and, while it shows promise of producing more accurate results, the variability of results remains large relative to the measured concentrations (Brooks et al., 2012; Haywood et al., 2012).

Dilution Test Methods

Dilution methods cool hot exhaust gas samples by mixing the gas with filtered air, both cooling and diluting the gas, and collecting particles in the diluted sample on a filter. Dilution methods collect filterable and condensable PM together on the same filter, without distinguishing between them. Dilution methods also duplicate conditions under which particles form as they mix and cool in the atmosphere near the stack, producing test results that are consistent with EPA's definition of primary particles at 40 CFR 51, §51.50. Dilution test methods are the international standard for measuring particulate matter in mobile source engine tests and have been so for several decades (e.g., ISO 8178). Although dilution methods reproduce conditions that govern particle formation in the atmosphere near the stack much more accurately than hot filter/iced impinger methods, they have not been widely used for stationary sources because the equipment is considered too bulky to transport and/or too complex to operate under field conditions at stationary sources.

As support for new National Ambient Air Quality Standards for $PM_{2.5}$ grew in the 1990's, researchers began to develop and apply portable dilution samplers for characterizing fine particle emissions from stationary sources (e.g., Hildemann et al., 1989). Dilution samplers were used extensively in the 1990's and 2000's to characterize fine particles from a wide variety of sources, including detailed chemical and physical attributes (e.g., Chow et al., 2004). England and Loos (1999) reported results of tests on a gas-fired refinery process heater and a gas-fired refinery boiler showing much higher levels of particulate matter measured using EPA Methods 201A1/202 compared with simultaneous measurements using a research dilution method. The difference was attributed to the Method 201A/202 condensable PM results, which accounted for effectively all of the PM measurable by these methods and was comprised primarily of sulfate. Wien et al. (2001) reported results of laboratory experiments and field tests showing that 50-100 percent of the sulfate in condensable PM measured using Method 202 on gas-fired refinery boilers and process heaters could be attributed to sulfate formed in the measurement process during sample collection and storage prior to analysis caused by sulfur dioxide gas (SO_2) in the sample. SO_2 does not condense at atmospheric conditions and therefore does not contribute to primary (condensable) PM emissions. Such measurement artifacts are absent in dilution methods, thus providing an explanation for the large difference in PM emissions measured by the two methods. U.S. EPA subsequently developed a conditional test method for determining PM_{10} and $PM_{2.5}$ emissions from stationary sources by dilution sampling (USEPA, 2004), but this has not been widely applied and it lacks sufficient sensitivity for gas-fired sources (Matis et al., 2008; England et al., 2010).

$PM_{2.5}$ EMISSION FACTORS

U.S. EPA published emission factors for particulate matter from gas-fired external combustion sources in *Compilation of Emission Factors*, AP-42 (U.S. EPA, 1998a). The AP-42 emission factors are based on 21 tests of approximately 10 different units for filterable particulate matter and only 4 tests for condensable particulate matter of an unreported number of units (most likely one or two) performed between 1990 and 1995 (USEPA, 1998b). The AP-42 natural gas PM emission factors (as shown in Table 1a) indicate that 75 percent of total PM emissions are from condensable PM. Corio and Sherwell (2000) noted that condensable PM comprised 50-90 percent of total PM_{10} emissions in tests of several gas-fired sources and pointed out anomalies suggesting positive bias in Method 202 results. England et al. reported new $PM_{2.5}$ emission factors for gas-fired combustion sources based on results from tests of several gas-fired boilers, refinery process heaters, and other sources using a research dilution method (England et al, 2004a,b; England et al., 2007). The emission factors for natural gas-fired boilers and process heaters (Table 1c) are a factor of 22 to 84 lower than those published in AP-42. U.S. EPA used the results of these same tests to develop new, more accurate $PM_{2.5}$ emission factors for gas-fired sources that have been used in National Emission Inventories (NEIs) starting in 2004 and continuing to the 2011 NEI currently under development (U.S. EPA, 2012). The emission factors for PM_{10} and $PM_{2.5}$ given by EPA are a factor of 15 and 18, respectively, lower than those published in AP-42.

Although England and USEPA used the same test results, the emission factors are slightly different because of differences in approach. Yet, both derived $PM_{2.5}$ emission factors that are at least an order of magnitude lower than those given in AP-42. Because the overwhelming significance of condensable PM measurement artifacts for gas-fired sources was discovered subsequent to publication of PM emission factors in AP-42, emissions estimates based on AP-42 will be significantly higher than actual emissions. More recent tests using dilution methods that simulate conditions in the stack gas plume as it mixes with the atmosphere indicate that actual $PM_{2.5}$ emissions from natural gas combustion are substantially lower than AP-42 would predict. Because dilution methods are not affected by the artifacts inherent in hot filter/iced impinge methods, ENVIRON considers emission factors based on dilution methods to be more accurate. Therefore, ENVIRON recommends using EPA's NEI primary $PM_{2.5}$ emission factor for modeling the visibility impacts of AEPCO Alternative.

USE OF UPDATED $PM_{2.5}$ EMISSIONS FACTORS IN CALPUFF

A 0.00042 lb/MMBtu natural gas $PM_{2.5}$ emissions factor for ST2 in the AEPCO Alternative would correspond to a $PM_{2.5}$ emissions rate of 0.0209 lb/hr and 0.1160 gm/s using the maximum daily heat rate of 2192.583 MMBtu/hr for AEPCO Apache ST2. England and co-workers (2007) reported PM2.5 speciation profiles for gas-fired boilers using the dilution measurement technology of 61% OC, 13% EC, 6.9% SO_4 and the remainder (19.1%) as various elements. Note, this speciation profile is applicable only to PM emission factors derived from dilution methods. This results in the following PM2.5 emissions for CALPUFF modeling of the natural gas-fired St2 EGU in the AEPCO Alternative emissions scenario:

OC	=	0.07076 gm/s
EC	=	0.01508 gm/s
SO_4	=	0.00800 gm/s
Other $PM_{2.5}$	=	0.02216 gm/s

Table 1. Comparison of Particulate Emission Factors for Gas-Fired Boilers and Process Heaters.

(a) AP-42 PM Emission Factors for Gas-Fired External Combustion Sources (USEPA, 1998a).

	Average lb/MMBtu*	RSD %	Uncertainty %	95% CUB lb/MMBtu	# of tests
Filterable PM	0.0019	111	51	0.0026	21
Condensable PM	0.0056	70	111	0.010	4
Total PM	**0.0075**	131	122	0.011	

(b) PM Emission Factors for Gas-Fired Boilers for EPA 2011 National Emission Inventory (USEPA, 2012).

Source	Average lb/MMBtu*	RSD %	Uncertainty %	95% CUB lb/MMBtu	# of tests
Natural gas-fired boilers – Primary PM10	**0.00051**	--	--	--	†
Natural gas-fired boilers – Primary PM2.5	**0.00042**	--	--	--	†

(c) PM2.5 Emission Factors for Gas-Fired Boilers and Process Heaters (England, 2004).

Source	Average lb/MMBtu	RSD %	Uncertainty %	95% CUB lb/MMBtu	# of tests
Gas-fired boilers (see Table 2)	0.00034	66	46	0.00047	10
Gas-fired process heaters (see Table 3)	0.000089	100	104	0.00016	9
Gas-Fired boilers & process heaters**	**0.00022**	96	47	0.00031	19

*Emission factors were converted from lb/10^6 scf to lb/MMBtu by dividing by 1020, as noted in Table 1.4-2 of AP-42 (1998a)

**Calculated from results presented in Tables 3-1 and 3-2 of England, 2004.

†Number of tests used in EPA's emission factors was not reported.

RSD = relative standard deviation

Uncertainty = measurement uncertainty at the 95% confidence level (per ASME PTC 19.1)

95% CUB = 95% confidence upper bound

Table 2. Boiler PM2.5 Test Results by Dilution Method (reproduced from England, 2004, Table 3-1).

Source	Description	Units	Value
Site C (API, 2001c)	Natural Gas-fired Steam Generator	lb/MMBtu	1.7E-05
Site C (API, 2001c)	Natural Gas-fired Steam Generator	lb/MMBtu	5.6E-05
Site C (API, 2001c)	Natural Gas-fired Steam Generator	lb/MMBtu	9.6E-05
Site A (API, 2001a)	Refinery Gas-fired Boiler	lb/MMBtu	2.7E-04
Site A (API, 2001a)	Refinery Gas-fired Boiler	lb/MMBtu	3.8E-04
Site Delta (Wien et al., 2004c)	Dual Fuel-fired Institutional Boiler (Nat. Gas)	lb/MMBtu	3.8E-04
Site A (API, 2001a)	Refinery Gas-fired Boiler	lb/MMBtu	4.3E-04
Site Delta (Wien et al., 2004c)	Dual Fuel-fired Institutional Boiler (Nat. Gas)	lb/MMBtu	5.6E-04
Site Delta (Wien et al., 2004c)	Dual Fuel-fired Institutional Boiler (Nat. Gas)	lb/MMBtu	5.7E-04
Site Delta (Wien et al., 2004c)	Dual Fuel-fired Institutional Boiler (Nat. Gas)	lb/MMBtu	6.3E-04
Average (mean)		**lb/MMBtu**	**3.4E-04**
Uncertainty (at 95% Confidence Level), %		%	46
95% Confidence Upper Bound, lb/MMBtu		lb/MMBtu	4.7E-04
5th Percentile		lb/MMBtu	3.4E-05
95th Percentile		lb/MMBtu	6.0E-04

Table 3. Process Heater PM2.5 Test Results by Dilution Method (reproduced from England, 2004, Table 3-2).

Source	Description	Units	Value
Site Alpha (Wien et al., 2003)	Refinery Gas-fired Process Heater	lb/MMBtu	5.0E-05
Site Alpha (Wien et al., 2003)	Refinery Gas-fired Process Heater	lb/MMBtu	6.1E-05
Site Alpha (Wien et al., 2003)	Refinery Gas-fired Process Heater	lb/MMBtu	ND
Site Alpha (Wien et al., 2003)	Refinery Gas-fired Process Heater	lb/MMBtu	4.5E-05
Site B (API, 2001b)	Refinery Gas-fired Process Heater	lb/MMBtu	1.3E-04
Site B (API, 2001b)	Refinery Gas-fired Process Heater	lb/MMBtu	2.3E-05
Site B (API, 2001b)	Refinery Gas-fired Process Heater	lb/MMBtu	7.0E-06
Site Charlie (Wien et al., 2004b)	Natural Gas-fired Process Heater with SCR	lb/MMBtu	1.6E-04
Site Charlie (Wien et al., 2004b)	Natural Gas-fired Process Heater with SCR	lb/MMBtu	3.0E-04
Site Charlie (Wien et al., 2004b)	Natural Gas-fired Process Heater with SCR	lb/MMBtu	NV
Site Charlie (Wien et al., 2004b)	Natural Gas-fired Process Heater with SCR	lb/MMBtu	2.5E-05
Average		**lb/MMBtu**	**8.9E-05**
Uncertainty (at 95% Confidence Level), %		%	104
95% Confidence Upper Bound, lb/MMBtu		lb/MMBtu	1.6E-04
5th Percentile		lb/MMBtu	1.3E-05
95th Percentile		lb/MMBtu	2.4E-04

REFERENCES

API. 2001a. Gas-Fired Boiler – Test Report Site A: Characterization of Fine Particulate Emission Factors and Speciation Profiles from Stationary Petroleum Industry Combustion Sources, Publication No. 4703, American Petroleum Institute, Washington, D.C.

API. 2001b. Gas-Fired Heater – Test Report Site B: Characterization of Fine Particulate Emission Factors and Speciation Profiles from Stationary Petroleum Industry Combustion Sources, Publication No. 4704, American Petroleum Institute, Washington, D.C.

API. 2001c. Gas-Fired Steam Generator – Test Report Site C: Characterization of Fine Particulate Emission Factors and Speciation Profiles from Stationary Petroleum Industry Combustion Sources, Publication No. 4712, American Petroleum Institute, Washington, D.C.

Brooks, J., England, G.C., Hogan, J. and Ponder, T. 2012. Evaluation of New Methods for Determining Filterable and Condensable PM10/2.5 Emissions from Natural Gas-Fired Combined Cycle Power Plants, in proceedings of the 105th Annual Conference & Exhibition, Air & Waste Management Association, Pittsburgh, Pennsylvania.

Chow, J.C., J.G. Watson, H. Kuhns, V. Etyemezian, D.H. Lowenthal, D. Crow, S.D. Kohl, J.P. Engelbrecht, M.C. Green. 2004. Source Profiles for Industrial, Mobile, and Area Sources in the Big Bend Regional Aerosol Visibility and Observational Study, Chemosphere **54**:185–208.

Corio, L.A.; Sherwell, J. In-Stack Condensible Particulate Matter Measurements

and Issues; J. Air & Waste Manage. Assoc. 2000, 50:207-218.Dewees, W.G., Steinberger, S.C., Plummer, G.M., Lay, L.T., McAlister, G.D. and Shigehara, R.T. 1989. Laboratory and Field Evaluation of the EPA Method 5 Impinger Catch for Measuring Condensable Matter from Stationary Sources, in proceedings of the EPA/A&WMA Symposium on Measurement of Toxic and Related Air Pollutants, EPA Report No. 600/89-060, Air & Waste Management Association, Pittsburgh, Pennsylvania.

DeWees,W.G. and Steinsberger, K.C. 1990. Test Report: Method Development and Evaluation of Draft Protocol for Measurement of Condensible Particulate Emissions, EPA-450/4-90-012, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

England, G.C. and Loos, K.R. 1999. Tests for Fine Particulate Source Profiles and Emission Factors for Gas-Fired Combustion Equipment, in proceedings of the specialty conference on The Emission Inventory: Regional Strategies for the Future, Air & Waste Management Association, Pittsburgh, Pennsylvania..

England, G.C. 2004a. Development of Fine Particulate Emission Factors and Speciation Profiles for Oil and Gas-fired Combustion Systems, Final Report, New York State Energy Research and Development Authority, Albany, New York, New York. http://www.nyserda.ny.gov//sitecore/content/Home/Publications/Research-and-Development - Technical-Reports/Environmental-Reports/EMEP-Publications/EMEP-Final-Reports.aspx (accessed March 8, 2013).

England, G.C. 2004b. Development of Fine Particulate Emission Factors and Speciation Profiles for Oil and Gas-fired Combustion Systems, Final Report, California Energy Commissions, Sacramento, California. http://www.energy.ca.gov/pier/project_reports/CEC-500-2005-032_to_44.html (accessed March 8, 2013).

England, G.C., J.G. Watson, J.C. Chow, B. Zielinska, M-C. O. Chang, K. Loos, and G.M. Hidy. 2007. Dilution-Based Emissions Sampling from Stationary Sources: Part 2. Gas-fired Combustors Compared with Other Fuel-fired Systems, J. Air & Waste Manage. Assoc., **57**:79-93.

England, G.C. and Brooks, J. 2010. Estimated PM10 Emission Quantitation Limits using Traditional and Dilution Methods at a Gas-Fired Combined Cycle Plant, in proceedings of the Symposium on Air Quality Measurement Methods and Technology, Air & Waste Management Association, Pittsburgh, Pennsylvania.

Filadelfia, E. J. and McDannel, M. D. 1996. Evaluation of False Positive Interferences Associated with the Use of EPA Method 202, in proceedings of the 89th Annual Meeting and Exhibition, Air and Waste Management Association, Pittsburgh, Pennsylvania.

Haywood, J.M., Kagolanu, R., Mahew, W. and Liang, K. 2012. Revised USEPA Particulate Matter Testing Methodology Evaluated on a Gas Turbine, in proceedings of the 105th Annual Conference & Exhibition, Air & Waste Management Association, Pittsburgh, Pennsylvania.

Hildemann, L.M., Cass, G.R. and Markowski, G.R. 1989. A dilution stack sampler for organic aerosol emissions: Design, characterization, and field tests. Aerosol Sci. and Technol. **10**:193-204.

Holder, T.E., Goshaw, D.G. and Richards, J.R. 2001. Artifact Formation in Method 202 Sampling Trains Used to Measure Condensible Particulate Matter Emissions from Portland Cement Kilns, in proceedings of the 94th Annual Conference & Exhibition, Air & Waste Management Association, Pittsburgh, Pennsylvania.

Matis, C., G.C. England, K. Crosby and G. Rubenstein. 2008. Field Demonstration of a Dilution-Based Particulate Measurement System, in proceedings of the Symposium on Air Quality Measurement Methods and Technology, Air & Waste Management Association, Pittsburgh, Pennsylvania.

USEPA. 1977. Federal Register, **42**:41754

USEPA. 1991. Federal Register, **56**:65433.

USEPA. 1998a. Section 1.4 – Natural Gas Combustion, in Compilation of Air Pollutant Emission Factors, 5th ed: EPA AP-42, United States Environmental Protection Agency, Research Triangle Park, North Carolina.

USEPA. 1998b. Emission Factor Documentation for AP-42 Section 1.4 Natural Gas Combustion, Compilation of Air Pollutant Emission Factors, 5th ed: EPA AP-42, United States Environmental Protection Agency, Research Triangle Park, North Carolina.

USEPA. 2004. Conditional Test Method 39: Measurement of PM2.5 and PM10 Emissions by Dilution Sampling (Constant Sampling Rate Procedures), Revised 7/04, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. http://www.epa.gov/ttn/emc/ctm.html (accessed March 8, 2013)

USEPA. 2010. Methods for Measurement of Filterable PM10 and PM2.5 and Measurement of Condensable PM Emissions From Stationary Sources, Federal Register, **75**:244 80118.

USEPA. 2012. PM Emission Factors for Natural Gas Combustion, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. http://www.epa.gov/ttn/chief/net/2011inventory.html (accessed March 8, 2013).

Wien, S., G.C. England, K.R. Loos, and K. Ritter. 2001. Investigation of Artifacts in Condensable Particulate Measurements for Stationary Combustion Sources, in proceedings of the 94th Annual Conference and Exhibition, Air & Waste Management Association, Pittsburgh, Pennsylvania.

Wien, S., England, G.C. and Chang, M.C. 2003. "Development of Fine Particulate Emission Factors and Speciation Profiles for Oil and Gas-fired Combustion Systems, Topical Report: Test Results for a Gas-Fired Process Heater (Site Alpha)," prepared for: U.S. Department of Energy, National Energy Technology Laboratory, Pittsburgh, PA; Gas Research Institute, Des Plaines, Illinois; and American Petroleum Institute, Washington, D.C. http://www.nyserda.ny.gov//sitecore/content/Home/Publications/Research-and-Development-Technical-Reports/Environmental-Reports/EMEP-Publications/EMEP-Final-Reports.aspx (accessed March 8, 2013).

Wien, S., England, G.C. and Chang, M.C. 2004b. "Development of Fine Particulate Emission Factors and Speciation Profiles for Oil and Gas-fired Combustion Systems, Topical Report: Test Results for a Gas-Fired Process Heater with Selective Catalytic Reduction (Site Charlie)," prepared for: U.S. Department of Energy, National Energy Technology Laboratory, Pittsburgh, PA; Gas Research Institute, Des Plaines, Illinois; and American Petroleum Institute, Washington, D.C. http://www.nyserda.ny.gov//sitecore/content/Home/Publications/Research-and-Development-Technical-Reports/Environmental-Reports/EMEP-Publications/EMEP-Final-Reports.aspx (accessed March 8, 2013).

Wien, S., England, G.C. and Chang, M.C. 2004c. "Development of Fine Particulate Emission Factors and Speciation Profiles for Oil and Gas-fired Combustion Systems, Topical Report: Test Results for Dual Fuel-Fired Commercial Boiler at Site Delta," prepared for: U.S. Department of Energy, National Energy Technology Laboratory, Pittsburgh, PA; Gas Research Institute, Des Plaines, Illinois; and American Petroleum Institute, Washington, D.C. http://www.nyserda.ny.gov//sitecore/content/Home/Publications/Research-and-Development-Technical-Reports/Environmental-Reports/EMEP-Publications/EMEP-Final-Reports.aspx (accessed March 8, 2013).

POWDER RIVER BASIN RESOURCE COUNCIL
* GREATER YELLOWSTONE COALITION * WILDEARTH GUARDIANS *
SIERRA CLUB * NATIONAL PARKS CONSERVATION ASSOCIATION

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Re: Docket ID No. EPA–R08–OAR–2012–0026, *revised* supplemental comments on EPA Proposed Approval, Disapproval, and Promulgation of Implementation Plans; State of Wyoming; Regional Haze State Implementation Plan; Federal Implementation Plan for Regional Haze.

Dear Mr. Daly:

On behalf of Powder River Basin Resource Council, Greater Yellowstone Coalition, Sierra Club, National Parks Conservation Association, and WildEarth Guardians (collectively referred to herein as the "Conservation Organizations") we respectfully submit these supplemental comments on EPA's proposed rule regarding the State of Wyoming Section 308 Regional Haze Implementation Plan published in the Federal Register on June 4, 2012 (77 Fed. Reg. 33022) ("Wyoming 308 RH SIP"). These comments: 1) alert EPA to the availability of new information regarding the potential cost of installing SCR on PacifiCorp's Wyoming plants; 2) respond to PacifiCorp's recent supplemental comments dated September 13, 2012; and, 3) formally submit "EPA Documentation of the Evaluation of CALPUFF and Other Long Range Transport Models Using Tracer Field Experiment Data," at 10 (May 2012)[1] ("EPA CALPUFF 2012 Evaluation") into the record for consideration. On August 2, 2012 we submitted separate written comments on EPA's Wyoming 308 RH SIP, which are incorporated herein by reference.

I. PacifiCorp Will Benefit From Economies of Scale When Installing SCR on Multiple Units

EPA's proposed action on the Wyoming 308 RH SIP requested comments on whether to require installation of BART controls on Jim Bridger Units 1 & 2 by 2021-2022 rather than within the legally required 5-year timeframe mandated by the regional haze regulations. 77 Fed. Reg. at 33054. EPA is taking comment on the alternative timeline for SCR installation in response to PacifiCorp's claim that "the schedule for installation of emission control devices envisioned in [EPA's BART proposal] would be excessively costly and would pose service interruption risks for electrical energy customers over a large part of the region." *Id.* Recent

[1] http://www.epa.gov/scram001/dispersion_prefrec.htm

admissions by a PacifiCorp official in a separate Wyoming Public Service Commission ("PSC") proceeding undermines PacifiCorp's arguments. This supplemental comment letter and the PacifiCorp's PSC testimony must be made part of EPA's record for decision-making because the testimony was submitted ***after*** EPA's August 2, 2012 comment deadline and it is of "central relevance" to EPA's consideration of alternative BART proposals for Jim Bridger Units 1 and 2. *See* 42 U.S.C. § 7607(d)(4)(B)(i) ("documents which become available after the proposed rule has been published and which the Administrator deems are of central relevance to the rulemaking shall be placed in the docket as soon as possible after their availability"); *see also Air Pollution Control Dist. of Jefferson County v. EPA*, 739 F.2d 1071, 1080-81 (6th Cir. 1984).

Mr. Chad A. Teply, Vice President of Resource Development and Construction of PacificCorp Energy of PacifiCorp recently submitted testimony before the Wyoming PSC regarding PacifiCorp's application for a Certificate of Public Convenience and Necessity to install SCR at Jim Bridger Units 3 & 4. In this testimony, PacifiCorp states:

> Initial capital costs are reduced by awarding and executing the EPC contract for two units at the same time. The savings include those from: (1) coordination and completion of the common urea to ammonia system in time to startup Unit 3, (2) shared engineering costs for nearly identical units and SCR systems, (3) shared structural support system design and erection staging effects, (4) shared project management, project support, and site supervision costs, (5) economy of scale benefits with fabricators and suppliers, (6) the EPC contractor is afforded the ability to maintain more consistent staffing levels by being enabled to shift labor resources between the units, (7) potential space conflicts are avoided if different contractors require concurrent access to critical work areas, (8) performance guarantee enforcement is uncompromised with a single-source of responsibility for all common systems, (9) benefits of the Unit 3 startup lessons learned can be incorporated, (10) engineering of the foundations for both units must be executed in the forced draft ("FD") fan bay alley early in the project to efficiently account for all required buried utility relocations, and (11) any forced unit outages can be utilized.

Teply Wyoming PSC testimony attached hereto as Exhibit 1, pages 8-9.

In summary, PacifiCorp argues that procurement and installation of multiple SCRs creates both a cost and time savings, not an increase. This fact is also true for installation of SCRs at Jim Bridger Units 1 and 2. This PacifiCorp admission is further proof that EPA should not permit PacifiCorp to delay installation of SCRs at Jim Bridger Units 1 & 2 and instead must require compliance within 5 years as is required by the BART regulations.

II. The D.C. Circuit Court of Appeals' Rejection of CSAPR is Irrelevant to EPA's Regional Haze Rulemaking for Wyoming.

PacifiCorp's letter to EPA dated September 13, 2012 misguidedly argues that the D.C. Circuit Court of Appeals decision in *EME Homer City Generation, L.P. v. Environmental*

Protection Agency, No. 11-1302, 2012 WL 3570721 (D.C. Cir. Aug. 21, 2012)[2], directs EPA to defer to the state of Wyoming in developing a regional haze plan. It does not.

EME Homer City Generation involved a challenge to the Cross-State Air Pollution Rule ("CSAPR"), which EPA promulgated to implement the Clean Air Act's "good neighbor" provision, a part of the Clean Air Act distinct from regional haze requirements. This provision prohibits states from polluting in "amounts which will … contribute" to a downwind state's nonattainment of ambient air quality standards. 42 U.S.C. § 7410(a)(2)(D)(i). The Court interpreted the good neighbor provision as only authorizing EPA to eliminate the "amount[]" of pollutants necessary to achieve attainment in downwind states; not more. 2012 WL 3570721, at * 10. The Court found that EPA exceeded its authority in promulgating CSAPR because the rule may result in greater emission reductions than necessary to achieve the good neighbor provision's end goal. *Id.* at *12-15. Further, the Court determined that EPA improperly imposed federal implementation plans to restrict power plant emissions under CSAPR without first giving states the opportunity to promulgate state implementation plans to meet these obligations. *Id.* at *15-16, 23.

The regional haze program differs from the Clean Air Act's good neighbor provision in fundamental ways that make the Court's rejection of CSAPR irrelevant to EPA's action on Wyoming's regional haze plan. First, the Clean Air Act's regional haze provisions establish a technology-based standard for eligible major sources, including PacifiCorp's coal-fired power plants in Wyoming. *See* 42 U.S.C. § 7491(b)(2)(A). To help achieve "reasonable progress" toward the national visibility goal, eligible sources must install the Best Available Retrofit Technology ("BART") for haze-causing pollutants. *Id.* BART is defined as:

> an emission limitation based on the degree of reduction achievable through the application of the ***best system*** of continuous emission reduction for each pollutant which is emitted by an existing stationary facility. The emission limitation must be established, on a case-by-case basis, taking into consideration the technology available, the costs of compliance, the energy and nonair quality (sic) environmental impacts of compliance, any pollution control equipment in use or in existence at the source, the remaining useful life of the source, and the degree of improvement in visibility which may reasonably be anticipated to result from the use of such technology.

40 C.F.R. § 51.301 (emphasis added). Unlike the Court's interpretation of the good neighbor provision, the BART definition establishes a floor for emissions reductions, but no ceiling. States must ensure that eligible sources install the best pollution control devices.

When a state plan fails to establish a program that meets Clean Air Act requirements, then EPA has an *obligation* to promulgate a federal implementation plan ("FIP"). 42 U.S.C. §§ 7410(a)(2)(J) & (c); *id.* § 7492(e)(2). Here, EPA acted within its statutory duty in proposing a partial FIP for Wyoming. EPA's role is not mere "rubber-stamping" of poor SIPs—EPA "has a duty to evaluate the adequacy of the existing SIP as a whole when approving SIP revisions." *Ass'n of Irritated Residents v. EPA*, 632 F.3d 584, 591 (9th Cir. 2011). A FIP "fill[s] all or a

[2] EPA has petitioned for rehearing of this case.

portion of a gap *or otherwise correct[s] all or a portion of an inadequacy in a State implementation plan*." 42 U.S.C. § 7602(y) (emphasis added). In proposing to reject many of Wyoming's inadequate BART determinations, and proposing a partial FIP, EPA is merely acting to fulfill its own regulatory obligations under the Act.

Second, it is entirely appropriate for EPA to promulgate a federal implementation plan at this time, rather than giving Wyoming even more time to fix an inadequate state plan that Wyoming has already had many years to develop. Wyoming's obligation to develop a plan that included BART controls for large sources of pollution first arose with the addition of the visibility requirements in Sections 169A and 169B of the Clean Air Act as part of the 1977 amendments to the Act. Within 24 months of August 1977, EPA was to develop BART guidelines that incorporated the definition of BART provided by Congress in the statute itself. EPA first issued BART guidelines in 1980.[3] In 2001, EPA proposed new guidelines for implementing the modified BART program that was established in 1999. After the D.C. Circuit Court of Appeals remanded the BART program for revisions, EPA issued a new set of proposed guidelines in 2004. Those very detailed guidelines were finalized in 2005. During this entire time, Wyoming failed to develop a SIP to satisfy BART requirements under 40 C.F.R. §§ 51.308 and 51.309(g). Finally, decades after Wyoming's regional haze obligations were triggered, EPA finally made a formal finding that Wyoming had failed to submit all of the required regional haze SIP elements set forth at 40 C.F.R. §§ 51.308 and 51.309 on January 15, 2009. 74 Fed. Reg. 2392, 2393 (Jan. 15, 2009). Section 110(c) of the Clean Air Act, 42 U.S.C. § 7410(c), requires the EPA Administrator to promulgate a federal implementation plan ("FIP") within two years of a finding that a state has failed to make a required state implementation plan ("SIP") submittal.

As of January 15, 2009, Wyoming still had two years during which it could comply with its long-existing obligation but even then, it failed to produce a plan that complied with the plain requirements of the law. The two-year clock ran out nearly two years ago giving Wyoming more time than the law warranted, and still it produced no adequate, legally compliant plan. PacifiCorp is wrong that EPA needs to give Wyoming still more opportunities to satisfy regional haze requirements with a SIP. A plan that complies with the Clean Air Act is required; there is no obligation to give endless chances. Rather, it was Congress' plain intent, in compelling EPA to promulgate a FIP once a state had failed to develop an adequate SIP, to avoid interminable delay from multiple attempts at the same simply stated goal. *See Coal. for Clean Air v. S. Cal. Edison Co.*, 971 F.2d 219, 223 (9th Cir. 1992) (Congress "ultimately enacted… and signed into law" a "mandatory obligation [for EPA] to promulgate a FIP whenever it disapproves a SIP" through the 1990 Amendments to the Clean Air Act.). Any suggestion that states should be given endless "bites at the apple" is directly contrary to the law.[4]

Third, contrary to PacifiCorp's claim, Wyoming was not forced to take a "stab in the dark" in developing its state regional haze plan. In *EME Homer City Generation*, the Court

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[3] *See* http://yosemite1.epa.gov/ee/epa/ria.nsf/vwAN/A80-18.pdf/$file/A80-18.pdf.

[4] In any event, EPA's proposed rule states that, "In lieu of this proposed FIP, or a portion thereof, we propose approval of a SIP revision if the State submits such a revision and the revision matches the terms of our proposed FIP." 77 Fed. Reg. at 33022. Accordingly, EPA has given Wyoming the opportunity that PacifiCorp urges.

accepted the state petitioners' argument that they had no obligation to submit SIPs until after EPA defined each state's contribution to interstate pollution and the necessary emissions reductions to address that contribution. *EME Homer City Generation*, 2012 WL 3570721, at *18 ("[L]ogically, a SIP cannot be deemed to lack a required submission … until after EPA has defined the State's good neighbor obligation."; "There is no way for an upwind State to know its obligation … until EPA defines it."). Unlike the petitioners in *EME Homer City Generation*, PacifiCorp does not dispute that Wyoming's regional haze SIP and BART determinations were "required submission[s]." Furthermore, the states' regional haze obligations have been clearly defined. EPA issued "BART Guidelines" establishing detailed parameters for state BART determinations in 2005. 70 Fed. Reg. 39156 (July 6, 2005). Although PacifiCorp apparently believes that EPA deviated from these guidelines in its proposed Wyoming action, PacifiCorp's remedy is to challenge EPA's final regional haze plan for Wyoming as arbitrary and capricious. PacifiCorp's charge that EPA may never issue a federal implementation plan in such circumstances is incorrect.

Finally, while PacifiCorp complains that EPA has not given enough deference to Wyoming's regional haze proposal, EPA has in fact improperly proposed to accept many of Wyoming's proposed BART determinations for coal-fired power plants that do not actually reflect the best system of continuous emission reduction. For example, as described in the conservation organizations' comments dated August 2, 2012, EPA accepted Wyoming's determination that low- NO_X burners plus advanced overfire air reflects NO_X BART for PacifiCorp's Dave Johnston Unit 4, even though SCR satisfies the five elements of the BART considerations and is therefore the appropriate control. Likewise, EPA approved Wyoming's NO_X BART determination for PacifiCorp's Naughton Units 1 and 2 of low-NO_X burners plus overfire air while adequate analysis demonstrates that BART for those units should instead be based on SCR, which would achieve far greater emissions reductions at a reasonable cost and otherwise fit well within the framework of the other three BART factors. Further, with respect to haze-causing oil and gas activities that ought to be controlled under the state's long-term strategy, EPA arbitrarily accepted Wyoming's conclusion that additional NO_X controls are not warranted to achieve reasonable progress even after EPA rejected Wyoming's rationale for this conclusion. All of these are examples of EPA giving too much deference to Wyoming's flawed proposal, in violation of the Clean Air Act and EPA's regional haze regulations. PacifiCorp's contrary argument should be rejected.

For all of these reasons, PacifiCorp's complaints about EPA's proposed partial federal implementation plan for Wyoming based on the D.C. Circuit Court of Appeals decision are inaccurate and misguided. While there is no merit to these arguments, the undersigned conservation organizations submit these comments to clarify misconceptions advanced by PacifiCorp's arguments for the record.

III. EPA Must Model Visibility Impacts at Class I Areas Beyond 300 km

As the conservation organizations previously commented, EPA arbitrarily failed to model visibility impacts of the various control options at all affected Class I areas, including those that are beyond 300 km from the source. EPA recently responded to a similar comment in its final action promulgating the Montana Regional Haze Federal Implementation Plan, 77 Fed. Reg. 57864 (Sep. 18, 2012), for the first time supporting its truncated modeling by referencing a now-discredited 1998 report regarding CALPUFF performance. Because EPA raised this issue only after the close of the public comment period on its Wyoming regional haze action, EPA should consider the conservation organizations' response.[5] *See* 42 U.S.C. §7607(d)(4)(B)(i).

In its response to public comments on the Montana FIP, EPA stated, "The Interagency Workgroup on Air Quality Modeling (IWAQM) Phase 2 report (EPA, 1998) reviewed model performance evaluations of CALPUFF as a function of distance from the source and concluded that: …[u]se of CALPUFF for characterizing transport beyond 200 to 300 km should be done cautiously with an awareness of the likely problems involved." 77 Fed. Reg. at 57867-68. EPA then concludes, "[t]herefore, given that the IWAQM guidance provides for the use of the CALPUFF model at receptor distances of up to 200 to 300 km, and given that EPA has already addressed uncertainty in the CALPUFF model, we believe it is reasonable to use CALPUFF to evaluate visibility impacts up to 300 km." *Id.* at 57868.

We agree that CALPUFF is reliable at distances of 300 km. However, EPA's use of the IWAQM Phase 2 report to support its decision to exclude modeling at distances beyond 300 km, *id.* at 57868-69, is arbitrary. First, changes to CALPUFF since 1998 may correct problems identified in the IWAQM Phase 2 report with modeling accuracy in the 200-1,000 km range. Second, a more recent study prepared for EPA called into question the conclusions of the IWAQM Phase 2 report upon which EPA relies. *See* Long Range Transport Models Using Tracer Field Experiment Data (May 2012) (EPA Contract No: EP-D-07-102, Work Assignment No: 4-06), attached hereto as Exhibit 2.[6] The May 2012 study concluded that "The inability of most (~90%) of the current study's CALPUFF sensitivity tests to reproduce the 1998 EPA study tracer test residence time on the 600 km receptor arc is a cause for concern." *Id.* at 11. Not only were the authors of the May 2012 study unable to reproduce the 1998 study's findings that CALPUFF overestimated pollutant concentrations at distances of 600 km, the 2012 study concluded that CALPUFF actually *underestimates* average pollutant concentrations at 600 km. *Id.* at 10. Accordingly, reliance on CALPUFF at long distances would result in conservative estimates of visibility impacts. It is not appropriate to assume, as EPA effectively did in its Wyoming proposal, that such impacts are non-existent. EPA's failure to model and consider visibility impacts at all affected Class I areas, including those beyond 300 km, is not supported.

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[5] We believe that EPA's 2012 CALPUFF study is already part of the record in the Montana proceeding due to its publication on EPA's visibility modeling web site and reference to related studies in the final Montana FIP. However, we formally submit the 2012 study into the record for the Montana FIP and in all other states where the reliability of CALPUFF has been called into question.

[6] Also available on EPA's website at http://www.epa.gov/scram001/dispersion_prefrec.htm.

Because the Regional Haze Rule, and SIPs and FIPs promulgated to implement it, are to fulfill Clean Air Act requirements to mitigate and ultimately eliminate anthropogenic sources of haze pollution at all Class I national parks and wilderness areas, it is imperative that states and EPA use models to completely and accurately depict the visibility impact of a source to the region's Class I areas as well as projected benefits from BART. In this regard, the conclusion of the May 2012 study that CALPUFF reliably (if conservatively) identifies visibility impacts to Class I areas beyond those previously evaluated are critical, and directs EPA to supplement the incomplete analysis presented in its proposed action on the Wyoming regional haze plan with additional modeling, or consider the more complete modeling submitted by the conservation organizations with their August 2, 2012 comments. In so doing, EPA may comply with its legal obligations to fully analyze the reach of a source's impairment and accurately assess the BART and long-term strategy measures that are necessary to achieve the national goal of restoring natural visibility conditions at all Class I areas.

Should you have any questions, please do not hesitate to contact us.

Sincerely yours,

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Exhibit 2

Documentation of the Evaluation of CALPUFF and Other Long Range Transport Models Using Tracer Field Experiment Data

EPA-454/R-12-003
May 2012

Documentation of the Evaluation of CALPUFF and Other Long Range Transport Models Using Tracer Field Experiment Data

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Contract No. EP-D-07-102
Work Order No. 4
Task Order No. 06

U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Air Quality Assessment Division
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FOREWARD

This report documents the evaluation of the CALPUFF and other Long Range Transport (LRT) dispersion models using several inert tracer study field experiment data. The LRT dispersion modeling was performed primarily by the U.S. Environmental Protection Agency (EPA) during the 2008-2010 time period and builds off several previous LRT dispersion modeling studies that evaluated models using tracer study field experiments (EPA, 1986; 1998a; Irwin, 1997). The work was performed primarily by Mr. Bret Anderson while he was with EPA Region VII, EPA/OAQPS and the United States Forest Service (USFS). Mr. Roger Brode and Mr. John Irwin (retired) of the EPA Office of Air Quality Planning and Standards (OAQPS) also assisted in the LRT model evaluation. The LRT modeling results were provided to ENVIRON International Corporation who quality assured and documented the results in this report under Task 4 of Work Assignment No. 4-06 of EPA Contract EP-D-07-102. The report was prepared for the Air Quality Modeling Group (AQMG) at EPA/OAQPS that is led by Mr. Tyler Fox. Dr. Sarav Arunachalam from the University Of North Carolina (UNC) Institute for Environment was the Work Assignment Manager (WAM) for the prime contractor to EPA. The report was prepared by Ralph Morris, Kyle Heitkamp and Lynsey Parker of ENVIRON.

Numerous people provided assistance and guidance to EPA in the data collection, operation and evaluation of the LRT dispersion models. We would like to acknowledge assistance from the following people:

- AJ Deng (Penn State University) – MM5SCIPUFF
- Doug Henn and Ian Sykes (Sage) – SCIPUFF guidance
- Roland Draxler (NOAA ARL) - HYSPLIT
- Petra Siebert (University of Natural Resources – Vienna), Andreas Stohl (NILU) – FLEXPART
- Joseph Scire and Dave Strimaitis (Exponent) – CAPTEX meteorological observations and puff-splitting sensitivity tests guidance
- Mesoscale Model Interface (MMIF) Development Team:
  - EPA OAQPS; EPA Region 7, EPA Region 10; US Department of Interior (USDOI) Fish & Wildlife Service Branch of Air Quality, USDOI National Park Service Air Division and US Department of Agriculture (USDA) Forest Service Air Resources Management Program

Contents

Appendices

EXECUTIVE SUMMARY

ABSTRACT

The CALPUFF Long Range Transport (LRT) air quality dispersion modeling system is evaluated against several atmospheric tracer field experiments. Meteorological inputs for CALPUFF were generated using MM5 prognostic meteorological model processed using the CALMET diagnostic wind model with and without meteorological observations. CALPUFF meteorological inputs were also generated using the Mesoscale Model Interface (MMIF) tool that performs a direct "pass through" of the MM5 meteorological variables to CALPUFF without any adjustments or re-diagnosing of meteorological variables, as is done by CALMET. The effects of alternative options in CALMET on the CALMET meteorological model performance and the performance of the CALPUFF LRT dispersion model for simulating observed atmospheric tracer concentrations was analyzed. The performance of CALPUFF was also compared against past CALPUFF evaluation studies using an earlier version of CALPUFF and some of the same tracer test field experiments as used in this study. In addition, up to five other LRT dispersion models were also evaluated against some of the tracer field experiments. CALPUFF and the other LRT models represent three distinct types of LRT dispersion models: Gaussian puff, particle and Eulerian photochemical grid models. Numerous sensitivity tests were conducted using CALPUFF and the other LRT models to elucidate the effects of alternative meteorological inputs on dispersion model performance for the tracer field studies, as well as to intercompare the performance of the different dispersion models.

INTRODUCTION

Near-Source and Far-Field Dispersion Models

Dispersion models, such as the Industrial Source Complex Short Term (ISCST) or American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) typically assume steady-state, horizontally homogeneous wind fields instantaneously over the entire modeling domain and are usually limited to distances of less than 50 kilometers from a source. However, dispersion model applications of distances of hundreds of kilometers from a source require other models or modeling systems. At these distances, the transport times are sufficiently long that the mean wind fields can no longer be considered steady-state or homogeneous. As part of the Prevention of Significant Deterioration (PSD) program, new sources or proposed modifications to existing sources may be required to assess the air quality and Air Quality Related Value (AQRV) impacts at Class I and sensitive Class II areas that may be far away from the source (e.g., > 50 km). AQRVs include visibility and acid (sulfur and nitrogen) deposition. At these far downwind distances, the steady-state Gaussian plume assumptions of models like ISCST and AERMOD are likely not valid and Long Range Transport (LRT) dispersion models are required.

The Interagency Workgroup on Air Quality Modeling (IWAQM) consists of the U.S. EPA and Federal Land Managers (FLMs; i.e., NPS, USFS and FWS) and was formed to provide a focus for the development of technically sound recommendations regarding assessment of air pollutant source impacts on Federal Class I areas. One objective of the IWAQM is the recommendation of LRT dispersion models for assessing air quality and AQRVs at Class I areas. One such LRT dispersion model is the CALPUFF Gaussian puff modeling system, which includes the CALMET diagnostic wind model and the CALPOST post-processor. In 1998, EPA published a report that evaluated CALPUFF against two short-term tracer test field experiments (EPA, 1998a). Later in 1998 IWAQM released their Phase II recommendations (EPA, 1998b) that included

recommendations for using the CALPUFF LRT dispersion model for addressing far-field air quality and AQRV issues at Class I areas. The IWAQM Phase II report did not recommend any specific settings for running CALMET and noted that the required expert judgment to develop a set of recommended CALMET settings would be developed over time.

In 2003, EPA issued revisions to the Guidelines on Air Quality Models (Appendix W) that recommended using the CALPUFF LRT dispersion model to address far-field (> 50 km) air quality issues associated with chemically inert compounds. The EPA Air Quality Modeling Guidelines were revised again in 2005 to include AERMOD as the EPA-recommended dispersion model for near-source (< 50 km) air quality issues.

CALPUFF Modeling Guidance

EPA convened a CALPUFF workgroup starting in 2005 to help identify issues with the 1998 IWAQM Phase II recommendations. The CALPUFF workgroup began to revisit the evaluation of CALPUFF against tracer test field experiments. In May 2009, EPA released a reassessment of the IWAQM Phase II recommendations (EPA, 2009a) that raised issues with settings used in recent CALMET model applications. CALMET is typically applied using prognostic meteorological model (i.e., MM5 or WRF) three-dimensional wind fields as an input first guess and then applying diagnostic wind effects (e.g., blocking, deflection, channeling and slope flows) to produce a STEP1 wind field. CALMET then blends in surface and upper-air meteorological observations into the STEP1 wind field using an objective analysis (OA) procedure to produce the resultant STEP2 to wind field that is provided as input into CALPUFF. CALMET also diagnoses several other meteorological variables (e.g., mixing heights). CALMET contains numerous options that can significantly affect the resultant meteorological fields. The EPA IWAQM reassessment report found that the CALMET STEP1 diagnostic effects and STEP2 OA procedures can degrade the MM5/WRF wind fields. Furthermore, the IWAQM reassessment report noted that options used in some past CALMET applications were selected based on obtaining a desired outcome rather than based on good science. Consequently, the 2009 IWAQM reassessment recommended CALMET settings that would “pass through” MM5/WRF meteorological fields as much as possible for input into CALPUFF. However, further testing of CALMET by the EPA CALPUFF workgroup found that the recommended CALMET settings in the May 2009 IWAQM reassessment report did not achieve the intended desired result to “pass through” as much as possible the MM5/WRF meteorological variables as CALMET still re-diagnosed some and modified other meteorological variables. Based in part on testing by the CALPUFF workgroup using the tracer test field experiments, on August 31, 2009 EPA released a Clarification Memorandum (EPA, 2009b) that contained specific EPA-FLM recommended settings for operating CALMET for regulatory applications.

Mesoscale Model Interface (MMIF) Tool

In the meantime, EPA has developed the Mesoscale Model Interface (MMIF) tool that will “pass through” as much as possible the MM5/WRF meteorological output to CALPUFF without modifying the meteorological fields (Emery and Brashers, 2009; Brashers and Emery 2011; 2012). The CALPUFF Workgroup has been evaluating the CALPUFF model using the CALMET and MMIF meteorological drivers for four tracer test field experiments. For some of the field experiments, additional LRT dispersion models have also been evaluated. This report documents the work performed by the CALPUFF workgroup over the 2009-2011 time frame to evaluate CALPUFF and other LRT dispersion models using four tracer test field experiment databases.

OVERVIEW OF APPROACH

Up to six LRT dispersion models were evaluated using four atmospheric tracer test field experiments.

Tracer Test Field Experiments

LRT dispersion models are evaluated using four atmospheric tracer test field studies as follows:

1980 Great Plains: The 1980 Great Plains (GP80) field study released several tracers from a site near Norman, Oklahoma in July 1980 and measured the tracers at two arcs to the northeast at distances of 100 and 600 km (Ferber et al., 1981).

1975 Savannah River Laboratory: The 1975 Savannah River Laboratory (SRL75) study released tracers from the SRL in South Carolina and measured them at receptors approximately 100 km from the release point (DOE, 1978).

1983 Cross Appalachian Tracer Experiment: The 1983 Cross Appalachian Tracer Experiment (CAPTEX) was a series of five three-hour tracer released from Dayton, OH or Sudbury, Canada during September and October, 1983. Sampling was made in a series of arcs approximately 100 km apart that spanned from 300 to 1,100 km from the Dayton, OH release site.

1994 European Tracer Experiment: The 1994 European Tracer Experiment (ETEX) consisted of two tracer releases from northwest France in October and November 1994 that was measured at 168 monitoring sites in 17 countries.

LRT Dispersion Models Evaluated

The six LRT dispersion models that were evaluated using the tracer test field study data in this study were:

CALPUFF[1]: The California Puff (CALPUFF Version 5.8; Scire et al, 2000b) model is a Lagrangian Gaussian puff model that simulates a continuous plume using overlapping circular puffs. CALPUFF was applied using both the CALMET meteorological processor (Scire et al., 2000a) that includes a diagnostic wind model (DWM) and the Mesoscale Model Interface (MMIF; Emery and Brashers, 2009; Brashers and Emery, 2011; 2012) tool that will "pass through" output from the MM5 or WRF prognostic meteorological models.

SCIPUFF[2]: The Second-order Closure Integrated PUFF (SCIPUFF Version 2.303; Sykes et al., 1998) is a Lagrangian puff dispersion model that uses Gaussian puffs to represent an arbitrary, three-dimensional time-dependent concentration field. The diffusion parameterization is based on turbulence closure theory, which gives a prediction of the dispersion rate in terms of the measurable turbulent velocity statistics of the wind field.

HYSPLIT[3]: The Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT Version 4.8; Draxler, 1997) is a complete system for computing simple air parcel trajectories to complex dispersion and deposition simulations. The dispersion of a pollutant is calculated by assuming either puff or particle dispersion. HYSPLIT was applied primarily in the default particle model where a fixed number of particles are advected about the model domain by the mean wind field and spread by a turbulent component.

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1 http://www.src.com/calpuff/calpuff1.htm
2 http://www.sage-mgt.net/services/modeling-and-simulation/scipuff-dispersion-model
3 http://www.arl.noaa.gov/HYSPLIT_info.php

FLEXPART[4]: The FLEXPART (Version 6.2; Siebert, 2006; Stohl et al., 2005[5]) model is a Lagrangian particle dispersion model. FLEXPART was originally designed for calculating the long-range and mesoscale dispersion of air pollutants from point sources, such as after an accident in a nuclear power plant. In the meantime FLEXPART has evolved into a comprehensive tool for atmospheric transport modeling and analysis

CAMx[6]: The Comprehensive Air-quality Model with extensions (CAMx; ENVIRON, 2010) is a photochemical grid model (PGM) that simulates inert or chemical reactive pollutants from the local to continental scale. As a grid model, it simulates transport and dispersion using finite difference techniques on a three-dimensional array of grid cells.

CALGRID: The California Mesoscale Photochemical Grid Model (Yamartino, et al., 1989, Scire et al., 1989; Earth Tech, 2005) is a PGM that simulates chemically reactive pollutants from the local to regional scale. CALGRID was originally designed to utilize meteorological fields produced by the CALMET meteorological processor (Scire et al., 2000a), but was updated in 2006 to utilize meteorology and emissions in UAM format (Earth Tech, 2006).

The six LRT dispersion models represent two non-steady-state Gaussian puff models (CALPUFF and SCIPUFF), two three-dimensional particle dispersion models (HYSPLIT and FLEXPART) and two three-dimensional photochemical grid models (CAMx and CALGRID). HYSPLIT can also be run in a puff and hybrid particle/puff modes, which was investigated in sensitivity tests. All six LRT models were evaluated using the CAPTEX Release 3 and 5 field experiments and five of the six models (except CALGRID) were evaluated using the ETEX field experiment database.

Evaluation Methodology

Two different model performance evaluation methodologies were utilized in this study. The Irwin (1997) fitted Gaussian plume approach, as used in the EPA 1998 CALPUFF evaluation study (EPA, 1998a), was used for the same two tracer test field experiments used in the 1998 EPA study (i.e., GP80 and SRL75). This was done to elucidate how updates to CALPUFF model over the last decade have improved its performance. The second model evaluation approach adopts the spatial, temporal and global statistical evaluation framework of ATMES-II (Mosca et. al., 1998; Draxler et al., 1998). The ATMES-II uses statistical performance metrics of spatial, scatter, bias, correlation and cumulative distribution to describe model performance. An important finding of this study is that the fitted Gaussian plume model evaluation approach is very limited and can be a poor indicator of LRT dispersion model performance, with the ATMES-II approach providing a more comprehensive assessment of LRT model performance.

Fitted Gaussian Plume Evaluation Approach

The fitted Gaussian plume evaluation approach fits a Gaussian plume across the observed and predicted tracer concentrations along an arc of receptors at a specific downwind distance from the tracer release site. The approach focuses on a LRT dispersion model's ability to replicate centerline concentrations and plume widths, modeled/observed plume centerline azimuth, plume arrival time, and plume transit time across the arc. We used the fitted Gaussian plume evaluation approach to evaluate CALPUFF for the GP80 and SRL75 tracer experiments where the tracer concentrations were observed along arcs of receptors, as was done in the EPA 1998 CALPUFF evaluation study (EPA, 1998a).

4 http://transport.nilu.no/flexpart
5 http://www.atmos-chem-phys.net/5/2461/2005/acp-5-2461-2005.html
6 http://www.camx.com/

CALPUFF performance is evaluated by calculating the predicted and observed cross-wind integrated concentration (CWIC), azimuth of plume centerline, and the second moment of tracer concentration (lateral dispersion of the plume [σ_y]). The CWIC is calculated by trapezoidal integration across average monitor concentrations along the arc. By assuming a Gaussian distribution of concentrations along the arc, a fitted plume centerline concentration (Cmax) can be calculated by the following equation:

$$Cmax = CWIC/[(2\pi)^{1/2}\sigma_y]$$

The measure σ_y describes the extent of plume horizontal dispersion. This is important to understanding differences between the various dispersion options available in the CALPUFF modeling system. Additional measures for temporal analysis include plume arrival time and the plume transit time on arc. Table ES-1 summarizes the spatial, temporal and concentration statistical performance metrics used in the fitted Gaussian plume evaluation methodology.

Table ES-1. Model performance metrics used in the fitted Gaussian plume evaluation methodology from Irwin (1997) and 1998 EPA CALPUFF Evaluation (EPA, 1998a).

Statistics	Description
Spatial	
Azimuth of Plume Centerline	Comparison of the predicted angular displacement of the plume centerline from the observed plume centerline on the arc
Plume Sigma-y	Comparison of the predicted and observed fitted plume widths (i.e., dispersion rate)
Temporal	
Plume Arrival Time	Compare the time the predicted and observed tracer clouds arrives on the receptor arc
Transit Time on Arc	Compare the predicted and observed residence time on the receptor arc
Concentration	
Crosswind Integrated Concentration	Compares the predicted and observed average concentrations across the receptor arc
Observed/Calculated Maximum	Comparison of the predicted and observed fitted Gaussian plume centerline (maximum) concentrations (Cmax) and maximum concentration at any receptor along the arc (Omax)

Spatial, Temporal and Global Statistics Evaluation Approach

The model evaluation methodology as employed in ATMES-II (Mosca et al., 1998) and recommended by Draxler et al., (2002) was also used in this study. This approach defines three types of statistical analyses:

- Spatial Analysis: Concentrations at a fixed time are considered over the entire domain. Useful for determining differences spatial differences between predicted and observed concentrations.
- Temporal Analysis: Concentrations at a fixed location are considered for the entire analysis period. This can be useful for determining differences between the timing of predicted and observed tracer concentrations.
- Global Analysis: All concentration values at any time and location are considered in this analysis. The global analysis considers the distribution of the values (probability), overall tendency towards overestimation or underestimation of measured values (bias and error), measures of scatter in the predicted and observed concentrations and measures of correlation.

Table ES-2 defines the twelve ATMES-II spatial and global statistical metrics used in this study, some of the temporal statistics were also calculated but not reported. The RANK model performance statistic is designed to provide an overall score of model performance by combining performance metrics of correlation/scatter (R^2), bias (FB), spatial (FMS) and cumulative distribution (KS). Its use as an overall indication of the rankings of model performance for different models was evaluated and found that it usually was a good indication, but there were some cases where it could lead to misleading results and is not a substitute for examining all performance attributes.

Table ES-2. ATMES-II spatial and global statistical metrics.

Statistical Metric	Definition	Perfect Score
Spatial Statistics		
Figure of Merit in Space (FMS)	$FMS = \frac{A_M \cap A_P}{A_M \cup A_P} \times 100\%$	100%
False Alarm Rate (FAR)	$FAR = \left(\frac{a}{a+b}\right) \times 100\%$	0%
Probability of Detection (POD)	$POD = \left(\frac{b}{b+d}\right) \times 100\%$	100%
Threat Score (TS)	$TS = \left(\frac{b}{a+b+d}\right) \times 100\%$	100%
where,	• "a" represents the number of times a condition that has been forecast, but was not observed (false alarm) • "b" represents the number of times the condition was correctly forecasted (hits) • "c" represents the number of times the nonoccurrence of the condition is correctly forecasted (correct negative); and • "d" represents the number of times that the condition was observed but not forecasted (miss).	
Global Statistics		
Factor of Exceedance (FOEX)	$FOEX = \left[\frac{N_{(P_i > Ni_i)}}{N} - 0.5\right] \times 100\%$	0%
Factor of α (FA2 and FA5)	$FA\alpha = \left[\frac{N(y - y0 = [x - x0]\alpha)}{N}\right] \times 100$	100%
Normalized Mean Squared Error (NMSE)	$NMSE = \frac{1}{N\overline{P}\overline{M}} \sum (P_i - M_i)^2$	0%
Pearson's Correlation Coefficient (PCC or R)	$R = \frac{\sum_i (M_i - \overline{M}) \bullet (P_i - \overline{P})}{\left[\sqrt{\sum (M_i - \overline{M})^2}\right]\left[\sqrt{\sum (P_i - \overline{P})^2}\right]}$	1.0
Fraction Bias (FB)	$FB = 2\overline{B} / (\overline{P} + \overline{M})$	0%
Kolmogorov-Smirnov (KS) Parameter	$KS = Max\lvert C(M_k) - C(P_k)\rvert$	0%
RANK	$RANK = \lvert R^2 \rvert + (1 - \lvert FB/2 \rvert) + FMS/100 + (1 - KS/100)$	4.0

MODEL PERFORMANCE EVALUATION OF LRT DISPERSION MODELS

The CALPUFF LRT dispersion model was evaluated using four tracer test field study experiments. Up to five additional LRT models were also evaluated using some of the field experiments.

1980 Great Plains (GP80) Field Experiment

The CALPUFF LRT dispersion model was evaluated against the GP80 July 8, 1980 GP80 tracer release from Norman, Oklahoma. The tracer was measured at two receptor arcs located 100 km and 600 km downwind from the tracer release point. The fitted Gaussian plume approach was used to evaluate the CALPUFF model performance, which was the same approach used in the EPA 1998 CALPUFF evaluation study (EPA, 1998a). CALPUFF was evaluated separately for the 100 km and 600 km arc of receptors.

GP80 CALPUFF Sensitivity Tests

Several different configurations of CALMET and CALPUFF models were used in the evaluation that varied CALMET grid resolution, grid resolution of the MM5 meteorological model used as input to CALMET, and CALMET and CALPUFF model options, including:

- CALMET grid resolution of 4 and 10 km for 100 km and 4 and 20 km for 600 km receptor arc.
- MM5 output grid resolution of 12, 36 and 80 km, plus no MM5 data.
- Use of surface and upper-air meteorological data used as input to CALMET:
  - A = Use surface and upper-air observations;
  - B = Use surface but not upper-air observations; and
  - C = Use no meteorological observations.
- Three CALPUFF dispersion algorithms:
  - CAL = CALPUFF turbulence dispersion;
  - AER = AERMOD turbulence dispersion; and
  - PG = Pasquill-Gifford dispersion.
- MMIF meteorological inputs for CALPUFF using 12 and 36 km MM5 data.

The “BASEA” CALPUFF/CALMET configuration was designed to emulate the configuration used in the 1998 EPA CALPUFF evaluation study, which used only meteorological observations and no MM5 data in the CALMET modeling and ran the CALPUFF CAL and PG dispersion options. However, an investigation of the 1998 EPA evaluation study revealed that the slug near-field option was used in CALPUFF (MSLUG = 1). The slug option is designed to better simulate a continuous plume near the source and is a very non-standard option for CALPUFF LRT dispersion modeling. For the initial CALPUFF simulations, the slug option was used for the 100 km receptor arc, but not for the 600 km receptor arc. However, additional CALPUFF sensitivity tests were performed for the 600 km receptor arc that investigated the use of the slug option, as well as alternative puff splitting options.

Conclusions of GP80 CALPUFF Model Performance Results

For the 100 km receptor arc, there was a wide variation in CALPUFF model performance across the sensitivity tests. The results were consistent with the 1998 EPA study with the following key findings for the GP80 100 km receptor arc evaluation:

- CALPUFF tended to overstate the maximum observed concentrations and understate the plume widths at the 100 km receptor arc.
- The best performing CALPUFF configuration in terms of predicting the maximum observed concentrations and plume width was when CALMET was run with MM5 data and surface meteorological observations but no upper-air meteorological observations.
- The CALPUFF CAL and AER turbulence dispersion options produced nearly identical results and the performance of the CAL/AER turbulence versus PG dispersion options varied by model configuration and statistical performance metric.
- The performance of CALPUFF/MMIF in predicting plume maximum concentrations and plume widths was comparable or better than all of the CALPUFF/CALMET configurations, except when CALMET used MM5 data and surface but no upper-air meteorological observations.
- The modeled plume centerline tended to be offset from the observed centerline location by 0 to 14 degrees.
- Use of CALMET with just surface and upper-air meteorological observations produced the best CALPUFF plume centerline location performance, whereas use of just MM5 data with no meteorological observations, either through CALMET or MMIF, produced the worst plume centerline angular offset performance.
- Different CALMET configurations give the best CALPUFF performance for maximum observed concentration (with MM5 and just surface and no upper-air observations) versus location of the plume centerline (no MM5 and both surface and upper-air observations) along the 100 km receptor arc. For Class I area LRT dispersion modeling it is important for the model to estimate both the location and the magnitudes of concentrations.

The evaluation of the CALPUFF sensitivity tests for the 600 km arc of receptors included both plume arrival, departure and residence time analysis as well as fitted Gaussian plume statistics. The observed residence time of the tracer on the 600 km receptor arc was at least 12 hours. Note that due to the presence of an unexpected low-level jet, the tracer was observed at the 600 km receptor arc for the first sampling period. Thus, the observed 12 hour residence time is a lower bound (i.e., the observed tracer could have arrived before the first sampling period). The 1998 EPA CALPUFF evaluation study estimated tracer plume residence times of 14 and 13 hours, which compares favorably with the observed residence time (12 hours). However, the 1998 EPA study CALPUFF modeling had the tracer arriving at least 1 hour later and leaving 2-3 hours later than observed, probably due to the inability of CALMET to simulate the low-level jet.

Most (~90%) of the current study CALPUFF sensitivity tests underestimated the observed tracer residence time on the 600 km receptor arc by approximately a factor of two. The exception to this was: (1) the BASEA_PG CALPUFF/CALMET sensitivity test (12 hours) that used just meteorological observations in CALMET and the PG dispersion option in CALPUFF; and (2) the CALPUFF/CALMET EXP2C series of experiments (residence time of 11-13 hours) that used 36 km MM5 data and CALMET run at 4 km resolution with no meteorological observations (NOOBS = 2). The remainder of the 28 CALPUFF sensitivity tests had tracer residence time on the 600 km receptor arc of 4-8 hours; that is, almost 90% of the CALPUFF sensitivity tests failed to reproduce the good tracer residence time performance statistics from the 1998 EPA study.

For the 600 km receptor arc, the CALPUFF sensitivity test fitted Gaussian plume statistics were very different than the 100 km receptor arc as follows:

- The maximum observed concentration along the arc or observed fitted centerline plume concentration was underestimated by -42% to -72% and the plume widths overestimated by 47% to 293%.
- The CALPUFF underestimation bias of the observed maximum concentration tends to be improved using CALMET runs with no meteorological observations.
- The use of the PG dispersion option tends to exacerbate the plume width overestimation bias relative to using the CAL or AER turbulence dispersion option.
- The CALPUFF predicted plume centerline tends to be offset from the observed value by 9 to 20 degrees, with the largest centerline offset (> 15 degrees) occurring when no meteorological observations are used with either CALMET or MMIF .
- The 1998 CALPUFF runs overestimated the observed CWIC by 15% and 30% but the current study's BASEA configuration, which was designed to emulate the 1998 EPA study, underestimates the observed CWIC by -14% and -38%.

The inability of most (~90%) of the current study's CALPUFF sensitivity tests to reproduce the 1998 EPA study tracer test residence time on the 600 km receptor arc is a cause for concern. For example, the 1998 EPA study CALPUFF simulation using the CAL dispersion option estimates a tracer residence time on the 600 km receptor arc of 13 hours that compares favorably to what was observed (12 hours). However, the current study CALPUFF BASEA_CAL configuration, which was designed to emulate the 1998 EPA CALPUFF configuration, estimates a residence time of almost half of the 1998 EPA study (7 hours). One notable difference between the 1998 EPA and the current study CALPUFF modeling for the GP80 600 km receptor arc was the use of the slug option in the 1998 EPA study. Another notable difference was the ability of the current version of CALPUFF to perform puff splitting, which EPA has reported likely extends the downwind distance applicability of the CALPUFF model (EPA, 2003). Thus, a series of CALPUFF sensitivity tests were conducted using the BASEA_CAL CALPUFF/CALMET and MMIF_12KM CAL and PG CALPUFF/MMIF configurations that invoked the slug option and performed puff splitting. Two types of puff splitting were analyzed, default puff splitting (DPS) that turns on the vertical puff splitting flag once per day and all hours puff splitting (APS) that turns on the puff splitting flag for every hour of the day. The following are the key findings from the CALPUFF slug and puff splitting sensitivity tests for the GP80 600 km receptor arc:

- Use of puff splitting had no effect on the tracer test residence time (7 hours) in the CALPUFF/CALMET (BASEA_CAL) configuration.
- Use of the slug option with CALPUFF/CALMET increased the tracer residence time on the 600 km receptor arc from 7 to 15 hours, suggesting that the better performance of the 1998 EPA CALPUFF simulations on the 600 km receptor arc was due to invoking the slug option.
- On the other hand, the CALPUFF/MMIF sensitivity tests were more sensitivity to puff splitting than CALPUFF/CALMET with the tracer residence time increasing from 6 to 8 hours using DPS and to 17 hours using APS when the CAL dispersion option was specified.
- The use of the slug option on top of APS has very different effect on the CALPUFF/MMIF residence time along the 600 km receptor depending on which dispersion option is utilized, with slug reducing the residence time from 17 to 15 hours using the CAL and increasing the residence time from 11 to 20 hours using PG dispersion options.

- The best performing CALPUFF configuration from all of the sensitivity tests when looking at the performance across all of the fitted plume performance statistics was use of the slug option with puff splitting in CALPUFF/MMIF.

A key result of the GP80 600 km receptor arc evaluation was the need to invoke the near-source slug option to adequately reproduce the CALPUFF performance from the 1998 EPA CALPUFF evaluation study. Given that the slug option is a very nonstandard option for LRT dispersion modeling, this finding raises concern regarding the previous CALPUFF evaluation. Another important finding of the GP80 CALPUFF sensitivity tests is the wide variation in modeling results that can be obtained using the various options in CALMET and CALPUFF. This is not a desirable attribute for regulatory modeling and emphasizes the need for a standardized set of options for regulatory CALPUFF modeling.

1975 Savannah River Laboratory (SRL75) Field Experiment

The 1975 Savannah River Laboratory (SRL75) field experiment released a tracer on December 10, 1975 and measured it at receptors located approximately 100 km downwind from the tracer release site. The fitted Gaussian plume model evaluation approach was used to evaluate numerous CALPUFF sensitivity tests. Several CALMET sensitivity tests were run to provide meteorological inputs to CALPUFF that varied whether MM5 data was used or not and how meteorological observations were used (surface and upper-air, surface only or no observations). As in the GP80 sensitivity tests, three dispersion options were used in CALPUFF (CAL, AER and PG). In addition, CALPUFF/MMIF sensitivity tests were performed using MM5 output at 36, 12 and 4 km resolution.

Because of the long time integrated sampling period used in the SRL75 experiment, the plume arrival, departure and residence statistics were not available and only the fitted Gaussian plume statistics along the 100 km receptor arc were used in the evaluation. The key findings of the SRL75 CALPUFF evaluation are as follows:

- The maximum plume centerline concentrations from the fitted Gaussian plume to the observed tracer concentrations is approximately half the maximum observed tracer concentration at any monitor along the 100 km receptor arc. As a plume centerline concentration in a Gaussian plume represents the maximum concentration, this indicates that the fitted Gaussian plume is a very poor fit to the observations. Thus, the plume centerline and plume width statistics that depend on the fitted Gaussian plume are a poor indication of model performance for the SRL75 experiment. The observed fitted Gaussian plume statistics were taken from the 1998 EPA study (EPA, 1998a).
- Given that there are many more (~5 times) CALPUFF receptors along the 100 km receptor arc than monitoring sites where the tracer was observed, the predicted maximum concentration along the arc is expected to be greater than the observed maximum concentration. Such is the case with the CALPUFF/MMIF runs, but is not always the case for the CALMET/CALPUFF sensitivity tests using no MM5 data.
- The CALPUFF plume centerline is offset from the observed plume centerline by 8 to 20 degrees. The largest angular offset occurs (17-20 degrees) when CALMET is run with no MM5 data. When MM5 data is used with the surface and upper-air observations the CALPUFF angular offset is essentially unchanged (18-19 degrees) and the removal of the upper-air observations also has little effect on the plume centerline angular offset. However, when only MM5 data are used, in either in CALMET (11-12 degrees) or MMIF (9-10 degrees), the CALPUFF plume centerline offset is improved.

The main conclusion of the SRL75 CALPUFF evaluation is that the fitted Gaussian plume evaluation approach can be a poor and misleading indicator of LRT dispersion model performance. In fact, the whole concept of a well-defined Gaussian plume at far downwind distances (e.g., > 50 km) is questionable since wind variations and shear can destroy the Gaussian distribution. Thus, we recommend that future studies no longer use the fitted Gaussian plume evaluation methodology for evaluating LRT dispersion models and adopt alternate evaluation approaches that are free from a priori assumption regarding the distribution of the observed tracer concentrations.

Cross Appalachian Tracer Experiment (CAPTEX)

The Cross Appalachian Tracer Experiment (CAPTEX) performed five tracer releases from either Dayton, Ohio or Sudbury, Ontario with tracer concentrations measured at hundreds of monitoring sites deployed in the northeastern U.S. and southeastern Canada out to distances of 1000 km downwind of the release sites. Numerous CALPUFF sensitivity tests were performed for the third (CTEX3) and fifth (CTEX5) CAPTEX tracer releases from, respectively, Dayton and Sudbury. The performance of the six LRT models was also intercompared using the CTEX3 and CTEX5 field experiments.

<u>CAPTEX Meteorological Modeling</u>

MM5 meteorological modeling was conducted for the CTEX3 and CTEX5 periods using modeling approaches prevalent in the 1980's (e.g., one 80 km grid with 16 vertical layers) that was sequentially updated to use a more current MM5 modeling approach (e.g., 108/36/12/4 km nested grids with 43 vertical layers). The MM5 experiments also employed various levels of four dimensional data assimilation (FDDA) from none (i.e., forecast mode) to increasing aggressive use of FDDA.

CALMET sensitivity tests were conducted using 80, 36 and 12 km MM5 data as input and using CALMET grid resolutions of 18, 12 and 4 km. For each MM5 and CALMET grid resolution combination, additional CALMET sensitivity tests were performed to investigate the effects of different options for blending the meteorological observations into the CALMET STEP1 wind fields using the STEP2 objective analysis (OA) procedures to produce the wind field that is provided as input to CALPUFF:

- A – RMAX1/RMAX2 = 500/1000
- B – RMAX1/RMAX2 = 100/200
- C – RMAX1/RMAX2 = 10/100
- D – no meteorological observations (NOOBS = 2)

Wind fields estimated by the MM5 and CALMET CTEX3 and CTEX5 sensitivity tests were paired with surface wind observations in space and time, then aggregated by day and then aggregated over the modeling period. The surface wind comparison is not an independent evaluation since many of the surface wind observations in the evaluation database are also provided as input to CALMET. Since the CALMET STEP2 OA procedure is designed to make the CALMET winds at the monitoring sites better match the observed values, one would expect CALMET simulations using observations to perform better than those that do not. However, as EPA points out in their 2009 IWAQM reassessment report, CALMET's OA procedure can also produce discontinuities and artifacts in the wind fields resulting in a degradation of the wind fields even though they may match the observed winds better at the locations of the observations (EPA,

2009a). The key findings from the CTEX5 MM5 and CALMET meteorological evaluation are as follows:

- The MM5 wind speed, and especially wind direction, model performance is better when FDDA is used then when FDDA is not used.
- The "A" and "B" series of CALMET simulations produce wind fields least similar to the MM5 simulation used as input, which is not surprising since CALMET by design is modifying the winds at the location of the monitoring sites to better match the observations.
- CALMET tends to slow down the MM5 wind speeds even when there are no wind observations used as input (i.e., the "D" series).
- For this period and MM5 model configuration, the MM5 and CALMET wind model performance is better when 12 km grid resolution is used compared to coarser resolution.

CAPTEX CALPUFF Model Evaluation and Sensitivity Tests

The CALPUFF model was evaluated against tracer observations from the CTEX3 and CTEX5 field experiments using meteorological inputs from the various CALMET sensitivity tests described above as well as the MMIF tool applied using the 80, 36 and 12 km MM5 databases. The CALPUFF configuration was held fixed in all of these sensitivity tests so that the effects of the meteorological inputs on the CALPUFF tracer model performance could be clearly assessed. The CALPUFF default model options were assumed for most CALPUFF inputs. One exception was for puff splitting where more aggressive vertical puff splitting was allowed to occur throughout the day, rather than the default where vertical puff splitting is only allowed to occur once per day.

The ATMES-II statistical model evaluation approach was used to evaluate CALPUFF for the CAPTEX field experiments. Twelve separate statistical performance metrics were used to evaluate various aspects of the CALPUFF's ability to reproduce the observed tracer concentrations in the two CAPTEX experiments. Below we present the results of the RANK performance statistic that is a composite statistic that represents four aspects of model performance: correlation, bias, spatial and cumulative distribution. Our analysis of all twelve ATMES-II statistics has found that the RANK statistic usually provides a reasonable assessment of the overall performance of dispersion models tracer test evaluations. However, we have also found situations where the RANK statistic can provide misleading indications of the performance of dispersion models and recommend that all model performance attributes be examined to confirm that the RANK metric is providing a valid ranking of the dispersion model performance.

CTEX3 CALPUFF Model Evaluation

Figure ES-1 summarizes the RANK model performance statistics for the CALPUFF sensitivity simulations that used the 12 km MM5 data as input. Using a 4 km CALMET grid resolution, the EXP6B (RMAX1/RMAX2 = 100/200) has the lowest rank of the CALPUFF/CALMET sensitivity tests. Of the CALPUFF sensitivity tests using the 12 km MM5 data as input, the CALPUFF/MMIF (12KM_MMIF) sensitivity test has the highest RANK statistic (1.43) followed closely by EXP4A (1.40; 12 km CALMET and 500/1000), EXP6C (1.38; 4 km CALMET and 10/500) with the lowest

RANK statistic (1.22) exhibited by EXP4B (12 km CALMET and 100/200) and EXP6B (4 km CALMET and 100/200).

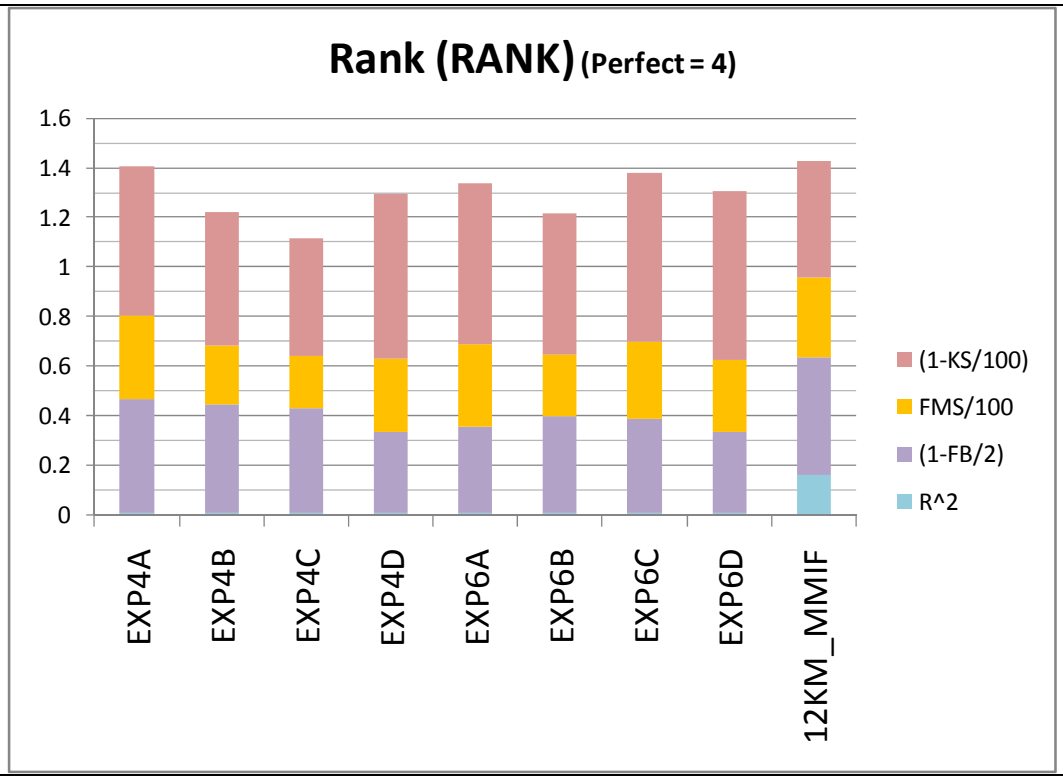


Figure ES-1. RANK performance statistics for CTEX3 CALPUFF sensitivity tests that used 12 km MM5 as input to CALMET or MMIF.

Figure ES-2 compares the RANK model performance statistics for "B" (RMAX1/RMAX2 = 100/200) and "D" (no observations) series of CALPUFF/CALMET sensitivity tests using different CALMET/MM5 grid resolutions of 18/80 (BASEB), 12/80 (EXP1), 12/36 (EXP3), 12/12 (EXP4) 4/36 (EXP5) and 4/12 (EXP6) along with the CALPUFF/MMIF runs using 36 and 12 km MM5 data. The CALPUFF/CALMET sensitivity tests using no observations ("D" series) generally have a higher rank metric than when meteorological observations are used with CALPUFF ("B" series). The CALMET/MMIF sensitivity test using 36 and 12 km MM5 data are the configurations with the highest RANK metric.The CALPUFF/MMIF show a strong relationship between observed and predicted winds than the CALPUFF/CALMET sensitivity tests, which had no to slightly negative correlations with the tracer observations.

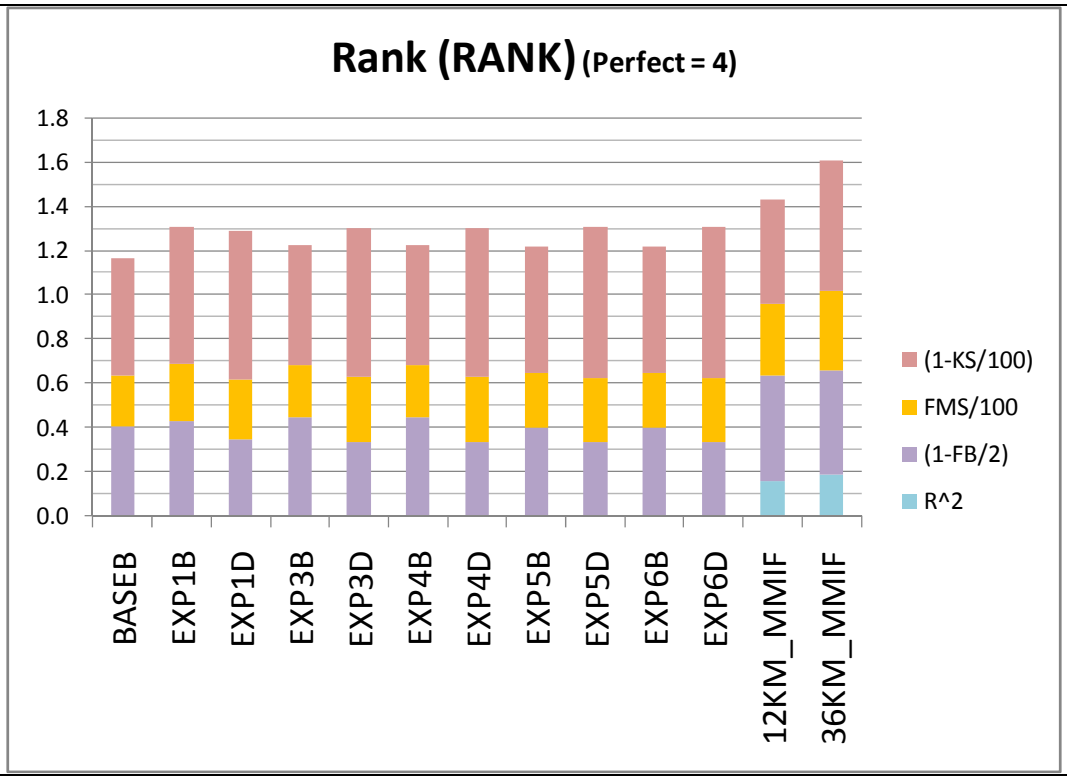


Figure ES-2. RANK performance statistics for CTEX3 CALPUFF sensitivity tests that used RMAX1/RMAX2 = 100/200 ("B" series) or no observations in CALMET ("D" series) and various CALMET/MM5 grid resolutions plus CALMET/MMIF using 36 and 12 km MM5 data.

Table ES-3 ranks all of the CALPUFF CTEX3 sensitivity tests using the RANK statistics. It is interesting to note that the EXP3A and EXP4A CALPUFF/CALMET sensitivity test that uses the, respectively, 36 km and 12 km MM5 data with 12 km CALMET grid resolution and RMAX1/RMAX2 values of 500/1000 have a rank metric that is third highest, but the same model configuration with alternative RMAX1/RMAX2 values of 10/100 (EXP3C and EXP4C) degrades the model performance of the CALPUFF configuration according to the RANK statistic, with a RANK value of 1.12. This is largely due to decreases in the FMS and KS metrics.

Note that the finding that CALPUFF/CALMET model performance using CALMET wind fields based on setting RMAX1/RMAX2 = 100/200 (i.e., the "B" series) produces worse CALPUFF model performance for simulating the observed atmospheric tracer concentrations is in contrast to the CALMET surface wind field comparison that found the "B" series most closely matched observations at surface meteorological stations. Since the CALPUFF tracer evaluation is an independent evaluation of the CALMET/CALPUFF modeling system, whereas the CALMET surface wind evaluation is not, the CALPUFF tracer evaluation may be a better indication of the best performing CALMET configuration. The CALMET "B" series approach for blending the wind observations in the wind fields may just be the best approach for getting the CALMET winds to match the observations at the monitoring sites, but possibly at the expense of degrading the wind fields away from the monitoring sites resulting in worse overall depiction of transport conditions.

Table ES-3. Final Rankings of CALPUFF CTEX3 Sensitivity Tests using the RANK model performance statistics.

Ranking	Sensitivity Test	RANK Statistics	MM5 (km)	CALGRID (km)	RMAX1/RMAX2	Met Obs
1	36KM_MMIF	1.610	36	--	--	--
2	12KM_MMIF	1.430	12	--	--	--
3	EXP3A	1.400	36	12	500/1000	Yes
4	EXP4A	1.400	12	12	500/1000	Yes
5	EXP5C	1.380	36	4	10/100	Yes
6	EXP6C	1.380	12	4	10/100	Yes
7	EXP1C	1.340	36	18	10/100	Yes
8	EXP5A	1.340	36	4	500/1000	Yes
9	EXP6A	1.340	12	4	500/1000	Yes
10	EXP5D	1.310	36	4	--	No
11	EXP6D	1.310	12	4	--	No
12	EXP1B	1.300	36	18	100/200	Yes
13	EXP3D	1.300	36	12	--	No
14	EXP4D	1.300	12	12	--	No
15	BASEA	1.290	80	18	500/1000	Yes
16	EXP1D	1.290	36	18	--	No
17	EXP1A	1.280	36	18	500/1000	Yes
18	EXP3B	1.220	36	12	100/200	Yes
19	EXP5B	1.220	36	4	100/200	Yes
20	EXP4B	1.220	12	12	100/200	Yes
21	EXP6B	1.220	12	4	100/200	Yes
22	BASEC	1.170	80	18	10/100	Yes
23	BASEB	1.160	80	18	100/200	Yes
24	EXP3C	1.120	36	12	10/100	Yes
25	EXP4C	1.120	12	12	10/200	Yes

CTEX5 CALPUFF Model Evaluation

Figure ES-3 summarizes the RANK model performance statistics for the CTEX5 CALPUFF sensitivity simulations that used the 12 km MM5 data as input to CALMET and the 12 and 4 km MM5 data as input to MMIF.

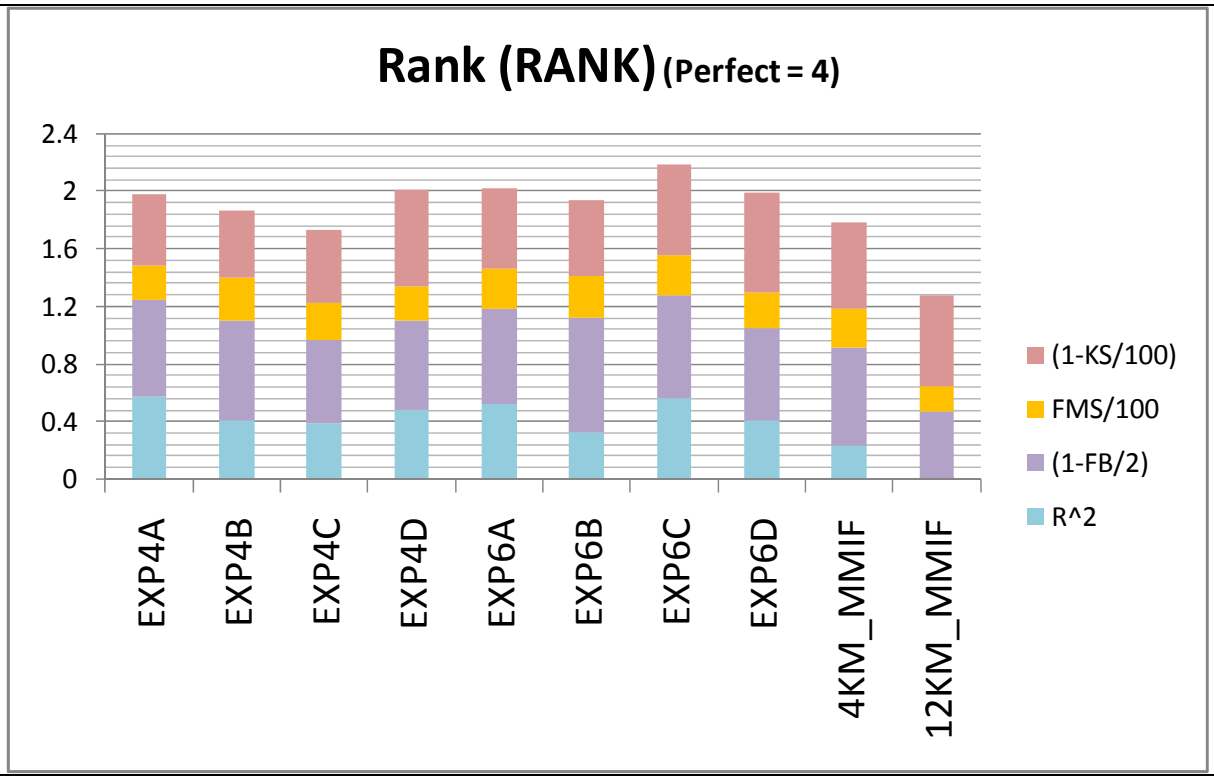


Figure ES-3. RANK performance statistics for CTEX5 CALPUFF sensitivity tests that used 12 km MM5 as input to CALMET or MMIF.

Table ES-4 ranks the model performance of the CTEX5 CALPUFF sensitivity tests using the RANK composite statistic. The 12, 36 and 80 km CALPUFF/MMIF sensitivity tests have the lowest RANK values in the 1.28 to 1.42 range.

Table ES-4. Final Rankings of CALPUFF CTEX5 Sensitivity Tests using the RANK model performance statistic.

Ranking	Sensitivity Test	RANK Statistics	MM5 (km)	CALGRID (km)	RMAX1/RMAX2	Met Obs
1	EXP6C	2.19	12	4	10/100	Yes
2	EXP5D	2.10	36	4	--	No
3	BASEA	2.06	80	18	500/1000	Yes
4	BASEC	2.05	80	18	10/100	Yes
5	EXP5A	2.03	36	4	500/1000	Yes
6	EXP6A	2.02	12	4	500/1000	Yes
7	EXP4D	2.00	12	12	--	No
8	EXP6D	1.99	12	4	--	No
9	EXP4A	1.98	12	12	500/1000	Yes
10	EXP6B	1.94	12	4	100/200	Yes
11	EXP5B	1.89	36	4	100/200	Yes
12	EXP4B	1.86	12	12	100/200	Yes
13	BASEB	1.82	80	18	100/200	Yes
14	EXP5C	1.80	36	4	10/100	Yes

15	BASED	1.79	80	18	--	No
16	EXP3A	1.79	36	12	10/100	Yes
17	EXP3B	1.79	36	12	100/200	Yes
18	EXP3C	1.79	36	12	500/1000	Yes
19	EXP3D	1.79	36	12	--	No
20	4KM_MMIF	1.78	4	--	--	No
21	EXP4C	1.72	12	12	10/100	Yes
22	36KM_MMIF	1.42	36	--	--	No
23	80KM_MMIF	1.42	80	--	--	No
24	12KM_MMIF	1.28	12	--	--	No

Conclusions of the CAPTEX CALPUFF Tracer Sensitivity Tests

There are some differences and similarities in CALPUFF's ability to simulate the observed tracer concentrations in the CTEX3 and CTEX5 field experiments. The overall conclusions of the evaluation of the CALPUFF model using the CAPTEX tracer test field experiment data can be summarized as follows:

- There is a noticeable variability in the CALPUFF model performance depending on the selected input options to CALMET.
  - By varying CALMET inputs and options through their range of plausibility, CALPUFF can produce a wide range of concentrations estimates.
- Regarding the effects of the RMAX1/RMAX2 parameters on CALPUFF/CALMET model performance, the "A" series (500/1000) performed best for CTEX3 but the "C" series (10/100) performed best for CTEX5 with both CTEX3 and CTEX5 agreeing that the "B" series (100/200) is the worst performing setting for RMAX1/RMAX2.
  - This is in contrast to the CALMET wind evaluation that found the "B" series was the CALMET configuration that most closely matched observed surface winds.
  - The CALMET wind evaluation was not an independent evaluation since some of the wind observations used in the model evaluation database were also used as input to CALMET.

Evaluation of Six LRT Dispersion Models using the CTEX3 Database

Six LRT dispersions models were applied for the CTEX3 experiment using common meteorological inputs based solely on MM5. Figure ES-4 displays the RANK model performance statistic for the six LRT dispersion models. The RANK statistical performance metric was proposed by Draxler (2001) as a single model performance metric that equally ranks the combination of performance metrics for correlation (PCC or R^2), bias (FB), spatial analysis (FMS) and unpaired distribution comparisons (KS). The RANK metrics ranges from 0.0 to 4.0 with a perfect model receiving a score of 4.0.

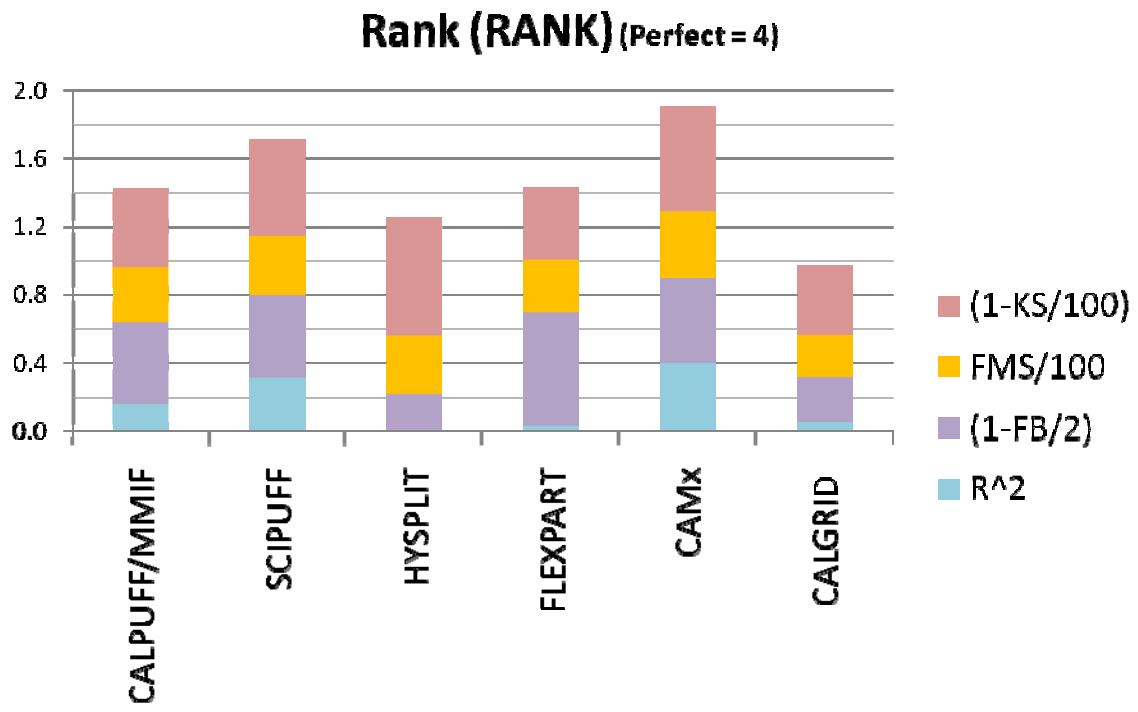


Figure ES-4. RANK statistical performance metric for the six LRT models and CAPTEX Release 3.

Table ES-5 summarizes the rankings between the six LRT models for the 11 performance statistics analyzed and compares them to the rankings obtained using the RANK performance statistic. In testing the efficacy of the RANK statistic for providing an overall ranking of model performance the ranking of the six LRT models using the average rank of the 11 performance statistics (Table ES-5) versus the ranking from the RANK statistical metric (Figure ES-4) are compared as follows:

Ranking	Average of 11 Statistics	RANK
1.	CAMx	CAMx
2.	SCIPUFF	SCIPUFF
3.	FLEXPART	FLEXPART
4.	HYSPLIT	CALPUFF
5.	CALPUFF	HYSPLIT
6.	CALGRID	CALGRID

For the CTEX3 experiment, the average rankings across the 11 statistics is nearly identical to the rankings produced by the RANK integrated statistic that combines the four of the statistics for correlation (PCC), bias (FB), spatial (FMS) and cumulative distribution (KS) with only HYSPLIT and CALPUFF exchanging places. This switch was due to CALPUFF having lower scores in the FA2 and FA5 metrics compared to HYSPLIT. If not for this, the average rank across all 11 metrics would have been the same as Draxler's RANK score. However, the analyst should use discretion in relying too heavily upon RANK score without consideration to which performance metrics are important measures for the particular evaluation goals. For example, if performance goals are not concerned with a model's ability to perform well in space and time, then reliance upon spatial statistics, such as the FMS, in the composite RANK value may not be appropriate.

Table ES-5. Summary of model ranking for the CTEX3 using the ATMES-II statistical performance metrics and comparing their average rankings to the RANK metric.

Statistic	1st	2nd	3rd	4th	5th	6th
FMS	CAMx	SCIPUFF	HYSPLIT	CALPUFF	FLEXPART	CALGRID
FAR	FLEXPART	CAMx	SCIPUFF	CALPUFF	HYSPLIT	CALGRID
POD	CAMx	FLEXPART	SCIPUFF	HYSPLIT	CALPUFF	CALGRID
TS	FLEXPART	CAMx	SCIPUFF	HYSPLIT	CALPUFF	CALGRID
FOEX	HYSPLIT	CAMx	SCIPUFF	CALPUFF	CALGRID	FLEXPART
FA2	CAMx	SCIPUFF	FLEXPART	HYSPLIT	CALGRID	CALPUFF
FA5	CAMx	SCIPUFF	FLEXPART	HYSPLIT	CALPUFF	CALGRID
NMSE	FLEXPART	CAMx	CALPUFF	SCIPUFF	CALGRID	HYSPLIT
PCC or R	CAMx	SCIPUFF	CALPUFF	CALGRID	FLEXPART	HYSPLIT
FB	FLEXPART	CAMx	SCIPUFF	CALPUFF	CALGRID	HYSPLIT
KS	HYSPLIT	CAMx	SCIPUFF	CALPUFF	FLEXPART	CALGRID
Avg. Ranking	CAMx	SCIPUFF	FLEXPART	HYSPLIT	CALPUFF	CALGRID
Avg. Score	1.55	2.72	3.0	4.0	4.27	5.55
RANK Ranking	CAMx	SCIPUFF	FLEXPART	CALPUFF	HYSPLIT	CALGRID
RANK	1.91	1.71	1.44	1.43	1.25	0.98

Evaluation of Six LRT Dispersion Models using the CTEX5 Database

Figure ES-5 displays the RANK model performance statistics for the six LRT models and the CTEX5 field experiment.

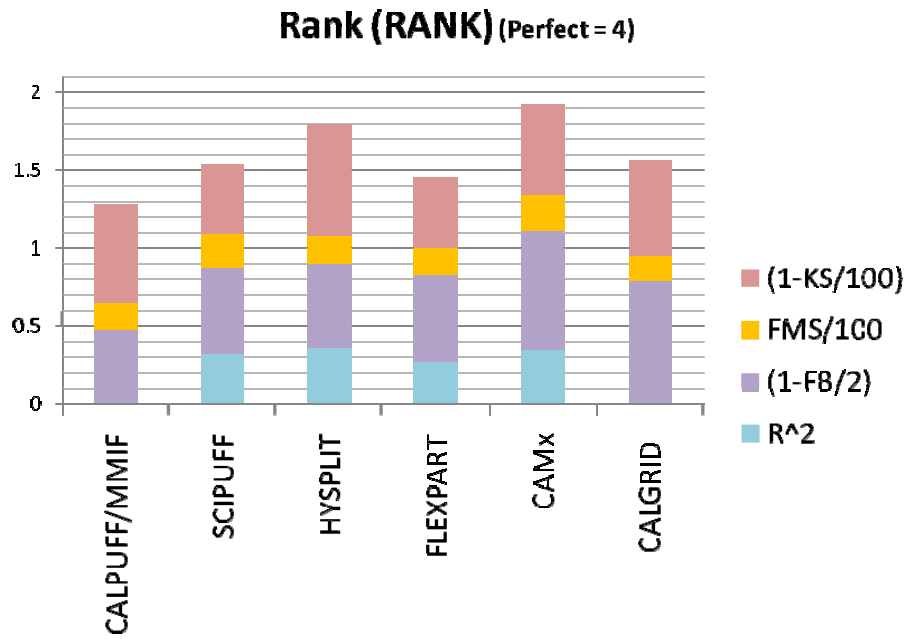


Figure ES-5. RANK statistical performance metric for the six LRT models and CAPTEX Release 5.

Table ES-6 summarizes the rankings of the six LRT models for the 11 performance statistics analyzed for CAPTEX Release 5 and compares the averaging ranking across the 11 statistics against the RANK metric rankings. Unlike the CTEX3 experiment, where CAMx (46%) and FLEXPART (36%) accounted for 82% of the first placed ranked models, there is a wide variation of which model was ranked best performing across the 11 statistical metrics in the CTEX5 experiment. In testing the efficacy of the RANK statistic, overall rankings across all eleven statics were obtained using an average modeled ranking. The average rank across all 11 performance statistics and the RANK model rankings are as follows:

Ranking	Average of 11 Statistics	RANK
1.	CAMx	CAMx
2.	HYSPLIT	HYSPLIT
3.	SCIPUFF	CALGRID
4.	FLEXPART	SCIPUFF
5.	CALPUFF	FLEXPART
6.	CALGRID	CALPUFF

The results from CAPTEX Release 5 present an interesting case study on the use of the RANK metric to characterize overall model performance. As noted in Table ES-6 and given above, the relative ranking of models using the average rankings across the 11 statistical metrics is considerably different than the RANK scores after the two highest ranked models (CAMx and

HYSPLIT). Both approaches show CAMx and HYSPLIT as the highest ranking models for CTEX5 with rankings that are fairly close to each other, however after that the two ranking techniques come to very different conclusions regarding the ability of the models to simulate the observed tracer concentrations for the CTEX5 field experiment.

The most noticeable feature of the RANK metric for ranking models in CTEX5 is the third highest ranking model using RANK, CALGRID (1.57). CALGRID ranks as the worst or second worst performing model in 9 of the 11 performance statistics, so is one of the worst performing model 82% of the time and has an average ranking of 5th best model out of the 6 LRT dispersion models. In examining the contribution to the RANK metric for CALGRID, there is not a consistent contribution from all four broad categories to the composite scores (Figure ES-5). As noted in Table ES-2, the RANK score is defined by the contribution of the four of the 11 statistics that represent measures of correlation/scatter (R^2), bias (FB), spatial (FMS) and cumulative distribution (KS):

$$RANK = \left|R^2\right| + \left(1 - \left|FB/2\right|\right) + FMS/100 + \left(1 - KS/100\right)$$

The majority of CALGRID's 1.57 RANK score comes from the fractional bias (FB) and Kolmogorov-Smirnov (KS) performance statistics with little or no contributions from the correlation (R^2) or spatial (FMS) statistics. As shown in Table ES-6, CALGRID performs very poorly for the FOEX and FA2/FA5 statistics due to a large underestimation bias. The FB component to the RANK composite score for CALGRID is one of the highest among the six models in this study, yet the underlying statistics indicate both marginal spatial skill and a large degree of under-prediction (likely due to the spatial skill of the model).

The current form of the RANK score uses the absolute value of the fractional bias. This approach weights underestimation equally to overestimation. However, in a regulatory context, EPA is most concerned with models not being biased towards under-prediction. Models can produce seemingly good (low) bias metrics through compensating errors by averaging over- and under-predictions. The use of an error statistic (e.g., NMSE) instead of a bias statistic (i.e., FB) in the RANK composite metrics would alleviate this problem.

Adaptation of RANK score for regulatory use will require refinement of the individual components to insure that this situation does not develop and to insure that the regulatory requirement of bias be accounted for when weighting the individual statistical measures to produce a composite score.

Table ES-6. Summary of model rankings using the statistical performance metrics and comparison with the RANK metric.

Statistic	1st	2nd	3rd	4th	5th	6th
FMS	SCIPUFF	CAMx	HYSPLIT	CALPUFF	FLEXPART	CALGRID
FAR	FLEXPART	HYSPLIT	CAMx	SCIPUFF	CALGRID	CALPUFF
POD	SCIPUFF	CAMx	HYSPLIT	FLEXPART	CALPUFF	CALGRID
TS	FLEXPART	HYSPLIT	CAMx	SCIPUFF	CALPUFF	CALGRID
FOEX	CALPUFF	CAMx	HYSPLIT	CALGRID	SCIPUFF	FLEXPART
FA2	HYSPLIT	CAMx	CALPUFF	SCIPUFF	FLEXPART	CALGRID
FA5	HYSPLIT	CAMx	SCIPUFF	CALPUFF	FLEXPART	CALGRID
NMSE	CAMx	SCIPUFF	FLEXPART	HYSPLIT	CALPUFF	CALGRID
PCC or R	HYSPLIT	CAMx	SCIPUFF	FLEXPART	CALGRID	CALPUFF
FB	CAMx	CALGRID	FLEXPART	SCIPUFF	HYSPLIT	CALPUFF
KS	HYSPLIT	CALPUFF	CALGRID	CAMx	FLEXPART	SCIPUFF
Avg. Ranking	CAMx	HYSPLIT	SCIPUFF	FLEXPART	CALPUFF	CALGRID
Avg. Score	2.20	2.4	3.4	3.8	4.3	5.0
RANK Ranking	CAMx	HYSPLIT	CALGRID	SCIPUFF	FLEXPART	CALPUFF
RANK	1.91	1.80	1.57	1.53	1.45	1.28

European Tracer Experiment (ETEX)

The European Tracer Experiment (ETEX) was conducted in 1994 with two tracer releases from northwest France that was measured at 168 samplers located in 17 European countries. Five LRT dispersion models were evaluated for the first (October 23, 1994) ETEX tracer release period (CALPUFF, SCICHEM, HYSPLIT, FLEXPART and CAMx). All five LRT dispersion models were exercised using a common 36 km MM5 database for their meteorological inputs. For CALPUFF, the MMIF tool was used to process the MM5 data. Default model options were mostly selected for the LRT dispersion models. An exception to this is that for CALPUFF puff splitting was allowed to occur throughout the day, instead of once per day which is the default setting. The MM5 simulation was evaluated using surface meteorological variables. The MM5 performance did not always meet the model performance benchmarks and exhibited a wind speed and temperature underestimation bias. However, since all five LRT dispersion models used the same MM5 fields, this did not detract from the LRT model performance intercomparison. The ATMES-II model evaluation approach was used in the evaluation that calculated 12 model performance statistics of spatial, scatter, bias, correlation and cumulative distribution.

ETEX LRT Dispersion Model Performance Evaluation

Figure ES-6 displays the ranking of the five LRT dispersion models using the RANK model performance statistic with Table ES-7 summarizing the rankings for the other 11 ATMES-II performance statistics. Depending on the statistical metric, three different models were ranked as the best performing model for a particular statistic with CAMx being ranked first most of the time (64%) and HYSPLIT ranked first second most (27%). In order to come up with an overall rank across all eleven statistics we average the modeled ranking order to come up with an average ranking that listed CAMx first, HYSPLIT second, SCIPUFF third, FLEXPART fourth and CALPUFF the fifth. This is the same ranking as produced by the RANK integrated statistics that combines the four statistics for correlation (PCC), bias (FB), spatial (FMS) and cumulative distribution (KS), giving credence that the RANK statistic is a potentially useful performance

statistic for indicating overall model performance of a LRT dispersion model for the ETEX evaluation.

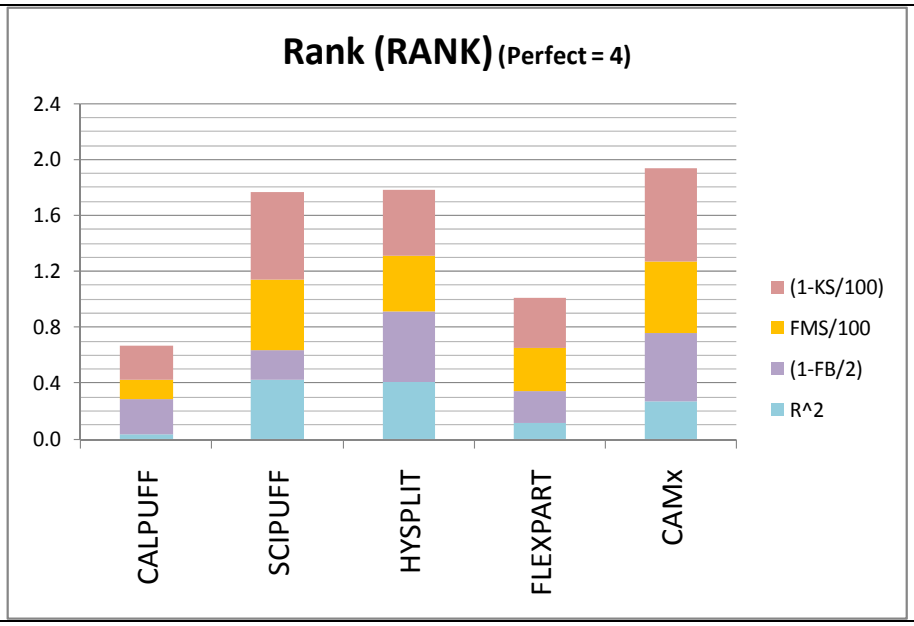


Figure ES-6. RANK statistical performance metric for the five LRT models and the ETEX tracer field experiment.

Table ES-7. Summary of ETEX model ranking using the eleven ATMES-II statistical performance metrics and their average rankings that are compared against the rankings by the RANK composite model performance metric.

Statistic	1st	2nd	3rd	4th	5th
FMS	CAMx	SCIPUFF	HYSPLIT	FLEXPART	CALPUFF
FAR	HYSPLIT	FLEXPART	CAMx	SCIPUFF	CALPUFF
POD	CAMx	SCIPUFF	HYSPLIT	FLEXPART	CALPUFF
TS	CAMx	HYSPLIT	SCIPUFF	FLEXPART	CALPUFF
FOEX	CAMx	SCIPUFF	HYSPLIT	FLEXPART	CALPUFF
FA2	CAMx	SCIPUFF	HYSPLIT	FLEXPART	CALPUFF
FA5	CAMx	SCIPUFF	HYSPLIT	FLEXPART	CALPUFF
NMSE	HYSPLIT	CAMx	CALPUFF	FLEXPART	SCIPUFF
PCC or R	SCIPUFF	HYSPLIT	CAMx	FLEXPART	CALPUFF
FB	HYSPLIT	CAMx	CALPUFF	FLEXPART	SCIPUFF
KS	CAMx	SCIPUFF	HYSPLIT	FLEXPART	CALPUFF
Avg. Ranking	CAMx	HYSPLIT	SCIPUFF	FLEXPART	CALPUFF
Avg. Score	1.55	2.27	2.73	3.82	4.64
RANK Ranking	CAMx	HYSPLIT	SCIPUFF	FLEXPART	CALPUFF
RANK Score	1.9	1.8	1.8	1.0	0.7

<u>Spatial Displays of Model Performance</u>

Figures ES-7 and ES-8 display the spatial distributions of the predicted and observed tracer concentrations 36 and 60 hours after the beginning of the ETEX tracer release. CALPUFF advects the tracer too far north keeping a circular Gaussian plume distribution and fails to

reproduce the northwest to southeast diagonal orientation of the observed tracer cloud. The other four LRT dispersion models do a much better job in reproducing the observed tracer cloud spatial distribution. SCIPUFF tends to overestimate the tracer cloud extent and surface concentrations. FLEXPART, on the other hand, underestimates the observed tracer cloud spatial extent and CAMx and HYSPLIT do the best job overall in reproducing the spatial extent of the observed tracer cloud.

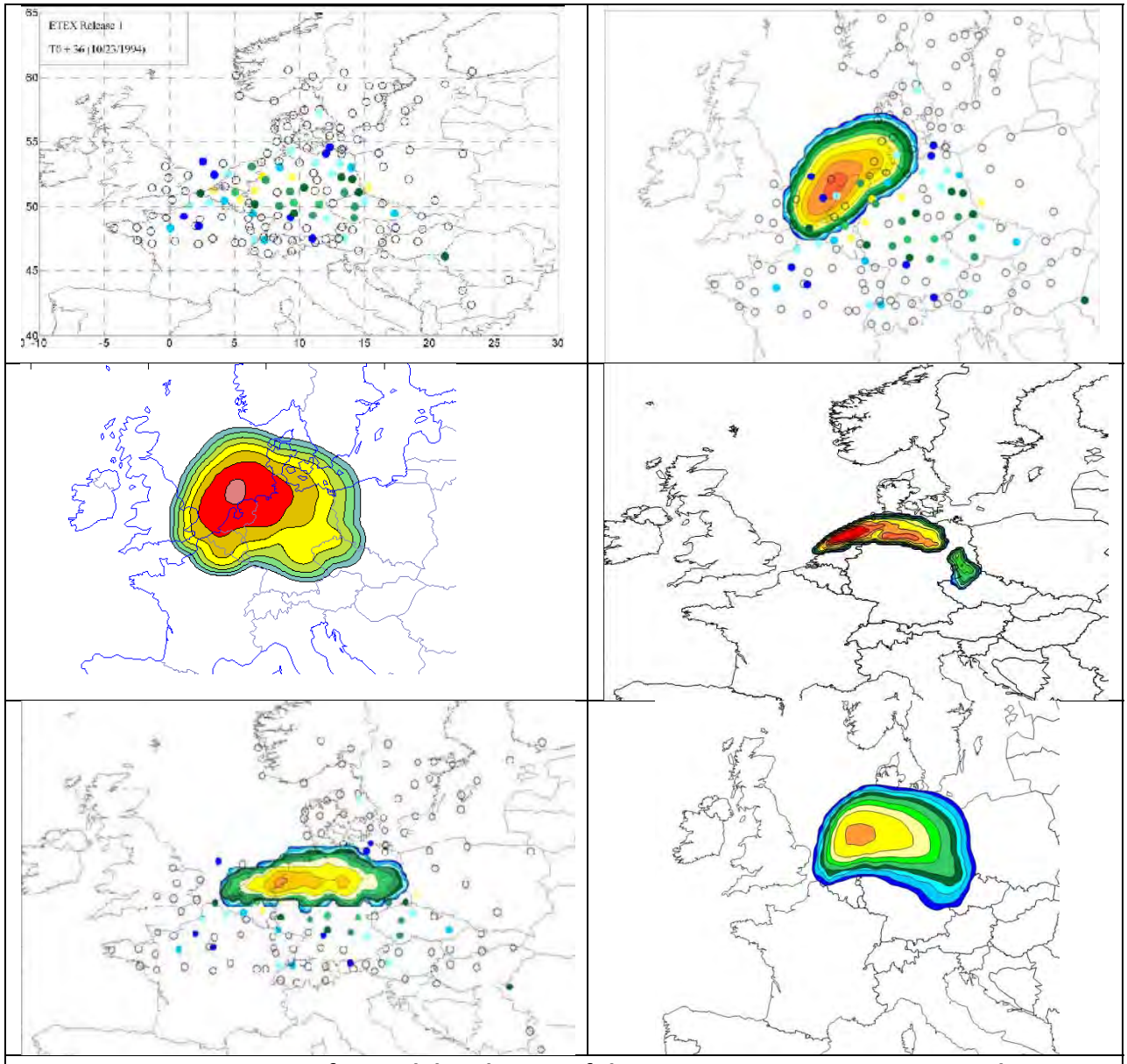


Figure ES-7. Comparison of spatial distribution of the ETEX tracer concentrations 36 hours after release for the observed (top left), CALPUFF (top right), SCIPUFF (middle left), FLEXPART (middle right), HYSPLIT (bottom left) and CAMx (bottom right).

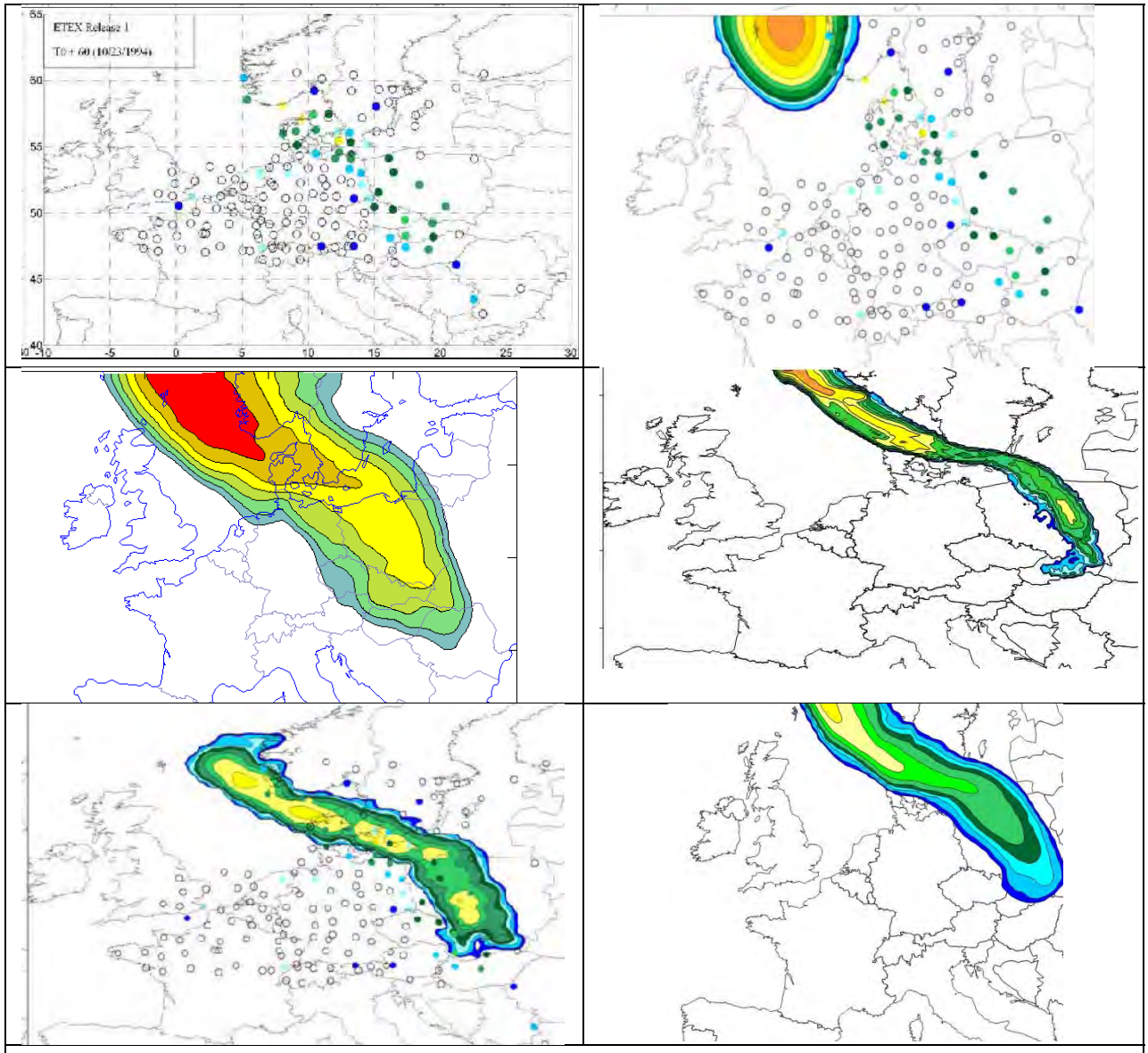


Figure ES-8. Comparison of spatial distribution of the ETEX tracer concentrations 60 hours after release for the observed (top left), CALPUFF (top right), SCIPUFF (middle left), FLEXPART (middle right), HYSPLIT (bottom left) and CAMx (bottom right).

ETEX LRT Dispersion Model Sensitivity Tests

Sensitivity tests were conducted using the CAMx, CALPUFF and HYSPLIT models and the ETEX field study data.

For CAMx, the effects of alternative vertical mixing coefficients (OB70, TKE, ACM2 and CMAQ), horizontal advection solvers (PPM and Bott) and use of the subgrid-scale Plume-in-Grid (PiG) module were evaluated. The key findings from the CAMx ETEX sensitivity tests were as follows:

- The vertical mixing parameter had the biggest effect on model performance, with the CMAQ vertical diffusion coefficients producing the best performing CAMx simulations.
- The horizontal advection solver had a much smaller effect on CAMx model performance with the PPM algorithm performing slightly better than Bott.
- The use of no PiG module produced slightly better performance than use of the PiG module.
- The default CAMx configuration used in the ETEX evaluation (CMAQ/PPM/No PiG) was the best performing CAMx sensitivity test.

CALPUFF sensitivity tests were performed to examine the effects of puff splitting on the CALPUFF model performance for the ETEX field experiment. When EPA listed CALPUFF as the EPA-recommended LRT dispersion model in 2003, they noted that the implementation of puff splitting likely will extend the models applicability beyond 300 km downwind (EPA, 2003). Since many of the ETEX monitoring sites are sited further than 300 km downwind from the release, one potential explanation for the poor CALPUFF model performance is that it is being applied farther downwind than the model is applicable for. Figure ES-9 displays a time series of the Figure of Merit in Space (FMS) performance statistic for the five LRT dispersion models. Although CALPUFF performs reasonably well within the first 12 hours of the tracer release, its performance quickly degrades even within 300 km of the source. Thus, CALPUFF's poor model performance is not due to applying the model to downwind distances beyond its applicability.

Eight CALPUFF puff splitting sensitivity tests were conducted ranging from no puff splitting to aggressive puff splitting for all hours of the day and relaxing some of the puff splitting initiation criteria so that even more puff splitting can occur. The CALPUFF ETEX model performance using no puff splitting and all hour puff splitting was very similar, thus we saw no evidence to support EPA's 2003 statements that puff splitting may extend the downwind applicability of the model. In fact, when some of the puff splitting initiation criteria were relaxed to allow more puff splitting, the CALUFF performance degraded.

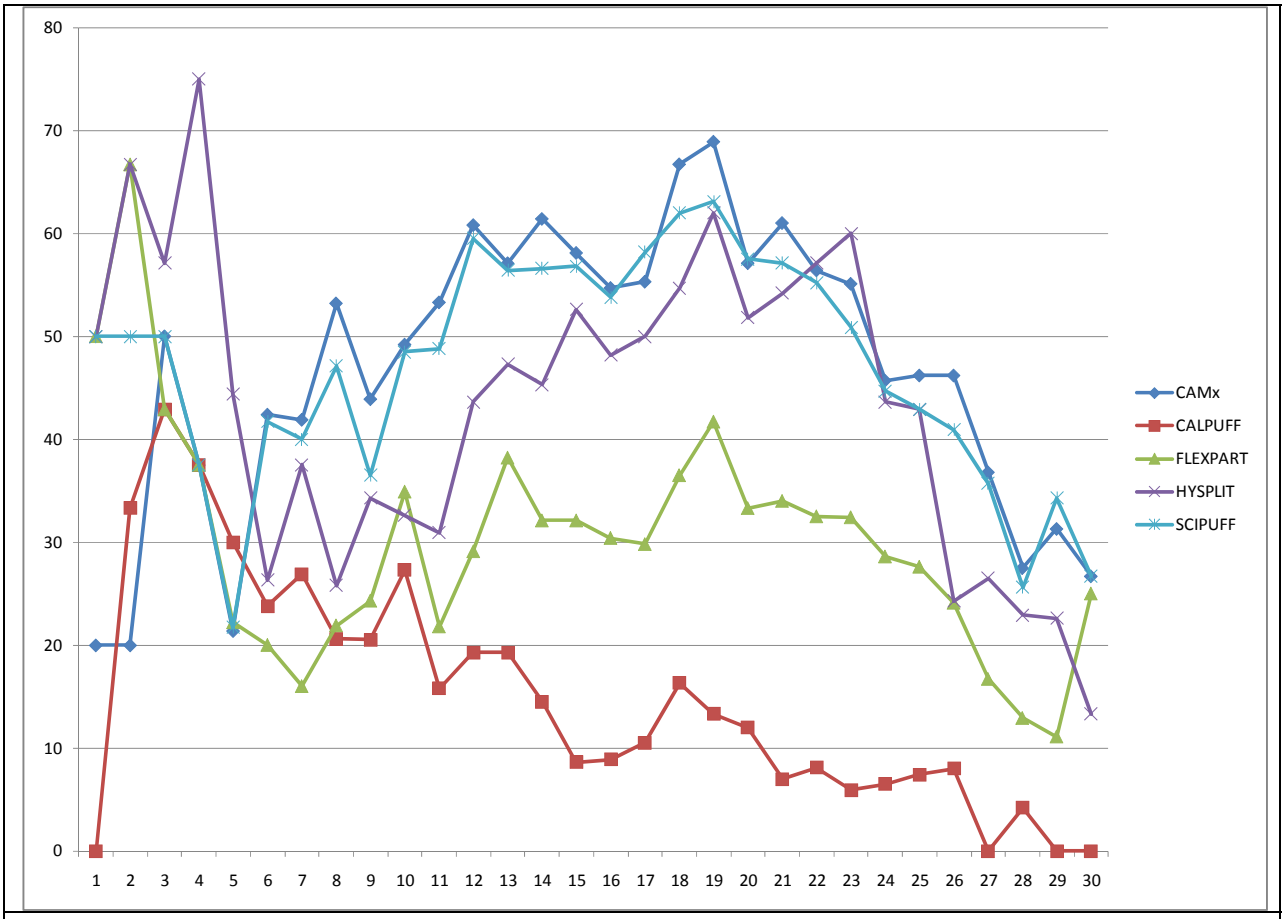


Figure ES-9. Figure of Merit (FMS) spatial model performance statistics as a function of time at three hour increments since the beginning of the tracer release.

The HYSPLIT LRT model was unique among the five LRT dispersion models examined in that it can be run in a particle mode, a Gaussian puff mode or hybrid particle/puff and puff/particle modes. The default configuration used in the HYSPLIT simulations presented previously was the three-dimensional particle mode. Nine HYSPLIT sensitivity tests were performed using different particle and puff formulation combinations. The RANK scores for the HYSPLIT ETEX sensitivity simulations ranged from 1.01 to 2.09, with the fully puff formulation ranked the lowest and hybrid puff/particle combinations ranked highest.

Conclusions of the ETEX LRT Dispersion Model Evaluation

Five LRT dispersion models were evaluated using the 1994 ETEX tracer test field experiment data. The CAMx, HYSPLIT and SCIPUFF models were the highest ranked LRT dispersions models, with CAMx performing slightly better than the other two models. The reasons for the poor performance of CALPUFF appear to be due to its inability to adequately treat horizontal and vertical wind shear. The CALPUFF Gaussian puff formulation retains a well-mixed circular puff despite the presence of wind variations across the puff that would advect tracer concentrations in different directions. Because the puff can only be transported by one wind, CALPUFF is unable to adequately treat such wind variations across the puff. The use of puff splitting, which EPA postulated in 2003 may extend the downwind applicability of the model, failed to have any significant effect on CALPUFF model performance.

CONCLUSIONS OF LRT DISPERSION MODEL TRACER TEST EVALUATION

The following are some of the key conclusions of the LRT dispersion model tracer test field experiment evaluation.

CALPUFF/CALMET Concentration Predictions are Highly Variable: Use of alternative CALMET input options within their range of reasonableness can produce wide variations in the CALPUFF concentration predictions. Given the regulatory use of CALPUFF, this result points toward the need to have a standard set of recommended CALMET settings for regulatory application of CALPUFF to assure consistency and eliminate the potential of selecting CALMET options to obtain a desired outcome in CALPUFF. No one CALMET configuration consistently produced the best CALPUFF model performance, although use of MM5 data with CALMET did tend to improve CALPUFF model performance with 36 and 12 km MM5 data being better than 80 km MM5 data.

Comparison of Current CALPUFF Model Performance with Previous Studies: The comparison of the model performance for current version of CALPUFF with past CALPUFF evaluations from the 1998 EPA study (EPA, 1998a) using the GP80 and SRL75 tracer study field experiments was mixed. For the GP80 100 km receptor arc, the current and past CALPUFF model performance evaluations were consistent with CALPUFF tending to overestimate the plume maximum concentrations and underestimate plume horizontal dispersion. The current version of CALPUFF had difficulty in reproducing the good performance of the past CALPUFF application in estimating the tracer residence time on the GP80 600 km receptor arc. Only by invoking the CALPUFF slug option, as used in the 1998 EPA study, was CALPUFF/CALMET able to reproduce the tracer residence time on the 600 km receptor arc. As the slug option is for near-source modeling and is a very non-standard option for LRT dispersion modeling, this result questions the validity of the 1998 CALPUFF evaluation study as applied for CALPUFF LRT modeling. The CALPUFF/MMIF was less sensitive to the slug option and more sensitive to puff splitting than CALPUFF/CALMET. For consistency, the current and EPA 1998 study CALPUFF evaluation approach both used the fitted Gaussian plume model evaluation methodology, along with angular plume centerline offset and tracer receptor arc timing statistics. The fitted Gaussian plume evaluation approach assumes that the observed and predicted concentration along a receptor arc has a Gaussian distribution. At longer downwind distances such an assumption may not be valid. For the CALPUFF evaluation using the SRL75 tracer field experiment, there was a very poor fit of the Gaussian plume to the observations resulting in some model performance statics that could be misleading. We do not recommend using the fitted Gaussian plume evaluation approach in future studies and instead recommend using approaches like the ATMES-II statistical evaluation approach that is free from any a priori assumption regarding the observed tracer distributions.

EPA-FLM Recommended CALMET Settings from the 2009 Clarification Memorandum: The EPA-FLM recommended CALMET settings in the 2009 Clarification Memorandum (EPA, 2009b) produces wind field estimates closest to surface wind observations based on the CAPTEX CALMET modeling. However, when used as input into CALPUFF, the EPA-FLM recommended CALMET settings produced one of the poorer performing CALPUFF/CALMET configurations when comparing CALPUFF predictions against the observed atmospheric tracer concentrations. Given that the CALMET wind evaluation is not an independent evaluation because some of the wind observations used in the evaluation database are also input into CALMET, the CALPUFF

tracer evaluation bears more weight. Other aspects of the EPA-FLM recommended settings generally produced better CALPUFF tracer model performance including use of prognostic meteorological data as input to CALPUFF. The CALPUFF evaluation also found better CALPUFF performance when 12 km grid resolution is used in MM5 or CALMET as opposed to 80 or 36 km.

CALPUFF Model Performance using CALMET versus MMIF: The CALPUFF tracer model performance using meteorological inputs based on the MMIF tool versus CALMET was mixed. The variations of the CALPUFF model predictions using MMIF were much less than when CALMET was used and the CALPUFF/MMIF model performance was usually within the range of the performance exhibited by CALPUFF/CALMET. Specific examples from the tracer tests are as follows:

- For the GP80 100 km receptor arc, the CALPUFF/MMIF exhibited better fitted plume observed tracer model performance statistics than all of the CALPUFF/CALMET configurations except when CALMET was run using MM5 and surface meteorological observations but no upper-air meteorological observations.
- CALPUFF/CALMET using no MM5 data and just meteorological observations exhibited the best plume centerline location on the GP80 100 km receptor arc with CALPUFF/CALMET using just MM5 data and no observations and CALMET/MMIF exhibiting the worst plume centerline location.
- For the GP80 600 km receptor arc, the CALPUFF/MMIF fitted plume model performance statistics are in the middle of the performance statistics for the CALPUFF/CALMET configurations.
- The slug option was needed for CALPUFF/CALMET to produce good 600 km receptor arc tracer residence time statistics but had little effect on CALPUFF/MMIF. However, use of puff splitting greatly improved the CALPUFF/MMIF tracer residence time statistics.
- Of all the CALPUFF sensitivity tests examined, CALPUFF/MMIF using the slug option and puff splitting produced the best CALPUFF fitted plume tracer model performance statistics for the GP80 600 km receptor arc.
- In an opposite fashion to the GP80 100 km receptor arc, for the SRL75 100 km receptor arc the best plume centerline offset was achieved when CALPUFF was run with just MM5 data and no meteorological observations (either with CALMET or MMIF) with performance degraded when meteorological observations are used with CALMET.
- The CALPUFF model performance using the MMIF tool and 36 and 12 km MM5 data performed better than all of the CALPUFF/CALMET sensitivity tests for the CAPTEX CTEX3 experiment. However, the CALPUFF/MMIF using 36 and 12 km MM5 data performed worse than all of the CALPUFF/CALMET sensitivity tests for the CAPTEX CTEX5 experiment.

Comparison of Model Performance of LRT Dispersion Models: Six LRT dispersion modeled were evaluated using the CAPTEX Release 3 and 5 tracer database and five LRT dispersion models were evaluated using the ETEX tracer test field experiment. In each case the same MM5 meteorological data were used as input into all of the dispersion models, although different MM5 configuration options were selected for each tracer experiement.

The CAMx and CALGRID Eulerian photochemical grid models, FLEXPART Lagrangian particle model, HYSPLIT Lagrangian particle, puff and particle/puff hybrid model and CALPUFF and SCIPUFF Gaussian puff models were evaluated. For all three tracer experiments (CTEX3, CTEX5 and ETEX), the CAMx model consistently ranked highest when looking across all of the model performance statistics or when using the RANK composite performance statistic. For the CTEX3 field experiment, the RANK composite performance statistic gave consistent rankings of model performance with the suite of statistical metrics with CAMx being the higheset RANK score (1.91) followed by SCICHEM (1.71).

The rankings of the models using all of the statistics versus the RANK composite statistic were inconsistent for the CTEX5 experiment. Both approaches showed CAMx and HYSPLIT were the highest ranking LRT dispersion model for the CTEX5 field experiment. However, the RANK statistic ranked CALGRID as the 3rd best performing model, whereas when looking at all the performance statistics it was the worst performing model because it exhibited a large spread underestimation bias, had no correlation with the observations and little skill in reproducing the spatial distribution of the observed tracer. The CTEX5 LRT model evaluation points out the need to examine all performance statistics and not rely solely on the RANK composite statistic. It also points out the need to define a RANK-type composite statistic that focuses on the regulatory application of LRT dispersion models where an underestimation bias is undesirable.

Of the three top performing LRT dispersion models, CAMx had the highest RANK composite statistic and scored the highest for most (64%) of the other ATMES-II statistical model performance metrics, with HYSPLIT scoring the highest for 27% of the metrics. Additional findings of the ETEX tracer test evaluation are as follows:

- The model performance rankings were preserved closer to the source (e.g., within 300 km) as well as further downwind.
- CALPUFF puff splitting sensitivity tests had little effect on CALPUFF model performance.
- CAMx vertical mixing and horizontal advection solver sensitivity tests found that use of the MM5CAMx CMAQ-like vertical mixing diffusion coefficients and the PPM advection solver produced the best tracer test model performance. Similar results were seen in the CTEX3 and CTEX5 sensitivity modeling.
- HYSPLIT sensitivity tests using solely particle, solely puff and hybrid particle/puff and puff/particle combinations found that the hybrid configurations performed best and the puff configuration performed worst, with the CTEX3 and CTEX5 sensitivity test producing similar results.

1.0 INTRODUCTION

Dispersion models, such as the Industrial Source Complex Short Term (ISCST; EPA, 1995) or American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD; EPA, 2004; 2009c) typically assume steady-state, horizontally homogeneous wind fields instantaneously over the entire modeling domain and are usually limited to distances of less than 50 kilometers from a source. However, dispersion model applications of distances of hundreds of kilometers from a source require other models or modeling systems. At these distances, the transport times are sufficiently long that the mean wind fields cannot be considered steady-state or homogeneous. As part of the Prevention of Significant Deterioration (PSD) program, new sources or proposed modifications to existing sources may be required to assess the air quality and Air Quality Related Values (AQRVs) impacts at Class I and sensitive Class II areas that may be far away from the source. AQRVs include visibility and acid (sulfur and nitrogen) deposition. There are 156 federally mandated Class I areas in the U.S. that consist of National Parks, Wilderness Areas and Wildlife Refuges that are administered by Federal Land Managers (FLMs) from the National Park Service (NPS), United States Forest Service (USFS) and Fish and Wildlife Service (FWS), respectively. Thus, non-steady-state Long Range Transport (LRT) dispersion models are needed to address air quality and AQRVs issues at distances beyond 50 km from a source.

1.1 BACKGROUND

The Interagency Workgroup on Air Quality Modeling (IWAQM) was formed to provide a focus for the development of technically sound recommendations regarding assessment of air pollutant source impacts on Federal Class I areas. Meetings were held with personnel from interested Federal agencies, including the Environmental Protection Agency (EPA), the USFS, NPS and FWS. The purpose of these meetings was to review respective modeling programs, to develop an organizational framework, and to formulate reasonable objectives and plans that could be presented to management for support and commitment. One objective of the IWAQM is the recommendation of LRT dispersion models for assessing air quality and AQRVs at Class I areas.

One such LRT dispersion model is the CALPUFF modeling system (Scire et al., 2000b). The CALPUFF modeling system consists of several components: (1) CALMET (Scire et al., 2000a), a meteorological preprocessor that can use as input surface, upper air, and/or on-site meteorological observations and/or prognostic meteorological model output data to create a three-dimensional wind field and derive boundary layer parameters based on gridded land use data; (2) CALPUFF, a Lagrangian puff dispersion model that can simulate the effects of temporally and spatially varying meteorological conditions on pollutant transport, remove pollutants through dry and wet deposition processes, and includes limited ability to transform pollutant species through chemical reactions; and (3) CALPOST, a postprocessor that takes the hourly estimates from CALPUFF and generates *n*-hr estimates as well as tables of maximum values.

In 1998, EPA published the report entitled “A Comparison of CALPUFF Modeling Results to Two Tracer Field Experiments” (EPA-454/R-98-009) (EPA, 1998a). The 1998 EPA study examined concentration estimates from the CALPUFF dispersion model that were compared to observed tracer concentrations from two short term field experiments. The first experiment was at the Savannah River Laboratory (SRL75) in South Carolina in December 1975 (DOE, 1978) and the second was the Great Plains experiment (GP80) near Norman, Oklahoma (Ferber et al., 1981) in

July 1980. Both experiments examined long-range transport of inert tracer materials to demonstrate the feasibility of using other tracers as alternatives to the more commonly used sulfur hexafluoride (SF_6). Several tracers were released for a short duration (3-4 hours) and the resulting plume concentrations were recorded at an array of monitors downwind from the source. For the SRL75 field experiment, monitors were located approximately 100 kilometers from the source. For the Great Plains experiment, arcs of monitors were located 100 and 600 kilometers from the source.

In 1998, IWAQM released their Phase 2 recommendations in a report "Interagency Workgroup on Air Quality Modeling (IWAQM) Phase 2 Summary Report and Recommendations for Modeling Long Range Transport Impacts" (EPA, 1998b[7]). These recommendations included a screening and refined LRT modeling approach based on the CALPUFF modeling system. The IWAQM recommendations were based in part on the 1998 EPA tracer test CALPUFF evaluation. It was IWAQM's conclusion at the time that it was not possible to prescribe all of the decisions needed in a CALPUFF/CALMET application: *"The control of the CALMET options requires expert understanding of mesoscale and microscale meteorological effects on meteorological conditions, and finesse to adjust the available processing controls within CALMET to develop the desired effects. The IWAQM does not anticipate the lessening in this required expertise in the future"* (EPA, 1998b).

On April 15, 2003, EPA issued a "Revision to the Guideline on Air Quality Models: Adoption of a Preferred Long Range Transport Model and Other Revisions" in the Federal Register (EPA, 2003[8]) that adopted the CALPUFF model as the EPA-recommended (Appendix W) model for assessing the far-field (> 50 km) air quality impacts due to chemically inert pollutants. In 2005, EPA issued another revision to the air quality modeling guidelines that recommended the AERMOD steady-state Gaussian plume model be used for near-source air quality issues. Thus, from 2005 on to present, there are two EPA-recommended models to address air quality issues due to primary pollutants: AERMOD for near-source (< 50 km) assessments; and CALPUFF for far-field (> 50 km) assessments.

In 2005, EPA formed a CALPUFF workgroup to help identify issues with the existing 1998 IWAQM guidance. In response to this, EPA initiated reevaluation of the CALPUFF system to update the 1998 IWAQM Phase 2 Recommendations.

In May 2009, EPA released a draft document entitled the "Reassessment of the Interagency Workgroup on Air Quality Modeling (IWAQM) Phase 2 Summary Report: Revisions to the Phase 2 Recommendations" (EPA, 2009a). In this document, EPA described the developmental status of the CALPUFF modeling system. CALPUFF has evolved continuously since the publication of the original 1998 IWAQM Phase 2 recommendations; however, the status of CALPUFF related guidance has not kept pace with the developmental process. The May 2009 IWAQM Phase 2 Reassessment Report noted that *"The required expertise and collective body of knowledge in mesoscale meteorological models has never fully emerged from within the dispersion modeling community to support the necessary expert judgment on selection of CALMET control options"* (EPA, 2009a). In regards to the 1998 IWAQM Phase 2 lack of prescribing recommended CALMET settings, the May 2009 IWAQM Phase 2 Reassessment Report states: *"In a regulatory context, this situation has often resulted in an 'anything goes' process, whereby model control option selection can be leveraged as an instrument to achieve a desired modeled outcome,*

7 http://www.epa.gov/scram001/7thconf/calpuff/phase2.pdf

8 http://www.federalregister.gov/articles/2003/04/15/03-8542/revision-to-the-guideline-on-air-quality-models-adoption-of-a-preferred-long-range-transport-model

without regard to the scientific legitimacy of the options selected" (EPA, 2009a). The CALPUFF working group noted that when running CALMET with prognostic meteorological model (e.g., WRF and MM5) output as input, the CALMET diagnostic effects and blending of meteorological observations with the WRF/MM5 output degraded the WRF/MM5 meteorological fields. Thus, the 2009 IWAQM Phase 2 Reassessment Report recommended CALMET settings with an objective to try and "pass through" the WRF/MM5 meteorological model output as much as possible for input into CALPUFF.

However, further testing of CALMET and CALPUFF by EPA's CALPUFF workgroup found that the recommended CALMET settings in the May 2009 IWAQM Phase 2 Reassessment Report did not achieve the intended result to "pass through" the WRF/MM5 meteorological variables as CALMET still re-diagnosed some and modified other meteorological variables thereby degrading the WRF/MM5 meteorological fields. Based in part of CALMET evaluations using tracer test field study databases (presented in Appendix B of this report), EPA determined interim CALMET settings that produced the best CALMET performance when compared to observed surface winds and on August 31, 2009 released a Clarification Memorandum "Clarification on EPA-FLM Recommended Settings for CALMET" (EPA, 2009b) with new recommended settings for CALMET. In the August 2009 Clarification Memorandum, EPA reiterated the desire to "pass through" meteorology from the WRF/MM5 prognostic meteorological models to CALPUFF, but the CALMET model at this time was incapable of achieving that objective.

In the meantime, EPA has developed the Mesoscale Model Interface (MMIF) software that where possible directly converts prognostic meteorological output data from the MM5 or WRF models to the parameters and formats required for direct input into the CALPUFF dispersion model thereby bypassing CALMET. Version 1.0 of MMIF was developed in June 2009 (Emery and Brashers, 2009) with versions 2.0 (Brashers and Emery, 2011) and 2.1 (Brashers and Emery, 2012) developed in, respectively, September 2011 and February 2012; we expect that MMIF Version 2.1 will be publicly released in February 2012. MMIF specifically processes geophysical and meteorological output files generated by the fifth generation mesoscale model (MM5) or the Weather Research and Forecasting (WRF) model (Advanced Research WRF [ARW] core, versions 2 and 3) and reformats the MM5/WRF output for input into CALPUFF..

The EPA CALPUFF workgroup has been evaluating CALPUFF using CALMET and MMIF meteorological drivers using data from several historical tracer field studies. In addition to a reevaluation of CALPUFF using CALMET and MMIF for the GP80 and SRL75 tracer studies that were used in the 1998 EPA CALPUF tracer evaluation report (EPA, 1998a), the CALPUFF workgroup has also evaluated CALPUFF using CALMET and MMIF meteorological drivers along with 5 other LRT dispersion models for the 1983 Cross Appalachian Tracer Experiment (CAPTEX). CALPUFF, along with four other LRT dispersion models, were also evaluated using data from the 1994 European Tracer Experiment (ETEX).

1.2 PURPOSE

The purpose of this report is to document the evaluation of the CALPUFF LRT dispersion model using data from four atmospheric tracer experiment field study databases. This includes the comparison of the CALPUFF model performance using meteorological inputs based on the CALMET and MMIF software and comparison of the CALPUFF model performance with other LRT dispersion models.

1.3 ORGANIZATION OF REPORT

Chapter one provides a background and purpose for the study. In Chapter 2, the four tracer field study experiments and LRT dispersion models used in the model performance evaluation are summarized. Chapter 2 also summarizes related previous studies and the approach and methods for the model performance evaluation of the LRT dispersion models.

Chapters 3, 4, 5 and 6 contain the evaluation of the LRT dispersions models using the GP80, SRL75, CAPTEX and ETEX tracer study field experiment data. References are provided in Chapter 7. Appendix A contains an evaluation of the MM5 and CALMET meteorological models using the CAPTEX Release #5 (CTEX5) database. Appendix B presents the evaluation of the CALMET meteorological model using the CAPTEX Release #3 (CTEX3) database that was used in part to formulate the EPA-FLM recommended settings in the 2009 Clarification Memorandum (EPA, 2009b). Results of the evaluation of six LRT dispersion models using the CAPTEX tracer field experiments are presented in Appendix C.

2.0 OVERVIEW OF APPROACH

2.1 SUMMARY OF TRACER TEST FIELD EXPERIMENTS

LRT dispersion models are evaluated using four atmospheric tracer test field studies as follows:

1980 Great Plains: The 1980 Great Plains (GP80) field study released several tracers from a release site near Norman, Oklahoma in July 1980 and measured the tracers at two arcs to the northeast at distances of 100 and 600 km (Ferber et al., 1981).

1975 Savannah River Laboratory: The 1975 Savannah River Laboratory (SRL75) study released tracers from the SRL in South Carolina and measured them at several receptors approximately 100 km from the release point (DOE, 1978).

1983 Cross Appalachian Tracer Experiment: The 1983 Cross Appalachian Tracer Experiment (CAPTEX) was a series of three-hour tracer released from Dayton, OH and Sudbury, Canada during September and October, 1983. Sampling was made in a series of arcs approximately 100 km apart that spanned from 300 to 1,100 km from the Dayton, OH release site (Ferber et al., 1986).

1994 European Tracer Experiment: The 1994 European Tracer Experiment (ETEX) consisted of two tracer releases from northwest France in October and November 1994 that was measured at 168 monitoring sites in 17 countries (Von Dop et al., 1998).

2.2 SUMMARY OF LRT DISPERSION MODELS

Up to six LRT dispersion models were evaluated using the tracer test field study data:

CALPUFF[9]: The California Puff (CALPUFF Version 5.8; Scire et al, 2000b) model is a Lagrangian Gaussian puff model that simulates a continuous plume using overlapping circular puffs. Included with CALPUFF is the CALMET meteorological processor (Scire et al., 2000a) that includes a diagnostic wind model (DWM). The EPA has developed a new Mesoscale Model Interface (MMIF; Emery and Brashers, 2009; Brashers and Emery, 2011; 2012) tool that will "pass through" output from the MM5 or WRF prognostic meteorological models without modifying or rediagnosing the meteorological variables, as is done in CALMET. A major objective of this study was to compare the CALPUFF model performance using CALMET and MMIF meteorological drivers.

SCIPUFF[10]: The Second-order Closure Integrated PUFF (SCIPUFF Version 2.303; Sykes et al., 1998) is a Lagrangian puff dispersion model using Gaussian puffs to represent an arbitrary, three-dimensional time-dependent concentration field. The diffusion parameterization is based on turbulence closure theory, which gives a prediction of the dispersion rate in terms of the measurable turbulent velocity statistics of the wind field. The SCIPUFF contains puff splitting when wind shear is encountered across a puff and puff merging when two puffs occupy the same space.

HYSPLIT[11]: The Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT Version 4.8; Draxler, 1997) is a complete system for computing simple air parcel trajectories to complex dispersion and deposition simulations. The dispersion of a pollutant is calculated by assuming either puff or particle or hybrid puff/particle dispersion. In the puff model,

9 http://www.src.com/calpuff/calpuff1.htm
10 http://www.sage-mgt.net/services/modeling-and-simulation/scipuff-dispersion-model
11 http://www.arl.noaa.gov/HYSPLIT_info.php

puffs expand until they exceed the size of the meteorological grid cell (either horizontally or vertically) and then split into several new puffs, each with its share of the pollutant mass. In the particle model, a fixed number of particles are advected about the model domain by the mean wind field and spread by a turbulent component. The model's default configuration assumes a 3-dimensional particle distribution (horizontal and vertical).

FLEXPART[12]: The FLEXPART (Version 6.2; Siebert, 2006; Stohl et al., 2005[13]) model is a Lagrangian particle dispersion model developed at the Norwegian Institute for Air Research in the Department of Atmospheric and Climate Research. FLEXPART was originally designed for calculating the long-range and mesoscale dispersion of air pollutants from point sources, such as after an accident in a nuclear power plant. In the meantime FLEXPART has evolved into a comprehensive tool for atmospheric transport modeling and analysis

CAMx[14]: The Comprehensive Air-quality Model with extensions (CAMx; ENVIRON, 2010) is a photochemical grid model (PGM) that simulates inert or chemical reactive pollutants from the local to continental scale. As a grid model, it simulates transport and dispersion using finite difference techniques on a three-dimensional array of grid cells. To treat the near-source dispersion of plumes, CAMx includes a subgrid-scale Lagrangian puff Plume-in-Grid (PiG) module whose mass is transferred to the grid model when the plume size is comparable to the grid size.

CALGRID: The California Mesoscale Photochemical Grid Model (Yamartino, et al., 1989, Scire et al., 1989; Earth Tech, 2005) is a PGM that simulates chemically reactive pollutants from the local to regional scale. As with CAMx, it is a grid model that simulates transport and dispersion using finite differencing techniques on a three-dimensional array of grid cells. CALGRID was originally designed to utilize meteorological fields produced by the CALMET meteorological processor (Scire et al., 2000a), but was updated in 2006 to utilize meteorology and emissions in UAM format (Earth Tech, 2006).

Although up to six LRT dispersion models were run for two of the tracer field experiments, a key component of this study was the evaluation of the CALPUFF model and running CALPUFF with various configurations of its meteorological drivers, CALMET and MMIF to help inform regulatory guidance on the operation of the CALPUFF system. Key to developing insight into the performance of any single model is to evaluate other models when configured similarly and using similar meteorological databases. Table 2-1 summarizes which LRT models were run with the four field study tracer experiments presented in this report.

For the GP80 CALPUFF/CALMET application, numerous CALPUFF sensitivity tests were performed using different configurations of CALMET including with and without MM5 data and use of no observations. A limited set of CALPUFF sensitivity tests were also conducted using different dispersion options. The other LRT models (save CALGRID) results were also evaluated for the 600 km distant arc of receptors, but are not presented in the CALPUFF comparison because this evaluation is based upon the NOAA DATEM statistical framework and is not consistent with how CALPUFF was evaluated by EPA for this experiment in 1998.

12 http://transport.nilu.no/flexpart
13 http://www.atmos-chem-phys.net/5/2461/2005/acp-5-2461-2005.html
14 http://www.camx.com/

The evaluation of the LRT models using the SRL75 tracer data only has results for CALPUFF. Several CALPUFF/CALMET sensitivity tests were run using only meteorological observations, only MM5 data and hybrid MM5 plus meteorological observations. CALPUFF/MMIF was run using 36, 12 and 4 km MM5 data.

Two tracer releases were evaluated using the CAPTEX database, Releases No. 3 and 5. While all of the models listed in Table 2-1 were run for the CAPTEX database, numerous CALMET sensitivity tests were also conducted, including the evaluation of CALMET using various configurations for CAPTEX Release No. 3 and 5 that helped define the EPA-FLM recommended CALMET settings in the August 2009 Clarification Memorandum (EPA, 2009b).

The LRT model intercomparison using the CAPTEX and ETEX databases was done differently than the other two tracer test evaluations. The objective of the ETEX with CAPTEX LRT model evaluation intercomparison was to evaluate the LRT dispersion models using a common meteorological input database. Thus, all LRT models used the same MM5 meteorological inputs.

Table 2-1. Model availability for the four tracer test field experiments.

Model	GP80	SRL75	CAPTEX	ETEX
CALPUFF/CALMET	Yes	Yes	Yes	No
CALMET/MMIF	Yes	Yes	Yes	Yes
SCIPUFF	No	No	Yes	Yes
HYSPLIT	No	No	Yes	Yes
FLEXPART	No	No	Yes	Yes
CAMx	No	No	Yes	Yes
CALGRID	No	No	Yes	No

2.3 RELEATED PREVIOUS STUDIES

Over the years there have been numerous studies that have evaluated dispersion models using tracer test and other field study databases. In fact, much of the early development of Gaussian plume dispersion formulation was assisted by radioactive ambient field data (Slade, 1968). The development and evaluation of the AERMOD steady-state Gaussian plume model used almost 20 near-source field study datasets[15]. The discussion below is limited to long range transport (LRT) dispersion model evaluations that have been related to the development of the CALPUFF modeling system, which in 2003 was identified as the EPA recommended regulatory LRT model for far-field (> 50 km) air quality modeling of chemically inert compounds (EPA, 2003).

2.3.1 1986 Evaluation of Eight Short-Term Long Range Transport Models

EPA sponsored a study to evaluate 8 LRT models using the GP80 tracer field experiment and Krypton-85 releases from the Savannah River Laboratory (SRL; Telegadas et al., 1980) databases (Policastro et al., 1986). The eight models were MESOPUFF, MESOPLUME, MSPUFF, MESOPUFF-II, MTDDIS, ARRPA, RADM and RTM-II. MESOPUFF, MSPUFF and MESOPUFF-II are Lagrangian puff models that all have their original basis on the MESOPUFF model. MESOPLUME is a Lagrangian plume segment model. MTDDIS is a variable trajectory model that also uses the Gaussian puff formulation. ARRPA is a single-source segmented plume model. RADM and RTM-II are Eulerian grid models. Model performance was evaluated by graphical and statistical methods. The primary means for the evaluation of model performance was the use of the American Meteorological Society (AMS) statistics (Fox, 1981). The AMS statistics recommends

15 http://www.epa.gov/ttn/scram/dispersion_prefrec.htm#aermod

that performance evaluation be based on comparisons of the full set of predicted/observed data pairs as well as the highest predicted and observed values per event and the highest N values (e.g., N=10) unpaired in space or time that represents the highest end of the concentration distribution.

Six of the eight LRT models were applied to both the GP80 and SRL75 experiments. The ARRPA model could only be applied to the GP80 database and the MTDDIS model could only be applied to the SRL75 database. Model performance was generally consistent between the two tracer databases and was characterized by three features:

- A spatial offset of the predicted and observed patterns.
- A time difference between the predicted and observed arrival of the plumes to the receptors.
- A definite angular offset of the predicted and observed plumes that could be as much as 20-45 degrees.

The LRT models tended to underestimate the horizontal spreading of the plume at ground level resulting in too high peak (centerline) concentrations when compared to the observations. For the Lagrangian models this is believed to be due to using sigma-y dispersion (Turner) curves that are representative of near-source and are applied for longer (> 50 km) downwind distances. The spatial and angular offsets resulted in poor correlations and large bias and error between the predicted and observed tracer concentrations when paired by time and location. However, when comparing the maximum predicted and observed concentrations unmatched by time and location, the models performed much better. For example, the average of the highest 25 predicted and observed concentrations (unpaired in location and time) were within a factor of two for six of the eight models evaluated (MESOPUFF, MESOPLUME, MESOPLUME, MTDDIS, ARRPA and RTM-II). The study concluded that the LRT models' observed tendency to over-predict the observed peak concentrations errs on the conservative side for regulatory applications. However, this over-prediction must be weighed against the general tendency of those models to underestimate horizontal spreading and to predict a plume pattern that is spatially offset from the observed data.

2.3.2 Rocky Mountain Acid Deposition Model Assessment Project – Western Atmospheric Deposition Task Force

A second round of LRT model evaluations was conducted as part of the Rocky Mountain Acid Deposition Model Assessment (EPA, 1990). In this study, the eight models from the 1986 evaluation were compared against a newer model, the Acid Rain Mountain Mesoscale Model (ARM3) (EPA, 1988). The statistical evaluation considered data paired in time/space and also unpaired in time/space equally. In this study, it was found that the MESOPUFF-II (Scire et al., 1984a, and 1984b) model performed best when using unpaired data, and that the ARM3 model performed best when using paired data. A final model score was assigned on the basis of a model's performance relative to the others in each of the areas (paired in time/space, unpaired in time/space, and paired in time, not space) for each of two tracer releases considered.

The primary objective was to assemble a mesoscale air quality model based primarily on models or model components available at the time for use by state and federal agencies to assess acid deposition in the complex terrain of the Rocky Mountains.

2.3.3 Comparison of CALPUFF Modeling Results to Two Tracer Field Experiments

The CALPUFF dispersion model (CALPUFF Version 4) was compared against tracer measurements from the GP80 and SRL75 field study experiments in a study conducted by James O. Paumier and Roger W. Brode (EPA, 1998a). The evaluation approach adopted the method used by Irwin (1997) that examined fitted predicted and observed plume concentrations across an arc of receptors. Meteorological inputs for the CALPUFF model were based on CALMET using observed surface and upper-air meteorological data. The study found that for these three tracer releases, there was overall agreement between the observed times and modeled times for both the time required for the plume to reach the receptor arc, as well as the time to pass completely by the arc. However, the transport direction had an angular offset. For the GP80 100 km arc, CALPUFF underestimated the lateral dispersion of the plume and overestimated the plume peak as well as the cross wind integrated concentration (CWIC) average concentrations across the plume; the lateral dispersion and CWIC were within a factor of two of the observed value and the CALPUFF fitted plume centerline concentrations was 2 to 2½ times greater than observed. Very different model performance was seen at the 600 km arc of receptors with simulated maximum and CWIC that were 2 to 2 ½ times lower than observed and lateral dispersion that was 2½ to 3½ times greater than observed.

2.3.4 ETEX and ATMES-II

After the Chernobyl accident in April 1986, the Atmospheric Transport Model Evaluation Study (ATMES) was initiated to compare the evolution of the radioactive cloud from Chernobyl with predictions by mathematical models for atmospheric dispersion, using as input the estimated source term and the meteorological data for the days following the accident. Considerable work was undertaken by ATMES in order to identify and make available the databases of radionuclide concentration in air measured after the Chernobyl accident and of meteorological conditions that occurred. The ATMES LRT dispersion modeling and model evaluation was conducted in the 1989-1990 time period. The performance of the LRT models to predict the observed radionuclides was hampered by the poor characterization of the emissions release from Chernobyl.

In May 1989, it was proposed to carry out a massive tracer experiment in Europe designed to address the weaknesses of ATMES modeling. In the following year the proposal was analyzed and modified to adapt it to the European context, and to take account of the ATMES results, as they became available. The experiment was named ETEX[16], European Tracer Experiment. It was designed to test the readiness of interested services to respond in the case of an emergency, to organize the tracer release and compile a data set of measured air concentrations and to investigate the performance of long range atmospheric transport and dispersion models using that data set.

The period 15 October-15 December 1994 was selected as the possible window for the two tracer experiments as part of ETEX. The first release started at 1600 UTC on October 23, 1994, and lasted 11 hours and 50 minutes. 340 kg of PMCH (perfluoromethylcyclohexane) tracer were released in Monterfil, France (48° 03’ 30’’ N, 2° 00’ 30’’ W) at an average flow rate of 8.0 g/s. The second ETEX tracer experiment started at 1500 UTC on November 14, 1994 and lasted for 9 hours and 45 minutes and released 490 kg of PMCP (perfluromethlcyclopentane) from Monterfil for an average release rate of 11.58 g/s.

16 http://rem.jrc.ec.europa.eu/etex/

The ETEX real-time LRT modeling phase was performed in parallel with the tracer field experiment. When the release started, 28 modeling groups were notified of the starting time, source location, and emission rate. They ran their LRT models in real-time to predict the evolution of the tracer cloud, and their predictions were sent as soon as they were available to the statistical evaluation team at JRC-Ispra. The capability of providing these predictions in real-time was considered to be an important factor, as well as the model performance itself. Therefore, only those institutions that had access to a meteorological model or that received real-time forecasts from a meteorological centre could participate.

The analysis of these calculations could not distinguish the differences between predictions and measurements arising from dispersion model inadequacies as opposed to those arising from the meteorological forecasts used. Almost two years after the ETEX releases, the ATMES-II modeling exercise was launched to evaluate the LRT models in hindcast mode. ATMES-II participants were required to calculate the concentration fields of the first ETEX tracer experiment using ECMWF analyzed meteorological data as input to their own dispersion models. Any institution operating a long-range dispersion model could now participate whether or not it had real-time access to the meteorological data, and the number of participants (49) was increased compared to the ETEX real-time modeling exercise, even though not all of the original ETEX modelers took part in ATMES-II.

Contrary to ETEX, the differences between the measured and modeled concentration fields in ATMES-II could be more directly related to the dispersion simulation, thanks to the use of the same meteorological fields. However, even in this case, discrepancies between models were due not only to the calculation of dispersion, but also to the different ways in which the meteorological information was used. Moreover, ATMES-II modelers could also submit results obtained with a meteorological analysis different from that of ECMWF.

As for the statistical analysis in ETEX real-time modeling exercise, the analysis of ATMES-II model results was divided into time, space and global analyses. The same statistical indices of the first ETEX release were computed in the time analysis, while for the other two analyses some different indices were computed following the requirements of modelers, and the experience gained during the two real-time exercises.

In a general, a substantial improvement in the models' performance in the ATMES-II modeling was seen compared to the ETEX real-time modeling phase for the common statistical indices.

When comparing the results of the ATMES-II statistical analysis with those for the real-time simulation of the first ETEX release, a general improvement of the model performances for those who took part in both exercises is evident. This can be explained by the better resolution of the meteorological fields used, the availability of the measured values of tracer concentration that allowed participants to tune some parameters in their long-range dispersion model and the time elapsed between the two exercises (2 years) during which improvements in model formulation and application procedures took place.

<u>Spatial Analysis</u>: In ATMES-II the spatial analysis consisted of the calculation of the Figure of Merit in Space (FMS) at 12, 24, 36, 48, 60 hours after the release start. The FMS is the ratio of the spatial distribution of the overlap of the predicted and observed tracer pattern to the union of the predicted and observed tracer pattern and is expressed as a percent (note that all statistical metrics are defined in detail in Section 2.4). A big improvement could be observed in the models' FMS compared to the ETEX real-time exercise for the first release. For instance, at 36 hours in ATMES-II all the models had a non-zero FMS, half of the models had FMS>45% and

a quarter of the models had FMS>55%, with a maximum FMS value of 71%. In ETEX, at 36 hours one tenth of the models had a zero FMS (i.e., no overlap of the predicted and observed tracer cloud) and a quarter had an FMS>45%, with a maximum FMS of 67%. At 60 hours in ATMES-II half of the models (against only a quarter of the models of ETEX) had a FMS>30% and the maximum FMS was 58%, while the maximum FMS for ETEX models was 52%.

Temporal Analysis: The temporal analysis was carried out at two arcs of receptors at distances of approximately 600 and 1,200-1,400 km from the release point. In general, the LRT models were better at predicting the time of arrival, duration and peak concentration of the tracer cloud for the central stations of the two arcs, and less satisfactory for the external stations. The Figure of Merit in Time (FMT, see Section 2.4 for definition) the best performances were observed for the central stations of the two arcs. For all the stations selected for the time analysis, FMT of models in ATMES-II improved when compared to the first ETEX release exercise.

Global Statistics: The global statistical indexes also indicate a general improvement of models' performance in ATMES-II compared to the ETEX real time modeling exercise. For instance, only eight models out of 49 (16%) had a bias higher than 0.4 ngm^{-3} (400 pg/m^3) in absolute value; the number of models above the same threshold in ETEX real time was 24 out of the 28 (86%) participants. Almost all models showed a satisfactory agreement with the measured values. However, few models were distinguished by a particularly good (or bad) performance in all respects. More than half of the models showed a relatively small error (NMSE), indicating a limited spread of the predictions around the corresponding measurements. Again, while in the ETEX real-time exercise only four models had an NMSE less than 100, 42 models were below this threshold in ATMES-II. Improvements compared to ETEX could also be seen in the number of predicted and observed pairs within a factor of 2 (FA2) and 5 (FA5) of each other; whereas in ATMES-II half of the models had FA5>45%, in ETEX no model reached that value. There was no negative Pearson correlation coefficient, with the best models showing values slightly less than 0.7.

Conclusions: The three main original objectives of ETEX as follows:

- to test the capability of institutes involved in emergency response to produce predictions of the cloud evolution in real-time;
- to evaluate the validity of their predictions; and
- to assemble a database that allows the evaluation of long-range atmospheric dispersion models.

The ETEX study has formulated the following conclusions:

- The objectives stated in the project design were met.
- ETEX demonstrated the feasibility of conducting a continental scale tracer experiment across Europe using the perfluorocarbon tracer technique.
- There is a large number of institutes that can (and will in the event of a real accident) predict the long-range atmospheric dispersion of a pollutant cloud.
- The rapidity of LRT dispersion modeling groups in predicting the tracer cloud evolution and transmitting the results to a central point was excellent.
- Regarding the quality of the predictions, differences between observations and calculations of 3 to 6 hours in arrival time and a factor of 3 in maximum airborne concentrations at ground level should be viewed as the best achievable with current LRT models.
- The simulation of cloud dispersion at short and mesoscale distances seems to have considerable influence on the long-range cloud development.
- The transition of the dispersion scales from local to long-range modeling should be investigated in more detail.
- ETEX assembled a unique experimental database of tracer concentrations and meteorological data accessible via the Internet.
- ETEX created widespread interest and resulted in considerable dispersion model development as well as the reinforcement of communication and collaboration between national institutes and international organizations.
- The ETEX network of national institutes and international organizations should be maintained and improved to continue model development and demonstrate the technical capability necessary to support emergency management in real cases.
- Further investigations are needed to determine the quality of predictions under complex meteorological conditions, and to quantify the uncertainty of models for emergency management.

2.3.5 Data Archive of Tracer Experiments and Meteorology (DATEM)

The Data Archive of Tracer Experiments and Meteorology (DATEM[17]) is not a single particular study but an archive of tracer experiment and meteorological data and suggested procedures for evaluating LRT dispersion models using atmospheric tracer data (Draxler, Heffter and Rolph, 2002). The DATEM archive currently incorporates data from five long-range dispersion experiments, which represent a collection of more than 19,000 air concentration samples, re-analysis fields from the National Center for Atmospheric Research (NCAR) / National Centers for Environmental Prediction (NCEP) re-analysis project, and statistical analysis programs based upon the ATMES-II evaluation of ETEX. All the emissions and sampling data are in space delimited text files, easily used by FORTRAN programs or imported into any spreadsheet. Meteorological data fields have been reformatted for use by HYSPLIT and are available for download. The statistical programs are all written in FORTRAN and include PC executables with the source code so that they can be compiled on other platforms.

The five long range transport tracer field experiments whose atmospheric and meteorological data reside on the DATEM website are as follows:

17 http://www.arl.noaa.gov/DATEM.php

ACURATE: The Atlantic Coast Unique Regional Atmospheric Tracer Experiment (ACURATE) operating during 1982-1983 and consisted of measuring Krypton^{85} air concentrations from emissions out of the Savannah River Plant in South Carolina (Heffter et al., 1984). 12- and 24-hour average samples were collected for 19 months at five monitoring sites that were 300 to 1,000 km from the release point.

ANATEX: The Across North America Tracer Experiment (ANATEX) consisted of 65 releases of three types of Perflurocarbon Tracers (PFTs) that were released from Glasgow, Montana and St. Cloud, Minnesota over three months (January-March, 1987). The PFTs were measured at 75 monitoring sites covering the eastern U.S. and southeastern Canada (Draxler and Heffter, Eds, 1989).

CAPTEX: The Cross Appalachian Tracer Experiment (CAPTEX) occurred during September and October, 1983 and consisted of 4 PFT releases from Dayton, Ohio and 2 PFT releases from Sudbury, Ontario, Canada (Ferber et al., 1986). Sampling occurred at 84 sites from 300 to 800 km from the PFT release sites.

INEL74: The Idaho National Engineering Laboratory (INEL74) experiment consisted of releases of Krypton^{85} during February-March, 1974 with sampling taken at 11 sites approximately 1,500 km downwind stretching from Oklahoma City to Minneapolis (Ferber et al., 1977; Draxler, 1982).

GP80: The 1980 Oklahoma City Great Plains (GP80) consisted of two releases of PFTs on July 8 and July 11, 1980. The first PFT release was sampled at two arcs at a distance 100 km and 600 km with 10 and 35 monitoring sites on each arc, respectively (Ferber et al., 1981). The second PFT release was only monitored at a distance of 100 km at the corresponding 10 sites from the July 8 release.

The DATEM website also includes a model evaluation protocol for evaluating LRT dispersion models using tracer field experiment that was designed following the procedures by Mosca et al. (1998) for the ATMES-II study and Stohl et al., (1998). The DATEM model evaluation protocol has four broad categories of model evaluation:

1. Scatter among paired measured and calculated values;
2. Bias of the calculations in terms of over- and under-predictions;
3. Spatial distribution of the calculation relative to the measurements; and
4. Differences in the distribution of unpaired measured and calculated values.

A recommended set of statistical performance measures are provided along with a FORTRAN program (statmain) to calculate them. The DATEM recommendations have been adopted in this study and more details on the DATEM recommended ATMES-II model evaluation approach is provided in section 2.4.3.

2.4 MODEL PERFORMANCE EVALUATION APROACHES AND METHODS

2.4.1 Model Evaluation Philosophy

To date, no specific guidance has been developed by the USEPA for evaluating LRT models. According to EPA's *Interim Procedures for Evaluating Air Quality Models (Revised)*, the rationale for selecting a particular data group combination depends upon the objective of the performance evaluation. For this it is necessary to translate the regulatory purposes of the intended use of the model into performance evaluation objectives (EPA, 1984; Britter, et al., 1995). Under the approach for both the 1986 and 1998 EPA LRT model evaluation projects, no particular emphasis was placed on any data group combination or set of statistical measures.

In this study we expand the LRT model performance philosophy to include spatial, correlation/scatter, bias, error and frequency distribution performance metrics.

In their regulatory use within the United States, LRT models are used to predict impacts of criteria pollutants for national ambient air quality standards (NAAQS) and Prevention of Significant Deterioration of Air Quality (PSD) Class I increments. Additionally, Federal Land Management Agencies rely upon the same LRT models in the PSD program for estimates of chemical transformation and removal to assess impacts on air quality related values (AQRV's) such as visibility and acid deposition. The chemistry of aerosol formation is highly dependent upon the spatial and temporal variability of meteorology (e.g., relative humidity and temperature) and precursors (e.g., ammonia).

Recognizing the need for developing an evaluation approach that reflects the intended regulatory uses of LRT models, the model performance evaluation approach of Mosca et al., (1998) and Stohl et al., (1998) used in the ATMES-II study and recommended by DATEM (Draxler, Heffter and Rolph, 2002) was adopted for this study.

We have also included elements of the plume fitting evaluation approach of Irwin (1997) for comparison with the results from the original 1998 tracer evaluation study (EPA, 1998a). The Irwin model evaluation approach is only applicable when you have an arc of receptors at a given distance downwind of the source so that a cross plume distribution and dispersion statistics can be generated. Whereas, the ATMES-II is more applicable when you have receptors spread over a large region and can calculate statistical parameters related to the predicted and observed distribution of the tracer concentrations. Accordingly, we use the Irwin plume fitting statistical evaluation approach for the GP80 and SRL75 tracer experiments whose receptors were defined along arcs at a given distance from the source and we used the ATMES-II statistical evaluation approach for the CAPTEX and ETEX tracer experiments that had receptors that were defined across a broad area.

2.4.2 Irwin Plume Fitting Model Evaluation Approach

Irwin (1997) focused his evaluation of the CALPUFF modeling system on its ability to replicate centerline concentrations and plume widths, with more emphasis placed upon these factors than data such as modeled/observed plume azimuth, plume arrival time, and plume transit time. The Great Plains and Savannah River tracer CALPUFF evaluations (EPA, 1998a) followed the tracer evaluation methodology of the Idaho National Engineering Laboratory (INEL) tracer study conducted on April 19, 1977 near Idaho Falls, Idaho (Irwin, 1997).

Irwin examined CALPUFF performance by calculating the cross-wind integrated concentration (CWIC), azimuth of plume centerline, and the second moment of tracer concentration (lateral dispersion of the plume [σ_y]). The CWIC is calculated by trapezoidal integration across average monitor concentrations along the arc. By assuming a Gaussian distribution of concentrations along the arc, a fitted plume centerline concentration (Cmax) can be calculated by the following equation:

$$\text{Cmax} = \text{CWIC}/[(2\pi)^{1/2}\sigma_y] \qquad (2\text{-}1)$$

The measure σ_y describes the extent of plume horizontal dispersion. This is important to understanding differences between the various dispersion options available in the CALPUFF modeling system. Additional measures for temporal analysis include plume arrival time and the plume transit time on arc. Table 2-2 summarizes the statistical metrics used in the Irwin fitted Gaussian plume evaluation methodology.

Table 2-2. Model performance metrics from Irwin (1997) and 1998 EPA CALPUFF Evaluation (EPA, 1998a).

Statistics	Description
Spatial	
Azimuth of Plume Centerline	Comparison of the predicted angular displacement of the plume centerline from the observed centerline on the arc
Plume Sigma-y	Comparison of the predicted and observed fitted plume widths (i.e., dispersion rate)
Temporal	
Plume Arrival Time	Compare the time the predicted and observed tracer clouds arrives on the receptor arc
Transit Time on Arc	Compare the predicted and observed residence time on the receptor arc
Performance	
Crosswind Integrated Concentration	Compares the predicted and observed average concentrations across the receptor arc (CWIC)
Observed/Calculated Maximum	Comparison of the predicted and observed fitted Gaussian plume centerline (maximum) concentrations (Cmax) and maximum concentration at any receptor along the arc Omax)

The measures employed by Irwin (1997) and EPA (1998a) provide useful diagnostic information about the performance of LRT modeling systems, such as CALPUFF, but they do not always lend themselves easily to spatiotemporal analysis or direct model intercomparison.

For tracer studies such as the Great Plains Tracer Experiment and Savannah River where distinct arcs of monitors were present, the Irwin plume fitting evaluation approach was used in this study.

2.4.3 ATMES-II Model Evaluation Approach

The model evaluation methodology employed for this study was designed following the procedures of Mosca et al. (1998) and Draxler et al. (2002). Mosca et al. (1998) defined three types of statistical analyses:

- Spatial Analysis: Concentrations at a fixed time are considered over the entire domain. Useful for determining differences spatial differences between predicted and observed concentrations.
- Temporal Analysis: Concentrations at a fixed location are considered for the entire analysis period. This can be useful for determining differences between the timing of predicted and observed tracer concentrations.
- Global Analysis: All concentration values at any time and location are considered in this analysis. The global analysis considers the distribution of the values (probability), overall tendency towards overestimation or underestimation of measured values (bias and error), measures of scatter in the predicted and observed concentrations and measures of correlation.

2.4.3.1 Spatial Analysis

To examine similarities between the predicted and observed ground level concentrations, the Figure of Merit in Space (FMS) is calculated at a fixed time and for a fixed concentration level. The FMS is defined as the ratio between the overlap of the measured (A_M) and predicted (A_P) areas above a significant concentration level and their union:

$$FMS = \frac{A_M \cap A_P}{A_M \cup A_P} \times 100\% \qquad (2\text{-}2)$$

The more the predicted and measured tracer clouds overlap one another, the greater the FMS values are. A high FMS value corresponds to better model performance, with a perfect model achieving a 100% FMS score.

Additional spatial performance measures of Probability Of Detection (POD), False Alarm Rate (FAR), and Threat Score (TS) are also used. Typically used as a method for meteorological forecast verification, these three interrelated statistics are useful descriptions of an air quality model's ability to spatially forecast a certain condition. The forecast condition for the model is the predicted concentration above a user-specified threshold (at the 0.1 ngm^{-3} (100 pgm^{-3}) level for ATMES-II study). In these equations:

- "a" represents the number of times a condition that has been forecast, but was not observed (false alarm)
- "b" represents the number of times the condition was correctly forecasted (hits)
- "c" represents the number of times the nonoccurrence of the condition is correctly forecasted (correct negative); and
- "d" represents the number of times that the condition was observed but not forecasted (miss).

The FAR (Equation 2-3) is described as a measure of the percentage of times that a condition was forecast, but was not observed. The range of the score is 0 to 1 or 0% to 100%, with the ideal FAR score of 0 or 0% (i.e., there are observed tracer concentrations at a monitor/time every time the model predicts there is a tracer concentration at that monitor/time).

$$FAR = \left(\frac{a}{a+b} \right) \times 100\% \qquad (2\text{-}3)$$

The POD is a statistical measure which describes the fraction of observed events of the condition forecasted was correctly forecasted. Equation 2-4 shows that POD is defined as the ratio of "hits" to the sum of "hits" and "misses." The range of the POD score is 0 to 1 (or 0%to 100%), with the ideal score of 1 (or 100%).

$$POD = \left(\frac{b}{b+d} \right) \times 100\% \qquad (2\text{-}4)$$

The TS (Equation 2-5) is described as the measure describing how well correct forecasts corresponded to observed conditions. The TS does not consider correctly forecasted negative conditions, but penalizes the score for both false alarms and misses. The range of the TS is the same as the POD, ranging from 0 to 1 (0% to 100%), with the ideal score of 1 (100%).

$$TS = \left(\frac{b}{a+b+d} \right) \times 100\% \qquad (2\text{-}5)$$

2.4.3.2 Temporal Analysis

In Section 2.4.1 temporal statistics related to the timing of when the predicted and observed tracer arrives at a monitor or arc of monitors, its residence time over a monitor (or arc) and when the tracer leaves the monitor (or arc) were discussed. Another temporal analysis statistics is the Figure of Merit in Time (FMT), which is analogous to the FMS only it is calculated at a fixed location (x) rather than a fixed time as the FMS. The FMT evaluates the overlap between the measures (M) and predicted (P) concentration at location x and time t_j. The FMT is normalized to the maximum predicted or measured value at each time interval and is expressed as a percentage value in the same manner as the FMS (Mosca et al., 1998).

$$FMT(\bar{x}) = \frac{\sum_j \min\{M(\bar{x}, t_j), P(\bar{x}, t_j)\}}{\sum_j \max\{M(\bar{x}, t_j), P(\bar{x}, t_j)\}} \times 100\% \qquad (2\text{-}6)$$

The FMT is sensitive to both differences between measured and predicted and any temporal shifts that may occur.

2.4.3.3 Global Analysis

Following Draxler et al. (2002), four broad categories were used for global analysis of model evaluation. These broad categories are: (1) scatter; (2) bias; (3) spatial distribution of predictions relative to measurements; and (4) differences in the distribution of unpaired measured and predicted values. One or more statistical measures are used from each of the four categories in the global analysis. These include the percent over-prediction, number of calculations within a factor of 2 and 5 of the measurements, normalized mean square error, correlation coefficient, bias, fractional bias, figure of merit in space, and the Kolmogorov-Smirnov parameter representing the differences in cumulative distributions (Draxler et al., 2002).

Factor of Exceedance: In the scatter category, better model performance is observed when the Factor of Exceedance (FOEX) measure is close to zero and FA2 (described next) has a high percentage. A high positive FOEX and high percentage of FA5 would indicate a model's tendency towards over-prediction when compared to observed values.

$$FOEX = \left[\frac{N_{(P_i > Ni_i)}}{N} - 0.5 \right] \times 100\% \qquad (2\text{-}7)$$

Where, N in the numerator is the number of pairs when the prediction (P) exceeds the measurement (M) and the N in the denominator is the total number of pairs in the evaluation. In FOEX, all 0-0 pairs are excluded from the analysis. FOEX can range from -50% to +50% with a perfect model receiving a 0% value.

Factor of α (FAα): FAα represents the percentage of predicted values that are within a factor of α, where we have used α = 2 or 5. As with FOEX, in FAα all 0-0 pairs are excluded.

$$FA\alpha = \left[\frac{N\left(y - y0 = \left[x - x0\right]\alpha\right)}{N} \right] \times 100 \qquad (2\text{-}8)$$

Normalized Mean Squared Error (NMSE): Normalized mean squared error is the average of the square of the differences divided by the product of the means. NMSE gives information about the deviations, but does not yield estimations of model over-prediction or under-prediction.

$$NMSE = \frac{1}{N\overline{P}\overline{M}} \sum \left(P_i - M_i\right)^2 \qquad (2\text{-}9)$$

Pearson's Correlation Coefficient (PCC): Also referred to as the linear correlation coefficient, its value ranges between -1.0 and +1.0. A value of +1.0 indicates "perfect positive correlation" or having all pairings of (M_i, P_i) lay on straight line on a scatter diagram with a positive slope. Conversely, a value of -1.0 indicates "perfect negative correlation" or having all pairings of (M_i, P_i) lie on a straight line with a negative slope. A value of near 0.0 indicates the clear absence of relationship between the model predictions and observed values.

$$R = \frac{\sum_i \left(M_i - \overline{M}\right) \bullet \left(P_i - \overline{P}\right)}{\left[\sqrt{\sum \left(M_i - \overline{M}\right)^2}\right]\left[\sqrt{\sum \left(P_i - \overline{P}\right)^2}\right]} \qquad (2\text{-}10)$$

Fractional Bias (FB): Calculated as the mean difference in prediction minus observation pairings divided by the average of the predicted and observed values.

$$FB = 2\overline{B} / \left(\overline{P} + \overline{M}\right) \qquad (2\text{-}11)$$

Kolmogorov-Smirnov Parameter (KS): The KS parameter is defined as the maximum difference between two cumulative distributions. The KS parameter provides a quantitative estimate where C is the cumulative distribution of the measured and predicted concentrations over the range of k. The KS is a measure of how well the model reproduces the measured concentration distribution regardless of when or where it occurred. The maximum difference between any two distributions cannot be more than 100%.

$$KS = Max\left|C\left(M_k\right) - C\left(P_k\right)\right| \qquad (2\text{-}12)$$

RANK: Given the large number of metrics, a single measure describing the overall performance of a model could be useful. Stohl et al. (1998) evaluated many of the above measures and

discovered ratio based statistics such as FA2 and FA5 were highly susceptible to measurement errors. Draxler proposed a single metric, which he calls RANK, which is the composite of one statistical measure from each of the four broad categories.

$$RANK = \left|R^2\right| + \left(1 - \left|FB/2\right|\right) + FMS/100 + \left(1 - KS/100\right) \qquad (2\text{-}13)$$

The final score, model rank (*RANK*), provides a combined measure to facilitate model intercomparison. RANK is the sum of four of the statistical measures for scatter, bias, spatial coverage, and the unpaired distribution. RANK scores range between 0.0 and 4.0 with 4.0 representing the best model ranking. Using this measure allows for direct intercomparison of models across each of the four broader statistical categories.

2.4.3.4 Treatment of Zero Concentration Data

One issue in the performance evaluation was how to treat zero concentration data. Mosca et al. (1998) filtered the ETEX observational dataset by only retaining non-zero data and zero data within two sample time intervals (6 hours) of the arrival and departure times of the tracer cloud along with any zero observations in between these two time points. Stohl (1998) employed a Monte Carlo approach by adding normally distributed “random errors” to the original values to test the sensitivity of certain statistical measures to zero or near zero values. Stohl (1998) identified that certain statistical parameters may be sensitive to small variations in measurements when using “zero” or near “zero” background concentration data. While the inclusion of “zero” data creates concern about the robustness of certain statistical measures, especially ratio based statistics, there was also concern that only examining model statistics at locations where the tracer cloud was observed provides a limited snapshot of a model’s performance at those locations, and did not offer any insight into a model that may show poorer performance by transporting emissions to incorrect locations or advection to correct locations at incorrect times.

While the arguments for “filtering” of data are valid, it is also important to consider additional statistical measures such as the FAR, POD, and TS where all zero data must be considered. All zero data was retained for inclusion in the spatial analysis, but was filtered for the global statistical analysis. The approach used in this project differs from the approach used by Draxler et al. (2001) in that all zero-zero pairs are considered in their analysis of HYSPLIT performance.

3.0 1980 GREAT PLAINS FIELD STUDY

3.1 DESCRIPTION OF 1980 GREAT PLAINS FIELD STUDY

LRT tracer test experiments were conducted in 1980 with the release of a perfluorocarbon and sulfur hexafluoride tracers from the National Oceanic and Atmospheric Administration (NOAA) National Severe Storms Laboratory (NSSL) in Norman, Oklahoma (Ferber et al., 1981). Two arcs of monitoring sites were used to sample the tracer plumes; an arc of 30 samplers with a 4-5 km spacing located approximately 100 km from the release point that sampled at 45 minute intervals and an arc of 38 samplers through Nebraska and Missouri located approximately 600 km from the release site that sampled at an hourly interval. Figure 3-1 displays the locations of the tracer release site and the monitoring sites on the arcs that are 100 km and 600 km downwind of the source. Two experiments were conducted, one on July 8, 1980 that included both the 100 km and 600 km sampling arcs and one on July 11, 1980 that only included the 100 km sampling arc. The July 8, 1980 tracer field experiment and subsequent Perfluoro-Dimethyl-cyclohexane (PDCH) observed concentrations were used in this model evaluation study. The PDCH tracer was released over a three-hour period from 1900-2200 GMT (1400-1700 CDT) on July 8, 1980 from an open field near the NOAA/NSSL.

3.2 MODEL CONFIGURATION AND APPLICATION

The CALPUFF modeling system uses a grid system consisting of an array of horizontal grid cells and multiple vertical layers. Two grids must be defined in the CALPUFF model, a meteorological grid and a computational grid. The meteorological grid defines the extent over which landuse, winds, and other meteorological variables are defined in the CALMET simulation. The computational grid defines the extent of the concentration calculations in the CALPUFF simulation, and is required to be identical to or a subset of the meteorological grid. For the GP80 simulations, the computational grid is defined to be identical to the meteorological grid. A third grid, the sampling grid, is optional, and is used by CALPUFF to define a rectangular array of receptor locations. The sampling grid must be identical to or a subset of the computational grid. It may also be nested inside the computational grid (i.e., several sampling grid cells per computational grid cell). For the GP80 applications, a sampling grid identical to the computational grid was used with a nesting factor of one (sampling grid cell size equal to the cell size of the computational grid).

To properly characterize the meteorology for the CALPUFF modeling system, a grid that spans, at a minimum, the distance between source and receptor is required. However, to allow for possible recirculation of puffs that may be transported beyond the receptors and to allow for upstream influences on the wind field, the meteorological and computational domains should be larger than this minimum.

The GP80 site is shown in Figure 3-1. Two arcs of monitors were deployed during the field experiment at 100 and 600 kilometers from the source. For this analysis, two separate modeling domains were defined for simulating tracer concentrations on the 100 km and 600 km receptor arcs. For the 100-kilometer arc, a grid extending approximately from 35º N to 36.5º N latitude and from 96º W to 98.5º W longitude was defined.

CALPUFF was operated for the July 8, 1980 GP80 tracer experiment using meteorological inputs based on CALMET and MMIF. For the CALPUFF simulations using CALMET, a UTM coordinate system was used to be consistent with past CALPUFF evaluations (Policastro et al., 1986; EPA, 1998a).

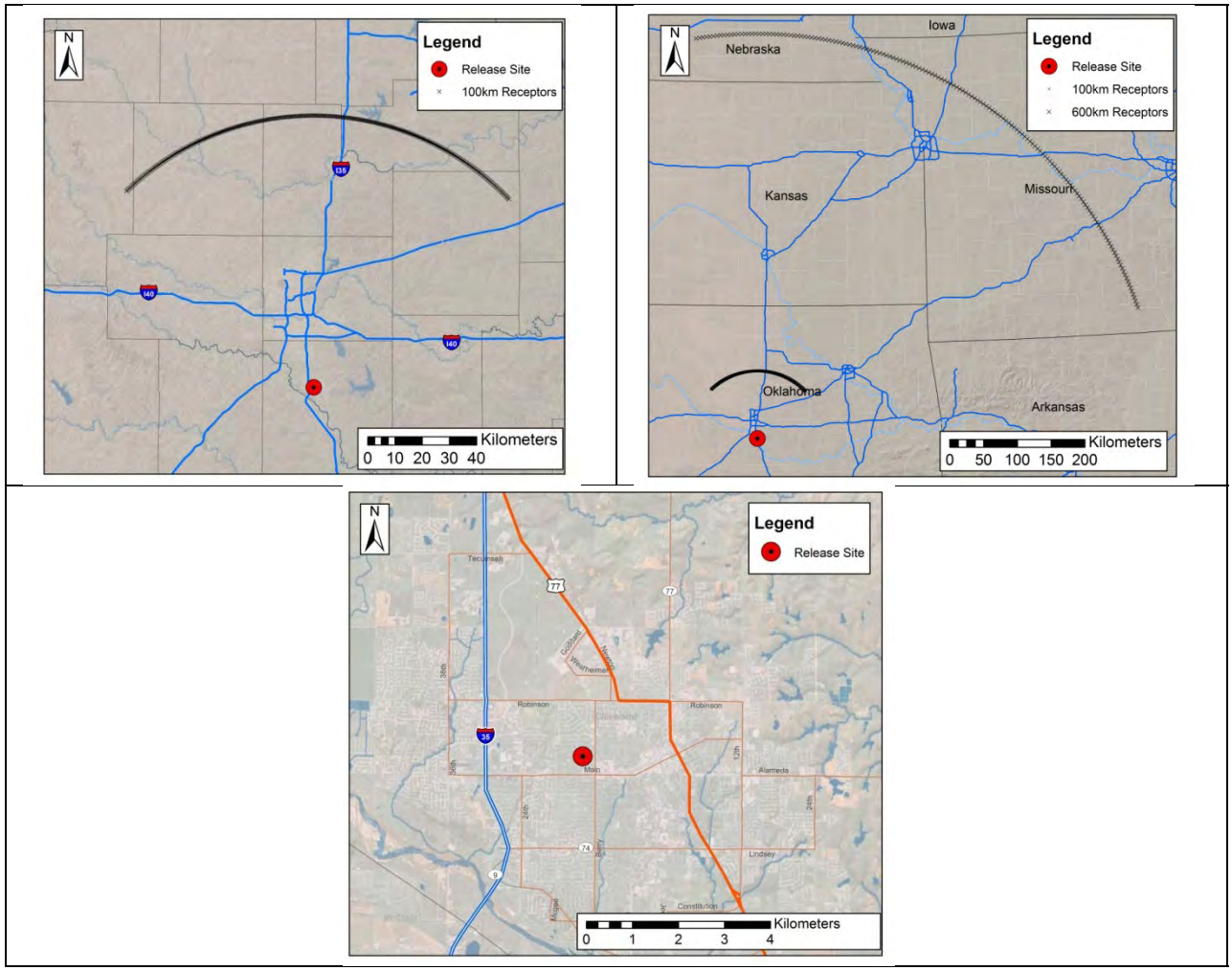


Figure 3-1. Locations of the release site and the 100 km arc (top left) and 600 km arc (top right) of monitoring sites along with a close in view of the release site (bottom) for the GP80 tracer experiment.

3.2.1 CALPUFF/CALMET BASE Case Model Configuration

For the CALPUFF/CALMET 100 km arc BASE case scenario, a 42 by 40 horizontal grid with a 10 km grid resolution was used for the meteorological and computational grids. For the 600 km arc BASE case, the grid extended from approximately 35° N to 42° N latitude and from 89° W to 100° W longitude using a 44 by 40 horizontal grid with a 20 km grid resolution. In addition, a 220 by 200 horizontal grid with a 4 km grid resolution was also used that encompassed both the 100 km and 600 km arcs.

To adequately characterize the vertical structure of the atmosphere, ten vertical layers were defined corresponding to layer heights at 0, 20, 40, 80, 160, 320, 640, 1,200, 2,000, 3,000 and 4,000 meters above ground level (AGL). The vertical layer structure conforms to the recommendations in EPA's August 2009 Clarification Memorandum on recommended settings for CALMET modeling (EPA, 2009b)

The CALMET preprocessor utilizes National Weather Service (NWS) meteorological data and on-site data to produce temporally and spatially varying three dimensional wind fields for CALPUFF. Only NWS data were used for this effort and came from two compact disc (CD) data sets. The first was the *Solar and Meteorological Surface Observation Network* (SAMSON)

compact discs, which were used to obtain the hourly surface observations. The following surface stations were used for each of the field experiments:

Table 3-1. Surface meteorological monitoring sites used in the GP80 CALMET modeling.

State	City
Arkansas	Fort Smith
Illinois	Springfield
Kansas	Dodge City, Topeka, Wichita
Missouri	Columbia, Kansas City, Springfield, St. Louis
Nebraska	Grand Island, Omaha, North Platte
Oklahoma	Oklahoma City, Tulsa
Texas	Amarillo, Dallas-Fort Worth, Lubbock, Wichita Falls

Twice daily upper-air meteorological soundings came from the second set of compact discs, the *Radiosonde Data for North America*. The following stations were used for each of the field experiments:

Table 3-2. Radiosonde monitoring sites used in the GP80 CALMET modeling.

State	City
Arkansas	Little Rock
Illinois	Peoria
Kansas	Dodge City, Topeka
Missouri	Monett
Nebraska	Omaha, North Platte
Oklahoma	Oklahoma City
Texas	Amarillo

Consistent with the August 2009 Clarification Memorandum, some of the CALPUFF/CALMET sensitivity tests utilized CALMET simulations using prognostic meteorological model output as the first-guess wind field for CALMET and then perform the CALMET STEP1 procedures to apply diagnostic effects to the wind fields. CALMET then uses the surface and upper air observations in the objective analysis (OA) phase that blends the meteorological observations with the STEP1 wind field to produce the STEP2 wind field. This method is often referred to as the “hybrid” method.

The terrain and GIS land use data on the original CALPUFF CD were used to define gridded land use data for each field experiment. These data are defined with a resolution of 1/6° latitude and 1/4° longitude. The program PRELND1.EXE, also provided on the CD, was run to extract the data from the GIS data base and map the data to the meteorological domain for each field experiment. The program ELEVAT.EXE (also provided on the CD) was used to process the raw terrain data into average gridded terrain data. The file of terrain and geophysical parameters required by CALMET was constructed from the output files generated by ELEVAT and PRELND1 with additional required records inserted manually to create the final forms of the file for GP80 tracer experiment.

One of the primary purposes of the GP80 experiment was to demonstrate the efficacy of perfluorocarbons as tracers in atmospheric dispersion field studies. Perfluoromonomethylcyclohexane (PMCH) and perfluorodimethylcyclohexane (PDCH) were released during this experiment. For the 1998 EPA CALPUFF evaluation report and the current analyses, the PDCH emission rate was used in the CALPUFF evaluation since the monitoring

data appeared to have a more complete record of PDCH concentrations than the other tracers. Table 3-3 displays the source characteristics for the PDCH tracer used in the CALPUFF modeling of the July 8, 1980 GP80 experiment.

Table 3-3. Source characteristics for the CALPUFF modeling of the July 8, 1980 GP80 experiment.

Source	Release height (m)	Stack diameter (m)	Exit velocity (m/s)	Exit temp. (°K)	Total tracer released (kg)	Length of release (hr)	PDCH emission rate (g s^{-1})
Oklahoma	10.0	1.0 [a]	0.001	Ambient [b] (250)	186	3.0	17.22

Notes:
a – The stack diameter was set to 1 meter in diameter to conform to previous tracer evaluation studies.
b – The exit temperature was assumed to be the same as ambient atmospheric temperature. CALPUFF checks the difference between the stack exit temperature and the surface station temperature. If this difference is less than zero, the difference is set to zero. To insure this condition, an exit temperature of 250 K was input to the model.

In the CALPUFF modeling system, each of the three programs (CALMET, CALPUFF, and CALPOST) uses a control file of user-selectable options to control the data processing. There are numerous options in each and several that can result in significant differences. The following model controls for CALMET and CALPUFF were employed for the analyses with the tracer data.

3.2.1.1 CALMET Options

The following CALMET control parameters and options were chosen for the BASE CALPUFF model simulations. The BASE control parameters and options were chosen to be consistent with two previous CALMET/CALPUFF evaluations (Irwin 1997, and EPA 1998a). The most important CALMET options relate to the development of the wind field and were set as follows for the BASE model configuration:

NOOBS	= 0	Use surface, overwater, and upper air station data
IWFCOD	= 1	Use diagnostic wind model to develop the 3-D wind fields
IFRADJ	= 1	Compute Froude number adjustment effects (thermodynamic blocking effects of terrain)
IKINE	= 1	Compute kinematic effects
IOBR	= 0	Do NOT use O'Brien procedure for adjusting vertical velocity
IEXTRP	= 4	Use similarity theory to extrapolate surface winds to upper layers
IPROG	= 0	Do NOT use prognostic wind field model output as input to diagnostic wind field model (for observations only sensitivity test)
ITPROG	= 0	Do NOT use prognostic temperature data output

Mixing heights are important in the estimating ground level concentrations. The CALMET options that affect mixing heights were set as follows:

IAVEZI	= 1	Conduct spatial averaging
MNDAV	= 3	**100km BASE case** – Maximum search radius (in grid cells) in averaging process
	= 1	**600km BASE Case**
HAFANG	= 30.	Half-angle of upwind looking cone for averaging

ILEVZI	= 1	Layer of winds to use in upwind averaging
DPTMIN	= .001	Minimum potential temperature lapse rate (K/m) in stable layer above convective mixing height
DZZI	= 200	Depth of layer (meters) over which the lapse rate is computed
ZIMIN	= 100	**100km BASE case** – Minimum mixing height (meters) over land
	= 50	**600km BASE Case**
ZIMAX	= 3200	**100km BASE case** – Maximum mixing height (meters) over land, defined to be the top of the modeling domain
	= 3000	**600km BASE Case**

A number of CALMET model control options have no default CALMET values, particularly radii of influence values for terrain and surface and upper air observations. The CALMET options that affect radius of influence were set as follows:

RMAX1	= 20	Minimum radius of influence in surface layer (km)
RMAX2	= 50	Minimum radius of influence over land aloft (km)
RMIN	= 2	**100km BASE case** – Minimum radius of influence in wind field interpolation (km)
	= 0.1	**600km BASE Case**
TERRAD	= 10	Radius of influence of terrain features (km)
RPROG	= 0	Weighting factors of prognostic wind field data (km)

A review of the respective CALMET parameters between the 1998 EPA CALMET/CALPUFF evaluation study using CALMET Version 4.0 and the 600 km BASE case scenario in the current CALMET/CALPUFF evaluation using CALMET Version 5.8 indicates differences in some CALMET options. The differences between the two scenarios are presented below in Table 3-4. All other major CALMET options for 600 km BASE case scenario matched the original 1998 EPA analysis. There were no significant differences between the CALMET parameters 100 km BASE case scenarios for the 1998 (CALMET Version 4.0) and the current evaluation (CALMET Version 5.8).

Table 3-4. CALMET Parameters July 8, 1980 GP80 experiment, 1998 and current 600 km analysis.

CALMET Option	Description	1998 EPA Setup	BASE Setup
MNDAV	Maximum search radius for averaging mixing heights (# grid cells)	3	1
ZIMIN	Minimum overland mixing height (in meters)	100	50
ZIMAX	Maximum overland mixing height (in meters)	3200	3000
RMIN	Minimum radius of influence in wind field interpolation (in km)	2.0	0.1

3.2.1.2 CALPUFF Control Options

The following CALPUFF control parameters, which are a subset of the control parameters, were used. These parameters and options were mostly chosen to be consistent with the 1977 INEL study (Irwin 1997) and 1998 EPA CALPUFF evaluation (EPA, 1998a) studies. This includes the use of the slug option (MSLUG = 1) for the 100 km arc CALPUFF simulations. The use of the slug option is very non-standard for LRT modeling and inconsistent with the EPA-FLM recommendations for far-field CALPUFF modeling. As stated on the CALPUFF website[18]:

> "A slug is simply an elongated puff. For most CALPUFF applications, the modeling of emissions as puffs is adequate. The selection of puffs produces very similar results as compared to the slug option, while resulting in significantly faster computer runtimes. However, there are some cases where the slug option may be preferred. One such case is the episodic time-varying emissions, e.g., an accidental release scenario. Another case would be where transport from the source to receptors of interest is very short (possibly involving sub-hourly transport times). These cases generally involve demonstration of causality effects due to specific events in the near- to intermediate-field."

For the farther out 600 km arc, the slug option was not selected (MSLUG = 0) for the initial CALPUFF sensitivity tests even through the slug option was used in the 1997 INEL and 1998 EPA studies. However, we did investigate the use of the slug option, as well as puff splitting, in a set of additional CALPUFF sensitivity tests for the 600 km arc.

CALPUFF options for technical options (group 2):

MCTADJ	= 0	No terrain adjustment
MCTSG	= 0	No subgrid scale complex terrain is modeled
MSLUG	= 1	**For 100 km BASE case** near-field puffs modeled as slugs
MSLUG	= 0	**For 600 km BASE case** modeled as puffs (i.e., no slugs)
MTRANS	= 1	Transitional plume rise is modeled
MTIP	= 1	Stack tip downwash is modeled
MSHEAR	= 0	**100 km BASE case** – Vertical wind shear is NOT modeled above stack top
	= 1	**600km BASE case**
MSPLIT	= 0	No puff splitting

18 **http://www.src.com/calpuff/FAQ-answers.htm**

MCHEM	= 0	No chemical transformations
MWET	= 0	No wet removal processes
MDRY	= 0	No dry removal processes
MPARTL	= 0	**100 km BASE case –** No partial plume penetration
	= 1	**600 km BASE case**
MPDF	= 0	**100 km BASE case –** PDF not used for dispersion under convective conditions
	= 1	**600 km BASE case**
MREG	= 0	No check made to see if options conform to regulatory Options

Two different values were used for the dispersion parameterization option MDISP:

= 2	Dispersion coefficients from internally calculated sigmas
= 3	PG dispersion coefficients for RURAL areas (PG)

In addition, under MDISP = 2 dispersion option, two different options were used for the MCTURB option that defines the method used to compute turbulence sigma-v and sigma-w using micrometeorological variables:

= 1	Standard CALPUFF routines (CAL)
= 2	AERMOD subroutines (AER)

Several miscellaneous dispersion and computational parameters (group 12) were set as follows:

SYTDEP	= 550.	Horizontal puff size beyond which Heffter equations are used for sigma-y and sigma-z
MHFTSZ	= 0	Do not use Heffter equation for sigma-z
XMXLEN	= 0.1	**100 km BASE case –** Maximum length of slug (in grid cells)
	= 1	**600 km BASE case**
XSAMLEN	= 0.1	**100 km BASE case –** Maximum travel distance of puff/slug (in grid cells) during one sampling step
	= 1	**600 km BASE case**
MXNEW	= 199	**100 km BASE case –** Maximum number of slugs/puffs released during one time step
	= 99	**600 km BASE case**
WSCALM	= 1.0	**100 km BASE case –** Minimum wind speed (m/s) for non-calm conditions
	= 0.5	**600 km BASE case**
XMAXZI	= 3300	**100 km BASE case –** Maximum mixing height (meters)
	= 6000	**600 km BASE case**
XMINZI	= 20	**100 km BASE case –** Minimum mixing height (meters)
	= 0	**600 km BASE case**
SL2PF	= 5	**100 km BASE case –** Slug-to-puff transition criterion factor (= sigma-y/slug length)
	= 10	**600 km BASE case**

A review of the respective CALPUFF parameters between the 1998 EPA CALMET/CALPUFF evaluation study using CALMET Version 4.0 and the 600 km BASE case scenario in the current CALMET/CALPUFF evaluation using CALPUFF Version 5.8 indicates differences in some parameters. The differences between the two scenarios are presented below in Table 3-5. All

other major CALPUFF options for 600 km BASE case scenario matched the original 1998 EPA analysis. There were no significant differences between the CALPUFF parameters 100 km BASE case scenarios for the 1998 (CALPUFF Version 4.0) and the current evaluation (CALPUFF Version 5.8).

Table 3-5. CALPUFF Parameters July 8, 1980 GP80 experiment, 1998 and Current 600km analysis.

CALPUFF Option	Description	1998 EPA Setup	600KM BASE Setup
MSHEAR	Vertical wind shear is modeled above stack top? (0 = No; 1 = Yes)	0	1
MPARTL	Partial plume penetration of elevated inversion? (0 = No; 1 = Yes)	0	1
WSCALM	Minimum wind speed (m/s) for non-calm conditions	1.0	0.5
XMAXZI	Maximum mixing height (meters)	3300	3000
XMINZI	Minimum mixing height (meters)	20	0
XMXLEN	Maximum length of slug (in grid cells)	0.1	1
XSAMLEN	Maximum travel distance of puff/slug (in grid cells) during one sampling step	0.1	1
MXNEW	Maximum number of slugs/puffs released during one time step	199	99
SL2PF	Slug-to-puff transition criterion factor (= sigma-y/slug length)	5.0	10.0

3.2.2 GP80 CALPUFF/CALMET Sensitivity Tests

Table 3-6 and 3-7 describe the CALMET/CALPUFF sensitivity tests performed for the modeling of the 100 km and 600 km arcs of receptors. The BASEA simulations use the same configuration as used in the 1998 EPA CALPUFF evaluation report for the 100 km arc simulations, only updated from CALPUFF Version 4.0 to CALPUFF Version 5.8. For the 600 km arc simulations, the BASEA used the same configuration as the 1998 EPA study only the near-field slug option was not used. The CALMET and CALPUFF parameters of the BASE case simulations were discussed earlier in this section.

The sensitivity simulations are designed to examine the sensitivity of the CALPUFF model performance to choice of grid resolution in the CALMET meteorological model simulation (10 and 4 km for the 100 km arc of receptors and 20 and 4 km for the 600 km arc of receptors), the use of and resolution of the MM5 output data used as input to CALMET (none, 12 and 36 km) and the use of surface and upper-air meteorological observations in CALMET through NOOBS = 0 (“A” series, use surface and upper-air observation), 1 (“B” series, use only surface observations) and 2 (“C” series, don’t use any meteorological observations).

In addition, for each experiment using different CALMET model configurations, three CALPUFF dispersion options were examined as shown in Table 3-8. Two of the CALPUFF dispersion sensitivity tests using dispersion based on sigma-v and sigma-w turbulence values using the CALPUFF (CAL) and AERMOD (AER) algorithms. Whereas the third dispersion test (PG) uses Pasquill-Gifford dispersion coefficients.

Table 3-6. CALPUFF/CALMET experiments for the 100 km arc and GP80 July 8, 1980 tracer experiment.

Experiment	CALMET Grid	MM5 Data	NOOBS	Comment
BASEA	10 km	None	0	Original met observations only configuration (no MM5)
EXP1A	10 km	12 km	0	Aug 2009 IWAQM w/10 km grid using 12 km MM5
EXP1B	10 km	12 km	1	Don't use observed upper-air meteorological data
EXP1C	10 km	12 km	2	Don't use observed surface/upper-air meteorological data
EXP2A	4 km	36 km	0	Aug 2009 IWAQM w/ 4 km grid and 36 km MM5
EXP2B	4 km	36 km	1	No upper-air meteorological data
EXP2C	4 km	36 km	2	No surface or upper-air meteorological data
EXP3A	4 km	12 km	0	Aug 2009 IWAQM w/ 4 km grid and 12 km MM5
EXP3B	4 km	12 km	1	No upper-air meteorological data
EXP3C	4 km	12 km	2	No surface or upper-air meteorological data

Table 3-7. CALPUFF/CALMET experiments for the 600 km arc and GP80 July 8, 1980 tracer experiment.

Experiment	CALMET Grid	MM5 Data	NOOBS	Comment
BASEA	20 km	None	0	Original met observations only configuration (no MM5)
EXP1A	20 km	12 km	0	Aug 2009 IWAQM recommendation using 12 km MM5
EXP1B	20 km	12 km	1	Don't use observed upper-air meteorological data
EXP1C	20 km	12 km	2	Don't use observed surface/upper-air meteorological data
EXP2A	4 km	36 km	0	Aug 2009 IWAQM w/ 4 km grid and 36 km MM5
EXP2B	4 km	36 km	1	No upper-air meteorological data
EXP2C	4 km	36 km	2	No surface or upper-air meteorological data
EXP3A	4 km	12 km	0	Aug 2009 IWAQM w/ 4 km grid and 12 km MM5
EXP3B	4 km	12 km	1	No upper-air meteorological data
EXP3C	4 km	12 km	2	No surface or upper-air meteorological data

Table 3-8. CALPUFF dispersion options examined in the CALPUFF sensitivity tests.

Experiment	MDISP	MCTURB	Comment
CAL	2	1	Dispersion coefficients from internally calculated sigma-v and sigma-w using micrometeorological variables and CALPUFF algorithms
AER	2	2	Dispersion coefficients from internally calculated sigma-v and sigma-w using micrometeorological variables and AERMOD algorithms
PG	3	--	PG dispersion coefficients for rural areas and MP coefficients for urban areas

The CALMET and CALPUFF simulations used for the sensitivity analyses were updated from the BASE case simulations and use the recommended settings for many variables from the EPA August 2009 Clarification Memorandum (EPA, 2009b). A summary of CALMET parameters that changed from the BASE case scenarios for the 100 km and 600 km CALPUFF sensitivity analyses are presented in Tables 3-9 and 3-10. The 100 km CALMET BASE case simulation (BASEA) matched up with the 1998 EPA study CALMET parameters, but did not match up with the EPA-FLM recommendations in the August 2009 Clarification Memorandum. Other than a few CALMET parameters, the 600 km CALMET BASE case simulation (BASEA) matched up well with August 2009 Clarification Memorandum, but not the 1998 EPA study CALMET parameters.

Table 3-9. CALMET wind field parameters for July 8, 1980 GP80 experiment, 100 km analysis.

CALMET Option	2009 EPA-FLM Default	BASEA	EXP1A	EXP1B	EXP1C	EXP2A	EXP2B	EXP2C	EXP3A	EXP3B	EXP3C
NOOBS	0	0	0	1	2	0	1	2	0	1	2
ICLOUD	0	0	0	0	3	0	0	3	0	0	3
IKINE	0	1	0	0	0	0	0	0	0	0	0
IEXTRP	-4	4	-4	-4	1	-4	-4	1	-4	-4	1
IPROG	14	0	14	14	14	14	14	14	14	14	14
ITPROG	0	0	0	1	2	0	1	2	0	1	2
MNDAV	1	3	1	1	1	1	1	1	1	1	1
ZIMIN	50	100	50	50	50	50	50	50	50	50	50
ZIMAX	3000	3200	3000	3000	3000	3000	3000	3000	3000	3000	3000
RMAX1	100	20	100	100	100	100	100	100	100	100	100
RMAX2	200	50	200	200	200	200	200	200	200	200	200
RMIN	0.1	2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
TERRAD	15	10	20	20	20	20	20	20	20	20	20
ZUPWND	1, 1000	1, 2000	1, 1000	1, 1000	1, 1000	1, 1000	1, 1000	1, 1000	1, 1000	1, 1000	1, 1000

Table 3-10. CALMET wind field parameters for July 8, 1980 GP80 experiment, 600 km analysis.

CALMET Option	2009 EPA-FLM Default	BASEA	EXP1A	EXP1B	EXP1C
NOOBS	0	0	0	1	2
ICLOUD	0	0	0	0	3
IKINE	0	1	0	0	0
IEXTRP	-4	4	-4	-4	1
IPROG	14	0	14	14	14
ITPROG	0	0	0	1	2
RMAX1	100	20	100	100	100
RMAX2	200	50	200	200	200
TERRAD	15	10	20	20	20

3.2.3 CALPUFF/MMIF Sensitivity Tests

With the MMIF software tool designed to pass through and reformat the MM5/WRF meteorological model output data for input into CALPUFF, there are not as many options available and hence much fewer sensitivity tests. Note that MMIF adopts the grid resolution and vertical layer structure of the MM5 model and passes through the meteorological variables to CALPUFF so only 36 km and 12 km grid resolutions were examined. The three alternative dispersion options in CALPUFF (CAL, AER and PG) were analyzed using the MMIF 12 km and 36 km CALPUFF inputs. Note that for the 600 km arc CALPUFF/MMIF modeling we found some issues in one of the CALPUFF runs using the AER dispersion option so do not present any AER dispersion results for the 600 km arc modeling; given the similarity in CALPUFF performance using the CAL and AER dispersion options this does not affect the study's results. In addition, 36 km CALPUFF/MMIF results are also not presented for the 600 km arc modeling.

Table 3-11. CALPUFF/MMIF sensitivity tests analyzed with the July 8, 1980 GP80 database.

Grid Resolution	MM5	MDISP	MCTURB	Comment
36 km	36 km	2	1	36 km MM5 with CALPUFF turbulence dispersion (CAL)
36 km	36 km	2	2	36 km MM5 with AERMOD turbulence dispersion (AER)
36 km	36 km	3		36 km MM5 with Pasqual-Gifford dispersion (PG)
12 km	12 km	2	1	12 km MM5 with CALPUFF turbulence dispersion (CAL)
12 km	12 km	2	2	12 km MM5 with AERMOD turbulence dispersion (AER)
12 km	12 km	3		12 km MM5 with Pasqual-Gifford dispersion (PG)

3.3 QUALITY ASSURANCE

The quality assurance (QA) of the CALPUFF modeling system simulations for the GP80 tracer experiment was assessed by analyzing the CALMET and CALPUFF input and output files and the dates they were generated. The input file options were compared against the August 2009 EPA-FLM recommended settings for CALMET and the definitions of the sensitivity tests to assure that the intended parameters were defined. The QA of the MMIF runs was not as complete because no input files or list files were provided to document the MMIF parameters. However, since all the MMIF tool does is pass through the MM5 output to CALPUFF there are not many options available.

The 100 km and 600 km receptor arc CALMET sensitivity simulations used a TERRAD value of 20 km (radius of influence of terrain on wind fields, in kilometers). The 2009 EPA-FLM clarification memorandum recommends that TERRAD = 15. Four CALMET parameters (BIAS, NSMTH, NINTR2, and FEXTR2) require a value for each vertical layer processed in CALMET. The 100 km and 600 km CALMET Base Cases are based on six vertical layers, but the sensitivity simulations are based on ten vertical layers. The CALMET sensitivity simulations were provided with only six values for BIAS, NSMTH, NINTR2, and FEXTR2 even though ten vertical layers were simulated. Therefore, CALMET used default values for the upper four vertical layers (1200 m, 2000 m, 3000 m, and 4000 m).

In addition to the three CALPUFF dispersion options (AERMOD, CALPUFF, and PG), there were other CALPUFF parameters that differed between the 100 km and 600 km CALPUFF/CALMET BASE case and sensitivity cases and CALPUFF/MMIF modeling scenarios. Differences in the CALPUFF parameters used in the 100 km and 600 km receptor arc simulation include:

- All of the CALPUFF 600 km sensitivity runs (CALPUFF/CALMET and CALPUFF/MMIF) and 100 km CALPUFF/MMIF runs were all conducted using only puffs (MSLUG = 0), but the 100 km CALPUFF/CALMET and 1998 CALPUFF simulations assume near-field slug formation (MSLUG = 1).
- CALPUFF 100 km CALPUFF/MMIF runs and all 600 km CALPUFF runs allowed for vertical wind shear (MSHEAR = 1), the 100 km BASE case and 100 km CALPUFF/CALMET sensitivity scenarios assume no vertical wind shear. The IWAQM Phase II (1998) guidance recommends MSHEAR = 0.
- The initial CALPUFF 100 km and 600 km sensitivity tests assumed no puff splitting (MSPLIT = 0), whereas the IWAQM Phase II (1998) recommends that default puff splitting be performed (MSPLIT = 1). This issue was investigated for the 600 km arc using additional CALPUFF sensitivity tests.

- CALPUFF 100 km (all dispersion options) and 600 km PG dispersion simulations, CALPUFF was set-up to not allow for partial plume penetration of inversion layer (MPARTL = 0). The IWAQM Phase II (1998) guidance recommends MPARTL = 1.
- CALPUFF 600 km AERMOD and CALPUFF turbulence dispersion simulations, CALPUFF was set-up to use the Probability Density Function (PDF) option for convective dispersion (MPDF = 1). The IWAQM Phase II guidance does not recommend using PDF for convective dispersion.
- CALPUFF 600 km simulations and 100 km CALPUFF/MMIF simulations use minimum and maximum mixing height values of 0 m and 6000 m, respectively. The CALPUFF 100 km BASE case and sensitivity simulations use minimum and maximum mixing height values of 20 m and 3300 m, respectively. The 1998 IWAQM Phase II guidance recommends the minimum and maximum mixing heights be set equal to 50 m and 3000 m, respectively.
- The CALPUFF 100 km BASE case and sensitivity simulations use a maximum slug length of 0.1 CALMET grid units (XMXLEN = 0.1), whereas the 100 km CALPUFF/MMIF simulations used a maximum length of 1.0 CALMET grid units. The IWAQM Phase II guidance recommends XMXLEN = 1.
- The CALPUFF 100 km BASE case and sensitivity simulations use a maximum slug/puff travel distance of 0.1 grid units per sampling period (XSAMLEN = 0.1), whereas the 100 km CALPUFF/MMIF simulations used a maximum travel distance of 1.0 grid units. The IWAQM Phase II guidance recommends XSAMLEN = 1.
- The CALPUFF 100 km BASE case and sensitivity simulations use a maximum of 199 slugs/puffs released from one source per sampling step (MXNEW = 199), whereas the 100 km CALPUFF/MMIF simulations used a maximum of 99 new slugs/puffs. The IWAQM Phase II guidance recommends MXNEW = 99.
- The CALPUFF 100 km BASE case and sensitivity simulations use a maximum of 5 sampling steps per slug/puff during one time step (MXSAM = 5), whereas the 100 km CALPUFF/MMIF simulations used a maximum of 99 sampling steps per slug/puff. The IWAQM Phase II guidance recommends MXSAM = 99.
- The CALPUFF 100 km BASE case and sensitivity simulations use a minimum sigma-y and sigma-z value of 0.01 m per new slug/puff (SYMIN = 0.01 and SZMIN = 0.01), whereas the 100 m CALPUFF/MMIF simulations used a minimum sigma-y and sigma-z value of 1 m per new slug/puff. The IWAQM Phase II guidance recommends SYMIN = 1 and SZMIN = 1.
- The CALPUFF 100 km BASE case and sensitivity simulations use a minimum wind speed of 1 m/s for non-calm conditions (WSCALM = 1), whereas the 100 km CALPUFF/MMIF simulations used a minimum wind speed of 0.5 m/s. The IWAQM Phase II guidance recommends WSCALM = 0.5.

We noted that the date on the CALMET input control file for the BASEA sensitivity test was later than the date on the CALMET output file for BASEA. We reran the BASEA CALMET and CALPUFF sensitivity tests and got slightly different results.

3.4 GP80 MODEL PERFORMANCE EVALUATION

Previous studies evaluated CALPUFF using the GP80 tracer experiment data using the Irwin plume fitting evaluation approach (EPA, 1998a). Thus, the same approach was adopted in this study so we could compare the performance of the newer version of CALPUFF with past

evaluation studies and evaluate whether new options in CALPUFF (e.g., puff splitting) improve CALPUFF's model performance.

3.4.1 CALPUFF GP80 Evaluation for the 100 km Arc of Receptors

Table 3-12 evaluates the CALPUFF sensitivity tests ability to estimate the timing of the plume arrival at the 100 km arc of receptors and the duration of time the plume resides on the 100 km receptor arc. The tracer was observed on the 100 km arc for 5 hours. The 1998 EPA report CALPUFF modeling matched this well using CALPUFF turbulence (CAL) dispersion and estimated the tracer remained on the arc one hour longer than observed using the PG dispersion option. The CALPUFF/CALMET sensitivity tests estimated that the predicted tracer cloud was on the arc the same amount of time as was observed (5 hours) or within one hour of that duration (i.e., within ±20%). With one exception, when the CALPUFF/CALMET estimated that the duration of time on the arc was off by one hour, it was underestimating the amount of time on the arc (i.e., 4 instead of 5 hours). The exception to this was the EXP2A_PG scenario that estimates the tracer plume was on the 100 km arc for 6 hours.

The CALPUFF/MMIF sensitivity tests had the tracer plume arriving at the 100 km arc one hour late and either leaving on time (12 km MMIF) or leaving an hour early. This results in the CALPUF/MMIF sensitivity test underestimating the observed time on the arc by 1 (12 km MMIF) to 2 (36 km MMIF) hours.

Table 3-12. Tracer plume arrival and duration statistics for the GP80 100 km arc.

Scenario	Arrival on Arc		Leave Arc		Duration on Arc	
	Day	Hour	Day	Hour	Hours	Difference
Observed	190	16	190	20	5	
1998 EPA Report						
1998EPA_PG	190	16	190	21	6	20%
1998_CAL	190	16	190	20	5	0%
CALPUFF/CALMET						
BASEA_AER	190	16	190	20	5	0%
BASEA_CAL	190	16	190	20	5	0%
BASEA_PG	190	16	190	20	5	0%
EXP1A_AER	190	16	190	20	5	0%
EXP1A_CAL	190	16	190	20	5	0%
EXP1A_PG	190	16	190	20	5	0%
EXP1B_AER	190	16	190	19	4	-20%
EXP1B_CAL	190	16	190	19	4	-20%
EXP1B_PG	190	16	190	19	4	-20%
EXP1C_AER	190	17	190	20	4	-20%
EXP1C_CAL	190	17	190	20	4	-20%
EXP1C_PG	190	17	190	20	4	-20%
EXP2A_AER	190	16	190	20	5	0%
EXP2A_CAL	190	16	190	20	5	0%
EXP2A_PG	190	16	190	21	6	20%
EXP2B_AER	190	16	190	19	4	-20%
EXP2B_CAL	190	16	190	19	4	-20%
EXP2B_PG	190	16	190	20	5	0%
EXP2C_AER	190	17	190	20	4	-20%
EXP2C_CAL	190	17	190	20	4	-20%
EXP2C_PG	190	17	190	20	4	-20%
EXP3A_AER	190	16	190	20	5	0%
EXP3A_CAL	190	16	190	20	5	0%
EXP3A_PG	190	16	190	20	5	0%
EXP3B_AER	190	16	190	20	5	0%
EXP3B_CAL	190	16	190	20	5	0%
EXP3B_PG	190	16	190	19	4	-20%
EXP3C_AER	190	17	190	20	4	-20%
EXP3C_CAL	190	17	190	20	4	-20%
EXP3C_PG	190	17	190	20	4	-20%
CALPUFF/MMIF						
MMIF12_AER	190	17	190	20	4	-20%
MMIF12_CAL	190	17	190	20	4	-20%
MMIF12_PG	190	17	190	20	4	-20%
MMIF36KM_AER	190	17	190	19	3	-40%
MMIF36KM_CAL	190	17	190	19	3	-40%
MMIF36KM_PG	190	17	190	19	3	-40%

Tables 3-13 and Figures 3-2 through 3-6 display the plume fitting model performance statistics for the various CALPUFF sensitivity tests and the 100 km arc of receptors in the GP80 field experiment and compares them with the previous results as reported by EPA (1998a). The fitted predicted and observed plume centerline concentrations (Cmax) and the percent differences, expressed as a mean normalized bias (MNB), are shown in Table 3-13 with the MNB results reproduced in Figure 3-2. Similar results are seen for the predicted and observed maximum concentrations at any monitoring site along the arc (Omax) that are shown in Table 3-13 and Figure 3-3. The use of either the CALPUFF (CAL) or AERMOD (AER) algorithms for the turbulence dispersion doesn't appear the affect the maximum concentration model performance. Most CALPUFF sensitivity simulations overestimate the observed Cmax value by over 40%, with the 1998EPA_PG and EXP2C_PG simulations overestimating the observed Cmax value by over a factor of 2 (> 100%). The overestimation of the observed Omax value is even greater, exceeding 60% for most of the CALPUFF simulations. The PG dispersion produces much higher maximum concentrations compared to CAL/AER dispersion for experiments EXP2B and EXP2C. But the PG maximum concentrations are comparable or even a little lower than CAL/AER for the other experiments; although in the 1998 EPA study the PG dispersion option produced much higher maximum concentrations. The EXP1B, EXP2B and EXP3B CALPUFF simulations do not exhibit the large overestimation bias of Cmax and Omax as seen in the other experiments and are closest to reproducing the observed maximum concentrations on the 100 km arc, matching the observed values to within ±25%; note that the "B" series of experiments use MM5 data (12, 36 and 12 km for EXP1, EXP2 and EXP3, respectively) but only surface and no upper-air meteorological observations. The CALPUFF/MMIF simulation using the 12 km MM5 data and PG dispersion also reproduced the maximum concentrations to within ±25%.

Most of the CALPUFF sensitivity simulations underestimate the plume spread (σ_y) by 20% to 35% (Figure 3-4), which is consistent with overestimating the observed maximum concentration (i.e., insufficient dispersion leading to overestimation of the maximum concentrations). The exceptions to this are again the "B" series of CALPUFF/CALMET experiments and MMIF12KM_PG. Another exception to this is the EPA1998_PG simulation which agrees with the observed plume spread amount quite well; the explanation for this is unclear and seems inconsistent with the fact that 1998BASE_PG overestimated the observed Cmax/Omax values. The 1998EPA_PG results were taken from the EPA (1998a) report and could not be verified or quality assured so we cannot explain this discrepancy.

The deviations between the observed and predicted plume centerline along the 100 km arc of receptors in degrees is shown in Figure 3-5. The modeled plume centerline tends to be 0 to14 degrees off from the observed plume centerline. The best performing model configuration for the plume centerline location is the BASEA series that uses CALMET with observed surface and upper-air meteorological data but no MM5 data. The CALPUFF/CALMET sensitivity tests that use surface and upper-air ("A" series) and just surface ("B" series) meteorological observations tend to perform best for the plume centerline location, whereas the sensitivity tests that uses no meteorological observations ("C" series) performs the worse, with the plume centerline tending to be 10 to 14 degrees too far west on the 100 km arc for the "C" series of CALPUFF/CALMET sensitivity tests. The CALPUFF/MMIF runs, which also do not include any meteorological observations, also tend to have plume centerlines that are 6 to 12 degrees too far to the west.

Most of the CALPUFF sensitivity tests have cross wind integrated concentrations (CWIC) that are within ±20% of the observed value along the 100 km arc (Figure 3-6 and Table 5-13). The

exceptions to this are the EPA1998_PG simulation, the BASEA series of simulations, EXP2A_PG, EXP2B_PG and EXP2C_PG. In general, the CAL and AER CALPUFF dispersion options are performing much better for the CWIC statistics along the 100 km arc than the PG dispersion option.

Table 3-13. CALPUFF model performance statistics using the Irwin plume fitting evaluation approach for the GP80 100 km arc of receptors, the EPA 1998 CALPUFF V4.0 modeling and the CALPUFF sensitivity tests.

CALPUFF Sensitivity Test	Cmax		Omax		Sigma-y		Plume Centerline		CWIC	
	(ppt)	MNB	(ppt)	MNB	(m)	MNB	(degrees)	Diff	(ppt-m)	MNB
Observed	**1.287**		**1.052**		**9,059**		**361.0**		**29,220**	
EPA 1998										
PG	2.700	110%	2.600	147%	9,000	-1%	357.0	-4.0	61,000	109%
Similarity	1.900	48%	1.800	71%	6,900	-24%	360.0	-1.0	33,000	13%
CALPUFF/CALMET										
BASEA_AER	2.221	73%	2.040	94%	7,136	-21%	361.4	0.4	39,720	36%
BASEA_CAL	2.214	72%	2.034	93%	7,165	-21%	361.4	0.4	39,770	36%
BASEA_PG	2.126	65%	1.934	84%	8,827	-3%	359.8	-1.2	47,050	61%
EXP1A_AER	2.086	62%	2.045	94%	5,977	-34%	357.1	-3.9	31,260	7%
EXP1A_CAL	2.088	62%	2.046	94%	5,999	-34%	357.0	-4.0	31,390	7%
EXP1A_PG	1.885	46%	1.839	75%	6,438	-29%	358.3	-2.7	30,420	4%
EXP1B_AER	1.407	9%	1.303	24%	8,492	-6%	358.8	-2.2	29,940	2%
EXP1B_CAL	1.414	10%	1.313	25%	8,478	-6%	358.8	-2.2	30,050	3%
EXP1B_PG	1.291	0%	1.217	16%	8,956	-1%	359.7	-1.3	28,980	-1%
EXP1C_AER	1.979	54%	1.937	84%	6,587	-27%	348.1	-12.9	32,670	12%
EXP1C_CAL	1.988	54%	1.945	85%	6,590	-27%	348.0	-13.0	32,840	12%
EXP1C_PG	2.016	57%	1.983	88%	6,041	-33%	349.4	-11.6	30,530	4%
EXP2A_AER	2.047	59%	1.996	90%	6,209	-31%	357.2	-3.8	31,860	9%
EXP2A_CAL	2.049	59%	1.999	90%	6,236	-31%	357.1	-3.9	32,020	10%
EXP2A_PG	2.013	56%	2.260	115%	11,330	25%	351.2	-9.8	57,180	96%
EXP2B_AER	1.265	-2%	1.145	9%	9,033	0%	359.4	-1.6	28,630	-2%
EXP2B_CAL	1.269	-1%	1.152	10%	9,030	0%	359.4	-1.6	28,710	-2%
EXP2B_PG	1.811	41%	2.034	93%	9,161	1%	357.6	-3.4	41,590	42%
EXP2C_AER	2.138	66%	2.106	100%	6,021	-34%	350.8	-10.2	32,270	10%
EXP2C_CAL	2.144	67%	2.112	101%	6,026	-33%	350.7	-10.3	32,380	11%
EXP2C_PG	2.938	128%	2.897	175%	6,044	-33%	349.4	-11.6	44,510	52%
EXP3A_AER	2.042	59%	1.992	89%	6,212	-31%	356.7	-4.3	31,800	9%
EXP3A_CAL	2.048	59%	1.998	90%	6,238	-31%	356.5	-4.5	32,030	10%
EXP3A_PG	1.827	42%	1.766	68%	6,805	-25%	358.0	-3.0	31,160	7%
EXP3B_AER	1.274	-1%	1.228	17%	8,928	-1%	357.9	-3.1	28,520	-2%
EXP3B_CAL	1.297	1%	1.247	19%	8,828	-3%	357.8	-3.2	28,700	-2%
EXP3B_PG	1.011	-21%	1.140	8%	11,010	22%	359.7	-1.3	27,900	-5%
EXP3C_AER	1.949	51%	1.911	82%	6,612	-27%	347.4	-13.6	32,300	11%
EXP3C_CAL	1.965	53%	1.927	83%	6,615	-27%	347.3	-13.7	32,590	12%
EXP3C_PG	1.999	55%	1.971	87%	6,085	-33%	349.0	-12.0	30,500	4%
CALPUFF/MMIF										
MMIF12KM_AER	1.872	45%	1.836	75%	6,811	-25%	349.5	-11.5	31,970	9%
MMIF12KM_CAL	1.897	47%	1.860	77%	6,805	-25%	349.3	-11.7	32,350	11%
MMIF12KM_PG	1.468	14%	1.318	25%	9,574	6%	350.3	-10.7	35,230	21%
MMIF36KM_AER	1.837	43%	1.811	72%	6,788	-25%	353.2	-7.8	31,250	7%
MMIF36KM_CAL	1.860	45%	1.832	74%	6,768	-25%	353.1	-7.9	31,550	8%
MMIF36KM_PG	1.608	25%	1.567	49%	7,055	-22%	355.1	-5.9	28,440	-3%

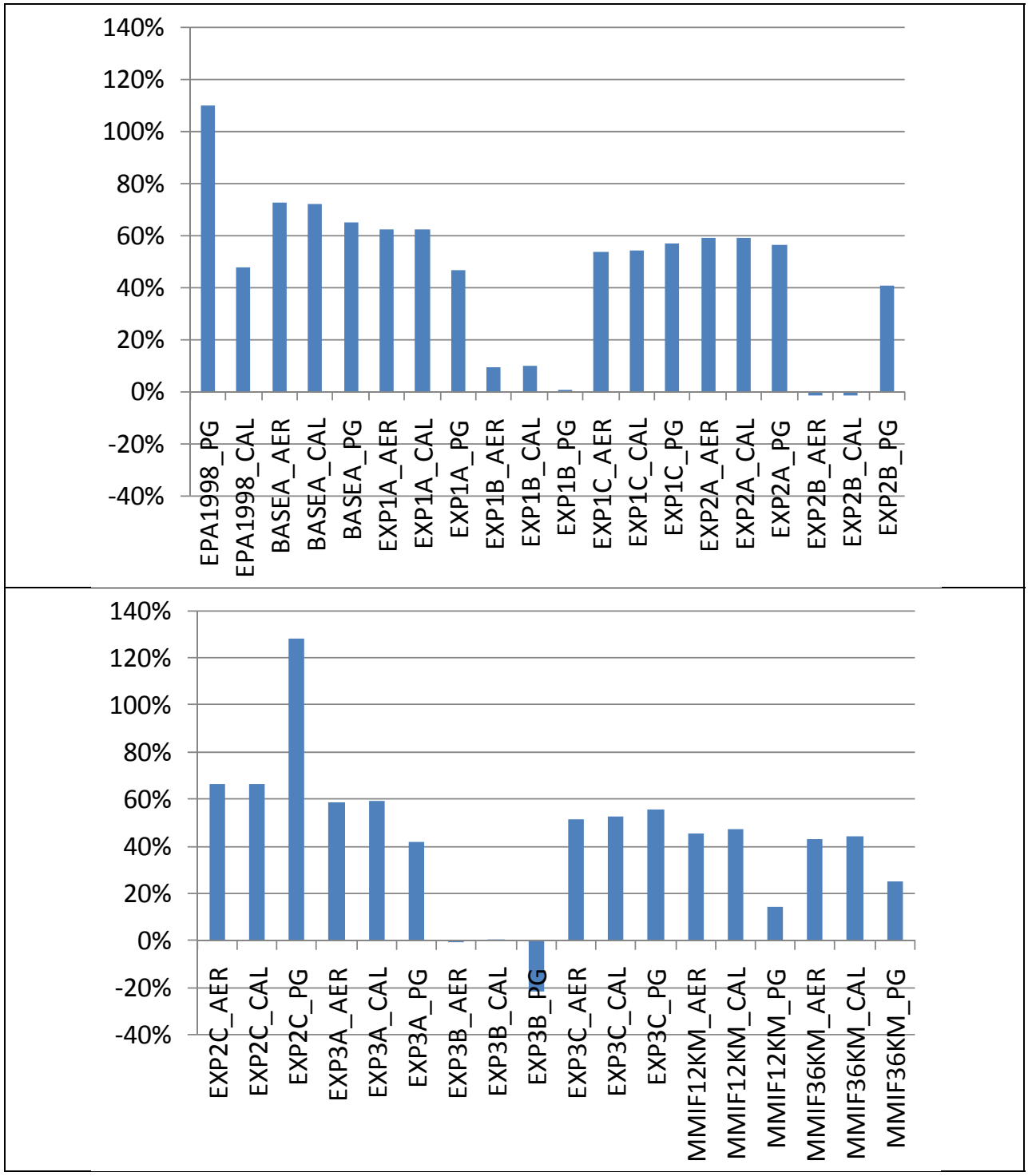


Figure 3-2. Percent difference (mean normalized bias) between the predicted and observed fitted plume centerline concentration (Cmax) for GP80 100 km receptor arc and the CALPUFF sensitivity tests.

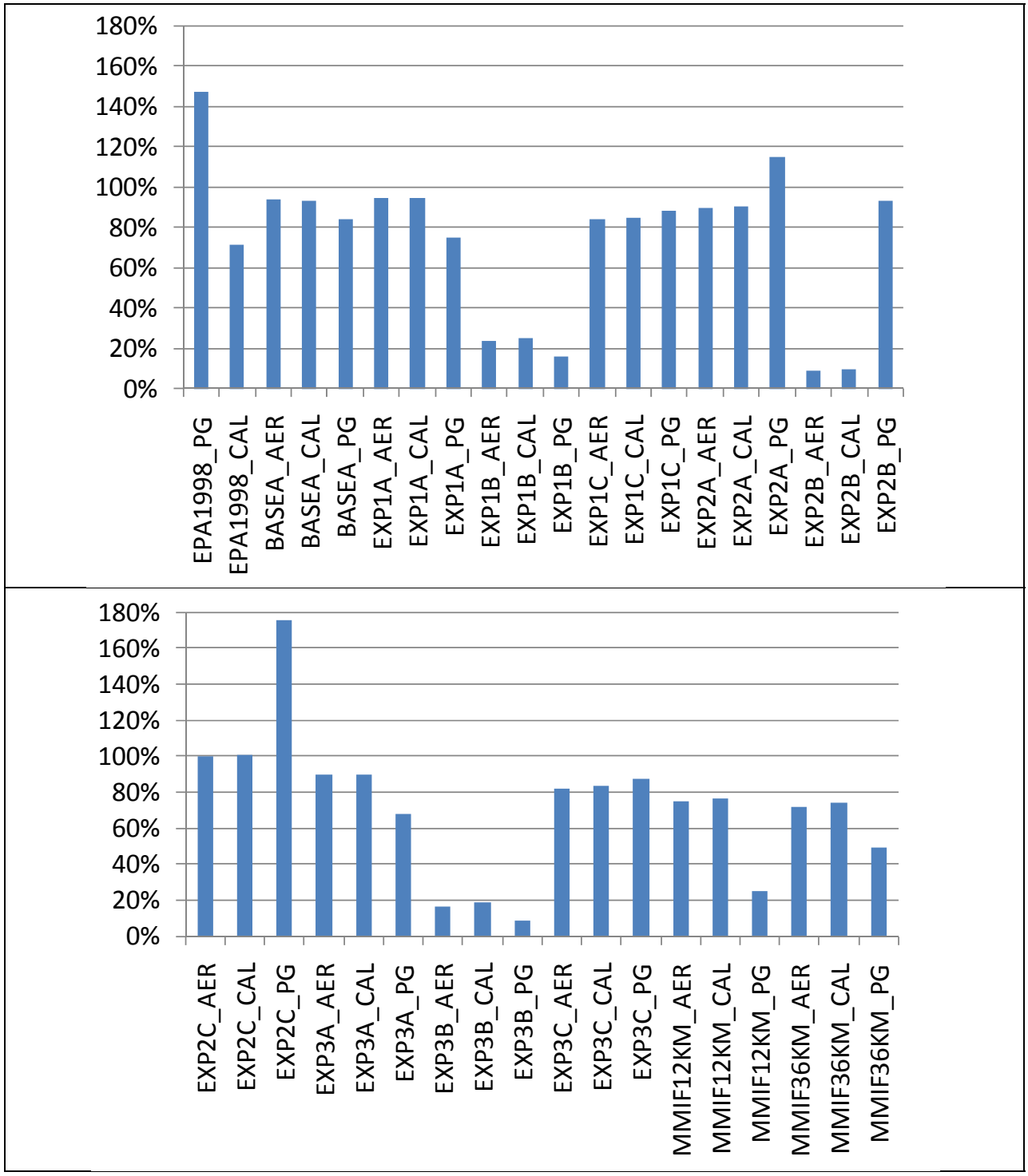


Figure 3-3. Percent difference (mean normalized bias) between the predicted and observed maximum concentration at any receptor/monitor (Omax) for GP80 100 km receptor arc and the CALPUFF sensitivity tests.

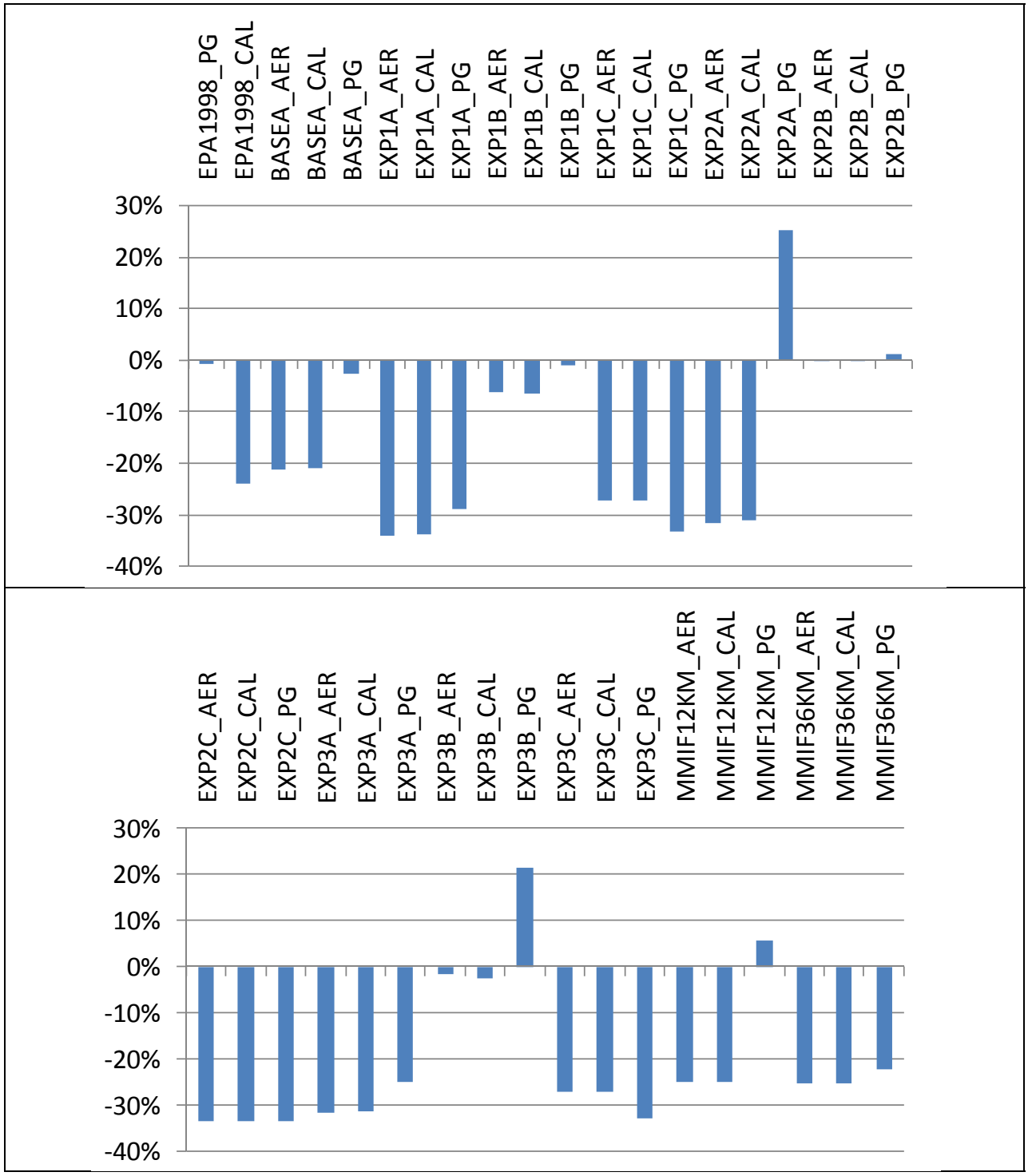


Figure 3-4. Percent difference (mean normalized bias) between the predicted and observed plume spread (σ_y) for GP80 100 km receptor arc and the CALPUFF sensitivity tests.

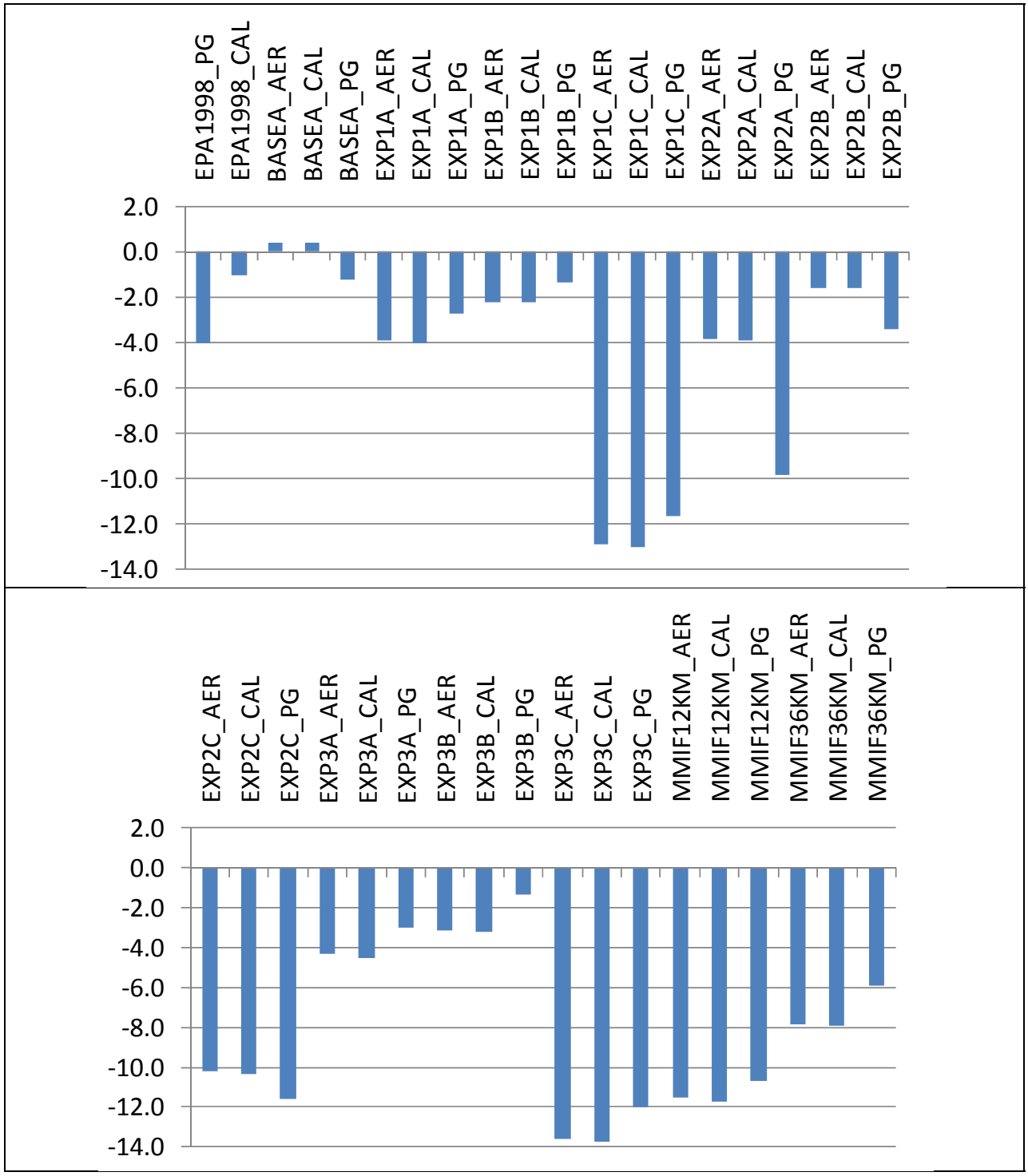


Figure 3-5. Difference in predicted and observed location of plume centerline (degrees) for the GP10 100 km receptor arc and the CALPUFF sensitivity tests.

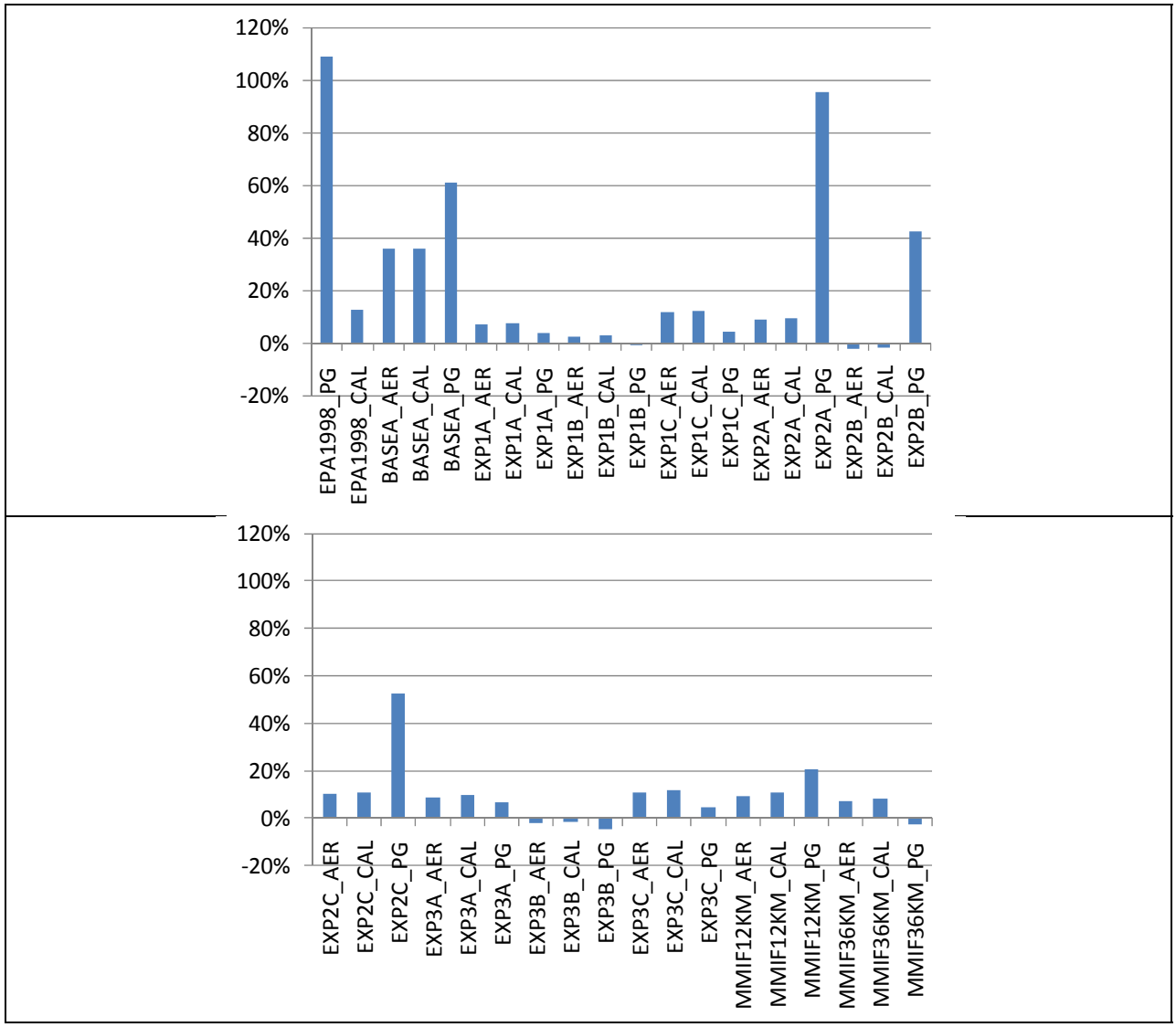


Figure 3-6. Percent difference (mean normalized bias) between the predicted and observed cross wind integrated concentration (CWIC) for the GP10 100 km receptor arc and the CALPUFF sensitivity tests.

3.4.2 CALPUFF GP80 Evaluation for the 600 km Arc of Receptors

Table 3-14 lists the predicted and observed plume arrival and exit time statistics from the 600 km arc of receptors and the duration of time the tracer resides on the 600 km arc for the initial CALPUFF sensitivity tests. Note that the observed tracer was found on the 600 km arc during the first sampling period (hour 2 on Julian Day 191) so the observed tracer may have arrived earlier than that. As explained by EPA (1998a), the observed tracer arrived earlier than expected due to the presence of a low-level jet that was not anticipated. Thus, the observed 12 hour tracer duration on the 600 km receptor arc that assumes it arrived during the first sampling interval at hour 2 could be an underestimate of the actual tracer residence time on the 600 km arc.

Figure 3-7 displays the percent differences in the tracer duration time on the 600 km arc for the initial CALPUFF 600 km sensitivity tests. For most of the initial CALPUFF sensitivity tests, the tracer duration time on the 600 km receptor arc is approximately half (5-6 hours) of what was observed (12 hours). This is in contrast to the 1998 EPA CALPUFF evaluation runs that overstate

the duration the tracer resides on the 600 km arc, with values of 14 hours (1998EPA_PG) and 13 hours (1998EPA_CAL). Since the 1998 EPA CALPUFF runs estimated that the tracer arrives after the sampling started (hour 3), then this is a true overstatement of the tracer residence time and not an artifact of the tracer sampling starting after, or at the same time, the observed tracer arrived at the arc. There are a couple exceptions to the initial CALPUFF simulations performed in this study that understated the observed tracer duration on the arc by approximately a factor of 2, which are discussed below.

The BASEA_PG scenario estimates that the tracer is on the arc for 12 hours, the same as the observed. However, it estimates the tracer leaves three hours earlier (hour 14) than observed (hour 11). Why the BASEA_PG tracer plume time statistics are so different from the two companion turbulence dispersion CALPUFF sensitivity tests (BASEA_CAL and BASEA_AER) is unclear. The same meteorological fields were used in the three BASEA CALPUFF sensitivity tests and the only difference was in the dispersion options. This large difference in the CALPUFF predicted tracer residence time due to use of the PG versus CAL or AER dispersion options (12 hours versus 6-7 hours) was not seen in any of the other CALPUFF sensitivity experiment configurations. Although use of the PG dispersion sometimes increases the estimated tracer residence time on the arc by one hour in some of the CALPUFF sensitivity tests (Table 3-14).

The EXP2C series of experiments have estimated tracer plume duration times (11-13 hours) that is comparable to what was observed. EXP2C uses 36 km MM5 data and CALMET was run using a 4 km grid resolution with no meteorological observations (NOOBS = 2). When meteorological observations are added, either surface data alone (EXP2B) or surface and upper-air measurements (EXP2A), the tracer duration statistics degrades to only 5 to 8 hours on the arc. It is interesting to note that all of the “C” series of experiments (i.e., use of no meteorological observations in CALMET) exhibit better plume residence time statistics than the experiments that used meteorological observations (with the exception of BASEA_PG discussed previously). But only experiment EXP2C (and BASEA_PG) using 36 km MM5 data and CALMET run with 4 km grid resolution was able to replicate the observed tracer residence time.

Most of the initial CALPUFF sensitivity tests were unable to reproduce the observed tracer residence time on the 600 km arc, as was done in the EPA 1998 study using earlier versions of CALPUFF. Even the BASEA_CAL sensitivity test, which was designed to be mostly consistent with the 1998EPA_CAL simulation, estimated tracer plume residence time that was half of what was observed and estimated by the 1998EPA_CAL simulation. In addition to using difference versions of the CALPUFF model (Version 4.0 versus 5.8), the BASEA_CAL simulation also did not invoke the slug option as was used in 1998EPA_CAL (MSLUG = 1). The use of the slug option is designed for near-source applications and is not typically used in LRT dispersion modeling, so in this study the initial CALPUFF sensitivity tests did not use the slug option for modeling of the 600 km arc. The effect of the slug option is investigated in additional CALPUFF sensitivity tests discussed later in this Chapter.

Figure 3-7. Percent difference in the predicted and observed duration of time tracer is residing on the GP80 600 km arc for the CALPUFF sensitivity tests using puff model formulation and no puff splitting.

Table 3-14. Tracer plume arrival and duration statistics for the GP80 600 km arc and the initial CALPUFF sensitivity tests.

Scenario	Arrival on Arc		Leave Arc		Duration on Arc	
	(Julian Day)	Hour (LST)	(Julian Day)	Hour (LST)	(Hours)	Difference (%)
Observed	191	2	191	14	12	
1998EPA_PG	191	3	191	17	14	17%
1998EPA_CAL	191	3	191	16	13	8%
CALPUFF/CALMET						
BASEA_AER	191	2	191	7	6	-50%
BASEA_CAL	191	2	191	8	7	-42%
BASEA_PG	191	0	191	11	12	0%
EXP1A_AER	191	2	191	6	5	-58%
EXP1A_CAL	191	2	191	6	5	-58%
EXP1A_PG	191	2	191	6	5	-58%
EXP1B_AER	191	1	191	5	5	-58%
EXP1B_CAL	191	1	191	5	5	-58%
EXP1B_PG	191	1	191	4	4	-67%
EXP1C_AER	191	3	191	8	6	-50%
EXP1C_CAL	191	3	191	8	6	-50%
EXP1C_PG	191	2	191	8	7	-42%
EXP2A_AER	191	2	191	6	5	-58%
EXP2A_CAL	191	2	191	6	5	-58%
EXP2A_PG	191	2	191	9	8	-33%
EXP2B_AER	191	1	191	6	6	-50%
EXP2B_CAL	191	1	191	6	6	-50%
EXP2B_PG	191	1	191	6	6	-50%
EXP2C_AER	191	0	191	10	11	-8%
EXP2C_CAL	191	0	191	10	11	-8%
EXP2C_PG	191	0	191	12	13	8%
EXP3A_AER	191	2	191	6	5	-58%
EXP3A_CAL	191	2	191	6	5	-58%
EXP3A_PG	191	2	191	6	5	-58%
EXP3B_AER	191	1	191	5	5	-58%
EXP3B_CAL	191	1	191	5	5	-58%
EXP3B_PG	191	1	191	6	6	-50%
EXP3C_AER	191	2	191	9	8	-33%
EXP3C_CAL	191	2	191	9	8	-33%
EXP3C_PG	191	2	191	9	8	-33%
CALPUFF/MMIF						
MMIF12_CAL	191	3	191	8	6	-50%
MMIF12_PG	191	2	191	8	7	-42%

The fitted Gaussian plume statistics for the GP80 600 receptor arc and the initial CALPUFF sensitivity tests are shown in Table 3-15, with the percent differences (or angular offset for the plume centerline location) between the model predictions and observations also shown graphically in Figures 3-8 through 3-12. Unlike the CALPUFF performance for the 100 km arc that mostly overestimated the fitted plume centerline (Cmax) and observed maximum concentrations at any receptor (Omax), the CALPUFF sensitivity tests under-estimate the Cmax/Omax values for the 600 km arc by 40% to 80% (Table 3-15 and Figures 3-8 and 3-9). The Cmax/Omax underestimation bias is lower (-40% to -60%) with the "C" series (i.e., no meteorological observations in CALMET) of CALPUFF sensitivity tests. The CALPUFF sensitivity tests overstate the amount of plume spread (σ_y) along the 600 km receptor arc compared to the plume that is fitted to the observations (Figure 3-10). The "A" and "B" series of CALPUFF experiments using the turbulence dispersion (CAL and AER) tend to overestimate the plume spread along the 600 km arc by ~50% with the "C" series overestimating plume spread by ~100%. For many of the experiments, use of the PG dispersion option greatly exacerbates the plume spread overestimation bias with overestimation amounts above 250% for EPA1998_PG and its related BASEA_PG scenarios. Given the similarity of the "C" series (CALMET with no meteorological observations) and MMIF CALPUFF sensitivity simulations, it is not surprising that the MMIF runs also overestimate plume spread by ~100%.

The predicted plume centerline angular offset from the observed value has an easterly bias of 9 to 19 degrees (Figure 3-12). The "A" series of CALPUFF/CALMET sensitivity runs tend to have larger (> 15 degrees) plume centerline offsets than the "B" and "C" series of experiments, indicating that using upper-air meteorological observations in CALMET tends to worsen the plume centerline predictions in the CALPUFF sensitivity runs. Surprisingly, the CALPUFF/MMIF sensitivity runs, which also do not use the upper-air meteorological measurements, have angular offsets in excess of 15 degrees.

The observed cross wind integrated concentration (CWIC) across the plume at the 600 km arc is matched better by the CALPUFF sensitivity tests than the maximum (Cmax/Omax) concentrations (Table 3-15 and Figure 3-12). The EPA1998_PG and EPA1998_CAL overestimate the CWIC by 30% and 15%, respectively. However, the BASEA_PG and BASEA_CAL experiments, which are designed to emulate the EPA 1998 CALPUFF runs, underestimate the CWIC by -14% and -38%, respectively. The use of meteorological observations in CALMET appears to have the biggest effect on the CALPUFF CWIC performance with the "A" series (use both surface and upper-air observations) have the largest CWIC underestimation bias and the CALPUFF CWIC performance statistics as upper-air ("B" series) and then surface and upper-air ("C" series) are removed from the CALPUFF modeling. The CALPUFF/MMIF runs underestimated the CWIC by approximately -30%.

Table 3-15. CALPUFF model performance statistics using the Irwin plume fitting evaluation approach for the GP80 600 km arc of receptors for the EPA 1998 CALPUFF V4.0 modeling and the current study CALPUFF V5.8 sensitivity tests.

CALPUFF Sensitivity Test	Cmax		Omax		Sigma-y		Centerline		CWIC	
	(ppt)	MNB	(ppt)	MNB	(m)	MNB	(deg)	Diff	(ppt-m)	MNB
Observed	0.3152		0.3068		16,533		369.06		13,060	
1998EPA_PG	0.1100	-65%	0.1300	-58%	64,900	293%	25.00	15.94	17,000	30%
1998EPA_CAL	0.1400	-56%	0.1300	-58%	42,600	158%	24.00	14.94	15,000	15%
CALPUFF/CALMET										
BASEA_AER	0.1024	-68%	0.1000	-67%	27,780	68%	29.43	20.37	7,133	-45%
BASEA_CAL	0.0875	-72%	0.0817	-73%	36,870	123%	27.55	18.49	8,084	-38%
BASEA_PG	0.0763	-76%	0.0780	-75%	58,780	256%	23.74	14.68	11,240	-14%
EXP1A_AER	0.1004	-68%	0.0985	-68%	25,490	54%	27.39	18.33	6,414	-51%
EXP1A_CAL	0.1020	-68%	0.0997	-68%	25,500	54%	27.30	18.24	6,520	-50%
EXP1A_PG	0.0991	-69%	0.0969	-68%	25,280	53%	28.12	19.06	6,277	-52%
EXP1B_AER	0.1141	-64%	0.1106	-64%	34,040	106%	18.91	9.85	9,739	-25%
EXP1B_CAL	0.1168	-63%	0.1136	-63%	33,600	103%	18.77	9.71	9,840	-25%
EXP1B_PG	0.1117	-65%	0.1085	-65%	29,660	79%	21.76	12.70	8,304	-36%
EXP1C_AER	0.1388	-56%	0.1365	-56%	34,660	110%	19.01	9.95	12,060	-8%
EXP1C_CAL	0.1412	-55%	0.1387	-55%	35,070	112%	18.54	9.48	12,410	-5%
EXP1C_PG	0.1313	-58%	0.1283	-58%	32,400	96%	20.06	11.00	10,660	-18%
EXP2A_AER	0.1068	-66%	0.1046	-66%	24,520	48%	27.72	18.66	6,565	-50%
EXP2A_CAL	0.1073	-66%	0.1052	-66%	24,600	49%	27.57	18.51	6,614	-49%
EXP2A_PG	0.1204	-62%	0.1180	-62%	39,900	141%	24.41	15.35	12,040	-8%
EXP2B_AER	0.1474	-53%	0.1463	-52%	25,520	54%	19.37	10.31	9,426	-28%
EXP2B_CAL	0.1539	-51%	0.1516	-51%	24,230	47%	19.12	10.06	9,346	-28%
EXP2B_PG	0.1007	-68%	0.1149	-63%	42,590	158%	21.27	12.21	10,750	-18%
EXP2C_AER	0.1603	-49%	0.1648	-46%	35,810	117%	21.55	12.49	14,390	10%
EXP2C_CAL	0.1660	-47%	0.1712	-44%	35,330	114%	21.47	12.41	14,700	13%
EXP2C_PG	0.1842	-42%	0.1736	-43%	40,850	147%	19.35	10.29	18,860	44%
EXP3A_AER	0.1075	-66%	0.1048	-66%	24,370	47%	26.82	17.76	6,568	-50%
EXP3A_CAL	0.1079	-66%	0.1057	-66%	24,510	48%	26.70	17.64	6,630	-49%
EXP3A_PG	0.1041	-67%	0.1015	-67%	24,180	46%	27.82	18.76	6,312	-52%
EXP3B_AER	0.1332	-58%	0.1305	-57%	24,030	45%	18.54	9.48	8,025	-39%
EXP3B_CAL	0.1357	-57%	0.1327	-57%	24,050	45%	18.41	9.35	8,179	-37%
EXP3B_PG	0.0733	-77%	0.0655	-79%	38,960	136%	23.12	14.06	7,160	-45%
EXP3C_AER	0.1470	-53%	0.1436	-53%	33,260	101%	18.33	9.27	12,250	-6%
EXP3C_CAL	0.1485	-53%	0.1454	-53%	33,210	101%	18.38	9.32	12,360	-5%
EXP3C_PG	0.1380	-56%	0.1360	-56%	31,260	89%	20.80	11.74	10,820	-17%
CALPUFF/MMIF										
MMIF12KM_CAL	0.1029	-67%	0.1012	-67%	34,290	107%	26.43	17.37	8,842	-32%
MMIF12KM_PG	0.0956	-70%	0.0887	-71%	39,120	137%	24.89	15.83	9,371	-28%

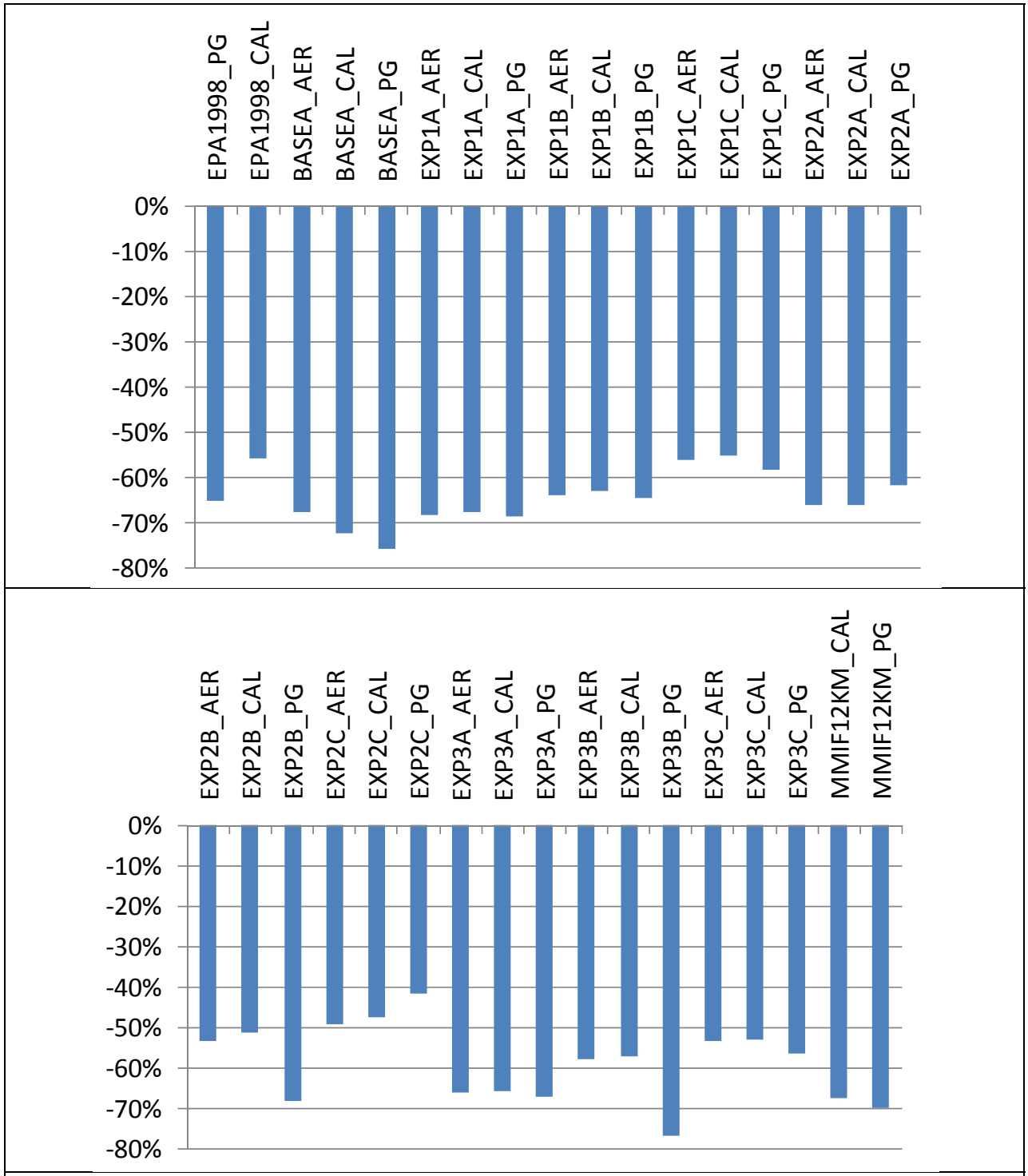


Figure 3-8. Percent difference (mean normalized bias) between the predicted and observed fitted plume centerline concentration (Cmax) for GP80 600 km receptor arc and the CALPUFF sensitivity tests.

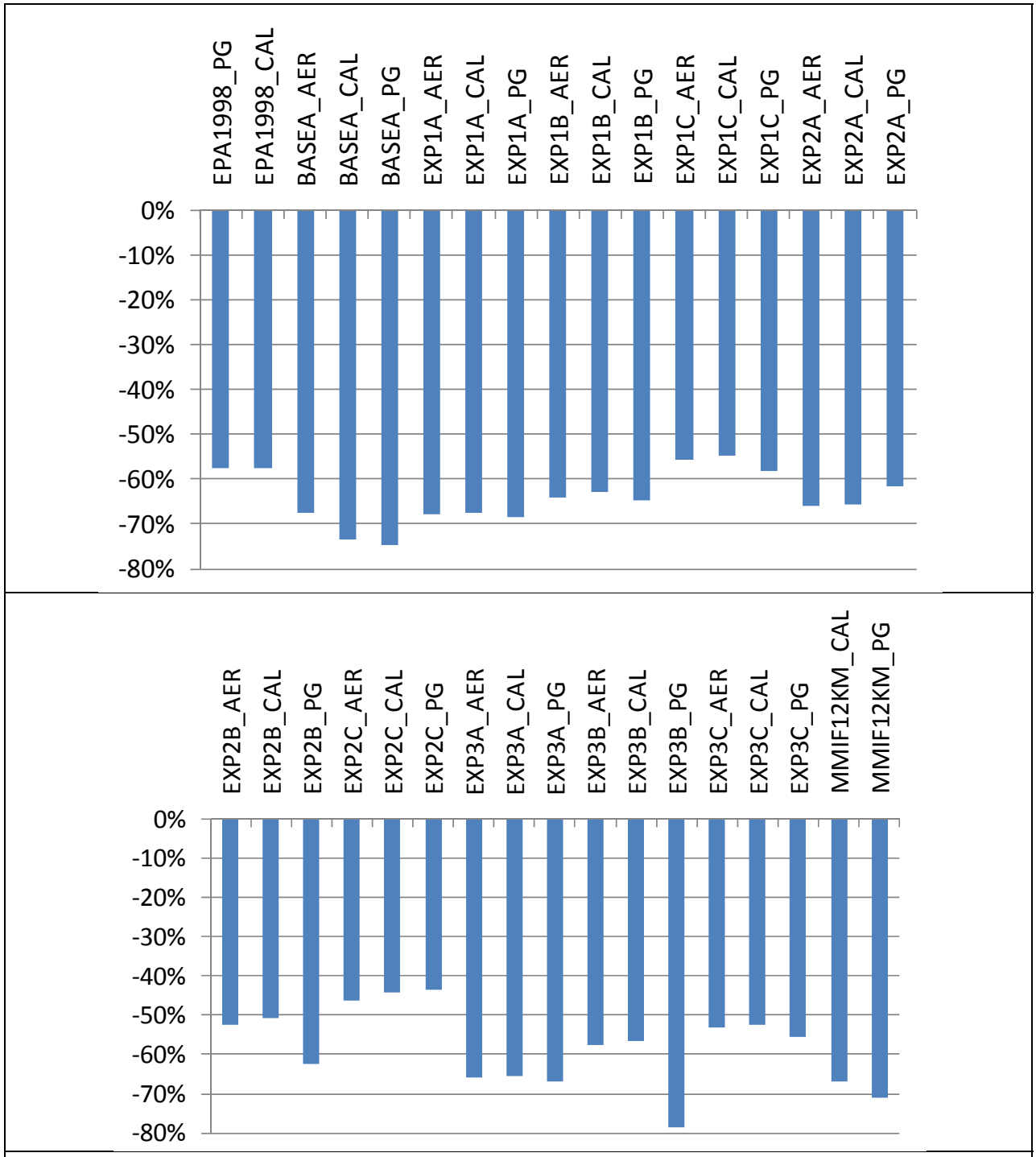
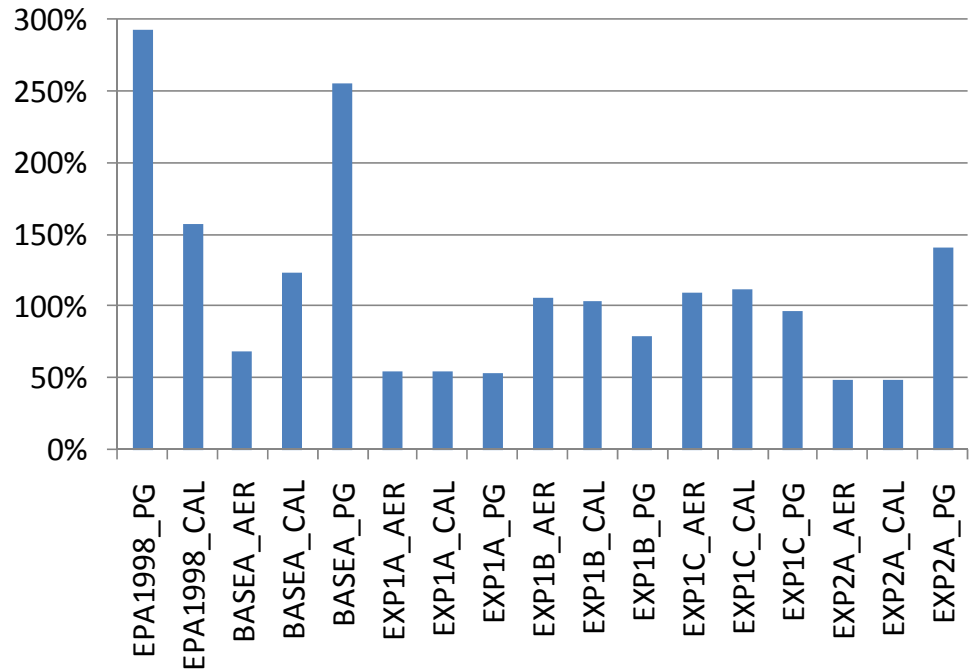


Figure 3-9. Percent difference (mean normalized bias) between the predicted and observed maximum concentration at any receptor/monitor (Omax) for GP80 600 km receptor arc and the CALPUFF sensitivity tests.



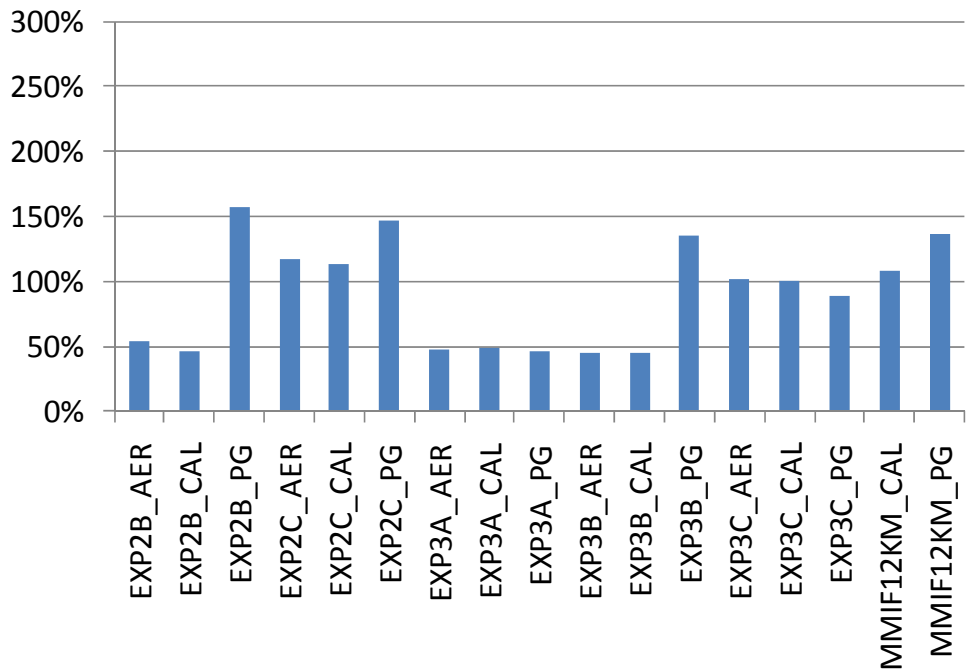
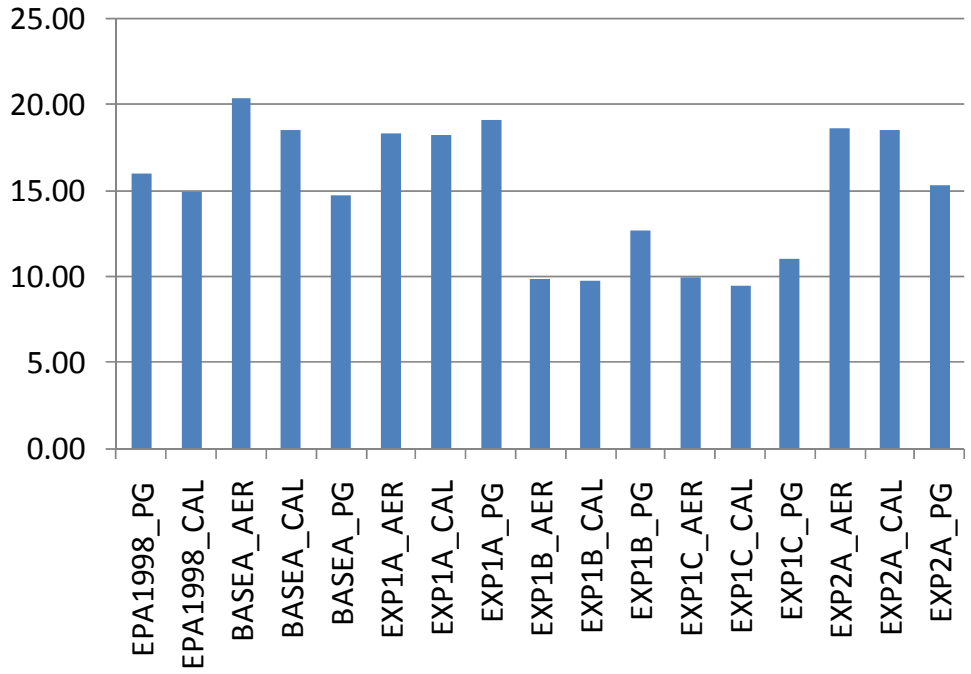


Figure 3-10. Percent difference (mean normalized bias) between the predicted and observed plume spread (σ_y) for GP80 600 km receptor arc and the CALPUFF sensitivity tests.



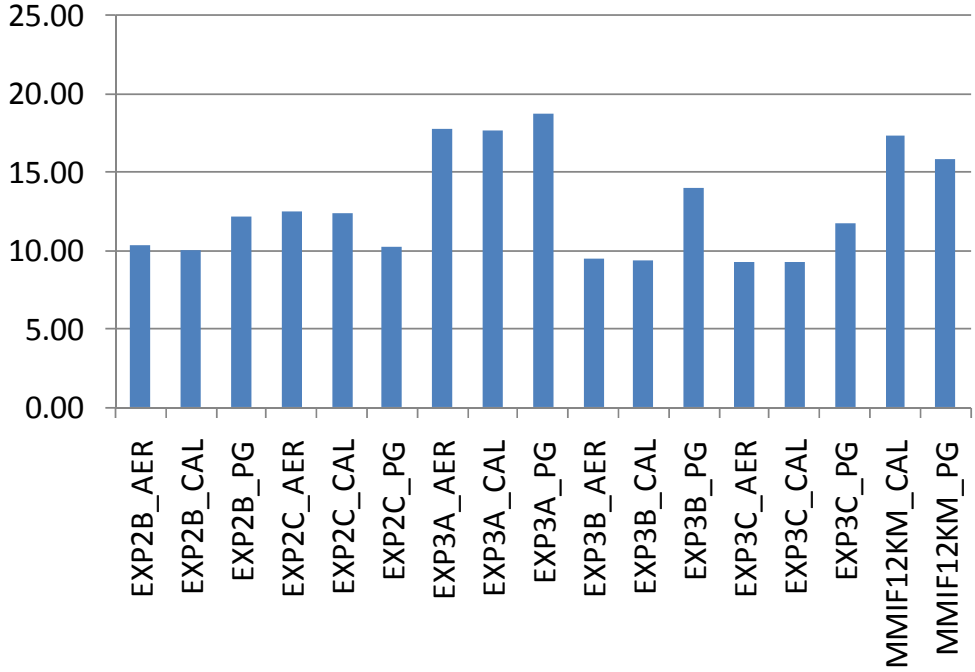


Figure 3-11. Difference in predicted and observed location of plume centerline (degrees) for the GP10 600 km receptor arc and the CALPUFF sensitivity tests.

Figure 3-12. Percent difference (mean normalized bias) between the predicted and observed cross wind integrated concentration (CWIC) for the GP10 600 km receptor arc and the CALPUFF sensitivity tests.

3.4.3 SLUG and Puff Splitting Sensitivity Tests for the 600 km Arc

One issue of concern with the initial CALPUFF sensitivity tests was the large differences between the estimated residence time of the tracer on the 600 km receptor arc in the EPA 1998 and current CALPUFF simulations using the CALPUFF (CAL) turbulence dispersion options when the same meteorological observations are used as input into CALPUFF. The 1998EPA_CAL CALPUFF sensitivity simulation estimated that the tracer would remain on the 600 km receptor arc for 13 hours, which compares favorably with what was observed (12 hours) but is almost double what the BASEA_CAL simulation estimated (7 hours). In addition to updates to the CALMET and CALPUFF models that have occurred over the last decade, a major difference in the 1998 EPA and current CALPUFF 600 km arc simulations was that the 1998 EPA CALPUFF modeling used the near-source slug option, whereas the current analysis did not. Another major difference between the version of CALPUFF used in the 1998 EPA and current study was that CALPUFF now has the ability to perform puff splitting. In fact, it was the presence of puff splitting in CALPUFF that caused EPA to comment that CALPUFF may be applicable to distances further downwind than 300 km in the 2003 air quality modeling guideline revision that led to CALPUFF being the recommended long-range transport model for chemically inert pollutants (EPA, 2003).

To investigate this issue, a series of slug and puff splitting sensitivity tests were carried out using the BASEA_CAL CALPUFF/CALMET configuration by incrementally adding the near-source slug option (MSLUG = 1) and puff splitting option (MSPLIT = 1) to the BASEA_CAL model configuration. CALPUFF slug and puff splitting sensitivity tests were also carried out using the MMIF12_CAL and MMIF12_PG model configurations. Two types of puff splitting sensitivity tests were carried out:

- Default Puff Splitting (DPS) whereby the vertical puff splitting flag was turned on for just hour 17 (i.e., IRESPLIT is equal to 1 for just hour 17 and is 0 the other hours); and
- All hours Puff Splitting (APS) that turned on the vertical puff splitting flag for all hours of the day (i.e., IRESPLIT has 24 values of 1).

Table 3-16 displays the tracer residence time statistic on the 600 km receptor arc for the slug and puff splitting sensitivity tests. Using the puff model formulation and no puff splitting (BASEA_CAL), CALPUFF estimates that the tracer resides on the 600 km arc for 7 hours, which is -42% less than observed (12 hours). Using all hours puff splitting in CALPUFF, but still using the puff model formation (BASEA_APS_CAL), does not affect the estimated plume residence time statistic (7 hours). However, when the slug option is used (BASEA_SLUG_CAL) the residence time of the estimate tracer on the 600 km receptor arc more than doubles increasing from 7 to 15 hours. And adding puff splitting (APS) to the slug model formulation increases the estimated tracer duration on the arc by another hour (16 hours).

The sensitivity of the CALPUFF/MMIF model configuration 600 km receptor arc tracer residence time statistic to the specification of the slug and puff splitting options is a little different than the CALPUFF/CALMET BASEA model configuration. Whereas the CALPUFF/CALMET BASEA model configuration saw little sensitivity of the estimated tracer concentration residence time on the arc due to puff splitting, the implementation of default puff splitting increases the tracer residence time from 6 to 8 hours (CAL dispersion) and from 7 to 11 hours (PG dispersion) with all hours puff splitting increasing the residence time even more. The effect of the slug option using the CALPUFF/MMIF modeling platform has a very different effect on the tracer duration time on the arc using the CAL and PG dispersion algorithms. Using the CAL dispersion option

with APS, implementing the slug option decreases the tracer residence time of the 600 km arc from 17 to 15 hours. However, using the PG dispersion option with APS, the tracer residence on the 600 km receptor arc increased from 11 to 20 hours when the slug option is invoked using the PG dispersion option.

Table 3-16. Duration of time tracer resides on the GP80 600 km receptor arc (hours) for the CALPUFF slug and puff splitting sensitivity tests.

Scenario	MSLUG	MSPLIT	Duration on 600 km Arc	
			Time (Hours)	Difference (%)
Observed			12	
CALPUFF/CALMET				
BASEA_CAL	0	0	7	-42%
BASEA_APS_CAL	0	1	7	-42%
BASEA_SLUG_CAL	1	0	15	+25%
BASEA_SLUG_APS_CAL	1	1	16	+33%
CALPUFF/MMIF				
MMIF12_CAL	0	0	6	-50%
MMIF12_DPS_CAL	0	1	8	-33%
MMIF12_APS_CAL	0	1	17	+42%
MMIF12_SLUG_APS_CAL	1	1	15	25%
MMIF12_PG	0	0	7	-42%
MMIF12_DPS_PG	0	1	11	-8%
MMMIF12_APS_PG	0	1	11	-8%
MMIF12_SLUG_APS_PG	1	1	20	+67%

Table 3-17 summarizes the plume fitting model performance statistics for the CALPUFF slug and puff splitting sensitivity tests. For the CALPUFF/CALMET BASEA_CAL slug and puff splitting sensitivity tests, the improvements in CALPUFF's estimated tracer residence time on the 600 km receptor arc when the slug option is invoked is accompanied by a further degradation in CALPUFF's ability to estimate the maximum concentrations (Cmax/Omax) as well as increasing CALPUFF's overestimate of the observed plume spread (σ_y) (~16,500 m) from ~120% (~35,000 m) without the slug option to over 250% (~60,000 m) with the slug option. The use of the slug option also improves the angular offset of the plume centerline from off by ~18 degrees to off by ~14 degrees. Finally, without using APS, CALPUFF's CWIC performance is improved from a -38% underestimation to a -12% underestimation, whereas with using APS the improvement in CWIC performance due to using the slug option is less dramatic (-31% to -25%)

Using the CALPUFF/MMIF modeling platform, the changes in the maximum (Cmax/Omax) and plume spread model performance statistics due to the use of the slug option are much less than seen with the BASEA CALPUFF/CALMET modeling platform. Use of the slug option using the CALPUFF/MMIF platform increases the maximum concentrations slightly, whereas with the CALPUFF/CALMET platform the slug option resulting in slight deceases in concentrations. The use of puff splitting had little effect on the CALPUFF/MMIF estimated maximum concentrations and resulted in slightly wider plume widths. The biggest effect puff splitting had on the CALPUFF/MMIF model performance was for the plume centerline angular displacement that improved from 16-17 to 7-8 degrees offset from observed due to the use of puff splitting (DPS or APS). In fact, of all the CALPUFF sensitivity tests examined, CALPUFF/MMIF using puff splitting is the best performing model configuration for estimating plume centerline location. Puff splitting resulted in small improvements in CALPUFF's ability to predict CWIC across the 600 km arc. But the slug option greatly improved CALPUFF/MMIF's ability to reproduce the

observed CWIC. For example, using the CAL turbulence dispersion option, CALPUFF/MMIF underestimates the observed CWIC at the 600 km receptor arc by -32% using the puff model configuration and no puff splitting. Using the DPS and APS puff splitting approach reduces the CWIC underestimation bias to -28% and -21%, respectively, And then adding the slug formulation with the APS completely eliminates the CWIC underestimation bias (-2%). In fact, use of the APS and slug options with the CALPUFF/MMIF modeling platform results in the best performing CALPUFF sensitivity test for estimating CWIC across the 600 km arc of all the CALPUFF sensitivity tests analyzed (Tables 3-15 and 3-17).

Table 3-17. Plume fitting statistics for the CALPUFF slug and puff splitting sensitivity tests.

CALPUFF slug and puff splitting sensitivity test	Cmax		Omax		Sigma-y		Centerline		CWIC	
	(ppt)	MNB	(ppt)	MNB	(m)	MNB	(deg)	Diff	(ppt-m)	MNB
Observed	0.3152		0.3068		16,533		369.06		13,060	
CALPUFF/CALMET										
BASEA_CAL	0.0875	-72%	0.0817	-73%	36,870	123%	27.55	18.49	8,084	-38%
BASEA_APS_CAL	0.1014	-68%	0.1029	-66%	35,510	115%	27.19	18.13	9,023	-31%
BASEA_SLUG_CAL	0.0728	-77%	0.0726	-76%	62,650	279%	22.49	13.43	11,430	-12%
BASEA_SLUG_APS_CAL	0.0673	-79%	0.0652	-79%	58,440	253%	23.56	14.50	9,855	-25%
CALPUF/MMIF										
MMIF12KM_CAL	0.1029	-67%	0.1012	-67%	34,290	107%	26.43	17.37	8,842	-32%
MMIF12KM_DPS_CAL	0.1049	-67%	0.1016	-67%	35,960	118%	16.74	7.68	9,454	-28%
MMIF12KM_APS_CAL	0.1108	-65%	0.1076	-65%	37,120	125%	16.30	7.24	10,310	-21%
MMIF12KM_SLUG_CAL	0.1458	-54%	0.1462	-52%	35,190	113%	16.92	7.86	12,860	-2%
MMIF12KM_PG	0.0956	-70%	0.0887	-71%	39,120	137%	24.89	15.83	9,371	-28%
MMIF12KM_DPS_PG	0.1085	-66%	0.1143	-63%	41,610	152%	17.04	7.98	11,310	-13%
MMIF12KM_APS_PG	0.1085	-66%	0.1143	-63%	41,610	152%	17.04	7.98	11,310	-13%
MMIF12KM_SLUG_PG	0.1251	-60%	0.1115	-64%	41,770	153%	17.43	8.37	13,100	0%

3.5 CONCLUSIONS ON GP80 TRACER TEST EVALUATION

For the 100 km receptor arc CALPUFF/CALMET sensitivity simulations, the ability of CALPUFF to simulate the observed tracer concentrations varied among the different CALMET configurations and were not inconsistent with the results of the 1998 EPA CALPUFF evaluation study (EPA, 1998a). The best performing CALPUFF/CALMET configuration was when CALMET was run using MM5 data and just surface meteorological observations and no upper-air meteorological observations. In general, the CAL and AER turbulence dispersion options in CALPUFF performed similarly and performed better than the PG dispersion option. The performance of CALPUFF using the MMIF tool tended to be in the middle of the range of model performance for the CALPUFF/CALMET sensitivity tests; not as good as the performance of CALPUFF/CALMET using MM5 and just surface observations data in CALMET, but better than the performance of CALPUFF using MM5 data and no meteorological observations in CALMET.

The CALPUFF sensitivity modeling results for the GP80 600 km receptor arc were quite variable. With two notable exception (the BASEA_PG and EXP2C configurations), the initial CALPUFF sensitivity tests were unable to duplicate the observed tracer residence time on the 600 km receptor arc as was seen in the 1998 EPA CALPUFF evaluation study (EPA, 1998a). However, when the near-source slug option was used, CALPUFF/CALMET was better able to reproduce

the amount of time that the tracer was observed on the 600 km receptor arc. The standard application of CALPUFF for LRT applications is the puff model formulation rather than the slug model formation, which is designed to better simulate a near-source continuous plume. The fact that the slug formulation is needed to produce reasonable CALPUFF model performance for residence time on the 600 km receptor suggests that the findings of the 1998 EPA CALPUFF evaluation study should be re-evaluated.

In general, the CALPUFF/CALMET sensitivity tests that are based on CALMET using MM5 data with no meteorological observations exhibit better plume fitting model performance statistics for the 600 km receptors arc than when meteorological observations are used with CALMET. The use of the slug option with CALMET/CALPUFF, which improved the plume residence time statistics, degrades the maximum concentrations and plume width statistics, but improves the plume centerline and CWIC average plume concentration statistics. Puff splitting had little effect on the CALPUFF/CALMET model predictions on the 600 km receptor arc. However, puff splitting did improve the CALPUFF/MMIF plume centerline and CWIC average plume concentration statistics, as well as the tracer residence time statistics. Puff splitting resulted in a slight degradation of the plume width statistics in CALPUFF/MMIF. Using the slug option with puff splitting in CALPUFF/MMIF results in the best performing CALPUFF model configuration of all the sensitivity tests for the plume centerline and CWIC average plume statistics, although the use of slug and puff splitting does degrade the plume width statistic.

4.0 1975 SAVANNAH RIVER LABORATORY FIELD STUDY

4.1 DESCRIPTION OF THE 1975 SAVANNAH RIVER LABORATORY FIELD STUDY

The 1975 Savannah River Laboratory (SRL75) field experiment was located in South Carolina and occurred in December 1975 (DOE, 1978). A SF_6 tracer was released for four hours between 10:25 and 14:25 LST on December 10, 1975 from a 62 m stack with a diameter of 1.0 m, exit velocity of 0.001 m/s and at ambient temperature. A single monitoring arc was used in the SRL75 experiment that was approximately 100 kilometers from the source with monitoring sites located along I-95 from Mile Post (MP) 76 near St. George, SC in the south to Hwy 36 west of Tillman, SC to the north and along SC 336.

The 1998 EPA CALPUFF evaluation (EPA, 1998a) used the SRL75 SF_6 tracer release in the CALPUFF model evaluation. However, the 1986 8 LRT dispersion model evaluation study (Policastro et al., 1986) used the longer-term SRL Krypton-85 release database (Telegadas et al., 1980). In this study we evaluated CALPUFF using the SRL75 SF_6 database to be consistent with the 1998 EPA study.

4.2 MODEL CONFIGURATION AND APPLICATION

Both the CALMET meteorological model and MMIF tools were used to provide meteorological inputs to CALPUFF. The CALMET modeling was performed using a Universal Trans Mercator (UTM) map projection in order to be consistent with the past CALPUFF applications (EPA, 1998a). The MMIF meteorological processing used a Lambert Conformal Conic (LCC) map projection because in must be consistent with the MM5 coordinate system. Figure 4-1 displays the CALMET/CALPUFF UTM modeling domain and locations of the ~200 receptors used in the CALPUFF modeling that lie along an arc 100 km from the source. The tracer was observed using ~40 monitors that were located along I-95 between MP 24 and 76 that were approximately 100 km from the source. When using the Irwin Gaussian plume fitting model evaluation approach, the tracer observations at the monitoring sites are assumed to be on an arc of receptors 100 km from the source.

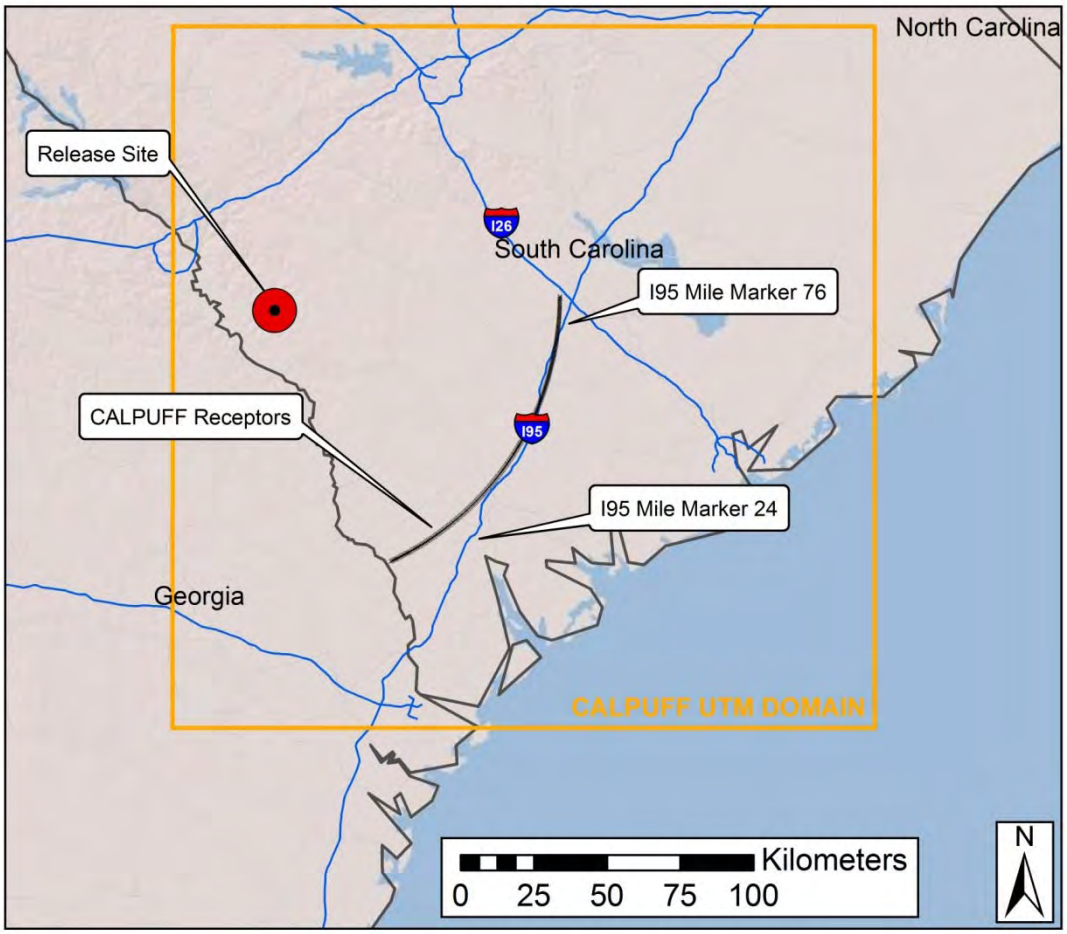


Figure 4-1. CALPUFF/CALMET UTM modeling domain and location of tracer release site and CALPUFF receptors along am arc 100 km from the source for the SRL75 CALPUFF modeling.

In the CALPUFF modeling system, each of the three programs (CALMET, CALPUFF, and CALPOST) uses a control file of user-selectable options to control the data processing. There are numerous options in each and several that can result in significant differences. The following model controls for CALMET and CALPUFF were employed for the analyses with the SRL75 tracer data.

4.2.1 CALMET Options

The following CALMET control parameters and options were chosen for the BASE case model evaluation. The BASE case control parameters and options were chosen to be consistent with two previous CALMET/CALPUFF evaluations (Irwin 1997 and EPA 1998a). The most important CALMET options relate to the development of the wind field and were set as follows:

NOOBS	= 0	Use surface, overwater, and upper air station data
IWFCOD	= 1	Use diagnostic wind model to develop the 3-D wind fields
IFRADJ	= 1	Compute Froude number adjustment effects (thermodynamic blocking effects of terrain)
IKINE	= 0	Do NOT compute kinematic effects
IOBR	= 0	Do NOT use O'Brien procedure for adjusting vertical velocity
IEXTRP	= 4	Use similarity theory to extrapolate surface winds to upper layers

IPROG	= 0	Do NOT use prognostic wind field model output as input to diagnostic wind field model (for observations only sensitivity test)
ITPROG	= 0	Do NOT use prognostic temperature data output

Mixing heights are important in the estimating ground level concentrations. The CALMET options that affect mixing heights were set as follows:

IAVEZI	= 1	Conduct spatial averaging
MNMDAV	= 1	Maximum search radius (in grid cells) in averaging process
HAFANG	= 30.	Half-angle of upwind looking cone for averaging
ILEVZI	= 1	Layer of winds to use in upwind averaging
DPTMIN	= .001	Minimum potential temperature lapse rate (K/m) in stable layer above convective mixing height
DZZI	= 200	Depth of layer (meters) over which the lapse rate is computed
ZIMIN	= 100	Minimum mixing height (meters) over land
ZIMAX	= 3200	Maximum mixing height (meters) over land, defined to be the top of the modeling domain

A number of CALMET model control options have no recommended default values, particularly radii of influence values for terrain and surface and upper air observations. The CALMET options that affect radius of influence were set as follows:

RMAX1	= 20	Minimum radius of influence in surface layer (km)
RMAX2	= 50	Minimum radius of influence over land aloft (km)
RMIN	= 0.1	Minimum radius of influence in wind field interpolation (km)
TERRAD	= 10	Radius of influence of terrain features (km)
RPROG	= 0	Weighting factors of prognostic wind field data (km)

A review of the respective CALMET parameters between the 1998 EPA CALMET/CALPUFF evaluation study using CALMET Version 4.0 and the BASE case scenario in the current CALMET/CALPUFF evaluation using CALMET Version 5.8 indicates differences in some CALMET options. The differences between the two scenarios are presented below in Table 4-1. All other major CALMET options for BASE case scenario matched the original 1998 EPA analysis.

Table 4-1. CALMET parameters for the SRL75 tracer field experiment modeling used in the, 1998 EPA and current BASE case analysis.

CALMET Option	Description	1998 EPA Setup	BASE Setup
IKINE	Adjust winds using Kinematic effects? (yes = 1 and no = 0)	1	0
MNMDAV	Maximum search radius for averaging mixing heights (# grid cells)	3	1
ZUPWND	Bottom and top layer through which domain-scale winds are calculated (in meters)	1,2000	1,1000
RMIN	Minimum radius of influence in wind field interpolation (in km)	2	0.1
RMIN2	Minimum upper air station to surface station extrapolation radius (in km)	-1	4

The CALMET preprocessor can utilize National Weather Service (NWS) meteorological data and on-site data to produce temporally and spatially varying three dimensional wind fields for CALPUFF. Only NWS data were used for this effort and came from two compact disc (CD) data sets. The first was the *Solar and Meteorological Surface Observation Network* (SAMSON)

compact discs, which were used to obtain the hourly surface observations. The surface stations used for the SRL75 CALMET modeling are shown in Table 4-2.

Table 4-2. 1975 Savannah River Laboratory surface meteorological stations.

State	Cities
Georgia	Athens, Atlanta, Augusta, Macon, Savannah
North Carolina	Asheville, Charlotte, Greensboro, Raleigh-Durham, Wilmington
South Carolina	Charleston, Columbia, Greer-Spartanburg

Twice daily soundings came from the second set of compact discs, the *Radiosonde Data for North America*. The upper-air rawinsonde meteorological observations used in the SRL75 CALMET modeling are shown in Table 4-3.

Table 4-3. 1975 Savannah River Laboratory tracer experiment rawinsonde sites.

State	Cities
Georgia	Athens, Waycross
North Carolina	Greensboro, Cape Hatteras
South Carolina	Charleston

Six vertical layers were defined for the CALPUFF modeling to be consistent with the Irwin (1997) and EPA (1998a) modeling as follows: surface-20, 20-50, 50-100, 100-500, 500-2000, and 2000-3300 meters.

MM5 prognostic meteorological model simulations were conducted using grid resolutions of 36, 12 and 4 km. The CALMET modeling used the 12 km MM5 data. The MMIF tool was applied using all three MM5 grid resolutions and using the first 27 MM5 vertical layers from the surface to approximately 6,500 m AGL.

4.2.2 CALPUFF Control Options

The following CALPUFF control parameters, which are a subset of the control parameters, were used. These parameters and options were chosen to be consistent with the 1977 INEL study (Irwin 1997) and 1998 EPA CALPUFF evaluation (EPA, 1998a) studies. Note that use of the slug option (MSLUG = 1) is fairly non-standard for LRT modeling. However, that was what was used in the 1997 INEL and 1998 EPA studies so it was also used in this study's CALPUFF evaluation using the SRL75 tracer database.

Technical options (group 2):

MCTADJ	= 0	No terrain adjustment
MCTSG	= 0	No subgrid scale complex terrain is modeled
MSLUG	= 1	Near-field puffs modeled as elongated (i.e., slugs)
MTRANS	= 1	Transitional plume rise is modeled
MTIP	= 1	Stack tip downwash is modeled
MSHEAR	= 0	Vertical wind shear is NOT modeled above stack top
MSPLIT	= 0	No puff splitting
MCHEM	= 0	No chemical transformations
MWET	= 0	No wet removal processes
MDRY	= 0	No dry removal processes
MPARTL	= 0	No partial plume penetration

MPDF	= 0	PDF NOT used for dispersion under convective conditions
MREG	= 0	No check made to see if options conform to regulatory Options

Two different values were used for the dispersion parameterization option MDISP:

= 2	Dispersion coefficients from internally calculated sigmas
= 3	PG dispersion coefficients for RURAL areas (PG)

In addition, under MDISP = 2 dispersion option, two different options were used for the MCTURB option that defines the method used to compute turbulence sigma-v and sigma-w using micrometeorological variables:

= 1	Standard CALPUFF routines (CAL)
= 2	AERMOD subroutines (AER)

Several miscellaneous dispersion and computational parameters (group 12) were set as follows:

SYTDEP	= 550.	Horizontal puff size beyond which Heffter equations are used for sigma-y and sigma-z
MHFTSZ	= 0	Do NOT use Heffter equation for sigma-z
XMXLEN	= 1	Maximum length of slug (in grid cells)
XSAMLEN	= 1	Maximum travel distance of puff/slug (in grid cells) during one sampling step
MXNEW	= 99	Maximum number of slugs/puffs released during one time step
WSCALM	= 0.5	Minimum wind speed (m/s) for non-calm conditions
XMAXZI	= 3000	Maximum mixing height (meters)
XMINZI	= 50	Minimum mixing height (meters)
SL2PF	= 10	Slug-to-puff transition criterion factor (= sigma-y/slug length)

A review of the respective CALPUFF parameters between the 1998 EPA CALMET/CALPUFF evaluation study using CALMET Version 4.0 and the BASE case scenario in the current CALMET/CALPUFF evaluation using CALPUFF Version 5.8 indicates differences in some parameters. The differences between the two scenarios are presented below in Table 4-4. All other major CALPUFF options for current BASE case scenario matched the original 1998 EPA analysis.

Table 4-4. CALPUFF parameters used in the SRL75 tracer field experiment modeling for the 1998 EPA and current BASE case analysis.

CALPUFF Option	Description	1998 EPA Setup	Current Study BASE Setup
SYMIN	Minimum sigma y (meters)	0.01	1
SZMIN	Minimum sigma z (meters)	0.01	1
WSCALM	Minimum wind speed (m/s) for non-calm conditions	1.0	0.5
XMAXZI	Maximum mixing height (meters)	3300	3000
XMINZI	Minimum mixing height (meters)	20	50
XMXLEN	Maximum length of slug (in grid cells)	0.1	1
XSAMLEN	Maximum travel distance of puff/slug (in grid cells) during one sampling step	0.1	1
MXNEW	Maximum number of slugs/puffs released during one time step	199	99
MXSAM	Maximum number of sampling steps per slug/puff during one time step	5	99
SL2PF	Slug-to-puff transition criterion factor (= sigma-y/slug length)	5.0	10.0

4.2.3 SRL75 CALPUFF/CALMET Sensitivity Tests

Table 4-5 describes the CALMET/CALPUFF sensitivity tests performed for the modeling of the 100 km arc of receptors in the SRL75 field study. The BASE simulation uses the same configuration as used in the 1998 EPA CALPUFF evaluation report, only updated from CALPUFF Version 4.0 to CALPUFF Version 5.8. The CALMET and CALPUFF parameters of the BASE case simulations were discussed earlier in this section.

The sensitivity simulations are designed to examine the sensitivity of the CALPUFF model performance to 10 km grid resolution in the CALMET meteorological model simulation, the use of 12 km resolution MM5 output data used as input to CALMET, and the use of surface and upper-air meteorological observations in CALMET through NOOBS = 0 (use surface and upper-air observation), 1 (use only surface observations) and 2 (don't use any observations).

In addition, for each experiment using different CALMET model configurations, three CALPUFF dispersion options were examined as shown in Table 4-6. Two of the CALPUFF dispersion sensitivity tests using dispersion based on sigma-v and sigma-w turbulence values using the CALPUFF (CAL) and AERMOD (AER) algorithms. Whereas the third dispersion option (PG) uses Pasquill-Gifford dispersion coefficients.

Table 4-5. CALPUFF/CALMET experiments for the SRL75 tracer experiment.

Experiment	CALMET Grid	MM5 Data	NOOBS	Comment
BASE	10 km	None	0	Original met observations only configuration
EXP1A	10 km	12 km	0	Aug 2009 IWAQM w/10 km grid using 12 km MM5
EXP1B	10 km	12 km	1	Don't use observed upper-air meteorological data
EXP1C	10 km	12 km	2	Don't use observed surface/upper-air meteorological data

Table 4-6. CALPUFF dispersion options examined in the CALPUFF sensitivity tests.

Experiment	MDISP	MCTURB	Comment
CAL	2	1	Dispersion coefficients from internally calculated sigma-v and sigma-w using micrometeorological variables and CALPUFF algorithms
AER	2	2	Dispersion coefficients from internally calculated sigma-v and sigma-w using micrometeorological variables and AERMOD algorithms
PG	3	--	PG dispersion coefficients for rural areas and MP coefficients for urban areas

The CALMET and CALPUFF simulations used for the sensitivity analyses were updated from the BASE case model configuration that was designed to be consistent with the 1998 EPA study by using recommended settings for many variables from the August 2009 EPA Clarification Memorandum. A summary of CALMET parameters that changed from the BASE case scenarios for the CALPUFF sensitivity tests are presented in Table 4-7.

Table 4-7. CALMET wind field parameters for the SRL75 tracer experiment.

CALMET Option	2009 EPA-FLM Default	BASE	EXP1A	EXP1B	EXP1C
NOOBS	0	0	0	1	2
ICLOUD	0	0	0	0	3
IEXTRP	-4	4	-4	-4	1
IPROG	14	0	14	14	14
ITPROG	0	0	0	1	2
ZIMIN	50	100	50	50	50
ZIMAX	3000	3200	3000	3000	3000
RMAX1	100	20	100	100	50
RMAX2	200	50	200	200	100

4.2.4 CALPUFF/MMIF Sensitivity Tests

With the MMIF software tool designed to reformat the MM5/WRF meteorological model output data for input into CALPUFF, there are much less options available and hence much fewer sensitivity tests as shown in Table 4-8.

Table 4-8. CALPUFF/MMIF sensitivity tests analyzed with the SRL75 tracer experiment.

Grid Resolution	MM5	MDISP	MCTURB	Comment
36 km	36 km	2	1	36 km MM5 with CALPUFF turbulence dispersion
36 km	36 km	2	2	36 km MM5 with AERMOD turbulence dispersion
36 km	36 km	3	--	36 km MM5 with Pasquill-Gifford dispersion
12 km	12 km	2	1	12 km MM5 with CALPUFF turbulence dispersion
12 km	12 km	2	2	12 km MM5 with AERMOD turbulence dispersion
12 km	12 km	3	--	12 km MM5 with Pasquill-Gifford dispersion
4 km	4 km	2	1	4 km MM5 with CALPUFF turbulence dispersion
4 km	4 km	2	2	4 km MM5 with AERMOD turbulence dispersion
4 km	4 km	3	--	4 km MM5 with Pasquill-Gifford dispersion

4.3 QUALITY ASSURANCE

The quality assurance (QA) of the CALPUFF modeling system simulations for the SRL tracer experiment was assessed by analyzing the CALMET and CALPUFF input and output files and the dates they were generated. The input file options were compared against the EPA-FLM recommended settings from the August 2009 Clarification Memorandum (EPA, 2009b) and the definitions of the sensitivity tests to assure that the intended parameters were varied. The QA of the MMIF runs was not completed because no input files or list files were provided to document the MMIF parameters.

The CALMET sensitivity simulations used a radius of influence of terrain on wind fields equal to 10 m (TERRAD = 10). The 2009 EPA Clarification Memorandum recommends TERRAD = 15. The CALMET sensitivity simulations used a minimum extrapolation distance between surface and upper air stations of 4 km (RMIN2 = 4). The 2009 EPA Clarification Memorandum recommends RMIN2 = -1.

Four CALMET parameters (BIAS, NSMTH, NINTR2, and FEXTR2) require a value for each vertical layer processed in CALMET. The CALMET BASE case has six vertical layers, but the sensitivity simulations are based on ten vertical layers. The CALMET sensitivity simulations were provided with only six values for BIAS, NSMTH, NINTR2, and FEXTR2 even though ten vertical layers were simulated. Therefore, CALMET used default values for the upper four vertical layers (i.e., 1200 m, 2000 m, 3000 m, and 4000 m).

In addition to the three CALPUFF dispersion options (AERMOD, CALPUFF, and PG), there were other CALPUFF parameters that differed between the CALPUFF/CALMET (BASE and sensitivity cases) and CALPUFF/MMIF modeling scenarios. The CALPUFF parameter differences include:

- CALPUFF/CALMET sensitivity runs using AERMOD and CALPUFF dispersion were conducted using near-field slug formation (MSLUG = 1), but the CALPUFF/CALMET PG and CALPUFF/MMIF runs were conducted using puffs (MSLUG = 0).
- CALPUFF/CALMET sensitivity runs using AERMOD and CALPUFF dispersion were set-up to not allow for partial plume penetration of inversion layer (MPARTL = 0).

The quality assurance of the post-processing of the SRL75 CALPUFF runs uncovered two errors. The first was that the conversion factor to convert the SF_6 tracer concentrations from mass per volume to ppt was approximately three times too large. The second error was that when calculating the integrated concentrations along the arc, the wrong time period was specified. These two errors were fixed and the CALPUFF results re-processed to generate new plume fitting statistical performance measures.

4.4 MODEL PERFORMANCE EVALUATION FOR THE SRL75 TRACER EXPERIMENT

The Irwin (1997) plume fitting evaluation approach was used to evaluate CALPUFF for the SRL75 field experiment. There are two components to the Irwin plume fitting evaluation approach:

1. A temporal analysis that examines the time the tracer arrives, leaves and resides on the receptor arc; and
2. A plume fitting procedures that compares the predicted observed peak and average plume concentrations and the width of the plume by fitting a Gaussian plume through the predicted or observed concentrations across the arc of receptors or monitors that lie on the 100 km receptor arc.

Because only long-term integrated average observed SF_6 samples were available, the timing component of the evaluation could not be compared against observed values in the SRL75 experiments.

Most of the CALPUFF sensitivity tests estimated that the tracer arrived at the 100 km arc on hour 13 LST, 2½ hours after the beginning to the tracer release. The exceptions to this are the CALPUFF/MMIF simulations using the 4 km MM5 data and CALPUFF/MMIF using the 36 km and PG dispersion that estimated the plume arrives at hour 14 LST. With one exception, the CALPUFF simulations estimated that the tracer resided either 5 or 6 hours on the arc. And with two exceptions, it was the meteorological data rather than the dispersion option that defined the residence time of the estimated tracer on the 100 km receptor arc. The exceptions were for the PG dispersion sensitivity test that in two cases predicted the tracer would remain one less hour on the arc; the CALPUFF/CALMET BASE sensitivity test using the PG dispersion estimated that the tracer would reside only 4 hours on the 100 km receptor arc. Without any observed tracer timing statistics, these results are difficult to interpret.

Table 4-9 displays the model performance evaluation for the various CALPUFF sensitivity tests using the Irwin plume fitting evaluation approach. The observed values were taken from the 1998 EPA CALPUFF tracer test evaluation report data (EPA, 1998a). Also shown in Table 4-4 are the statistics from the 1998 EPA report for the CALPUFF V4.0 modeling using Pasquill-Gifford (PG) and similarity (CAL) dispersion. Note that the EPA 1998 CALPUFF modeling used CALMET with just observations so is analogous to the BASE sensitivity scenario that used CALPUFF V5.8. There are five statistical parameters evaluated using the Irwin plume fitting evaluation approach:

- Cmax, which is the plume fitted centerline concentration.
- Omax, which is the maximum observed value at the ~40 monitoring sites or maximum predicted value across the ~200 receptors along the 100 km arc.
- Sigma-y, which the second moment of the Gaussian distribution and a measure of the plume spread.
- Plume Centerline, which is the angle of the plume centerline from the source to the 100 km arc.
- CWIC, the cross wind integrated concentration (CWIC) across the predicted and observed fitted Gaussian plume.

The first thing we note in Table 4-9 is that the maximum centerline concentration of the fitted Gaussian plume to the observed SF_6 tracer concentrations across the 12 monitors (2.739 ppt) is almost half the observed maximum at any of the monitors (5.07 ppt). As the centerline concentrations in a Gaussian plume represents the maximum concentration, this means that

the fitted Gaussian plume is not a very good fit of the observations and the Cmax parameter is not a good indicator of model performance. Comparison of the predicted and observed Omax values that represents the maximum observed concentration across the monitoring sites and the maximum predicted value at any of the 200 receptors along the arc is an apple-orange comparison. We would expect the predicted Omax value to be the same or larger than the observed Omax value given there are ~5 times more samples of the plume in the model predictions compared to the observations. This is the case for all of the CALPUFF/MMIF sensitivity tests. However, when CALPUFF is run using CALMET with no MM5 data (BASE), the predicted Omax value is less than the observed value for both CALPUFF V4.0 and CALPUFF V5.8, which is an undesirable attribute.

The fitted plume width (sigma-y) based on observations is almost doubled the fitted plume width based on the CALPUFF model predictions for all the CALPUFF simulations. However, this is likely due in part to the poor Gaussian plume fit of the observations. Figure 4-2 is reproduced from the 1998 EPA CALPUFF tracer test report and compares the CALPUFF fitted Gaussian plume concentrations with the 13 observed tracer concentrations, where the predicted and observed tracer distributions have been rotated so that their centerlines match up. Of the 13 monitors pictured along the 100 km arc, four have substantial (> 2.0 ppt) concentrations whereas the tracer concentrations at the remaining monitoring sites are mostly <0.2 ppt. Based on this figure, the predicted and observed plume widths match quite well. However, when fitting a Gaussian plume to the observations it appears that the "observed" width is overstated due to the low tracer concentration monitoring sites on the wings of the plume. These results suggest that in the real world the concept of a Gaussian plume may not hold at longer downwind distances, such as the 100 km receptor arc used in the SRL75 field experiment. Consequently, the use of a fitted Gaussian plume as a model evaluation tool may be a poor indicator of model performance for LRT dispersion models.

The plume centerline metric is a useful tool for evaluating the main flow of the center of mass of a plume from the source to receptor arc. The observed plume centerline is at 126 degrees. The CALPUFF/MMIF estimated centerline is off by 8-10 degrees too far south. However, CALPUFF using CALMET and just observations is off by 17 degrees (EPA, 1998a) and 20 degrees (BASE) and it is too far south. Adding the 12 km MM5 data with the observations in CALPUFF (EXP1) only improves the centerline angular offset from 20 to 19 degrees. Removing the upper-air meteorological observations from the CALMET modeling (EXP2) results in no improvements in the CALPUFF/CALPUFF centerline offset (still 19 degrees). However, also removing the surface meteorological observations from the CALMET modeling (EXP3, NOOBS = 2) improves the CALPUFF/CALMET centerline angular offset from 19 to 12 degrees so that it is almost as good as the CALPUFF/MMIF simulations (8 to 10 degrees offset).

Table 4-9. CALPUFF model performance statistics using the Irwin plume fitting evaluation approach using the SRL75 field experiment and the 1998 EPA study and the CALPUFF sensitivity tests.

CALPUFF	Cmax[1]		Omax		Sigma-y[1]		Plume Centerline		CWIC	
Sensitivity Test	(ppt)	MNB	(ppt)	MNB	(meters)	MNB	(degrees)	Diff (deg)	(ppt/m^2)	MNB
Observed	2.739		5.07		11643		125.59		79,940	
EPA 1998										
PG	7.20	163%	6.90	36%	7200	-38%	143	17	129,000	61%
Similarity	5.1	86%	5.00	-1%	6000	-48%	143	17	77,000	-4%
MMMIF										
4KM_AER	8.791	221%	8.625	70%	6810	-42%	135.9	10.31	150,100	88%
4KM_CAL	8.79	221%	8.625	70%	6801	-42%	135.9	10.31	149,800	87%
4KM_PG	8.798	221%	8.656	71%	6844	-41%	135.9	10.31	150,900	89%
12KM_AER	10.63	288%	10.41	105%	6587	-43%	133.8	8.21	175,500	120%
12KM_CAL	10.79	294%	10.42	106%	6492	-44%	133.8	8.21	175,500	120%
12KM_PG	10.7	291%	10.49	107%	6545	-44%	133.8	8.21	175,500	120%
36KM_AER	11.61	324%	11.4	125%	6315	-46%	134.1	8.51	183,800	130%
36KM_CAL	11.62	324%	11.41	125%	6311	-46%	134.1	8.51	183,800	130%
36KM_PG	12.46	355%	12.24	141%	6072	-48%	133.7	8.11	189,700	137%
CALMET										
BASE_AER	3.495	28%	3.241	-36%	6640	-43%	145.8	20.21	58,180	-27%
BASE_CAL	3.505	28%	3.239	-36%	6612	-43%	145.8	20.21	58,100	-27%
BASE_PG	7.322	167%	6.734	33%	6941	-40%	144.8	19.21	127,400	59%
EXP1A_AER	4.849	77%	4.691	-7%	6383	-45%	144.5	18.91	77,580	-3%
EXP1A_CAL	4.849	77%	4.691	-7%	6385	-45%	144.5	18.91	77,600	-3%
EXP1A_PG	7.138	161%	7.337	45%	6307	-46%	143.4	17.81	112,800	41%
EXP1B_AER	5.318	94%	5.289	4%	6132	-47%	145.3	19.71	81,740	2%
EXP1B_CAL	5.303	94%	5.277	4%	6148	-47%	145.3	19.71	81,720	2%
EXP1B_PG	6.468	136%	7.022	39%	6190	-47%	144.7	19.11	100,300	25%
EXP1C_AER	7.892	188%	7.754	53%	5939	-49%	137.4	11.81	117,500	47%
EXP1C_CAL	7.981	191%	7.843	55%	5926	-49%	137.4	11.81	118,600	48%
EXP1C_PG	8.318	204%	8.167	61%	5697	-51%	137.1	11.51	118,800	49%

1. Because of the poor fit of the fitted Gaussian plume with the observed tracer concentrations in the SRL75 experiment, the Cmax and Sigma-y are not meaningful metrics of model performance.

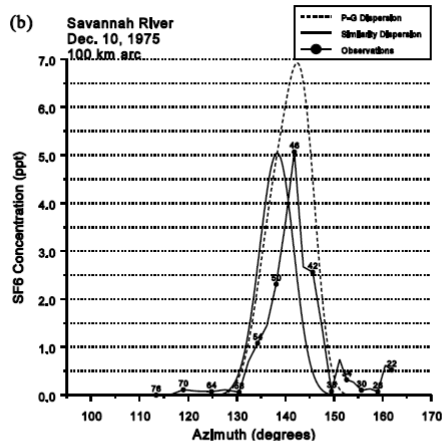


Figure 3. Simulated and observed 7-hour average plume for the Savannah River Laboratory tracer study for a) actual locations and b) observed plume offset 17° to the south.

Figure 4-2. Comparison of predicted fitted plume with observations for the SRL75 tracer experiments (Source: EPA, 1998a). Note that results from this study are not shown.

With the exception of the plume centerline statistic, the Irwin plume fitting evaluation approach was not a very useful evaluation tool for comparing the model predictions and observations using the SRL75 field experiment data. However, it is a useful tool for comparing the CALPUFF simulations using the different versions of CALPUFF/CALMET. The BASE CALPUFF/CALMET sensitivity test in this study was designed to be setup in the same fashion as the 1998 EPA tracer modeling study. Although there are some similarities, there are also some differences. For example, using the PG dispersion results in much higher CWIC in both the 1998 EPA (129,000 ppt/m^2) and BASE (127,400 ppt/m^2) sensitivity tests versus using the CAL turbulence/similarity dispersions options (77,000 ppt/m^2 for 1998 EPA and ~58,000 ppt/m^2 for BASE). The maximum estimated concentration at any of the 200 receptors along the 100 km arc using the PG dispersion are very similar for the 1998 EPA (6.9 ppt) and BASE sensitivity (6.7 ppt) scenario and lower concentrations are estimated using the CAL turbulence dispersion in the 1998 EPA (5.0 ppt) and the BASE (3.2 ppt) sensitivity test.

4.5 CONCLUSIONS OF THE SRL75 MODEL PERFORMANCE EVALUATION

Because the fit of the Gaussian plume to the observed tracer concentrations along the SRL75 100 km receptor arc did not match the observed values well, the fitted plume evaluation approach did not work well using the SRL75 database. Thus, there are few conclusions that can be drawn about the CALPUFF model performance using the SRL75 tracer field experiment data. The plume centerline evaluation is still valid and the use of CALPUFF without using meteorological observations with CALMET either through MMIF or with CALMET using no observations (NOOBS = 2) produces better plume centerline performance than when meteorological observations are used with CALMET. These results are consistent with EPA's thoughts in the 2009 IWAQM Reassessment Report (EPA, 2009a) and August 2009 Clarification Memorandum (EPA, 2009b); it is better to pass through the wind fields and other meteorological field from MM5/WRF to CALPUFF, rather than running them through CALMET, which can introduce artifacts and upset the dynamic balance of the meteorological fields.

5.0 1983 CROSS APPALACHIAN TRACER EXPERIMENT

5.1 DESCRIPTION OF THE 1983 CROSS APPALACHIAN TRACER EXPERIMENT

A series of tracer test field experiments were conducted between September 18 and October 29, 1983 over the northeastern U.S. and southeastern Canada (Ferber et al., 1986; Draxler et al., 1988). The Cross-Appalachian Tracer Experiment (CAPTEX) consisted of 5 tracer releases from Dayton, Ohio and 2 tracer releases from Sudbury, Ontario. Each release was independent of the others and was conducted when the forecast was for the tracer to pass through the center of the sampling network. Samplers were placed at a variety of locations in the northeast U.S. and southeast Canada to distances of about 1,000 km from Dayton. Although synoptic meteorological conditions were similar between releases at each location, there were large differences in the spatial concentration patterns, from narrow to wide. There was even a case of the tracer plume passing over the samplers without mixing to the surface.

The CALPUFF LRT modeling system was evaluated for various model configurations and meteorological inputs using two of the five CAPTEX tracer release experiments:

> CTEX3: The third CAPTEX tracer release occurred on October 2, 1983 where a tracer was released from Dayton, Ohio for two hours between the hours of 1400 and 1600 LST with a release rate of 18.611 g/s.
>
> CTEX5: The fifth CAPTEX tracer release occurred during the end of October with a two hour tracer release from Sudbury, Ontario between hour 23 on October 25, 1983 and hour 01 on October 26, 1983 with a release rate of 16.667 g/s.

Figure 5-1 displays the locations of the two tracer release sites and the tracer sampling network for the CAPTEX tracer field experiments. Also shown in Figure 5-1 are the CALPUFF, CALMET and MMIF modeling domains.

This section describes the evaluation of the CALPUFF LRT dispersion model using the CTEX3 and CTEX5 field experiments using numerous sensitivity tests with alternative meteorological inputs. Appendices A and B present the evaluation of the MM5 and CALMET sensitivity simulations using surface meteorological observations for the, respectively, CTEX5 and CTEX3 experiments. Appendix C presents the evaluation of six LRT dispersion models using the CTEX3 and CTEX5 field studies and common MM5 meteorological inputs.

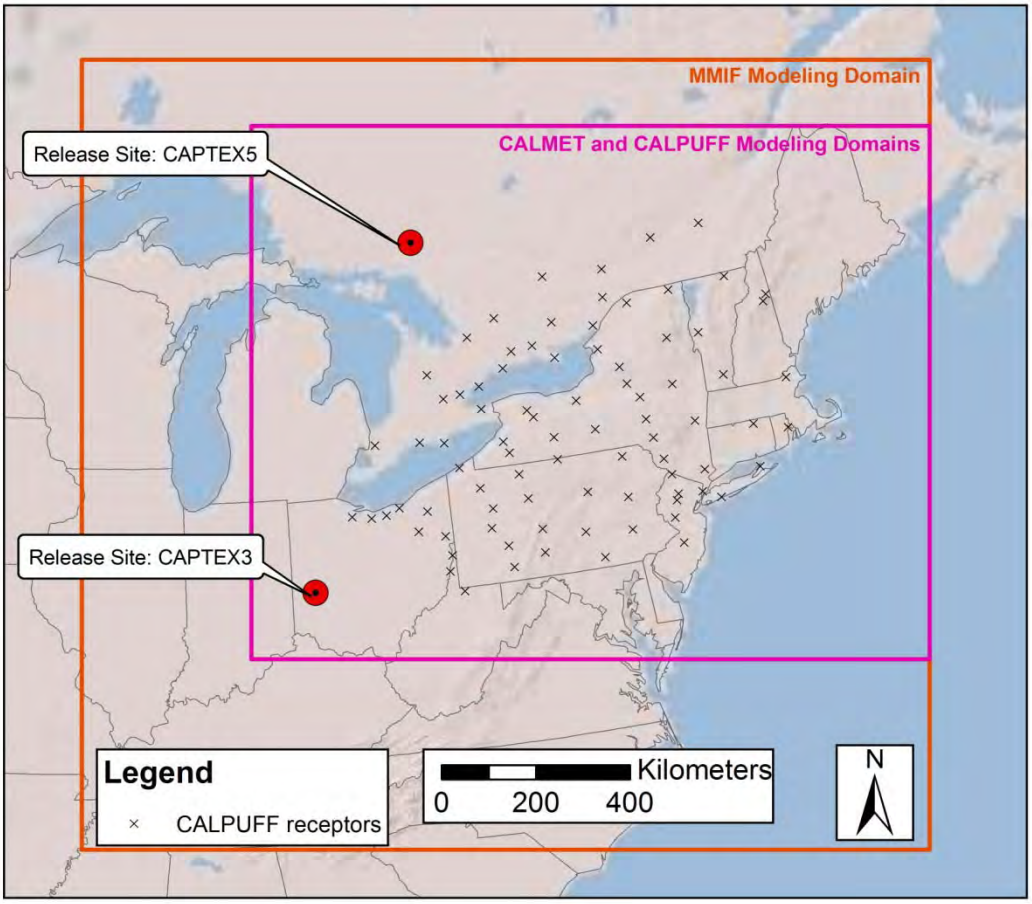


Figure 5-1. Location of Dayton and Sudbury tracer release sites and the tracer sampling network for the CAPTEX tracer field experiments.

5.2 MODEL CONFIGURATION AND APPLICATION

CALPUFF was applied using several different meteorological inputs. The first set was designed to use the same meteorological modeling technology as used in previous years to evaluate CALPUFF V4.0 only using the current regulatory versions of CALPUFF (V5.8) to document the effects of version changes. For the CTEX5 experiment period, the MM5 prognostic meteorological model was applied using grid resolutions of 80, 36 and 12 km to investigate the sensitivity of CALMET and CALPUFF model performance to MM5 grid resolution. For the CTEX3 experiment period, MM5 modeling was performed using grid resolution of 36 and 12 km, for the MM5 80 km sensitivity tests historical 80 km MM4 output data were utilized. CALMET was also run with different grid resolutions (18, 12 and 4 km) using the different MM5/MM4 grid resolution data as input. CALPUFF V5.8 was evaluated using the ATMES-II procedures using the various MM5/CALMET meteorological inputs, as well as inputs from the Mesoscale Model Interface (MMIF) tool that performs a “pass through” of the MM5 meteorological output to provide meteorological inputs to CALPUFF.

5.2.1 MM5 Prognostic Meteorological Modeling

The most recent version of the publicly available non-hydrostatic version of MM5 (version 3.7.4) was used. The MM5 preprocessors pregrid, regrid, little_r, and interpf were used to develop initial and boundary conditions. Nine separate MM5 sensitivity tests were performed for the CTEX5 field experiment period as listed in Table 5-1. As noted previously, for CTEX3 period no 80 km MM5 modeling was performed and historical 80 km MM4 data were used for the CTEX3 CALPUFF sensitivity tests.

The MM5 modeling for this study was based on three vertical structures designed to replicate common vertical structures of meteorological modeling from the 1980's to 2000's with vertical definitions of 16, 33, and 43 layers. The MM5 vertical domain definition for the 33 and 43 layer MM5 sensitivity simulations are presented in both sigma and height coordinates in Tables 5-2 and 5-3. Topographic information for the MM5 system was developed using the NCAR and the United States Geological Survey (USGS) terrain databases. Vegetation type and land use information was developed using the most recent NCAR/PSU databases provided with the MM5 distribution [available at ftp://ftp.ucar.edu/mesouser]. Standard MM5 surface characteristics corresponding to each land use category were used.

Four different grid configurations were defined for the MM5 sensitivity modeling. The first experiment (EXP1) was a baseline run using the horizontal and vertical configuration of MM4 simulations of the late 1980's and early 1990's (similar to the original MM4 dataset published by the EPA). The baseline simulation uses a single domain (no nests) with a horizontal grid resolution of 80 km and 16 vertical levels. The baseline configuration used older physics options more consistent with physics options available at the time of publication of the original EPA MM4 dataset. Physics options include the Blackadar (BLKDR) Planetary Boundary Layer (PBL) parameterization, Anthes-Kuo (AK) convective parameterization, Dudhia Radiation (DRAD), Dudhia Simple Ice Microphysics (SIM), and a 5-layer soil model (5LAYSOIL).

The second MM5 experiment (EXP2) was designed to reflect common grid and physics configurations used in numerical weather modeling for air quality simulations in the late 1990's and early 2000's. EXP2A through EXP2C used three nested domains (108, 36, and 12 km) with a 33 vertical layer vertical structure (Table 5-2). Physics options include the Medium Range Forecast model (MRF) PBL parameterization, Kain-Fritsch (KF) convective parameterization, rapid radiative transfer model (RRTM) radiation, SIM microphysics, and the 5LAYSOIL soil model. EXP2H is a variation of EXP2C, reflecting another common configuration of the period, but using the BLKDR PBL parameterization instead of the MRF PBL.

The third MM5 experiment (EXP3) was designed to reflect the more recent advances in numerical weather modeling for air quality simulations, both in terms of grid configuration and physics options. These options are largely consistent with annual MM5 simulations conducted by the EPA and the Regional Haze Regional Planning Organizations (RPOs). Consistent with EXP2, EXP3 uses three nested domains (108, 36, and 12 km). EXP3 uses the Pleim-Xu (PX) PBL parameterization, the Kain-Fritsch 2 (KF2) convective parameterization, DRAD radiation, and the Pleim-Xu (PX) land surface model (LSM).

A key facet in the MM5 sensitivity modeling was to measure the effectiveness of various four-dimensional data assimilation (FDDA) strategies on meteorological model performance and also determine the importance of assimilated fields in enhancing the performance of long range transport (LRT) model simulations. In EXP1 and EXP2 series, there are a minimum of three

MM5 runs, the first without FDDA (i.e., in forecasting mode), the second with three-dimensional analysis nudging above the PBL only, and the third using both three-dimensional analysis nudging above the PBL and surface analysis nudging below the PBL. Nudging within the PBL was turned off for temperature and mixing ratio. Default nudging strengths were used for both three-dimensional analysis and surface analysis nudging in these scenarios.

In scenarios EXP2I and EXP2J, alternative data assimilation strategies were tested while keeping the three-dimensional and surface analysis nudging. In EXP2I, the nudging strength was doubled. Observational nudging was turned on for EXP2J in addition to the nudging strengths used in EXP2I. The NCAR ds472.0 dataset was used to provide surface observations for the observational nudging.

Although new MM5 meteorological modeling was performed for the scenarios in Table 5-1 for the CTEX5 field experiment, for the CTEX3 field experiment the historical 80 km MM4 data was used for the 80 km MM5/MM4 scenarios and the FDDA sensitivity tests were not performed.

Table 5-1. Summary of CTEX5 MM5 sensitivity tests. design.

Sensitivity Test	Horizontal Grid	Vertical Layers	Physics Options	FDDA Used
EXP1A	80 km	16	BLKDR, AK, DRAD, SIM, 5LAYSOIL	No FDDA
EXP1B	80 km	16	BLKDR, AK, DRAD, SIM, 5LAYSOIL	Analysis Nudging
EXP1C	80 km	16	BLKDR, AK, DRAD, SIM, 5LAYSOIL	Analysis Nudging Surface Analysis Nudging
EXP2A	108/36/12km	33	MRF, KF, RRTM, SIM, 5LAYSOIL	No FDDA
EXP2B	108/36/12km	33	MRF, KF, RRTM, SIM, 5LAYSOIL	Analysis Nudging
EXP2C	108/36/12km	33	MRF, KF, RRTM, SIM, 5LAYSOIL	Analysis Nudging Surface Analysis Nudging
EXP2F	108/36/12km	43	BLKDR, KF, DRAD, SIM, 5LAYSOIL	No FDDA
EXP2G	108/36/12km	43	BLKDR, KF, DRAD, SIM, 5LAYSOIL	Analysis Nudging
EXP2H	108/36/12km	43	BLKDR, KF, DRAD, SIM, 5LAYSOIL	Analysis Nudging Surface Analysis Nudging
EXP2I	108/36/12km	43	BLKDR, KF, DRAD, SIM, 5LAYSOIL	Analysis Nudging Surface Analysis Nudging FDDA x 2 strength
EXP2J	108/36/12km	43	BLKDR, KF, DRAD, SIM, 5LAYSOIL	Analysis Nudging Surface Analysis Nudging FDDA x 2 strength Observational Nudging
EXP4	108/36/12km	43	PXPBL, KF2, DRAD, R2, PXLSM	Analysis Nudging Surface Analysis Nudging
4 km	4 km	43	BLKDR, KF, DRAD, SIM, 5LAYSOIL (EXP2H)	Analysis Nudging Surface Analysis Nudging

Table 5-2. MM5 sensitivity tests EXP2A through EXP2C vertical domain definition using 33 vertical layers.

k(MM5)	sigma	Press. (bar)	height(m)	depth(m)
33	0.0000	10000	14662	1841
32	0.0500	14500	12822	1466
31	0.1000	19000	11356	1228
30	0.1500	23500	10127	1062
29	0.2000	28000	9066	939
28	0.2500	32500	8127	843
27	0.3000	37000	7284	767
26	0.3500	41500	6517	704
25	0.4000	46000	5812	652
24	0.4500	50500	5160	607
23	0.5000	55000	4553	569
22	0.5500	59500	3984	536
21	0.6000	64000	3448	506
20	0.6500	68500	2942	480
19	0.7000	73000	2462	367
18	0.7400	76600	2095	266
17	0.7700	79300	1828	259
16	0.8000	82000	1569	169
15	0.8200	83800	1400	166
14	0.8400	85600	1235	163
13	0.8600	87400	1071	160
12	0.8800	89200	911	236
11	0.9100	91900	675	154
10	0.9200	92800	598	153
9	0.9300	93700	521	152
8	0.9400	94600	445	151
7	0.9500	95500	369	149
6	0.9600	96400	294	74
5	0.9700	97300	220	111
4	0.9800	98200	146	37
3	0.9850	98650	109	37
2	0.9900	99100	73	36
1	0.9950	99550	36	36
0	1.0000	100000	0	0

Table 5-3. MM5 sensitivity tests EXP2F through EXP2H vertical domain definition using 43 vertical layers.

k(MM5)	sigma	Press(mb)	height(m)	depth(m)
43	0.0000	10000	14662	409
42	0.0100	10900	14253	571
41	0.0250	12250	13682	696
40	0.0450	14050	12986	635
39	0.0650	15850	12351	724
38	0.0900	18100	11627	660
37	0.1150	20350	10966	724
36	0.1450	23050	10242	663
35	0.1750	25750	9579	710
34	0.2100	28900	8869	742
33	0.2500	32500	8127	681
32	0.2900	36100	7446	630
31	0.3300	39700	6815	587
30	0.3700	43300	6228	483
29	0.4050	46450	5745	458
28	0.4400	49600	5287	435
27	0.4750	52750	4852	415
26	0.5100	55900	4436	341
25	0.5400	58600	4095	329
24	0.5700	61300	3766	318
23	0.6000	64000	3448	307
22	0.6300	66700	3141	297
21	0.6600	69400	2844	288
20	0.6900	72100	2556	279
19	0.7200	74800	2277	271
18	0.7500	77500	2005	220
17	0.7750	79750	1785	215
16	0.8000	82000	1569	211
15	0.8250	84250	1359	206
14	0.8500	86500	1153	122
13	0.8650	87850	1031	120
12	0.8800	89200	911	119
11	0.8950	90550	792	271
10	0.9100	91900	675	154
9	0.9200	92800	598	153
8	0.9300	93700	521	152
7	0.9400	94600	445	151
6	0.9500	95500	369	149
5	0.9600	96400	294	74
4	0.9700	97300	220	74
3	0.9800	98200	146	73
2	0.9900	99100	73	44
1	0.9960	99640	29	29
0	1.0000	100000	0	0

5.2.2 CALMET Diagnostic Meteorological Modeling

The CALMET (Scire, 2000a) diagnostic meteorological model generates wind fields and other meteorological variables required by the CALPUFF LRT dispersion model in a two-step process.

In STEP 1, an initial first guess wind field is modified through parameterized diagnostic wind field effects due to terrain: blocking and deflection, channeling and slope flows. The first guess wind field can be provided using prognostic meteorological model output (e.g., MM5) or interpolated from observations. The resultant STEP 1 wind field is then modified in STEP 2 by incorporating (blending) surface and upper-air wind observations with the STEP 1 wind field in an Objective Analysis (OA) procedure. CALMET has numerous options on how to generate the STEP 1 wind field as well as how the STEP 2 OA procedure is performed. A series of CALMET sensitivity tests were performed to examine the efficacy of OA, optimal radii of influence for CALMET OA operations, and also to examine the role of horizontal grid resolution on performance of both the diagnostic meteorological model and the performance of the CALPUFF (Scire, 2000b) LRT dispersion model. CALMET was operated at three horizontal grid resolutions (18, 12 and 4 km) with input prognostic meteorological data at horizontal resolutions of 80 km (MM5 EXP1C), 36 km (MM5 EXP2H), and 12 km (MM5 EXP2H). Additionally, the Mesoscale Model Interface (MMIF) tool (Emery and Brashers, 2009) was also applied using MM5 output at 80 km (MM5 EXP1C), 36 km (MM5 EXP2H), and 12 km (MM5 EXP2H) for CTEX5. Since no 80 km MM5 data was available for CTEX3, MMIF was only used using the 36 and 12 km MM5 output for CTEX3. In addition, for CTEX5 MMIF was run using 4 km MM5 output that was generated in a "nest down" simulation from the 12 km MM5 simulation.

33 separate CALMET sensitivity tests were performed using MM5 output from the MM5 sensitivity simulations listed in Table 5-1 and the CALMET sensitivity test experimental configuration design given in Tables 5-4 and 5-5. The definitions of the 33 CALMET sensitivity tests are given in Table 5-6. CALPUFF sensitivity simulations were performed using a subset of the 33 CALMET sensitivity tests for the CTEX3 and CTEX5 tracer test field experiments. For both the CTEX3 and CTEX5 modeling periods, the CALMET EXP2 sensitivity test series was not run with CALPUFF, as well as the EXP1 series for CTEX5. The BASED CALPUFF simulation encountered an error in execution and failed to finish for the CTEX3 modeling period. The 80KM_MMIF was also not run for CTEX3 because MMIF was not designed to use MM4 data. For CTEX5, a 4 km MM5 nest down simulation was performed off of the MM5 EXP2H sensitivity test (see Figure 5-1) so that a 4KM_MMIF CALPUFF sensitivity test could also be performed.

Table 5-4. CALMET sensitivity test experiment configuration for grid resolution.

Experiment	CALMET Resolution (km)	MM5 Resolution (km)
BASE	18	80
EXP1	12	80
EXP2	4	80
EXP3	12	36
EXP4	12	12
EXP5	4	36
EXP6	4	12

Table 5-5. CALMET Objective Analysis (OA) sensitivity test configurations.

Experiment Series	RMAX1 (km)	RMAX2 (km)	NOOBS	Comment
A	500	1000	0	Use surface and upper-air met obs
B	100	200	0	Use surface and upper-air met obs
C	10	100	0	Use surface and upper-air met obs
D	0	0	2	Don't use surface and upper-air met obs

Table 5-6. Definition of the CALMET sensitivity tests and data sources.

Sensitivity Test	MM5 Experiment and Resolution	CALMET Resolution	RMAX1/RMAX2	NOOBS	CTEX3	CTEX5
BASEA	EXP1C – 80 km	18 km	500/1000	0	Yes	Yes
BASEB	EXP1C – 80 km	18 km	100/200	0	Yes	Yes
BASEC	EXP1C – 80 km	18 km	10/100	0	Yes	Yes
BASED	EXP1C – 80 km	18 km	0/0	2	No	Yes
1A	EXP1C – 80 km	12 km	500/1000	0	Yes	No
1B	EXP1C – 80 km	12 km	100/200	0	Yes	No
1C	EXP1C – 80 km	12 km	10/100	0	Yes	No
1D	EXP1C – 80 km	12 km	0/0	2	Yes	No
2A	EXP1C – 80 km	4 km	500/1000	0	No	No
2B	EXP1C – 80 km	4 km	100/200	0	No	No
2C	EXP1C – 80 km	4 km	10/100	0	No	No
2D	EXP1C – 80 km	4 km	0/0	2	No	No
3A	EXP2H – 36 km	12 km	500/1000	0	Yes	Yes
3B	EXP2H – 36 km	12 km	100/200	0	Yes	Yes
3C	EXP2H – 36 km	12 km	10/100	0	Yes	Yes
3D	EXP2H – 36 km	12 km	0/0	2	Yes	Yes
4A	EXP2H – 12 km	12 km	500/1000	0	Yes	Yes
4B	EXP2H – 12 km	12 km	100/200	0	Yes	Yes
4C	EXP2H – 12 km	12 km	10/100	0	Yes	Yes
4D	EXP2H – 12 km	12 km	0/0	2	Yes	Yes
5A	EXP2H – 36 km	4 km	500/1000	0	Yes	Yes
5B	EXP2H – 36 km	4 km	100/200	0	Yes	Yes
5C	EXP2H – 36 km	4 km	10/100	0	Yes	Yes
5D	EXP2H – 36 km	4 km	0/0	2	Yes	Yes
6A	EXP2H – 12 km	4 km	500/1000	0	Yes	Yes
6B	EXP2H – 12 km	4 km	100/200	0	Yes	Yes
6C	EXP2H – 12 km	4 km	10/100	0	Yes	Yes
6D	EXP2H – 12 km	4 km	0/0	2	Yes	Yes
80KM_MMIF	EXP1C – 80 km	MMIF	NA	NA	No	Yes
36KM_MMIF	EXP2H – 36 km	MMIF	NA	NA	Yes	Yes
12KM_MMIF	EXP2H – 12 km	MMIF	NA	NA	Yes	Yes
4KM_MMIF	4 km EXP2H nest down	MMIF	NA	NA	No	Yes

5.3 QUALITY ASSURANCE

Quality assurance (QA) of the CALMET and CALPUFF sensitivity modeling was performed by analyzing the run control files to confirm that the intended options and inputs of each sensitivity test were used. For the MM5 datasets, performance for meteorological parameters of wind (speed and direction), temperature, and humidity (mixing ratio) are examined. For the CALMET experiments, just model estimated winds (speed and direction) were compared to observations because the two-dimensional temperature and relative humidity fields output are simple interpolated fields of the observations. Therefore, the performance evaluation for CALMET was restricted to winds where the majority of change can be induced by both diagnostic terrain adjustments and varying the OA strategy. Note that except for the NOOBS = 2 CALMET sensitivity tests (experiment K), surface meteorological observations are blended in the wind fields used in the CALMET STEP 2 OA procedure. Thus, this is not a true independent

evaluation as the surface meteorological observations used in the evaluation were also used as input into CALMET.

The METSTAT software (Emery et al., 2001) was used to match MM5 output with observation data. The MMIFStat software (McNally, 2010) tool was used to match CALMET output with observation data. Emery and co-workers (2001) have developed a set of "benchmarks" for comparing prognostic meteorological model performance statistics metrics. These benchmarks were developed after examining the performance of the MM5 and RAMS prognostic meteorological models for over 30 applications. The purpose of the benchmarks is not to assign a passing or failing grade, rather it is to put the prognostic meteorological model performance in context. The surface meteorological model performance benchmarks from Emery et al., (2001) are displayed in Table 5-7. Note that the wind speed RMSE benchmark was also used for wind speed MNGE given the similarity of the RMSE and MNGE performance statistics. These benchmarks are not applicable for diagnostic model evaluations.

Table 5-7. Wind speed and wind direction benchmarks used to help judge the performance of *prognostic* meteorological models (Source: Emery et al., 2001).

Wind Speed	Root Mean Squared Error (RMSE) Mean Normalized Bias (NMB) Index of Agreement (IOA)	≤ 2.0 m/s ≤ ±0.5 m/s ≥ 0.6
Wind Direction	Mean Normalized Gross Error (MNGE) Mean Normalized Bias (MNB)	≤ 30° ≤ ±10°
Temperature	Mean Normalized Gross Error (MNGE) Mean Normalized Bias (NMB) Index of Agreement (IOA)	≤ 2.0 K ≤ ±0.5 m/s ≥ 0.8
Humidity	Mean Normalized Gross Error (MNGE) Mean Normalized Bias (NMB) Index of Agreement (IOA)	≤ 2.0 g/kg ≤ ±1.0 g/kg ≥ 0.6

The MM5 and CALMET comparisons to observations for CTEX3 and CTEX5 are provided in the Appendix. The key findings of the CTEX5 MM5 and CALMET model performance evaluation are as follows:

- The MM5 performance using the MRF PBL scheme (EXP2A-C) was extremely poor. For example the temperature exhibited an underestimation bias of over -4 °K, compared to the benchmark of ≤±0.5 °K. Thus, MM5 sensitivity simulations using MRF PBL scheme were discontinued.
- The MM5 wind speed, and especially wind direction, model performance is noticeably better when FDDA was utilized.
- The "A" series of CALMET runs (RMAX1/RMAX2 = 500/1000) always has a wind speed underestimation bias.
- The "C" and "D" series of CALMET sensitivity tests exhibit wind performance that is comparable to the MM5 simulation used as input to CALMET.
- The 36 km and 12 km MM5 simulations exhibit substantially better model performance than the 80 km MM5 simulation.

The CTEX3 and CTEX5 CALMET comparison for wind speed and direction needs to be viewed with the caveat that because the winds are used as input in some of the sensitivity tests, then this is not a true independent evaluation. Thus, it is at all not surprising that the CALMET wind

performance at the monitor locations is improved in the CALMET sensitivity tests that used meteorological observations as input compared to those that used no observations. As clearly pointed out in the 2009 Revised IWAQM Guidance (EPA, 2009a), the better wind model performance at the monitors produced when CALMET blends observed surface wind data in the wind fields can produce unrealistic discontinuities and other artifacts in the wind fields.

5.4 CALPUFF MODEL PERFORMANCE EVALUATION FOR CAPTEX

CALPUFF was applied for the CTEX3 and CTEX5 tracer release field experiments using the meteorological inputs corresponding to each of the meteorological sensitivity tests given in Table 5-6. Figure 5-1, presented earlier, displays the locations of the CTEX3 (Dayton, Ohio) and CTEX5 (Sudbury, Ontario) tracer release sites and the tracer monitoring network in northeastern U.S. and southeastern Canada.

A common CALPUFF model configuration was used in all sensitivity tests. This was done to isolate the sensitivity of the model to the different meteorological inputs and not confound the interpretation by changing the CALPUFF model configuration. The CALPUFF model configuration used the options listed in Table 5-8. Mostly default options were utilized for CALPUFF. One parameter that was not the default value was for vertical puff splitting. The default for vertical puff splitting is to turn it on using the vertical puff splitting flag (IRESPLIT) for just hour 17. After the vertical puff splitting flag is turned on a puff performs vertical puff splitting if certain criteria are met based on criteria using the ZISPLIT and ROLDMAX parameters for which default values were specified (see discussion on CALPUFF puff splitting sensitivity tests for the ETEX experiment in Chapter 6 for more details). Once a puff splits in the vertical, the vertical puff splitting is turned off and the puff is not allowed to split until after the puff splitting flag is turned on again at hour 17. In the CTEX3 and CTEX5 CALPUFF sensitivity simulations, the IRESPLIT input was set to turn on the vertical puff splitting flag 24 hours a day so that vertical puff splitting flag for all puffs is always on so vertical puff splitting will always occur whenever the other criteria are met.

Table 5-8. CALPUFF model configuration used in the CTEX3 and CTEX5 sensitivity tests.

Option	Value	Comment
MGAUSS	1	Use Gaussian vertical distribution initially
MCTADJ	0	No terrain adjustment
MSLUG	0	Near-field puffs not modeled as slugs
MTRANS	1	Use transitional plume rise
MTIP	1	Use stack tip downwash
MBDW	1	Use ISC method to simulate building downwash
MSHEAR	1	Model vertical wind shear above stack top
MSPLIT	1	Use puff splitting
MCHEM	0	No chemistry
MWET	0	No wet deposition
MDRY	0	No dry deposition
MDISP	2	Dispersion from internally calculate sigma-y and sigma-z using turbulence
MTURBW	3	Both sigma-y and sigma-z from PROFILE.DAT
MDISP3	3	PG dispersion coefficients for rural areas
MCTURB	2	Use AERMOD subroutine for turbulence variables
MROUGH	0	Don't adjust sigma-y and sigma-z for roughness
MPARTL	1	Use partial plume penetration
MTINV	0	Compute strength of temperature inversion
MPDF	1	Use PDF for dispersion under convective conditions
NSPLIT	3	Split puff into 3 puffs when performing vertical puff splitting
IRESPLIT	24*1	Keep vertical puff splitting flag on all the time (default is just hour 17 = 1, rest 0)
ZISPLIT	100	Vertical splitting is allowed if mixing height exceeds 100 m.
ROLDMAX	0.25	Vertical splitting is allowed if ratio of maximum to current mixing height is > 0.25
NSPLITH	5	Number of puffs that result when horizontal splitting is performed
SYSPLITH	1.0	Minimum width of puff (in grid cells) before horizontal splitting
SHSPLITH	2.0	Minimum puff elongation factor for horizontal splitting
CNSPLITH	1.E-7	Minimum concentrations (g/m^3) in puff for horizontal splitting

5.4.1 CALPUFF CTEX3 Model Performance Evaluation

Because of the large number of CALPUFF sensitivity tests performed for the CTEX3 tracer test field experiment, they are first compared by groups that used a common MM5/MM4 prognostic meteorological grid resolution output as input into CALMET or MMIF. We then compare the CALPUFF sensitivity tests using different MM4/MM5 grid resolutions but common CALMET/MMIF configurations to determine the sensitivity of MM4/MM5 grid resolution on CALPUFF tracer model performance.

5.4.1.1 CALPUFF CTEX3 Model Evaluation using 80 km MM4 Data

Figure 5-2 displays the spatial model performance statistics metrics for the CALPUFF CTEX3 sensitivity tests that used the 80 km MM4 data. There are variations in the rankings across the spatial statistical performance metrics for the CALPUFF sensitivity tests using the 80 km MM4 data. These sensitivity tests use the finest CALMET grid resolution tested in this series (12 km vs. 18 km) and minimizes the influence of the meteorological observations either through the lowest RMAX1/RMAX2 values (EXP1C) or not using meteorological observations at all by running CALMET in the NOOBS = 2 mode (EXP1D).

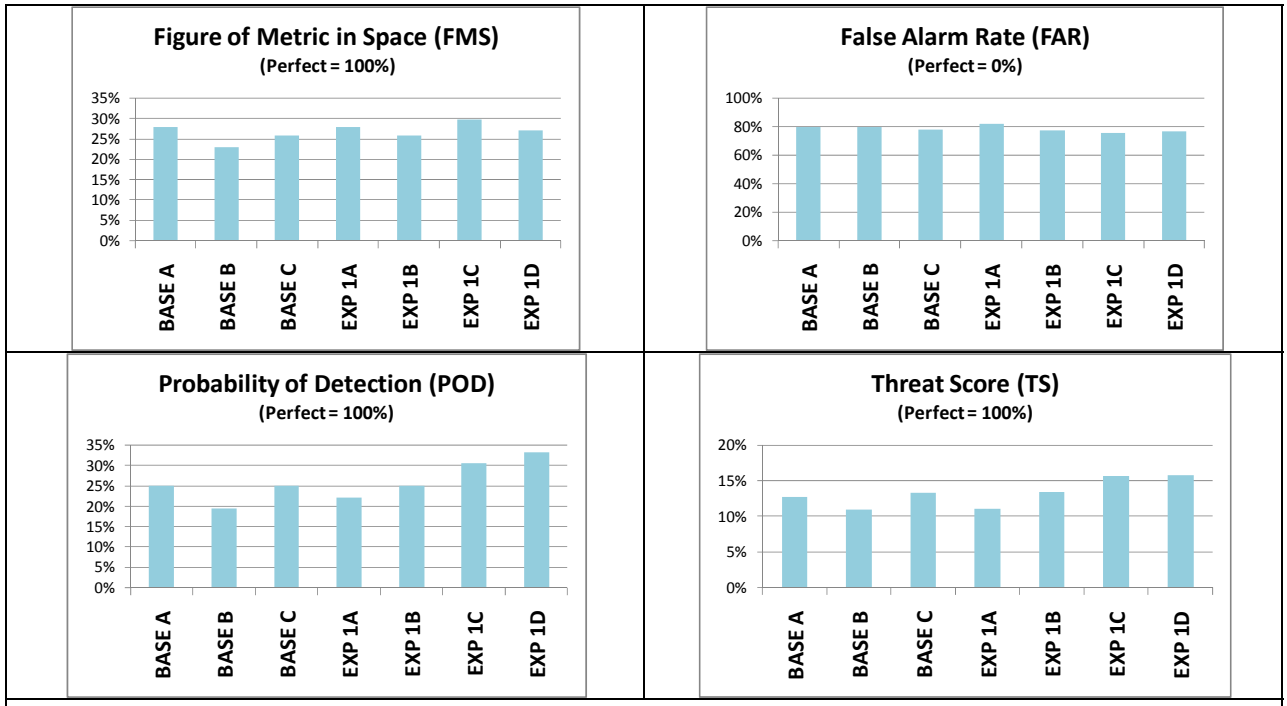


Figure 5-2. Spatial model performance statistics for the CTEX3 CALPUF sensitivity tests that used the 80 km MM4 data.

The global model performance statistics for the CALPUFF sensitivity tests using 80 km MM4 data are compared in Figure 5-3.

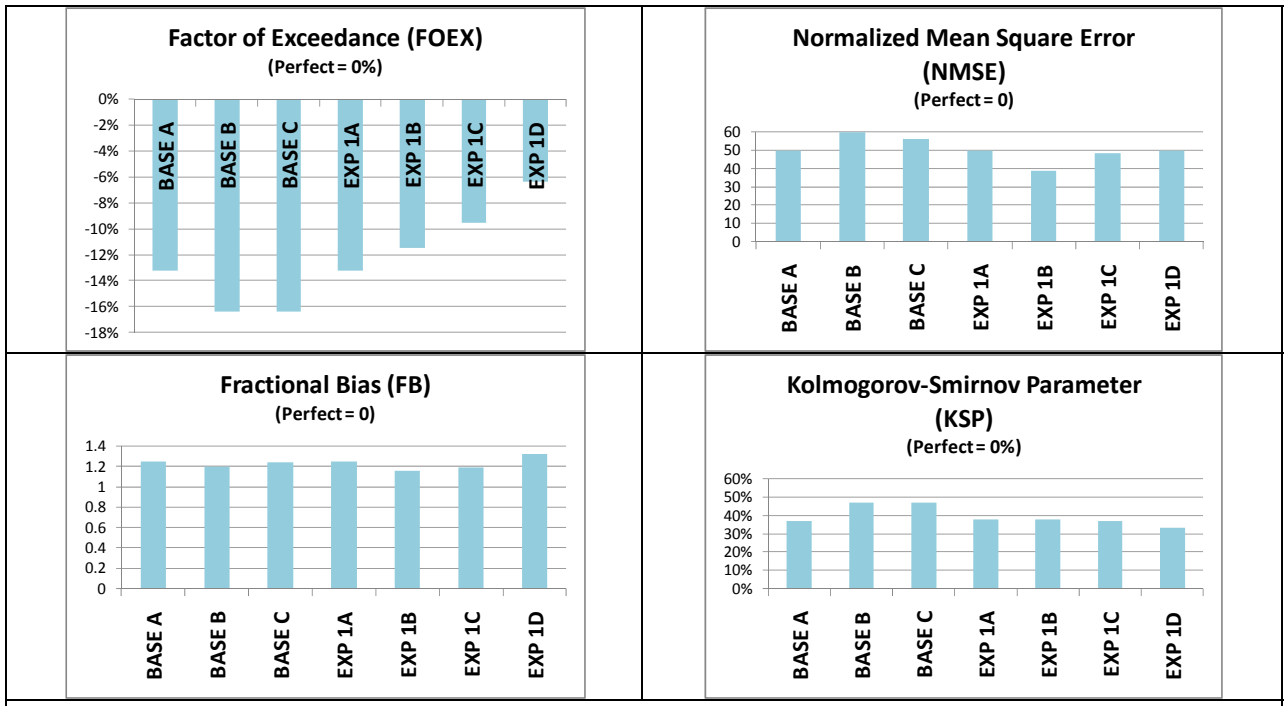
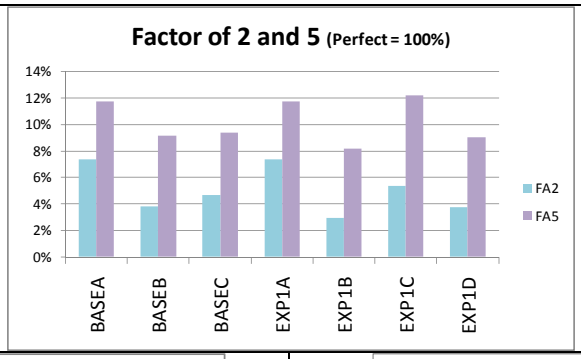
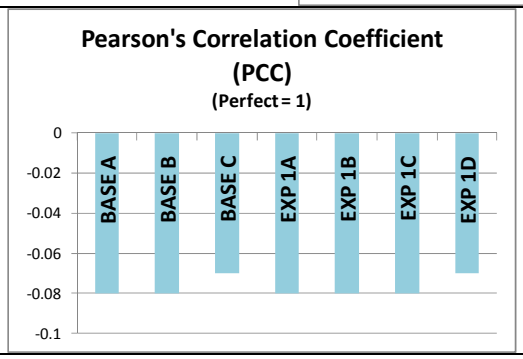


Figure 5-3a. Global model performance statistics for the CTEX3 CALPUFF sensitivity tests using the 80 km MM4 data.





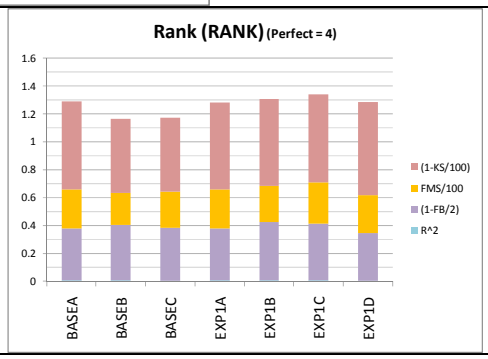


Figure 5-3b. Global model performance statistics for the CTEX3 CALPUFF sensitivity tests using the 80 km MM4 data.

5.4.1.2 CALPUFF CTEX3 Model Evaluation using 36 km MM5 Data

For the CTEX3 CALPUFF sensitivity tests using the 36 km MM5 data, there are 9 CALPUFF sensitivity tests 7 that use CALMET meteorological inputs with 12 and 4 km grid resolution and different OA options and one that uses MMIF meteorological inputs that as a MM5 “pass through” tool uses 36 km grid resolution.

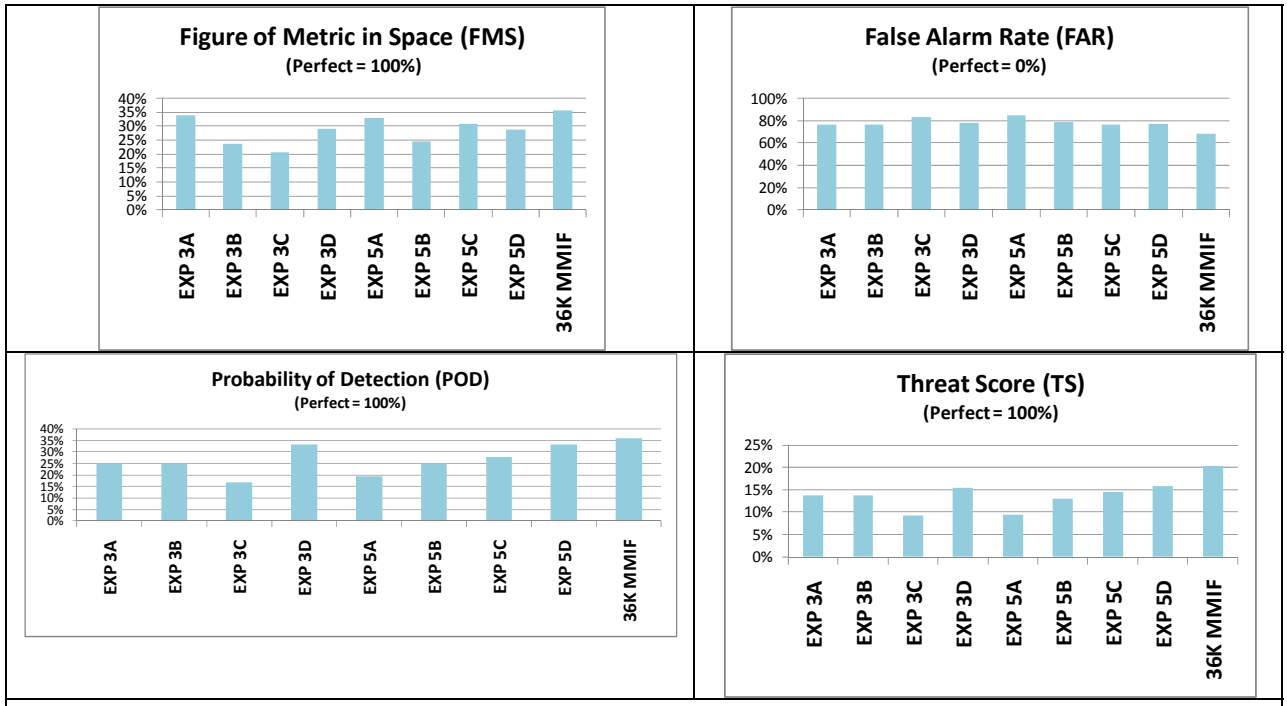


Figure 5-4. Spatial model performance statistics for the CTEX3 CALPUF sensitivity tests that used the 36 km MM5 data.

The global model performance statistics for the CALPUFF sensitivity tests using 36 km MM5 data are shown in Figure 5-5.

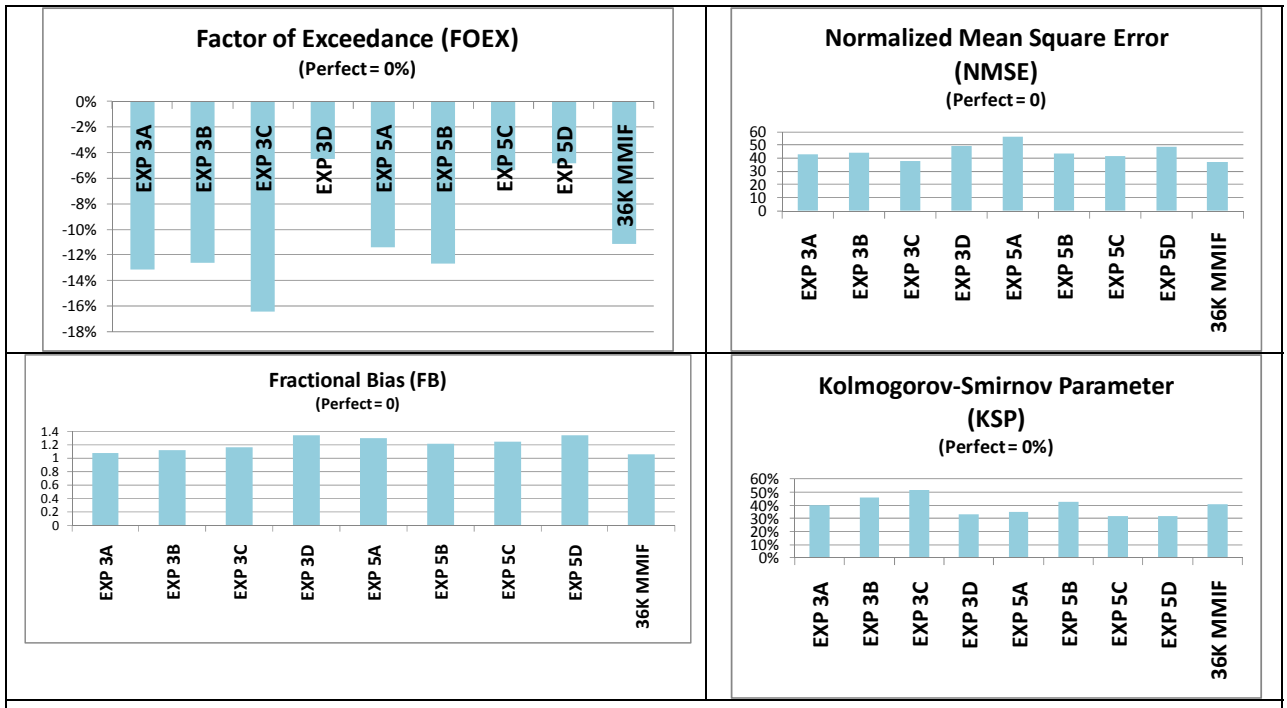
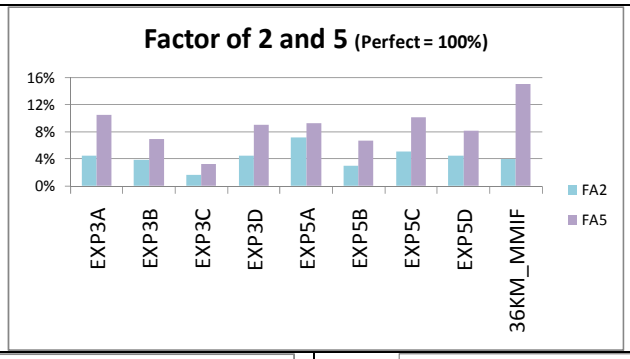
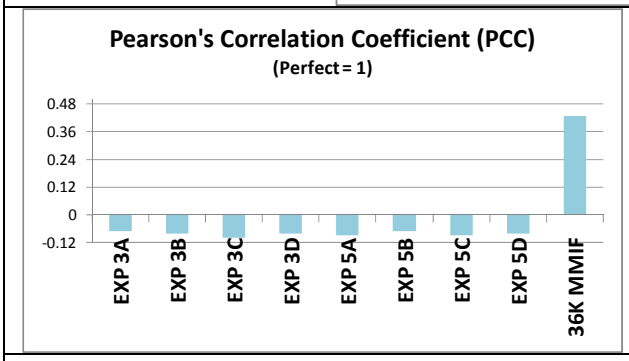


Figure 5-5a. Global model performance statistics for the CTEX3 CALPUFF sensitivity tests using the 36 km MM5 data.





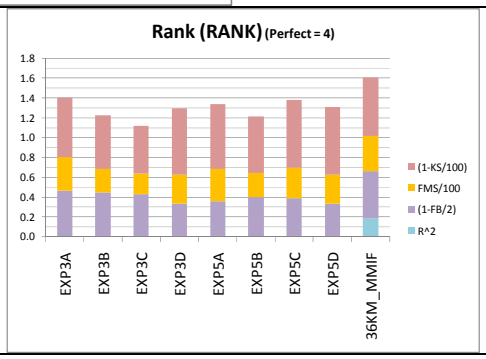


Figure 5-5b. Global model performance statistics for the CTEX3 CALPUFF sensitivity tests using the 36 km MM5 data.

5.4.1.3 CALPUFF CTEX3 Model Evaluation using 12 km MM5 Data

The spatial model performance statistical metrics for the CTEX3 CALPUFF sensitivity tests using 12 km MM5 data are shown in Figure 5-6.

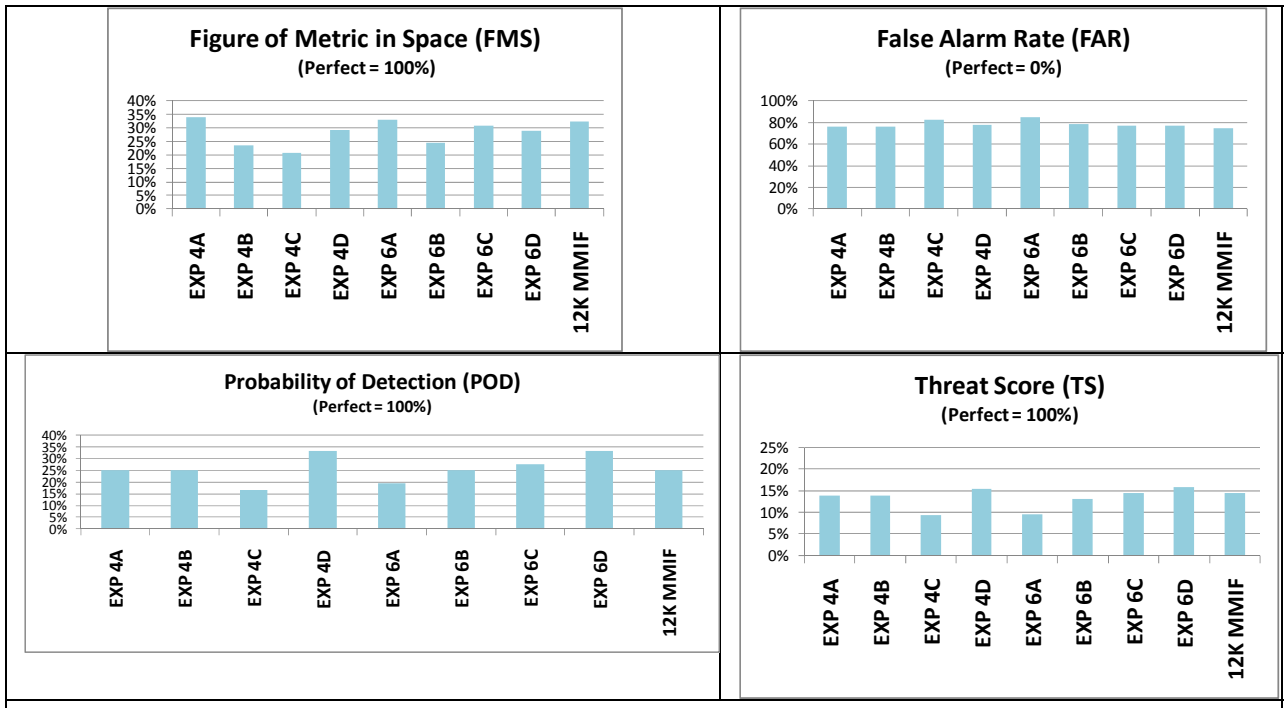


Figure 5-6. Spatial model performance statistics for the CTEX3 CALPUF sensitivity tests that used the 12 km MM5 data.

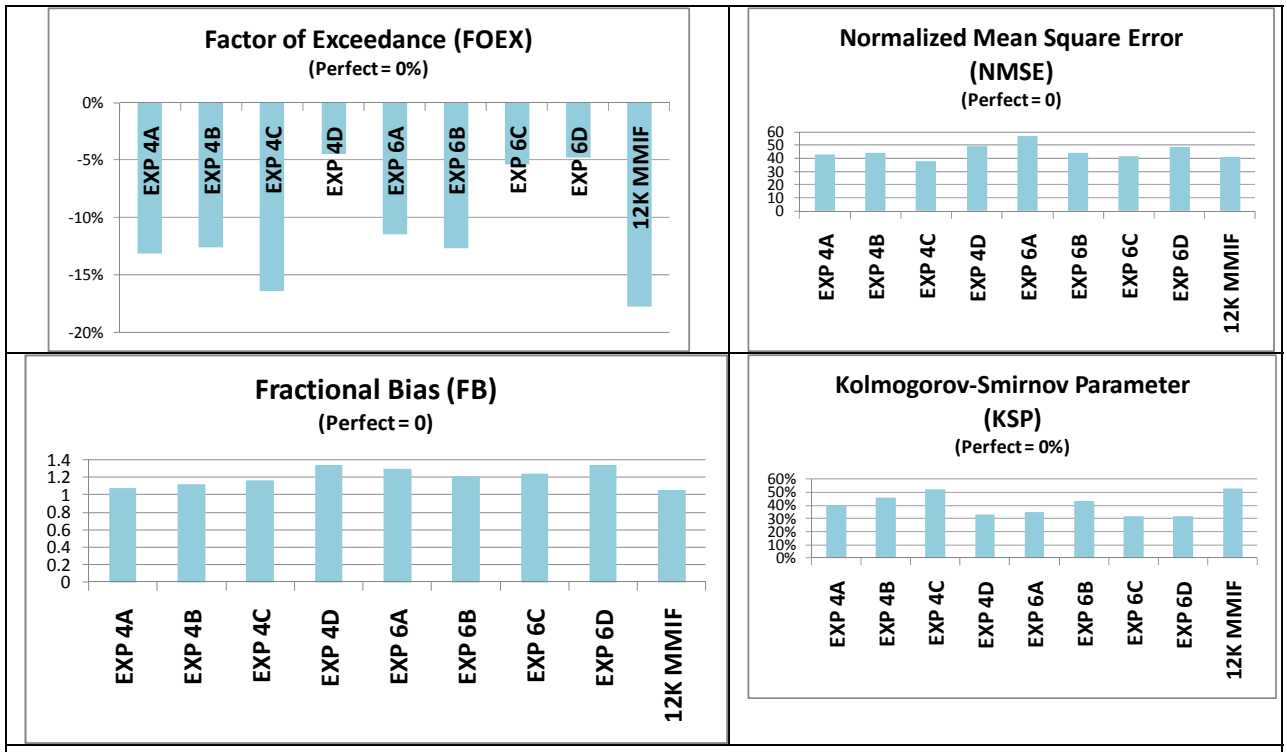


Figure 5-7a. Global model performance statistics for the CTEX3 CALPUFF sensitivity tests using the 12 km MM5 data.

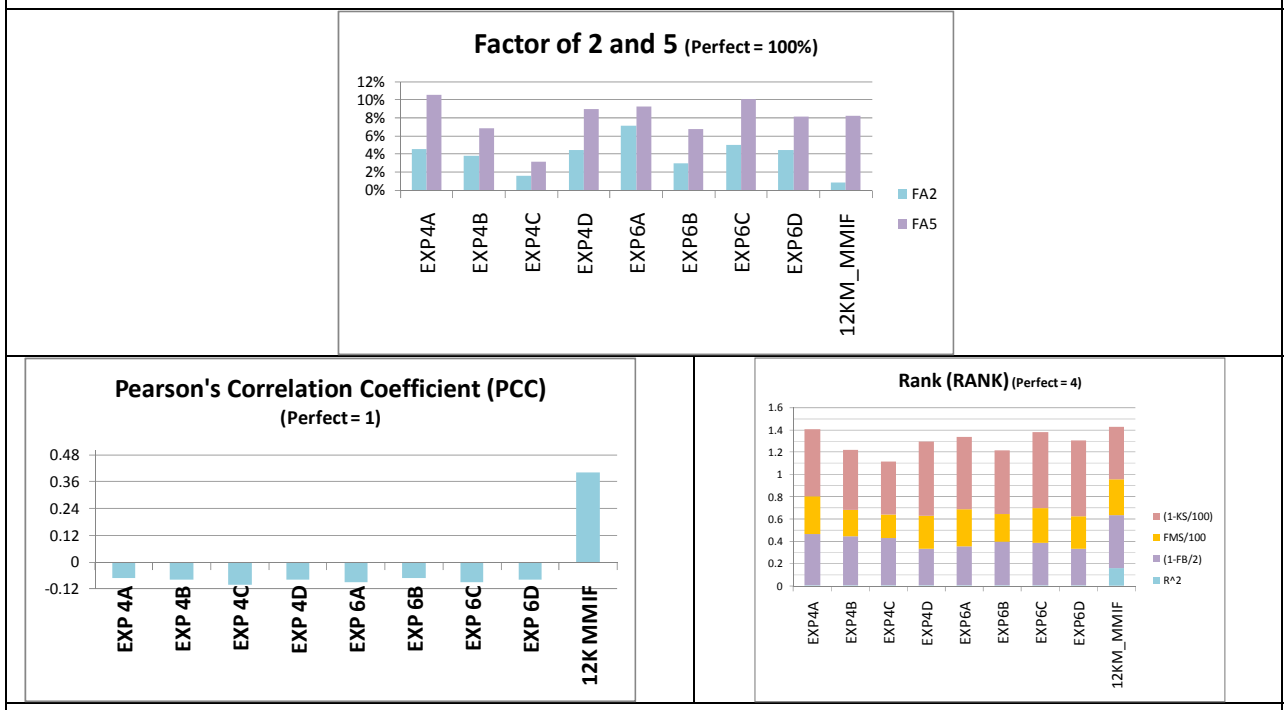


Figure 5-7b. Global model performance statistics for the CTEX3 CALPUFF sensitivity tests using the 12 km MM5 data (high scores indicate better model performance).

5.4.1.4 Comparison of CALPUFF CTEX3 Model Evaluation using Different MM4/MM5 Grid Resolutions

In the final series of CTEX3 CALPUFF sensitivity tests we grouped the "B" and "D" series of CALPUFF/CALMET sensitivity tests that use the EPA-FLM recommended RMAX1/RMAX2 settings (100/200) and no met observations, respectively, using the various MM5 data and grid resolutions in CALMET with the 12KM_MMIF and 36KM_MMIF CALPUFF sensitivity tests. The spatial model performance statistics are shown in Figure 5-8. The 36KM_MMIF and 12KM_MMIF have the best and second best FMS statistics (36% and 32%) followed by EXP3D and EXP6D (29%). The worst performing FMS statistics are given by the "B" series of CALPUFF/CALMET sensitivity tests with values ranging from 23% to 25%. The 36KM_MMIF has by far the lowest (best) FAR value (68%) followed by 12KM _MMIF (74%) with the "B" series of CALPUFF/CALMET sensitivity tests having the worst (highest) FAR values that approach 80%. A clear pattern is seen in the POD statistic for the CALPUFF/CALMET sensitivity tests with the "D" series using no met observations clearly performing better (33%) than the "B" series (19% to 25%). However, the best performing CALPUFF sensitivity test using the POD statistics is 36KM_MMIF (36%). Oddly, the 12KM_MMIF is one of the worst performing configurations with POD value the same as many of the "B" series (25%). 36KM_MMIF (20%) is also the best performing CALPUFF sensitivity test according to the TS statistic with the no met observations ("D" series) CALPUFF/CALMET sensitivity tests (15% to 16%) and 12KM_MMIF (15%) having better TS values than when met observations are used with CALMET (10% to 14%).

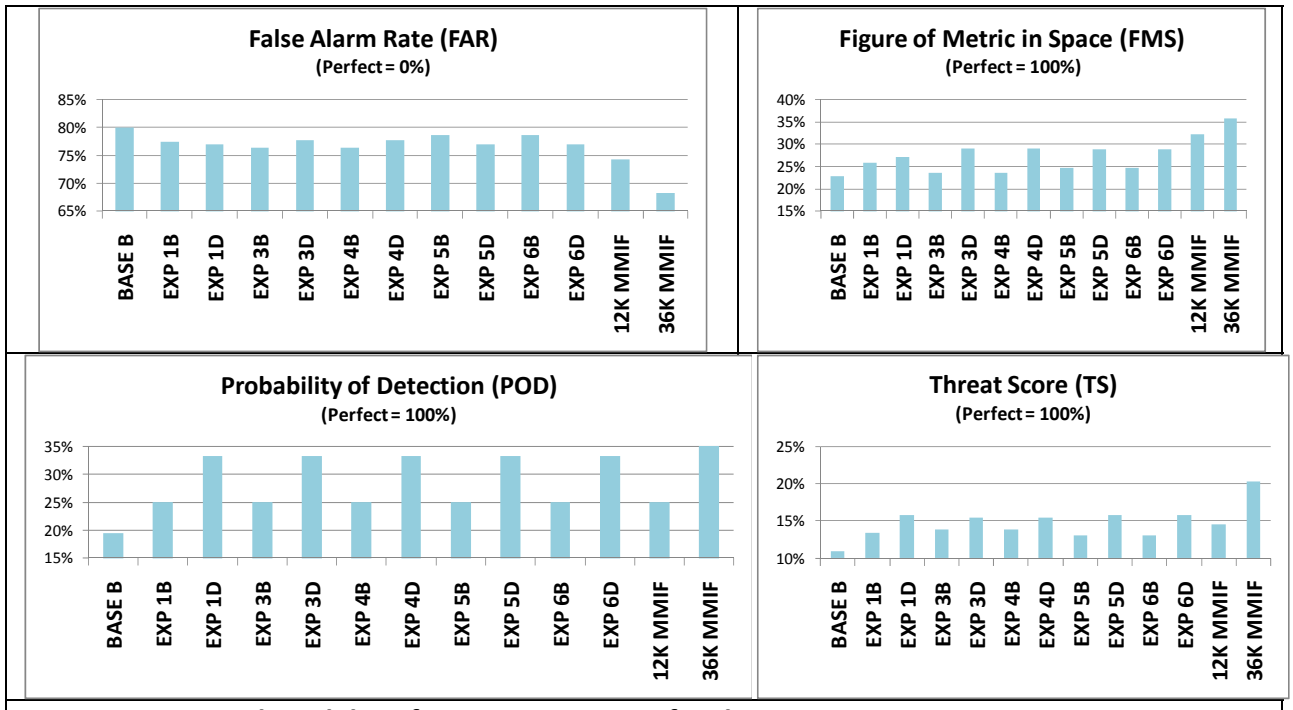


Figure 5-8. Spatial model performance statistics for the CTEX3 CALPUF sensitivity tests using different MM4/MM5 grid resolutions.

For the FOEX and KSP global statistical metrics, the "D" series of CALPUFF/CALPUFF sensitivity tests is clearly performing better than the "B" series with 12KM_MMIF one of the worst performing model configurations for these two statistics (Figure 5-9a). However, the "B" series of CALPUFF/CALMET sensitivity tests is exhibiting lower bias (FB) and error (NMSE) than

the “D” series of CALPUFF/CALMET sensitivity tests with the 36KM_MMIF exhibiting the lowest bias and error statistics; 12KM_MMIF has the second lowest FB and third lowest NMSE. For the within a factor of 2 and 5 statistics the “D” series performs better than the “B” series of CALPUFF/CALMET sensitivity tests. The 12KM_MMIF has by far the lowest FA2 metric but has a FA5 metric that is comparable to the “D” series of CALPUFF/CALMET sensitivity tests. By far the best performing model configuration for the FA5 metric is 36KM_MMIF whose value (15%) is almost double the next best performing CALPUFF model configurations (7% to 9%). The 36KM_MMIF (0.43) followed closely by the 12KM_MMIF (0.40) are by far the best performing sensitivity tests according to the correlation coefficient statistical metric with the CALPUFF/CALMET tracer estimates showing a small negative correlation with the observations (-0.07 to -0.08). According to the composite RANK statistic, 36KM_MMIF (1.61) is the best performing CALPUFF sensitivity test of this group followed by 12KM_MMIF (1.43). The CALPUFF/CALMET RANK statistics range from 1.16 to 1.32 with the “D” series typically performing better (~1.3) than the “B” series (~1.2) with the exception of EXP1B (1.3).

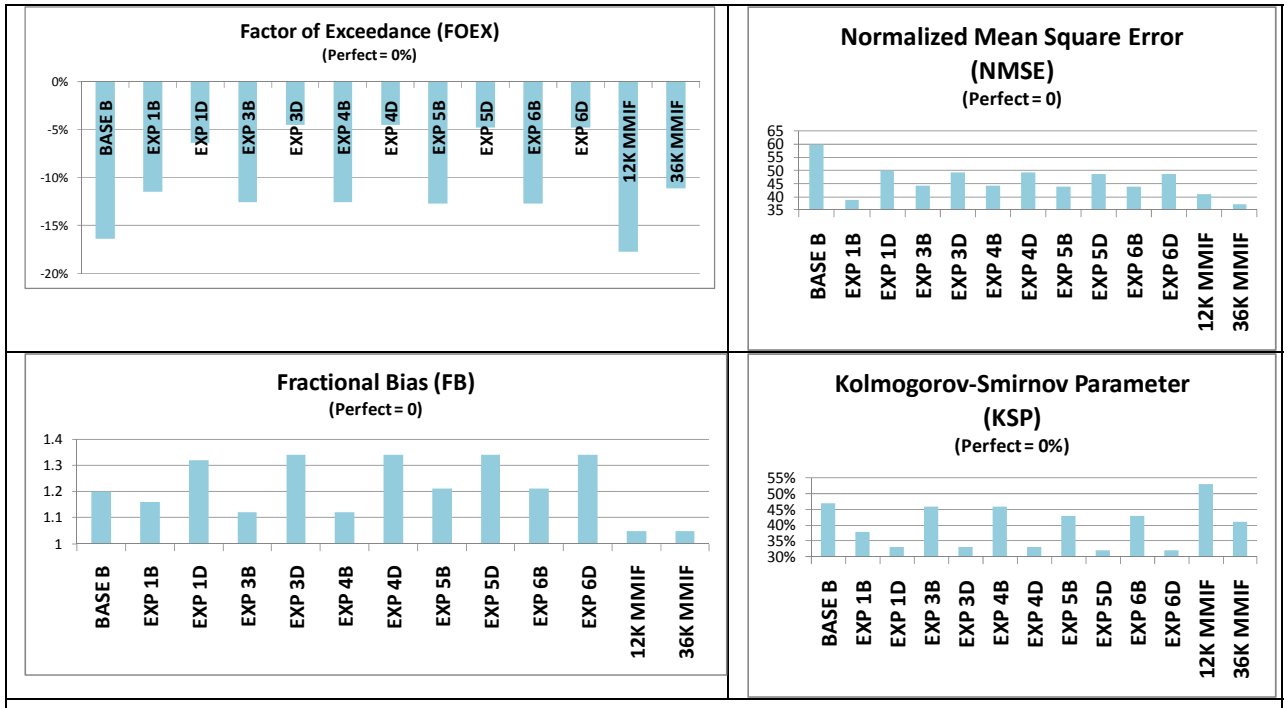


Figure 5-9a. Global model performance statistics for the CTEX3 CALPUFF sensitivity tests using different MM4/MM5 grid resolutions.

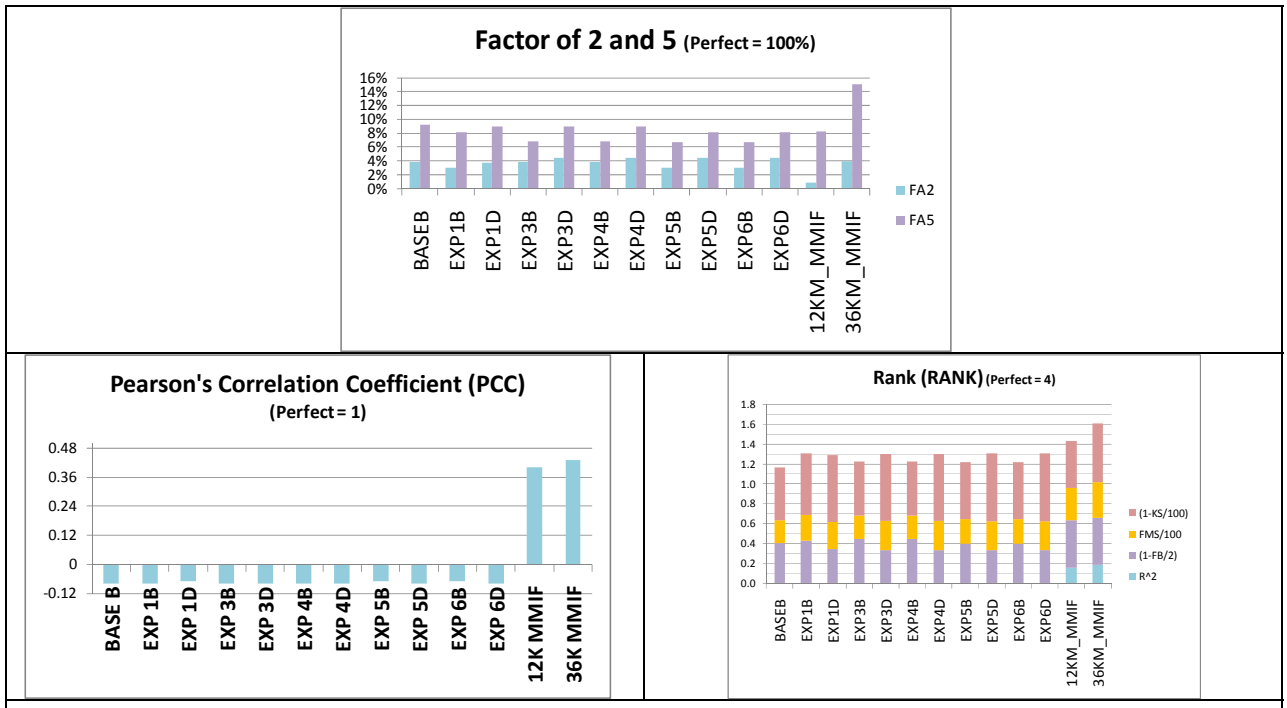


Figure 5-9b. Global model performance statistics for the CTEX3 CALPUFF sensitivity tests using different MM4/MM5 grid resolutions (high scores indicate better model performance).

5.4.1.5 Rankings of CTEX3 CALPUFF Sensitivity Tests using the RANK Statistic

The ranking of all of the CTEX3 CALPUFF sensitivity tests using the composite RANK model performance statistics is given in Table 5-9. The 36KM_MMIF (1.61) is the highest ranked CALPUFF sensitivity test using RANK followed by 12KM_MMIF (1.43) which is very close to EXP3A and EXP4A that are tied for third with a RANK value of 1.40. It is interesting to note that the EXP3A and EXP4A CALPUFF/CALMET sensitivity test that uses the, respectively, 36 km and 12 km MM5 data with 12 km CALMET grid resolution and RMAX1/RMAX2 values of 500/1000 is tied for third best performing CALPUFF/CALMET configuration using the RANK statistic, but the same model configuration with alternative RMAX1/RMAX2 values of 10/100 (EXP3C and EXP4C) degrades the model performance to the worst performing CALPUFF configuration according to the RANK statistics with a RANK value of 1.12.

Based on the RANK statistic and the CALPUFF sensitivity test rankings in Table 5-9 we conclude the following for the CTEX3 CALPUFF sensitivity tests:

- The CALPUFF MMIF sensitivity tests are the best performing configuration for the CTEX3 experiments.
- The CALPUFF/CALMET "B" series (RMAX1/RMAX2 = 100/200) appears to be the worst performing configuration for RMAX1/RMAX2.
- The CALMET/CALPUFF "A" series seems to be the best performing RMAX1/RMAX2 setting (500/1000) followed by the "C" series (10/100) then "D" series (no met observations).
- Ignoring the "B" series of sensitivity tests, the CALPUFF/CALMET sensitivity tests that use higher MM5 grid resolution (36 and 12 km) tend to produce better model performance than those that used the 80 km MM4 data.

- When using the "A" series model configuration, the use of higher CALMET resolution does not produce better CALPUFF model performance, however for the "C" and "D" series of CALMET runs use of higher CALMET grid resolution does produce better CALPUFF model performance.
- Note that the finding that CALPUFF/CALMET model performance using CALMET wind fields based on setting RMAX1/RMAX2 = 100/200 (i.e., the "B" series) produces worse CALPUFF model performance for simulating the observed atmospheric tracer concentrations is in contrast to the CALMET evaluation that found the "B" series produced winds closest to observations (see Appendices A and B). Since the CALPUFF tracer evaluation is an independent evaluation of the CALMET/CALPUFF modeling system, whereas the CALMET surface wind evaluation is not, the CALPUFF tracer evaluation may be a better indication of the best performing CALMET configuration. The CALMET "B" series approach for blending the wind observations in the wind fields may just be the best approach for getting the CALMET winds to match the observations at the monitoring sites, but at the expense of degrading the wind fields.

Table 5-9. Final Rankings of CALPUFF CTEX3 Sensitivity Tests.

Ranking	Sensitivity Test	RANK Statistics	MM5 (km)	CALGRID (km)	RMAX1/RMAX2	Met Obs
1	36KM_MMIF	1.610	36	--	--	--
2	12KM_MMIF	1.430	12	--	--	--
3	EXP3A	1.400	36	12	500/1000	Yes
4	EXP4A	1.400	12	12	500/1000	Yes
5	EXP5C	1.380	36	4	10/100	Yes
6	EXP6C	1.380	12	4	10/100	Yes
7	EXP1C	1.340	36	18	10/100	Yes
8	EXP5A	1.340	36	4	500/1000	Yes
9	EXP6A	1.340	12	4	500/1000	Yes
10	EXP5D	1.310	36	4	--	No
11	EXP6D	1.310	12	4	--	No
12	EXP1B	1.300	36	18	100/200	Yes
13	EXP3D	1.300	36	12	--	No
14	EXP4D	1.300	12	12	--	No
15	BASEA	1.290	80	18	500/1000	Yes
16	EXP1D	1.290	36	18	--	No
17	EXP1A	1.280	36	18	500/1000	Yes
18	EXP3B	1.220	36	12	100/200	Yes
19	EXP5B	1.220	36	4	100/200	Yes
20	EXP4B	1.220	12	12	100/200	Yes
21	EXP6B	1.220	12	4	100/200	Yes
22	BASEC	1.170	80	18	10/100	Yes
23	BASEB	1.160	80	18	100/200	Yes
24	EXP3C	1.120	36	12	10/100	Yes
25	EXP4C	1.120	12	12	10/200	Yes

5.4.2 CALPUFF CTEX5 Model Performance Evaluation

The model performance of the CALPUFF sensitivity tests for the CTEX5 (October 25, 1983) field experiment are presented below grouped by MM5 grid resolution. The MM5 output were used as input to the CALMET or MMIF meteorological drivers for CALPUFF, as was done for the

CTEX3 discussed in Section 5.4.1. As noted in Table 5-6, CTEX5 CALPUFF sensitivity tests were not performed for the EXP1 and EXP2 series of experiments.

5.4.1.1 CALPUFF CTEX5 Model Evaluation using 80 km MM5 Data

The spatial model performance statistics for the CTEX5 CALPUFF sensitivity tests using the 80 km MM5 data are shown in Figure 5-10. The BASEA and BASEB sensitivity tests are performing the best followed by BASEC, then BASED with 80KM_MMIF coming in last.

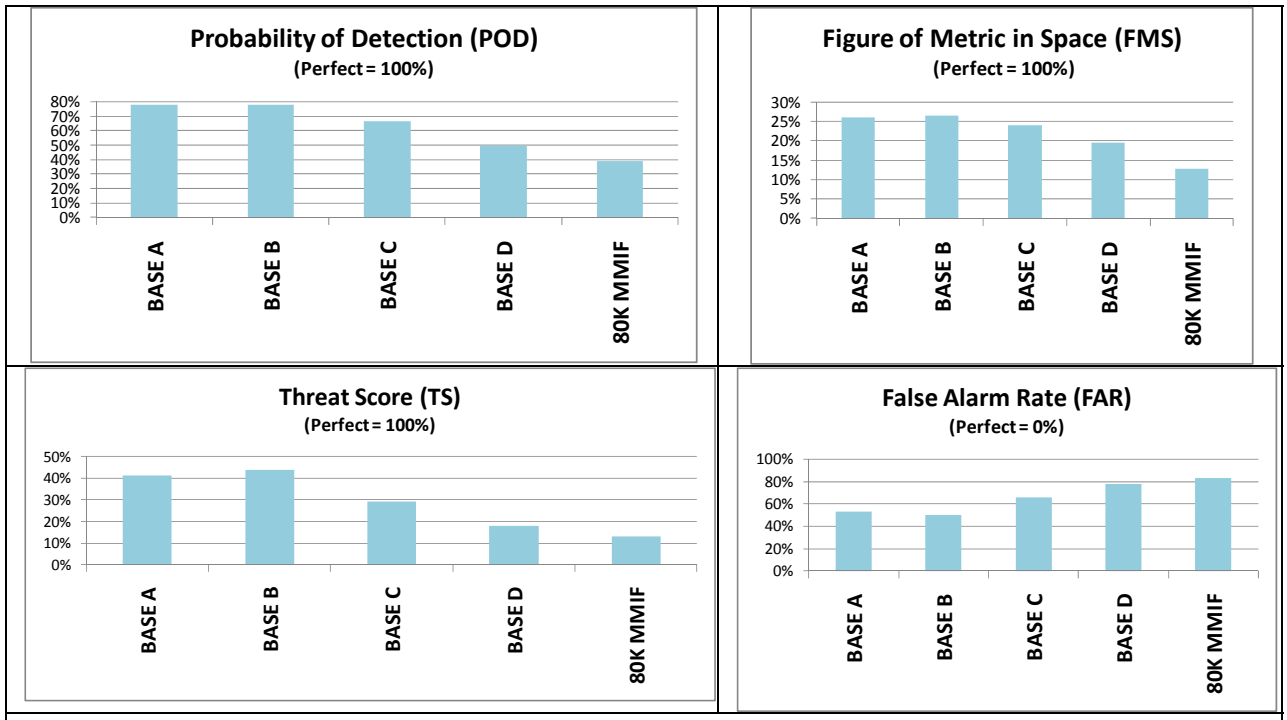


Figure 5-10. Spatial model performance statistics for the CTEX5 CALPUF sensitivity tests that used the 80 km MM5 data.

Although 80KM_MMIF has the lowest FOEX statistic, for all the other global statistic it is the worst or almost worst performing CALPUFF sensitivity test using 80 km MM5 data. BASEA has the best bias, error, FA2 and FA5 statistics of this group with either BASEB or BASEC coming in second and then BASED next to last and 80KM_MMIF last. The RANK composite statistics ranks BASEA (2.06) and BASEC (2.05) the highest followed by BASEB (1.82) and BASED (1.79) next and 80KM_MMIF (1.42) in last.

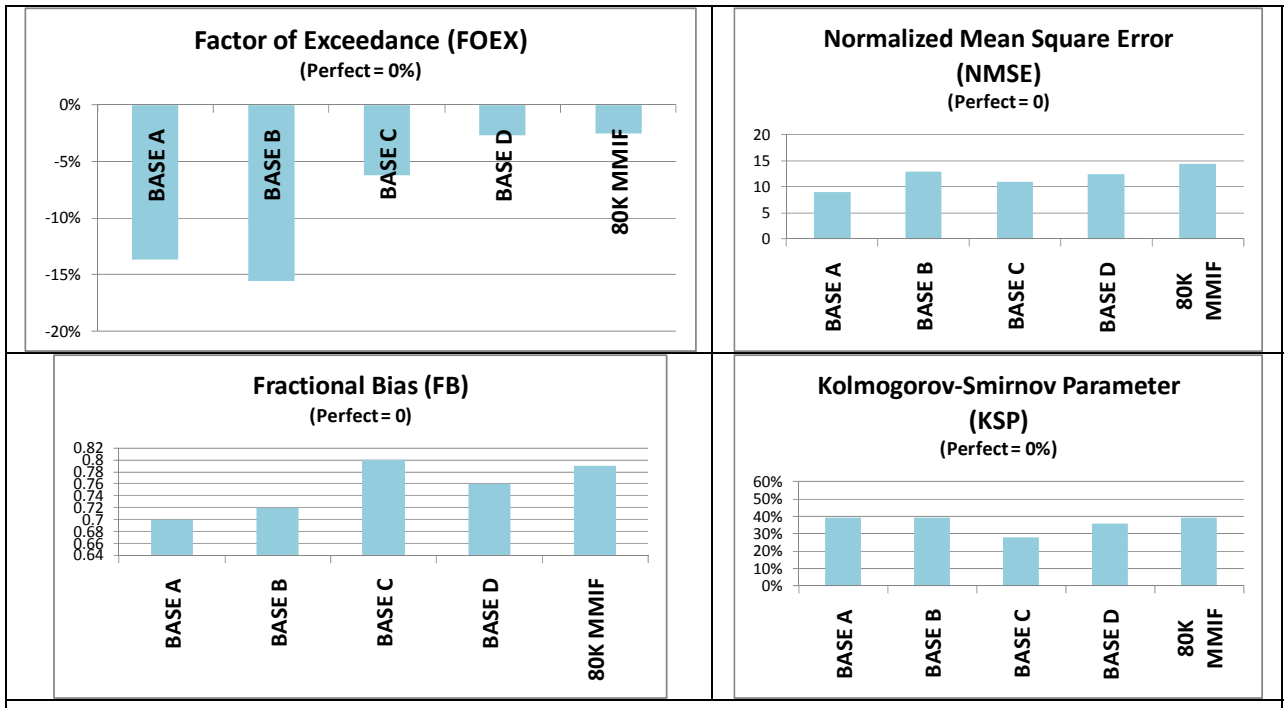


Figure 5-11a. Global model performance statistics for the CTEX5 CALPUFF sensitivity tests using the 80 km MM5data (lower values indicate better performance).

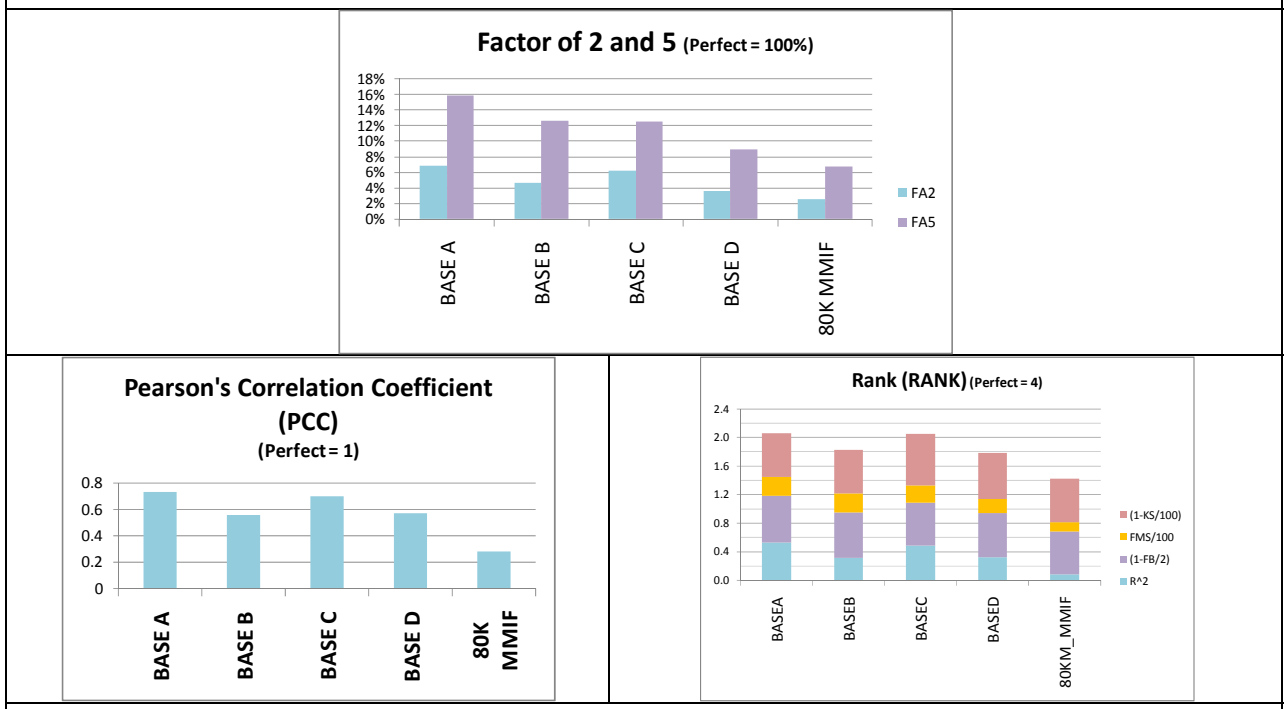


Figure 5-11b. Global model performance statistics for the CTEX5 CALPUFF sensitivity tests using the 80 km MM5 data (higher values indicate better performance).

5.4.2.2 CALPUFF CTEX5 Model Evaluation using 36 km MM5 Data

Figure 5-12 displays the spatial statistical metrics for the CTEX5 CALPUFF sensitivity tests using the 36 km MM5 data. Note that the CALMET simulation for EXP3D encountered an error in HTOLD so no CALPUFF sensitivity modeling results are available. The "A" and "B" series of

CALPUFF sensitivity simulations are performing best for the spatial performance statistics with the 36KM_MMIF performing worst.

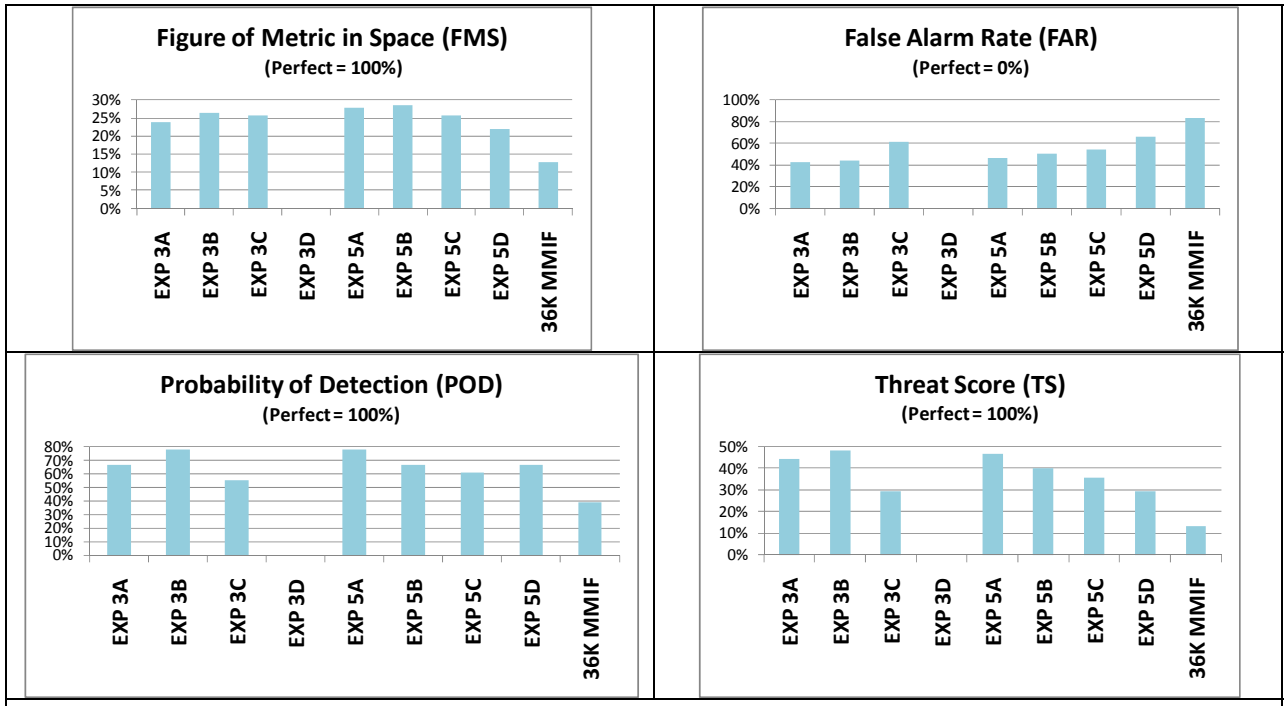


Figure 5-12. Spatial model performance statistics for the CTEX5 CALPUF sensitivity tests that used the 36 km MM5 data.

The global statistics for the CALPUFF sensitivity tests using the 36 km MM5 data are shown in Figure 5-13. EXP5D and 36KM_MMIF have the FOEX that is closest to zero. The EXP5B and EXP5D sensitivity simulations have the lowest bias and error followed by EXP3C with 36KM-MMIF having the worst bias and error metrics. The lowest (best) KSP statistics is given by EXP5D followed by 36KM_MMIF and EXP3C. EXP3B and EXP5A have the best FA2 and FA5 values, with 36KM_MMIF having the worst ones. EXP3A, EXP3C and EXP5A all have correlation coefficients above 0.7 with 36km_MMIF having the lowest correlation coefficient that is below 0.3. Using the overall composite RANK statistics, EXP3C and EXP5D (2.1) are ranked first followed by EXP3A and EXP5A (2.0) with 36KM_MMIF (1.4) having the lowest RANK statistic.

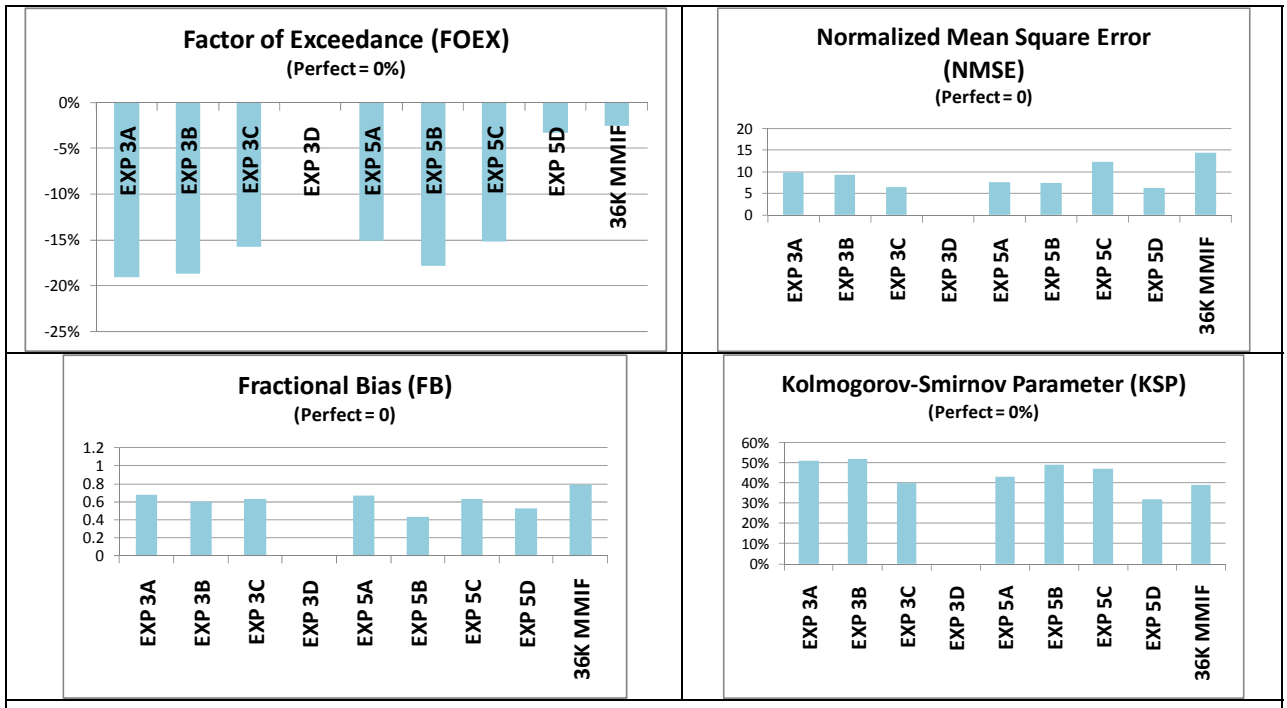


Figure 5-13a. Global model performance statistics for the CTEX5 CALPUFF sensitivity tests using the 36 km MM5 data.

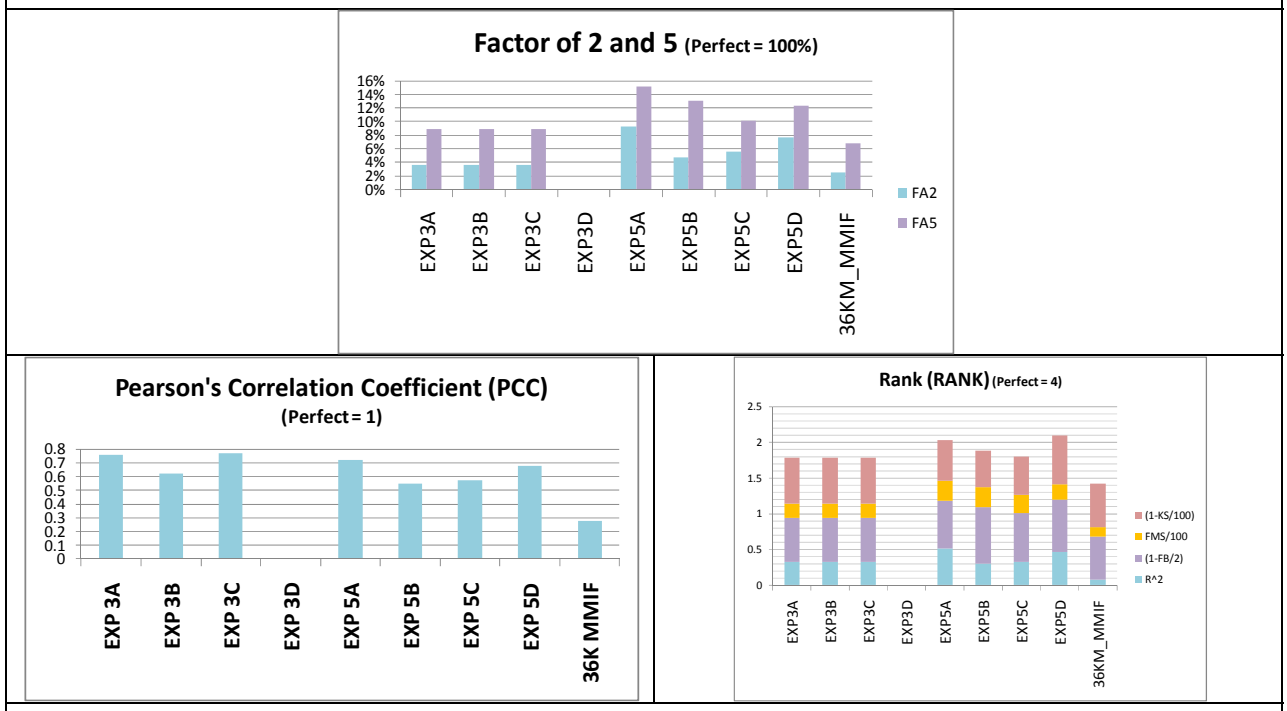


Figure 5-13b. Global model performance statistics for the CTEX5 CALPUFF sensitivity tests using the 36 km MM5 data (higher values indicate better performance).

5.4.2.3 CALPUFF CTEX5 Model Evaluation using 12 and 4 km MM5 Data

The spatial statistics for the CALPUFF/CALMET and CALPUFF/MMIF sensitivity tests using the 12 km MM5 data along with the 4 km MM5 CALPUFF/MMIF sensitivity test are given in Figure 5-

14. Across all the spatial statistics, EXP6A performs the best with EXP4A, EXP4B, EXP6B and 4KM_MMIF next best and 12KM_MMIF being worst.

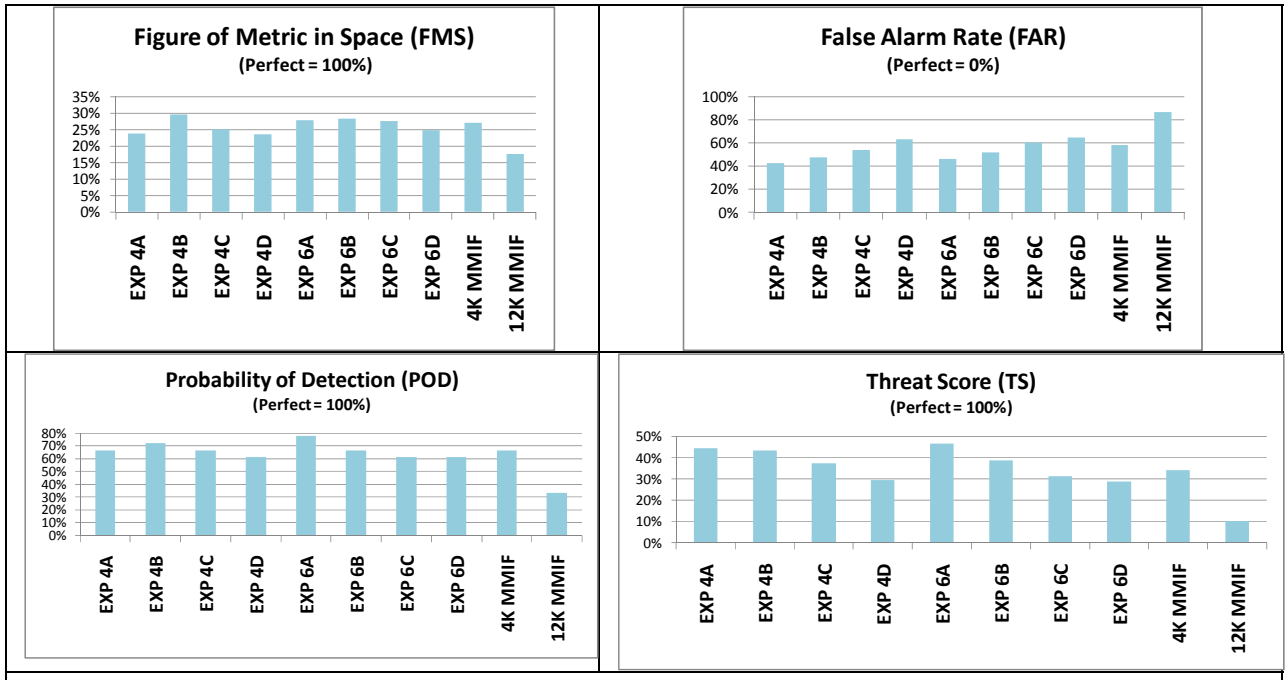


Figure 5-14. Spatial model performance statistics for the CTEX5 CALPUF sensitivity tests that used the 12 and 4 km MM5 data.

The lowest error of the 12 km MM5 CALPUFF sensitivity tests is given by EXP4B and EXP6A-C, with 12KM_MMIF having the highest error (Figure 5-15). EXP6B has the lowest bias follows by EXP6C and EXP4B, with 12KM_MMIF having the largest bias. EXP6A and EXP6B have the most model predictions within a factor of 2 of the observations and EXP4C has the most within a factor of 5. The CALMET/CALPUFF correlation coefficients range from 0.57 to 0.76 with EXP4A (0.76) and EXP6C (0.75) have the highest values and EXP6B (0.57) having the lowest value. The 4KM_MMIF has an even lower correlation coefficient (0.48) with the 12KM_MMIF having no to slight anti-correlation with the observed values (-0.07). According to the RANK composite statistics the best performing 12 km CALPUFF sensitivity test in EXP6C (2.19) followed by EXP6A (2.02) and EXP4A (1.98) with 12KM_MMIF (1.28) performing worst.

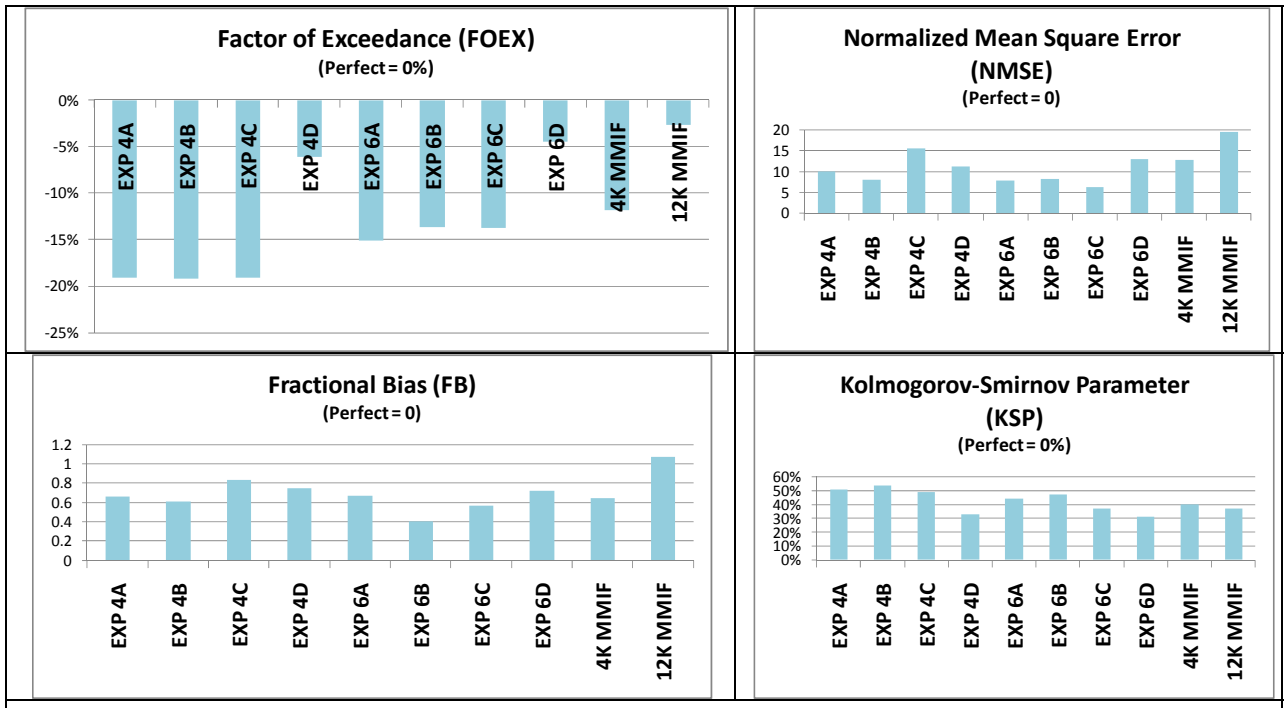


Figure 5-15a. Global model performance statistics for the CTEX5 CALPUFF sensitivity tests using the 12 km MM5 data.

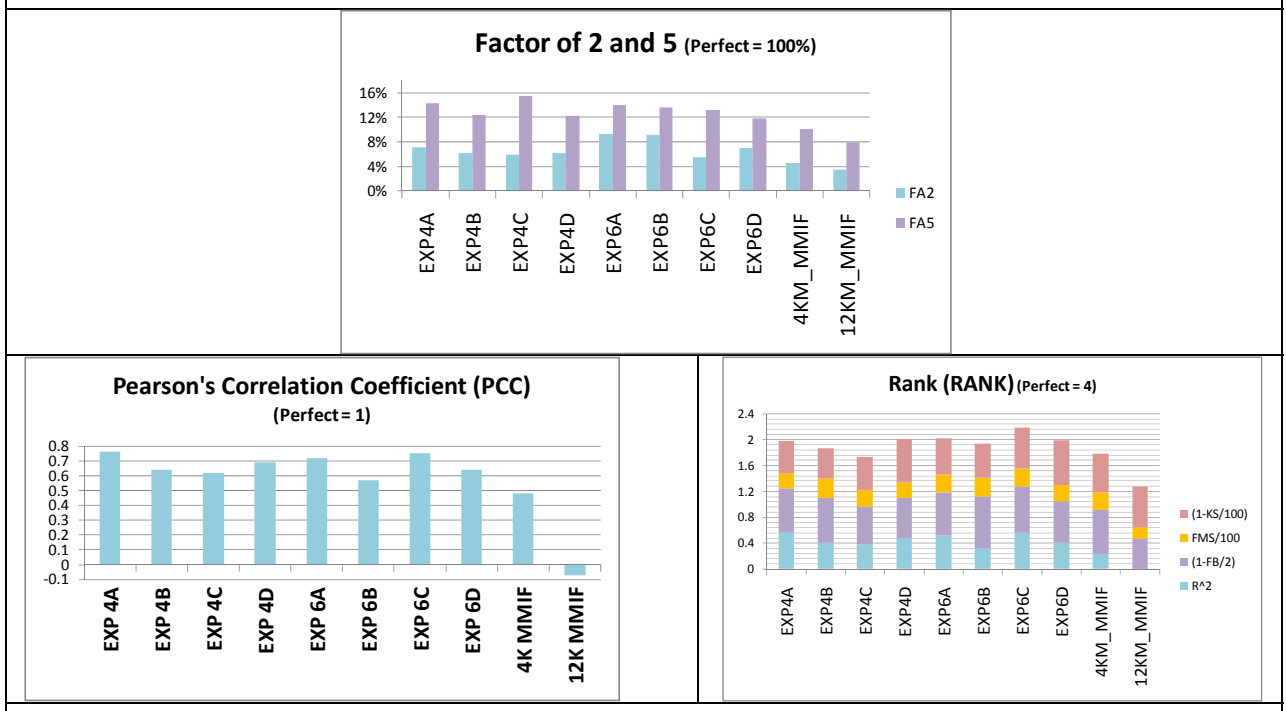


Figure 5-15b. Global model performance statistics for the CTEX5 CALPUFF sensitivity tests using the 12 km MM5 data (higher values indicate better performance).

5.4.2.4 Comparison of CALPUFF CTEX5 Model Evaluation using Different MM5 Grid Resolutions

This section analyzes the CALPUFF model performance across different MM5 and CALMET grid resolutions using the "B" and "D" series of CALPUFF/CALMET and the CALPUFF/MMIF

sensitivity tests. The "B" series (EXP4B, EXP5B, EXP6B and EXP3B) and 4KM_MMIF have the highest FMS values between 25% and 30% with 36KM_MMIF and 80KM_MMIF have the lowest FMS scores between 10% and 15%. Again the "B" series of CALPUFF/MMIF sensitivity tests have the best FAR scores with the worst scores given by the 12KM, 36KM and 80KM MMIF sensitivity tests. The "D" series using no met observations has the worst (highest) FAR scores of the CALPUFF/CALMET sensitivity tests. EXP3B has the best POD value follows by EXP4B with EXP5B, EXP5D, EXP6B and 4KM_MMIF ties for third best; the 12KM, 36KM and 80KM MMIF CALPUFFs have the worst FAR scores. Similar results are seen with the TS statistics with the four top performing sensitivity tests ordered by EXP4B, EXP5B, EXP6B and 4KM_MMIF,

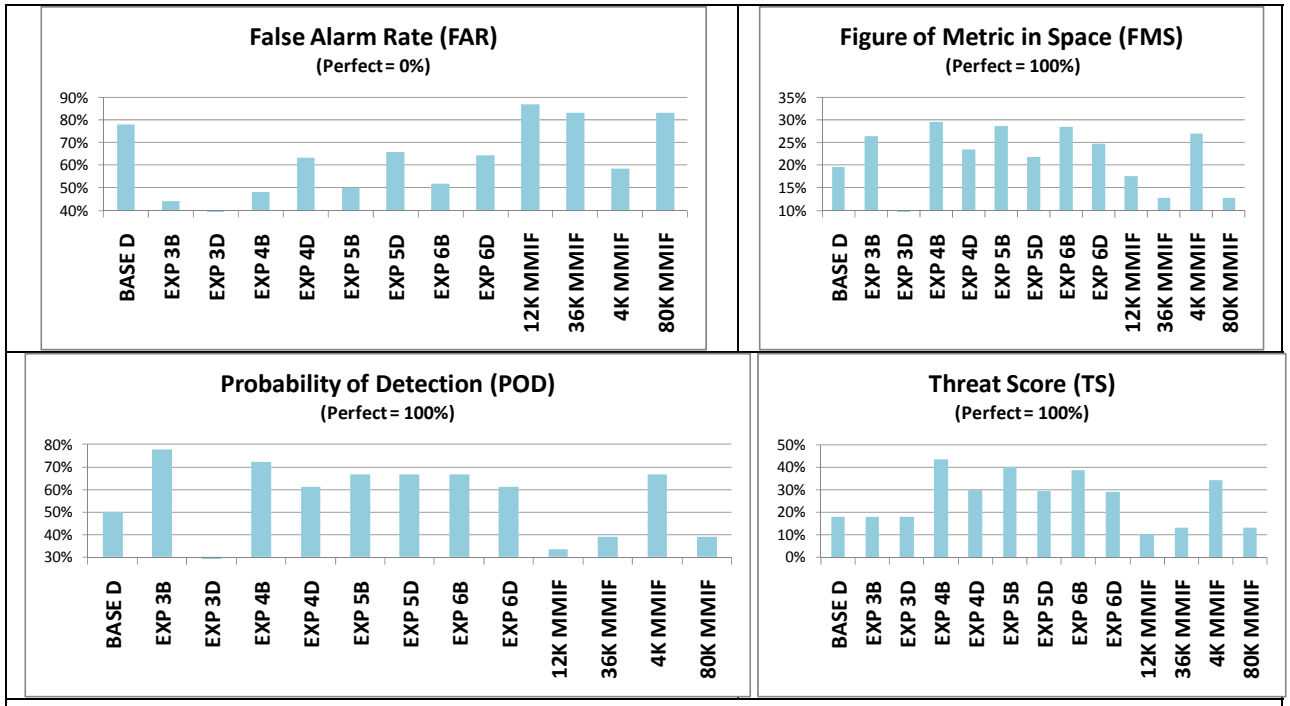


Figure 5-16. Spatial model performance statistics for the CTEX5 CALPUF sensitivity tests using different MM4/MM5 grid resolutions.

Although EXP5D has the lowest error, the "B" series of sensitivity tests consistency have the lowest bias and error (Figure 5-17). The 12KM_MMIF has the highest bias and error followed by the 80KM_MMIF sensitivity test. The "D" series of sensitivity tests have the best (lowest) KS parameter at ~30% with the "B" series of tests have the worst (highest) KSP at ~50% with the other sensitivity test in between.

The best sensitivity test for predicting the observed tracer within a factor of 2 and 5 is EXP3B followed by EXP6B with the 12KM, 36KM and 80KM MMIF runs being the worst. The correlation coefficients for the CALPUFF/CALMET CTEX sensitivity tests in this group range from 0.57 to 0.69 with 4km_MMIF being the best performing MMIF configuration with a 0.48 PCC with the other MMIF runs being much worse. The composite RANK statistics scores the CALPUFF/CALMET and 4KM_MMIF sensitivity tests in the 1.8 to 2.1 range with EXP5D (2.1) scoring the highest followed by EXP4D (1.99), EXP6D (1.99), EXP6B (1.94), EXP5B (1.89) and EXP4B (1.86). The 12KM, 36KM and 80KM CALPUFF/MMIF sensitivity tests have the lowest RANK scores (1.28 to 1.42).

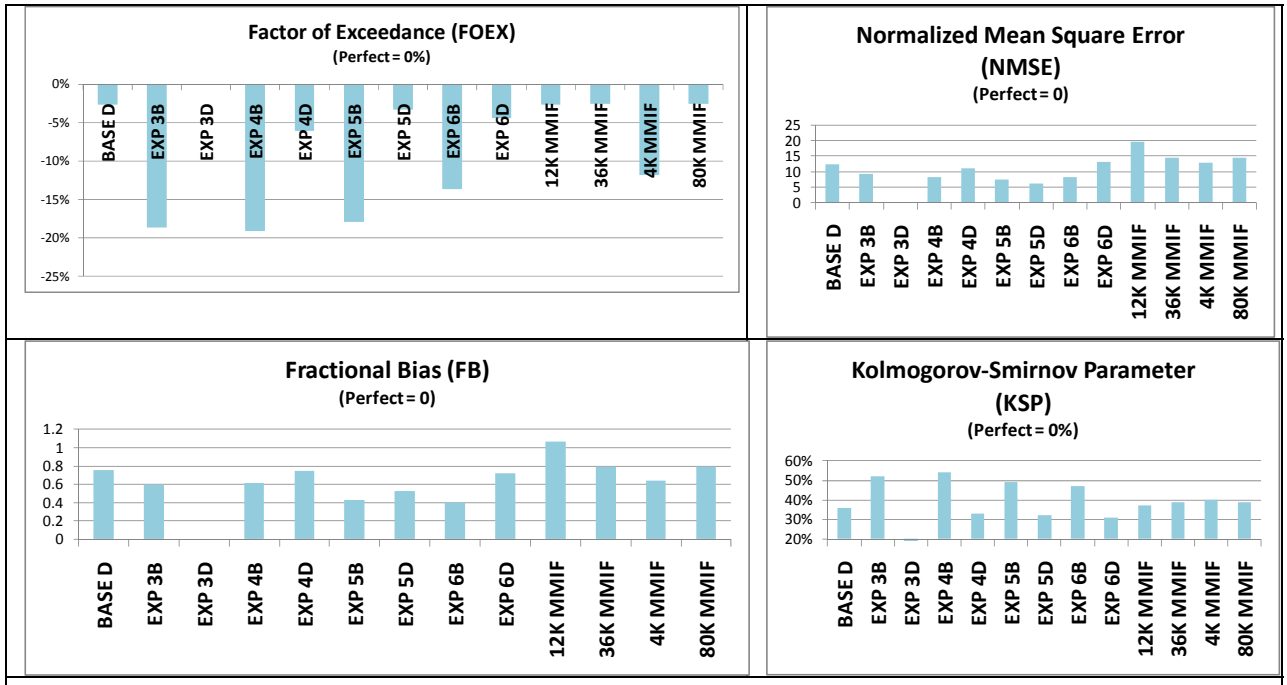


Figure 5-17a. Global model performance statistics for the CTEX5 CALPUFF sensitivity tests using different MM4/MM5 grid resolutions.

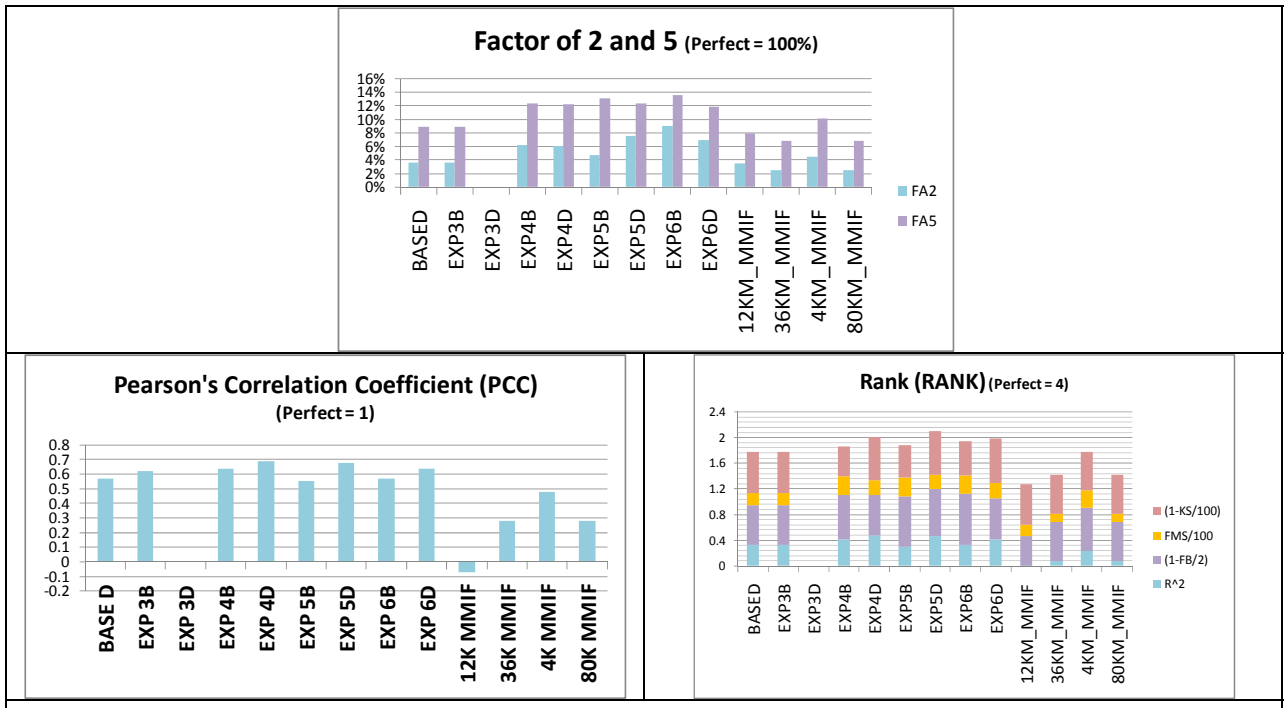


Figure 5-17b. Global model performance statistics for the CTEX5 CALPUFF sensitivity tests using different MM4/MM5 grid resolutions (higher values indicate better performance).

5.4.2.5 Rankings of CTEX5 CALPUFF Sensitivity Tests using the RANK Statistic

Table 5-10 ranks the model performance of the CTEX5 CALPUFF sensitivity tests using the RANK composite statistic. Outside of the 12KM, 36KM and 80KM MMIF CALPUFF sensitivity tests being by far the worst performing configurations with RANK values in the 1.28 to 1.42 range, the remaining sensitivity tests have RANK values in the 1.7 to 2.2 range, with the 4KM_MMIF run being in the lower end of this range. Examining trends in the CALPUFF sensitivity tests, the EXP6 series that uses the highest MM5 (12 km) and CALMET (4 km) grid resolution tends to have better model performance, whereas the "B" series of sensitivity tests tends to have worst model performance. Although the BASEA scenario is ranked 4th, the other BASE series using the 80 km MM5 and 18 km CALMET grid resolution have RANK scores on the lower end of the distribution. Based on these results we conclude the following for the CTEX5 sensitivity tests:

- Use of higher MM5 grid resolution (12 km) produces better CALPUFF model performance using both CALMET and MMIF.

5.5 CONCLUSIONS OF THE CAPTEX TRACER SENSITIVITY TESTS

There are some differences and similarities in CALPUFF's ability to simulate the observed tracer concentrations in the CTEX3 and CTEX5 field experiments. The overall conclusions of the evaluation of the CALPUFF model using the CAPTEX tracer test field experiment data can be summarized as follows:

- Regarding use of CALMET versus MMIF as a meteorological driver for CALPUFF, no definitive conclusion can be made since the CALPUFF/MMIF was the best performing model configuration for CTEX3 and the worst performing configuration for CTEX5.

Table 5-10. Final Rankings of CALPUFF CTEX5 Sensitivity Tests using the RANK statistic.

Ranking	Sensitivity Test	RANK Statistics	MM5 (km)	CALGRID (km)	RMAX1/RMAX2	Met Obs
1	EXP6C	2.19	12	4	10/100	Yes
2	EXP5D	2.10	36	4	--	No
3	BASEA	2.06	80	18	500/1000	Yes
4	BASEC	2.05	80	18	10/100	Yes
5	EXP5A	2.03	36	4	500/1000	Yes
6	EXP6A	2.02	12	4	500/1000	Yes
7	EXP4D	2.00	12	12	--	No
8	EXP6D	1.99	12	4	--	No
9	EXP4A	1.98	12	12	500/1000	Yes
10	EXP6B	1.94	12	4	100/200	Yes
11	EXP5B	1.89	36	4	100/200	Yes
12	EXP4B	1.86	12	12	100/200	Yes
13	BASEB	1.82	80	18	100/200	Yes
14	EXP5C	1.80	36	4	10/100	Yes
15	BASED	1.79	80	18	--	No
16	EXP3A	1.79	36	12	10/100	Yes
17	EXP3B	1.79	36	12	100/200	Yes
18	EXP3C	1.79	36	12	500/1000	Yes
19	EXP3D	1.79	36	12	--	No
20	4KM_MMIF	1.78	4	--	--	No
21	EXP4C	1.72	12	12	10/100	Yes
22	36KM_MMIF	1.42	36	--	--	No
23	80KM_MMIF	1.42	80	--	--	No
24	12KM_MMIF	1.28	12	--	--	No

- The use of 12 to 36 km resolution MM5 data tends to produce better CALPUFF model performance than using coarse grid data (e.g., 80 km).
- Regarding the effects of the RMAX1/RMAX2 parameters on CALPUFF/CALMET model performance, the "A" series (500/1000) is performing best for CTEX3 but the "C" series (10/100) is performing best for CTEX5 with both CTEX3 and CTEX5 agreeing that the "B" series (100/200) is the worst performing setting for RMAX1/RMAX2.
    - This is in contrast to the CALMET surface wind model evaluation that found the EPA-FLM Clarification Memorandum recommended settings used in the "B" series of CALMET experiments produced the wind fields that most closely matched observations (see Appendices A and B).
    - However, the CALMET surface wind evaluation was not a valid independent evaluation since surface wind observations are also used as input to CALMET for some of the experiments.

6.0 1994 EUROPEAN TRACER EXPERIMENT

6.1 DESCRIPTION OF THE 1994 EUROPEAN TRACER EXPERIMENT

The European Tracer Experiment (ETEX) was initiated in 1992 by the European Commission (EC), International Atomic Energy Agency (IAEA), and World Meteorological Organization (WMO) to address many of the questions that arose from the 1986 Chernobyl accident regarding the capabilities of LRT models and the ability to properly handle and disseminate large volumes of data. ETEX was designed to validate long-range transport models used for emergency response situations and to develop a database which could be used for model evaluation and development purposes.

6.1.1 ETEX Field Study

Two releases of a perflurocarbon tracer called perfluromonomethylcyclohexane (PMCH) were made in October and November 1994 from France. For this evaluation, model simulations are focused upon the first PMCH release. The first ETEX release has been used extensively to evaluate operational LRT models for numerous countries so was also used in this study. In many ways, it represents an ideal database for LRT evaluation because of the volume and high frequency of observations taken.

The PMCH was released at a constant rate of approximately 8 g/s (340 kg total) for 12 hours beginning at 1600 UTC on 23 October 1994 from Monterfil, France. The release of PMCH was a dynamic release, with an outlet temperature of 84°C and velocity of 47.6 m/s (JRC, 2008). Air concentrations were sampled at 168 monitoring sites in 17 European countries with a sampling frequency of every three hours for approximately 90 hours. Figure 6-1 displays the location of the PMCH release point in northwestern France and the array of sampling receptors.

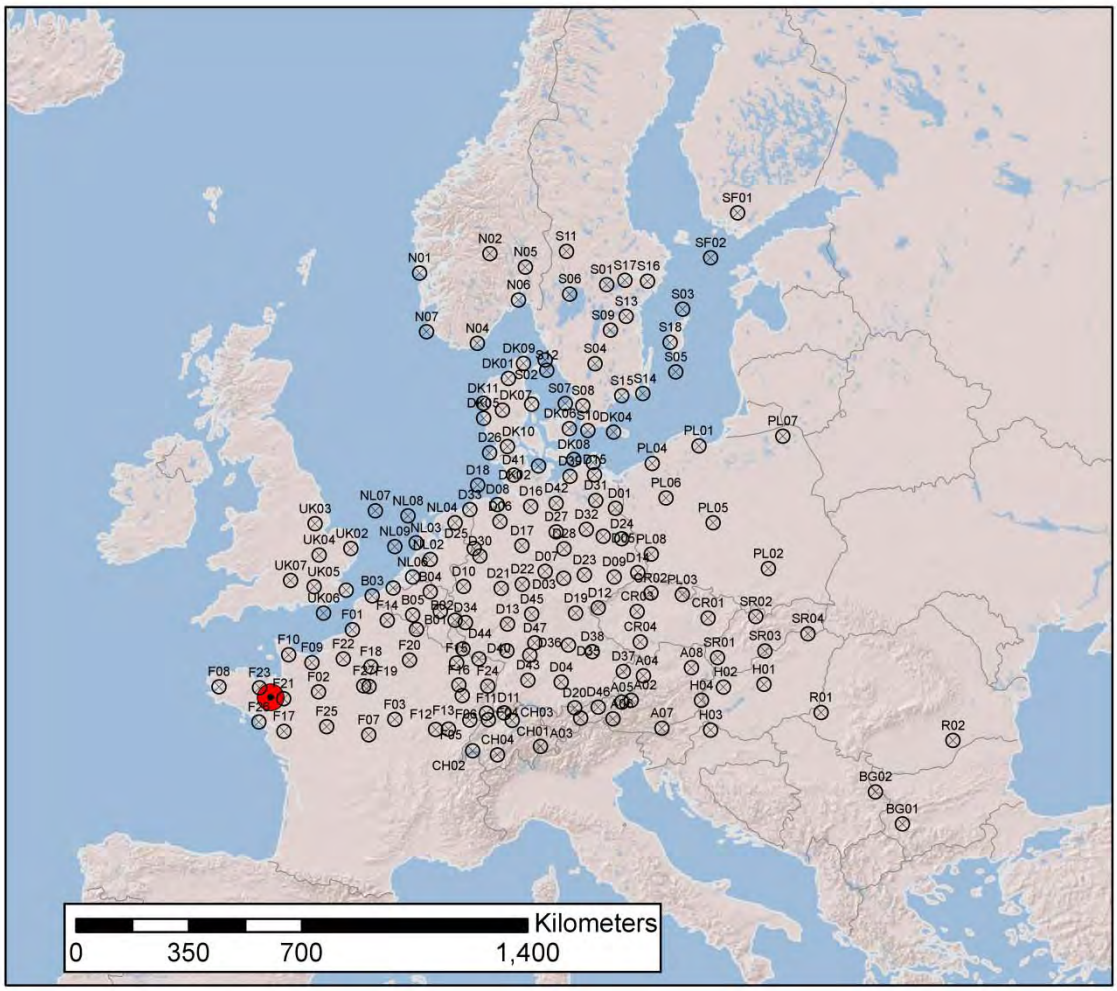


Figure 6-1. Locations of the PMCH tracer release point in Monterfil , France and sampling receptors for the 1994 European Tracer Experiment (ETEX).

6.1.2 Synoptic Conditions

Numerous synoptic surface and upper air observations were made by participating meteorological agencies as part of this experiment. Two separate extratropical cyclonic systems were present over the European continent at the time of the release. A strong extratropical cyclone was located over the North Sea with a central pressure of 980 mb. A second, significantly weaker, extratropical cyclone was located near the Balkan Peninsula over the Black Sea, having a central pressure of 1010 mb. These cyclonic systems were important to the transport of the PMCH tracer cloud. Figure 6-2 depicts the locations of the extratropical cyclonic systems during the ETEX field study.

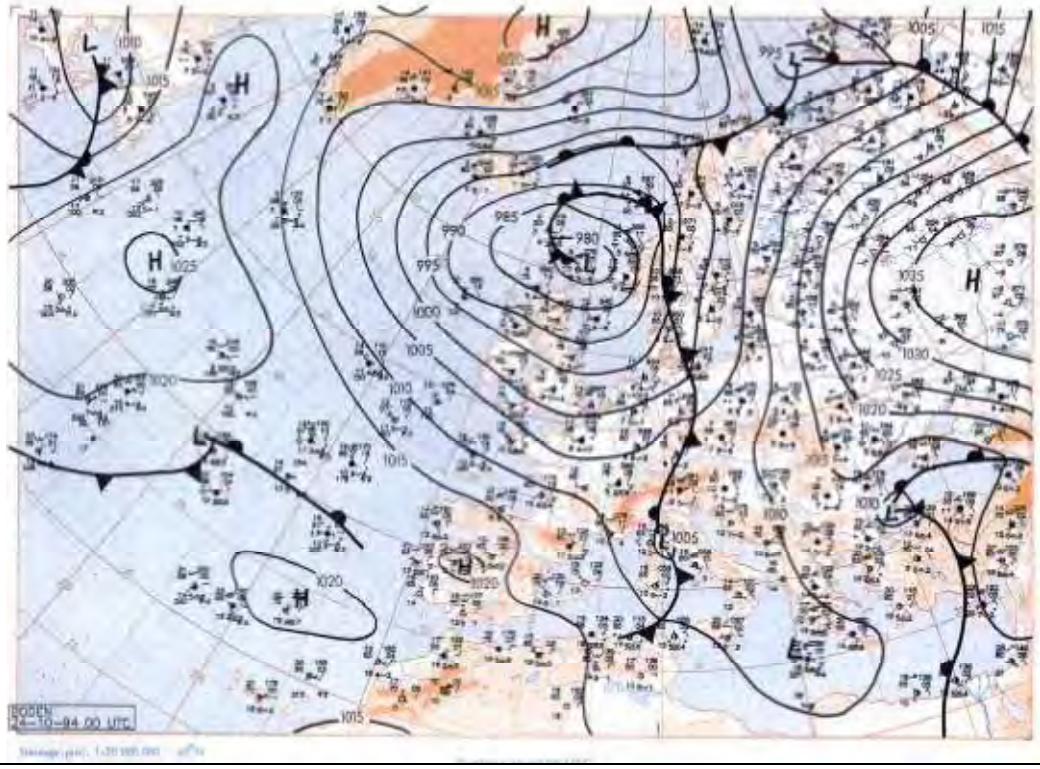


Figure 6-2a. Surface synoptic meteorological conditions for Europe at 0000 UTC on October 24, 1994 eight hours after the release of the PMCH tracer in ETEX (Source: http://rem.jrc.ec.europa.eu/etex/).

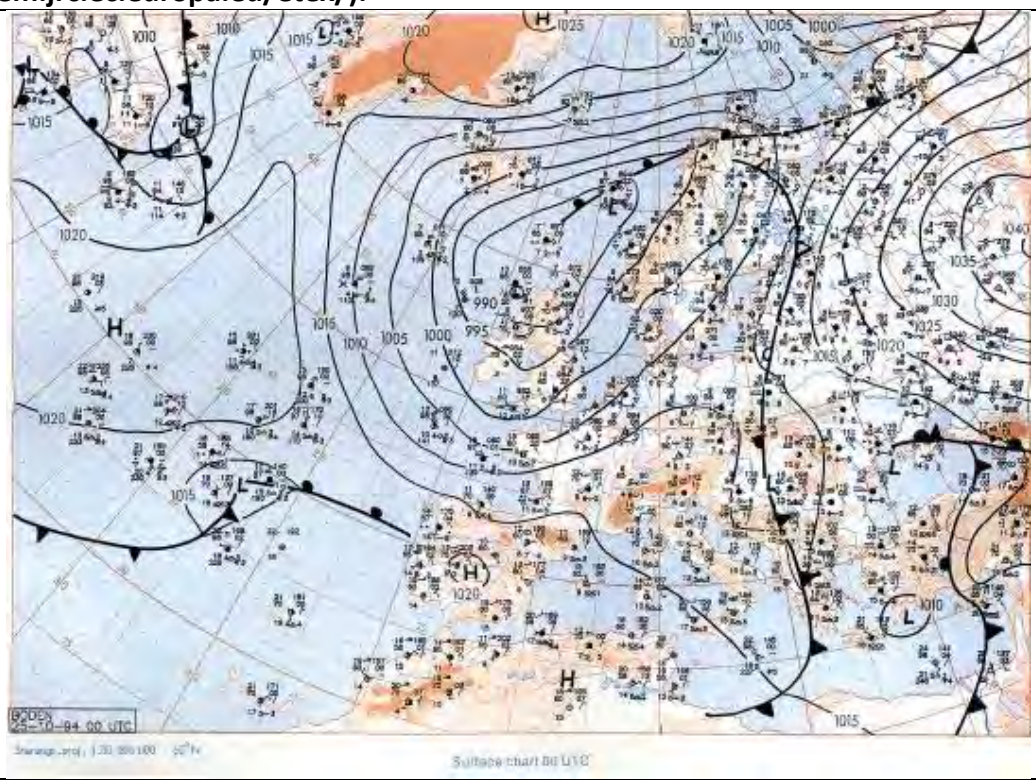


Figure 6-2b. Surface synoptic meteorological conditions for Europe at 0000 UTC on October 25, 1994 32 hours after the release of the PMCH tracer in ETEX (Source: http://rem.jrc.ec.europa.eu/etex/).

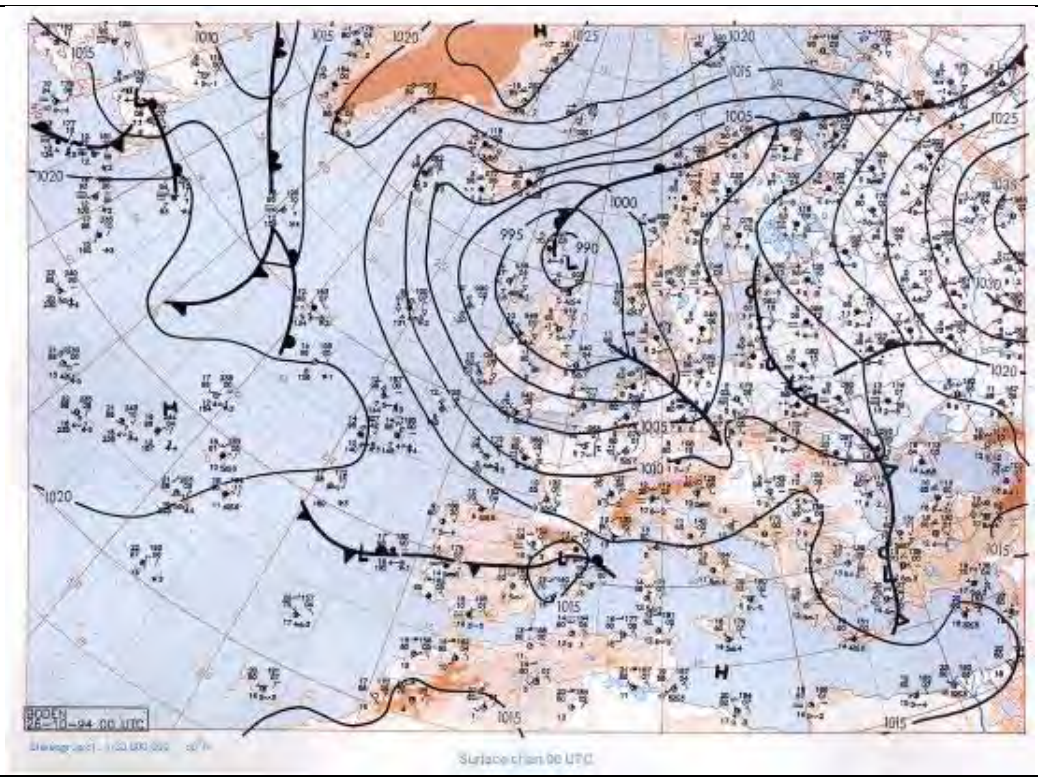


Figure 6-2c. Surface synoptic meteorological conditions for Europe at 0000 UTC on October 26, 1994 56 hours after the release of the PMCH tracer in ETEX (Source: http://rem.jrc.ec.europa.eu/etex/).

Figure 6-3 displays the spatial distribution of the observed PMCH tracer concentration in pico-grams per cubic meter (pgm^{-3}) 24, 36, 48 and 60 hours after the release in Monterfil, France. During the first 24 hours after the release of the PMCH, the tracer cloud was advected generally east-northeast from the release point in northwestern France into the Netherlands and Luxembourg and into western Germany. By 36 hours after the initial release, the tracer cloud had advected well into Germany (Figure 6-3, top right). In this region, the wind flow split between the two cyclonic systems northwest and southeast of Germany (see Figure 6-2), causing the tracer cloud to essentially bifurcate, with one portion advecting around the core of the cyclonic system over the North Sea, and the other portion advecting southeast towards the cyclonic system in the Balkan Peninsula region. 48 and 60 hours after the tracer release (Figure 6-3, lower panels), the tracer cloud stretches from Norway to the Black Sea in a narrow northwest to southeast orientation.

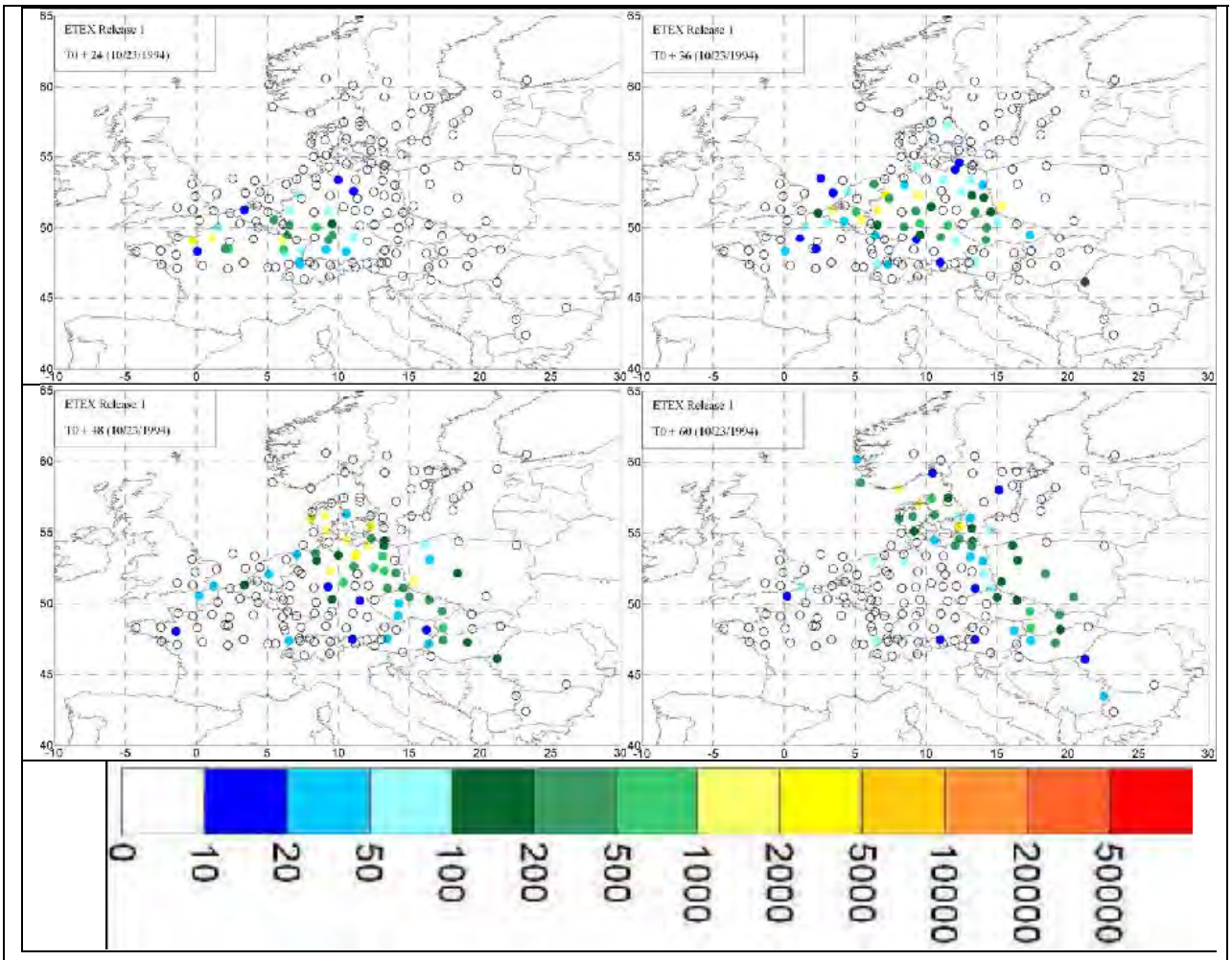


Figure 6-3a. Distribution of the observed PMCH tracer concentrations (pgm^{-3}) 24 (top right), 36 (top right), 48 (bottom left) and 60 (bottom right) hours after the release.

6.2 MODEL CONFIGURATION AND APPLICATION

6.2.1 Experimental Design

The objectives of the LRT model evaluation using the ETEX field study database was somewhat different than the other three tracer test evaluations. In the GP80, SRL75 and CAPTEX tracer test LRT model evaluations, one major objective was an evaluation of the CALPUFF LRT dispersion model using two different sets of meteorological inputs, one based on the CALMET diagnostic wind model and the other using the MMIF WRF/MM5 pass-through tool. However, in the ETEX LRT model tracer test evaluation an objective was to use the same meteorological inputs in all of the LRT dispersion models. This approach is similar to the one taken by Chang and co-workers (2003) who conducted an evaluation of three Lagrangian puff models (HPAC/SCIPUFF, VLSTRACK, and CALMET/CALPUFF). While all three puff models are based on a Gaussian puff formulation, these models varied significantly in terms of the level of sophistication of their technical formulation. Chang and co-workers (2003) proposed a framework to perform an objective and meaningful evaluation when such models vary significantly in their formulation. A primary focus of their model evaluation framework

centered upon the use of the same observed meteorological data and similar modeling domains. To the extent practical, default model options were selected for all models in their evaluation. Reflecting that evaluation paradigm, a major focus of the LRT model evaluation using the ETEX database in this study was to provide a common source of meteorological fields to each of the dispersion models evaluated.

Five different LRT dispersion models were evaluated using the ETEX database. Each of the LRT models in this exercise requires three-dimensional meteorological fields as input to the model. For the majority of these models, meteorological fields from prognostic meteorological models are the primary source of the meteorological inputs. However, CALPUFF and SCIPUFF typically rely upon their own diagnostic meteorological models to provide three-dimensional meteorological fields to the dispersion model. In cases where prognostic meteorological model data are ingested to set the initial conditions within the diagnostic meteorological model, much of the original prognostic meteorological data is not preserved, and key parameters are rediagnosed. This compromises a key component of the evaluation paradigm of Chang et al. (2003) that we have adopted for the ETEX evaluation, namely a common meteorological database. The Mesoscale Model Interface (MMIF) software program (Emery and Brashers, 2009) was developed to facilitate direct ingestion of prognostic meteorological model data by the LRT dispersion model, bypassing the diagnostic meteorological model component and rediagnosing algorithms effectively overcoming the challenge to this evaluation paradigm.

6.2.2 Meteorological Inputs

During the original ATMES-II project, participating agencies during ETEX were required to calculate concentration fields for their respective models using analysis fields from the European Center for Medium-Range Weather Forecasts (ECMWF). ECMWF analysis fields were available at 6-hour intervals and a horizontal resolution of 0.5° (~50 km) latitude-longitude (D'Amours, 1998). Participating agencies could also submit results obtained using different meteorological analyses. Van Dop et al. (1998) and Nasstrom et al. (1998) found that increasing the resolution of the input meteorological fields enhanced the performance of the dispersion models evaluated in the ATMES-II study. Similarly, Deng et al. (2004) found that SCIPUFF model performance for the Cross-Appalachian Tracer Experiment (CAPTEX) improved by increasing meteorological model horizontal and vertical resolution, use of four dimensional data assimilation (FDDA), and more advanced meteorological model physics. However, they also noted that use of the more advanced physics options were responsible for more improvement in model performance than merely increasing horizontal grid resolution.

For the LRT model evaluation exercise using the ETEX database presented in this report, meteorological inputs were generated using a limited-area mesoscale meteorological model to produce higher temporally and spatially resolved meteorological data than used in the ATMES-II project. By producing more accurate meteorological fields, it should be possible to maximize performance of the LRT models under evaluation in this study. Furthermore, by using a common source of meteorological data between each of the five modeling systems, it reduces the potential contribution of differences in meteorological data on dispersion model performance and facilitates a more direct intercomparison of dispersion model results.

Hourly meteorological fields were derived from the PSU/NCAR Mesoscale Meteorological Model (MM5) Version 3.74 (Grell et al., 1995). MM5 was initialized with National Center for Environmental Prediction (NCEP) reanalysis data (NCAR, 2008). NCEP reanalysis fields are available every 6 hours on a 2.5° x 2.5° (~275 km) grid. The MM5 horizontal grid resolution was

36 kilometers and the vertical structure contained 43 vertical layers. Physics options were not optimized for northern European operations, but were based upon more advanced physics options available in MM5, reflecting the findings of Deng et al. (2004). Key MM5 options included:

- ETA Planetary Boundary Layer (PBL) scheme;
- Kain-Fritsch II cumulus parameterization (Kain, 2004);
- Rapid Radiative Transfer Model (RRTM) radiation scheme (Mlawer et al. 1997);
- NOAH land surface model (LSM) (Chen et al. 2001); and
- Dudhia Simple Ice microphysics scheme (Dudhia, 1989).

Four dimensional data assimilation (FDDA) (Stauffer et al. 1990, 1991) was employed for this study. "Analysis nudging" based upon the NCEP reanalysis fields were used with default values for nudging strengths.

6.2.3 LRT Model Configuration and Inputs

Three distinct classes of LRT dispersion models were included as part of the ETEX tracer evaluation including four Lagrangian models and one Eulerian model. CALPUFF Version 5.8 (Scire et al. 2000b) and SCIPUFF Version 2.303 (Sykes et al., 1998) are Lagrangian Gaussian puff models. HYSPLIT Version 4.8 (Draxler 1997) and FLEXPART Version 6.2 (Siebert 2006) are Lagrangian particle models. CAMx Version 5.2 (ENVIRON, 2010) is an Eulerian grid model. The respective user's guides provide a complete description of the technical formulations of each of these models.

Both CALPUFF and SCIPUFF are based upon Gaussian puff formulation. The two puff models have the advantage of more robust capabilities for source characterization, having the ability to treat dispersion for point, area, or line sources. Furthermore, these models can more accurately characterize dynamic releases of pollutants by accounting for initial plume rise of the pollutant. Conversely, the two particle models are very limited in their capability to characterize sources, having no direct ability to account for variations in source configurations or consider plume rise. The CAMx grid model is limited in its ability to simulate "plumes" by the grid resolution specified. CAMx includes a subgrid-scale Plume-in-Grid (PiG) module to treat the early evolution, transport and dispersion of point source plumes whose effect on model performance was investigated using sensitivity tests.

Since plume rise varies from hour-to-hour as a function of ambient temperature, wind speed and stability it is not possible to define a release height which would reflect this variation. Therefore, a constant release height of 10 meters was assigned for the two particle models in this study. This limitation of the particle models is problematic when comparing against models such as CALPUFF, SCIPUFF and CAMx that can simulate dynamic releases of emissions and calculate hour-specific plume rise using hourly meteorological data. Iwasaki et al. (1998) found that the initial release height assigned to the Japan Meteorological Agency (JMA) particle model had a large impact on the predicted ground level concentrations. Investigation of initial release height sensitivity of the two particle models was beyond the scope of this evaluation. However, this limitation should be noted when considering the uncertainty of concentration estimates from the two particle models.

Each of the four models requires gridded meteorological fields for dispersion calculations. CALPUFF normally uses output from the CALMET diagnostic wind field model (Scire et al.,

2000a). SCIPUFF also has its own simplified mass-consistent wind field processor referred to as MC-SCIPUFF (Sykes et al., 1998). Gridded meteorological fields are normally supplied to HYSPLIT and FLEXPART using software that converts prognostic meteorological data into formats that are directly ingested into the respective dispersion models. The CAMx model also uses software to reformat output from a prognostic meteorological model into the variables and formats used by CAMx.

Use of a diagnostic wind field model (DWM) as the primary method to supply meteorological data to the dispersion models under review creates additional uncertainty in the intercomparison of the five dispersion models. DWM's, such as CALMET, have the ability to ingest prognostic data from models such as the PSU/NCAR MM5 (Grell et al.,1995) or the Advanced Research Weather Research and Forecasting (WRF-ARW) (Skamarock et al. 2008) as its first guess wind field. However, this method of using the prognostic meteorological data as the first guess field for the DWM does not preserve the integrity of the original meteorological field. For example, the CALMET DWM adjusts the wind fields for kinematic and thermodynamic effects of terrain and also rediagnoses key meteorological parameters such as planetary boundary layer heights. Thus, to conduct a proper evaluation of the dispersion models on the same basis, each of the models should be operated with the same meteorological dataset. In order to maintain consistency with this study objective, it would not have been appropriate to use either MC-SCIPUFF or CALMET to produce three-dimensional meteorological fields for their respective dispersion model.

In order to facilitate direct intercomparison of models using a common prognostic meteorological dataset, it is necessary to supply meteorological fields to CALPUFF and SCIPUFF in the same manner as the particle models and grid model included in this study. SCIPUFF has the ability to ingest prognostic data sets directly in either MEDOC (Multiscale Environmental Dispersion Over Complex terrain) (Sykes et al., 1998) or HPAC formats. The Pennsylvania State University developed the MM5SCIPUFF utility program (A. Deng, pers. comm.) to convert MM5 fields into the MEDOC format which is directly ingested into the SCIPUFF. Similarly, the US EPA developed the Mesoscale Model Interface (MMIF) software to convert MM5 fields into the CALPUFF meteorological input format (Emery and Brashers, 2009). With these two utility programs, it was now possible to evaluate the five LRT models using a consistent set of meteorological inputs.

Due to the inherent differences that exist between each of the five LRT models, it was not possible to standardize dispersion model options. Rather, options selected for each class of models were similar to the extent possible. For example, more advanced model features (turbulence dispersion, puff splitting) were used for CALPUFF simulations as these represent the state-of-the-practice for puff dispersion models and are most consistent with the capabilities of the SCIPUFF modeling system, helping to facilitate greater inter-model consistency for this evaluation.

CALPUFF is typically only recommended to distances of about 300 km or less (EPA, 2003). This would effectively limit the useful range of CALPUFF to the first 24-36 hours of ETEX simulation. However, recent enhancements to the CALPUFF modeling system include both horizontal and vertical puff splitting, incorporating the effects of wind shear on puff growth, potentially allowing for use of CALPUFF at distances greater than the nominal recommended limit of about 300 km, and allowing for more direct intercomparison with the two particle models and one grid model used in this study which are free of this restriction. The default method for CALPUFF vertical puff splitting is to allow for splitting to occur once per day by turning on the puff

splitting flag near sunset (hour 17), artificially limiting the number of split puffs that are generated by the model. However, for the ETEX evaluation puff-splitting was enabled for each simulation hour instead of the default option of once per day in order to allow for full treatment of wind shear. The puff splitting feature of the CALPUFF modeling system does not have a complementary puff "merging" feature which aggregates puffs according to specified rules when they occupy the same space. Without the complementary puff merging capability, the number of puffs generated by puff-splitting can rapidly increase, resulting in extensive computational requirements of the model and eventual simulation termination once the maximum number of puffs allowed by the model is exceeded. Since the ETEX CALPUFF application was of short duration, the number of puffs allowed was increased so no termination occurred. However, the use of all hour puff splitting with CALPUFF in an annual simulation could be problematic. The SCIPUFF Lagrangian puff model also performs puff splitting when a sheared environment is encountered, however it can perform puff merging when two puffs occupy the "same" space so does not suffer from the extensive computer time of CALPUFF when aggressive puff splitting is desired.

The horizontal and vertical grid structures of CALPUFF were similar to the parent MM5 data. Twenty-seven (27) vertical levels were used in CALPUFF with each of the first 27 MM5 layers matched explicitly to the CALPUFF vertical structure, through the lowest 4,900 m vertical depth of the atmosphere. Additionally, 168 discrete receptors were included in the modeling analysis, with the location of each corresponding to the location and elevation of the ETEX monitors. AERMOD (EPA, 2004) turbulence coefficients, no complex terrain adjustment, and puff-splitting were selected for this analysis. A constant emission rate of 7.95 g/s was assigned for twelve hours of release of the PMCH tracer. Plume rise and momentum were also simulated in CALPUFF according to the release characteristics detailed on the ETEX website. CALPUFF results were integrated for 90 hours, and model results were post-processed in order to generate 30 three (3) hour averages for each of the 168 discrete receptors.

For SCIPUFF simulations, the horizontal and vertical grid structures of the extracted MM5 data were similar to the original MM5 data. Twenty-eight (28) vertical levels were extracted, encompassing a depth of approximately 5,000 m, similar to the CALPUFF simulations. Plume rise and momentum were also simulated in SCIPUFF in the same manner as the CALPUFF simulations. SCIPUFF results were also integrated for 90 hours, and model results were post-processed in order to generate 30 three (3) hour averages for each of the same 168 discrete receptors.

FLEXPART simulations used a 375 x 175 horizontal grid at a resolution 0.16° (~18 km) latitude/longitude. All MM5 vertical layers were extracted for the transport simulation. The FLEXPART concentration grid consisted of 15 vertical levels from the surface to 1,500 m with 9 layers below the first 500 m. Emissions were released at 10 meters. Concentrations were bi-linearly interpolated to grid cells corresponding to the 168 ETEX monitoring locations that were used.

HYSPLIT simulations used a 60 x 60 concentration grid with a horizontal resolution 0.25° (~28 km) latitude/longitude, consistent with NOAA's model configuration for ETEX described on the DATEM website. All MM5 vertical layers to 5000 meters were extracted for the transport simulation. Emissions were released at 10 meters. The gridded concentration output was linearly interpolated to the sampling locations utilizing software from NOAA's Data Archive of Tracer Experiments and Meteorology (DATEM) project. HYSPLIT was configured as a puff-

particle hybrid (same used by the NOAA ARL for their ETEX evaluation) was used for the model intercomparison (i.e., INITD = 104)

Note that the FLEXPART and HYSPLIT meteorological inputs were based on the 36 km MM5 meteorological model output, so they used the same transport conditions and resolution as the other LRT models. The FLEXPART (~18 km) and HYSPLIT (~28 km) horizontal grid resolution is used to convert the particles (mass) to concentrations (mass divided by volume).

CAMx was operated on a 148 x 112 horizontal grid with 36 km grid resolution with 25 vertical layers up to a 50 mb pressure level (~15 km). CAMx is a photochemical grid model that includes state-of-science gas, aerosol and aqueous phase chemistry modules and dry and wet deposition algorithms. However, for the ETEX tracer modeling CAMx was operated with no chemistry and no wet or dry removal mechanisms. The MM5CAMx processor was used to process the MM5 output to the variables and formats required by CAMx. CAMx has several options for vertical mixing (from MM5CAMx), horizontal advection as well as a subgrid-scale Plume-in-Grid (PiG) module. Several alternative configurations of CAMx were investigated using sensitivity tests. When comparing with the other LRT models, we used a CAMx configuration with the following attributes, which are fairly typical for many CAMx simulations:

- CMAQ-like vertical diffusion coefficients from MM5CAMx;
- Piecewise Parabolic Method (PPM) horizontal advection solver; and
- No PiG module.

6.3 QUALITY ASSURANCE

Quality assurance (QA) of the LRT dispersion runs was conducted by evaluating the MM5 meteorological model output against surface meteorological observations and by examining of the LRT model inputs and outputs, as available, to assure that the intended options and configurations were used.

6.3.1 Quality Assurance of the Meteorological Inputs

A limited statistical evaluation of the MM5 simulation for the ETEX period was conducted as part of this evaluation. The meteorological observations collected at the 168 sampling stations during the ETEX exercise were not used as part of the MM5 data assimilation strategy; therefore, these observations could reliably be used to provide an independent evaluation of the MM5 simulation.

MM5 model performance evaluation results are presented in Figure 6-4. The MM5 performance statistics presented in Figure 6-4 are compared to performance criteria typically recommended for meteorological model applications for regional air quality studies in the United States (Emery et al. 2001) that were presented previously in Table 5-7. In general, MM5 verification scores indicate a persistent negative bias and higher error for both wind speed (-1.67 m/s and 4.73 m/s, respectively) and temperature (-1.1 °K and 2.36 °K, respectively) averaged across all 168 sites that are outside of target performance benchmark values for each of these meteorological parameters. Wind direction bias and error were within the performance benchmarks. Typically, these performance statistics would likely cause the modeler to consider experimenting with additional physics configurations and/or altering the data assimilation strategy to enhance meteorological model verification statistics. However, the MM5 simulation was not optimized for this project for several reasons:

- First, from an operational perspective, the meteorological model errors are likely consistent with the magnitude of model prediction errors that would have been

experienced during the original ETEX exercise if forecast fields rather ECMWF analysis fields had been employed. Additionally, the MM5 simulation has the added advantage of data assimilation to constrain the growth of forecast error as a function of time.

- Second, since each of the five LRT model platforms evaluated in this project are presented with the same meteorological database; a systemic degradation of performance due to advection error would have been observed if the meteorology was a primary source of model error. However, since poor model performance was only noted in one of the five models, meteorological error was not considered the primary cause of poor performance.
- Finally, since wind direction is likely one of the key meteorological parameters for LRT simulations, the operational decision to use the existing MM5 forecasts was made because the MM5 wind direction forecasts were within acceptable statistical limits.

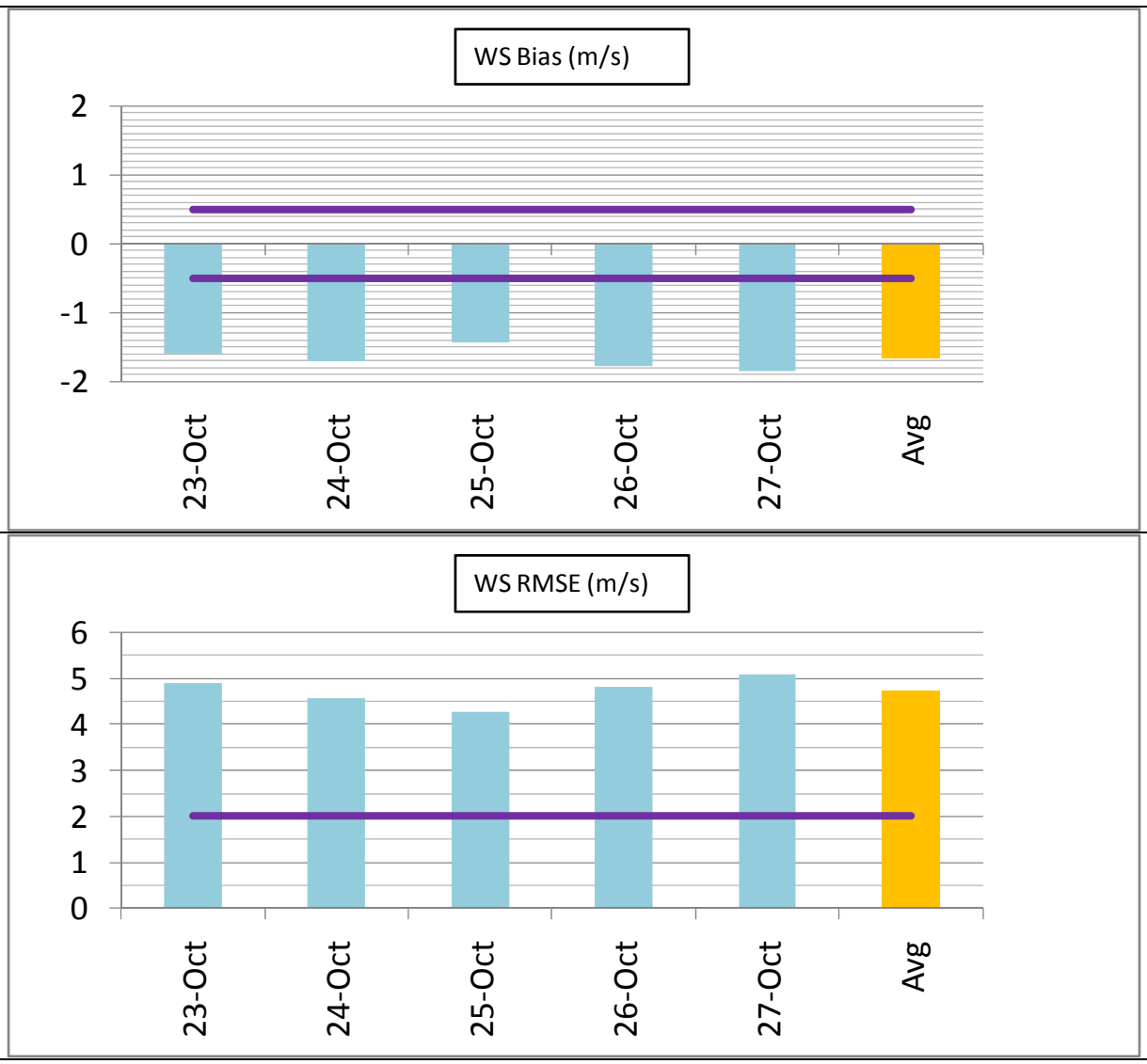


Figure 6-4a. ETEX MM5 model performance statistics of Bias (top) and RMSE (bottom) for wind speed and comparison with benchmarks (purple lines).

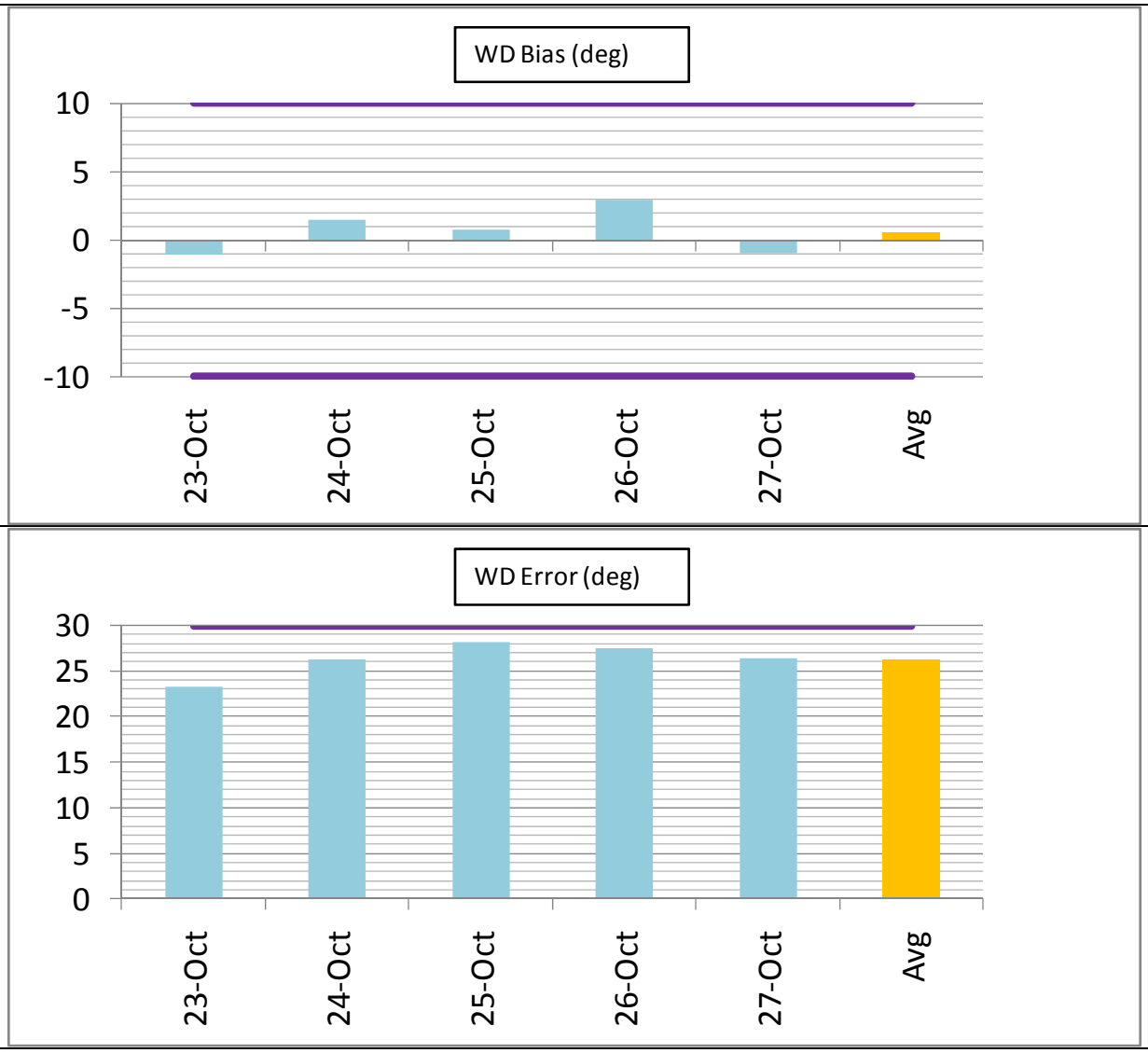
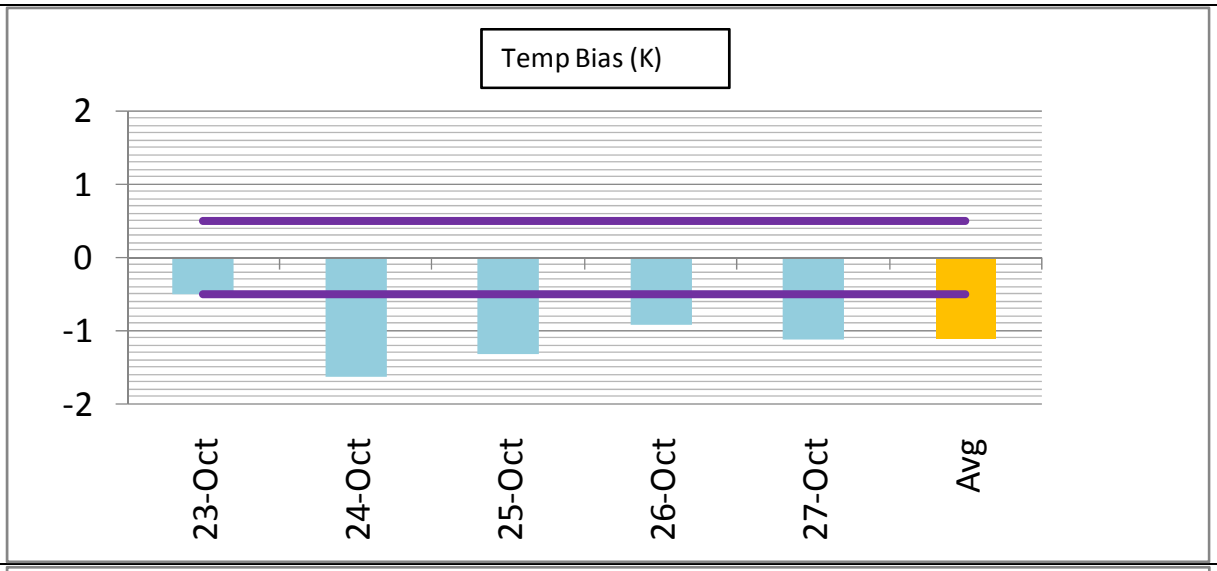


Figure 6-4b. ETEX MM5 model performance statistics of Bias (top) and Error (bottom) for wind direction and comparison with benchmarks (purple lines).



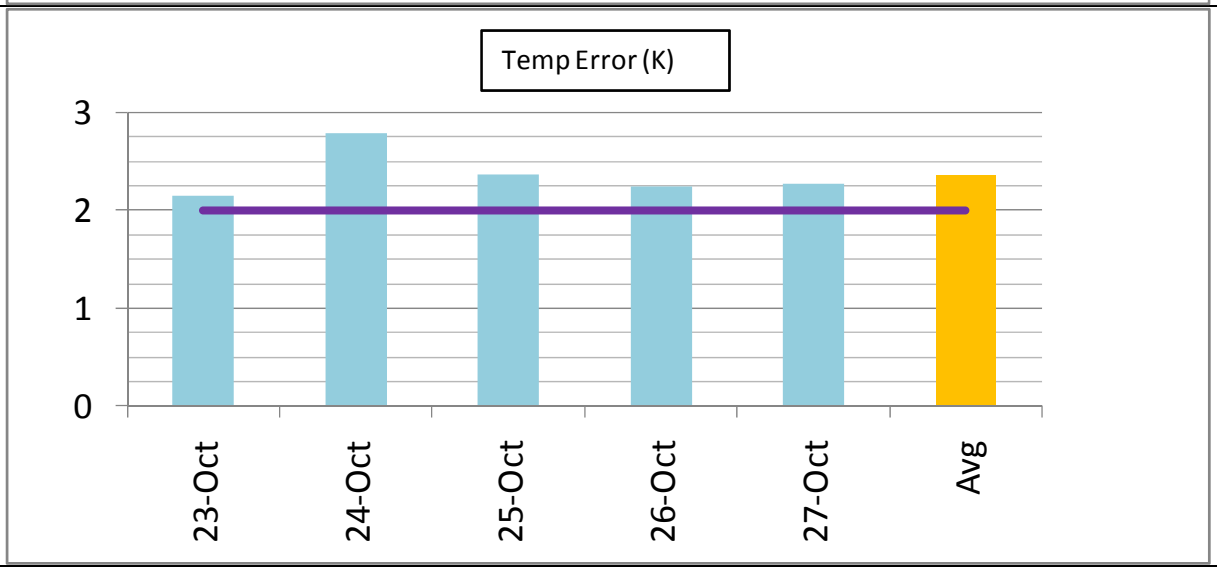


Figure 6-4c. ETEX MM5 model performance statistics of Bias (top) and Error (bottom) for temperature and comparison with benchmarks (purple lines).

6.3.2 Quality Assurance of the LRT Model Inputs

The input control files for the five LRT dispersion models were examined to assure that the intended model options were used in each of the simulations.

6.4 MODEL PERFORMANCE EVALUATION

The model performance of the five LRT dispersion models are evaluated using statistical measures as used in the ATMES-II study (Mosca et al., 1998) and recommended by DATEM (Draxler, Heffter and Rolph, 2002). Graphical comparisons are generated of the predicted and observed tracer spatial distributions.

6.4.1 Statistical Model Performance Evaluation

The spatial, temporal and global model performance of the five LRT models is evaluated using the statistical model performance metrics described in Section 2.4.

6.4.1.1 Spatial Analysis of Model Performance

Four spatial analysis model performance statics have been identified and are discussed in this section: FMS, FAR, POD and TS. Figure 6-5 displays the FMS spatial analysis performance metrics for the five LRT models and the ETEX tracer study field experiment. Recall that the FMS statistic is define as the overlap divided by the union of the predicted and observed tracer clouds with a perfect model receiving an FMS score of 100%.

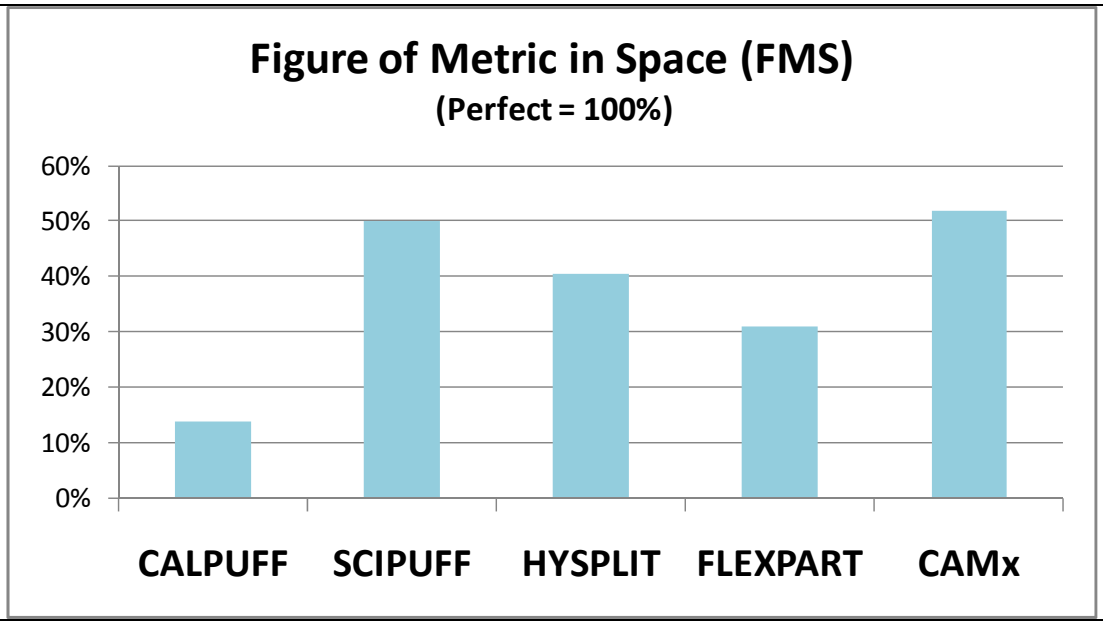


Figure 6-5. Figure of Merit in Space (FMS) statistical performance metric for the five LRT models and the ETEX tracer field experiment.

Figure 6-6 displays the False Alarm Rate (FAR) performance metrics. The FAR metric is defined by the number of times that a tracer concentration was predicted to occur at a monitor-time when no tracer was observed (i.e., a miss) divided by the number of times a tracer was predicted to occur at a monitor-time (i.e., sum of misses and hits); a perfect model (i.e., one that had no misses) would have a FAR score of 0%.

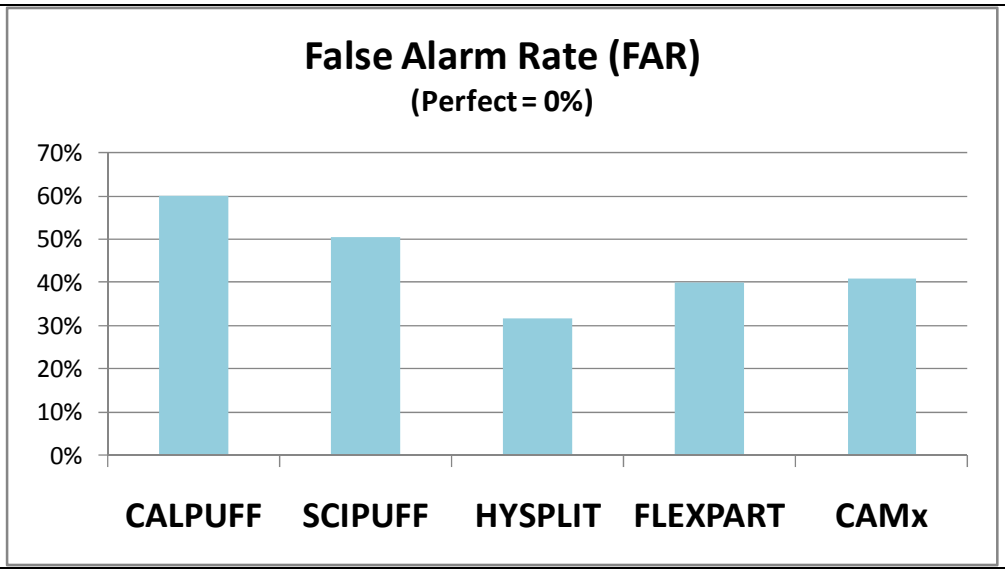


Figure 6-6. False Alarm Rate (FAR) statistical performance metric for the five LRT models and the ETEX tracer field experiment.

The Probability of Detection (POD) performance statistic is defined as the percent of the time the predicted and observed tracer both occurred at a monitor-time (i.e., a hit of tracer concentrations greater than 1 ngm^{-3}) divided by the number of times that the tracer was observed at any monitor-time (i.e., sum of hits and misses); a perfect model POD score would be 100% (i.e., anytime there was observed tracer at a monitor there was also predicted tracer at the monitor).

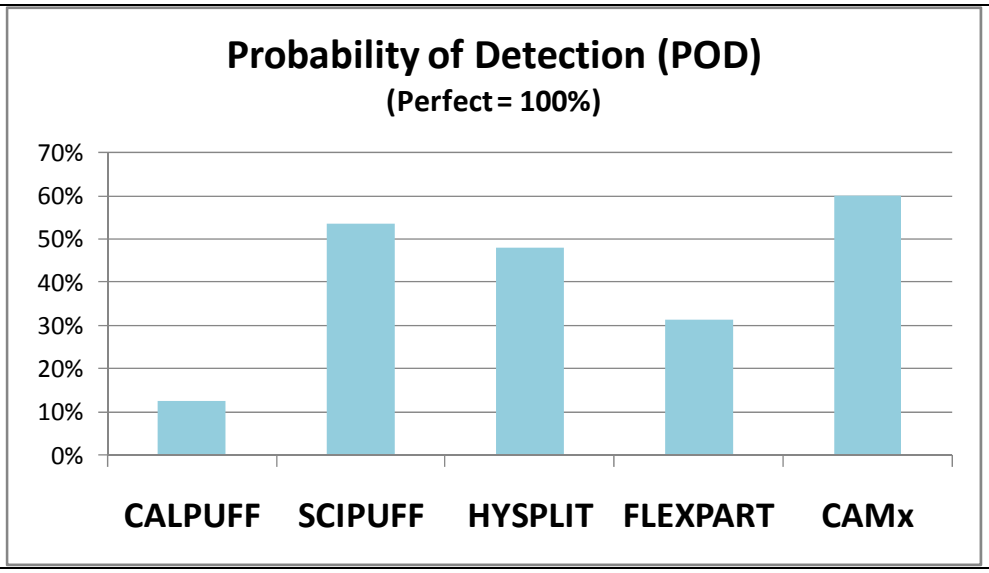


Figure 6-7. Probability of Detection (POD) statistical performance metric for the five LRT models and the ETEX tracer field experiment.

The Threat Score (TS) is the ratio of the number of times that a tracer is both predicted and observed at a monitor-time at the same time (i.e., common hits among the predictions and

observations) divided by the number of monitor-time events that either a prediction or observed tracer occurred at a monitor (i.e., either a predicted or observed hits), with a perfect score of 100% (which means there were no occurrences when there was a predicted hit but an observed miss and vice versa).

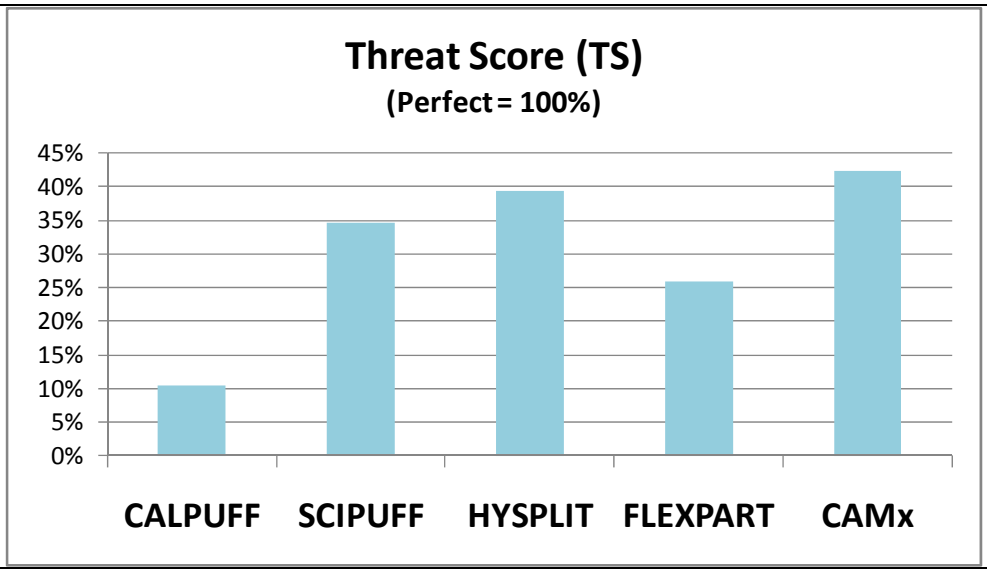


Figure 6-8. Threat Score (TS) statistical performance metric for the five LRT models and the ETEX tracer field experiment.

6.4.1.2 Global Analysis of Model Performance

Eight global statistical analysis metrics are used to evaluate the five LRT model performance using the ETEX data base that are described in Section 2.4 and consist of the FOEX, FA2, FA5, NMSE, PCC, FB, KS and RANK statistical metrics.

The Factor of Exceedance (FOEX) gives a measure of the scatter of the modeled predicted and observed and a level of underestimation versus overestimation of the model. FOEX is bounded by -50% to +50%. The within a Factor of α (FAα), where we used within a Factor of 2 (FA2) and 5 (FA5), also gives an indication of the amount of scatter in the predicted and observed tracer pairs, but no information on whether the model is over- or under-predicting. A perfect model would have an FAα score of 100%. A good performing model would have a FOEX score near zero and high FAα values. A model with a large negative FOEX and low FAα values would indicate an under-prediction tendency. Whereas a model with a large positive FOEX and low FAα would suggest a model that over-predicts.

Figure 6-9 displays the FOEX performance metrics for the five LRT models and the ETEX modeling period.

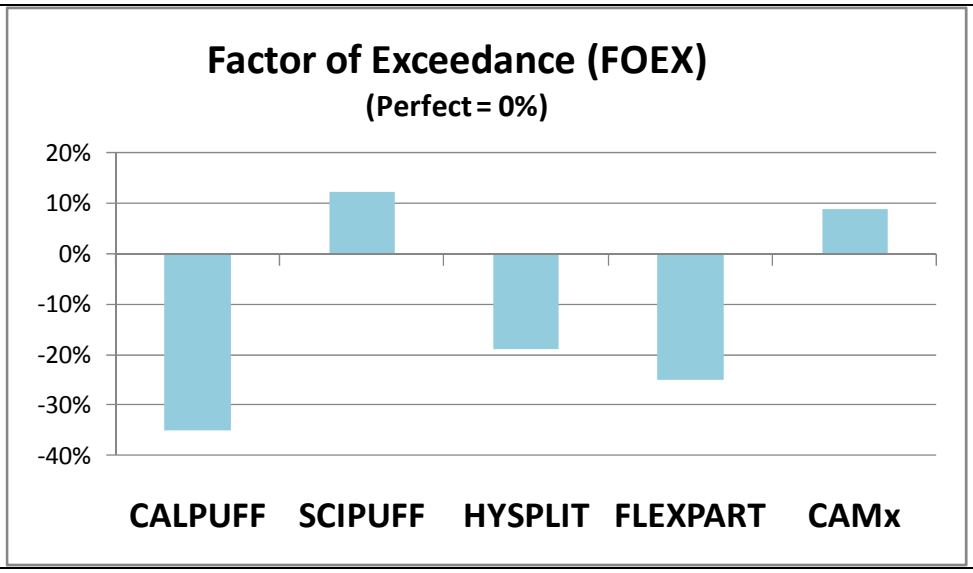


Figure 6-9. Factor of Exceedance (FOEX) statistical performance metric for the five LRT models and the ETEX tracer field experiment.

The rankings of the five LRT models are the same whether using the FA2 or FA5 performance metric.

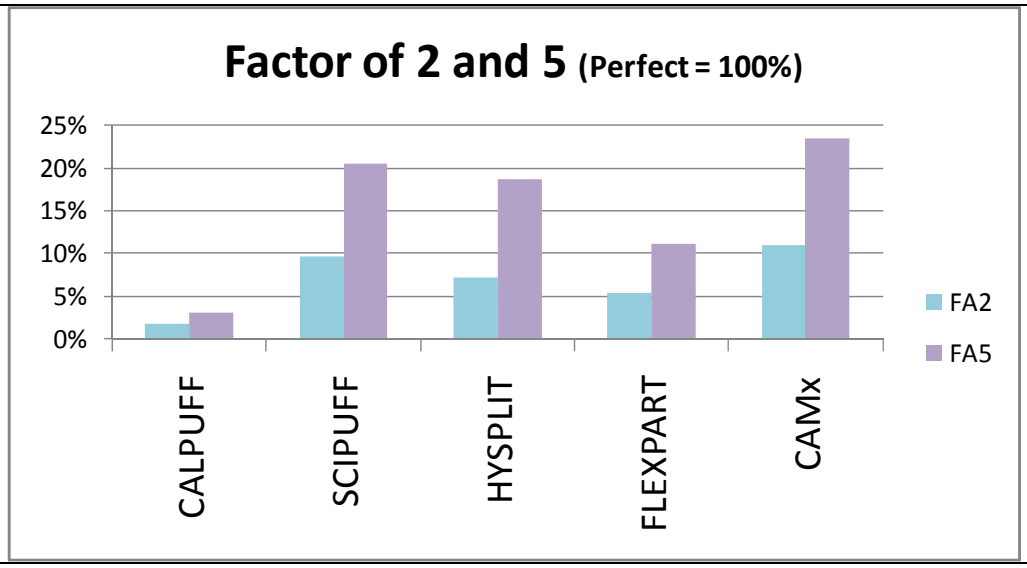


Figure 6-10. Factor of 2 (FA2, top) and Factor of 5 (FA5, bottom) statistical performance metric for the five LRT models and the ETEX tracer field experiment.

The scores for the Normalized Mean Squared Error (NMSE) statistical metrics for the five LRT models are given in Figure 6-11. The NMSE provides an indication of the deviations between the predicted and observed tracer concentrations paired by time and location with a perfect model receiving a 0.0 score.

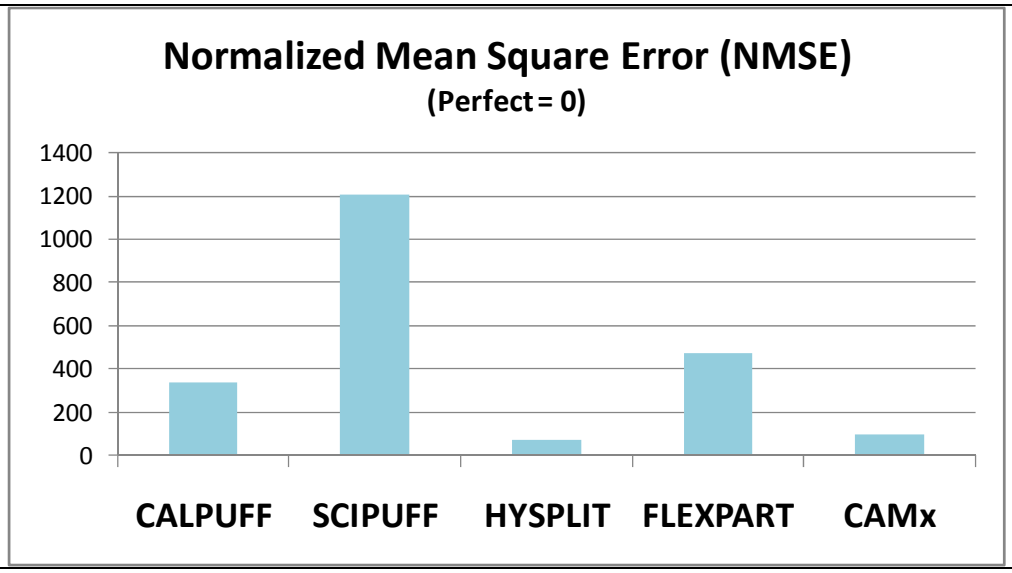


Figure 6-11. Normalized Mean Square Error (NMSE) statistical performance metric for the five LRT models and the ETEX tracer field experiment (pgm^{-3}).

The Pearson's Correlation Coefficient (PCC or R) ranges between -1.0 and +1.0, a model that has a perfect correlation with the observations would have a PCC value of 1.0. The PCC values for the five LRT models are shown in Figure 6-12. All of the models have positive PCCs so none are negatively correlated with the observe data.

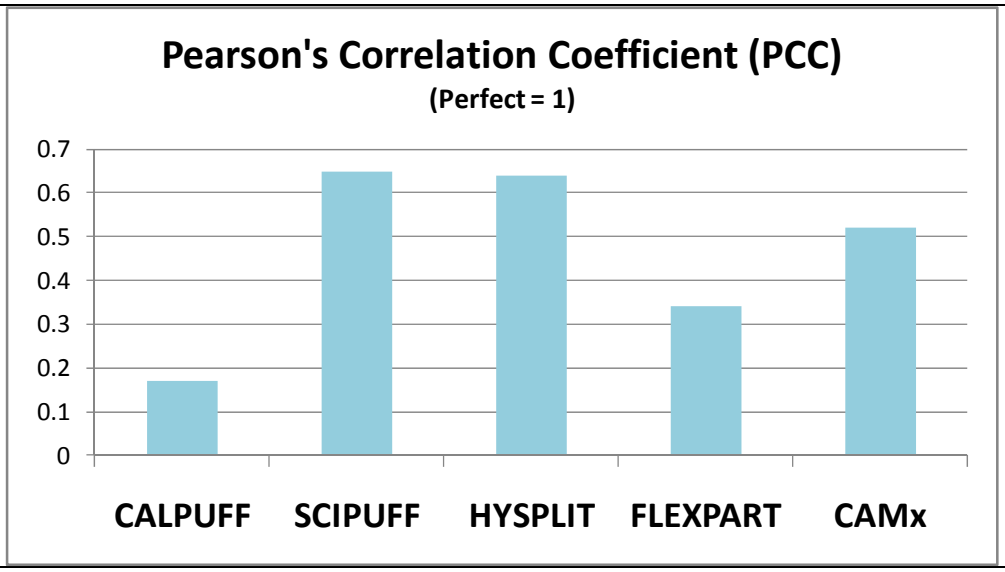


Figure 6-12. Pearson's Correlation Coefficient (PCC) statistical performance metric for the five LRT models and the ETEX tracer field experiment.

The Fractional Bias (FB) is a measure of bias in the deviations between the predicted and observed paired tracer concentrations and ranges from -2.0 to +2.0 with a perfect model

receiving a 0.0 score. Figure 6-13 displays the FB parameter for the five LRT models. All five models exhibit a positive FB, which suggests an overestimation tendency.

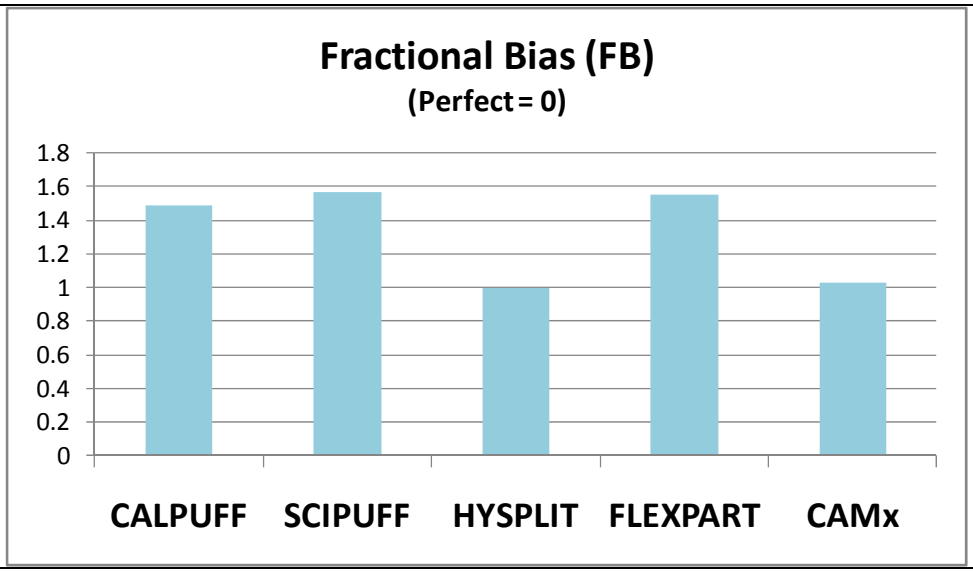


Figure 6-13. Fractional Bias(FB) statistical performance metric for the five LRT models and the ETEX tracer field experiment.

The Kolmogorov-Smirnoff (KS) parameter compares the frequency distributions of the predicted and observed tracer concentrations unmatched by time and location. It is the only unpaired statistical metric in the global statistics. The KS parameter ranges from 0% to 100% with a perfect model receiving a score of 0%. The KS parameters for the five LRT models and the ETEX modeling are shown in Figure 6-14.

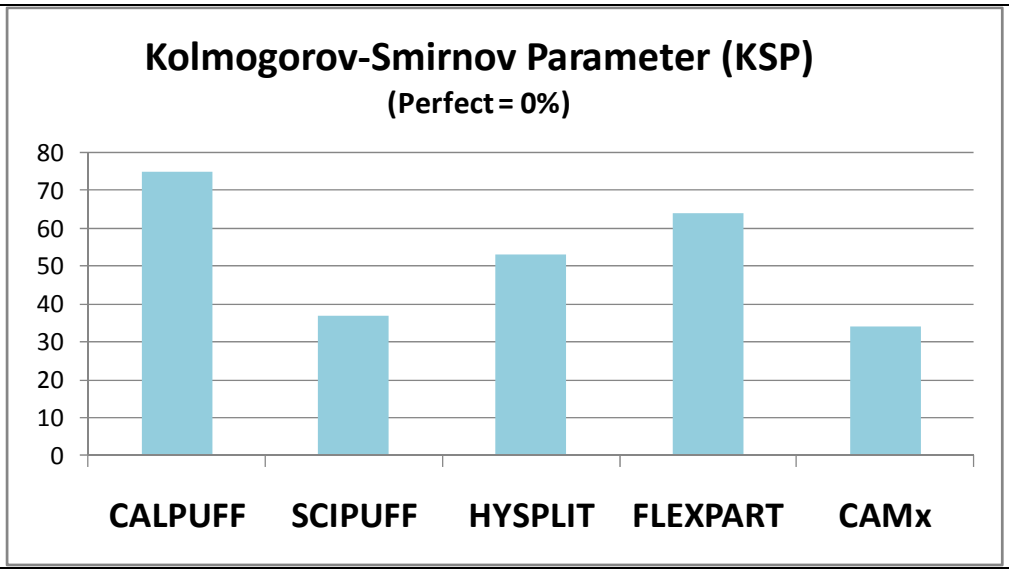


Figure 6-14. Kolmogorov – Smirnov Parameter (KSP) statistical performance metrics for the five LRT models and the ETEX tracer field experiment.

The RANK statistical performance metric was proposed by Draxler (2001) as a single model performance metric that equally ranks the combination of performance metrics for correlation (PCC or R), bias (FB), spatial analysis (FMS) and unpaired distribution comparisons (KS). The RANK metrics ranges from 0.0 to 4.0 with a perfect model receiving a score of 4.0. Figure 6-15 lists the RANK model performance statistics for the five LRT models. CAMx is the highest ranked model using the RANK metric with a value of 1.9. Note that CAMx scores high in all four areas of model performance (correlation, bias, spatial and cumulative distribution). The next highest ranking models according to the RANK metric are SCIPUFF and HYSPLIT with a score of 1.8.

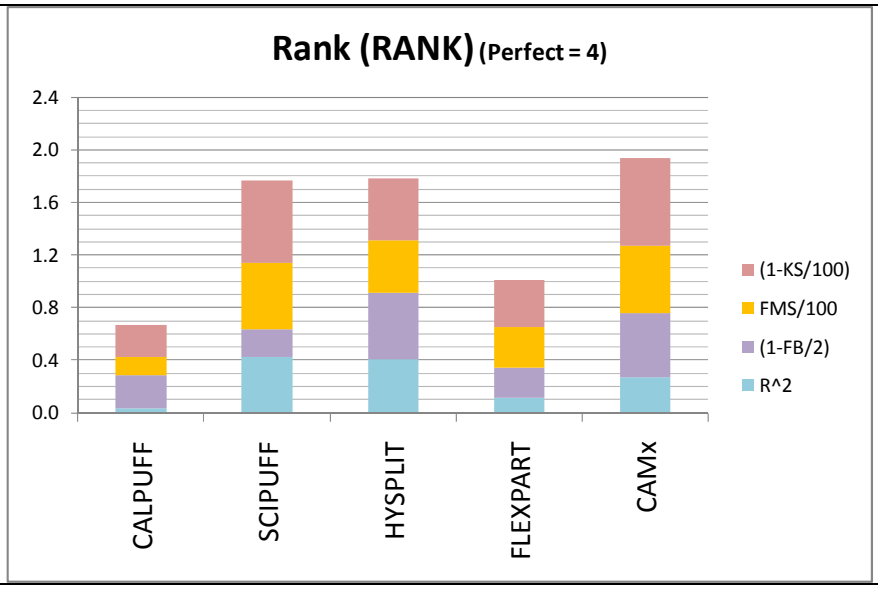


Figure 6-15. RANK statistical performance metric for the five LRT models and the ETEX tracer field experiment.

6.4.1.3 Summary of Model Ranking using Statistical Performance Measures

Table 6-1 summarizes the rankings between the five LRT models for the 11 performance statistics analyzed. Depending on the statistical metric, three different models were ranked first for a particular statistic with CAMx being ranked first most of the time (64%) and HYSPLIT ranked first second most (27%). In order to come up with an overall rank across all eleven statistics we average the modeled ranking order in order to come up with an average ranking that listed CAMx first, HYSPLIT second, SCIPUFF third, FLEXPART fourth and CALPUFF the fifth. This is the same ranking as produced by the RANK integrated statistics that combines the four statistics for correlation (PCC), bias (FB), spatial (FMS) and cumulative distribution (KS) giving credence that the RANK statistic is a potentially useful performance statistic for indicating over all model performance of a LRT dispersion model.

Table 6-1. Summary of model ranking using the statistical performance metrics.

Statistic	1st	2nd	3rd	4th	5th
FMS	CAMx	SCIPUFF	HYSPLIT	FLEXPART	CALPUFF
FAR	HYSPLIT	FLEXPART	CAMx	SCIPUFF	CALPUFF
POD	CAMx	SCIPUFF	HYSPLIT	FLEXPART	CALPUFF
TS	CAMx	HYSPLIT	SCIPUFF	FLEXPART	CALPUFF
FOEX	CAMx	SCIPUFF	HYSPLIT	FLEXPART	CALPUFF
FA2	CAMx	SCIPUFF	HYSPLIT	FLEXPART	CALPUFF
FA5	CAMx	SCIPUFF	HYSPLIT	FLEXPART	CALPUFF
NMSE	HYSPLIT	CAMx	CALPUFF	FLEXPART	SCIPUFF
PCC or R	SCIPUFF	HYSPLIT	CAMx	FLEXPART	CALPUFF
FB	HYSPLIT	CAMx	CALPUFF	FLEXPART	SCIPUFF
KS	CAMx	SCIPUFF	HYSPLIT	FLEXPART	CALPUFF
Avg. Ranking	CAMx	HYSPLIT	SCIPUFF	FLEXPART	CALPUFF
Avg. Score	1.55	2.27	2.73	3.82	4.64
RANK Ranking	CAMx	HYSPLIT	SCIPUFF	FLEXPART	CALPUFF

6.4.2 Spatial Displays of Model Performance

Figure 6-16 displays the observed tracer distribution 24, 36, 48 and 60 hours after the beginning of the tracer release as well as the predicted tracer distribution by CALPUFF, SCIPUFF, FLEXPART and CAMx. Note that the observed tracer spatial distribution plots in Figure 6-16 are color coded at the monitoring sites. Previously the spatial distribution of the observed tracer distribution was also presented using spatial interpolation from the monitoring sites in Figure 6-3b. However, such an interpolation is in itself a model and may not be correct, so in Figure 6-16 the observed tracer concentrations at the monitoring sites is presented for comparison with the five LRT models.

24 hours after the tracer release, the observed tracer was advected to the east-northeast and was present across northern France and Germany (Figure 6-16a, top left). CALPUFF advected the tracer with a more northeasterly direction than observed and underestimated the plume spread thereby missing the observed tracer concentrations in southern Germany (Figure 6-16a, top right). SCIPUFF (Figure 6-16a, middle left) also appeared to advect the tracer with more of a northeast direction than observed, but had more plume spread so was better able to capture the occurrence of observed tracer concentrations in southern Germany. FLEXPART (Figure 6-16a, middle right) and HYSPLIT (Figure 6-16a, bottom left) both correctly advect the tracer initially in the east-northeast direction, but FLEXPART greatly underestimates the observed plume spread on the ground with HYSPLIT also underestimating the plume spread but not as much as FLEXPART. CAMx also appears to initially transport the tracer with more of a northeasterly than east-northeast direction as seen with SCIPUFF. Like SCIPUFF, the CAMx tracer plume has a southerly bulge that begins to capture the occurrence of the observed tracer concentrations in southern Germany that the other three LRT dispersion models miss completely. All of the models fail to reproduce the leading edge of the observed tracer cloud in northeastern Germany, with SCIPUFF and CAMx best able to simulate the observed front of the tracer cloud. The LRT dispersion models underestimation of the location of the leading edge of the observed tracer cloud is likely related to the MM5 model wind speed underestimation bias (see Figure 6-4a). SCIPUFF tends to have an overestimation bias of both concentrations and spatial extend of the observed tracer 24 hours after its release.

The predicted and observed tracer distribution 36 hours after its release is shown in Figure 6-16b. The observed tracer plume moved eastward and traverses Germany 36 hours after the

start of the release and is stretched from the west coast of Sweden in the north to Hungary in the South. CALPUFF is displacing the tracer too far to the northeast with the centerline over the North Sea stretching from the northern tip of France to southern tip of Sweden and missing most of the observed tracer concentrations in France, Germany and Czechoslovakia. SCIPUFF covers the spatial extent of the observed tracer cloud, and then some, correctly estimating the coverage across Germany and Czechoslovakia. FLEXPART reproduces the easterly transport of the observed tracer clouds 36 hours after the start of the release, but greatly underestimates the ground level plume spread. HYSPLIT also reproduces the easterly transport of the observed tracer plume but also understates the plume spread missing the observed tracer concentrations in southern Germany and Czechoslovakia. CAMx has a similar distribution as SCIPUFF with less of an overestimation bias locating the tracer center of mass slightly too far north. After 36 hours from the start of the tracer release the leading edge of the observed tracer is just entering Poland from Germany, which is reproduced well by SCIPUFF, HYSPLIT and CAMx with FLEXPART having a lag and CALPUFF locating the leading edge of the tracer too far north.

By 48 hours after the beginning of the tracer release, the observed tracer cloud is exhibiting a northwest to southeast orientation stretching from Denmark in the northwest to Hungary in the southeast (Figure 6-16c). The CALPUFF tracer plume, however, is advected too far north into the North Sea and southern Finland with a circular Gaussian puff distribution. SCIPUFF correctly reproduces the northwest to southeast orientation of the observed tracer cloud and almost completely covers the observed tracer cloud but appears to overestimate the spatial extent and concentrations of the observed tracer. HYSPLIT and FLEXPART also are exhibiting a northwest to southeast orientation of the observed tracer cloud but both models, and especially FLEXPART, understate the spatial spread of the observed ground level tracer concentrations. CAMx reproduces the northwest to southeast orientation of the observed tracer distribution and appears to better match the observed tracer plume spread than SCIPUFF (overstated) and FLEXPART and HYSPLIT (understated).

After 60 hours after the beginning of the tracer release, the observed tracer cloud still has the northwest to southeast orientation that stretches from southern Finland in the northwest to the most western point of Romania. The CALPUFF model has advected its circular puffs to the north with the center over the North Sea just west of southern Finland almost completely missing the spatial extent of the observed tracer. The other four LRT dispersion models are correctly estimating the northwest to southeast orientation of the observed tracer pattern 60 hours after the beginning of the tracer release. However, the remaining four LRT models (less CALPUFF) estimate different amounts of plume spread with FLEXPART estimating a very narrow predicted tracer cloud that understates the observed spread of the tracer footprint. SCIPUFF estimated the largest spatial extent of the tracer cloud that is much larger than observed. HYSPLIT and CAMx estimated tracer spread that is closer to what was observed.

The comparison of the spatial distribution of the predicted and observed tracer concentrations from the ETEX1 experiment helps explain the statistical model performance presented earlier. The poor performance of the CALPUFF model is because it keeps the tracer in a circular Gaussian plume distribution that is advected too far north and fails to reproduce the elongation and stretching of the observed tracer cloud in the northwest to southeast orientation. The other four LRT dispersion models do allow the predicted tracer cloud to take on the northwest to southeast distribution matching the basic features of the observed tracer footprint well, but with different amounts of plume spread. FLEXPART greatly understates the amount of tracer

plume spread and observed surface concentrations, whereas SCIPUFF overstates the amount of plume spread as well as the surface concentrations.

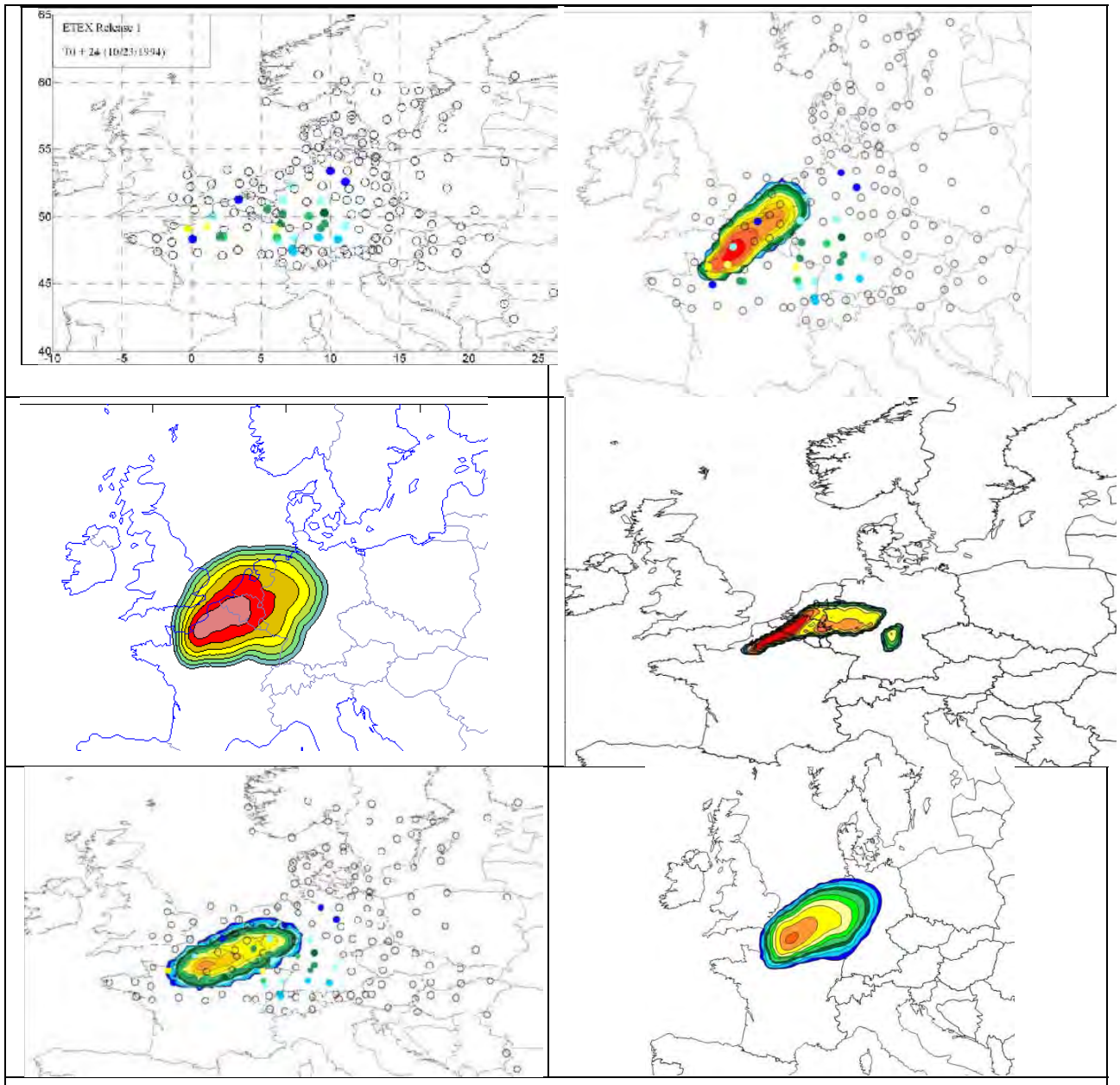


Figure 6-16a. Comparison of spatial distribution of the ETEX tracer concentrations 24 hours after release for the observed (top left), CALPUFF (top right), SCIPUFF (middle left), FLEXPART (middle right), HYSPLIT (bottom left) and CAMx (bottom right).

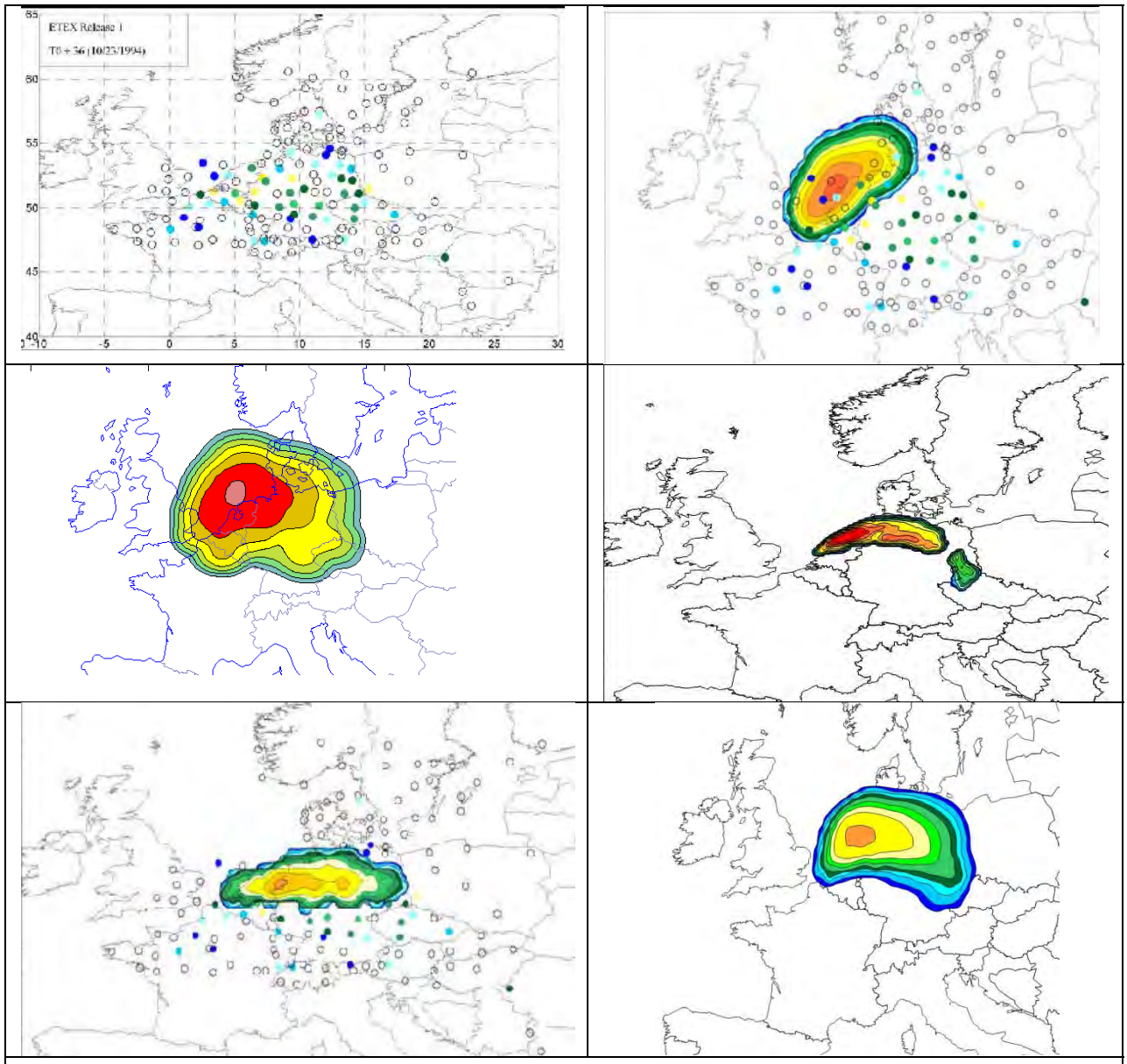


Figure 6-16b. Comparison of spatial distribution of the ETEX tracer concentrations 36 hours after release for the observed (top left), CALPUFF (top right), SCIPUFF (middle left), FLEXPART (middle right), HYSPLIT (bottom left) and CAMx (bottom right).

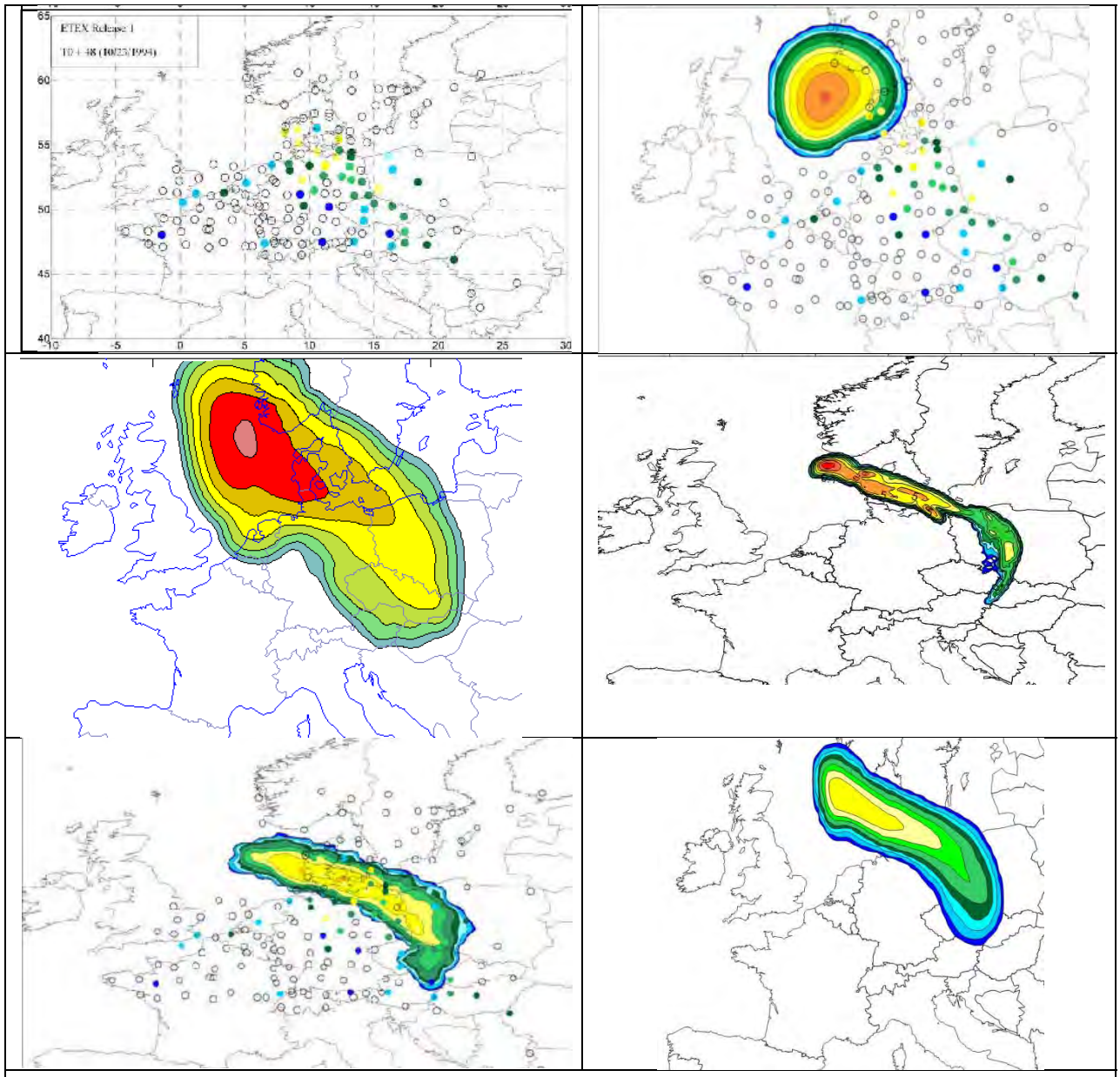


Figure 6-16c. Comparison of spatial distribution of the ETEX tracer concentrations 48 hours after release for the observed (top left), CALPUFF (top right), SCIPUFF (middle left), FLEXPART (middle right), HYSPLIT (bottom left) and CAMx (bottom right).

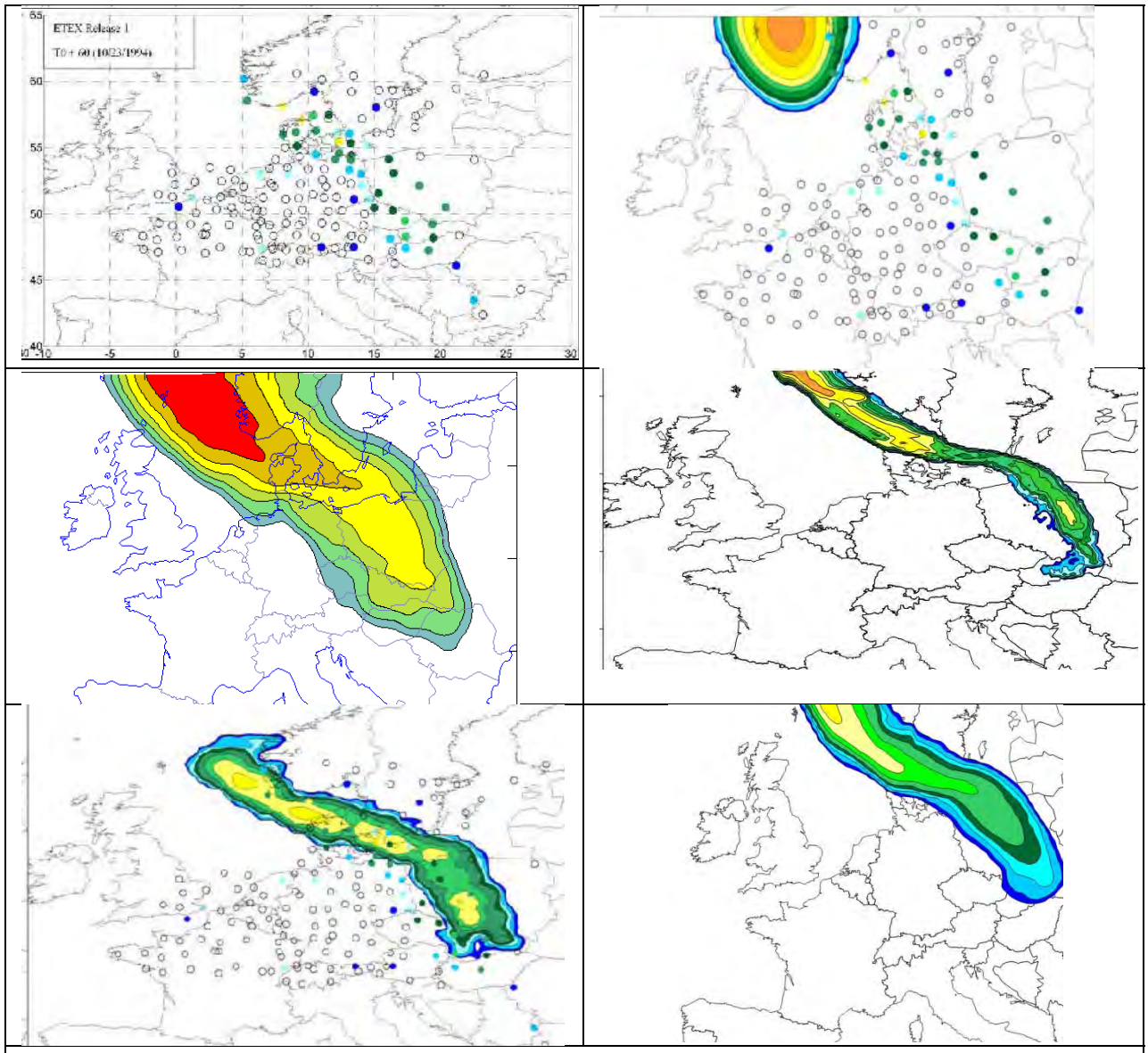


Figure 6-16d. Comparison of spatial distribution of the ETEX tracer concentrations 60 hours after release for the observed (top left), CALPUFF (top right), SCIPUFF (middle left), FLEXPART (middle right), HYSPLIT (bottom left) and CAMx (bottom right).

6.4.3 CAMx Sensitivity Tests

Sixteen CAMx sensitivity tests were conducted to investigate the effects of vertical diffusion, horizontal advection solvers and use of the sub-grid scale Plume-in-Grid (PiG) module on the model performance for the ETEX tracer experiment.

Plume-in-Grid (PiG) Module: The PiG module treats the near-source plume dispersion (and chemistry if applicable) of a point source plume using a subgrid-scale Lagrangian puff module. The mass from the PiG puff module is transferred to the grid model when the plume size is commensurate with the grid cell size used in the CAMx simulation. Two types of PiG sensitivity tests were conducted in this study to investigate the effects of the PiG module on model performance:

- NoPiG: The tracer emissions were released directly into the CAMx 36 km grid cell containing the tracer release location calculating plume rise using the local meteorological conditions to inject the emissions into the appropriate vertical layer.
- PiG: Calculate plume rise using local meteorological conditions and simulate the early evolution of plume dispersion using the PiG module.

Vertical Diffusion Coefficients (Kz): The Kz coefficients define the rate of vertical mixing in a column of grid cells in CAMx. MM5 meteorological model does not directly output Kz, thus the MM5CAMx pre-processor has several different algorithms for diagnosing the Kz coefficients. Four different Kz algorithms were evaluated in the CAMx sensitivity tests in this study:

- OB70: O'Brien 1970 algorithm for calculation Kz values by diagnosing them from the MM5 output.
- TKE: The Eta planetary boundary layer (PBL) scheme used in the ETEX MM5 meteorological modeling has a Turbulent Kinetic Energy (TKE) formulation. When using a TKE PBL scheme, MM5CAMx can calculate the Kz coefficients directly from the TKE values, rather than diagnosing them from the other meteorological variables in the MM5 output.
- ACM2: The Asymmetric Convective Mixing (ACM2) algorithm has two components: a standard Kz scheme that calculates diffusion between two adjacent grid cells in a column; and a non-local diffusion scheme that can calculate diffusion between grid cells in a column that are not adjacent. In CAMx, the ACM2 scheme will deduce when convective activity is present in a column of grid cells and add the non-local diffusion to the standard local diffusion based on the Kz coefficients.
- CMAQ: Use the algorithm for calculating Kz from the CMAQ modeling system (Byun and Ching, 1999).

Horizontal Advection Solver: Horizontal advection (transport) is solved in CAMx using finite difference algorithms that were explicitly developed for simulating transport and limit numerical diffusion that can artificially reduce concentration peaks. Two horizontal transport algorithms are implemented in CAMx and their effect on model performance for the ETEX experiment was evaluated:

Bott: The Bott (1989) scheme is a positive definite transport scheme that limits numerical diffusion.

PPM: The Piecewise Parabolic Method (PPM; Colella and Woodward, 1984) is a higher order positive definite transport scheme that is also designed to limit numerical diffusion.

The configuration of CAMx presented in the previous sections comparing model performance against the other four LRT models was a standard configuration used in many regional model applications:

- Don't use PiG subgrid-scale puff module (NoPiG)
- Use of CMAQ-like Kz vertical diffusion coefficients (CMAQ)
- Use of PPM horizontal advection solver (PPM)

6.4.3.1 NoPiG CAMx Sensitivity Tests

Figure 6-17 displays the CAMx spatial model performance statistics for the sensitivity tests that were run without using the PiG subgrid-scale puff module. For the FMS statistic, the CMAQ Kz and PPM horizontal transport sensitivity test (CMAQ/PPM) is performing the best with a FMS value of 51.8% followed by CMAQ/Bott (50.9%) and ACM2/PPM (50.8%). Vertical diffusion has

the biggest effect with the ranking of the algorithms from best to worst using the FMS statistic being CMAQ, ACM2, TKE and OB70. Whereas, for the horizontal advection solver the PPM algorithm performs slightly better than Bott using the FMS statistic.

For the FAR statistic, CMAQ/Bott has the best score (39.0%) followed by CMAQ/PPM (41.0%). Overall CMAQ is the best performing vertical diffusion formulation and Bott performs better than PPM for horizontal advection using the FAR statistic.

For the POD and TS spatial statistics, the CMAQ and TKE vertical diffusion algorithms perform substantially better than the OB70 and ACM2 approaches. There are much smaller differences in the model performance using the two advection solvers for the POD and TS statistics.

In summary, based on the spatial statistics, the CMAQ Kz algorithm appears to be the best performing approach for vertical mixing followed by TKE. And with the exception of the FAR statistic, PPM produces slightly better spatial model performance statistics than the Bott horizontal advection solver. The differences in vertical diffusion algorithms has a greater effect on CAMx model performance than the differences in horizontal advection solvers.

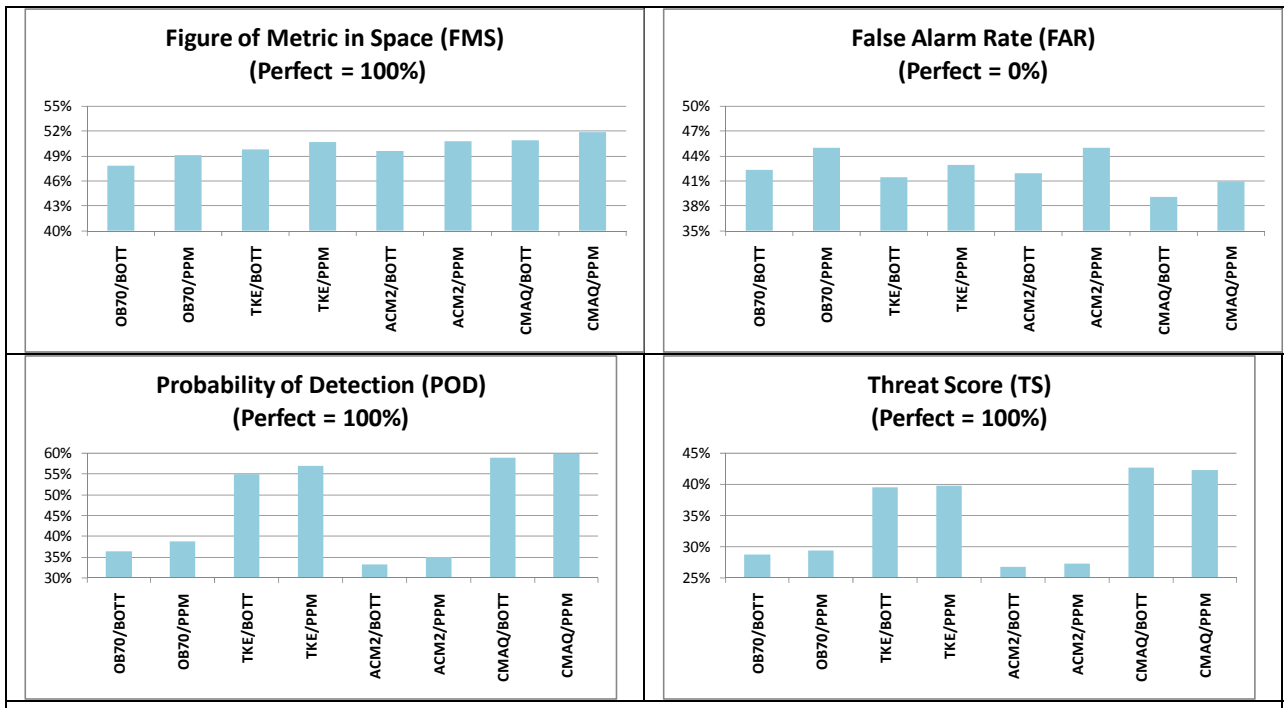


Figure 6-17. Spatial model performance statistics for the CAMx sensitivity tests without using the PiG subgrid-scale puff module (NoPiG).

Figure 6-18 displays the global statistics for the CAMx NoPiG sensitivity tests with Figures 6-18a and 6-18b containing the statistical metrics where the best performing model has the, respectively, lowest and highest score. For the FOEX metric, the vertical diffusion algorithm has the biggest effect with the ACM2 scoring the best with an essentially zero FOEX score followed by OB70 with values -2.4% (OB70/Bott) and -3.4% (OB70/PPM). The TKE (8.5%) and PPM (8.7% and 9.1%) have the highest (worst) FOEX scores. The FOEX metrics using the two alternative horizontal advection algorithms are essentially the same.

Using the NMSE statistical performance metric, the CMAQ vertical diffusion scheme performs best with OB70 and TKE producing very similar results next, with the ACM2 exhibiting the worst NMSE performance results (Figure 6-18a, top right). The PPM horizontal advection scheme is performing slightly better than the Bott algorithm based on the NMSE metric.

The CMAQ vertical diffusion scheme is also the best performing method according to the FB metrics followed by the TKE then ACM2 and then OB70 in last. According to the FB metrics, PPM performs slightly better than Bott.

For the KS parameter, the OB70 is the best vertical mixing method with CMAQ barely beating out ACM2 in second and TKE slightly worse. The PPM horizontal advection solver is performing slightly better than Bott for the KS parameter.

For the within a factor of 2 and 5 metrics (FA2 and FA5, Figure 6-18b, top), the CMAQ and TKE vertical mixing approaches are clearly performing better than the OB70 and ACM2 methods and the PPM horizontal advection solver is clearly performing better than Bott. For the FA2, the TKE/PPM is the best performing configuration (11.4%) followed by CMAQ/PPM (10.9%), Whereas for the FA5 the reverse is true with CMAQ/PPM being the best performing configuration (23.4%) followed by TKE/PPM (22.2%).

There is essentially no difference in the PCC statistic using the two horizontal advection solvers (Figure 6-18b, bottom right). According to the PCC metric, CMAQ is the best performing vertical diffusion approach (0.52) followed by TKE (0.37 and 0.38), OB70 (0.35) and ACM2 (0.26 and 0.27).

The final panel in Figure 6-18b (bottom right) displays the overall RANK statistic. The RANK statistics orders the model performance of the CAMx configurations without PiG as follows:

1. CMAQ/PPM (1.94)
2. CMAQ/Bott (1.90)
3. TKE/PPM (1.70)
4. OB70/PPM (1.66)
5. TKE/Bott (1.65)
6. ACM2/PPM (1.60) (tied)
7. OB70/Bott (1.60) (tied)
8. ACM2/Bott (1.54)

Based on this analysis the CMAQ Kz coefficients is the best performing vertical diffusion approach followed by TKE and the PPM horizontal advection algorithm is performing slightly better than Bott. The vertical diffusion algorithm has a greater effect on CAMx model performance compared to the choice of horizontal advection solvers.

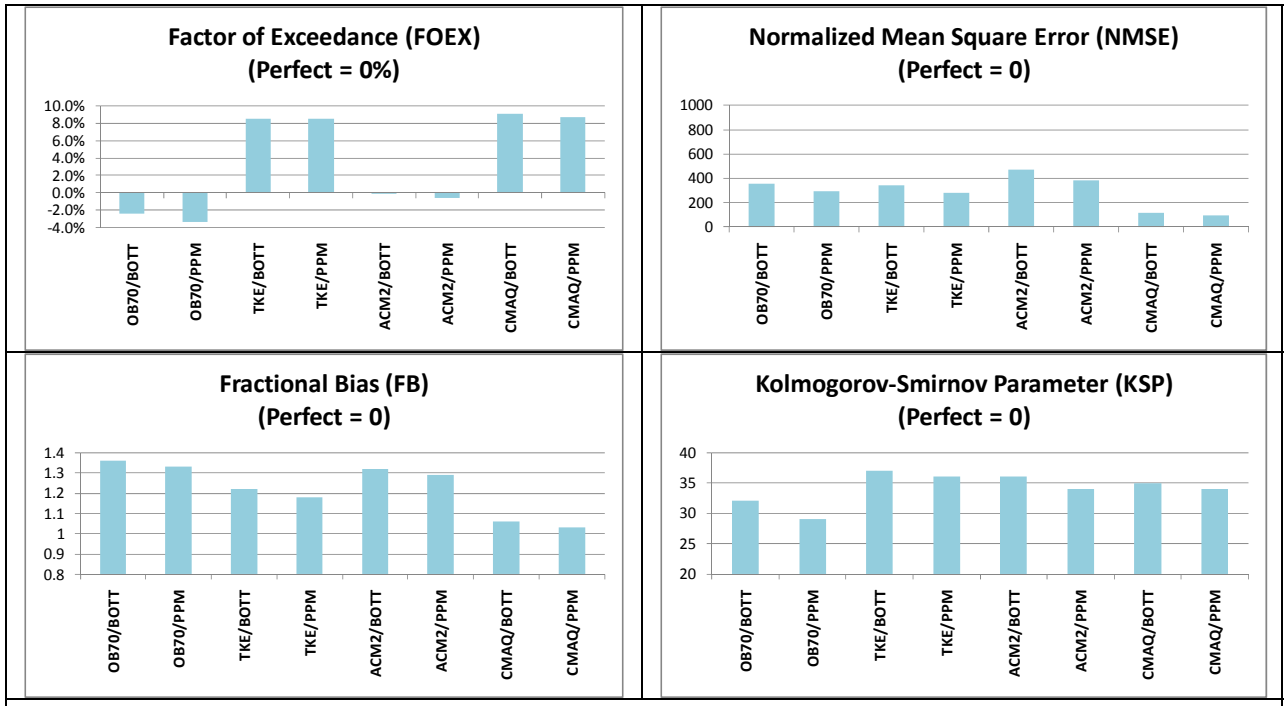


Figure 6-18a. Global model performance statistics for the CAMx sensitivity tests without using the PiG subgrid-scale puff module.

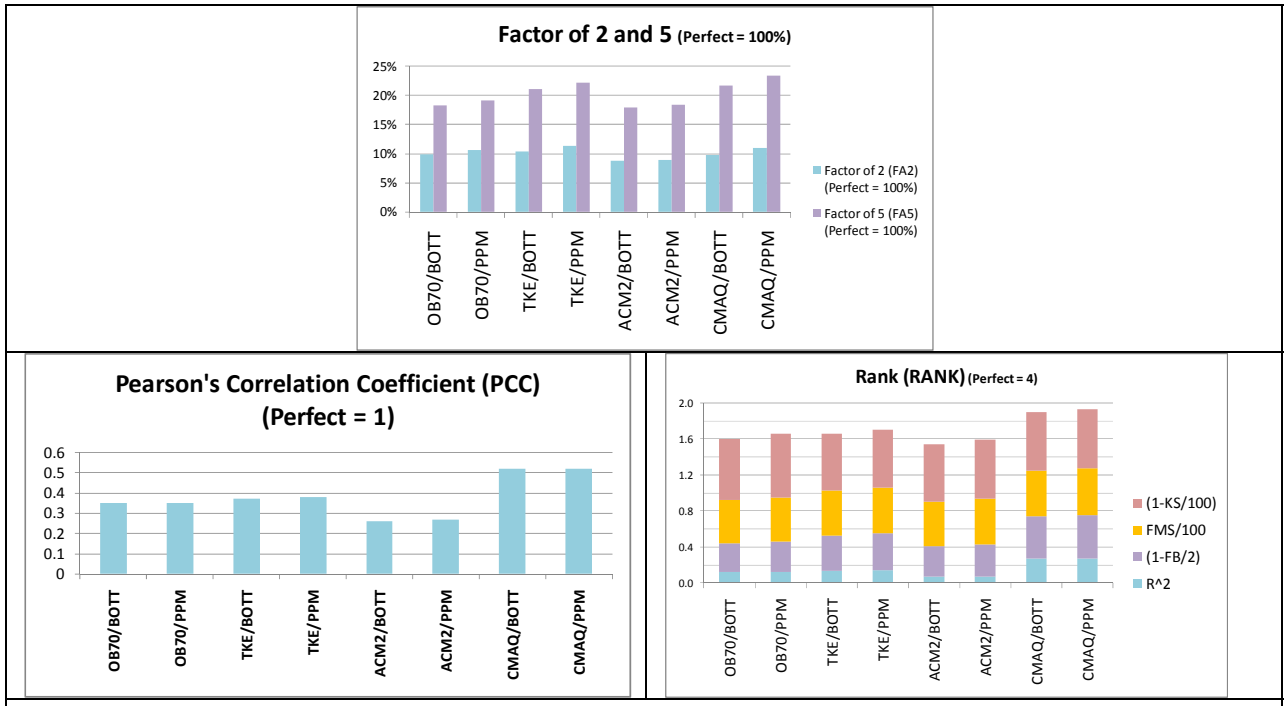


Figure 6-18b. Global model performance statistics for the CAMx sensitivity tests without using the PiG subgrid-scale puff module.

6.4.3.2 Effect of PiG on Model Performance

Whether better model performance is obtained using the PiG module or not frequently depends on the statistical metric being analyzed and the CAMx model configuration (vertical diffusion algorithm and horizontal advection solver). However, whether the PiG is used or not has very little difference on the rankings of the CAMx model performance using the alternative vertical mixing and horizontal advection approaches. In general, it appears that the CAMx model performance without the PiG is performing slightly better than its performance using the PiG.

The spatial performance statistics are sometimes improved and sometimes degraded when the PiG module is invoked. For the global statistics, the PCC performance statistic is degraded by -11% to -37% (-0.03 to -0.13 points) when the PiG module is invoked. Similarly, use of the PiG versus NoPiG module increases (degrades) the FB metric by 5 to 18 percent and also increases (degrades) the NMSE metrics for all model configurations.

Table 6-2 summarized the RANK model performance statistic for the different CAMx model configurations with and without the PiG module. For each model vertical diffusion/horizontal advection configuration, using the PiG module always results in slightly lower RANK statistics that are from -3.9% to -8.5% lower than when the PiG module is not used. The ranking of the top four CAMx vertical diffusion/horizontal advection configurations remains unchanged whether the PiG module is used or not. And by far the most important parameter examined in regards to the RANK model performance statistics for the ETEX experiment in the CAMx sensitivity tests is the vertical mixing algorithm, with the CMAQ Kz parameterization producing the best four RANK model performance statistics out of the 16 sensitivity tests: (1) NoPiG/CMAQ/PPM; (2) NoPiG/CMAQ/Bott; (3) PiG/CMAQ/PPM; and (4) PiG/CMAQ/Bott.

Table 6-2. CAMx RANK model performance statistic and model rankings for different model configurations with and without using the PiG subgrid-scale puff model.

Model Configuration	Without PiG Module		With PiG Module		PiG-NoPiG	
	RANK	Model Ranking	RANK	Model Ranking	ΔRANK	Percent
OB70/BOTT	1.60	7[a]	1.53	6[a]	-0.07	-4.4%
OB70/PPM	1.66	4	1.55	4	-0.11	-6.6%
TKE/BOTT	1.65	5	1.51	7	-0.14	-8.5%
TKE/PPM	1.70	3	1.56	3	-0.14	-8.2%
ACM2/BOTT	1.54	8	1.48	8	-0.06	-3.9%
ACM2/PPM	1.60	6[a]	1.53	5[a]	-0.07	-4.4%
CMAQ/BOTT	1.90	2	1.76	2	-0.14	-7.4%
CMAQ/PPM	1.94	1	1.80	1	-0.14	-7.2%

[a] tied

6.4.4 CALPUFF Sensitivity Tests

Most CALPUFF applications have limited the distance downwind that the model is applied for to less than 300 km from the source. However, the evaluation of CALPUFF in the ETEX study has applied the model to much farther downwind distances. The issue of the downwind applicability of the CALPUFF model was raised in the FLAG (2000) report and EPA's June 26-27, 2000 7th Conference on Air Quality Modeling[19] that proposed to list CALPUFF as an EPA recommended model for far-field applications. However, when CALPUFF was designated an EPA recommended far-field model in a 2003 Federal Register (FR) notice, EPA noted that "*…since the 7th Modeling Conference, enhancements were made to CALPUFF that allow puffs to be split both horizontally (to address wind direction shear) and vertically (to address spatial variation in meteorological conditions). These enhancements likely will extend the system's ability to treat transport and dispersion beyond 300 km*" (68 FR 18441). EPA goes on to further state that "*…Future performance comparisons for transport beyond 300 km are likely to extend the applicability and use of the modeling system, and we intend to watch for such evaluations very diligently. In an effort to keep the public abreast with the latest findings, EPA requests that evaluation results of the CALPUFF modeling system be sent to us (SCRAM webmaster) in an electronic format suitable for distribution, or that citations be provided for copyrighted material. EPA will post this information on its website for review and assessment*" (EPA, 2003).

Despite the passage of eight years since EPA's request for CALPUFF evaluation regarding its suitability for application beyond 300 km, no such documentation has been submitted. Thus, the ETEX CALPUFF evaluation serves as an important source of information on the downwind applicability of CALPUFF. In this section we present two types of performance analysis:

- Analyze the CALPUFF model performance as a function of distance from the source to determine whether the poor performance of CALPUFF relative to the other LRT models is related to applying the model beyond its downwind distance of applicability; and
- Perform CALPUFF puff splitting sensitivity tests to determine whether puff splitting can increase the downwind distance applicability of CALPUFF, as suggested in the 2003 Federal Register notice.

6.4.4.1 Time Dependent Model Performance

Figure 6-19 displays the FMS model performance statistic for the five LRT models as a function of time from the beginning of the tracer release in the ETEX experiment. Although the CALPUFF model performance does degrade with time (distance), even close to the source it is performing worse than the other LRT models. This was also seen in the spatial maps of the model performance presented previous in Figure 6-16 where the CALPUFF model had spatial alignment problems compared with the observed tracer 24 hours after the tracer was released. Thus, CALPUFF does not perform comparably to the other evaluated LRT models even within 300 km of the source.

19 http://www.epa.gov/ttn/scram/7thmodconf.htm

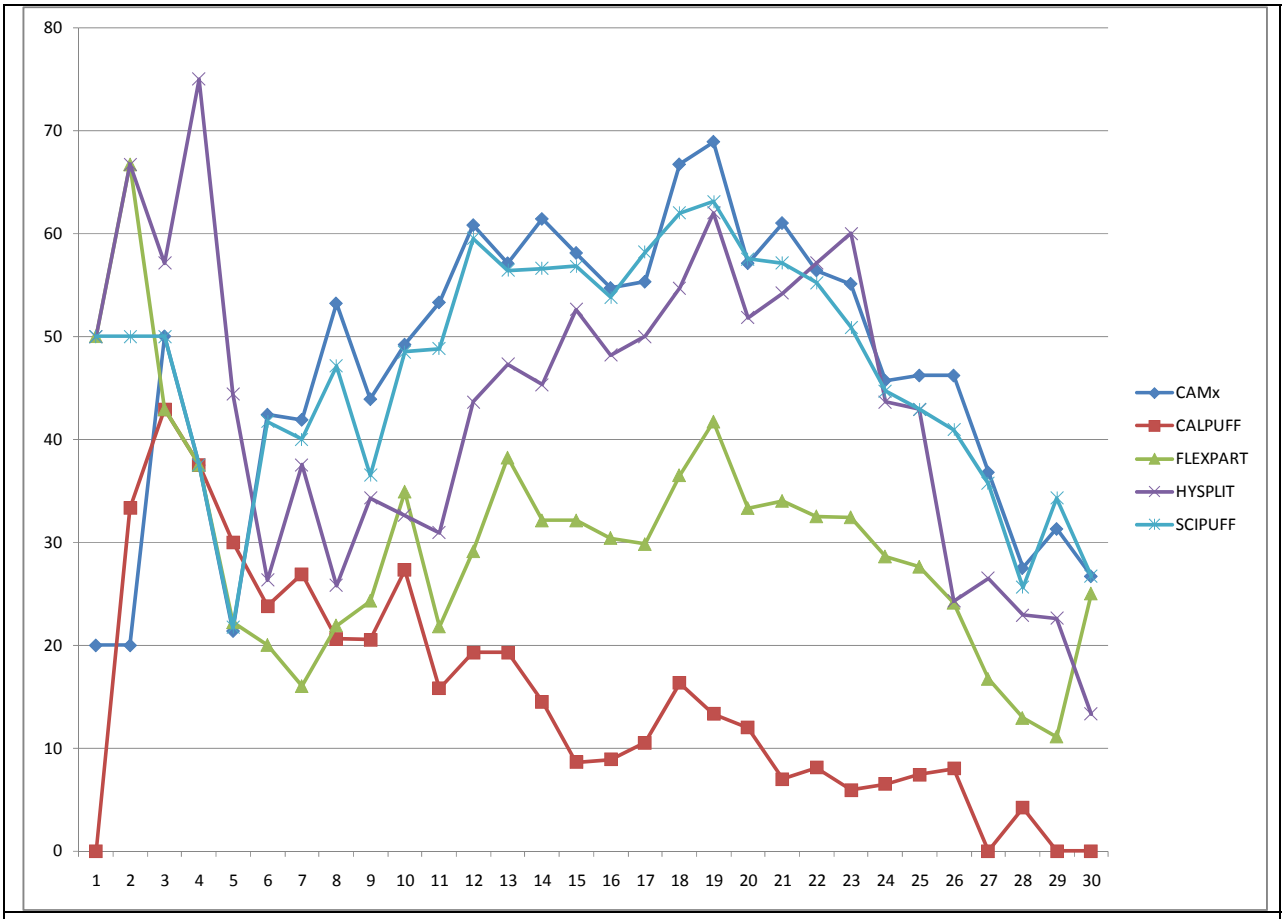


Figure 6-19. Figure of Merit (FMS) spatial model performance statistics as a function of time since the beginning of the tracer release.

6.4.4.2 CALPUFF Puff Splitting Sensitivity Tests

The CALPUFF puff splitting algorithm is controlled by several model options that are defined in the CALPUFF control input file. Two types of puff splitting may be invoked in CALPUFF: (1) vertical puff splitting when vertical wind shear is present across vertical layers in a well-mixed puff; and (2) horizontal puff splitting when there is sufficient horizontal wind shear across the horizontal extent of the puff.

The MSPLIT control option turns on puff splitting when set to 1, when MSPLIT is 0 no vertical or horizontal puff splitting is allowed to occur.

Four criteria must occur in order for vertical puff splitting to occur in CALPUFF:

1. The puff must be in contact with the ground.
2. The puff splitting flag must be turned on (i.e., IRESPLIT = 1).
3. The previous hours mixing height must be above a certain height (mixing height > ZISPLIT).
4. The ratio of the last hours mixing height to the maximum mixing height encountered by the puff is less than a maximum value (current mixing height/maximum mixing height > ROLDMAX).

The puff splitting flag (item 2) is turned on using the IRESPLIT input option. IRESPLIT consists of 24 values corresponding to the hour of the day with values that are either 0 or 1, where 1 turns on the puff splitting flag for puffs. Once the puff splitting flag is turned on, it remains on until the puff splitting occurs at which point the puff splitting flagged is turned off until it is turned back on again by IRESPLIT. The default setting for IRESPLIT is to have all hours zero except for setting hour 17 to 1. The reasoning behind this is to invoke puff splitting in the evening when a nocturnal inversion occurs and there is a decoupling of the winds between the nocturnal inversion layer and above the nocturnal inversion (i.e., the residual "mixed layer"). Setting IRESPLIT to all zeros will result in the puffs never performing vertical puff splitting and setting IRESPLIT to all ones will result in the puff splitting flag always turned on and puffs will always split when the other three criteria for vertical puff splitting are met.

The default value for the previous hours minimum mixing height value (item 3) is ZISPLIT = 100 m. This minimum value is used to assure that the current mixing height is not negligible.

The ratio of the previous hours mixing height to maximum mixing height encountered by the puff (item 4) is controlled by the ROLDMAX parameter with a default value of 0.25.

When vertical puff splitting occurs in CALPUFF, the number of puffs that the puff is split into is controlled by the NSPLIT parameter that has a default value of 3.

Horizontal puff splitting occurs when the puff concentrations are above a minimum value (CNSPLITH), the puff has a minimum width that is defined by its sigma-y in grid cell units (SYSPLITH) and the minim puff elongation rate (SYSPLITH per hour) is above a SHSPLITH factor. The default minimum concentration is CNSPLITH = 10^{-7} g/m^3 (0.1 µg/m^3). Default SYSPLITH value is 1.0 and default SHSPLITH factor is 2.0. When horizontal puff splitting occurs in CALPUFF the number of puffs the puff is split into is controlled by the NSPLITH parameter that has a default of 5.

Eight CALPUFF puff splitting sensitivity tests were conducted, which are defined in Table 6-3. When vertical and horizontal puff splitting occurs in CALPUFF, the default number of puffs to split into was used in the CALPUFF sensitivity tests (i.e., NSPLIT = 3 and NSPLITH = 5). The NOSPLIT sensitivity test set MSPLIT = 0 so no vertical or horizontal puff splitting was allowed to occur. The DEFAULT puff splitting turned on puff splitting (MSPLIT = 1) but only turned on the vertical puff splitting flag at hour 17 every day. Whereas, the ALLHRS sensitivity test made sure that the vertical puff splitting flag was turned on all the time (i.e., IRESPLIT = 24*1) removing criteria 2 from the vertical puff splitting requirement. The ZISPLIT sensitivity test set ZISPLIT to zero thereby removing criteria 3 in the vertical puff splitting, as well as requirement 2 (like ALLHRS). ROLD relaxed the minimum ratio of the previous hours to maximum mixing height for vertical puff splitting from 0.25 to 0.50. The SYS sensitivity test allows horizontal puff splitting to occur more frequently by allowing puff splitting to occur with a puff sigma-y value is greater than SYSPLITH values of 0.1 (2.6 km) versus the default 1.0 (36 km) value. The last sensitivity test combines the ROLD and SYS sensitivity tests.

Table 6-3. Summary of CALPUFF puff splitting sensitivity tests performed using the ETEX database.

Sensitivity Test	MSPLIT	NSPLIT	IRESPLT	ZISPLIT	ROLDMAX	NSPLITH	SYSPLITH	CNSPLITH
NOSPLIT	0	NA	NA	NA	NA	NA	NA	NA
DEFAULT	1	3	Hr 17=1	100	0.25	5	1.0	10^{-7}
ALLHRS	1	3	24*1	100	0.25	5	1.0	10^{-7}
CNSMIN	1	3	24*1	100	0.25	5	1.0	10^{-20}
ZISPLIT	1	3	24*1	0	0.25	5	1.0	10^{-20}
ROLD	1	3	24*1	0	0.50	5	1.0	10^{-20}
SYS	1	3	24*1	0	0.25	5	0.1	10^{-20}
SYSROLD	1	3	24*1	0	0.50	5	0.1	10^{-20}

Figure 6-20 displays the spatial model performance statistics for the CALPUFF puff splitting sensitivity tests. The DEFAULT, ALLHRS and CNSMIN CALPUFF sensitivity tests obtained the exactly same model performance statistics indicating that CALPUFF model performance was not affected by the IRESPLT and CNSMIN puff splitting parameters. There are some small difference in the spatial model performance statistics for the other CALPUFF puff splitting sensitivity tests with the ROLD parameter having the biggest effect when changed from 0.25 to 0.50 that improved model performance a couple of percentage points for the FMS, POD and TS spatial statistics but degraded the FAR spatial statistic by several percentage points.

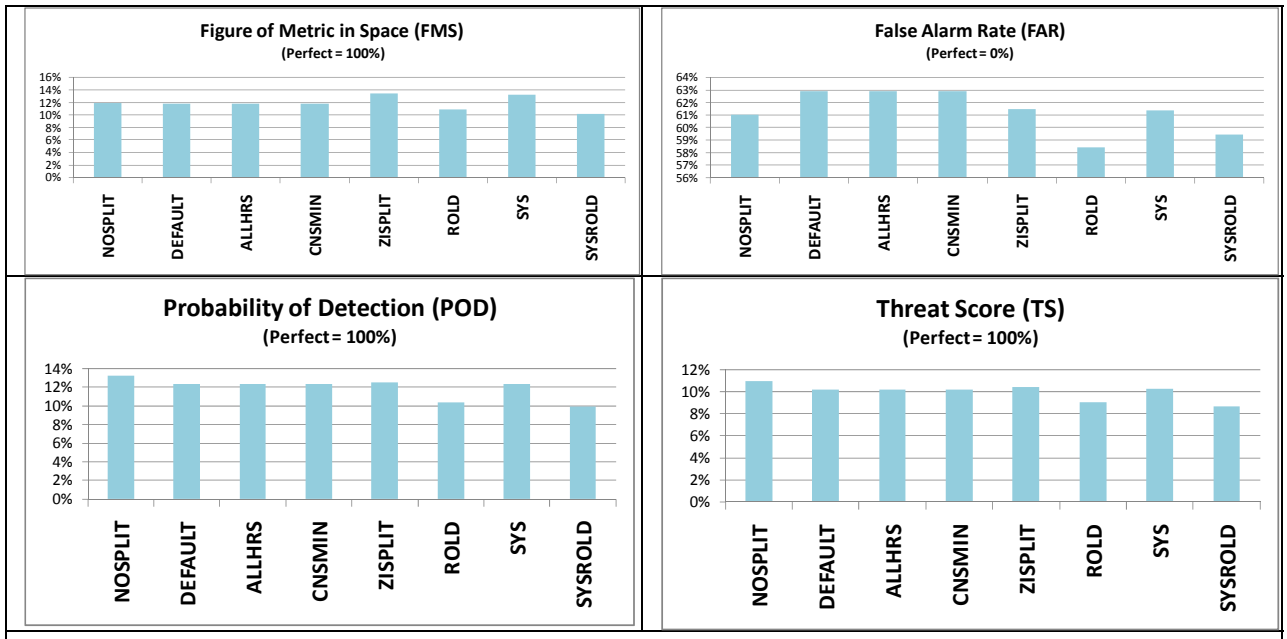


Figure 6-20. Spatial model performance statistics for the CALPUFF puff splitting sensitivity tests.

The global model statistics for the CALPUFF puff splitting sensitivity tests are shown in Figure 6-20, with Figures 6-21a and 6-21b displays statistics where the best performing model configuration has the lowest and highest score, respectively. The puff splitting sensitivity tests have a very small effect on the CALPUFF model performance. Again, the biggest effect on CALPUFF performance of all the puff splitting parameters comes from changing ROLD from 0.25 to 0.50, which appears to slightly degrade most CALPUFF model performance metrics with the exception of bias and error that are improved. Again, in terms of the CALPUFF global model performance versus other four LRT dispersion models (Figures 6-9 through 6-15), the CALPUFF puff splitting sensitivity tests are exhibiting by far the worst model performance. For example, the RANK model performance statistic varies from 0.6 to 0.7 across the CALPUFF puff splitting sensitivity tests as compared to much higher values for CAMx (1.9), SCIPUFF (1.8), HYPLIT (1.8) and FLEXPART (1.0).

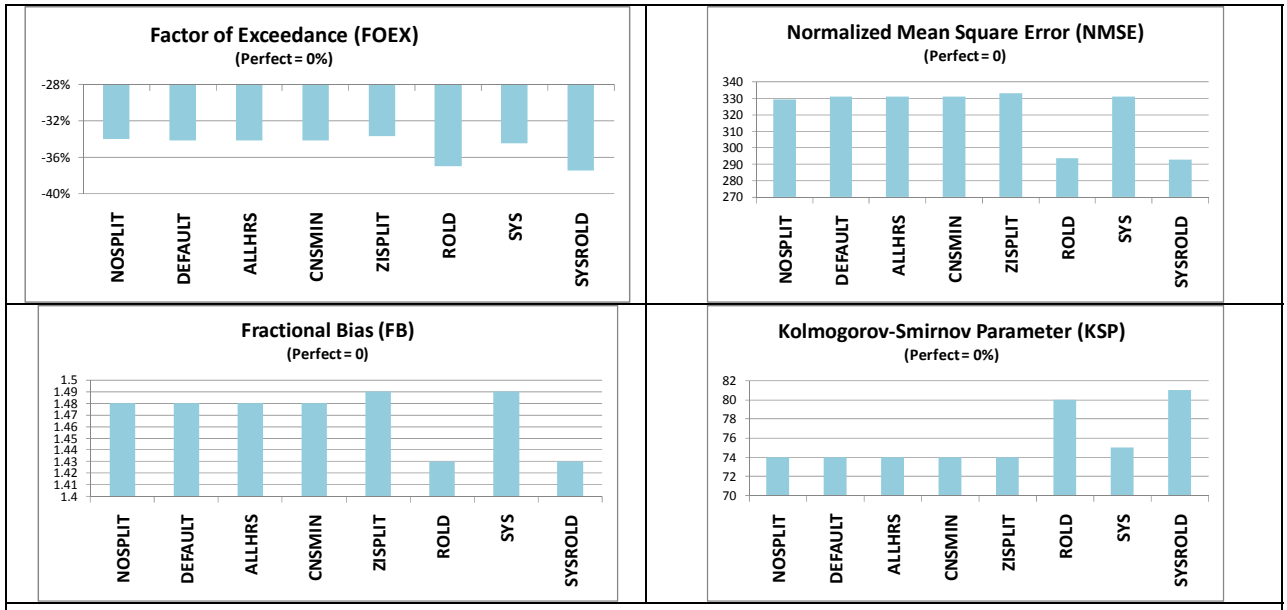


Figure 6-21a. Global model performance statistics for the CALPUFF puff splitting sensitivity tests.

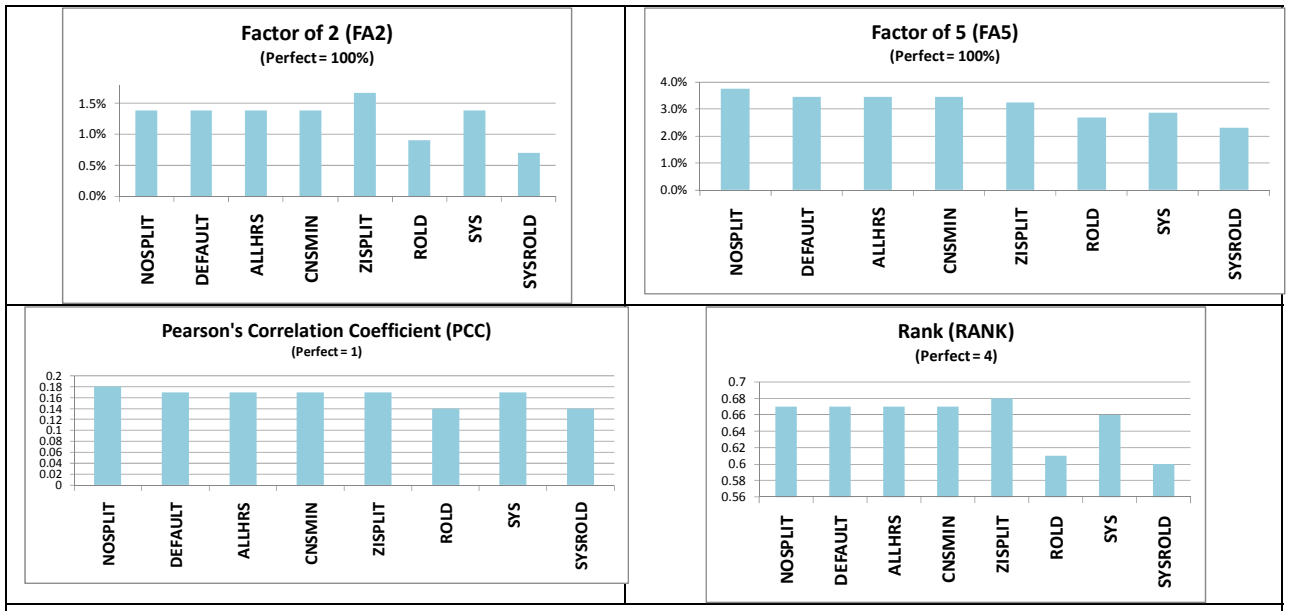


Figure 6-21b. Global model performance statistics for the CALPUFF puff splitting sensitivity tests.

In conclusion, the CALPUFF puff splitting sensitivity tests did not have any significant effect on CALPUFF model performance. Whether puff splitting was used or not produced essentially identical model performance for the ETEX experiment and certainly did not improve the CALPUFF model performance.

6.4.5 HYSPLIT Sensitivity Tests

HYSPLIT is unique among the models analyzed in this project in that its configuration is highly flexible, allowing for treatment of atmospheric dispersion purely as a Lagrangian particle model (default configuration), puff-particle hybrid model, or purely as a puff model. Nine sensitivity analyses were conducted against the ETEX database to provide information about the various configurations of HYSPLIT, but more importantly to provide additional information regarding the two distinct classes (puff and particle) of Lagrangian models evaluated as part of this project. Model configuration (puff, particle, puff-particle hybrid) are governed through the HYSPLIT parameter INITD. A description of the INITD variable options is provided in Table 6-4.

Model configuration options for the nine sensitivity runs are detailed in Table 6-5. In general, model control options were held to default values with two notable exceptions, the INITD and NUMPAR variables. HYSPLIT performance is highly sensitive to the number of particles released in the simulation. The HYSPLIT parameter NUMPAR controls the number of particles released over the duration of the emissions release. The default value for NUMPAR is set to 2500, but the user must take caution to insure that a sufficient number of particles are released to provide a "smooth temporal change" in concentration fields (NOAA, 2009). The original NOAA configuration for HYSPLIT was for INITD = 104 that is a particle/puff hybrid configuration (3D part – THh-Pv) with NUMPAR set to 1500. Original sensitivity runs found that the concentration fields were spotty; therefore, NUMPAR was set to 10000 to provide for smoother temporal evolution of the concentration fields.

Table 6-4. HYSPLIT INITD options and descriptions.

INITD Value	Description
0 (Default)	3D Particle Horizontal and Vertical
1	Gaussian horizontal and top-hat vertical puff (Gh-THv)
2	Top-hat horizontal and vertical puff (THh-THv)
3	Gaussian horizontal puff and vertical particle distribution (Gh-Pv)
4	Top-hat horizontal puff and vertical particle distribution (THh-Pv)
103	3D particle (#0) converts to Gh-Pv (#3)
104	3D particle (#0) converts to THh-Pv (#4)
130	Gh-Pv (#3) converts to 3D particle (#0)
140	THh-Pv (#4) converts to 3D particle (#0)

Table 6-5. HYSPLIT sensitivity runs and relevant configuration parameters.

Sensitivity Test	INITD	NUMPAR	ISOT	KSPL	FRHS	FRVS	FRTS	FRME
INITD0	0	10000	1	NA	NA	NA	NA	NA
INITD1	1	10000	1	1	1.0	0.01	0.10	0.10
INITD2	2	10000	1	1	1.0	0.01	0.10	0.10
INITD3	3	10000	1	1	1.0	0.01	0.10	0.10
INITD4	4	10000	1	1	1.0	0.01	0.10	0.10
INITD103	103	10000	1	1	1.0	0.01	0.10	0.10
INITD104	104	10000	1	1	1.0	0.01	0.10	0.10
INITD130	130	10000	1	1	1.0	0.01	0.10	0.10
INITD140	140	10000	1	1	1.0	0.01	0.10	0.10

Figure 6-22 displays the spatial model performance statistics for the HYSPLIT INITD sensitivity tests. Wide variation in spatial performance is noted across the nine runs and requires closer examination. For example, the two puff based configurations (INITD1 and INITD2) showed the poorest spatial performance of all of the runs with low POD and TS values and much higher FAR values compared to all other configurations. The 3D particle based configuration (INITD0) had higher POD, TS, and lower FAR in comparison, yet it had a comparably low FMS to INITD1 and INITD2. Since the FMS score examines all model/observed values greater than 0 and the additional spatial metrics use a contingency level of 100 pg m^{-3}, it can be interpreted that the 3D particle configuration performed significantly better at concentration levels above 100 pg m^{-3}, but its spatial performance degraded with concentration ranges below the contingency level. The puff-particle hybrid configurations (INITD3, INTID4, INITD103, INITD104) performed consistently better overall across all four spatial metrics.

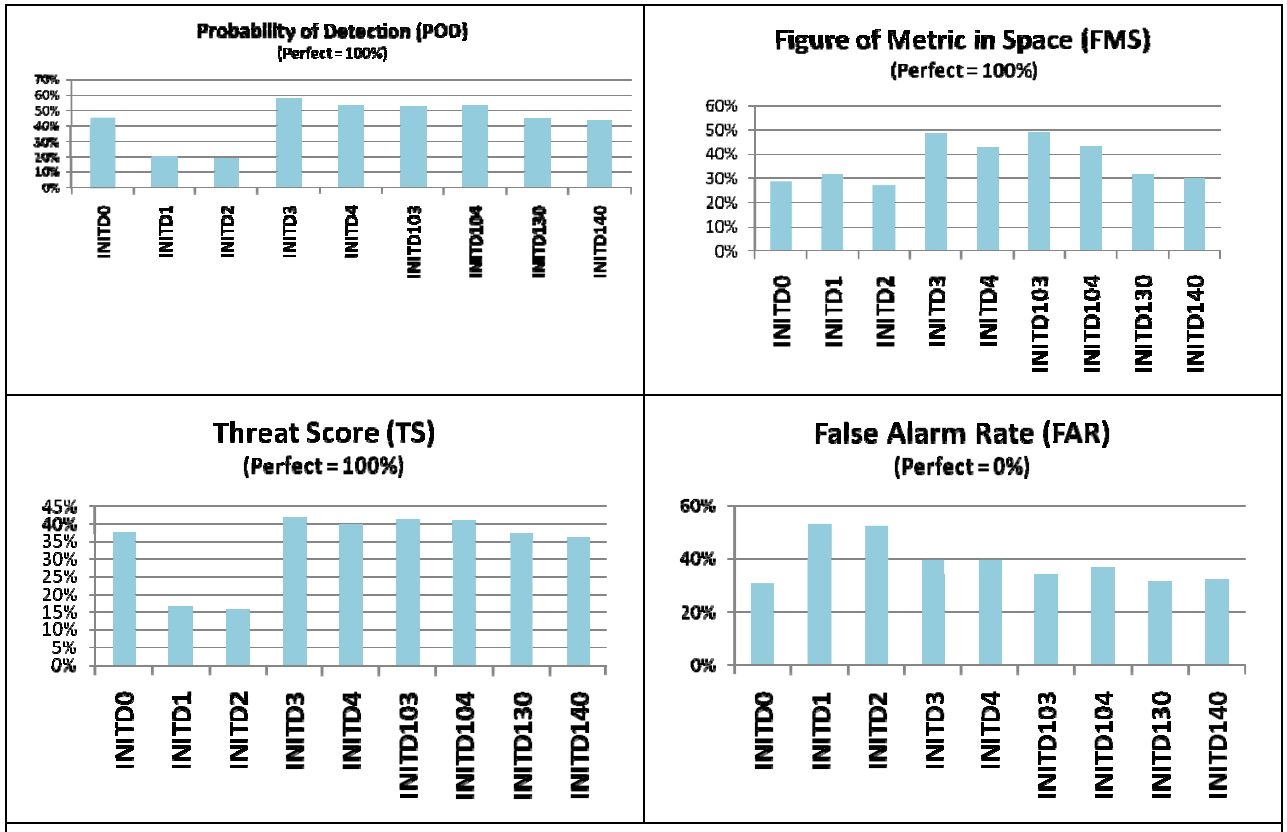


Figure 6-22. Spatial model performance statistics for nine HYSPLIT INITD sensitiviity experiments.

Figure 6-23 displays the global statistics for the HYSPLIT sensitivity tests with Figures 6-23a and 6-23b containing the statistical metrics where the best performing model has the, respectively, lowest and highest score. For the FOEX metrics, the INITD3 scores the best with a 3.4% FOEX score followed by INITD4 (-7%), INITD104 (-8.6%), and finally INITD103 (-9.5%). INITD2 scored worst with a -28.9%. INITD0, 1, 130, and 140 performed nearly as poorly with scores ranging between -21.9% to -24%. Using the NMSE statistical performance metric, the best performing configuration was INITD130, 140, and 3 with values of 17, 18, 19 pg m^{-3} respectively. The model configurations with the highest predicted error were INITD1 and INITD2 with values of approximately 325 and 333 pg m^{-3}. For the KS parameter, the four puff-particle model configuration options (INITD3,4,103,104) again showed the best scores.

For the within a factor of 2 and 5 metric (FA2 and FA5, Figure 6-23b, top), the hybrid puff-particle configurations INITD3 and INITD4 and their counterpart particle-puff configurations INITD103 and INITD104 are clearly performing better than pure particle (INITD0) or puff (INITD1 and INITD2) configurations. For the PCC metric, INITD140 had the highest (0.69) followed by INITD104 (0.64) and INITD0 and 103 (0.63). Interestingly, it appears that the higher PCC score for INITD103 is the main reason for the highest overall model RANK as both INITD3 and 103 had nearly identical spatial performance while INITD3 had slightly better KS scores.

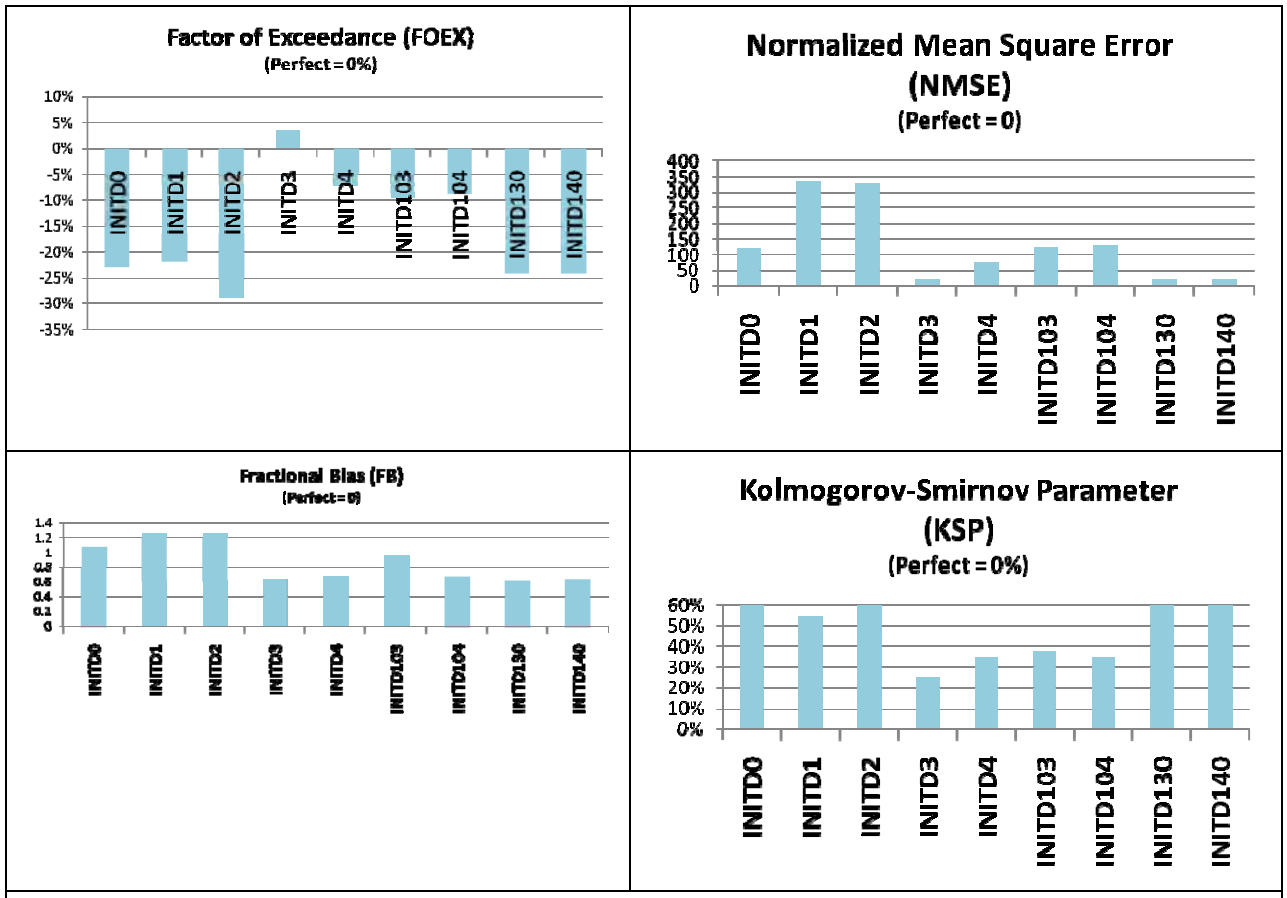


Figure 6-23a. Global model performance statistics for nine HYSPLIT INITD sensitivity tests.

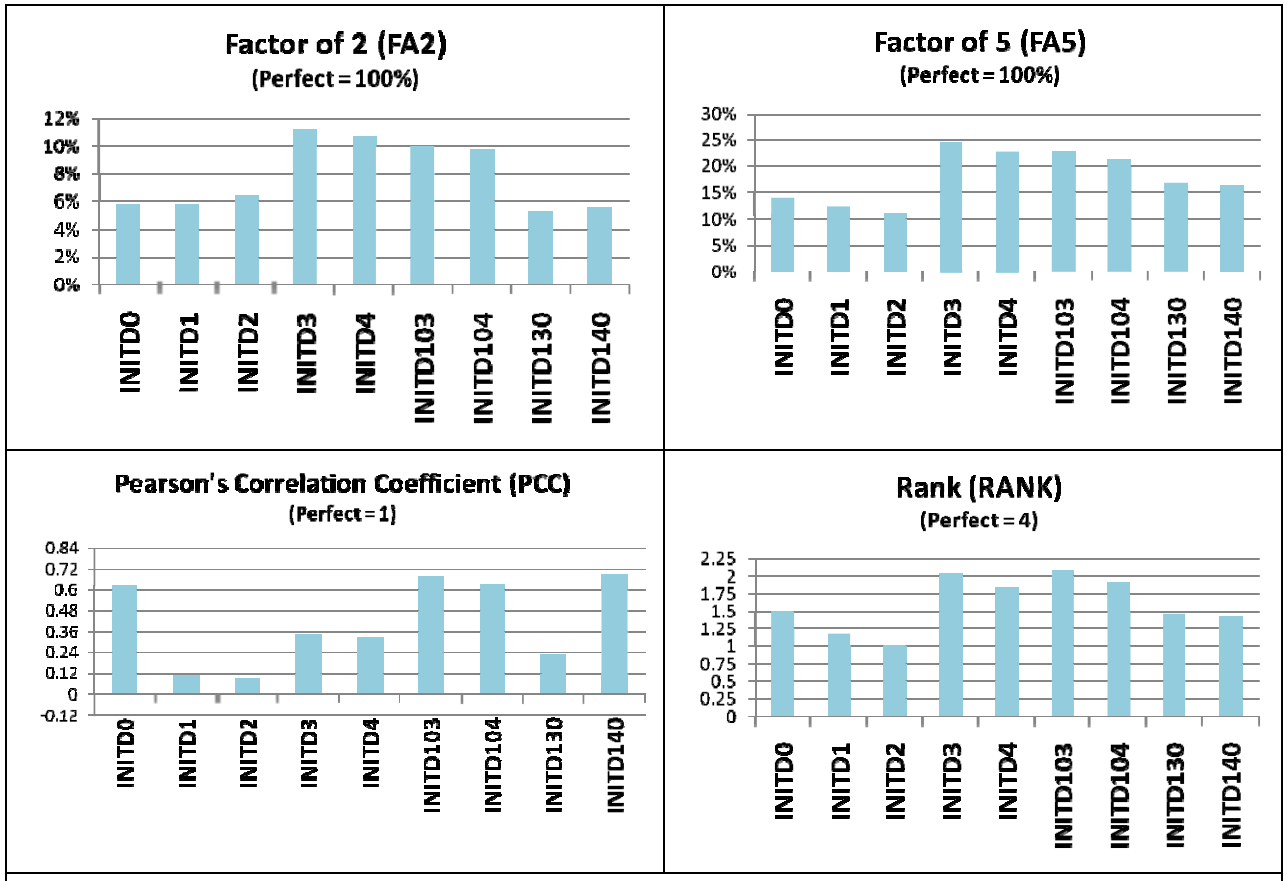


Figure 6-23b. Global model performance statistics for nine HYSPLIT INITD sensitivity tests.

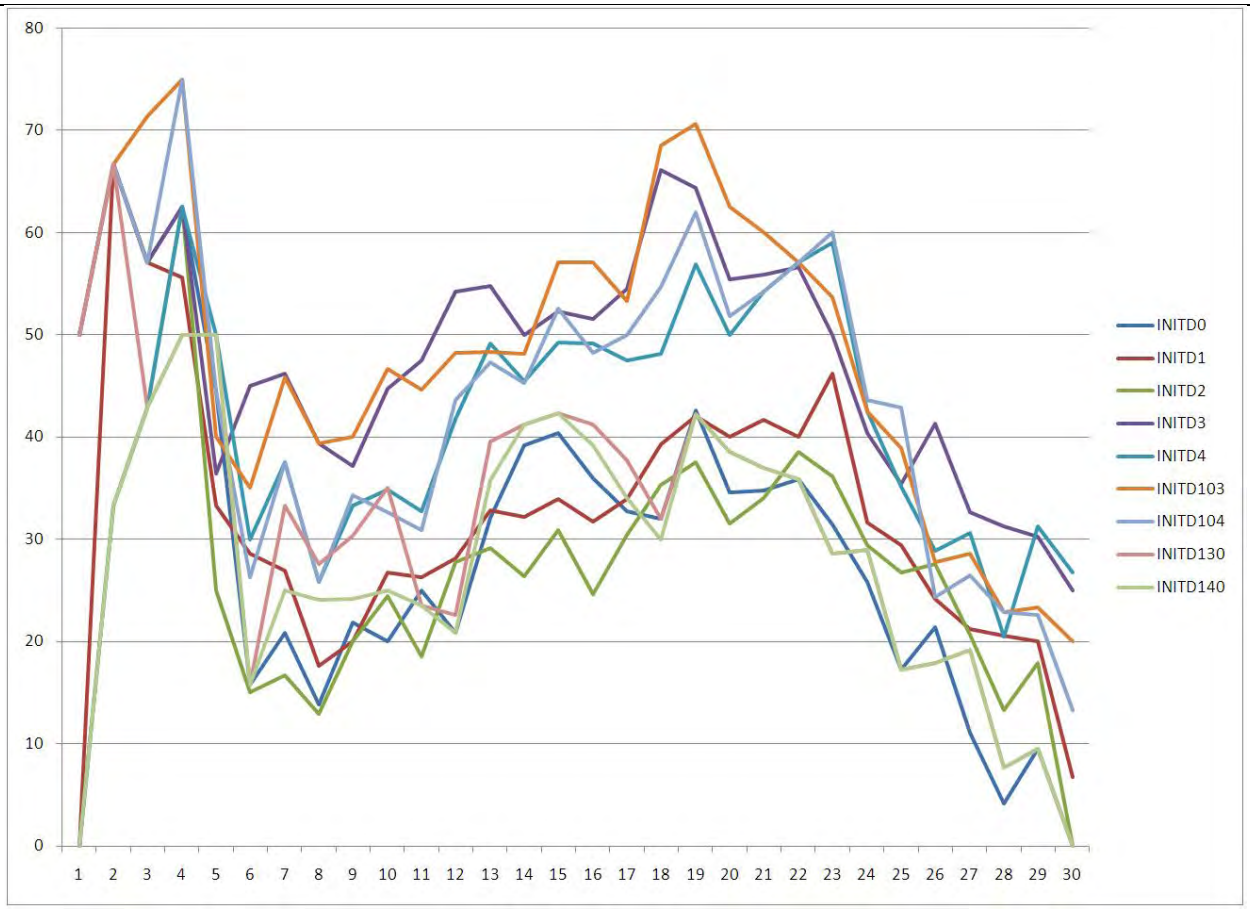


Figure 6-24. Figure of Merit (FMS) spatial model performance statistics as a function of time since the beginning of the tracer release for HYSPLIT INITD sensitivity analyses.

The final panel in Figure 6-23b (bottom right) displays the overall RANK statistic. The RANK statistics orders the model performance of the HYSPLIT INITD configurations are as follows:

1. INITD103 (2.09)
2. INITD3 (2.03)
3. INITD104 (1.91)
4. INITD4 (1.85)
5. INITD0 (1.50)
6. INITD130 (1,47)
7. INITD140 (1.44)
8. INITD1 (1.16)
9. INITD2 (1.01)

Based on this analysis the puff-particle and particle-puff hybrid configurations of the HYSPLIT system are clearly the best performing, indicating a distinct operational advantage over pure puff or particle configurations.

6.5 CONCLUSIONS OF THE MODEL PERFORMANCE EVALUATION OF THE LRT DISPERSION MODELS USING THE ETEX TRACER EXPERIMENT FIELD STUDY DATA

The evaluation of the five LRT dispersion models using a common MM5 dataset and the ETEX database has provided interesting results about the current capability of LRT models to reproduced observed tracer concentrations. Four of the five LRT models were able to reproduce the observed tracer bifurcation at the farther downwind distances. The CALPUFF model was unable reproduce the observed bifurcation of the tracer cloud and kept the estimated tracer cloud in a circular Gaussian distribution that was advected too far north. CALPUFF puff splitting sensitivity tests were performed to determine whether it would help simulate the bifurcation of the tracer cloud but puff splitting had little effect on the CALPUFF predictions.

CAMx sensitivity tests were conducted to examine vertical mixing and horizontal advection solvers and the best performing CAMx model configuration was the one that is most frequently used in applications, which includes using the CMAQ-like vertical diffusion coefficients in MM5CAMx and the PPM advection solver. The vertical diffusion algorithm had a much bigger effect on CAMx model performance than the choice of horizontal advection solver.

The HYSPLIT sensitivity tests with different particle-puff variations resulted in a wide range of model performance with RANK scores that varied from 1.01 to 2.09.

7.0 REFERENCES

Anderson, B. 2008. The USEPA MM5CALPUFF Software Project. 12th Annual George Mason University Conference on Atmospheric Transport and Dispersion Modeling, Fairfax, VA, July 8-10, 2008.

Anthes, R.A. and T.T. Warner. 1978. Development of Hydrodynamic Models Suitable for Air Pollution and other Mesometeorological Studies. Mon. Wea. Rev., 106, 1045-1078. 1078. (http://journals.ametsoc.org/doi/abs/10.1175/1520-0493(1978)106%3C1045%3ADOHMSF%3E2.0.CO%3B2).

Bott, A. 1989. A Positive Definite Advection Scheme Obtained by Nonlinear Renormalization of the Advective Fluxes. Mon. Wea. Rev., **117**, 1006-1015.

Boybeyi, Z., N. Ahmad, D. Bacon, T. Dunn, M. Hall, P. Lee, R. Sarma, and T. Wait. 2001. Evaluation of the Operational Multiscale Environment Model with Grid Adaptivity against the European Tracer Experiment. J. App. Meteor., **40**, 1541-1558.

Brashers, B. and C. Emery. 2011. The Mesoscale Model Interface Program (MMIF) Version 2.0 – Draft User's Manual. Prepared by ENVIRON International Corporation Novato California and Lynnwood Washington. EPA Contract No. EP-D-07-102, Work Assignments 2-06 and 4-06. September 30.

Brashers, B. and C. Emery. 2012. The Mesoscale Model Interface Program (MMIF) Version 2.1, 2012-01-31 – Draft User's Manual. Prepared by ENVIRON International Corporation Novato California and Lynnwood Washington. EPA Contract No. EP-D-07-102, Work Assignments 2-06, 4-06 and 5-08. January 31.

Byun, D.W., and J.K.S. Ching. 1999. "Science Algorithms of the EPA Models-3 Community Multiscale Air Quality (CMAQ) Modeling System", EPA/600/R-99/030.

Carhart, R.A., A. Policastro, M. Watag and L. Coke. 1989. Evaluation of Eight Short-Term Long-Range Transport Models using Field Data. Atmos. Env., 23, 85-105.

Chang, J.C., K. Chayantrakom, and S.R. Hanna. 2003. Evaluation of CALPUFF, HPAC, and VLSTRACK with Two Mesoscale Field Datasets. J. App. Meteor., **42**, 453-466.

Chang, J. C., S.R. Hanna, Z. Boybeyi, and P. Franzese. 2005. Use of Salt Lake City URBAN 2000 Field Data to Evaluate the Urban Hazard Prediction Assessment Capability (HPAC) Dispersion Model. J. App. Meteor., **44**, 485 – 501.

Chen, F. and J. Dudhia. 2001. Coupling an advanced land-surface/hydrology model with the Penn State/NCAR MM5 modeling system. Part I: Model implementation and sensitivity. Mon. Wea. Rev., **129**, 569 – 585.

Colella, P., and P.R. Woodward. 1984. The Piecewise Parabolic Method (PPM) for Gas-dynamical Simulations. J. Comp. Phys., **54**, 174-201.

D'Amours, R. 1998. Modeling the ETEX Plume Dispersion with the Canadian Emergency Response Model. Atmos. Environ., **32**, 4335 – 4341. 34

Deng, A. N.L. Seaman, G.K. Hunter, and D.R. Stauffer, 2004: Evaluation of Interregional Transport Using the MM5-SCIPUFF System. J. App. Meteor., **43**, 1864-1885.

Deng, A. N. and D.R. Stauffer. 2006. On Improving 4-km Mesoscale Model Simulations. J. App. Meteor., **45**, 361-381. Director General Joint Research Centre, cited 2008: European Tracer Experiment: Overview of the ETEX Project. (http://rem.jrc.europa.eu/etex).

DOE. 1978. Heavy Mathane-SF6 Tracer test Conducted at the Savannah River Laboratory, December 10, 1975. DP-1469. U.S. Department of Energy. Prepared by E.I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina.

Draxler, R.R., and B.J.B. Stunder. 1988. Modeling the CAPTEX vertical tracer concentration profiles. J. Appl. Meteorol., 27:617-625.

Draxler, R.R. and J.L. Heffter. 1989. Across North America Tracer Experiment (ANATEX). Volume I: Description, Ground-Level Sampling at Primary Sites, and Meteorology. January. NOAA Tech Memo ERL ARL-142.

Draxler, R.R. and G.D. Hess. 1997. Description of the HYSPLIT_4 Modeling System. NOAA Technical Memorandum ERL ARL-224. National Oceanic and Atmospheric Administration, Air Resources Laboratory, Silver Springs, MD. Revised August 1998, September 2002, October 2003 and January 2004. (http://www.arl.noaa.gov/documents/reports/arl-224.pdf).

Draxler, R.R., J.L. Heffter, and G.D. Rolph. 2002. DATEM: Data Archive of Tracer Experiments and Meteorology. National Oceanic and Atmospheric Administration, Silver Springs, MD. Last Revised 23 July 2002. (http://www.arl.noaa.gov/documents/datem/datem.pdf).

DTRA, 2001: Hazard prediction and assessment capability (HPAC), User Guide Version 4.0.1. Prepared for Defense Threat Reduction Agency, Contract DSWA01-98-C-0110, by Science Applications International Corporation, Rep. HPAC-UG-01-U-R0C0, 631 pp.

Dudhia, J. 1989. Numerical study of convection observed during the winter monsoon experiment using a mesoscale two-dimensional model. J. Atmos. Sci., **46**, 3077-3107. Draxler, R.R., and G.D. Hess, 1997: Description of the Hysplit_4 modeling system, Tech. Rep. NOAA Tech Memo ERL ARL-224, National Oceanic and Atmospheric Administration, Silver Springs, MD, 24 pp.

Dudhia, J. 1993. A Non-hydrostatic Version of the Penn State/NCAR Mesoscale Model: Validation Tests and Simulation of an Atlantic Cyclone and Cold Front. Mon. Wea. Rev., Vol. 121. pp. 1493-1513.

Earth Tech. 2005. CALGRID (Version 2) User Instructions. Final report prepared for the Ozone Transport Commission, Washington D.C. Earth tech, Inc., Concord, MA. May.

Emery, C.A., E. Tai, and G. Yarwood. 2001. Enhanced Meteorological Modeling and Performance Evaluation for Two Texas Ozone Episodes. Prepared for the Texas Natural Resource Conservation Commission, by ENVIRON International Corp., Novato, CA.

Emery, C. and B. Brashers. 2009. The Mesoscale Model Interface Program (MMIF) – Version 1.0. Draft User's Manual. ENVIRON International Corporation, Novato, CA. Prepared for U.S. Environmental Protection Agency. June 11.

ENVIRON. 2010. User's Guide – Comprehensive Air Quality Model with Extensions – Version 5.30. ENVIRON International Corporation, Novato, CA http://www.camx.com. May.

EPA, 1984: Interim Procedures for Evaluating Air Quality Models (Revised). EPA-450/4-84-023, Research Triangle Park, NC.

EPA, 1986a: Evaluation of Short-Term Long-Range Transport Models, Vol. I – Analysis Procedures and Results. EPA-450/4-86-016a, Research Triangle Park, NC.

EPA, 1986b: Evaluation of Short-Term Long-Range Transport Models, Vol. II – Appendices A through E. EPA-450/4-86-016b, Research Triangle Park, NC..

EPA, 1990.: Rocky Mountain Acid Deposition Model Assessment: ARM3 Model Performance Evaluation. EPA/600/S3-90/024, Research Triangle Park, NC. June.

EPA. 1989. Evaluation and Sensitivity Analysis Results of the MESOPUFF II Model with CAPTEX Measurements. United States Environmental Protection Agency, Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, NC. July. (EPA/600/S3-89/058).

EPA. 1991. Guidance for Regulatory Application of the Urban Airshed Model (UAM). U.S., Environmental Protection Agency, Office of Air Quality, Planning and Standards, Research Triangle Park, NC. July. (http://www.epa.gov/ttn/scram/guidance/guide/uamreg.pdf).

EPA. 1995. User's Guide for the Industrial Source Complex (ISC) Dispersion Model – Volume I User Instructions. U.S. Environmental Protection Agency, Office of Air Quality, Planning and Standards, Research Triangle Park, NC. September. (http://www.epa.gov/ttn/scram/userg/regmod/isc3v1.pdf).

EPA. 1998a. A Comparison of CALPUFF Modeling Results to Two Tracer Field Experiments. Tech. Rep., EPA-454/R-98-009, Research Triangle Park, NC. (http://www.epa.gov/ttn/scram/7thconf/calpuff/tracer.pdf).

EPA. 1998b. Interagency Workgroup on Air Quality Modeling (IWAQM) Phase 2 Summary Report and Recommendations for Modeling Long Range Transport Impacts. Tech Rep., EPA-454/R-98-009, Research Triangle Park, NC, 160 pp. (http://www.epa.gov/scram001/7thconf/calpuff/phase2.pdf).

EPA. 2003. Revisions to the Guideline on Air Quality Models: Adoption of a Preferred Long Range Transport Model and Other Revisions, Final Rule. 40 CFR Part 51. Federal Register, Vol. 68, 72, Tuesday April 15, 2003. (http://frwebgate3.access.gpo.gov/cgi-bin/PDFgate.cgi?WAISdocID=xoakAq/0/2/0&WAISaction=retrieve).

EPA. 2004: AERMOD: Description of Model Formulation. Tech Rep., EPA-454/R- 03-004, Research Triangle Park, NC, 91 pp. (http://www.epa.gov/scram001/7thconf/aermod/aermod_mfd.pdf).

EPA. 2005. Revisions to the Guideline on Air Quality Models: Adoption of a Preferred General Purpose (Flat and Complex Terrain) Dispersion Model and Other Revisions; Final Rule. Federal Register, Vol. 70, No 216, Wednesday, November 9, 2005. (http://www.epa.gov/ttn/scram/guidance/guide/appw_05.pdf).

EPA. 2007. "Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, PM2.5 and Regional Haze". U.S. Environmental Protection Agency, Research Triangle Park, NC. EPA-454/B-07-002. April. (http://www.epa.gov/ttn/scram/guidance/guide/final-03-pm-rh-guidance.pdf).

EPA. 2009a. Reassessment of the Interagency Workgroup on Air Quality Modeling (IWAQM) Phase 2 Summary Report: Revisions to Phase 2 Recommendations. Draft. U.S.

Environmental Protection Agency, Office of Air Quality, Planning and Standards, Air Quality Analysis Division, Air Quality Modeling Group, Research Triangle Park, NC. May 27. (http://www.epa.gov/scram001/guidance/reports/Draft_IWAQM_Reassessment_052709.pdf).

EPA. 2009b. Clarification on EPA-FLM Recommended Settings for CALMET. Memorandum from Tyler J. Fox, Group Leader, Air Quality Modeling Group, Office of Air Quality, Planning and Standards, U.S. Environmental Protection Agency to Regional Modeling Contacts. August 31. (http://www.epa.gov/ttn/scram/CALMET%20CLARIFICATION.pdf).

EPA. 2009c. AERMOD Implementation Guide. AERMOD Implementation Workgroup, U.S. Environmental Protection Agency, Office of Air Quality, Planning and Standards, Air Quality Assessment Division. Last Revised March 19, 2009. (http://www.epa.gov/scram001/7thconf/aermod/aermod_implmtn_guide_19March2009.pdf).

Ferber G.J., K. Telegadas, J.L. Heffter, C.R. Dickson, R.N. Dietz and P.W. Krey. 1981. Demonstration of a Long-Range Atmospheric Tracer System using Perfluorocarbons - Final Report. EPA-600/7-81-006, U.S EPA Office of Research and Development, Washington, D.C., January, 55 p.

Ferber G.J., J.L. Heffter, R.R. Draxler, R.J. Lagomarsino, F.L. Thomas, R.N. Dietz, and C.M. Benkovitz. 1986. Cross-Appalachian tracer experiment (CAPTEX-83). Final Report. NOAA Tech. Memo ERL ARL-142, Air Resources Laboratory, Silver Spring, MD, 60 p.

Fox, D. 1981. Judging Air Quality Model Performance. Bull. Amer. Meteor. Soc., 62, 599-609.

Graziani, G., W. Klug, and S. Mosca. 1998. Real-Time Long-Range Dispersion Model Evaluation of the ETEX First Release, EUR 17754 EN. ISBN 92-828-3657-6.

Grell, G.A., J. Dudhia, and D.R. Stauffer. 1995. A Description of the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5), NCAR Tech. Note NCAR/TN-398+STR, National Center for Atmospheric Research, Boulder, CO, 117 pp. (http://www.mmm.ucar.edu/mm5/documents/mm5-desc-pdf).

Heffter, J.L., J.F. Schubert and G.A. Meade. 1984. Atlantic Coast Unique Regional Atmospheric Tracer Experiment. ACCURATE. NOAA Tech Memo ERL ARL-130.

Irwin, J. 1997. A Comparison of CALPUFF Modeling Results with 1977 INEL Field Data Results. Presented at 22nd NATO/CCMS International technical Meeting on Air Pollution Modeling and its Application. Clermont-Ferrand, France. June 2-6, 1997.

Iwasaki, T., T. Maki, and K. Katayama. 1998: Tracer Transport Model at Japan Meteorological Agency and Its Application to the ETEX Data. Atmos. Environ., **32**, 4285 – 4295.

Kain, J.S.. 2004. The Kain-Fritsch convective parameterization: An update. J. App. Meteor., **43**, 170-181. 36

Kang, D., R. Mathur, K. Schere, S. Yu, and B. Eder. 2007. New Categorical Metrics for Air Quality Model Evaluation. J. App. Meteor., **46**, 549-555.

McNally, D. 2010. MMIFstat Evaluation Tool. Alpine Geophysics, LLC, Arvada, Colorado.

Mlawer, E.J., S.J. Taubman, P.D. Brown, M.J. Iacono, and S.A. Clough. 1997. Radiative transfer for inhomogeneous atmosphere: RRTM, a validated correlated-k model for the long-wave. J. Geophys. Res., **102** (D14), 16663-16682.

Mosca, S., G. Graziani, W. Klug, R. Ballasio, and R. Bianconi. 1998. A Statistical Methodology for the Evaluation of Long-Range Dispersion Models: An Application to the ETEX Exercise. Atmos. Environ., **32**, 4307- 4324.

National Center for Atmospheric Research, cited 2008: NCEP/NCAR Reanalysis – Data Product Description. (http://dss.ucar.edu/pub/reanalysis/prod_des.html).

Nasstrom, J.S., and J.C. Pace. 1998. Evaluation of the Effect of Meteorological Data Resolution on Lagrangian Particle Dispersion Simulations Using the ETEX Experiment. Atmos. Environ., **32**, 4187-4194.

Policastro, A.J., M. Wastag, L. Coke, R.A. Carhart and W.E. Dunn. 1986. Evaluation of Short-Term Long-Range Transport Models – Volume I. Analysis Procedures and Results. Argonne National Laboratory. Prepared for U.S. Environmental Protection Agency, Office of Air Quality, Planning and Standards. EPA-450/4-86-016a. October.

Scire, J.S., R. Yamartino, G.R. Carmichael, Y.S. Chang. 1989. CALGRID: A Mesoscale Photochemical Grid Model. Tech. Rep., Sigma Research Corporation, Concord, MA, 222 pp. (http://gate1.baaqmd.gov/pdf/2516_CALGRID_Mesoscale_Photochemical_Grid_Model_Volume_II_Users_Guide_Part1_1989.pdf)

Scire, J.S., F.R. Robe, M.E. Fernau, and R.J. Yamartino. 2000a. A User's Guide for the CALMET Meteorological Model (Version 5). Tech. Rep., Earth Tech, Inc., Concord, MA 332 pp. (http://www.src.com/calpuff/download/CALMET_UsersGuide.pdf).

Scire, J.S., D.G. Strimaitis, and R.J. Yamartino. 2000b. A User's Guide for the CALPUFF Dispersion Model (Version 5), Tech. Rep., Earth Tech, Inc., Concord, MA, 521 pp. (http://www.src.com/calpuff/download/CALPUFF_UsersGuide.pdf).

Seaman, N.L. 2000. Meteorological modeling for air quality assessments. Atmos. Environ., Vol. 34, No. 12-14, 2231-2260.

Seaman, N.L., D.R. Stauffer, and L.M. Lario. 1995. A multiscale four-dimensional data assimilation system applied to the San Joaquin Valley during SARMAP. Part I: Modeling design and basic performance characteristics. J. Appl. Meteo., Vol. 34, pp. 1739-1761.

Skamarock, W.C., J.B. Klemp, J. Dudhia, D.O. Gill, D.M. Barker, M.G. Duda, X. Huang, W. Wang, and J.G. Powers. 2008. A Description of the Advanced Research WRF Version 3, NCAR Tech. Note NCAR/TN-475+STR, National Center for Atmospheric Research, Boulder, CO, 125 pp. (http://www.mmm.ucar.edu/wrf/users/docs/arw_v3.pdf).

Slade, D.H. 1968. Meteorology and Atomic Energy. Air Resources Laboratories, Research Laboratories, Environmental Sciences Services Administration, United States Department of Commerce. For the Division of Reactor Development and technology, United States Atomic Energy Commission, Office of Information Services. Silver Spring, Maryland (TID-24190). July.

Stauffer, D.R., and N.L. Seaman. 1990. Use of four-dimensional data assimilation in a limited-area mesoscale model. Part I: Experiments with synoptic-scale data. Mon. Wea. Rev., **118**, 1250 – 1277.

Stauffer, D.R., N.L. Seaman, and F.S. Binkowski. 1991. Use of four-dimensional assimilation in a limited-area mesoscale model. Part II: Effects of data assimilation within the planetary boundary layer. Mon. Wea. Rev., **119**, 734 – 754.

Stohl, A., M. Hittenberger, and G. Wotawa. 1998. Validation of the Lagrangian Particle Dispersion Model FLEXPART Against Large-Scale Tracer Experiment Data. Atmos. Environ., **32**, 4245 – 4264. 39.

Stohl, A., H. Sodemann, S. Eckhardt, A. Frank, P. Siebert and G. Wotawa. 2010. The Lagrangian Particle Dispersion Model FLEXPART Version 8.2. Norwegian Institute of Air Research, Kjeller, Norway. (http://zardoz.nilu.no/~flexpart/flexpart/flexpart82.pdf).

Stohl, A., C. Forster, A. Frank, P. Seibert, and G. Wotawa. 2005. Technical Note: The Lagrangian particle dispersion model FLEXPART version 6.2. Atmos. Chem. Phys. **5**, 2461 – 2474.

Sykes, R.I., S.F. Parker, D.S. Henn, C.P. Cerasoli, and L.P. Santos. 1998. PC-SCIPUFF Version 1.2PD, Technical Documentation. ARAP Report 718, Titan Research and Technology Division, Titan Corp., Princeton, NJ, 172 pp. (http://www.titan.com/appliedtech/Pages/TRT/pages/scipuff/scipuff_files.htm).

Telegadas, K., G.J. Ferber, R.R. Draxler, M.M Penderdast, A.L. Boni, J.P. Hughes and J. Gray. 1980. Measured Weekly and Twice-Daily Krypton-85 Surface Air Concentrations within 150 km of the Savannah River Plant (March 1975 through September 1977) – Final Report. NOAA Technical Memorandum ERL ARL-80. United States Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Research Laboratories, Air Resources Laboratories, Silver Spring, Maryland. January.

Wendum, D., 1998: Three long-range transport models compared the ETEX experiment: A performance study. Atmos. Environ., **32**, 4297-4305.

Van Dop, H., R. Addis, G. Fraser, F. Girardi, G. Graziani, Y. Inoue, N. Kelly, W. Klug, A. Kulmala, K. Nodop, and J. Pretel. 1998. ETEX: A European Tracer Experiment: Observations, Dispersion Modeling and Emergency Response. Atmos. Environ., **32**, 4089 – 4094.

Xiu, A. and J.E. Pleim. 2000. Development of a land surface model. Part I: application in a mesoscale meteorology model. J. App. Met., 40, pp. 192-209.

Yamartino, R., J.S. Scire, S.R. Hanna, G.R. Carmichael, and Y.S. Chang. 1989. CALGRID: A Mesoscale Photochemical Grid Model. Volume I: Model Formulation Document, Tech. Rep., Sigma Research Corporation, Concord, MA, 81 pp.

Appendix A

Evaluation of the MM5 and CALMET Meteorological Models Using the CAPTEX CTEX5 Field Experiment Data

EVALUATION OF THE MM5 AND CALMET METEOROLOGICAL MODELS USING THE CAPTEX CTEX5 FIELD EXPERIMENT DATA

Statistical evaluation of the prognostic (MM5) and diagnostic (CALMET) meteorological model applications for the CTEX5 CAPTEX release was conducted using surface meteorological measurements. For the MM5 datasets, performance for meteorological parameters of wind (speed and direction), temperature, and humidity (mixing ratio) was examined. For the CALMET experiments, CALMET estimated winds (speed and direction) were examined because the two-dimensional temperature and relative humidity fields output are simple interpolated fields of the observations. Therefore, the evaluation for CALMET was restricted to winds where the majority of change can be induced by both diagnostic terrain adjustments and varying the OA strategy. Note that except for the NOOBS = 2 CALMET sensitivity tests (i.e., the "D" series of CALMET sensitivity tests), surface meteorological observations are blended with the wind fields in the CALMET STEP2 objective analysis (OA) procedure. Thus, the evaluation of the CALMET wind fields is not a true independent evaluation as the surface meteorological observations used in the evaluation are also used as input into CALMET. So we expect the CALMET wind fields to compare better with observations than MM5, but that does not mean that CALMET is producing better meteorological fields. As clearly shown by EPA (2009a,b), the CALMET diagnostic (STEP1) and blending of observations using the STEP2 OA procedure can introduce discontinuities and artifacts in the wind fields generated by the MM5/WRF prognostic meteorological model that is used as input to CALMET, even though the CALMET winds may match the observed surface winds at the locations of the monitoring sites does not necessarily mean that CALMET is performing better than MM5/WRF.

The METSTAT software (Emery et al., 2001) was used to match MM5 output with observation data. The MMIFStat software (McNally, 2010) tool was used to match CALMET output with observation data. Emery and co-workers (2001) have developed a set of "benchmarks" for comparing prognostic meteorological model performance statistics metrics. These benchmarks were developed after examining the performance of the MM5 and RAMS prognostic meteorological models for over 30 applications. The purpose of the benchmarks is not to assign a passing or failing grade, rather it is to put the prognostic meteorological model performance in context. The surface meteorological model performance benchmarks from Emery et al., (2001) are displayed in Table A-1. Note that the wind speed RMSE benchmark was also used for wind speed MNGE given the similarity of the RMSE and MNGE performance statistics. These benchmarks are not applicable for diagnostic model evaluations.

Table A-1. Wind speed and wind direction benchmarks used to help judge the performance of prognostic meteorological models (Source: Emery et al., 2001).

Wind Speed	Root Mean Squared Error (RMSE) Mean Normalized Bias (NMB) Index of Agreement (IOA)	≤ 2.0 m/s ≤ ±0.5 m/s ≥ 0.6
Wind Direction	Mean Normalized Gross Error (MNGE) Mean Normalized Bias (MNB)	≤ 30° ≤ ±10°
Temperature	Mean Normalized Gross Error (MNGE) Mean Normalized Bias (NMB) Index of Agreement (IOA)	≤ 2.0 K ≤ ±0.5 m/s ≥ 0.8
Humidity	Mean Normalized Gross Error (MNGE) Mean Normalized Bias (NMB) Index of Agreement (IOA)	≤ 2.0 g/kg ≤ ±1.0 g/kg ≥ 0.6

Table A-2 lists the CTEX5 MM5 sensitivity tests that are evaluated in this section. For the first set of MM5 experiments (EXP1) MM5 was configured as it would be run during the late 1980s and early 1990s using only 16 vertical layers, a single 80 km grid resolution and older (Blackadar) planetary boundary layer (PBL) and land soil module (LSM). There were several four dimensional data assimilation (FDDA) experiments using this first MM5 configuration from none (EXP1A) to analysis nudging above the PBL and at the surface (EXP1C).

The second set of MM5 experiments (EXP2A-C) used a more recent MRF PBL scheme and 33 vertical layers with three levels of grid nesting (108/26/12 km) and was meant to represent the way MM5 was run in the late 1990s/early 2000s. Three different levels of FDDA were used with this MM5 configuration: none (EXP2A), analysis nudging above the PBL (EXP2B) and analysis nudging above the PBL as well as at the surface (EXP2C). Note that additional sensitivity experiments were planned using this second MM5 configuration (e.g., EXP2D and EXP2E), but the MM5 model performance using the MRF PBL scheme was so poor that this MM5 configuration was abandoned.

The third set of MM5 experiments (EXP2F-J) used a MM5 configuration similar to the second set of MM5 experiments only with more vertical layers (43) and going back to the Blackadar PBL scheme due to the poor performance of MRF. Additional FDDA sensitivity tests were performed that increased the FDDA nudging strength by a factor of 2 and then added in observation nudging. The final MM5 configuration (EXP3) was exactly the same as the third configuration MM5 experiment EXP2H, only using the Pleim-Xiu PBL/LSM scheme.

The CALMET sensitivity tests are listed in Table A-3. The MM5 output from either MM5 EXP1C (80 km) or MM5 EXP2H (36 and 12 km) were used as initial guess winds in the CALMET experiments. The CALMET sensitivity tests varied by the CALMET grid resolution, the source and grid resolution of the MM5 output data used and how the surface and upper-air meteorological data were blended into the STEP1 wind fields in the STEP2 OA procedure. There were seven basic CALMET configurations:

BASE Use 80 km MM5 data from EXP1C and 18 km CALMET grid resolution.
1. Use 80 km MM5 data from EXP1C and 12 km CALMET grid resolution.
2. Use 80 km MM5 data from EXP1C and 4 km CALMET grid resolution.
3. Use 36 km MM5 data from EXP2H and 12 km CALMET grid resolution.
4. Use 12 km MM5 data from EXP2H and 12 km CALMET grid resolution.
5. Use 36 km MM5 data from EXP2H and 4 km CALMET grid resolution.
6. Use 12 km MM5 data from EXP2H and 4 km CALMET grid resolution.

The variations in the CALMET STEP2 OA procedures in the CALMET sensitivity test were as follows:

A. Use meteorological observations with RMAX1/RMAX2 = 500/1000.
B. Use meteorological observations with RMAX1/RMAX2 = 100/200.
C. Use meteorological observations with RMAX1/RMAX2 = 10/100.
D. Don't use any meteorological observations (NOOBS = 2).

Table A-2. Summary of CTEX5 MM5 sensitivity tests.

Sensitivity Test	Horizontal Grid	Vertical Layers	PBL	LSM	FDDA Used
1A_80km	80 km	16	BLKDR	5LAY	No FDDA
1B_80km	80 km	16	BLKDR	5LAY	Analysis Nudging
1C_80km	80 km	16	BLKDR	5LAY	Analysis Nudging Surface Analysis Nudging
2A_36km 2A_12km	108/36/12km	33	MRF	5LAY	No FDDA
2B_36km 2B_12km	108/36/12km	33	MRF	5LAY	Analysis Nudging
2C_36km	108/36/12km	33	MRF	5LAY	Analysis Nudging Surface Analysis Nudging
2F_36km 2G_12km	108/36/12km	43	BLKDR	5LAY	No FDDA
2G_36km 2G_12km	108/36/12km	43	BLKDR	5LAY	Analysis Nudging
2H_36km 2H_12km	108/36/12km	43	BLKDR	5LAY	Analysis Nudging Surface Analysis Nudging
2I_36km 2I_12km	108/36/12km	43	BLKDR	5LAY	Analysis Nudging Surface Analysis Nudging FDDA x 2 strength
2J_36km 2J_12km	108/36/12km	43	BLKDR	5LAY	Analysis Nudging Surface Analysis Nudging FDDA x 2 strength Observational Nudging
4_36km 4_12km	108/36/12km	43	PX	PX	Analysis Nudging Surface Analysis Nudging

Table A-3. Definition of the CTEX5 CALMET sensitivity tests and data sources.

Sensitivity Test	MM5 Experiment and Resolution	CALMET Resolution	RMAX1/RMAX2	NOOBS[A]
BASEA	EXP1C – 80 km	18 km	500/1000	0
BASEB	EXP1C – 80 km	18 km	100/200	0
BASEC	EXP1C – 80 km	18 km	10/100	0
BASED	EXP1C – 80 km	18 km	NA	2
1A	EXP1C – 80 km	12 km	500/1000	0
1B	EXP1C – 80 km	12 km	100/200	0
1C	EXP1C – 80 km	12 km	10/100	0
1D	EXP1C – 80 km	12 km	NA	2
2A	EXP1C – 80 km	4 km	500/1000	0
2B	EXP1C – 80 km	4 km	100/200	0
2C	EXP1C – 80 km	4 km	10/100	0
2D	EXP1C – 80 km	4 km	NA	2
3A	EXP2H – 36 km	12 km	500/1000	0
3B	EXP2H – 36 km	12 km	100/200	0
3C	EXP2H – 36 km	12 km	10/100	0
3D	EXP2H – 36 km	12 km	NA	2
4A	EXP2H – 12 km	12 km	500/1000	0
4B	EXP2H – 12 km	12 km	100/200	0
4C	EXP2H – 12 km	12 km	10/100	0
4D	EXP2H – 12 km	12 km	NA	2
5A	EXP2H – 36 km	4 km	500/1000	0
5B	EXP2H – 36 km	4 km	100/200	0
5C	EXP2H – 36 km	4 km	10/100	0
5D	EXP2H – 36 km	4 km	0/0	2
6A	EXP2H – 12 km	4 km	500/1000	0
6B	EXP2H – 12 km	4 km	100/200	0
6C	EXP2H – 12 km	4 km	10/100	0
6D	EXP2H – 12 km	4 km	NA	2
6K	EXP2H – 12 km	4 km	NA	2

A. NOOBS = 0 use surface and upper-air meteorological observations
NOOBS = 2 do not use surface and upper-air meteorological observations
NOOBS = 1 use surface but not upper-air meteorological observations

Figure A-1 compares the MM5 model estimated wind fields. Figures A-2 and A-3 display the temperature and humidity model performance for the MM5 simulations. As shown in Figure A-2, the temperature performance for the three MM5 sensitivity tests using the MRF PBL scheme (2A, 2B and 2C) is extremely poor using either the 36 or 12 km grid resolution having an underestimation bias greater than -4 degrees that does not meet the temperature bias performance goal (≤±0.5 degrees).

The wind speed and, especially, the wind direction performance of the MM5 simulations with no FDDA (1A, 2A and 2F) is noticeably worse than when FDDA is used with the wind direction bias and error exceeding the performance benchmarks when no FDDA is used. With the exception of the EXP2H temperature underestimation tendency that barely exceeds the performance benchmark, the MM5 EXP1C and EXP2H MM5 sensitivity tests that were used in the CALMET sensitivity tests achieve the model performance benchmarks for wind speed, wind direction, temperature and humidity.

Tables A-4 and A-5 show CALMET estimated winds compared to observations. The "A" series of CALMET sensitivity tests (RMAX1/RMAX2 =500/1000) tends to have a wind speed underestimation bias compared to the other RMAX1/RMAX2 settings for most of the base CALMET settings (Figure A-1). The "A" and "B" series of CALMET runs tend to have the winds that closest match observations compared to the "C" (RMAX1/RMAX2 = 10/100) and "D" (no observations) series of CALMET runs. The use of 12 km CALMET grid resolution appears to improve the CALMET model performance slightly compared to 80 and 36 km. The CALMET runs using the MM5 EXP2H 36/12 km data appear to perform better than the ones that used the MM5 EXP1C 80 km data. CALMET tends to slow down the MM5 wind speeds with the slowdown increasing going from the "D" to "C" to "B" to "A" series of CALMET configurations such that the "A" series has a significant wind speed underestimation tendency.

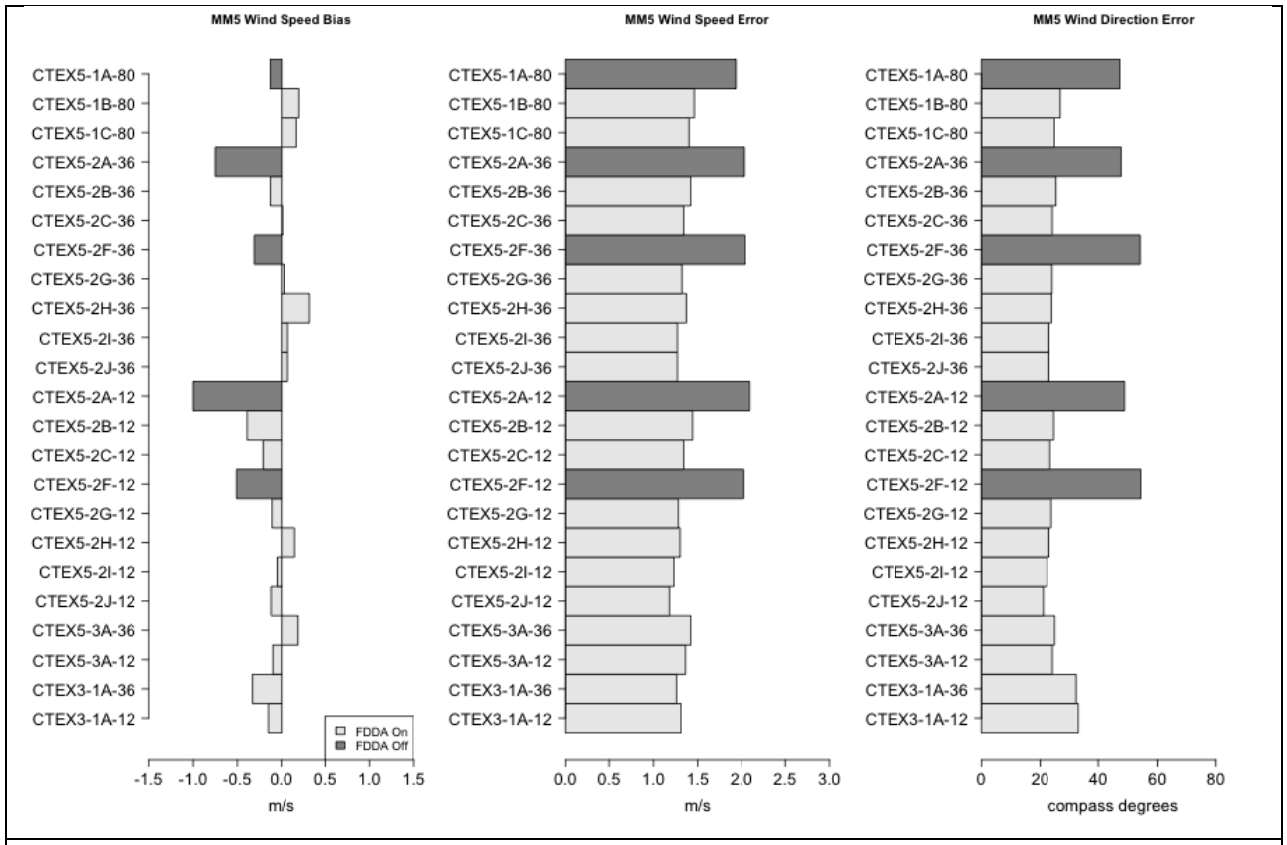


Figure A-1. Wind speed bias (m/s), wind speed error (m/s) and wind direction error (degrees) for MM5 runs.

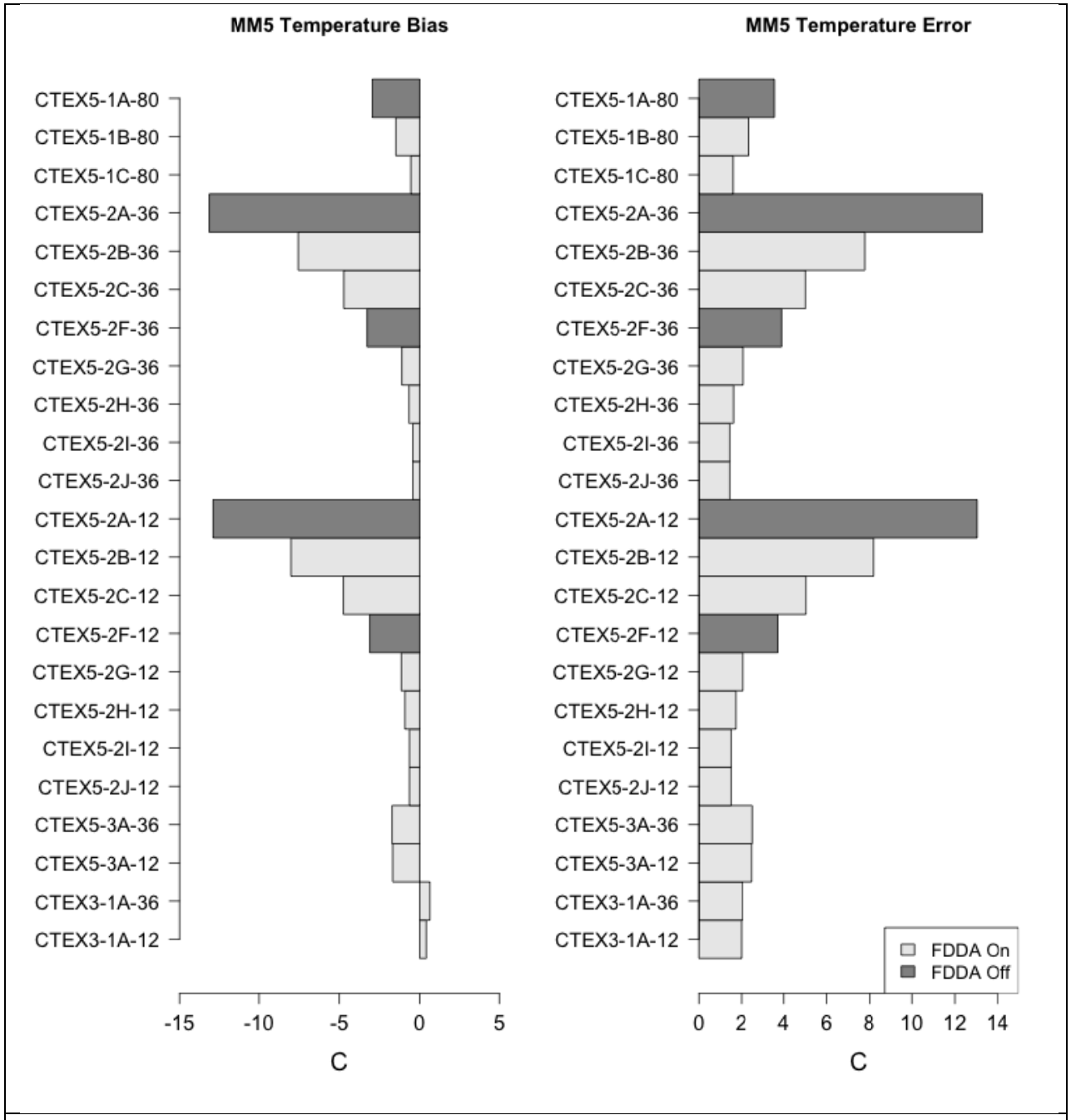


Figure A-2. Temperature bias and error (degrees K) of the CTEX5 MM5 meteorological modeling.

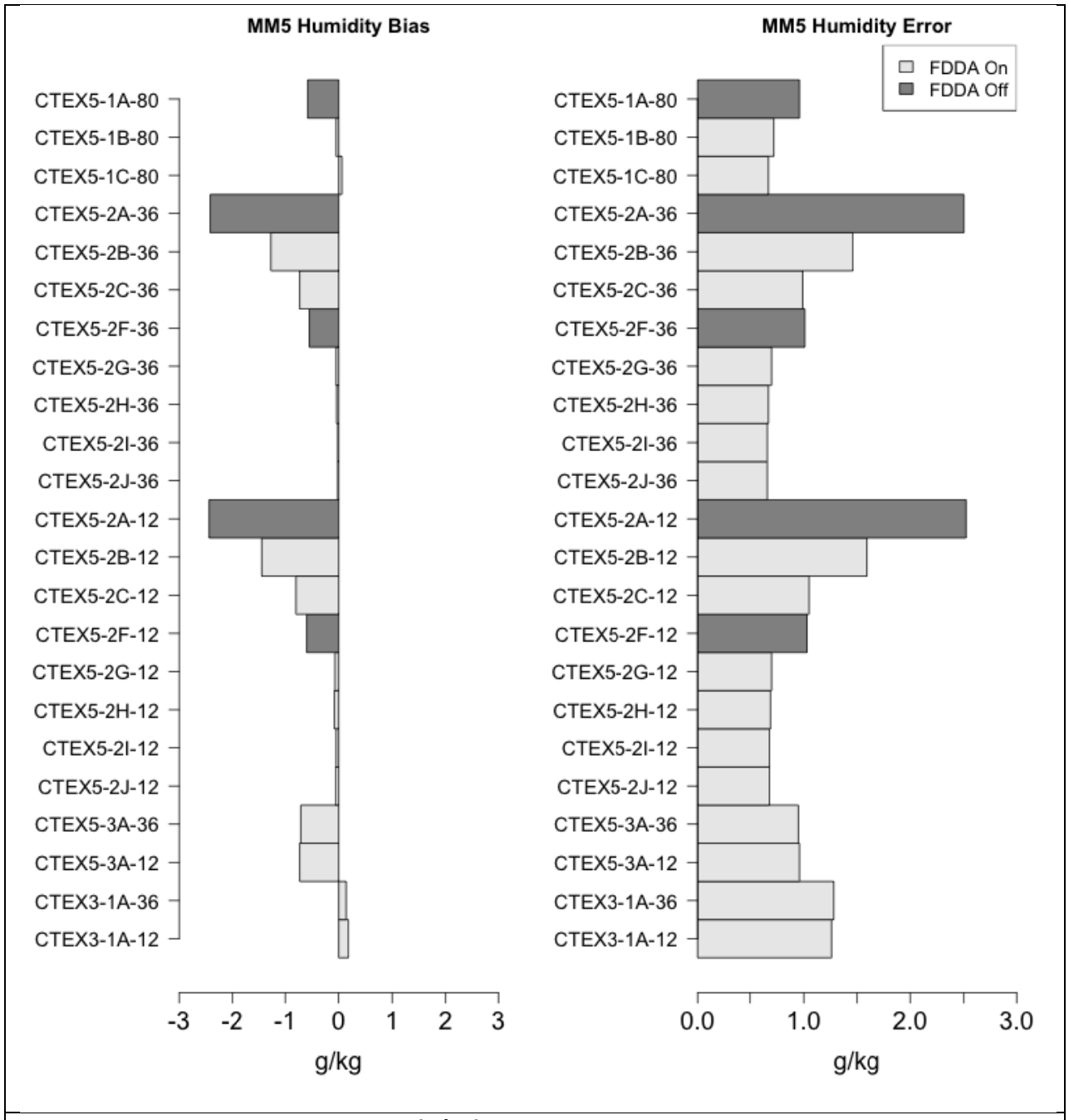


Figure A-3. Humidity bias and error (g/kg) of the CTEX5 MM5 meteorological modeling.

Table A-4. Comparison of CTEX5 MM5 meteorological simulation EXP1C and CALMET simulations using EXP1C MM5 80 km data as input.

	Wind Speed (m/s)			Wind Direction (°)	
	Bias	**Error**	**RMSE**	**Bias**	**Error**
Benchmark	≤±0.5	≤2.0	≤2.0	≤±10	≤30
MM5_EXP1C	0.17	1.40	1.83	4.52	25.1
CALMET					
BASEA	-0.35	0.89	1.38	-0.42	15.9
BASEB	-0.11	0.84	1.32	1.01	15.2
BASEC	-0.01	1.26	1.67	4.26	23.8
BASED	0.03	1.34	1.76	4.53	25.1
1A	-0.29	0.82	1.36	-0.56	14.9
1B	0.06	0.78	1.3	0.67	14.3
1C	-0.03	1.22	1.62	3.80	22.9
1D	0.02	1.34	1.77	4.45	25.1
2A	-0.21	0.71	1.33	-0.78	13.9
2B	-0.02	0.69	1.29	0.31	13.3
2C	-0.08	0.96	1.40	2.28	17.9
2D	0.00	1.34	1.77	4.08	25.0

Table A-5. Comparison of CTEX5 MM5 meteorological simulation EXP2H and CALMET simulations using EXP2H MM5 36 and 12 km data as input.

	Wind Speed (m/s)			Wind Direction (°)	
	Bias	**Error**	**RMSE**	**Bias**	**Error**
Benchmark	≤±0.5	≤2.0	≤2.0	≤±10	≤30
MM5_EXP2H	0.32	1.37	1.78	5.07	24.2
CALMET					
3A	-0.29	0.82	1.35	-0.56	14.9
3B	-0.01	0.78	1.29	0.83	14.2
3C	0.17	1.20	1.59	4.50	22.0
3D	0.24	1.34	1.74	5.13	24.1
4A	-0.29	0.82	1.35	-0.56	14.9
4B	-0.03	0.76	1.25	0.36	14.0
4C	0.07	1.16	1.54	3.36	21.4
4D	0.13	1.28	1.67	3.83	23.5
5A	-0.21	0.71	1.33	-0.78	13.9
5B	0.03	0.69	1.28	0.50	13.2
5C	0.08	0.95	1.39	2.87	17.4
5D	0.21	1.33	1.75	4.79	24.1
5K	0.04	0.69	1.28	0.47	13.2
6A	-0.21	0.71	1.33	-0.79	13.9
6B	-0.05	0.67	1.24	0.04	13.0
6C	-0.02	0.92	1.33	1.84	16.7
6D	-0.26	1.33	1.77	4.67	24.5
6K	0.00	0.66	1.23	0.00	13.0

Appendix B

EVALUATION OF VARIOUS CONFIGURATIONS OF THE CALMET METEOROLOGICAL MODEL USING THE CAPTEX CTEX3 FIELD EXPERIMENT DATA

B.1 CALMET MODEL EVALUATION TO IDENTIFY RECOMMENDED CONFIGURATION

The CAPTEX Release #3 (CTEX3) meteorological database was used to evaluate different configurations of the CALMET meteorological model for the purposes of helping to identify a recommended configuration for regulatory far-field CALMET/CALPUFF modeling. The results from these CALMET CTEX3 sensitivity tests were used in part to define the recommended CALMET model options in the August 31, 2009 Memorandum from the EPA/OAQPS Air Quality Modeling Group "Clarifications on EPA-FLM Recommended Settings for CALMET (i.e., the 2009 Clarification Memorandum). The EPA Clarification Memorandum on CALMET settings (EPA, 2009a) was a follow-up to a draft May 27, 2009 document: "Reassessment of the Interagency Workgroup on Air Quality Modeling (IWAQM) Phase 2 Summary Report: Revisions to Phase 2 Recommendations" (EPA, 2009a). The IWAQM Phase 2 Reassessment Report recommended settings for CALMET that were intended to facilitate the direct "pass through" of prognostic meteorological model (e.g., MM5 and WRF) output to CALPUFF as much as possible. However, in subsequent testing of the new recommended CALMET settings in the IWAQM Phase 2 Reassessment Report using the CTEX3 database, the performance of CALMET degraded compared to some other settings. This led to the August 31, 2009 Clarification Memorandum of recommended CALMET settings for regulatory far-field modeling.

EPA examined 31 different configurations of the CALMET diagnostic meteorological model using the CTEX3 database. The resultant CALMET wind fields were paired in space and time with observations using the CALMETSTAT tool. CALMETSTAT is an adaptation of the METSTAT program that is typically used to evaluate the MM5 and WRF prognostic meteorological models against surface meteorological observations.

Note that since CALMET uses some of the same meteorological observations as input as used in the evaluation database, this is not a true evaluation as by design CALMET's STEP2 objective analysis (OA) will modify the wind field to make the winds better match the observations at the locations of the monitoring sites. But as noted by EPA (2009a,b), this can be at the expense of degrading the wind fields.

Table B-1 lists the 31 CALMET sensitivity tests that were performed using the CTEX3 modeling database. These CALMET sensitivity tests differed in the following aspects:

- The resolution of the CALMET gridded fields (18, 12 and 4 km);
- The resolution of the MM5 prognostic meteorological model output used as input to CALMET (80, 36 and 12 km);
- How the MM5 data was used in CALMET (i.e., as a first guess field prior to the STEP 1 diagnostic effects, as the STEP 1 wind fields prior to STEP 2 blending (objective analysis or OA) of observations or the MM5 data are not used at all); and
- Whether the surface and upper-air meteorological observations were used (NOOBS=0) or not (NOOBS=2).

Table B-1. CTEX3 CALMET sensitivity simulations performed for the CTEX3 database.

RUN	CALMET Resolution	MM4/MM5 Resolution	NOOBS	RMAX1/RMAX2	IPROG
BASE A	18-km	80-km MM4	0	500/1000	STEP 1
BASE B	18-km	80-km MM4	0	500/1000	First Guess
BASE C	18-km	80-km MM4	0	10/100	First Guess
BASE D	18-km	80-km MM4	0	100/200	First Guess
BASE E	18-km	80-km MM4	0	10/100	STEP 1
BASE F	18-km	80-km MM4	0	10/100	First Guess
BASE G[A]	18-km	80-km MM4	2	NA	First Guess
BASE H	18-km	NA	0	500/1000	NA
BASE I	18-km	NA	0	100/200	NA
BASE J	18-km	NA	0	10/100	NA
BASE K	18-km	80-km MM4	0	100/200	First Guess[B]
EXP 1A	18-km	36-km MM5	0	500/1000	First Guess
EXP 1B	18-km	36-km MM5	0	100/200	First Guess
EXP 1C	18-km	36-km MM5	0	10/100	First Guess
EXP 1D	18-km	36-km MM5	2	NA	First Guess
EXP 3A	12-km	36-km MM5	0	500/1000	First Guess
EXP 3B	12-km	36-km MM5	0	100/200	First Guess
EXP 3C	12-km	36-km MM5	0	10/100	First Guess
EXP 3D	12-km	36-km MM5	2	NA	First Guess
EXP 4A	12-km	12-km MM5	0	500/1000	First Guess
EXP 4B	12-km	12-km MM5	0	100/200	First Guess
EXP 4C	12-km	12-km MM5	0	10/100	First Guess
EXP 4D	12-km	12-km MM5	2	NA	First Guess
EXP 5A	4-km	36-km MM5	0	500/1000	First Guess
EXP 5B	4-km	36-km MM5	0	100/200	First Guess
EXP 5C	4-km	36-km MM5	0	10/100	First Guess
EXP 5D	4-km	36-km MM5	2	NA	First Guess
EXP 6A	4-km	12-km MM5	0	500/1000	First Guess
EXP 6B	4-km	12-km MM5	0	100/200	First Guess
EXP 6C	4-km	12-km MM5	0	10/100	First Guess
EXP 6D	4-km	12-km MM5	2	NA	First Guess

A. Base G CALMET simulation obtained an Error in MIXDT2 – HTOLD so run not completed
B. Base K did not do any diagnostic adjustments to the wind fields

Figure B-1 displays the wind speed and direction model performance statistical metric for the Base A through Base K CALMET sensitivity test simulations that used either the 80 km MM4 or no prognostic meteorological model data as input. The dark gray bar represents the CALMET model configuration that is consistent with the recommendations in the August 31, 2009 Clarification Memorandum. The numerical values of the model performance statistics are provided in Table B-2. CALMET sensitivity simulations Base D, H, I and K are the best performing simulations for winds from this group. Base D is the current recommended CALMET settings, whereas Base H and I use no MM4 data and Base K is like Base D only CALMET does not perform any diagnostic wind field adjustments. The wind speed statistics for Base D and K are identical, whereas the ones for Base H and I are slightly worse than Base D and K. The wind direction statistics for Base D and K are almost identical and again the ones for Base H and I are slightly worse.

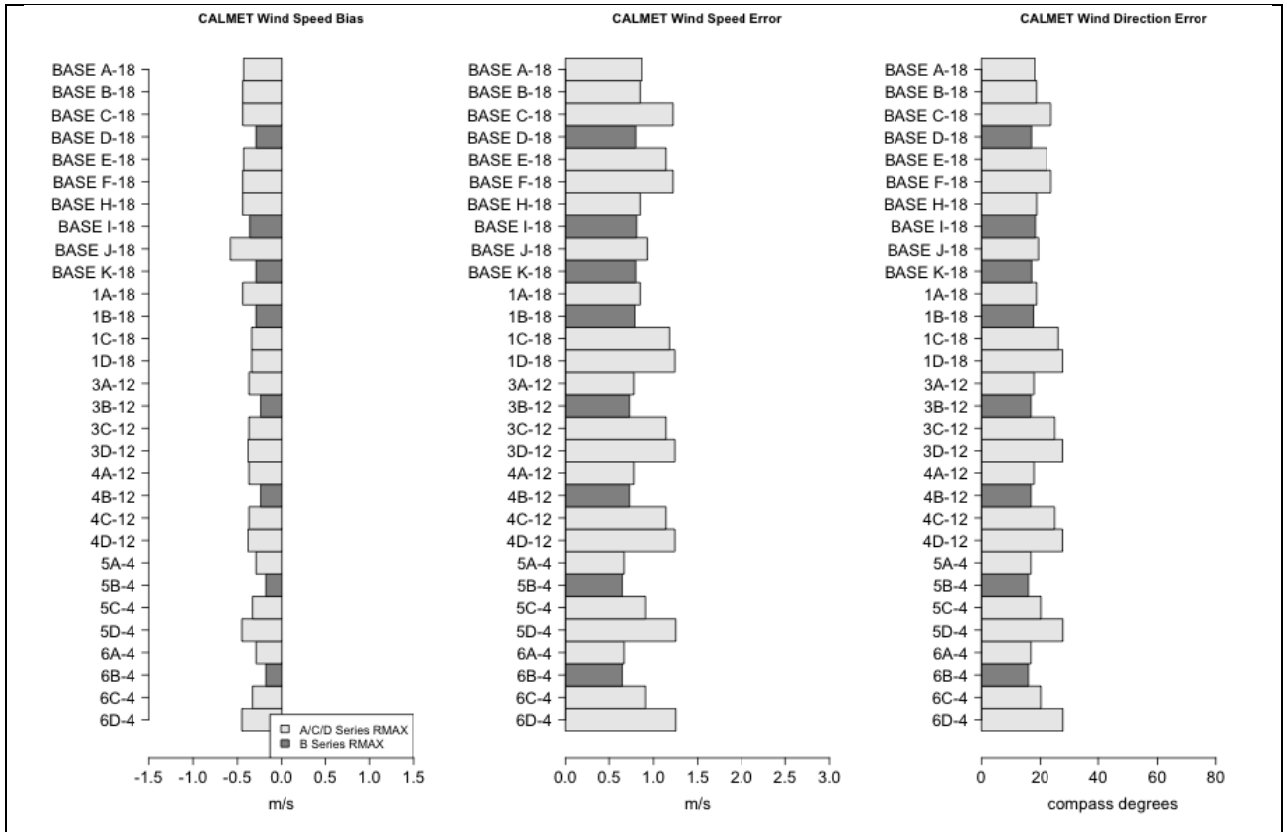


Figure B-1. Wind speed and wind direction comparisons with observations for CTEX3 CALMET sensitivity simulations.

Figure B-1 displays the wind speed and direction performance metrics for the second group of CALMET sensitivity tests that uses CALMET grid resolutions of 18 km (EXP1) and 12 km (EXP3 and EXP4) and uses 36 km MM5 (EXP1 and EXP3) and 12 km MM5 (EXP4) data as input to CALMET. EXP1B, EXP3B and EXP4B CALMET sensitivity tests all conform to the recommended settings in the Clarification Memorandum. The "B" series most closely matches observation data.

The CALMET model performance statistics for the final group of CTEX3 sensitivity tests corresponding to the EXP5 and EXP6 series of experiments are shown in Figure B-1. These experiments correspond to using a 4 km grid resolution in CALMET, which is the finest scale recommended in the Clarification Memorandum. They differ in the resolution of MM5 data used as input (36 or 12 km) and how observations are blended into the wind fields (different RMAX1/RMAX2 or no observations). When looking across all wind speed and direction statistics, the CALMET sensitivity simulations that conform to the CALMET settings in the August 2009 Clarification Memorandum (EXP5B and EXP6B) compare most closely to observations.

Figure B-1 displays the CALMET model performance statistics for all sensitivity tests that conform to the recommended CALMET settings in the Clarification Memorandum. The Clarification Memorandum specifies that prognostic meteorological model output data should be used as a first guess wind field in CALMET (IPROG = 14), but doesn't specify the resolution that the prognostic meteorological model should be run at. For the CALMET grid resolution, the Clarification Memorandum just specifies that it should be ≥ 4 km. Thus these CALMET sensitivity tests vary by grid resolution used in the prognostic meteorological model (80, 36 and 12 km) whose output is used as input to CALMET and the CALMET grid resolution (18, 12 and 4 km).

Table B-2a. Summary wind speed model performance statistics for the CALMET CTEX3 sensitivity tests.

RUN	WS Gross Error (ms^{-1})	WS Bias (ms^{-1})	WS RMSE (ms^{-1})	IOA
BASE A	0.87	-0.43		0.81
BASE B	0.85	-0.44	1.60	0.82
BASE C	1.22	-0.44	1.62	0.63
BASE D	0.80	-0.29	1.23	0.83
BASE E	1.14	-0.43	1.52	0.68
BASE F	1.22	-0.44	1.62	0.63
BASE G	NA	NA	NA	NA
BASE H	0.85	-0.44	1.30	0.82
BASE I	0.81	-0.36	1.30	0.82
BASE J	0.93	-0.58	1.36	0.80
BASE K	0.80	-0.29	1.23	0.83
EXP 1A	0.85	-0.44	1.29	0.82
EXP 1B	0.79	-0.29	1.22	0.83
EXP 1C	1.18	-0.34	1.57	0.68
EXP 1D	1.24	-0.34	1.64	0.65
EXP 3A	0.78	-0.37	1.26	0.83
EXP 3B	0.73	-0.24	1.20	0.85
EXP 3C	1.14	-0.37	1.52	0.70
EXP 3D	1.24	-0.38	1.64	0.65
EXP 4A	0.78	-0.37	1.26	0.83
EXP 4B	0.73	-0.24	1.20	0.85
EXP 4C	1.14	-0.37	1.52	0.70
EXP 4D	1.24	-0.38	1.64	0.65
EXP 5A	0.67	-0.29	1.24	0.84
EXP 5B	0.65	-0.18	1.19	0.85
EXP 5C	0.91	-0.33	1.31	0.80
EXP 5D	1.25	-0.45	1.25	0.65
EXP 6A	0.67	-0.29	1.24	0.84
EXP 6B	0.65	-0.18	1.19	0.85
EXP 6C	0.91	-0.33	1.31	0.80
EXP 6D	1.25	-0.45	1.66	0.65

Table B-2b. Summary wind direction model performance statistics for the CALMET CTEX3 sensitivity tests.

RUN	WD Gross Error (deg.)	WD Bias (deg.)
BASE A	18.06	0.73
BASE B	18.62	-0.74
BASE C	23.91	2.63
BASE D	16.92	0.40
BASE E	22.31	2.68
BASE F	23.91	2.63
BASE G	NA	NA
BASE H	18.70	-0.79
BASE I	18.22	-0.65
BASE J	19.30	-0.85
BASE K	16.97	0.38
EXP 1A	18.64	-0.72
EXP 1B	17.59	1.15
EXP 1C	26.43	2.99
EXP 1D	27.99	3.11
EXP 3A	17.80	-0.82
EXP 3B	16.75	0.98
EXP 3C	25.25	2.57
EXP 3D	27.93	2.94
EXP 4A	17.80	-0.82
EXP 4B	16.75	0.98
EXP 4C	25.25	2.57
EXP 4D	27.93	2.94
EXP 5A	16.73	-1.00
EXP 5B	15.85	0.72
EXP 5C	20.11	1.42
EXP 5D	28.05	2.43
EXP 6A	16.73	-1.00
EXP 6B	15.85	0.72
EXP 6C	20.11	1.42
EXP 6D	28.05	2.43

B.2 CONCLUSIONS OF CTEX3 CALMET SENSITIVITY TESTS

The evaluation of the CALMET modeling system using the CTEX3 field experiment database is not a true independent evaluation because some of the surface meteorological observations used as the evaluation database are also used as input into CALMET. Thus, care should be taken in the interpretation of the CALMET meteorological model evaluation. In fact, EPA has demonstrated that CALMET's blending of meteorological observations with MM5 prognostic meteorological model fields can actually produce unrealistic results in the wind fields (e.g., discontinuities around the wind observation sites) at the same time as improving the CALMET statistical model performance at the meteorological monitoring sites.

Given these caveats, when looking at the alternative CALMET settings for RMAX1/RMAX2 the CALMET configuration that best matches observed winds is with the 100/200 RMAX1/RMAX2 setting as recommended in the 2009 Clarification Memorandum. Other recommended settings in the 2009 Clarification Memorandum (e.g., use of prognostic meteorological data as the initial first guess wind field) are supported by the CALMET CTEX3 model evaluation. Note that better wind field comparisons using the 2009 Clarification Memorandum recommended settings for RMAX1/RMAX2 was also seen for the CTEX5 CALMET evaluation presented in Appendix A.

Although the CALMET meteorological model performance evaluation for alternative model settings support the recommended 100/200 CALMET settings for RMAX1/RMAX2 in the Clarification Memorandum, the evaluation of the CALPUFF/CALMET modeling system for the CTEX3 and CTEX5 field experiments against observed tracer data presented in Chapter 5 come to an alternative conclusion. The CALPUFF/CALMET evaluation against the observed tracer observations in the CTEX3 and CTEX5 experiments found that different RMAX1/RMAX2 configurations produced better CALPUFF/CALMET tracer model performance for the two CAPTEX experiments, but that the 100/200 recommended setting always produced the worst CALPUFF/CALMET model performance. Given the large differences in the in the rankings of the ability of the CALPUFF to reproduce the observed tracer concentrations across the different meteorological model configurations in the two CAPTEX field experiments, it is unclear whether a third experiment would produce another set of rankings.

Appendix C

INTERCOMPARISON OF SIX LRT MODELS AGAINST THE CAPTEX RELEASE 3 AND RELEASE 5 FIELD EXPERIMENT DATA

C.1 INTRODUCTION

In this section, the evaluation of six LRT dispersion models (CALPUFF, SCIPUFF, HYSPLIT, FLEXPART, CAMx, and CALGRID) against the Cross Appalachian Tracer Study (CAPTEX) (Section 5) is presented. The ATMES-II evaluation framework described in Section 2.4.3.1 and 2.4.3.3 are utilized to conduct this evaluation. The CAPTEX evaluations generally follow the ETEX evaluation paradigm, all models presented in this section use a common 36 km MM5 meteorological data source. Thus the results from the CALMET/CALPUFF sensitivities are not presented because they are not within the scope of this evaluation framework. However, we do wish to note that CALPUFF/CALMET performance for CAPTEX-5 (EXP6C) was quite good, and exceeded that of the other models involved in the model intercomparison portion of this section; however, due to a different source of meteorology, only the MMIF/CALPUFF results for the same MM5 run and grid resolution are included.

In addition to the six model intercomparison, sensitivities of the HYSPLIT INITD and CAMx vertical diffusion and horizontal advection solver (Kz/advection solver) combinations are also presented. The best performing INITD and Kz/advection solver combinations are presented for purposes of model intercomparison.

C.2 HYSPLIT SENSITIVITY TESTS

Consistent with the approach taken for evaluating HYSPLIT for the European Tracer Experiment discussed in Section 6.4.5, HYSPLIT was evaluated using each of the nine INITD model configurations. The HYSPLIT INITD option defines the technical formulation of the dispersion model from fully particle to fully Lagrangian puff with several hybrid particle/puff combinations. A description of the INITD variable options is provided in Table 6-4. The HYSPLIT configurations for each INITD option are presented in Table C-1.

Table C-1. HYSPLIT sensitivity runs and relevant configuration parameters.

Sensitivity Test	INITD	NUMPAR	ISOT	KSPL	FRHS	FRVS	FRTS	FRME
INITD0	0	10000	1	NA	NA	NA	NA	NA
INITD1	1	10000	1	1	1.0	0.01	0.10	0.10
INITD2	2	10000	1	1	1.0	0.01	0.10	0.10
INITD3	3	10000	1	1	1.0	0.01	0.10	0.10
INITD4	4	10000	1	1	1.0	0.01	0.10	0.10
INITD103	103	10000	1	1	1.0	0.01	0.10	0.10
INITD104	104	10000	1	1	1.0	0.01	0.10	0.10
INITD130	130	10000	1	1	1.0	0.01	0.10	0.10
INITD140	140	10000	1	1	1.0	0.01	0.10	0.10

C.2.1 HYSPLIT SPATIAL PERFORMANCE FOR CAPTEX RELEASE 3

Figure C-1 displays the spatial model performance statistics for the HYSPLIT INITD sensitivity tests. Unlike the results from the HYSPLIT sensitivities from ETEX, the variation in spatial performance is much smaller. While the puff based INITD configurations showed slightly lower scores for POD, their scores for all other spatial categories is nearly identical to the other INITD configurations. INITD3 has the highest FMS score (34%) with INITD1 nearly the same at 33%. Consistent with the ETEX results, the puff configuration INITD1 (Gh-Thv) yielded slightly better performance statistics across spatial categories than the INITD2 puff configuration (Thh-Thv). Overall for CAPTEX Release 3, there appears to be little advantage of one INITD configuration over another for the four spatial categories of model performance metrics.

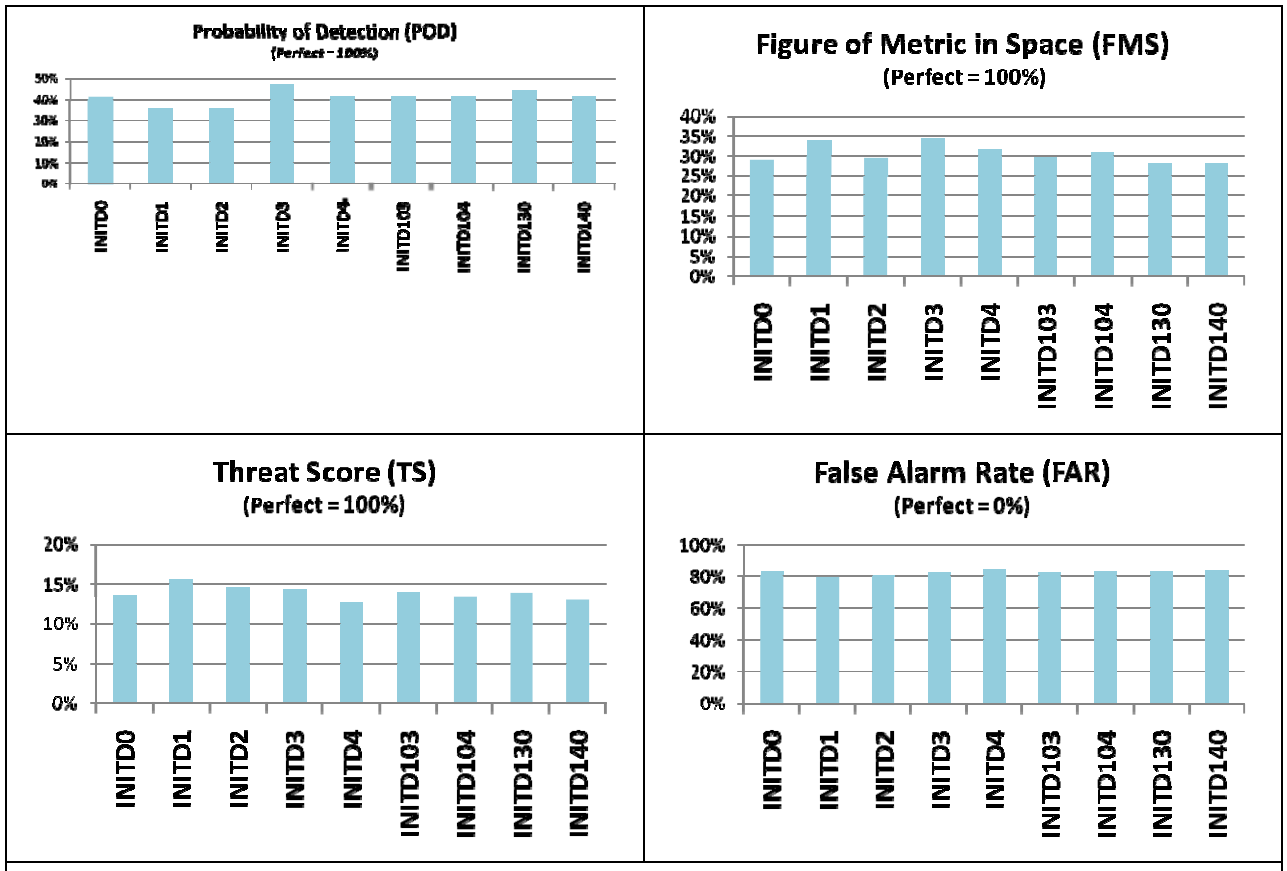


Figure C-1. Spatial model performance statistics for nine HYSPLIT INITD sensitiviity experiments for CAPTEX Release 3.

C.2.2 HYSPLIT GLOBAL STATISTICS FOR CAPTEX RELEASE 3

Figures C-2 and C-3 display the global statistics for the HYSPLIT sensitivity tests with Figures C-2 and C-3 containing the statistical metrics where the best performing model has the, respectively, lowest and highest score. For the FOEX metrics, INITD140 scores the best with nearly 0%, followed closely by INITD1 and INITD2. INITD3 scores the poorest with a 21% FOEX score followed by INITD4. The two puff configurations had the poorest NMSE and FB statistical performance metrics (with values of approximately 127 and 130 pg m^{-3} for error and 1.56 and 1.57 for FB). The four puff-particle model configuration options (INITD3,4,103,104) exhibited the best overall scores for both NMSE and FB. INITD1 and INITD2 exhibited the best overall KSP score with 30% and 31% respectively, with the poorest performing being INITD3 with 49%.

For the within a factor of 2 and 5 metric (FA2 and FA5, Figure C-3, top), the hybrid puff-particle configurations INITD3 and INITD4 and their counterpart particle-puff configurations INITD103 and INITD104 perform slightly better than the other configurations. For the PCC metric (PCC, Figure C.2.2-2, bottom left), all of the HYSPLIT configurations show a slight negative correlation ranging from -0.04 to -0.09.

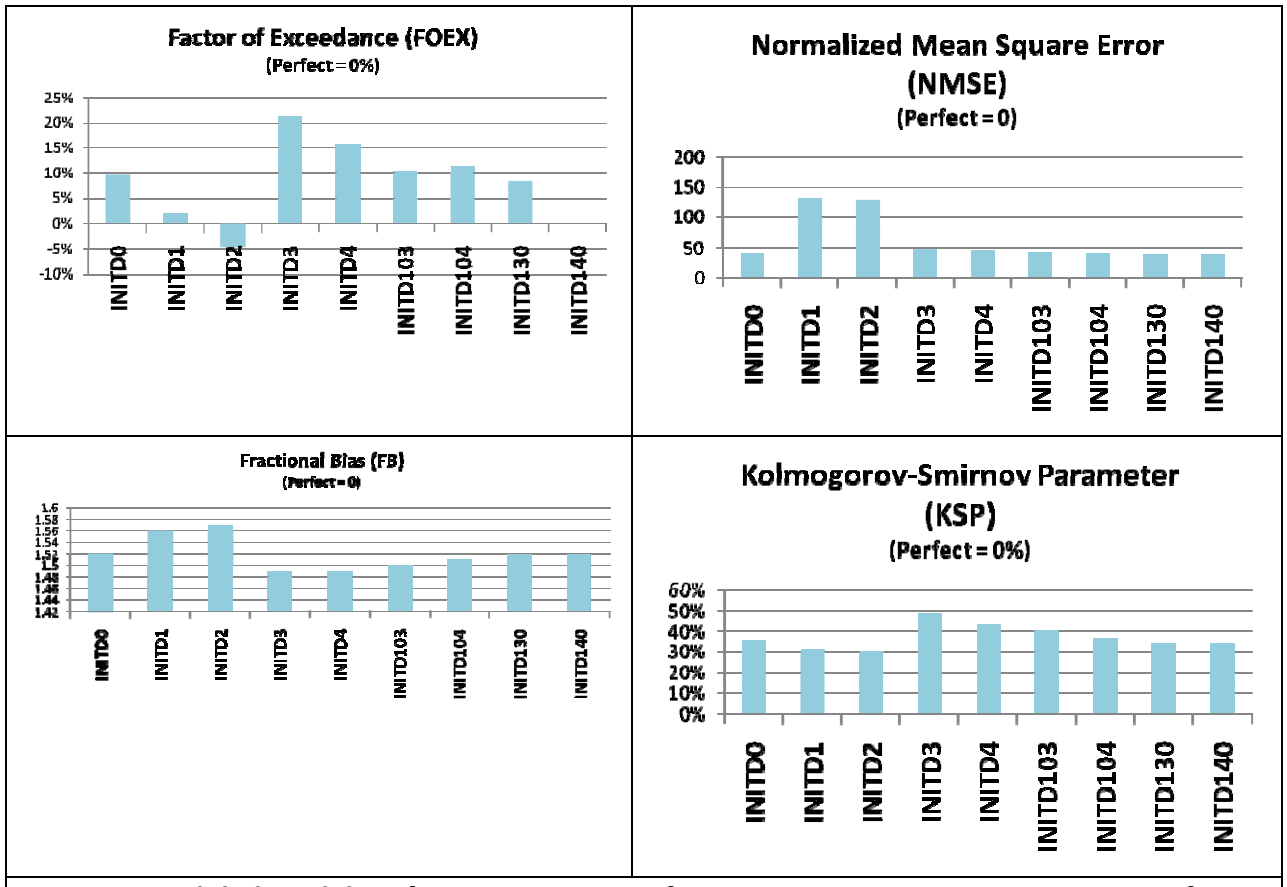


Figure C-2. Global model performance statistics for nine HYSPLIT INITD sensitivity tests for CAPTEX Release 3.

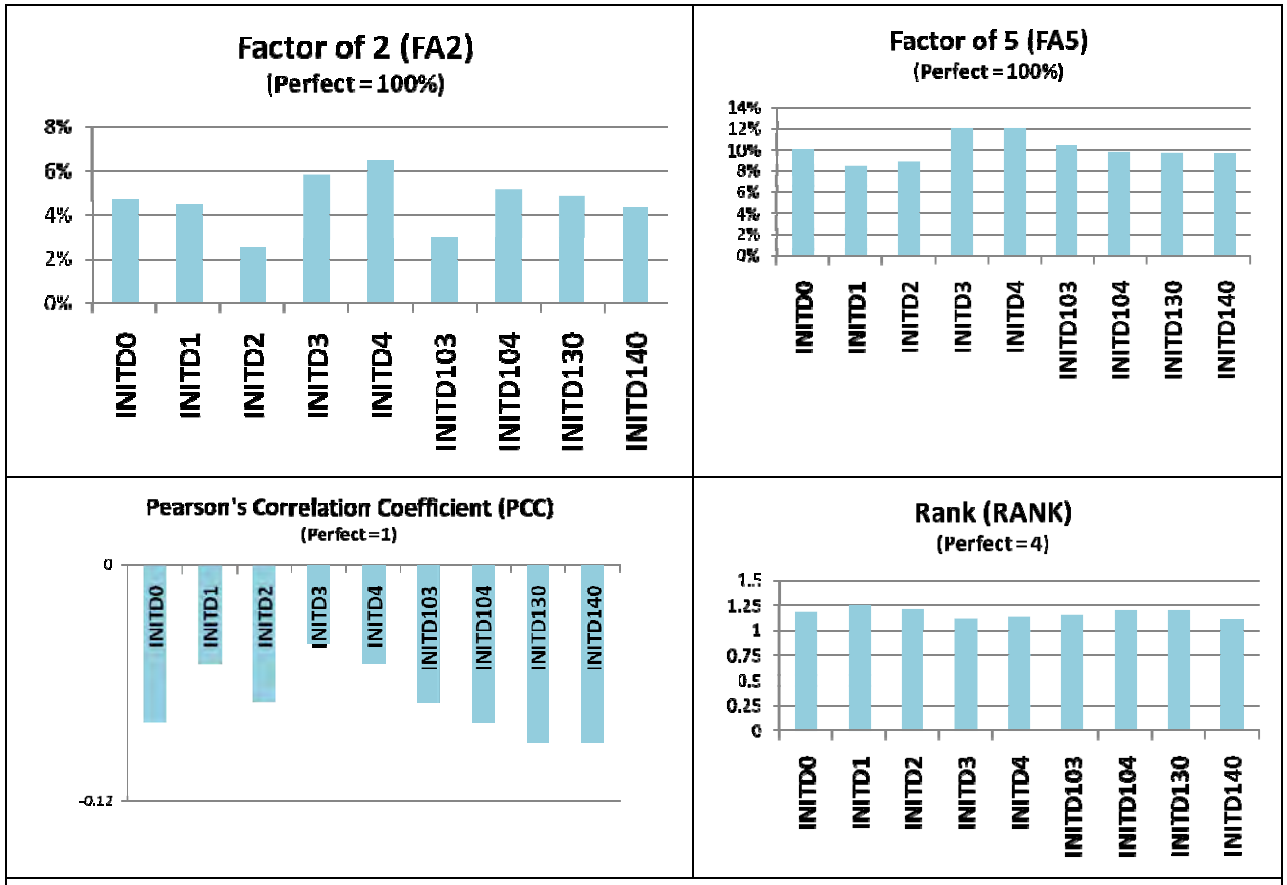


Figure C-3. Global model performance statistics for nine HYSPLIT INITD sensitivity tests for CAPTEX Release 3.

The final panel in Figure C-3 (bottom right) displays the overall RANK statistic. The RANK statistics orders the model performance of the HYSPLIT INITD configurations as follows:

1. INITD1 (1.25)
2. INITD2 (1.21)
3. INITD104 (1.19)
4. INITD130 (1.19)
5. INITD0 (1.18)
6. INITD103 (1.15)
7. INITD4 (1.14)
8. INITD3 (1.11)
9. INITD140 (1.10)

The RANK performance statistics results presented above raise some interesting questions about the RANK metric. The puff based configurations (INITD1 and INITD2) are the highest ranking with scores using the RANK metric with values of 1.25 and 1.21 respectively. However, each of these options had the worst (highest) NMSE and FB scores, while puff-particle configurations ranking slightly less using the RANK metric (1.1 to 1.19) have NMSE scores that are much better (only one-third) those for the puff configurations as well as slightly lower FB scores. On the basis of RANK scores, the INITD1 and INITD2 configurations are the best performing, but based upon other model performance statistics that are not included as the four statistical metrics that make up the RANK metric (i.e., PCC, FB, FMS and KSP), the puff-particle hybrid configurations are better performing. Thus care must be taken in interpreting model performance based solely on the RANK score and its use in performing model intercomparisons and we recommend examining the whole suite of statistical performance metrics, as well as graphical representation of model performance, to come to conclusions regarding model performance.

C.2.3 HYSPLIT SPATIAL STATISTICS FOR CAPTEX RELEASE 5

Figure C-4 displays the spatial model performance statistics for the HYSPLIT INITD sensitivity tests for CAPTEX Release 5. Overall, the spatial performance for this experiment is very similar to the results obtained from the ETEX INITD sensitivities for HYSPLIT. The puff configurations (INITD1 and INITD2) exhibited the poorest performance across all of the spatial statistics. INITD2 had the poorest FMS score with 5%, followed by INITD1 with 9.6%. INITD3 had the best FMS score of 19.66%, but less than 2% separated all of the remaining particle and puff-particle INITD configurations. The particle mode (INITD0) exhibited the best TS with 24.4% with less than 1.5% separating INITD103, 130, and 140 from INITD0. Consistently, the puff configurations exhibited the lowest TS among the nine configurations, both with 7.9%.

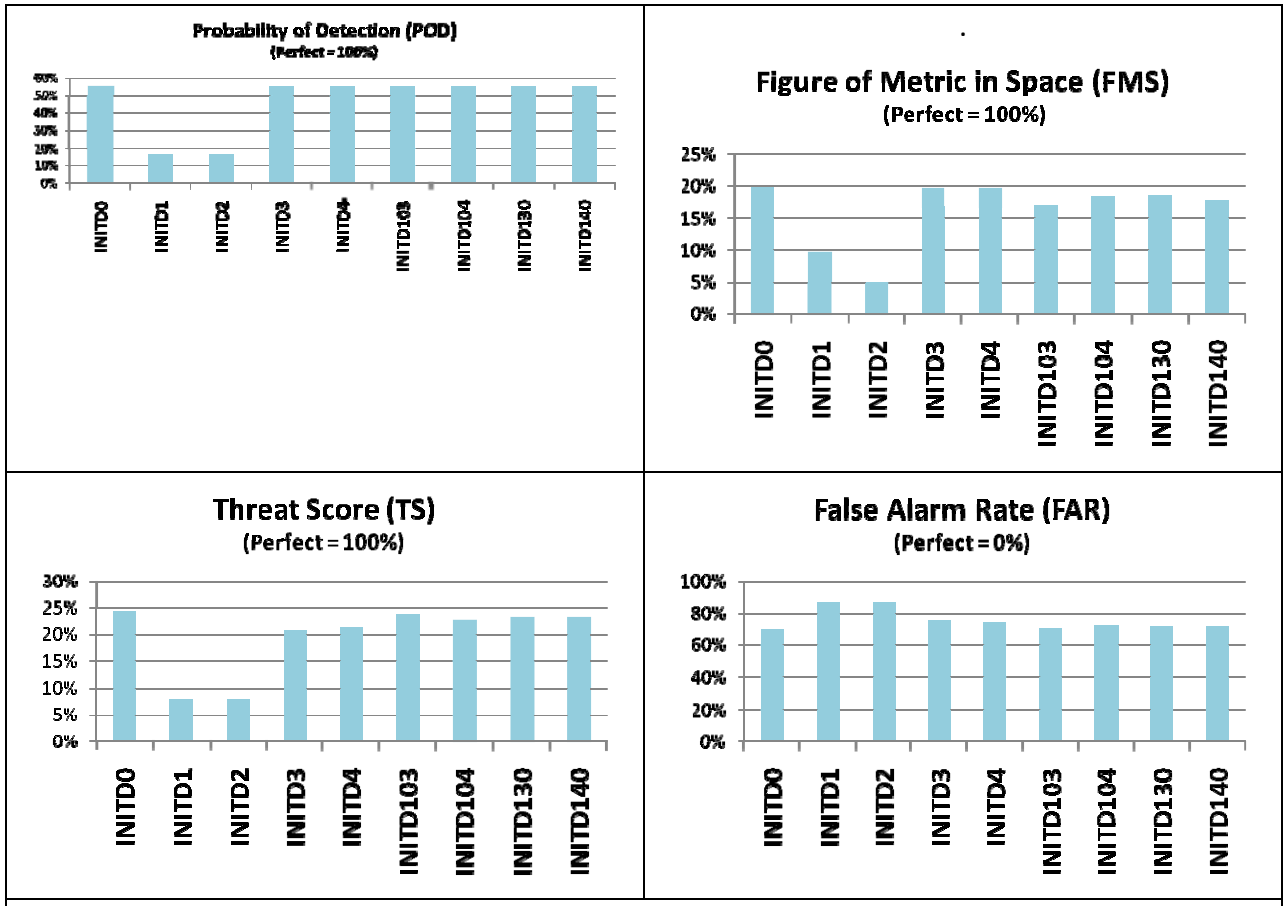


Figure C-4. Spatial model performance statistics for nine HYSPLIT INITD sensitiviity experiments for CAPTEX Release 5.

C.2.4 HYSPLIT GLOBAL STATISTICS FOR CAPTEX RELEASE 5

Figures C-5 and C-6 display the global statistics for the HYSPLIT sensitivity tests for CAPTEX Release 5 where the two figures containing the statistical metrics where the best performing model has the, respectively, lowest and highest score. For the FOEX metrics (Figure C-5, top left), INITD3 and INITD4 showed the best scores with -3% and -7.9% respectively. INITD2 scored the poorest with a -22% FOEX score followed by INITD1 with -18.3%. The two puff configurations had the poorest NMSE and FB statistical performance metrics (with values of approximately 72.7 and 63.6 pg m^{-3} for error and 1.45 and 1.41 for FB). INITD3 exhibited the best overall scores for both NMSE and FB (16.6 pg m^{-3} and 0.88 respectively. INITD1 and INITD2 exhibited the poorest KSP scores with 44% and 48% respectively. INITD104 had the best KSP score with 28%, followed by INITD4 (30%), INITD0 and INIT130 (31%), and INITD140 (32%).

For the within a factor of 2 and 5 metric (FA2 and FA5, Figure C-6, top), the puff INITD configurations performed the poorest with scores between 0% - 1% for FA2 and 1% - 4.8% for FA5. INITD0 showed the best FA2/FA5 scores with 6.9%/11.8%, followed by INITD130 and INITD140 for FA2 and INITD3 and INITD4 for FA5. Curiously, INITD3 and INITD4 had slightly lower FA2 scores (3.4%/2.8%) than the other puff-particle hybrid configurations, but higher FA5 scores. For the PCC metric (PCC, Figure C-6, bottom left), INITD3 had the highest score with 0.63, followed closely by the other puff-particle or particle configurations ranging from 0.51 (INITD0) to 0.62 (INITD2).

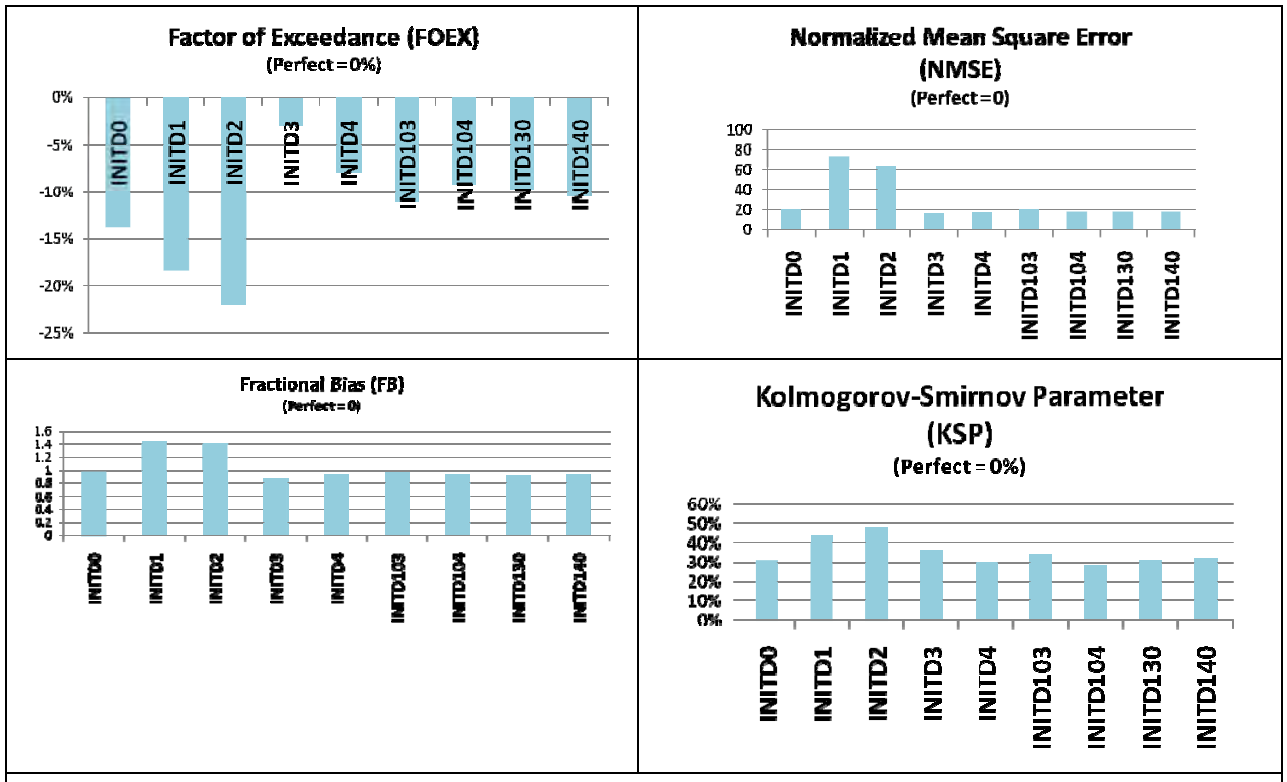


Figure C-5. Global model performance statistics for nine HYSPLIT INITD sensitivity tests for CAPTEX Release 5.

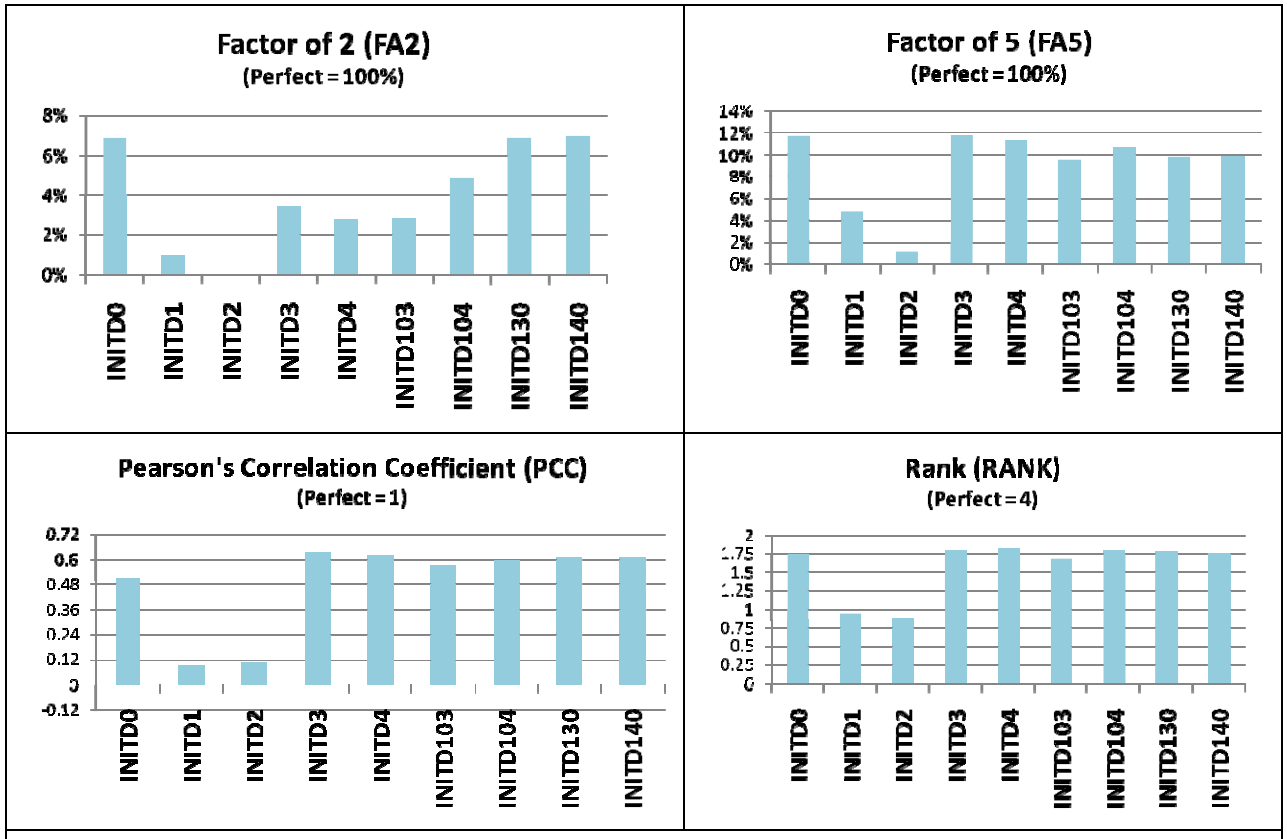


Figure C-6. Global model performance statistics for nine HYSPLIT INITD sensitivity tests for CAPTEX Release 5.

The final panel in Figure C-6 (bottom right) displays the overall RANK statistic. The RANK statistics orders the model performance of the HYSPLIT INITD configurations are as follows:

1. INITD4 (1.82)
2. INITD104 (1.80)
3. INITD3 (1.79)
4. INITD130 (1.78)
5. INITD140 (1.76)
6. INITD0 (1.75)
7. INITD103 (1.68)
8. INITD1 (0.94)
9. INITD2 (0.88)

C.3 CAMX SENSITIVITY TESTS

Following the general design of the study for the ETEX tracer database, CAMx sensitivity tests described in Section 6.4.3, thirty-two CAMx sensitivity tests were conducted to investigate the effects of vertical diffusion, horizontal advection solvers and use of the sub-grid scale Plume-in-Grid (PiG) module on the model performance for the CAPTEX tracer experiment releases 3 and 5. In addition to the sixteen sensitivities conducted for ETEX, a similar set of sensitivity analyses were conducted using the newer ACM2 vertical diffusion scheme (Pleim, 2007; ENVIRON, 2010) introduced into CAMx as of Version 5.20 as an alternative to the more traditional fully K-theory vertical diffusion schemes that were the only options available in previous versions of CAMx.

C.3.1 SPATIAL PERFORMANCE FOR CTEX3 NOPIG EXPERIMENTS

Figure C-7 displays the CAMx spatial model performance statistics for the sensitivity tests that were run without using the PiG subgrid-scale puff module. For the FMS statistic, the ACM2, TKE, and CMAQ Kz exhibit very similar performance (40.9%, 40.9%, and 39.4% respectively). OB70 exhibits the poorest performance with 33.5% for FMS.

For the FAR statistic, ACM2/Bott has the best score (55.6%) followed by TKE/PPM and ACM2/PPM (tied at 58.5%). Overall ACM2 is the best performing vertical diffusion formulation and PPM performs better than BOTT for horizontal advection using the FAR statistic.

For the POD and TS spatial statistics, the CMAQ, TKE, and ACM2 vertical diffusion algorithms perform similarly, and all are substantially better than the OB70 approach (15% lower than other vertical diffusion schemes). ACM2/BOTT has the best TS score with 28.6% followed by ACM2/PPM and TKE/PPM (tied at 28.33%). CMAQ/PPM exhibits the best POD score with 52.8% followed by CMAQ/BOTT, ACM2/PPM, and TKE/PPM (tied at 47.2%). Consistent with the ETEX spatial results, there are much smaller differences in the model performance using the two advection solvers for the POD and TS statistics compared to differences between Kz options.

In summary, based on the spatial statistics, the ACM2, CMAQ, and TKE Kz algorithms appear to be performing similarly, with the older OB70 option exhibiting much poorer overall performance. The differences in vertical diffusion algorithms have a greater effect on CAMx model performance than the differences in horizontal advection solvers.

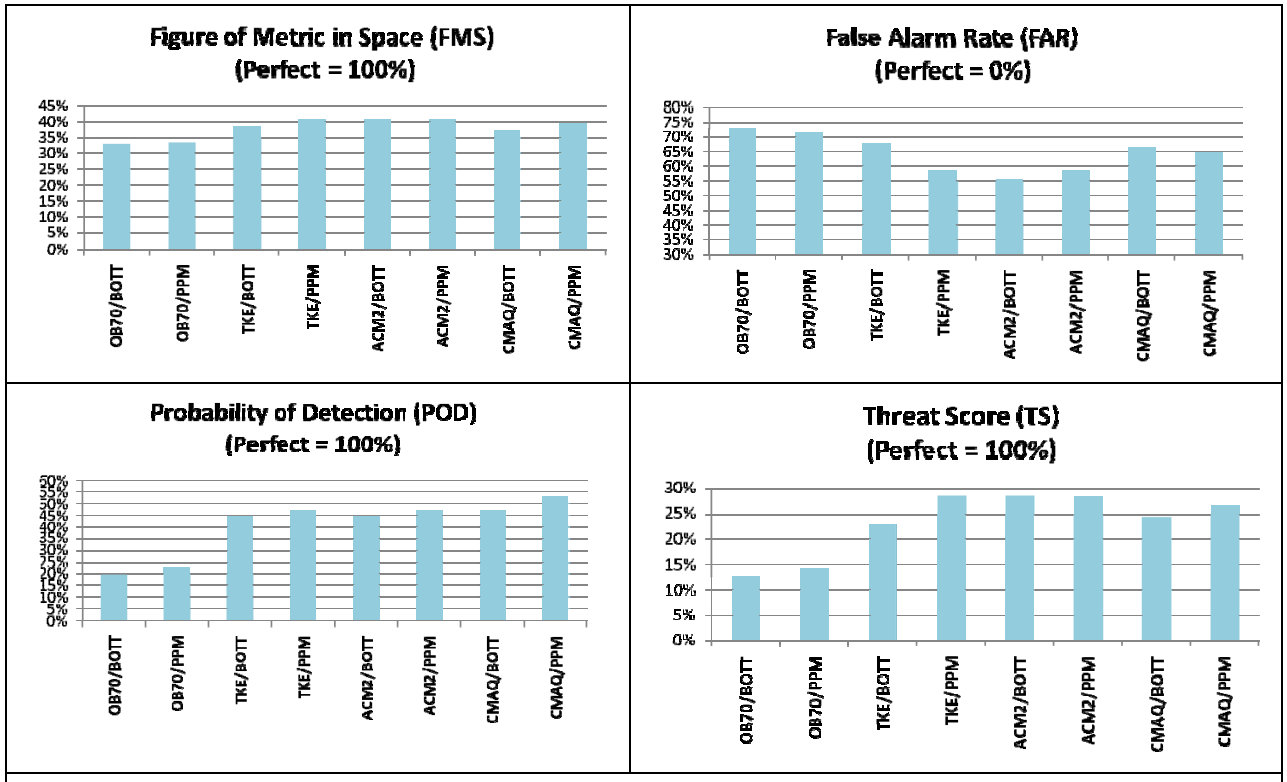


Figure C-7. Spatial model performance statistics for the CAMx sensitivity tests without using the PiG subgrid-scale puff module (NoPiG) for CAPTEX Release 3.

C.3.2 Global Statistical Performance for CTEX3 NoPiG Experiments

Figures C-8 and C-9 displays the global statistics for the CAMx NoPiG sensitivity and contain the statistical metrics where the best performing model has the, respectively, lowest and highest score. For the FOEX metric, the vertical diffusion algorithm that has the best score was the ACM2 algorithm with scores of 3.26% (ACM2/BOTT) and 3.6% (ACM2/PPM). The next best vertical diffusion algorithm/advection solver combination was OB70/BOTT with a -3.8% FOEX score. The CMAQ/BOTT (9.1%) and CMAQ/PPM (9.6%) have the highest (worst) FOEX scores.

For the NMSE statistical performance metric, the ACM2 and TKE vertical diffusion schemes perform best (28 to 30 pgm^{-3}) (Figure C-8, top right). Both OB70 scenarios yielded the poorest NMSE scores with error values more than twice that of the other Kz/advection solver configurations. Consistent with both FOEX and NMSE, the ACM2 vertical diffusion scheme is also the best performing method according to the FB and KSP metrics followed by the TKE scheme (Figure C-8, bottom left). The OB70 vertical diffusion algorithm performs the poorest for both of the FB and KSP metrics.

For the within a factor of 2 and 5 metrics (FA2/FA5, Figure C-9, top), the ACM2 combinations are the best performing with values of 8.8%/17.1% and 8.2%/16.3%. The TKE and CMAQ combinations perform similarly, with the TKE options having slightly higher FA2 percentages, but the CMAQ combinations exhibit higher FA5 percentages than the TKE.

For the PCC metric, the CMAQ and TKE combinations yield the best correlation performance with values ranging from 0.54 to 0.63 with CMAQ having slightly higher correlation values overall. Interestingly, for most other spatial and global statistical categories for the NoPiG tests

ACM2 Kz combinations rank as the best performing. However, the ACM2 Kz combinations have the lowest PCC correlation values of the four Kz combinations, with values of 0.22 and 0.30.

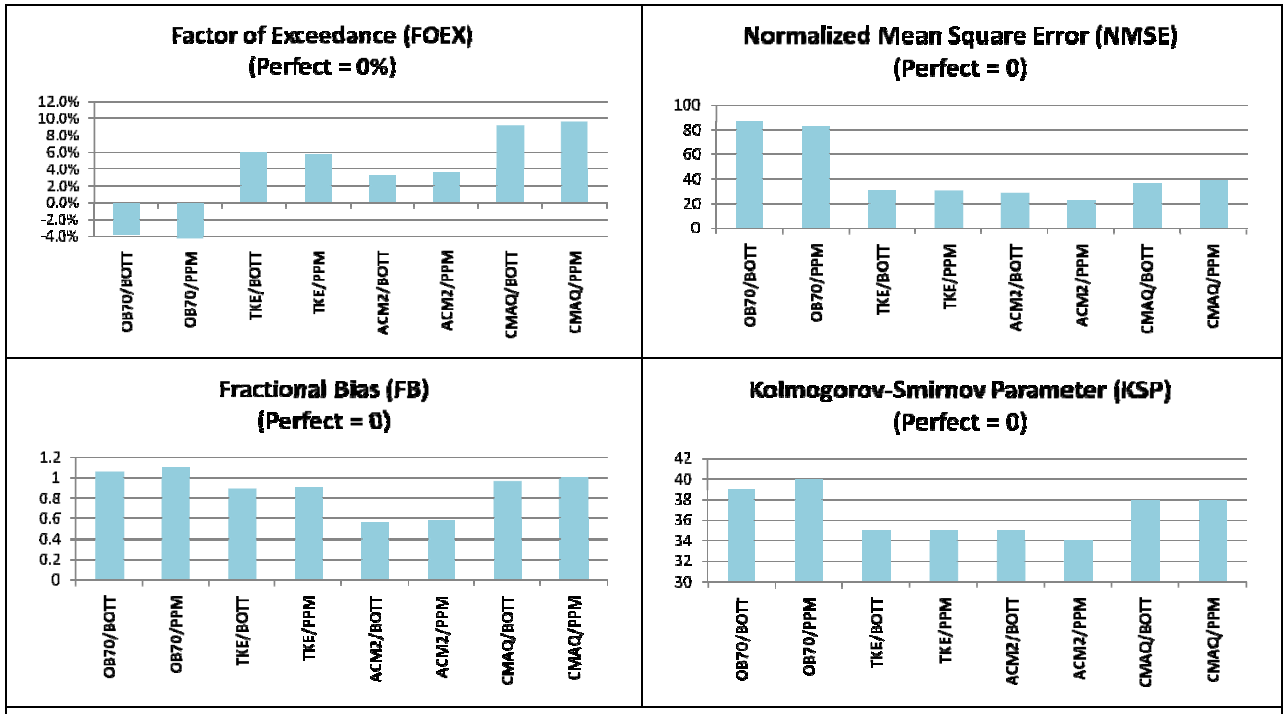


Figure C-8. Global model performance statistics for the CAMx sensitivity tests without using the PiG subgrid-scale puff module for CAPTEX Release 3.

The final panel in Figure C-9 (bottom right) displays the overall RANK statistic. The RANK statistics orders the model performance of the CAMx configurations without PiG as follows:

1. TKE/PPM (1.97)
2. CMAQ/PPM (1.91)
3. TKE/BOTT (1.89)
4. ACM2/PPM (1.87)
5. CMAQ/BOTT (1.83) (tied)
6. ACM2/BOTT (1.83) (tied)
7. OB70/PPM (1.67)
8. OB70/BOTT (1.56)

Based on this analysis, the TKE Kz coefficients is the best performing vertical diffusion approach followed closely by CMAQ. As noted previously, the vertical diffusion algorithm has a greater effect on CAMx model performance compared to the choice of horizontal advection solvers.

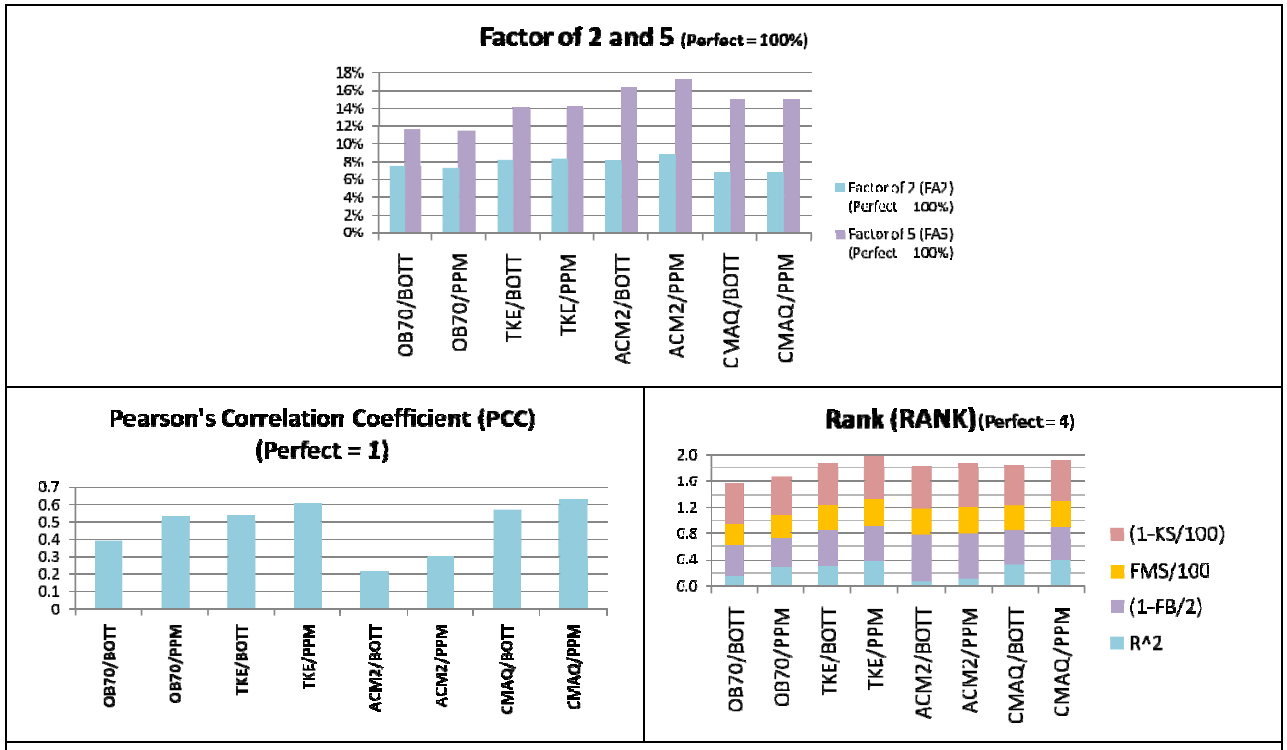


Figure C-9. Global model performance statistics for the CAMx sensitivity tests without using the PiG subgrid-scale puff module for CAPTEX Release 3.

C.3.3 SPATIAL PERFORMANCE FOR CTEX3 PIG EXPERIMENTS

Figure C-10 displays the CAMx spatial model performance statistics for the sensitivity tests that were run using the PiG subgrid-scale puff module. For the FMS statistic, the CMAQ Kz/BOTT combination has the best performance at 36.2%. TKE/BOTT and TKE/PPM followed closely with FMS scores of 36% and 35.6% respectively. OB70 exhibits the poorest performance with 23.5% for FMS.

For the FAR statistic, ACM2/Bott has the best score (61.5%) followed by TKE/BOTT and ACM2/PPM (62.8% and 63% respectively). OB70 exhibited the poorest performance with a 72% FAR. For the POD metric, the TKE/BOTT combination performs substantially better than the other Kz/advection solver combinations (44.4%). Both OB70 scenarios showed the poorest performance at 13.9%. For the TS spatial metric, the CMAQ/PPM exhibits the best score with 30.6% followed by TKE/BOTT and CMAQ/BOTT(25.4% and 23.3% respectively). OB70 again performs poorest with a TS value of 10.2% for both advection solver combinations. Consistent with the ETEX spatial results, there are much smaller differences in the model performance using the two advection solvers for the POD and TS statistics compared to differences between Kz options.

In summary, the effect of using the CAMx subgrid scale puff module appears to slightly degrade performance in comparison to the NoPiG experiments. A similar pattern was noted in the spatial statistics compared to the NoPiG experiments with the ACM2, CMAQ, and TKE Kz algorithms performing similarly, with the older OB70 option exhibiting much poorer overall performance.

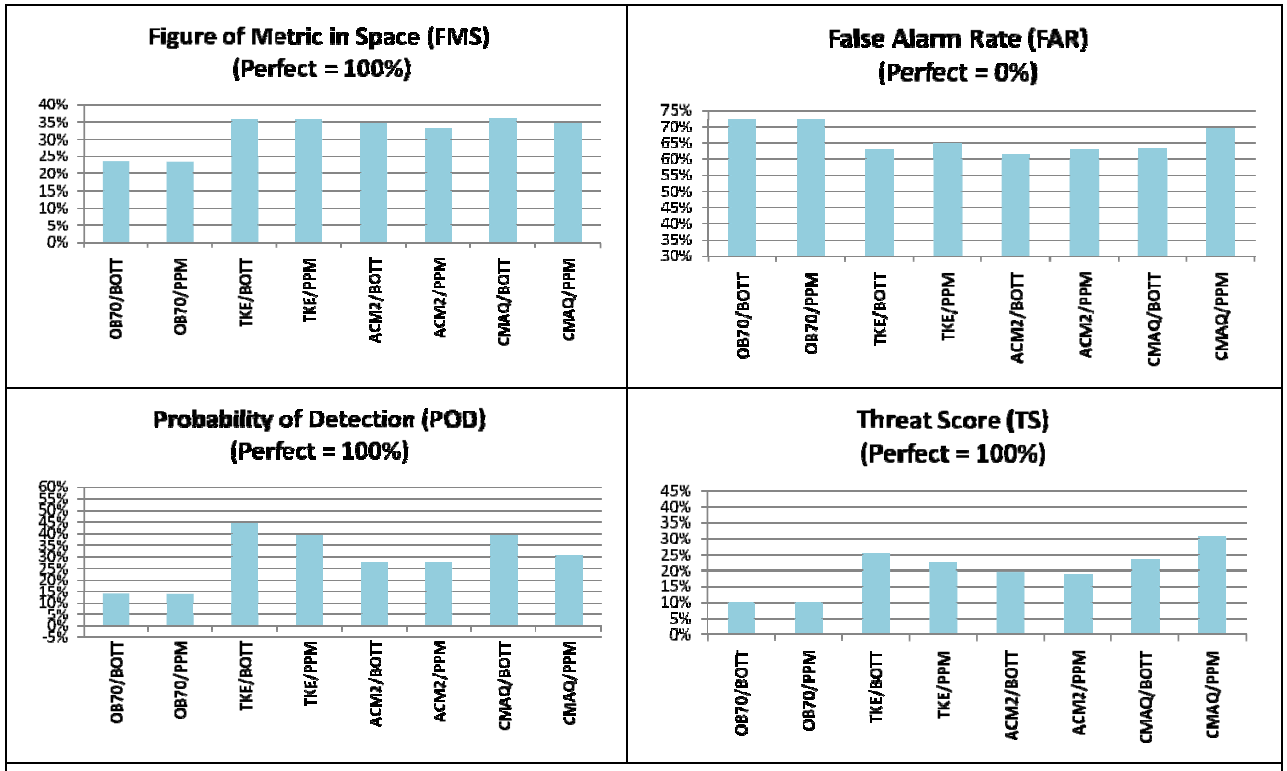


Figure C-10. Spatial model performance statistics for the CAMx CTEX3 sensitivity tests using the PiG subgrid-scale puff module (PiG).

C.3.4 GLOBAL STATISTICAL PERFORMANCE FOR CTEX3 CAMX PIG SENSITIVITY TESTS

Figures C-11 and C-12 displays the global statistics for the CAMx NoPiG sensitivity tests with the two figures containing the statistical metrics where the best performing model has the, respectively, lowest and highest score. For the FOEX metric, the vertical diffusion algorithm has the biggest effect was the TKE and CMAQ algorithms with scores near zero. The OB70 combinations exhibit significantly poorer FOEX performance with values of -13.6% (OB70/BOTT) and -16.9% (OB70/PPM).With the NMSE statistical performance metric, the ACM2 and TKE vertical diffusion schemes performs best (38 – 42 pgm^{-3}) (Figure C-11, top right). Both OB70 scenarios yielded the poorest scores with error values more than twice that of the other Kz/advection solver configurations (111 – 116 pgm^{-3}). For fractional bias (Figure C-11, bottom left), the ACM2 combinations have the best scores with 0.58/0.59 (BOTT/PPM). TKE Kz combinations follow with values 0.82/0.83 (BOTT/PPM). OB70 again has the poorest FB performance with values of 1.18/1.19 (BOTT/PPM).

For the within a factor of 2 and 5 metrics (FA2 and FA5, Figure C-12, top), ACM2, TKE, and CMAQ are very similar for FA2, but the TKE Kz option clearly performs best for the FA5 metric, followed by CMAQ. There is essentially no difference in the PCC statistic using the two horizontal advection solvers. According to the PCC metric (Figure C-11, bottom right), CMAQ is the best performing vertical diffusion approach (0.52/0.59 – BOTT/PPM) followed by TKE (0.33/0.44 – BOTT/PPM)ACM2 has the lowest PCC values with scores 0.17 – 0.23 (BOTT/PPM).

The final panel in Figure C-12 (bottom right) displays the overall RANK statistic. The RANK statistics orders the model performance of the CAMx configurations with PiG as follows:

1. CMAQ/PPM (1.86)

2. TKE/PPM (1.83)
3. CMAQ/BOTT (1.81)
4. TKE/BOTT (1.74)
5. ACM2/BOTT (1.69)
6. ACM2/PPM (1.68)
7. OB70/PPM (1.26)
8. OB70/BOTT (1.25)

Based on this analysis, the CMAQ Kz coefficients are the best performing vertical diffusion approach followed closely by TKE. Consistent with the NoPiG experiments, the vertical diffusion algorithm has a greater effect on CAMx model performance compared to the choice of horizontal advection solvers.

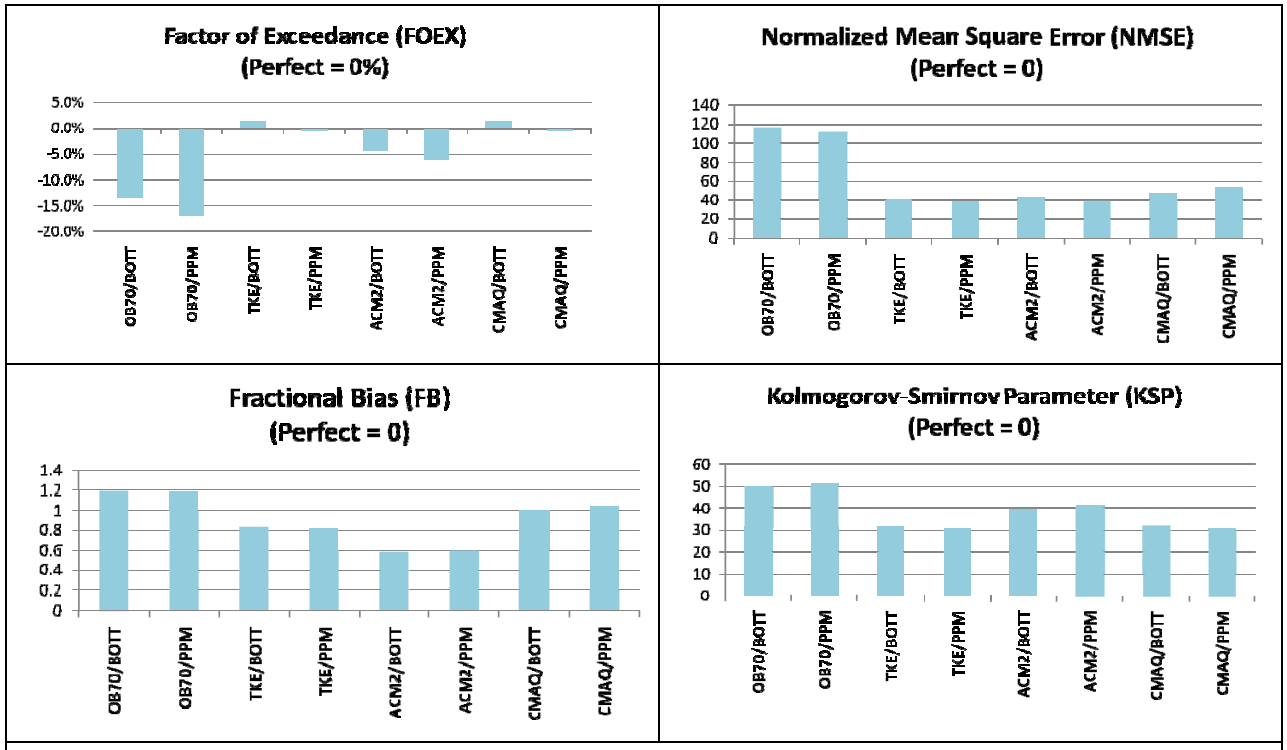


Figure C-11. Global model performance statistics for the CAMx CTEX3 sensitivity tests using the PiG subgrid-scale puff module.

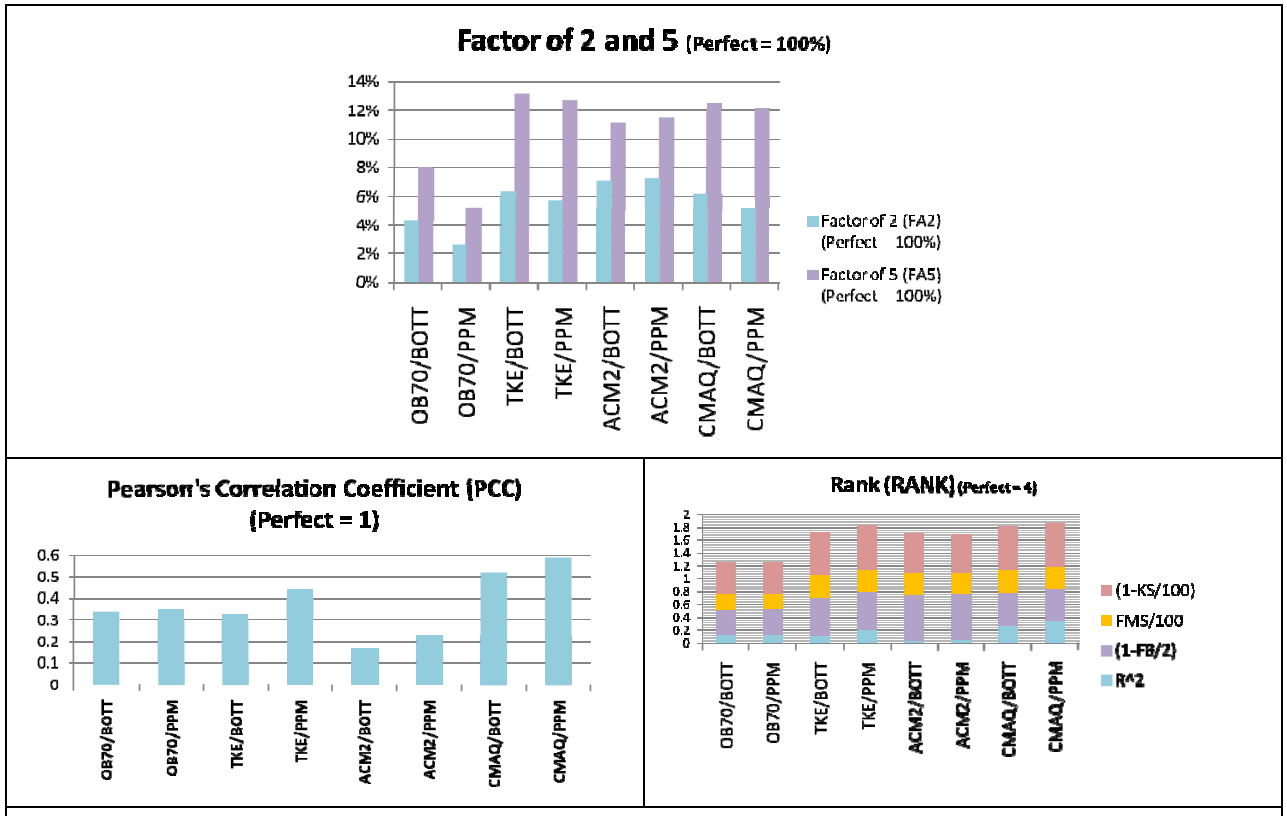


Figure C-12. Global model performance statistics for the CAMx CTEX3 sensitivity tests using the PiG subgrid-scale puff module.

C.3.4.1 EFFECT OF PIG ON MODEL PERFORMANCE

The effect of using the PiG module versus NoPiG results in similar results as seen in the ETEX experiments for CAMx; use of the subgrid-scale PiG module has very little effect on the CAMx model performance and the rankings of the CAMx model performance using the alternative vertical mixing and horizontal advection approaches. In general, it appears that the CAMx model performance without the PiG is performing slightly better than its performance using the PiG.

The spatial performance statistics are sometimes improved and sometimes degraded when the PiG module is invoked. For the global statistics, the PCC performance statistic is degraded by -11% to -37% (-0.03 to -0.13 points) when the PiG module is invoked. Similarly, use of the PiG versus NoPiG module increases (degrades) the FB metric by 5 to 18 percent and also increases (degrades) the NMSE metrics for all model configurations.

Table C-2 summarizes the RANK model performance statistic for the different CAMx model configurations with and without the PiG module. For each model vertical diffusion/horizontal advection configuration, using the PiG module always results in slightly lower RANK statistics that are from -3.9% to -8.5% lower than when the PiG module is not used.

Table C-2. CTEX3 CAMx RANK model performance statistic and model rankings for different model Kz/advection solver configurations with and without using the PiG subgrid-scale puff model.

Model Configuration	Without PiG Module		With PiG Module		PiG-NoPiG	
	RANK	Model Ranking	RANK	Model Ranking	ΔRANK	Percent
OB70/BOTT	1.56	8	1.25	8	-0.41	-26.4%
OB70/PPM	1.67	7	1.26	7	-0.41	-24.5%
TKE/BOTT	1.89	3	1.74	4	-0.15	-8.0%
TKE/PPM	1.97	1	1.83	2	-0.14	-7.1%
ACM2/BOTT	1.83	6[a]	1.69	5	-0.14	-7.6%
ACM2/PPM	1.87	4	1.68	6	-0.19	-10.1%
CMAQ/BOTT	1.83	5[a]	1.81	3	-0.02	-1.0%
CMAQ/PPM	1.91	2	1.86	1	-0.05	-2.6%

[a] tied

C.3.5 SPATIAL PERFORMANCE FOR CTEX5 NOPIG EXPERIMENTS

Spatial performance for CTEX5 and the NoPiG CAMx sensitivities posed a slightly more difficult challenge to interpret due to similarities amongst the Kz/advection solver options for the FMS metric (Figure C-13). The range of difference for the FMS between the minimum and maximum for all of the eight combinations was less than 2.1%, with all in the range of 22% to 24%. This would indicate that each of the model configurations performs similarly across all concentration ranges. However, in the extended spatial statistics of FAR, POD, and TS, greater differentiation in model spatial performance metrics are seen. For example, for POD and TS, the CMAQ Kz combinations perform best of all of the vertical diffusion options, and have POD/TS statistics that are nearly twice as good as the OB70 diffusion combinations with POD/TS values of ~60%/~22% for CMAQ versus ~33%/~10% for OB70 diffusion algorithm options. Since these statistics are valid for concentration ranges above the 100 pg m^{-3} concentration level, similarity in model performance for the FMS metric is likely due to better performance of OB70 and ACM2 at levels below the threshold concentration used for the FAR, POD and TS statistics. Above the concentration threshold spatial performance for OB70 and ACM2 lags behind that of the TKE and CMAQ, indicating that the TKE and CMAQ Kz options perform better across all concentration ranges compared to similar performance at the lower concentration levels below the threshold. Overall, it appears that the CMAQ Kz option yields the best performance of the diffusion options when examining the performance across all of the spatial metrics.

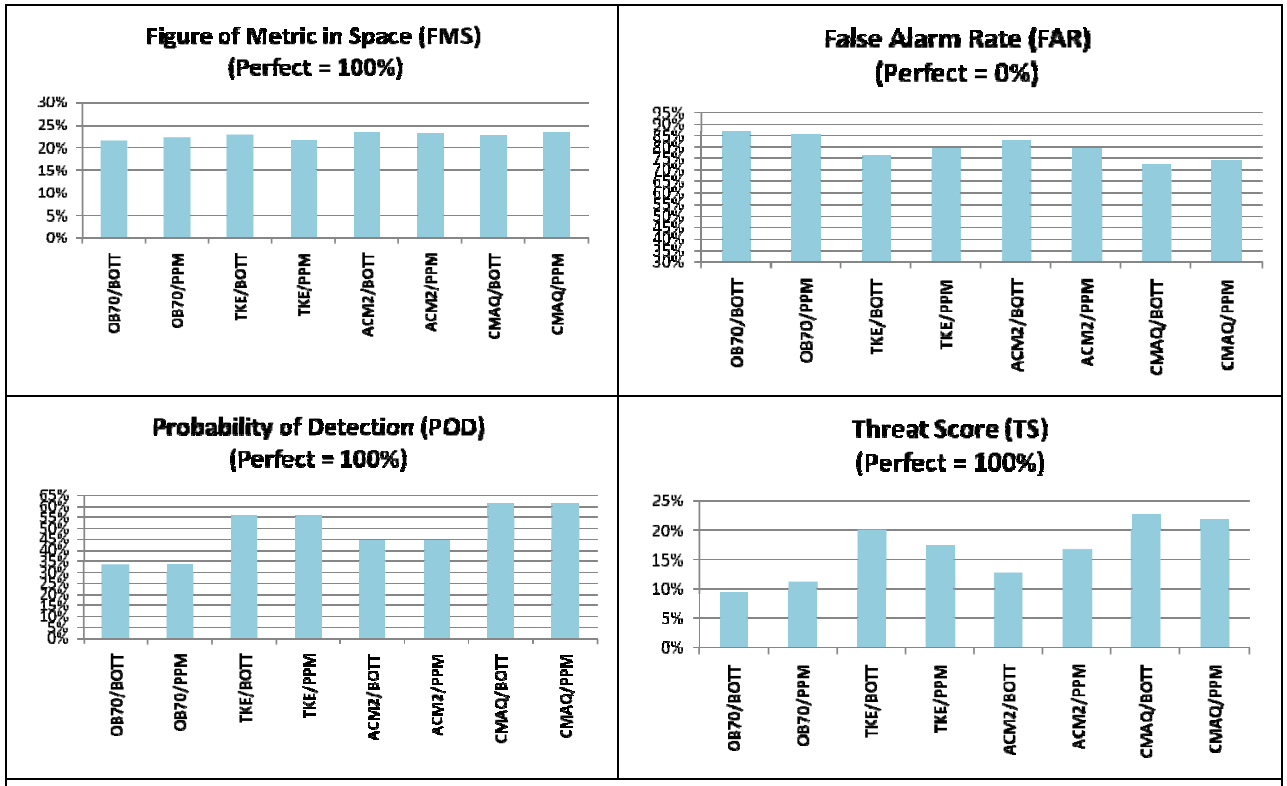


Figure C-13. Spatial model performance statistics for the CAMx CTEX5 sensitivity tests without using the PiG subgrid-scale puff module (NoPiG).

C.3.6 Global Statistical Performance for CTEX5 NoPiG Experiments

Figures C-14 and C-15 displays the global statistics for the CAMx NoPiG CTEX5 sensitivity tests for the statistical metrics with the best performing model has the, respectively, lowest and highest score. For the FOEX metric, all of the Kz/advection solver options are within 4% of each other (1% - 5%), with the best performance coming from OB70 and TKE options and degrading slightly across the ACM2 and CMAQ options.

The NMSE, FB, and PCC metrics provide clear differentiation in performance across the Kz options, with the TKE and CMAQ options yielding significantly better performance than either OB70 or ACM2. For NMSE, the CMAQ combinations have the best scores with 9.3 – 9.4 pg m^{-3}, followed by the TKE combinations with 12.6 – 13.6 pg m^{-3}. NMSE values are nearly double that for OB70 and ACM2. A similar relationship is found with the FB and PCC metrics, with the CMAQ and TKE performing significantly better than either ACM2 or OB70.

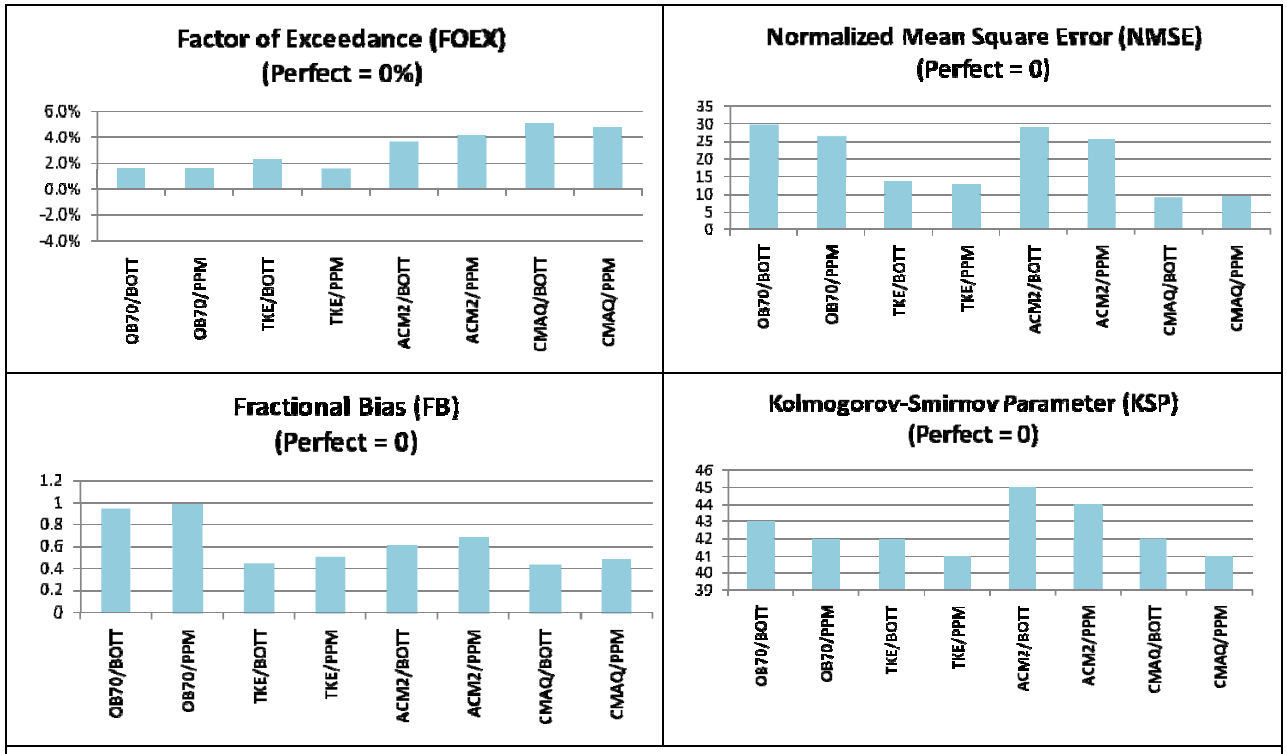


Figure C-14. Global model performance statistics for the CAMx CTEX5 sensitivity tests using the PiG subgrid-scale puff module.

The final panel in Figure C-15 (bottom right) displays the overall RANK statistic. The RANK statistics orders the model performance of the CTEX5 CAMx configurations without PiG as follows:

1. CMAQ/PPM (1.92) (tied)
2. CMAQ/BOTT (1.92) (tied)
3. TKE/PPM (1.73)
4. TKE/BOTT (1.71)
5. ACM2/BOTT (1.50)
6. ACM2/PPM (1.48)
7. OB70/PPM (1.34)
8. OB70/BOTT (1.33)

As with CTEX3, for the CTEX5 experiment the CMAQ Kz algorithm is the best performing vertical mixing approach in CAMx based on both the spatial and global statistical analyses. What differs in the CAMx CTEX3 and CTEX5 NoPiG sensitivity test performance is the composition of the RANK metric. Spatial performance for CTEX3 was significantly better than for CTEX5 (10% - 15% greater), thus FMS contributes less to the RANK statistical metric for CTEX5 compared to CTEX3. Similarly, the PCC metric is much more variable across the Kz options with CTEX5 experiment, with essentially no contribution of PCC to the RANK score for OB70 and ACM2 Kz options in CTEX5. Additionally, the KSP scores comprise a much greater portion of the RANK scores for CTEX5.

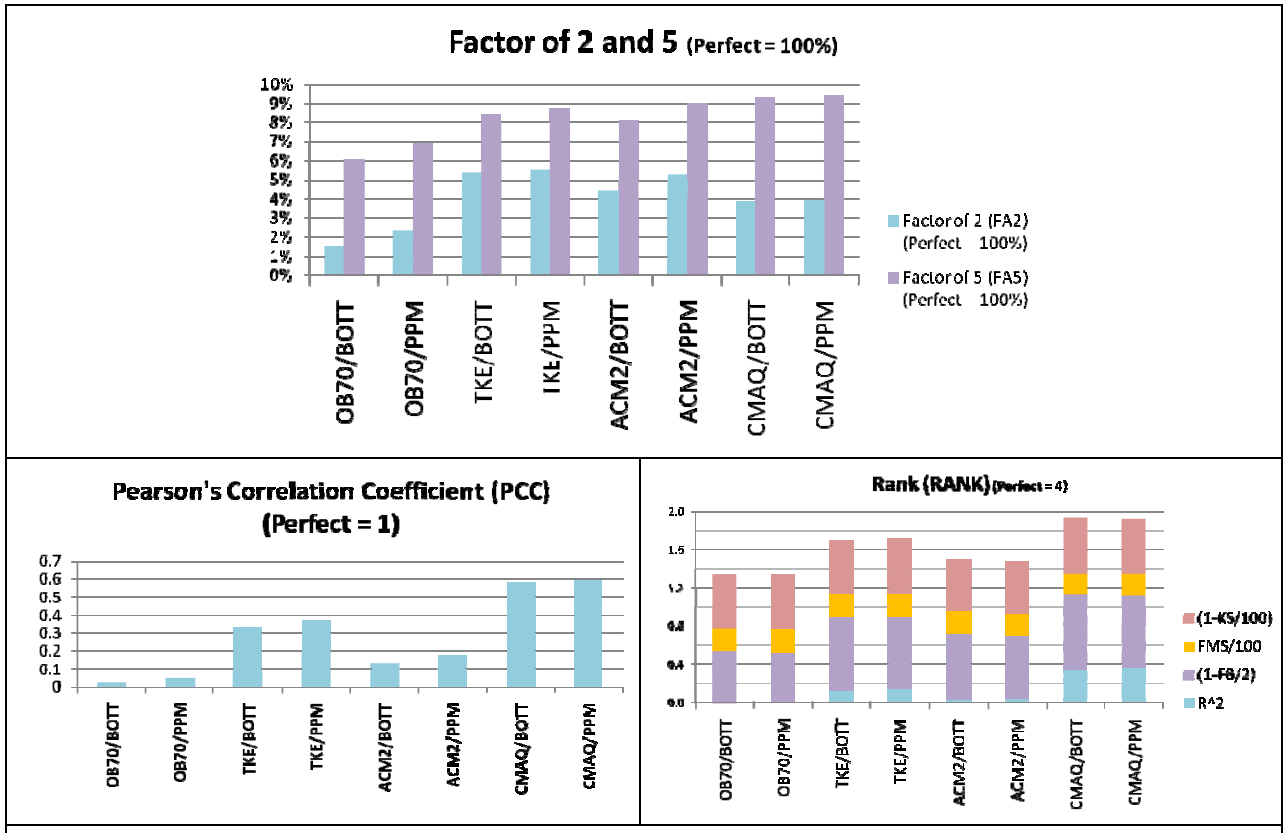


Figure C-15. Global model performance statistics for the CAMx sensitivity tests without using the PiG subgrid-scale puff module for CAPTEX Release 5 (NoPiG).

C.3.7 SPATIAL PERFORMANCE FOR CTEX5 PIG EXPERIMENTS

As with the CTEX5 NoPiG experiments, interpretation of the spatial performance for CTEX5 for the PiG CAMx sensitivities posed a slightly more difficult challenge to interpret due to similarities amongst the Kz/advection solver options for the FMS metric (Figure C-16). The range of difference for the FMS between the minimum and maximum for all of the eight combinations was less than 2%, with all in the range of 21.5% - 23.3%, noting a slight degradation across the board from the corresponding NoPiG experiments (0.2% - 3.1%).

Examination of the extended spatial statistics reveals a similar pattern in performance compared to the NoPiG equivalent tests. Greater differences in performance are observed across the various Kz/advection solver combinations, especially for the POD and TS metrics. For both of these metrics, the CMAQ Kz combinations clearly yield better spatial performance than the other Kz options (5% - 10% better for POD and 2% - 5% for TS than the second best Kz option (TKE)).

Consistent with results from the NoPiG scenarios, the CMAQ Kz option appears to perform best across the majority of the spatial metrics. The largest difference in spatial performance is determined by the user's selection of the Kz option than either the choice of advection solver or use of the subgrid scale PiG module in CAMx.

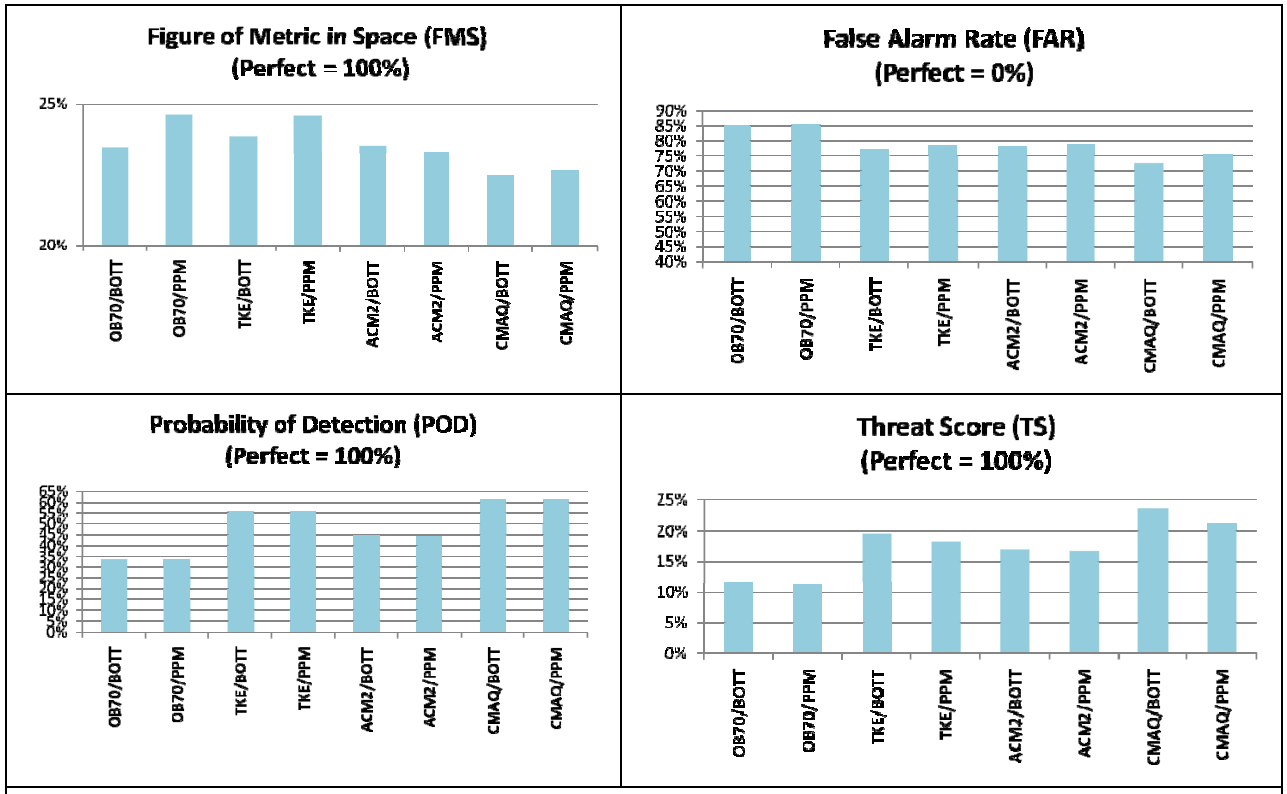


Figure C-16 Spatial model performance statistics for the CAMx CTEX5 sensitivity tests using the PiG subgrid-scale puff module (PiG).

C.3.8 Global Statistical Performance for CAMx CTEX5 PiG Experiments

Figures C-17 and C-18 displays the global statistics for the CAMx sensitivity tests using the PiG module with statistical metrics for the best performing model has the, respectively, lowest and highest score. For the FOEX metric, all of the Kz/advection solver options are within 5% - 6% of each other (-1.2% - 4.7%), with the best performance coming from OB70 and TKE options and degrading slightly across the ACM2 and CMAQ options, which is largely consistent with the equivalent NoPiG scenarios.

For NMSE and KSP, the CMAQ and TKE options perform better than either OB70 or ACM2. The CMAQ Kz option has the best NMSE values with 9.9 – 10.8 pg m^{-3} (PPM/BOTT), followed by TKE with values of 14.2 – 15.8 pg m^{-3} (PPM/BOTT). The TKE/PPM combination had the best scores for KSP, followed by CMAQ/PPM. All of the Kz options save OB70 had very similar FB and FA2/5 scores. OB70 consistently scored the poorest across all of the global statistical metrics.

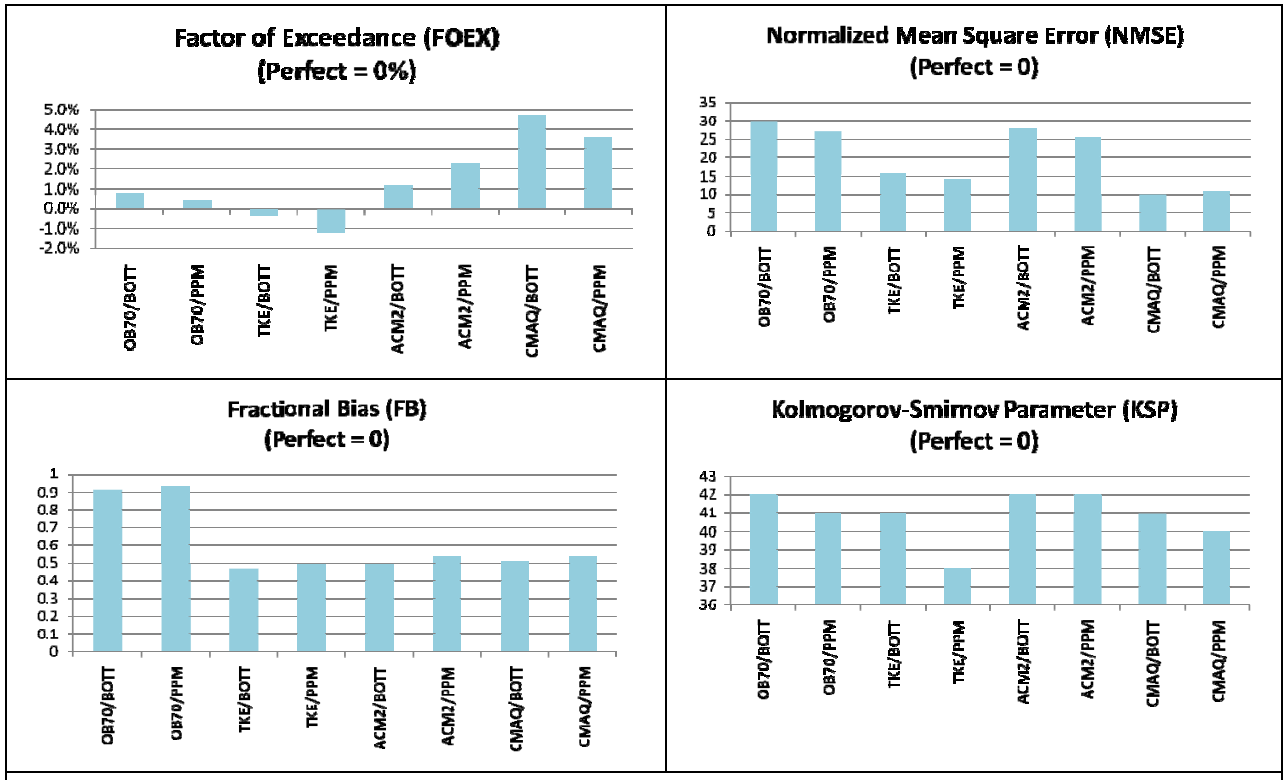


Figure C-17. Global model performance statistics for the CAMx sensitivity tests using the PiG subgrid-scale puff module for CAPTEX Release 5.

The final panel in Figure C-17 (bottom right) displays the overall RANK statistical metric. The RANK statistics orders the model performance of the CAMx configurations using the PiG module as follows:

1. CMAQ/BOTT (1.95)
2. CMAQ/PPM (1.92)
3. TKE/PPM (1.67)
4. TKE/BOTT (1.65)
5. ACM2/BOTT (1.58)
6. ACM2/PPM (1.56)
7. OB70/PPM (1.35)
8. OB70/BOTT (1.34)

Consistent with the NoPiG scenarios for CTEX5, CAMx performance using the CMAQ Kz option for vertical mixing is the best performing vertical diffusion algorithm overall for both the spatial and global statistical analyses and the choice of advection solver has a much smaller effect on model performance compared to vertical diffusion.

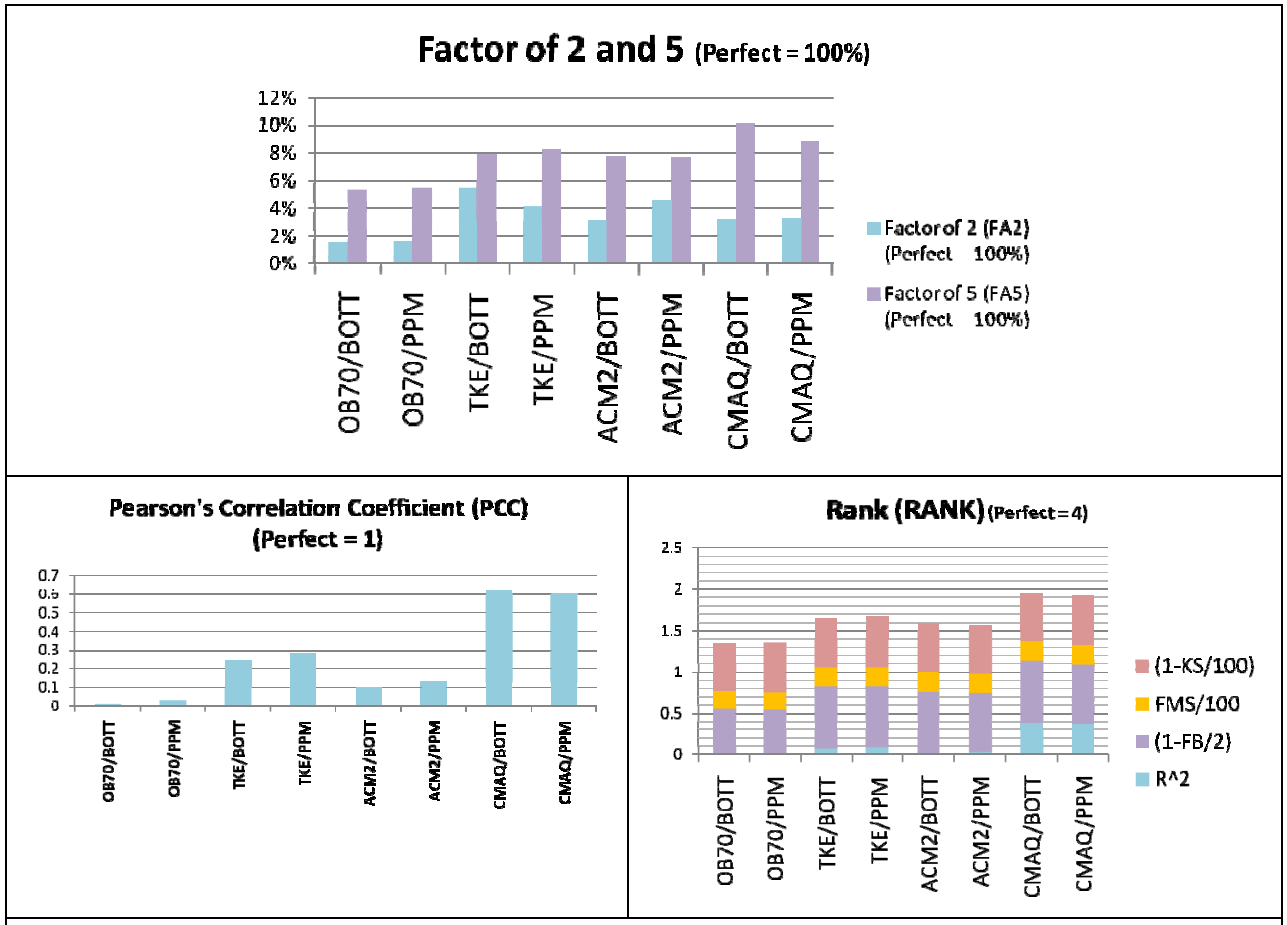


Figure C-18. Global model performance statistics for the CAMx sensitivity tests using the PiG subgrid-scale puff module for CAPTEX Release 5 (PiG).

C.3.8.1 EFFECT OF PIG ON MODEL PERFORMANCE FOR CTEX5

Similar to the results from the ETEX and CTEX3 experiments for CAMx, whether the PiG is used or not has very little effect on the CAMx model performance and the rankings of the CAMx model performance using the alternative vertical mixing and horizontal advection solver options. In general, it appears that the CAMx model performance without the PiG is performing slightly better than its performance using the PiG.

The spatial performance statistics are sometimes improved and sometimes degraded when the PiG module is invoked. Table C-3 examines the effect of PiG treatment of the tracer using two of the four spatial statistics, FMS and POD. Slight degradation of spatial performance when the PiG module is invoked is noted using the OB70, TKE, and ACM2 Kz diffusion combinations (from -3.1% to -0.2% for FMS and from -11.1% to 0% for POD). However, CAMX using the CMAQ Kz diffusion/advection solver combinations experienced a 0.2% to 0.5% improvement for FMS and no change for POD.

Table C-3. CAMx FMS and POD spatial performance statistic and model rankings for different model configurations with and without using the PiG subgrid-scale puff model for CAPTEX Release 5.

Model Configuration	Without PiG Module		With PiG Module		NoPiG-PiG	
	FMS	POD	FMS	POD	ΔFMS	ΔPOD
OB70/BOTT	23.48	33.33	21.54	27.78	-1.9%	-5.6%
OB70/PPM	24.62	33.33	22.05	33.33	-2.6%	0%
TKE/BOTT	23.85	55.56	22.83	55.56	-1.0%	0%
TKE/PPM	24.6	55.56	21.49	50	-3.1%	-5.6%
ACM2/BOTT	23.53	44.44	23.26	33.33	-0.3%	-11.1%
ACM2/PPM	23.31	44.44	23.08	44.44	-0.2%	0%
CMAQ/BOTT	22.48	61.11	22.66	61.11	0.2%	0%
CMAQ/PPM	22.66	61.11	23.2	61.11	0.5%	0%

Table C-4 summarizes the RANK model performance statistic for the different CAMx model configurations with and without using the PiG module. The results for the global statistics are somewhat varied across the Kz/advection solver configurations. OB70, ACM2, and CMAQ/BOTT showed slight improvements in their RANK score when using the PiG module (improvements ranged from 0.7% to 5.4%). However, the TKE combinations experienced performance degradations with changes ranging from -3.5% to 4.0%.

Table C-4. CAMx RANK model performance statistic and model rankings for different model configurations with and without using the PiG subgrid-scale puff model for CAPTEX Release 5.

Model Configuration	Without PiG Module		With PiG Module		PiG-NoPiG	
	RANK	Model Ranking	RANK	Model Ranking	ΔRANK	Percent
OB70/BOTT	8	1.33	1.34	8	+0.01	+0.7%
OB70/PPM	7	1.34	1.35	7	+0.01	+0.7%
TKE/BOTT	4	1.71	1.65	4	-0.06	-3.5%
TKE/PPM	3	1.73	1.67	3	-0.07	-4.0%
ACM2/BOTT	5	1.50	1.58	5	+0.08	+5.0%
ACM2/PPM	6	1.48	1.56	6	+0.08	+5.4%
CMAQ/BOTT	1[a]	1.92	1.95	1	+0.03	+1.5%
CMAQ/PPM	2[a]	1.92	1.92	2	0.0	0.0%

[a] tied

In general, it is difficult to discern a consistent pattern of performance across the Kz/advection solver combinations when using the CAMx subgrid scale PiG module or not. There appears to be only modest benefit in cases where performance improvement is detected and only modest degradation in model performance when the PiG module causes a worsening of model performance. The CAMx PiG module was originally developed primarily to treat the near-source chemistry of large point source plumes that can be quite different from its surrounding environment. The decision to employ the CAMx puff module relates not so much in improvement advection and diffusion performance, but rather whether or not it is appropriate to allow emissions of ozone and secondary $PM_{2.5}$ precursors from large point sources to be instantaneously mixed into the grid and what impact this would have on local chemical reactions.

C.4 COMPARISON OF SIX LRT DISPERSION MODELING USING CAPTEX RELEASE 3

The model performance of six LRT dispersion models (CALPUFF, SCIPUFF, HYSPLIT, FLEXPART, CAMx and CALGRID) are evaluated using common MM5 meteorological inputs and the CAPTEX Release 3 tracer experiment.

C.4.1 SPATIAL ANALYSIS OF MODEL PERFORMANCE

The performance of the six LRT dispersion models using the four spatial analysis model performance statics that were defined in Section 2.4 are discussed in this section. Figure C-19 displays the FMS spatial performance metrics for the six LRT models and the CTEX3 tracer study field experiment. The CAMx (39.4%) and SCIPUFF (35.2%) models are the two best performing models for the FMS statistic. They are followed by HYSPLIT (33.9%), CALPUFF (32.2%), and FLEXPART (32.1%). CALGRID has the poorest score for the FMS statistics with a value of only 24.1%.

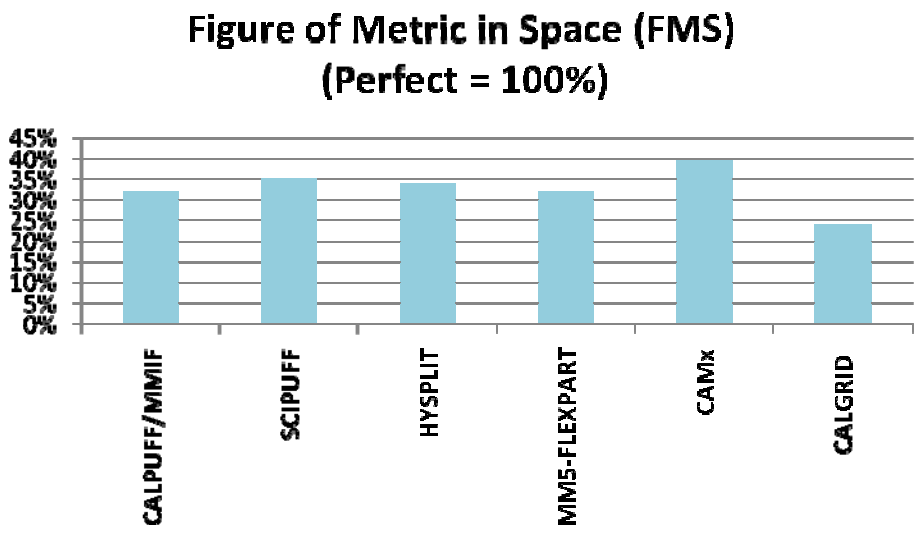


Figure C-19. Figure of Merit in Space (FMS) statistical performance metric for the six LRT models and CAPTEX Release 3.

Figure C-20 displays the FAR performance metric for the six LRT models. FLEXPART was the best performing model using the FAR statistics with a score of 54.1%. The next two best performing models using the FAR was CAMx (64.8%) and SCIPUFF (71.2%). CALPUFF and HYSPLIT exhibited similar performance for the FAR metric with values of 74.3% and 79.3% respectively. CALGRID had the worst FAR score with a value of 91.7%.

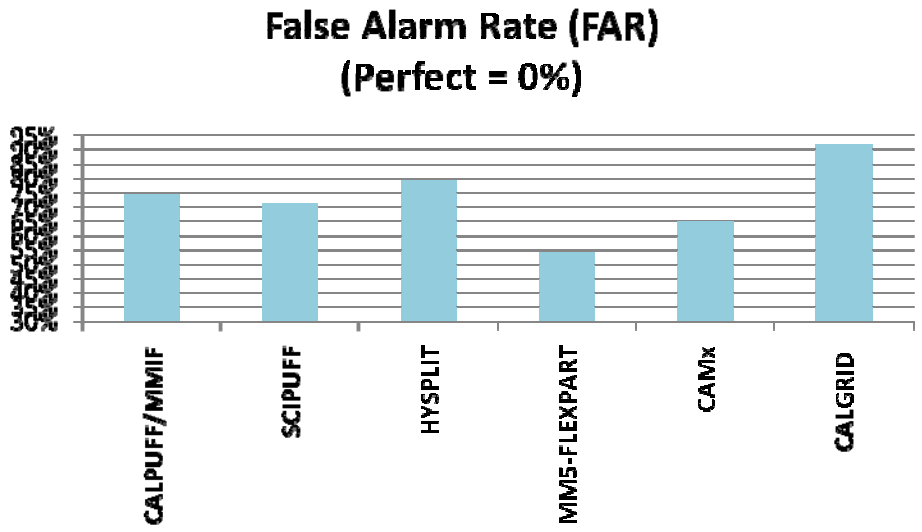


Figure C-20. False Alarm Rate (FAR) statistical performance metric for the six LRT models and CAPTEX Release 3.

Results for the Probability of Detection (POD) metric are presented in Figure C-21. CAMx was the best performing model using the POD performance statistic with a value of 52.6%. It is followed closely by FLEXPART with a score of 47.2%. SCIPUFF (41.7%) and HYSPLIT (36.1%) were in the middle, and CALPUFF and CALGRID had the worst POD score with a value of 25%.

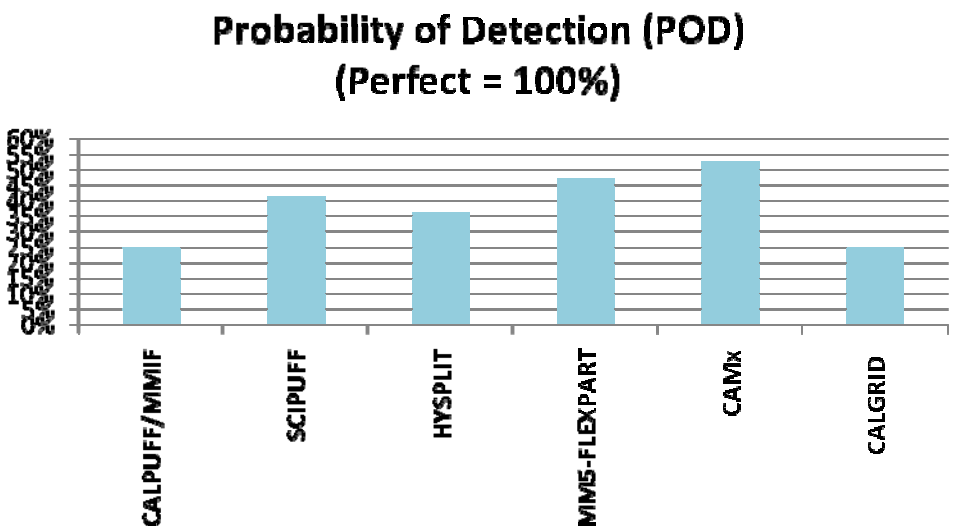


Figure C-21. Probability of Detection (POD) statistical performance metric for the six LRT models and CAPTEX Release 3.

Results for the TS metric and the six LRT models are presented in Figure C-22. FLEXPART had the highest TS statistics with a score with a value of 30.4% and was followed closely by CAMx

(26.8%). SCIPUFF (20.6%), HYSPLIT (15.1%), and CALPUFF (14.1%) were in the middle, and CALGRID exhibited the poorest TS performance with a score of 6.7%.

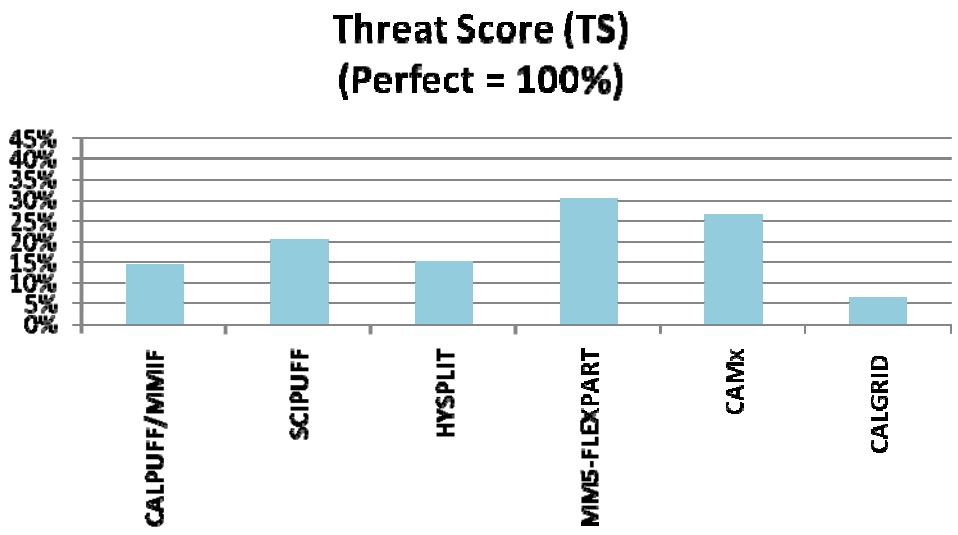


Figure C-22. Threat Score (TS) statistical performance metric for the six LRT models and CAPTEX Release 3.

Overall spatial performance was relatively equal between FLEXPART and CAMx, with CAMx having the best performance for the FMS and POD statistics and FLEXPART having better performance in the FAR and TS categories. CALPUFF, SCIPUFF, and HYSPLIT were comparable in their spatial performance for the CTEX3 experiment, with SCIPUFF showing marginally better scores in all of the four spatial performance metrics. CALGRID exhibited the poorest performance across all four spatial metrics.

C.4.2 GLOBAL ANALYSIS OF MODEL PERFORMANCE

Eight global statistical analysis metrics are used to evaluate the five LRT model performance using the ETEX data base that are described in Section 2.4 and consist of the FOEX, FA2, FA5, NMSE, PCC, FB, KS and RANK statistical metrics.

Figure C-23 displays the FOEX performance metrics for the six LRT models. HYSPLIT has the best FOEX score with a value of 2.0% that is closest to zero. The second best performing model using the FOEX metric is CAMx (9.6%) that is followed by SCIPUFF (11.5%). CALGRID has the poorest FOEX score with 20.6%.

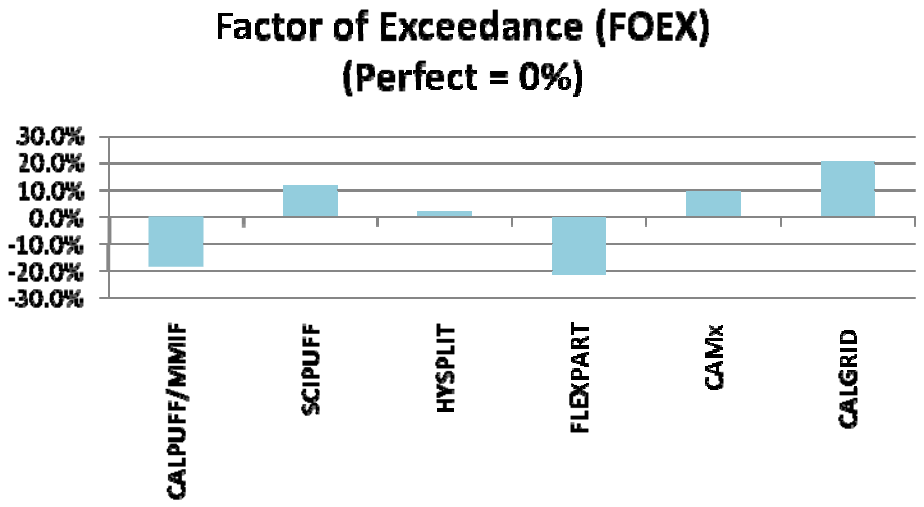


Figure C-23. Factor of Exceedance (FOEX) statistical performance metric for the six LRT models and CAPTEX Release 3.

FA2 and FA5 scores are presented in Figure C.-24. CAMx and SCIPUFF have nearly identical FA2 and FA5 scores with values of 6.6% - 6.7% (FA2) and 15% (FA5). The third best performing model for the FAα statistics is FLEXPART (5.3% and 12.2%) followed by HYSPLIT (4.5% and 8.5%). CALPUFF and CALGRID flip positions in FA2 and FA5 for the final position, with CALPUFF having a lower FA2 (0.8%) and a higher FA5 (8.2%) compared to CALGRID (FA2 – 1.05% and FA5 – 4.6%).

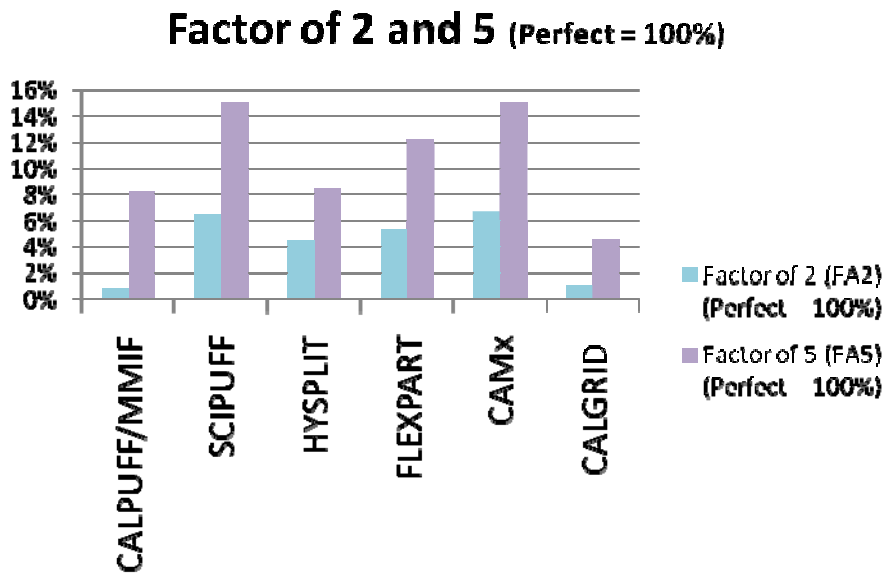


Figure C-24. Factor of 2 (FA2) and Factor of 5 (FA5) statistical performance metric for the six LRT models and CAPTEX Release 3.

The scores for the Normalized Mean Squared Error (NMSE) statistical metrics for the six LRT models are given in Figure C-25. The NMSE provides an indication of the deviations between the predicted and observed tracer concentrations paired by time and location with a perfect model receiving a 0.0 score. FLEXPART is the best performing model using the NMSE metric with a score of 21.4 pg m^{-3} followed closely by CAMx (38.9 pg m^{-3}) and CALPUFF (40.9 pg m-3). The worst performing LRT model according to the NMSE metric is HYSPLIT (130.5 pg m^{-3}).

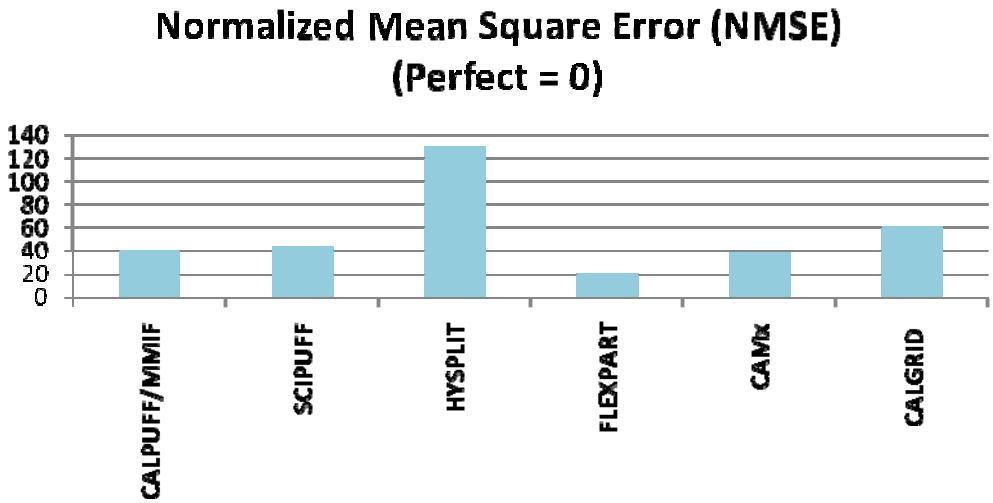


Figure C-25. Normalized Mean Square Error (NMSE) statistical performance metric for the six LRT models for CAPTEX Release 3. Values are expressed in pg m^{-3}.

The PCC values for the six LRT models are shown in Figure C-26. All models but HYSPLIT have positive correlation coefficients. The two best models according to the PCC statistical metric are CAMx (0.63) and SCIPUFF (0.56). The middle group of models consists of CALPUFF (0.4), CALGRID (0.23), and FLEXPART (0.19). The model with the least correlation with the observations is HYSPLTI (-0.1), indicating a weak negative correlation with observed data.

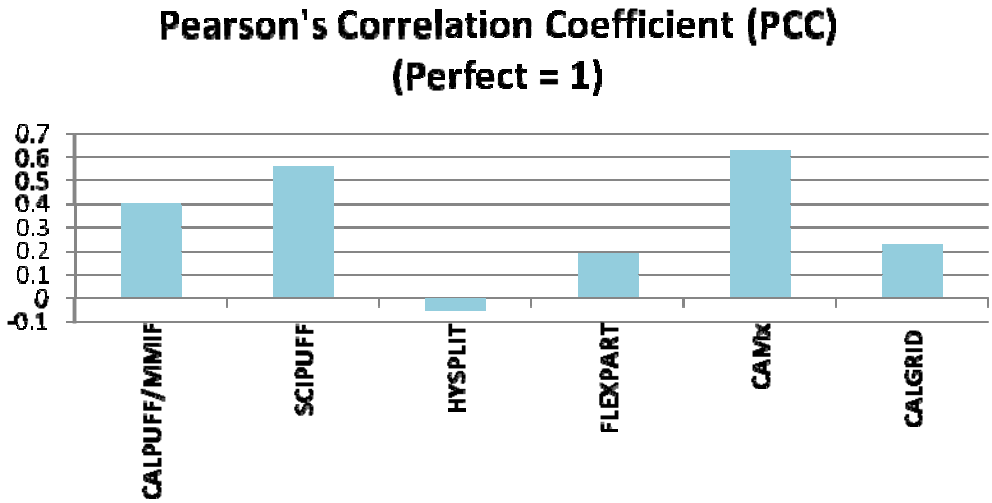


Figure C-26. Pearson's Correlation Coefficient (PCC) statistical performance metric for the six LRT models and CAPTEX Release 3.

Figure C-27 displays the FB parameter for the six LRT models. All six models exhibit a positive FB, which suggests an overestimation tendency. The best performing model with an FB value closest to zero are FLEXPART with a FB value of 0.68. CAMx (1.00), SCIPUFF (1.04) and CALPUFF (1.05) all have similar FB values are the second best performing group of models using the FB metric. CALGRID and HYSPLIT have the worst FB scores with values of 1.47 and 1.56 respectively.

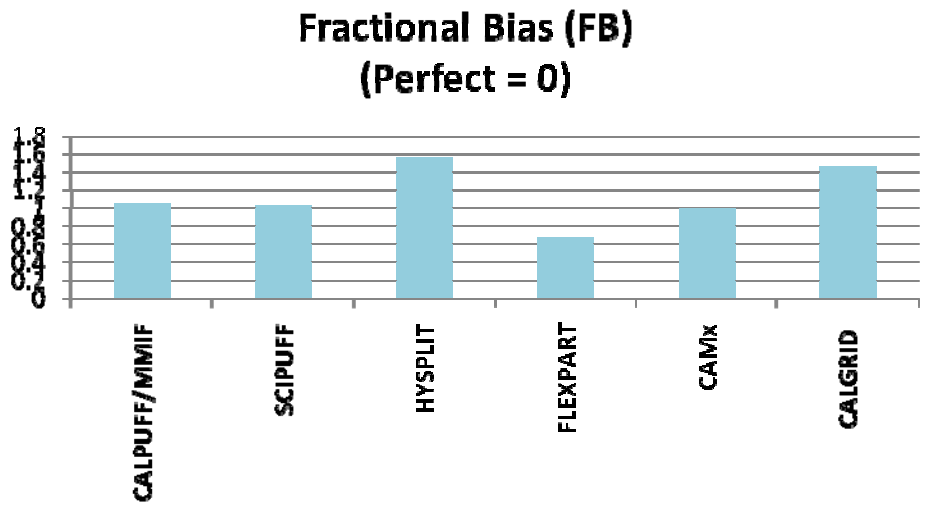


Figure C-27. Fractional Bias(FB) statistical performance metric for the six LRT models and CAPTEX Release 3.

The KS parameters for the six LRT models are shown in Figure C-28. HYSPLIT (31%) has the best KS parameter, which indicates the best match between the predicted and observed tracer concentration distributions, followed by CAMx (38%) and then SCIPUFF (43%). FLEXPART and CALGRID are essentially tied with the worst KS parameter with a value of 58%.

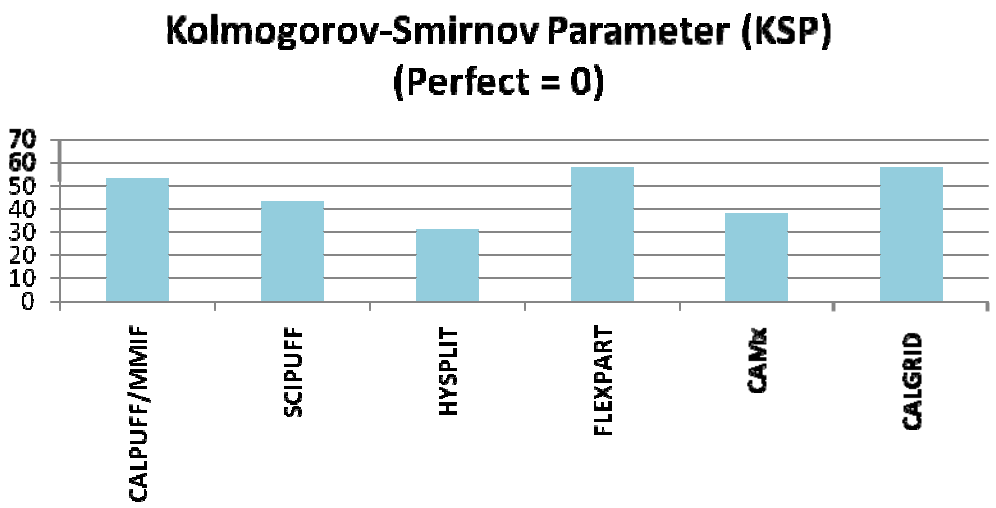


Figure C-28. Kolmogorov – Smirnov Parameter (KSP) statistical performance metrics for the six LRT models for CAPTEX Release 3.

The RANK statistical performance metric was proposed by Draxler (2001) as a single model performance metric that equally ranks the combination of performance metrics for correlation (PCC or R), bias (FB), spatial analysis (FMS) and unpaired distribution comparisons (KS). The RANK metrics ranges from 0.0 to 4.0 with a perfect model receiving a score of 4.0. Figure C-29 lists the RANK model performance statistics for the six LRT models. CAMx is the highest ranked model using the RANK metric with a value of 1.91. Note that CAMx scores high in all four areas of model performance (correlation, bias, spatial and cumulative distribution). The next best performing model according to the RANK metric is SCIPUFF with a score of 1.71. SCIPUFF scores relatively well across all of the four metrics, with slightly lower scores in cumulative distribution and correlation metrics compared to CAMx, contributing to its second rank. FLEXPART and CALPUFF are nearly even in terms of their performance with RANK values of 1.44 and 1.43 respectively. FLEXPART scores better than CALPUFF with the bias (FB) metric, whereas the reverse is true for the correlation (R^2) metric.

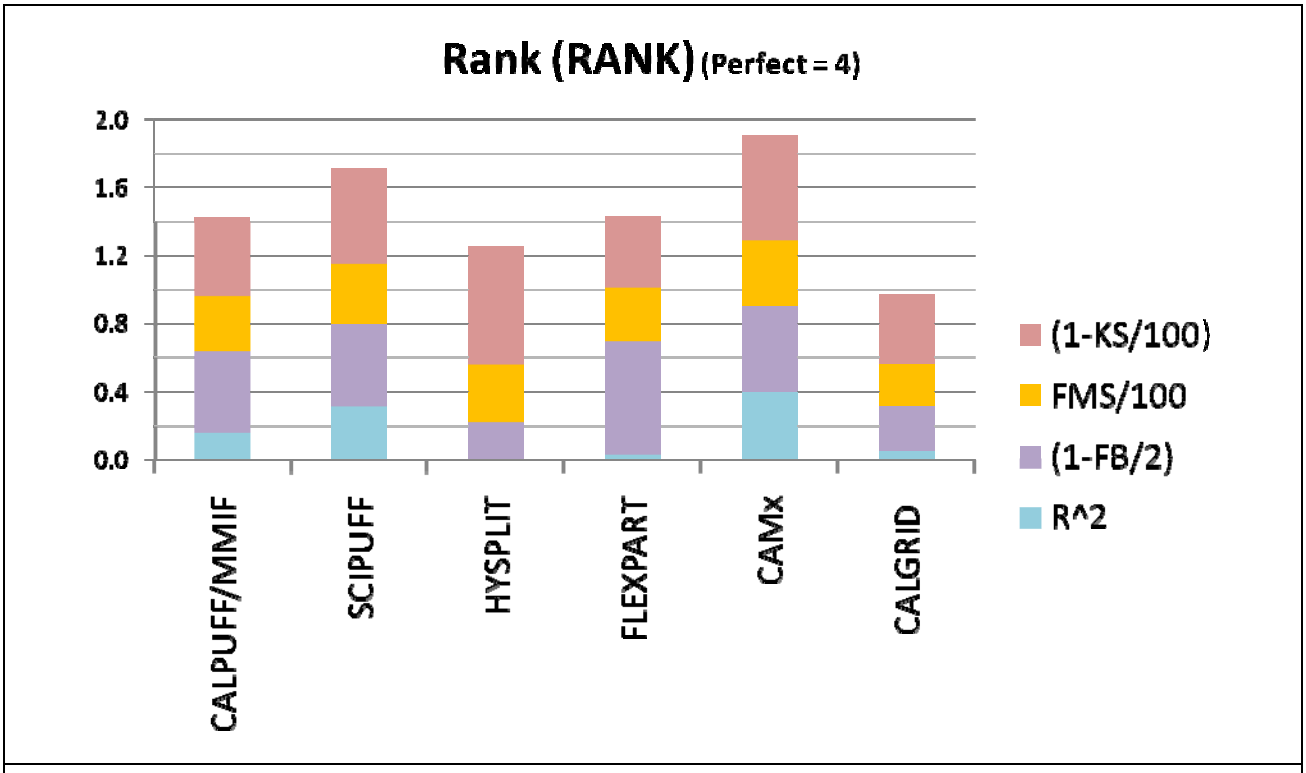


Figure C-29. RANK statistical performance metric for the six LRT models and CAPTEX Release 3.

C.4.2.1 SUMMARY OF LRT MODEL RANKINGS FOR CTEX3 USING STATISTICAL PERFORMANCE MEASURES

Table C-5 summarizes the rankings between the six LRT models for the 11 performance statistics analyzed. Depending on the statistical metric, three different models were ranked as the best performing model for a particular statistic with CAMx being ranked first more than the other models (46%) and FLEXPART ranked first second most (36%). CALGRID was consistently ranked the worst performing model being the poorest performing model for 6 of the 11 performance statistics.

In testing the efficacy of the RANK statistic for providing an overall ranking of model performance we the ranking of the six LRT models using the average rank of the 11 performance statistics versus the ranking from the RANK statistical metric (Table C-5). The average rank of model performance for the six LRT dispersion models and the CTEX3 experiment averaged across all 11 performance statistics and the comparison to the RANK rankings was as follows:

Ranking	Average of 11 Statistics	RANK
1.	CAMx	CAMx
2.	SCIPUFF	SCIPUFF
3.	FLEXPART	FLEXPART
4.	HYSPLIT	CALPUFF
5.	CALPUFF	HYSPLIT
6.	CALGRID	CALGRID

For the CTEX3 experiment, the average rankings across the 11 statistics is nearly identical to the rankings produced by the RANK integrated statistics that combines the four statistics for correlation (PCC), bias (FB), spatial (FMS) and cumulative distribution (KS) with only HYSPLIT and CALPUFF exchanging places as the 4th and 5th best performing models. CALPUFF performance was weighted down in the average statistic rankings due to lower scores in the FA2 and FA5 metrics compared to HYSPLIT. If not for this, the average rank across all 11 metrics would have been the same as Draxler's RANK score. Although this deviation did occur in the fourth and fifth ranked positions, the RANK statistic remains a valid performance statistic for indicating over all model performance of a LRT dispersion model. However, the analyst should use discretion in relying too heavily upon RANK score without consideration to which performance metrics are important measures for the particular evaluation goals. For example, if performance goals are not concerned with a model's ability to perform well in space and time, then reliance upon spatial statistics such as the FMS in the composite RANK value may not be appropriate. In the case of this evaluation, since space/time considerations are paramount for proper LRT model performance, the RANK metric is a valuable tool to rapidly assess model performance across a broad range of metrics being evaluated.

Table C-5. Summary of model ranking using the statistical performance metrics.

Statistic	1st	2nd	3rd	4th	5th	6th
FMS	CAMx	SCIPUFF	HYSPLIT	CALPUFF	FLEXPART	CALGRID
FAR	FLEXPART	CAMx	SCIPUFF	CALPUFF	HYSPLIT	CALGRID
POD	CAMx	FLEXPART	SCIPUFF	HYSPLIT	CALPUFF	CALGRID
TS	FLEXPART	CAMx	SCIPUFF	HYSPLIT	CALPUFF	CALGRID
FOEX	HYSPLIT	CAMx	SCIPUFF	CALPUFF	CALGRID	FLEXPART
FA2	CAMx	SCIPUFF	FLEXPART	HYSPLIT	CALGRID	CALPUFF
FA5	CAMx	SCIPUFF	FLEXPART	HYSPLIT	CALPUFF	CALGRID
NMSE	FLEXPART	CAMx	CALPUFF	SCIPUFF	CALGRID	HYSPLIT
PCC or R	CAMx	SCIPUFF	CALPUFF	CALGRID	FLEXPART	HYSPLIT
FB	FLEXPART	CAMx	SCIPUFF	CALPUFF	CALGRID	HYSPLIT
KS	HYSPLIT	CAMx	SCIPUFF	CALPUFF	FLEXPART	CALGRID
Avg. Ranking	CAMx	SCIPUFF	FLEXPART	HYSPLIT	CALPUFF	CALGRID
Avg. Score	1.55	2.72	3.0	4.0	4.27	5.55
RANK Ranking	CAMx	SCIPUFF	FLEXPART	CALPUFF	HYSPLIT	CALGRID
RANK	1.91	1.71	1.44	1.43	1.25	0.98

C.5 COMPARISON OF SIX LRT MODEL MODELING PERFORMANCE USING THE CAPTEX-5 EXPERIMENT

C.5.1 SPATIAL ANALYSIS OF MODEL PERFORMANCE

Figure C-30 displays the FMS spatial analysis performance metrics for the six LRT models and the CTEX5 tracer study field experiment. SCIPUFF (22.67%) and CAMx (22.66%) models are the two best performing models for the FMS statistic with nearly identical scores. They are followed by HYSPLIT (18.5%), CALPUFF (17.5%), FLEXPART (17.2), and CALGRID (16.1%).

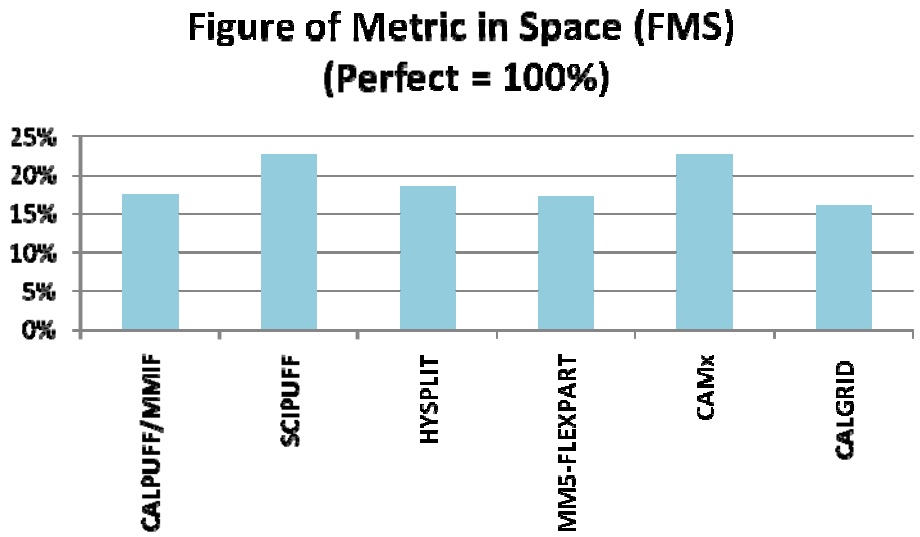


Figure C-30. Figure of Merit in Space (FMS) statistical performance metric for the six LRT models and CAPTEX Release 5.

Figure C-31 displays the FAR performance metrics. FLEXPART was the best (lowest) performing model using the FAR statistics with a score of 61.9%. The next two best performing models using the FAR metric were HYSPLIT (72.2%) and CAMx (75.6%). SCIPUFF, CALGRID, and CALPUFF had the worst (highest) FAR scores with values of 79.7%, 84.2%, and 87% respectively.

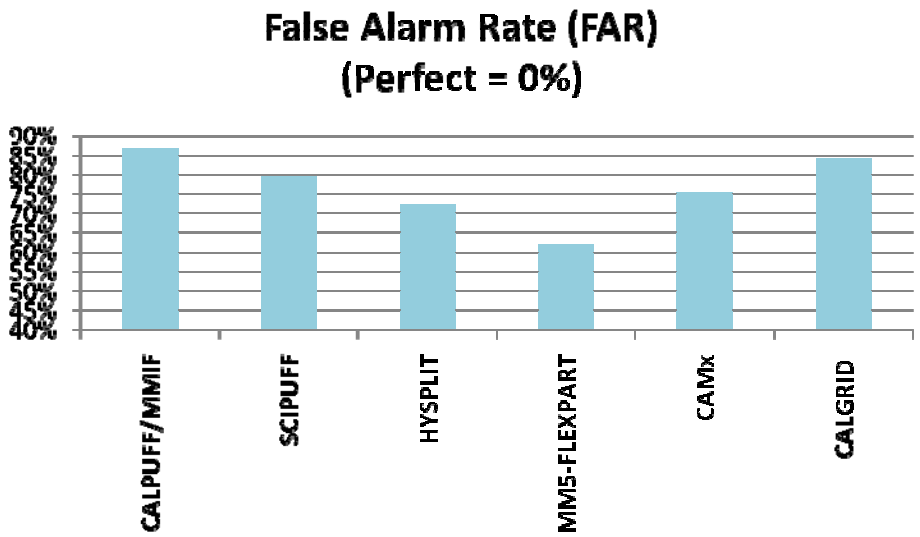


Figure C-31. False Alarm Rate (FAR) statistical performance metric for the six LRT models and CAPTEX Release 5.

Results for the Probability of Detection (POD) metric are presented in Figure C-32. SCIPUFF was the best performing model using the POD performance statistic with a value of 72.2%. CAMx was the second best performing model using POD followed by HYSPLIT, FLEXPART, CALPUFF and CALGRID.

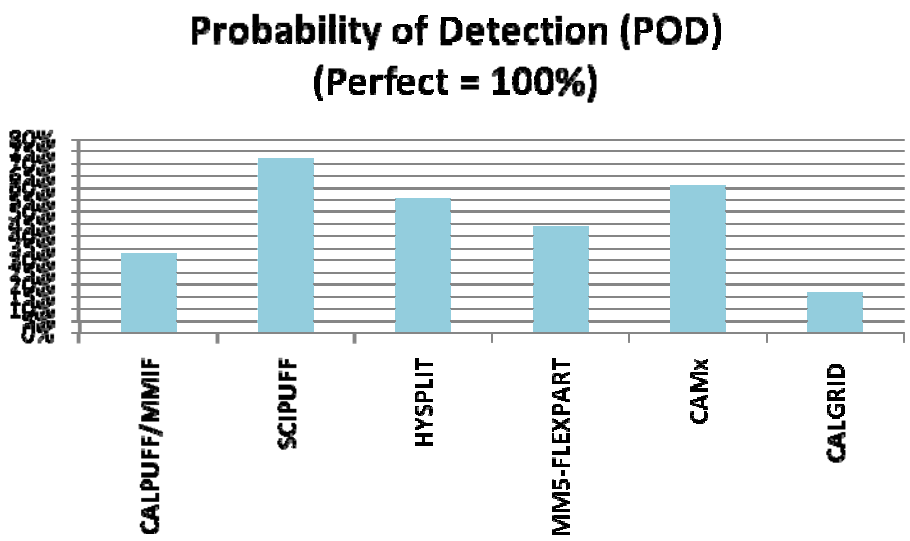


Figure C-32. Probability of Detection (POD) statistical performance metric for the six LRT models and CAPTEX Release 5.

Results for the TS metric are presented in Figure C-33. FLEXPART had the highest TS statistics with a score of 25.8%. HYSPLIT (22.7%), CAMx (21.2%), and SCIPUFF (18.8%) followed, and CALPUFF and CALGRID closed out with the worst (lowest) TS values of 10.3% and 8.8% respectively.

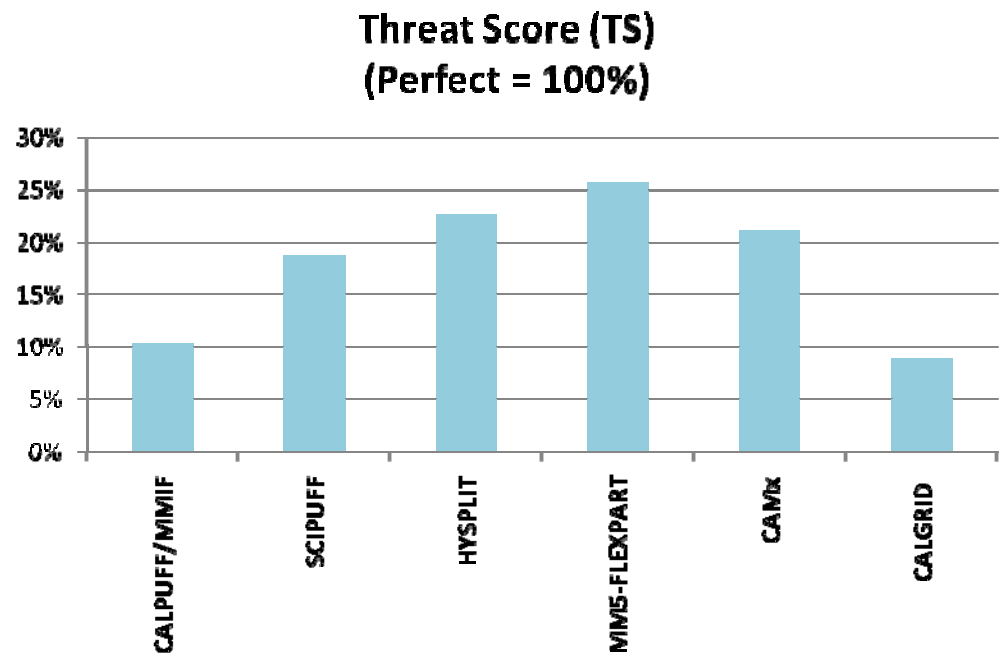


Figure C-33. Threat Score (TS) statistical performance metric for the six LRT models and CAPTEX Release 5.

Overall, the spatial performance for CTEX5 was relatively equal between FLEXPART and CAMx, with CAMx having the best performance for the FMS and POD statistics and FLEXPART having the best performance for the FAR and TS statistics. CALPUFF, SCIPUFF, and HYSPLIT were generally comparable in their spatial performance for CTEX5, with SCIPUFF showing marginally better scores in all four of the spatial metrics. CALGRID consistently exhibited the poorest performance across all four spatial metrics.

C.5.2 GLOBAL ANALYSIS OF MODEL PERFORMANCE

Figure C-34 displays the FOEX performance metrics for the six LRT models. CALPUFF had the best FOEX score (closest to zero) with a value of -2.6%. The second best performing model using the FOEX metric is CAMx (4.7%) followed by HYSPLIT (-9.2%) and CALGRID (-11.9%). SCIPUFF and FLEXPART had the poorest FOEX scores with values of 20.4% and -28.2% respectively.

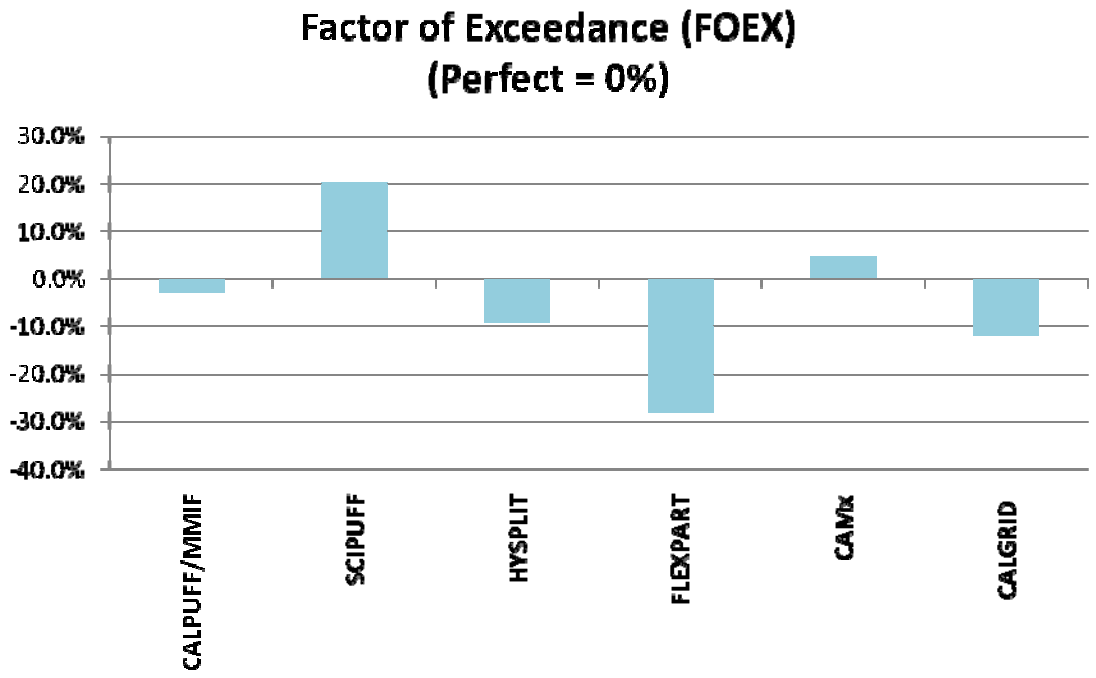


Figure C-34. Factor of Exceedance (FOEX) statistical performance metric for the six LRT models and CAPTEX Release 5.

The FA2 and FA5 scores are presented in Figure C-35. HYSPLIT has the best FAα scores with FA2 and FA5 values of 4.9% and 10.7%, respectively. CAMx and SCIPUFF have nearly identical FAα with values of 3.5% to 3.9% (FA2) and 9.3% to 9.4% (FA5). CALPUFF and FLEXPART follow with FA2/FA5 values of, respectively, 3.5%/7.9% and 2.3%/6.9%. CALGRID has the lowest FAα scores with FA2 and FA5 values of 0% and 0.9% respectively.

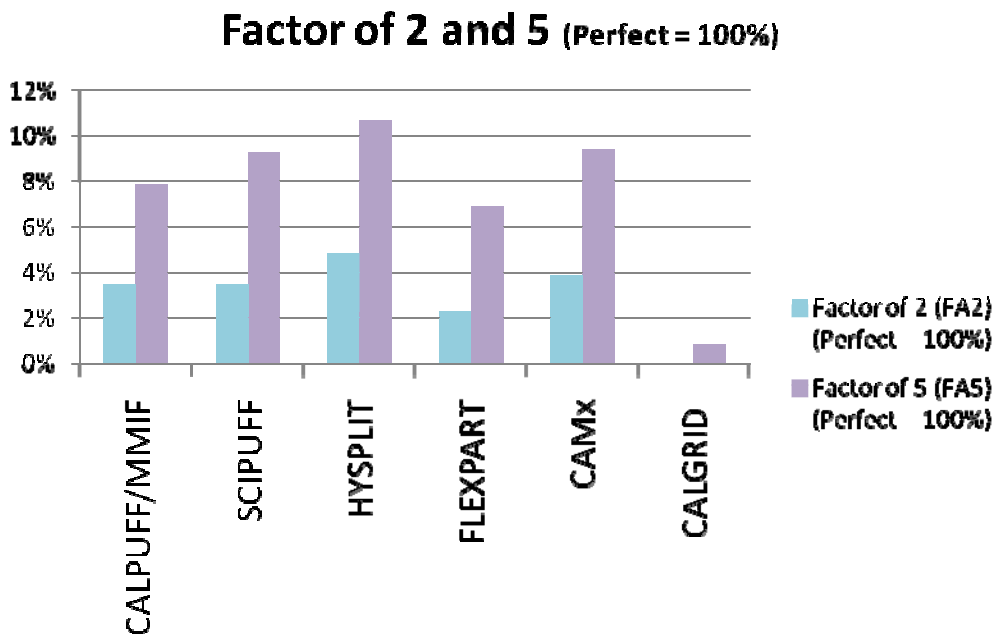


Figure C-35. Factor of 2 (FA2) and Factor of 5 (FA5) statistical performance metric for the six LRT models and CAPTEX Release 5.

The scores for the Normalized Mean Squared Error (NMSE) statistical metrics and the six LRT models are given in Figure C-36. CAMx is the best performing model using the NMSE metric with a score of 9.4 pg m^{-3} followed by SCIPUFF (14.8 pg m^{-3}). The middle tier of models are comprised of FLEXPART, HYSPLIT, and CALPUFF with values of 17.0, 17.2, and 19.5 pg m^{-3} respectively. CALGRID closes out with a NMSE value of 29.6 pg m^{-3}.

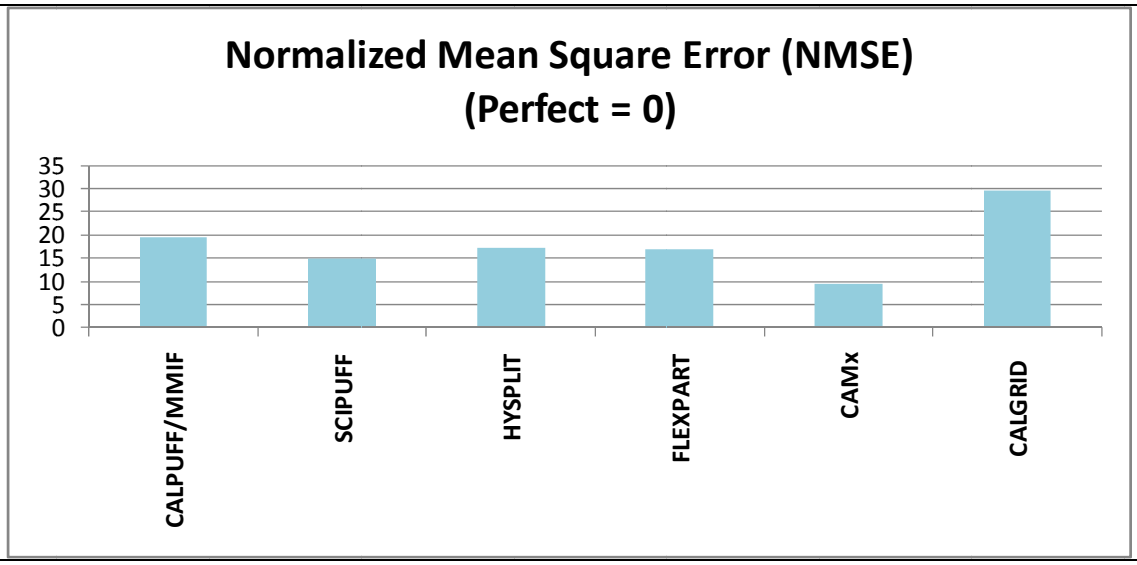


Figure C-36. Normalized Mean Square Error (NMSE) statistical performance metric for the six LRT models and CAPTEX Release 5. Values are expressed in pg m^{-3}.

The PCC values for the six LRT models are shown in Figure C-37. All models but CALGRID and CALPUFF have positive PCCs. The three best models according to the PCC statistical metric are HYSPLIT (0.60), CAMx (0.59) and SCIPUFF (0.56). FLEXPART has a PCC of 0.51. Both CALPUFF and CALGRID have negative PCC scores, indicating the modeled concentrations are anti-correlated with the observed data. CALGRID and CALPUFF have PCC values of -0.06 and -0.07, respectively.

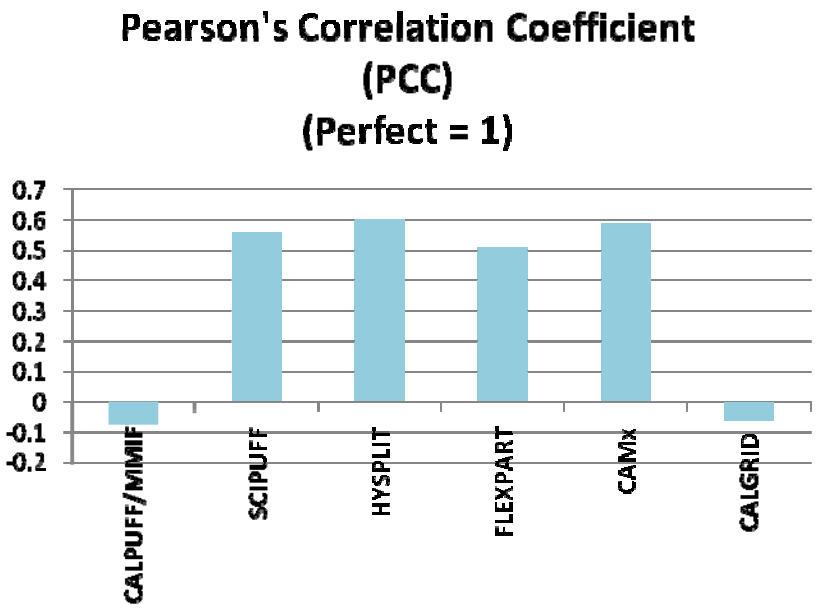


Figure C-37. Pearson's Correlation Coefficient (PCC) statistical performance metric for the six LRT models for CAPTEX Release 5.

Figure C-38 displays the FB parameter for the six LRT models and CTEX5. Four of the six models exhibit a positive FB, which suggests an overestimation tendency, whereas the other two have

a negative FB. The best performing models with the FB parameter closest to zero are CAMx with a FB score of 0.49 indicating overestimation and CALPUFF with a FB value of -0.49 indicating underestimation. Next best is FLEXPART (-0.87) with an underestimation bias and SCIPUFF (0.89) with an overestimation bias followed by HYSPLIT (0.93) and CALPUFF (1.07).

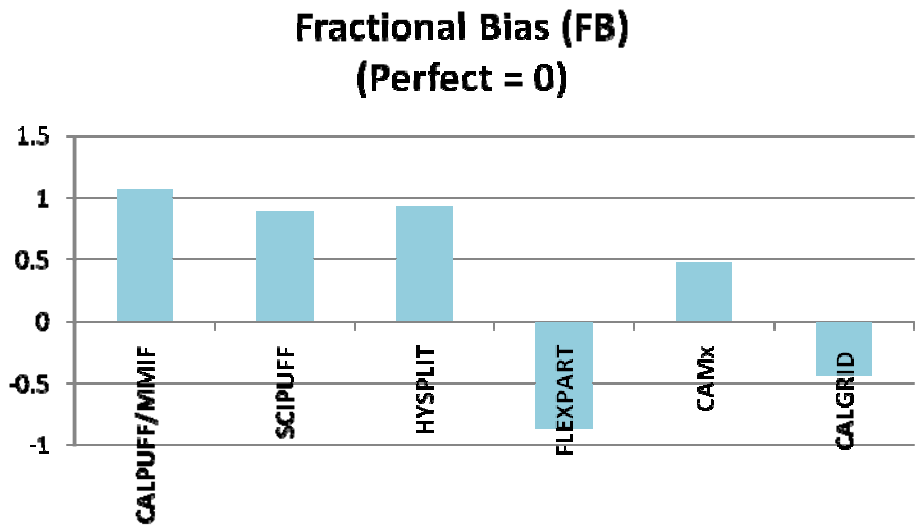


Figure C-38. Fractional Bias (FB) statistical performance metric for the six LRT models and CAPTEX Release 5.

The KS parameters for the six LRT models are shown in Figure C-39. HYSPLIT (28%) has the lowest KS parameter, which indicates the best match between the predicted and observed tracer concentration distributions according to the KS parameter, followed by CALPUFF (37%) and CALGRID (38%). CAMx follows with a score of 41% and FLEXPART and SCIPUFF close out with scores of 55% and 56% respectively.

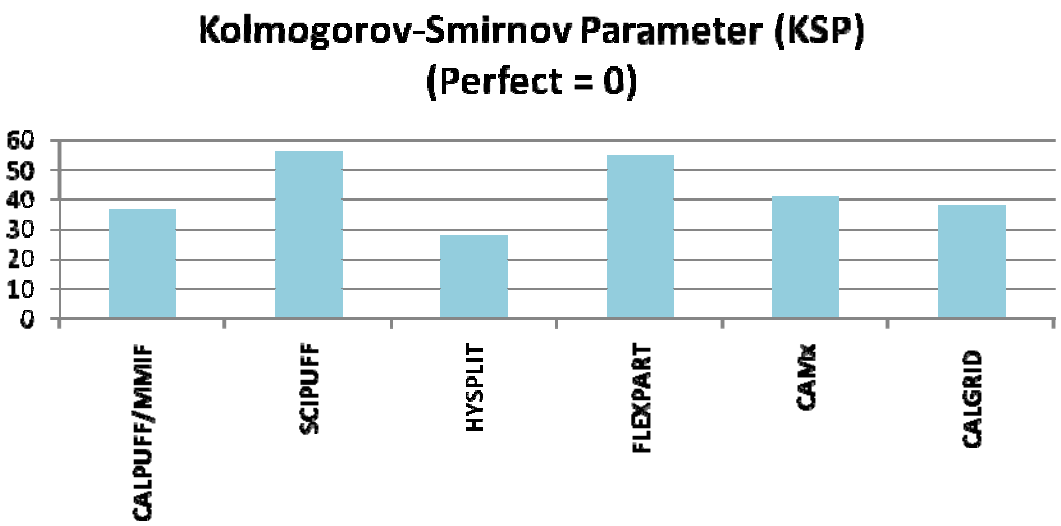


Figure C-39. Kolmogorov – Smirnov Parameter (KSP) statistical performance metrics for the six LRT models and CAPTEX Release 5.

Figure C-40 lists the RANK model performance statistics for the six LRT models. CAMx is the highest ranked model using the RANK metric with a value of 1.91 followed by HYSPLIT at 1.8. It is important to note, however, that both CAMx and HYSPLIT exhibit high scores in all four areas of model performance (correlation, bias, spatial and cumulative distribution). It is an important attribute of model performance to score high in all areas of model performance. The next best performing model according to the RANK metric is CALGRID with a score of 1.57, followed by SCIPUFF (1.53), FLEXPART (1.45), and finally CALPUFF (1.28). However, the CALGRID third best RANK metric comes at the expense of low spatial (FMS) and zero correlation (PCC or R2) performance skill.

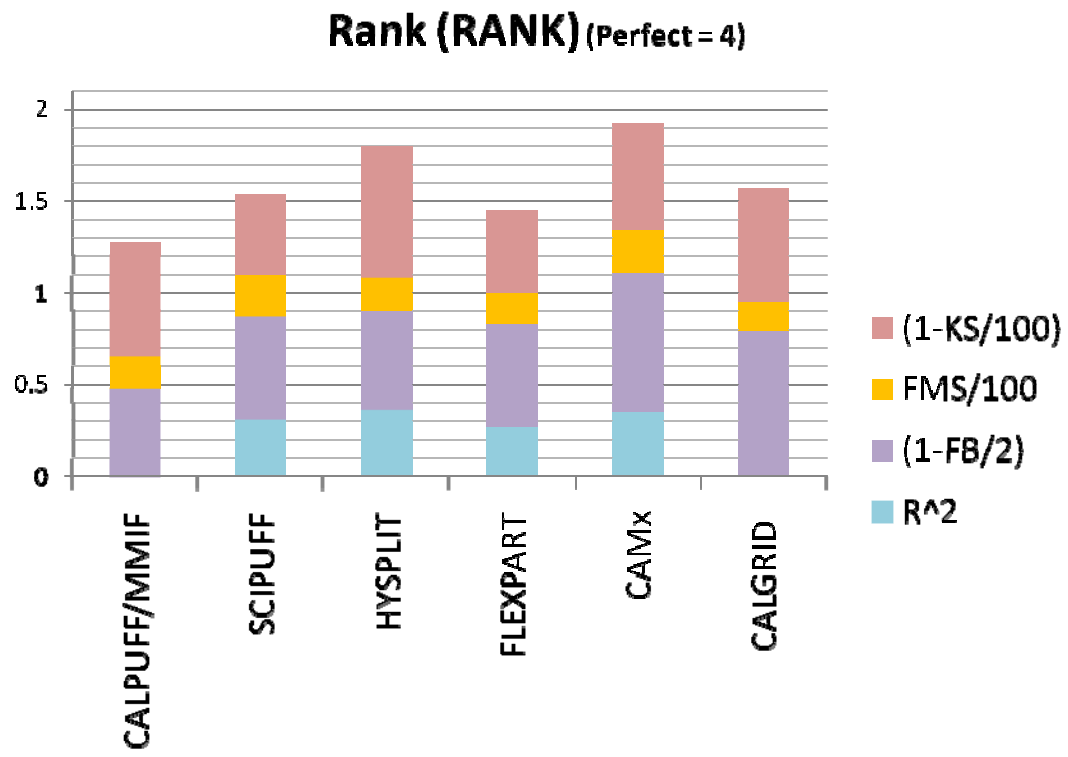


Figure C-40. RANK statistical performance metric for the six LRT models and CAPTEX Release 5.

C.5.2.1 SUMMARY OF SIX LRT MODEL RANKINGS FOR CTEX5 USING STATISTICAL PERFORMANCE MEASURES

Table C-6 summarizes the rankings of the six LRT models for the 11 performance statistics analyzed in CAPTEX Release 5 and compares the averaging ranking across the 11 statistics against the RANK metric. Depending on the statistical metric, five of the six models were ranked as the best performing model for a particular statistic. CALGRID was the only model not ranked first for any performance statistics, although it tied with CAMx for having the lowest (best) FB value (-0.49), but it was ranked behind CAMx (FB of +0.49) due to a desire for regulatory models to not have an underestimation bias. HYSPLIT was ranked the best

performing model the most often scoring best in 4 of the 11 statistics (36% of the time). SCIPUFF, FLEXPART and CAMx all scored best with 2 of the 11 statistics (18%) with CALPUFF scoring best for just one statistical metric.

In testing the efficacy of the RANK statistic, overall rank across all eleven statistics was used to come up with an average modeled ranking to compare with the RANK statistic rankings. The average rank across all 11 performance statistics and the RANK rankings are as follows:

Ranking	Average of 11 Statistics	RANK
1.	CAMx	CAMx
2.	HYSPLIT	HYSPLIT
3.	SCIPUFF	CALGRID
4.	FLEXPART	SCIPUFF
5.	CALPUFF	FLEXPART
6.	CALGRID	CALPUFF

The results from CAPTEX Release 5 present an interesting case study on the use of the RANK metric to characterize overall model performance. As noted in Table C-6 and given above, the relative ranking of models using the average rankings across the 11 statistical metrics is considerably different than the RANK scores after the two highest ranked models. Both approaches rank CAMx as the best and HYSPLIT as the next best performing models for CTEX5, with rankings that are fairly close to each other. However, after that the two ranking techniques come to different conclusions regarding the ability of the models to simulate the observed tracer concentrations for the CTEX5 field experiment.

The most noticeable feature of the RANK metric for ranking models in CTEX5 is the third highest ranking model using RANK, CALGRID (1.57). CALGRID ranks as the worst or second worst performing model in 9 of the 11 performance statistics (82% of the time) and have an average ranking of 5.0, which means on average it is the 5th best performing model out of 6. In examining the contribution to the RANK metric for CALGRID, there is not a consistent contribution from all four broad categories to the composite score (Figure C-40). Recall from equation 2-12 in Section 2.4.3.2 that the RANK score is defined by the contribution of the four of the 11 statistics that represent measures of correlation/scatter (R2), bias (FB), spatial (FMS) and cumulative distribution:

$$RANK = \left|R^2\right| + \left(1 - \left|FB/2\right|\right) + FMS/100 + \left(1 - KS/100\right)$$

The majority of CALGRID's 1.57 RANK score comes from fractional bias and Kolmogorov-Smirnov parameter values. Recall from Figures C-36 and C-39 that the FOEX and FB metrics indicate that CALGRID consistently underestimates. The FB component to the composite score for CALGRID is one of the highest among the six models in this study, yet the underlying statistics indicate both marginal spatial skill and a degree of under-prediction (likely due to the spatial skill of the model).

The current form of the RANK score uses the absolute value of the fractional bias. This approach weights underestimation equally to overestimation. However, in a regulatory context, EPA is most concerned with models not being biased towards underestimation. When looking at all of the performance statistics, CALGRID is clearly one of the worst performing LRT

models for CTEX5, and is arguably the worst performing model. Adaptation of RANK score for regulatory use will likely require refinement of the individual components to insure that this situation does not develop and to insure that the regulatory requirement of bias be accounted for when weighting the individual statistical measures to produce a composite score.

Table C-6. Summary of model rankings using the statistical performance metrics and comparison with the RANK metric.

Statistic	1st	2nd	3rd	4th	5th	6th
FMS	SCIPUFF	CAMx	HYSPLIT	CALPUFF	FLEXPART	CALGRID
FAR	FLEXPART	HYSPLIT	CAMx	SCIPUFF	CALGRID	CALPUFF
POD	SCIPUFF	CAMx	HYSPLIT	FLEXPART	CALPUFF	CALGRID
TS	FLEXPART	HYSPLIT	CAMx	SCIPUFF	CALPUFF	CALGRID
FOEX	CALPUFF	CAMx	HYSPLIT	CALGRID	SCIPUFF	FLEXPART
FA2	HYSPLIT	CAMx	CALPUFF	SCIPUFF	FLEXPART	CALGRID
FA5	HYSPLIT	CAMx	SCIPUFF	CALPUFF	FLEXPART	CALGRID
NMSE	CAMx	SCIPUFF	FLEXPART	HYSPLIT	CALPUFF	CALGRID
PCC or R	HYSPLIT	CAMx	SCIPUFF	FLEXPART	CALGRID	CALPUFF
FB	CAMx	CALGRID	FLEXPART	SCIPUFF	HYSPLIT	CALPUFF
KS	HYSPLIT	CALPUFF	CALGRID	CAMx	FLEXPART	SCIPUFF
Avg. Ranking	CAMx	HYSPLIT	SCIPUFF	FLEXPART	CALPUFF	CALGRID
Avg. Score	2.20	2.4	3.4	3.8	4.3	5.0
RANK Ranking	CAMx	HYSPLIT	CALGRID	SCIPUFF	FLEXPART	CALPUFF
RANK	1.91	1.80	1.57	1.53	1.45	1.28

C.5.3 SUMMARY AND CONCLUSIONS OF CAPTEX LRT MODEL EVALUATION

Following the ATMES-II evaluation paradigm described in Section 2.4.3.1 (spatial) and 2.4.3.3 (global), the performance of the six LRT dispersion models described in Section 2.2 have been evaluated for the Cross Appalachian Tracer Experiment (CAPTEX) Releases 3 and 5. Sensitivities of the INITD (particle/puff) configuration for HYSPLIT and Kz/advection solver combination for CAMx were examined for each CAPTEX release as well as in intercomparison of the model performance for the six models.

The model sensitivity results for HYSPLIT and CAMx are largely comparable to the conclusions from those of the ETEX experiment. For HYSPLIT, the puff-particle hybrid configurations appear to offer a distinct performance advantage over either HYSPLIT's pure particle or puff based formulations. For CAMx, the CMAQ Kz option typically performs the best, followed closely by TKE. The OB70 combination consistently performs the poorest for both CAPTEX releases. The evaluation of the use of the CAMx model's subgrid scale PiG module generally yields slightly degraded performance statistics over the NoPiG option.

United States
Environmental Protection
Agency

Office of Air Quality Planning and Standards
Air Quality Assessment Division
Research Triangle Park, NC

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May, 2012

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RESPONSIVENESS SUMMARY
Comments Taken at the Public Hearing and Written Comments Received on the Proposed Arizona State Implementation Plan Revision for Regional Haze Under Section 308 of the Federal Regional Haze Rule and Associated Significant Revision to AEPCO's Operating Permit No. 55412

The Arizona Department of Environmental Quality (ADEQ) has made corrections to the State Implementation Plan revision to reflect grammatical and editorial errors. ADEQ also notes that the topic of the public hearing was incorrectly identified at the beginning of the hearing. This error was subsequently clarified during the hearing.

ADEQ received 274 postcards and 46 emails from the public stating their support of Arizona Electric Power Cooperative's alternative proposal and the proposed Arizona State Implementation Plan Revision for Regional Haze. This correspondence is not included in the SIP submittal but is available upon request.

GENERAL COMMENTS

(1) Comment: The federal requirements proposed by the U.S. Environmental Protection Agency (EPA) would have required Arizona Electric Power Cooperative (AEPCO) to invest approximately $200 million at Apache Generating Station, doubling the debt load on the plant. An investment of that magnitude could have resulted in a substantial rate increase on rural Californians served by our electric cooperative, as well as thousands of rural residents and businesses in Arizona. AEPCO's proposal reduces that investments to approximately $30 million and results in "better than Best Available Retrofit Technology (BART)" visibility improvements. If the end result is approximately the same or better visibility and the proposed SIP costs approximately $170 million less, it would seem to be an appropriate balancing of cost and environmental benefit as required by the Clean Air Act. ANZA supports AEPCO's proposed alternative and the proposed revision to its Regional Haze State Implementation Plan (SIP) and the significant permit revision.

(Comment submitted by ANZA Electric Cooperative, Inc.)

Response: ADEQ thanks the commenter for their statement.

(2) Comment: Trico Electric Cooperative, Inc. is a not-for-profit distribution cooperative serving roughly 42,000 residential and small commercial customers across the rural and suburban areas surrounding Tucson. Trico purchases nearly 100 percent of the power it distributes to customers from AEPCO, thus any issues affecting AEPCO in turn greatly affect Trico and its customers. Trico's customer base is predominantly residential, so cost and rate increases are acutely felt by its members. Trico's rates are already higher than neighboring utilities and a large rate increase at AEPCO would be detrimental to Trico's customers. EPA's federally mandated plan would have required AEPCO to invest approximately $200 million at Apache Station, doubling the debt load on the plant. An investment of that magnitude could have resulted in a substantial rate increase not only for Trico and its customers, but for rural Arizonans served by electric cooperatives across the state. AEPCO's proposal reduces this investment to approximately $30 million and results in "better than BART" visibility improvements. This is truly a "win-win" solution, one that balances cost and expense while providing comparable or better environmental benefits. ADEQ's proposed SIP revision and AEPCO's significant permit revision should be approved.

(Comment submitted by Trico Electric Cooperative, Inc.)

Response: ADEQ thanks the commenter for their statement.

(3) Comment: Sulphur Springs Valley Electric Power Cooperative (SSVEC) serves approximately 52,000 residential, businesses, small industrial and irrigation services. SSVEC purchases most of its electric power from AEPCO and the Apache Generating Station. EPA's federally mandated plan would have required AEPCO to invest approximately $200 million at Apache Station, doubling the debt load on the plant. An investment of that magnitude could have resulted in a substantial rate increase on rural Arizonans served by electric cooperatives across the state. For a measure not related to health issues, the original propose FIP would place an undue hardship on SSVEC members. Unlike investor owned utilities, where investors seek to make a profit, cooperatives, like SSVEC provide electric service at cost and any profits are eventually returned to the members/owners. The incentive at cooperatives is to keep prices as low as possible to benefit those members using the service. The per capita income of AEPCO consumers is $29,183, a staggering 39 percent lower than the national average. These factors make affordable rates even more critical for AEPCO and their customers. The additional $58 million, required by the FIP that would be charged to SSVEC members, is a great deal of money in any context. The additional cost to members, given that this is a rural area and a depressed economy, would be burdensome on local citizens who will be required to pay it. Given the estimate of the increased cost of the proposed FIP, SSVEC supports the revised SIP.

(Comment submitted by Sulphur Springs Valley Electric Cooperative, Inc.)

Response: ADEQ thanks the commenter for their statement.

(4) Comment: The Apache Plant is a critical power supplier and employer in this region. It supports nearly 260 jobs and serves approximately 150,000 customers throughout rural Southeastern Arizona. The EPA's original proposal, in my view, threatened to eliminate these local jobs and raise electricity rates. This top down, one size fits all approach just doesn't work for Arizona and this is why I brought the EPA to the table. To show them that working with AEPCO we can find a much better plan. A plan that was unique to Arizona's needs and one that will actually lead to more emission reductions, less cost and will prevent a dramatic increase in electricity rates.

At my request, the EPA met with AEPCO and after a series of meetings and the exchange of technical information, agreed that our local solution is better. In fact, EPA sent the Regional Administrator out to see AEPCO in action and actual understood, for the first time perhaps, what an incredible facility this is. The solution that we are talking about is really a win win win out come for AEPCO and for EPA and the rate payers. And I am very please that EPA has agreed and has allowed the Apache facility to submit its revised plan. I want to thank the EPA for working in partnership with AEPCO, and with our community to find a solution that fits the local situation. I'm also pleased that ADEQ is allowing the public to have comment on this plan, because it's extremely important that all stakeholders are able to participate in the review process.

(Comment submitted by Congressman Ron Barber.)

Response: ADEQ thanks the commenter for their statement.

(5) Comment: AEPCO supports ADEQ's proposed revision to the Arizona Regional Haze plan for AEPCO's Apache Generating Station as well as ADEQ's significant permit revision #5959195 Operating Permit 55412 and believes they meet the criteria for issuance under both the Arizona and Federal rules. AEPCO is a rural member owned and not for profit generating transmission cooperative. AEPCO is a relatively small entity with limited financial means and it is imperative that AEPCO finds ways to meet environmental requirements without massive financial impacts so it can continue to provide rural customers with reliable power and affordable power. The EPA's FIP would have imposed selective catalytic reduction technology on two of our major generating units. It would have cost at least $192 million dollars; it would significantly threatened AEPCO's long term liability and our ability to provide our Co-op members affordable power. ADEQ's proposed SIP and permit revisions on the other hand will reduce overall visibility impacts below what would have been obtained by the EPA FIP but at a fraction of the cost approximately; $30 million dollars instead of $192 million dollars under the FIP. ADEQ's proposed Regional Haze SIP and operating permit revision should be adopted because the plan will be better than BART. ADEQ's proposal includes transition of one batches station, primary coal-fired generating unit to a primary natural gas-fired generating unit. This transition combined with additional emission upgrades will substantially lower SO_2 and particulate matter emissions. Combined with additional investment of control technology on the remaining coal-fired unit with less expensive selective non-catalytic reduction technology achieves better visibility than EPA's FIP.

AEPCO supports the significant permit modification proposed by ADEQ. The proposed permit revision provides the necessary requirement for AEPCO to meet the standards mandated by the ISP revision while still allowing reasonable flexibility for operation and ensuring reliable power supply for AEPCO's rural electric cooperative members.

(Comment submitted by AEPCO.)

Response: ADEQ thanks the commenter for their statement.

(6) Comment: I am pastor of a church in Benson as well as Chamber President, and represent the free market and free enterprise. The Benson San Pedro Valley Chamber of Commerce has 114 members of which there are over 1,000 households represented by our member's employees. We support the alternative plan that Arizona G&T Cooperatives have provided to ADEQ. The plan supports reasonable requirements that show good stewardship of our environment by minimizing emissions and does not endanger our environment.

As a member of AEPCO and Arizona's G&T Cooperatives, we ask that the plan is accepted as proposed. EPA's alternative, requiring more than 200 million in capital investment would result in consequences beyond our control and would harm our rural economy by raising the cost of wholesale power. The AEPCO alternative plan, at a cost of approximately 30 million, achieves results that are better than what the EPA and your agency sought at a much lower cost, one that will not have serious negative and long-term affects on our economy. We call that a win-win. Thank you for your support of the alternative plan.

(Comment submitted by Lupe Diaz.)

Response: ADEQ thanks the commenter for their statement.

(7) Comment: I appreciate that ADEQ is present to hear what the constituents and the people who take power from AEPCO and what they have to say about the program that has been put in place. I have been aware of the EPA standards since they came out and I am concerned with the requirements for AEPCO.

In the beginning, I think everyone thought that EPA has a solution and we have to accept it, but AEPCO did not accept it. AEPCO has developed a win-win situation by working with EPA. I am truly grateful that you have sat the table and become a partner with us. I represent a lot of constituents; the AEPCO power plant and Sulphur Springs Valley Electric is very important to rural Arizona. We need dependable power, as inexpensive as possible. This is the reason why we created the Co-op and why we created AEPCO, so we can control our destiny. I appreciate ADEQ working with AEPCO and ask that the significant permit revision is approved. We have gotten to the table and ADEQ was willing to sit and listen to a better alternative than what was proposed by EPA.

(Comment submitted by Ann English.)

Response: ADEQ thanks the commenter for their statement.

(8) Comment: For the record my name is Philip Bashaw, I'm the Director of Government Relations for the Grand Canyon State Electric Cooperative Association. My association has submitted written comments so I will keep my oral comments brief. The Grand Canyon State Electric Cooperative Association is a statewide association representing the six distribution Co-ops in the State of Arizona as well as one cooperative in California. We serve consumers in Arizona, California and New Mexico; in total a little more than 400,000 consumers of electricity. AEPCO is also a member of our association. We are here today to support the significant permit revisions to the AEPCO plan in the Apache Generating Station. AEPCO is the supplier of wholesale electricity for our electrical Co-ops throughout the State of Arizona the consumers that they provide electricity to. The cost of EPA's FIP would have to been born by our consumers day to day. We believe that the permit and SIP revisions create a balance between the cost and environmental benefits from the changes in these revisions. And so, we ask that you support and approve those changes to the SIP and the department as well. Thank you very much.

(Comment submitted by Grand Canyon State Electric Cooperative Association.)

Response: ADEQ thanks the commenter for their statement.

(9) Comment: I moved here in 1981 and am an electrician by trade and worked for AEPCO for 27 years. I am 100 percent in support of AEPCO's alternative plan and strongly recommend that it is accepted and implemented. AEPCO has demonstrated their ethical nature and responsibility in their concern to come up with this alternative plan in order to keep costs down to the end users, the people and businesses and other Co-ops.

(Comment submitted by Walter Risch.)

Response: ADEQ thanks the commenter for their statement.

(10) Comment: I am the Executive Director for the Wilcox Chamber of Commerce and Agriculture. We have about 175 members, both manufacturing and agriculture. We are in support of AEPCO's revision. Our businesses could not bear the cost of the EPA regulations if they are put into place. Our businesses manufacture food and it would have consequences not just for us locally, but for people throughout the State and the country and even the world. I thank ADEQ for working on the revision, which we support.

(Comment submitted by Alan Baker.)

Response: ADEQ thanks the commenter for their statement.

(11) Comment: I was born and raised in Benson and want to thank ADEQ for allowing us to speak today at the public hearing. I am in support of the proposed revision by ADEQ. AEPCO's proposal is more sustainable than EPA's because it accomplishes the same thing and a lower cost. I also own a small motel and RV park. More and more people are living in RV units because that is all they can afford. If the 192 million dollar retrofit is implemented, people are not going to be able to afford to live in these RV units. I commend ADEQ for working with AEPCO in this revision.

(Comment submitted by Dan Barrera.)

Response: ADEQ thanks the commenter for their statement.

(12) Comment: I serve on the Board of Directors for Trico Electric Cooperative, which is one of the Arizona Electric Generation members. Trico has an advantage over many rural cooperatives in that we have more consumers per mile per line, 11 consumers per mile per line. Our members pay more for their electricity since we are so close to Tucson. There are 42 million Co-op members in the United States and they serve about 85percent of the land mass in the United States. We are out where no one else would go but our people count too. We are small Co-op, but people living in very rural areas have trouble paying their electricity bills already.

We are grateful to have this opportunity to try an alternative and that our Cooperative rose up and decided to try to find something better and that ADEQ helped us. We appreciate EPA listening to what it is like living in rural Arizona. The visibility in Southern Arizona is mostly because of dirt roads. So, like I say, we appreciate what we have from Arizona Electric.

Executive Order 12866, which was promulgated in 1993, requires that a federal agency assess both the cost and benefits of a proposed regulation and adopt it only upon a reasonable determination the benefits justifies its cost. Recently, the Office of Management and Budget said that the cost and benefits calculation should help determine whether a regulation is worth implementing at all. Thank you for being here and letting us comment. I'm passionate about the needs of the people in my town and what we need is reliable and affordable electric energy.

(Comment submitted by Barbara Stockwell.)

Response: ADEQ thanks the commenter for their statement.

(13) Comment: I am a life long resident in Benson and represent the Southeast Arizona Economic Development Group, which is a regional nonprofit organization that helps business. Thank you for the opportunity to comment on the proposed revision to the Regional Haze State Implementation Plan to modify and retrofit the requirements for the Apache Generating Station. On behalf of Southeast Arizona Economic Development Group, its Board of Directors and Regional Business Membership we urge you to approve ADEQ's proposed revision to the SIP and AEPCO's permit revision number 59195. Our region and rural economy depend on reliable and affordable electrical power. We need to know that not only will the electric rates remain as low as possible but also that they will remain stable so we can plan for future needs and those of the community we represent. The revised plans will help AEPCO maintain those reliable rates. EPA's mandated plan on the other hand would have required AEPCO to invest around 200 million dollars at the Apache Generating Station. This would have resulted in the increase

cost that would have been absorbed by our rural users in Arizona. AEPCO's proposal reduces the investment to around 32 million dollar and results in improvements to the air quality or probably better than what EPA was seeking. If the end result is the same or better through the proposed SIP and it costs around 170 million dollars less, it seems to be a good balance of environmental benefit and cost to AEPCO and to its members. The Economic Development Group and our supporters thank you for the opportunity to comment and encourage the panel and ADEQ to support the plan.

(Comment submitted by George Scott.)

Response: ADEQ thanks the commenter for their statement.

(14) Comment: I represent Benson Unified School District and I also speak in support of the ADEQ proposal. I am an avid outdoors man, enjoy clean fresh air, and a runner and a hiker. To follow the EPA plan would be very detrimental to our community. About 60 percent of students receive free or reduced lunch; many of our parents are at poverty level. To increase rates would be very devastating. Electricity is the number two cost of our school district. We have been frozen for six of the last eight years, as it pertains to school funding and it would be very difficult for us to have a rate increase in electricity. The ADEQ proposal sounds like a win-win proposal, something that will benefit all of us and I do strongly support that.

(Comment submitted by Dr. David Woodall.)

Response: ADEQ thanks the commenter for their statement.

(15) Comment: I have heard many comments saying we need to accept this revised bid and I agree to a certain point. It is way better than EPA's choice, which would absolutely devastate rural Arizona. But I the fact is EPA does not need to be doing anything down here. The haze is not caused by the generating station, it's not caused by electricity being produced or caused by dust in the air. This will not change anything as far as our haze. But, the EPA needs to step back and not do this to any State especially to Arizona.

(Comment submitted by Kathleen Miller.)

Response: ADEQ thanks the commenter for their statement.

(16) Comment: My wife and I own a small farm in the area and we pay about $1,000 a year for electricity for our irrigation system. An increase in electricity of the amount that would have been required if the EPA regulations would have been promulgated and enforced would make our non-profitable business even more non-profitable. I agree with what has been said so far at this hearing. The idea that the federal government comes in and lays regulations on it seems like the federal government is having a fight with Arizona and the Arizona Government. I think it is wonderful that Arizona fought back and it looks like we won. .

(Comment submitted by Stuart Kershner.)

Response: ADEQ thanks the commenter for their statement.

(17) Comment: Implementing this 30 million dollar project is going to affect our rates. My monthly income is just slightly over $1,000 a month and every entity, city, schools, the Wal-Mart, the gas stations, everyone that has to suffer this rate increase is going to pass that on to the rest of us. Some of us are on fixed incomes. This does not mean that I am opposed to this but I think that EPA has taken us hostage. Everyone in this room, including ADEQ, is being forced to spend money on our power generating plant that probably that does not need to be spent. I think the benefits are minimal, probably even negligible. The on-going drought we've had here in Arizona leads to less vegetation and less ground cover, resulting in more dust. The prevailing winds come from south of the border, going north or northeast. There is no EPA south of the border and they do not have the strict pollution standards requirements that we have in the U.S. Primarily, they do not have the requirements are on their mines, trucks, vehicles, open burning, and power plants. All of those pollutants are blowing our way. If Apache Generating Station was completely shut down, there would probably be minimal benefit. The cost of EPA's proposal to upgrade the plant is alarming and does not really need to be done. There will be such a slight benefit in haze from reduced particulates, as compared to what comes from across the border. Even though we are all held hostage, I thank AEPCO and all of their employees and all of their Co-ops for working to minimize the cost to all of the members. ADEQ's part is to help negotiate the ransom that EPA is pushing on us and I am in support of AEPCO's proposal.

(Comment submitted by Jeff Cook.)

Response: ADEQ thanks the commenter for their statement.

TECHNICAL COMMENTS

(18) Comment: The proposed SIP revision shows total emissions of 3,440 under the proposed alternative and 3,355 under BART.[1] The references on this page and in many other places to "facility-wide emissions" are incorrect; examination of the TSD clearly states that only emissions from Units 2 and 3 are included, as the emissions from Unit 1 are not expected to change from BART to the proposed alternative.

(Comment submitted by the National Parks Conservation Association and Sierra Club.)

Response: ADEQ concurs that the use of "facility-wide" in reference to emissions was incorrectly used in portions of the AEPCO Apache Generating Station BART Alternative Control Review Technical Support Document (Alternative TSD). This document has been revised to account for the incorrect usage of this term on the following pages: 3, 12, and page 13.

(19) Comment: Please clarify as to whether the modeled results reflect the emissions scenarios in the May 29, 2013, proposal or the more recent emissions estimates.

(Comment submitted by the National Parks Conservation Association and Sierra Club.)

Response: The modeling results are based on the emissions rates presented in Tables 8 and 9 of the TSD. This differs slightly from the emission scenarios presented in the May 29, 2013 submittal. The

[1] AEPCO Apache Generating Station BART Alternative Control Review Technical Support Document. December 17th, 2013. Arizona Department of Environmental Quality, page 4

difference included modeling increases of H_2SO_4 for the SCR scenario due to catalyst oxidation and utilizing the 2013 9bv2 PNGt scenario.

Please refer to the TSD for additional information.

(20) Comment: A BART alternative – as is proposed here – may be implemented in lieu of BART if it *"achieve[s] greater reasonable progress than would be achieved through the installation and operation of BART."* This can be demonstrated in two ways, or *"otherwise based on the clear weight evidence."*

1) First, if the *"distribution of emissions"* is the same under the alternative and under BART, the alternative need only have *"greater emissions reductions."*
2) Second, if the distribution of emissions is dissimilar, visibility modeling is required.

In this case, ADEQ has not demonstrated that the alternative achieves greater reasonable progress through any of these approaches. With regard to the first test, ADEQ determined that the distribution of emissions is not the same because the proportion of pollutants is dissimilar.

The proposed alternative would emit more nitrogen oxides (NO_X) and less sulfur dioxide (SO_2) and particulate matter (PM).

We agree with ADEQ's determination that this method of demonstrating greater reasonable progress does not apply. In line with BART determinations that are pollutant specific, the test for "greater emissions reductions" clearly contemplates emissions reductions of the same pollutant, e.g., NO_X emissions for NO_X emissions. Indeed, if this were not the case, the result would be ludicrous – opening the door for trading non-equivalent pollutants without regard to their relative impact on visibility. A reduction of one ton of NO_X does not necessarily have the same visibility impact as one ton of SO_2, PM, or other pollutants, and moreover this relationship varies depending on site-specific circumstances. The impact of a trade-off in pollutants can only be accurately determined by visibility modeling.

However, EPA has elsewhere proposed finding that the "distribution of emissions" is the same if the emissions emanate from the same facility under both BART and the alternative. If this test of greater emissions reductions is applicable, ADEQ's proposed alternative appears to fail. The combined annual tons of NO_X, SO_2, and PM under the alternative are 85 tons higher than under BART. It is unclear why this balance has changed from AEPCO's May 29, 2013, proposal, which showed, conversely, that the emissions under the alternative would be 65 tons per year less than under BART. With the information given, we can only conclude that the alternative does not provide greater emissions reductions, and thus would fail the first test if it were deemed applicable.

Even where it has proposed using the first test, however, EPA has admitted the necessity of visibility modeling – the second test. With regard to a proposed BART alternative for a facility in Tesoro, Washington, that would increase NO_X while decreasing SO_2 and PM, it acknowledged that visibility modeling was "appropriate" in light of concerns about the non-equivalence of pollutant impact. Furthermore, with regard to the Sundt facility in Arizona, EPA prepared visibility modeling "to verify the visibility benefits of the proposed alternative" even though all three visibility-impairing pollutants – NO_X, SO_2, and PM – will decrease under the alternative. Thus it is clear that even if the first test applies, visibility modeling should be considered, particularly when pollutant trade-offs are

proposed, and must definitely show that the alternative provides greater reasonable progress than BART.

Furthermore, in the case of single source modeling like CALPUFF, only the meteorological factors are influenced by the years modeled. Thus, while a more recent timeframe might arguably make more sense at this point than Arizona's BART baseline of 2001-2003, unless the meteorology has changed significantly in the last decade, it would make more of a difference under a multi-source photochemical grid model. CALPUFF modeling over the BART baseline years are sufficient to determine the relative benefit of different technologies applied at a single source; this is no different. Indeed, EPA has used CALPUFF in several similar situations.

Thus we disagree with ADEQ, and believe that the second test applies. Nevertheless, as described by EPA, "the underlying purpose of both prongs of the test is to assess whether visibility conditions at Class I areas would be better with the alternative program in place than they would without it." This is also the ultimate test that any "clear weight of evidence" must show.

In this case, ADEQ claims that the second test does not apply because the appropriate point of comparison is in the future and requires photochemical grid modeling. We disagree. The regulations state only that "dispersion modeling" is required. ADEQ cites the preamble to the final rule setting the tests in 51.308(e)(3), which notes "the logical reference point [for comparing a BART alternative] is visibility conditions as they are expected to be at the time of program implementation" (that is, in the future). However, that same section notes "we did not specify the time period which should serve as the starting point for comparison." The point of comparison is discretionary and not necessarily in the future.

(Comment submitted by the National Parks Conservation Association and Sierra Club.)

Response: One of the required elements of a better-than-BART finding is:

> *"A determination under [308(e)(3)] or otherwise based on the clear weight of evidence that the . . . alternative measure achieves greater reasonable progress than would be achieved through the installation and operation of BART at the covered sources."* [2]

There are two options for making a determination under 51 CFR 308(e)(3):

a. *"If the distribution of emissions is not substantially different than under BART, and the alternative measure results in greater emission reductions, then the alternative measure may be deemed to achieve greater reasonable progress.*
b. *If the distribution of emissions is significantly different, the State (or EPA) must conduct dispersion modeling to determine differences in visibility between BART and the trading program [or the alternative] for each impacted Class I area, for the worst and best 20 percent of days. The modeling would demonstrate "greater reasonable progress" if both of the following two criteria are met:*

    i. *Visibility does not decline in any Class I area, and*
    ii. *There is an overall improvement in visibility, determined by comparing the average differences between BART and the alternative over all affected Class I areas."* [3]

[2] 308(e)(2)(i)(E).
[3] Id. 308(e)(3).

The preamble to the rule explains that:

> *"The underlying purpose of both prongs of the test [under 308(e)(2)(b)] is to assess whether visibility conditions at Class I areas would be better with the alternative program in place than they would without it. The first prong ensures that the program does not cause a decline in visibility at any particular Class I area. It addresses the possibility that the alternative program might allow local increases in emissions which could result in localized degradation. The second prong assesses whether the alternative program produces greater visibility improvement in the aggregate than would source specific BART."*[4]

While ADEQ holds that the method utilized for determining better-than-BART status in this case should be "based on the clear weight of evidence" for those reasons listed in the technical support document (TSD) (see pages 1 and 2) for the SIP revision, ADEQ asserts that it provided a better-than-BART determination which is consistent with the two prong test listed above. ADEQ recognizes that 308(e)(3)(a) does not apply to this alternative as there is a dissimilar distribution of pollutants between EPA's BART and the AEPCO alternative (ADEQ acknowledges the comment regarding EPA interpretation of the term "distribution of emissions). Compared to the EPA BART determination, implementation of the AEPCO alternative will increase NO_x emissions while resulting in reduced SO_2 and PM emissions.

As noted by the commenter, ADEQ calculated emissions differ from those presented in AEPCO's May 29, 2013 proposal due to the use of differing average heat rates [MMBtu/hr] and annual percentage days of operation (i.e. Annual Capacity Factor). The heat rates used by ADEQ in Table 1 of the Alternative TSD and the average days of operation were determined from analysis of 2008 to 2010 data from EPA's Clean Air Market Database (CAMD) data for the AEPCO facility. Furthermore, ADEQ utilized CAMD data to determine the Baseline NO_X emission factor. In AEPCO's submission, the heat inputs utilized were closer to maximum achievable heat rates, while ADEQ's were intended to represent the average heat rate as determined from CAMD data from 2008 to 2010. ADEQ utilized the percentage of annual days of operation as calculated from CAMD data. ADEQ utilized CAMD average data in order to provide a more consistent average baseline emission inventory for the facility as determined from operating conditions between the years of 2008 and 2010. However, the changes employed by ADEQ in the annual emissions estimates do not affect the visibility modeling inputs as the inputs are based on maximum heat rates and/or maximum recorded emission rates. In summary, calculated annual emissions reflect average emissions from the facility for one year while modeling assumes continuous emissions at the facility at the highest recorded emission rate.

For the 2 prong test, the preamble to 40 CFR 51.308 specifies that the addition of the alternative control technology should not result in visibility degradation at any Class I area in relation to the base case emissions.[5] The results of the modeling (Table 10 of the Alternative TSD) clearly show that in comparison to base case emissions (i.e. 2013 Baseline) implementation of the AEPCO alternative (i.e. 2013 9bv2 PNGt) results in visibility degradation at none of the Class I areas. ADEQ notes that only the second prong of the rule, which addresses aggregate visibility improvement, requires comparison of visibility degradation in relation to BART, and even then it does not require an area by area comparison. Therefore, while not bound to the two prong test, the requirements of this test have been met as the AEPCO alternative will result in visibility enhancement at all nine Class I areas in comparison to base

[4] 70 CFR 39138
[5] IBID

case facility emissions and shows visibility enhancement for the aggregated nine Class I areas when comparing the AEPCO alternative to BART.

With regard to the comment on the "appropriate point of comparison", ADEQ acknowledges the comment and understands the confusion that the two apparent conflicting statements may cause. However, ADEQ believes these two statements should be considered in the context in which they were written in EPA's original preamble. The statement *"we did not specify the time period which should serve as the starting point for comparison",* in the context of the paragraph in which it is contained, is referring to the how the original rule was written. The original rule was not written to "specify the time period". EPA continues to state:

> *"…we [EPA] did not specify whether potential degradation should be determined in relation to visibility conditions existing at the time of the proposed program, or in relation to base case visibility projections for the time of program implementation. While either option is, we believe, reasonable…"*

EPA continues two paragraphs down by specifying that:

> *"the logical reference point is visibility conditions as they are expected to be at the time of program implementation but in the absence of the program. This insures that the visibility improvements or degradations determined are due to the programs being compared—source-specific BART and the cap-and-trade alternative—and not to other extrinsic factors…By comparing the alternative to future projected baseline conditions, such extrinsic variables are accounted for. We are thus able to ascertain (to the extent possible where future projections are concerned) whether visibility under the alternative would decline at any Class I area, all other things being equal."*

ADEQ, in consultation with EPA, determined that it was not feasible to model the Apache facility using the projected emissions method, which is EPA's "logical reference point", and instead determined, in consultation with EPA, that it is appropriate to apply the option of "otherwise based on the clear weight of evidence" under 308(e)(2)(i)(E) to the AEPCO alternative. This weight of evidence demonstration includes both a calculation of emission reductions and an analysis of visibility benefits. In general, visibility benefits should be determined for the better than BART demonstration in the same manner as for the original BART determination, which is what was done for this alternative proposal.

(21) Comment: The regulations require looking at both the best 20% and the worst 20% of days. ADEQ's discussion of the 98th percentile values is valuable, but under the "clear weight of evidence" standard, the analysis should include results from both less impacted and more heavily impacted days.

(Comment submitted by the National Parks Conservation Association and Sierra Club.)

Response: ADEQ considers the BART visibility metric as the appropriate approach when performing comparisons for single source visibility degradation determinations. When performing this comparison, the use of the 20% best day visibility background would result in the most conservative single source effects on a Class I area. This is due to the relative proportion of visibility impairing emissions originating from the source in comparison to total visibility impairing emissions in the atmosphere. Therefore ADEQ contends the modeling method utilized represents a conservative approach for evaluation of visibility degradation and fulfills the requirement to achieve greater reasonable progress than BART based on a clear weight of evidence.

However, in order to provide additional evidence of the Class I area visibility benefit of the AEPCO alternative, additional modeling was performed to determine the visibility benefit of the AEPCO alternative in comparison to EPA's BART and the base case scenario. Based on the comments provided during the public comment period, AEPCO conducted additional CALPUFF modeling to determine the effect of the AEPCO alternative control strategy against EPA's BART and the baseline scenario.

AEPCO's analysis concluded that:

> "*ENVIRON post-processed the CALPUFF modeling results for the current base case, EPA SCR BART scenario and the relevant AEPCO Alternative for the B20% and W20% days at Class I areas within 300 km of Apache and found each of the AEPCO Alternative scenarios resulted in: (1) no decline in visibility for the B20% and W20% days at each Class I area over current conditions; and (2) improvement in visibility over the EPA SCR BART scenario averaged over all Class I areas. Thus, the AEPCO BART Alternative satisfies the Better-than-BART test.*"[6]

On page 6 of the memorandum, AEPCO provided the following table to support this statement:

Table 2a. USEPA's two-prong Better-than-BART test for three representations of the AEPCO Alternative control strategy using CALPUFF modeling results with constant (1 ppb) background ammonia concentrations (deciview).

	Prong 1[a]		Prong 2[b]	
	EPA Base minus AEPCO Alternative (range is across Class I areas)		EPA BART minus AEPCO Alternative (averaged across all Class I areas)	
AEPCO Alternative	B20% (dv)	W20% (dv)	B20% (dv)	W20% (dv)
EPA Control 9b PNGt	0.10 to 0.30	0.01 to 0.16	0.003	0.021
EPA Control 9bv2 PNGt	0.02 to 0.30	0.01 to 0.25	0.006	0.024
Updated PM Factor	0.01 to 0.33	0.01 to 0.28	0.016	0.035
a. Since the difference in visibility impacts between EPA Base minus AEPCO Alternative at all Class I areas are positive, then the AEPCO alternative always results in improvements in visibility therefore satisfying Prong 1 of the Better-than-BART test to not have any decline in visibility at any Class I area.				
b. Since the difference in visibility impacts between the EPA SCR BART minus AEPCO Alternative averaged across all Class I areas is positive, then the AEPCO Alternative demonstrates more visibility improvements than the EPA SCR BART therefore satisfying Prong 2 of the Better-than-BART test to have more overall visibility improvements than BART				

(22) Comment: The modeled emission rate for Unit 3 (0.225 lbs/mmbtu) is lower than the permitted limit (0.23 lbs/mmbtu). Modeled results might underestimate the impacts, and we encourage conservative interpretation of the results as a margin of safety.

(Comment submitted by the National Parks Conservation Association and Sierra Club.)

Response: In general, under standard operating conditions, AEPCO believes Steam Unit 3 will achieve a maximum emission rate of 0.225 lb/MMBtu. However, should there be a number of startups and shutdowns within a single 30-day period, the unit may not be able to achieve the lower value. Because Steam Unit 3 is anticipated to serve in a load-following fashion, ADEQ has determined that the 0.225 lb/MMBtu rate is the most appropriate for visibility modeling purposes. While the emission limit of

[6] Additional Post Processing of CALPUFF Visibility Modeling of the AEPCO BART Alternative Scenarios to address Better than BART requirements. April 17, 2014. ENVIRON Corp.

0.230 lbs/MMBtu does not match the emission rate modeled in scenario 9bv2 PNGt, the modeled emission rate of 0.225 lb/MMBtu represents 97.8% of the NO_X emissions for this Unit. In respect to annual emissions, this represents an approximate difference of only 35 tons/year of NO_X for the facility, or only approximately 1.7% of the total estimated NO_X emissions of Units 2 and 3 combined. However, a conservative modeling comparison can still be made from the modeling performed and the results presented by AEPCO in their May 29, 2013, documentation.

In AEPCO's May 29th, 2013, documentation, the 9b PNGt alternative control modeling scenario utilized similar, yet more conservative, emission factors for NO_X and PM than the 9bv2 PNGt scenario analyzed in ADEQ's TSD. For the 9b PNGt scenario, an emission factor of 0.230 lb/MMBtu was modeled for the ST3 NO_X emissions (i.e. the same factor as allowed by the proposed permit), and a PM emission factor of 0.010 lb/MMBtu was modeled for Unit 2 (i.e. 20% higher than the permitted limit). This more conservative modeling approach resulted in the following visibility impacts on Class I areas within a 300 km buffer:

	2013 Baseline		**2013 SCR**		**2013 9b PNGt**	
Site	**Avg 98th**	**22nd high**	**Avg 98th**	**22nd high**	**Avg 98th**	**22nd high**
Chiricahua NM	3.328	3.409	1.978	1.996	1.926	1.960
Chiricahua WA	3.418	3.464	1.886	1.979	1.905	1.913
Galiuro WA	2.178	2.219	1.208	1.205	1.148	1.181
Gila WA	0.642	0.629	0.262	0.279	0.294	0.307
Mazatzal WA	0.266	0.277	0.156	0.147	0.130	0.127
Mt. Baldy WA	0.269	0.282	0.109	0.114	0.115	0.118
Saguaro NP	2.502	2.493	1.421	1.463	1.388	1.357
Sierra Ancha WA	0.289	0.287	0.153	0.158	0.133	0.131
Superstition WA	0.596	0.612	0.313	0.315	0.282	0.293
Average	**1.499**	**1.519**	**0.832**	**0.851**	**0.813**	**0.821**

Comparison of these modeling results to the Baseline and EPA's BART (SCR) utilizing EPA's two pronged Better-than-BART analysis shows more benefit from the conservative modeling approach (9b PNGt) for the AEPCO proposed alternative controls than EPA's BART. The first prong of EPA's two pronged approach for determination of Better-than-BART requires the BART alternative to show visibility enhancements at all impacted Class I areas when compared to current controls. The following graph relates the resulting visibility impairment to the modeled baseline approach at impacted Class I areas (a negative value indicates visibility enhancement for the AEPCO alternative as compared to the currently implemented facility controls):

dv difference between 2013 Baseline and AEPCO Alternative 2013 9b PNGt (Alt - Base)		
Site	**Avg 98th**	**22nd high**
Chiricahua NM	-1.402	-1.449
Chiricahua WA	-1.513	-1.551
Galiuro WA	-1.030	-1.038
Gila WA	-0.348	-0.322
Mazatzal WA	-0.136	-0.150
Mt. Baldy WA	-0.154	-0.164

dv difference between 2013 Baseline and AEPCO Alternative 2013 9b PNGt (Alt - Base)		
Site	**Avg 98th**	**22nd high**
Saguaro NP	-1.114	-1.136
Sierra Ancha WA	-0.156	-0.156
Superstition WA	-0.314	-0.319

The second prong of EPA's Better-than-BART analysis requires that there is an average visibility enhancement across all Class I areas for the alternative control as compared to BART. The following table presents the average visibility impact of EPA BART and the AEPCO alternative across all modeled Class I areas and then compares the two averages (a negative "Difference" indicates the AEPCO alternative results in better visibility averaged across all modeled Class I areas than BART):

Average Impact of 2013 BART and AEPCO Alternative 2013 9bPNGt over all Class I areas		
Control Type	**Avg 98th**	**22nd high**
2013 SCR	0.832	0.851
2013 9b PNGt	0.813	0.821
Difference (Alt - SCR)	**-0.018**	**-0.030**

Therefore, from the information provided above, ADEQ has determined that a NO_X limit of 0.230 lb/MMBtu is appropriate as a permit limit for ST3 as it meets EPA's 2-prong test for a better-than-BART alternative.

(23) Comment: The regulations clearly contemplate the potential impacts at "any" and "all affected" Class I areas. ADEQ's results only discuss Class I areas within 300 kilometers (km). There is no boundary at 300 km that limits the impact of pollutants; rather, it is a historical artifact based on perceived limits of the CALPUFF model. In fact, there are impacts well beyond 300 km that can be modeled by CALPUFF. In this case there are 14 more Class I areas between 300 and 600 km. The impacts to these and any other impacted Class I areas must be considered.

(Comment submitted by the National Parks Conservation Association and Sierra Club.)

Response: The Clean Air Act, federal Regional Haze Rule, and EPA guidance do not specify a range or distance from Class I areas to use in visibility analyses. EPA's modeling guidance in Appendix W (40 CFR Part 51), indicates that 300 km is an appropriate and reasonable transport distance when using the CALPUFF dispersion model:

> *"It was concluded from these case studies that the CALPUFF dispersion model had performed in a reasonable manner, and had no apparent bias toward over or under prediction, so long as the transport distance was limited to less than 300km." (40 CFR Part 51, Appendix W)*

In addition, because there is no stipulated boundary or transport distance, ADEQ used the distance that most states and EPA utilized for their visibility analyses. For example, EPA approved California's Regional Haze SIP in June 2011, which used a transport distance of 300 km for its visibility analysis. EPA also used a transport distance of 300 km for the technical analyses as part of their Federal

Implementation Plans (FIP) for Hawaii, Nevada, and Montana. EPA's BART analysis for Arizona's FIP took into consideration improvement in visibility impacts that were expected to occur at all Class I areas within 300 km of each source (77 FR 42834; 77 FR 72511). In addition, EPA conducted CALPUFF modeling to check ADEQ's conclusion regarding potential impacts of PM10 from the ASARCO Hayden smelter on Class I areas. EPA's analysis used a transport distance of 300 km and confirmed ADEQ's conclusion that impacts was so small that no additional analyses was necessary (78 FR 29292; 78 FR 46142). To be consistent with the analyses conducted by other states and EPA, ADEQ assessed Class I areas within a 300 km boundary for its evaluation of the AEPCO alternative.