# ADDENDUM TO:

# STATE OF ARIZONA EXCEPTIONAL EVENT DOCUMENTATION FOR WILDFIRE-CAUSED EXCEEDANCES ON JUNE 20, 2015 IN THE MARICOPA NONATTAINMENT AREA – SEPTEMBER 2016

## Expanded Conceptual Model Linking Ozone and Ozone Precursors From the Lake Fire with the Ozone Exceedances in the Maricopa Nonattainment Area


Prepared by:

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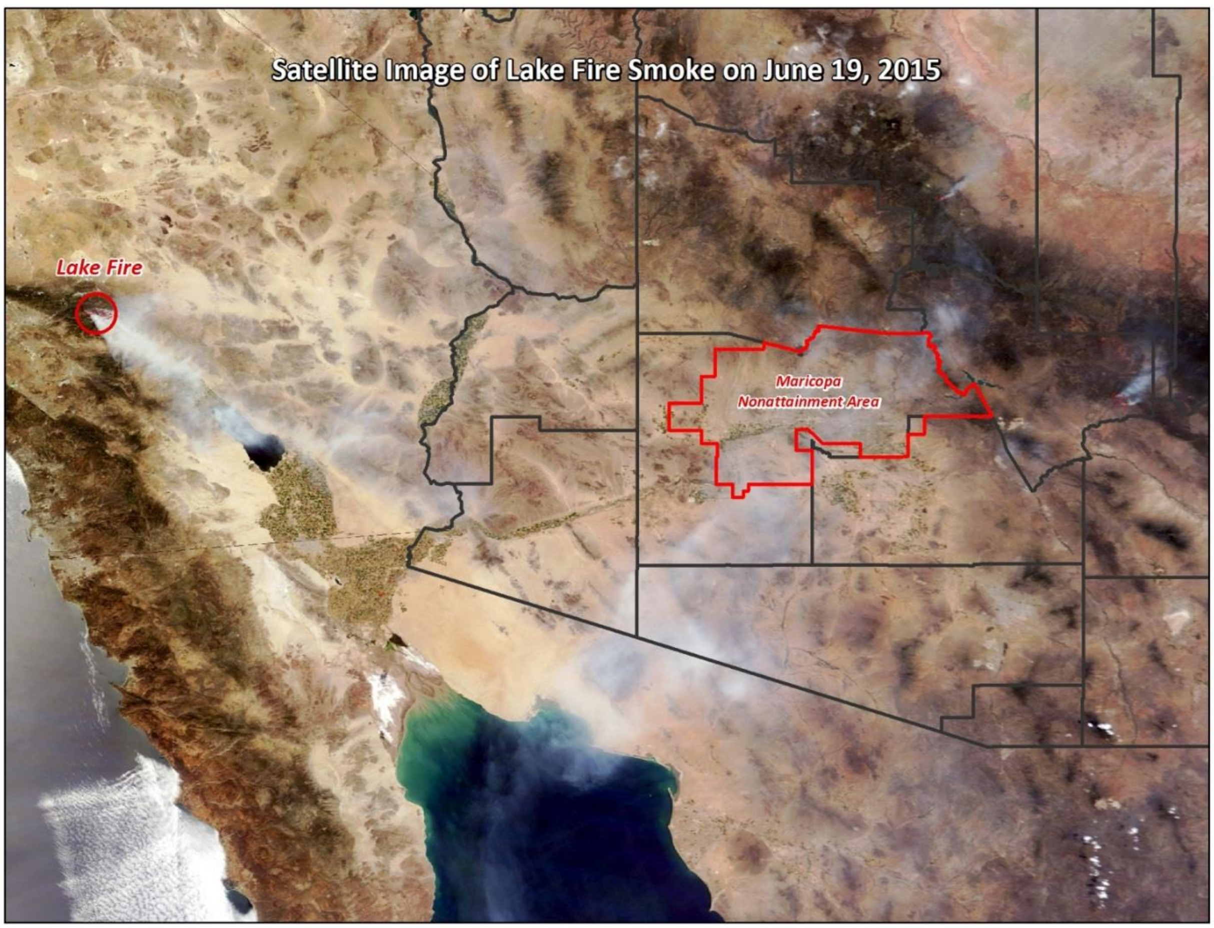

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## INTRODUCTION

The prior exceptional event documentation submitted to the Environmental Protection Agency (EPA) in September 2016 and May 2018 by the Arizona Department of Environmental Quality (ADEQ) provided substantial evidence that exceedances of the 2008 ozone standard on June 20, 2015 in the Maricopa nonattainment area were caused by transported ozone and ozone precursors from the Southern California Lake Fire, qualifying the exceedances for exclusion as exceptional events. The documentation satisfied the statutory and regulatory requirements for excluding exceedances as exceptional events and followed the suggestions for presenting evidence of a wildfire-caused exceptional event as described in EPA's guidance document on wildfire exceptional events.

Subsequent to the submittal of the prior documentation, additional analyses have been performed to expand upon the conceptual and narrative model of the wildfire event, providing new and additional evidence linking the ozone and ozone precursors from the Lake Fire with the exceedances of the 2008 ozone standard in the Maricopa nonattainment area on June 20, 2015. This addendum provides the expanded conceptual model of the wildfire event based upon new and additional analyses.

### Public Comment Period

The Arizona Department of Environmental Quality posted this addendum on the ADEQ webpage and placed a hardcopy of the report in the ADEQ Records Management Center for public review. ADEQ opened a 30-day public comment period on March 25, 2019. In order to speed the review and approval of this exceptional event demonstration by EPA Region 9, ADEQ is following a parallel processing procedure whereby this addendum was submitted to EPA for review and approval on the same day as the opening of the public comment period. ADEQ will respond promptly to any comments received during the comment period and provide EPA with a list of comments received and responses to those comments. A copy of the public notice certification is included in Appendix C.

## EXPANDED CONCEPTUAL AND NARRATIVE MODEL OF THE WILDFIRE EVENT

In the prior documentation, the conceptual model describes the transport of smoke, ozone and ozone precursors (e.g., NOx and VOCs) generated by the Lake Fire on June 18-19, 2015, into the Maricopa nonattainment area on June 20, 2015. Prior submitted satellite photos and National Oceanic and Atmospheric Administration (NOAA) smoke maps provide visual evidence of the transport of smoke across a large portion of Arizona on June 18-19, 2015.

The conceptual model also highlighted the effect of the transported ozone and ozone precursors from the Lake Fire on local ozone concentrations in the Maricopa nonattainment area and other areas across Arizona including: Alamo Lake, the Grand Canyon and Yuma, Arizona. Elevated ozone concentrations were noted in all of these areas as the ozone and ozone precursors from the Lake Fire transported from west to east across Arizona on June 18-20, 2015.

The expanded conceptual model presented in this addendum provides additional analyses designed to provide detailed data on the (1) specific air flow patterns that brought ozone and ozone precursors from the Lake Fire into the nonattainment area; and (2) meteorological mechanisms that would allow for the transport and mixing of aloft ozone and ozone precursors from the Lake Fire down to the ground-level ozone monitors in the Maricopa nonattainment area.

In particular, detailed analysis of HYSPLIT forward and backward trajectories on June 18-20, 2015 reveal two distinct pathways for the horizontal transport of smoke, ozone and ozone precursors from the Lake Fire into the Maricopa nonattainment area; an upper-air pathway and a lower-air pathway. HYSPLIT trajectories run at elevations between 1,500 – 3,000 meters (upper-air) mirror the dispersion of smoke from the Lake Fire seen on satellite imagery. Many of the forward upper-air trajectories terminate within the Maricopa nonattainment area. Similarly, many of the upper-air backward trajectories originating within the Maricopa nonattainment area on June 20, 2015 terminate or cross within 50 kilometers of the Lake Fire area.

HYSPLIT trajectories run at elevations between 10 – 1,000 meters (lower-air) also provide a pathway for the horizontal transport of smoke, ozone and ozone precursors from the Lake Fire to the Maricopa nonattainment area. Examination of lower trajectories reveal that ozone and ozone precursors were transported first to Yuma, Arizona on June 18-19, 2015, and then were transported into the Maricopa nonattainment area from Yuma on June 19-20, 2015. Both the upper-air and lower-air pathways delivered the ozone and ozone precursors from the Lake Fire that caused the exceedances of the 2008 ozone standard in the Maricopa nonattainment area on June 20, 2015.

Additionally, detailed examination of dew point and water vapor data across southeastern California and southern Arizona provides supporting evidence for a mechanism that would allow for the vertical mixing of aloft ozone and ozone precursors from the Lake Fire to the ground level ozone monitors. First, National Weather Service (NWS) data in Phoenix and Yuma reveal that unusually dry air was present at the ground level in Yuma and Phoenix, Arizona on June 19-20, 2015. Second, the examination of the vertical cross section of dew point and water vapor data over the Lake Fire, Yuma, and the Maricopa nonattainment area reveals that the very dry air recorded at ground level monitors in Yuma and Phoenix, Arizona originated in the upper atmosphere (3,000 meters and higher) and was vertically mixed down towards the ground in the afternoon and evening of June 19, 2015. The vertical cross section data serve as a tracer for the downward movement of air, and provide evidence that a mechanism existed for the ozone and ozone precursors from the Lake Fire that were transported in the upper-air pathway to reach ground level ozone monitors in Yuma and Phoenix.

Finally, observed atmospheric conditions within the Maricopa nonattainment area on June 20, 2015 support the fumigation (downward mixing) of aloft ozone and ozone precursors within the upper-air pathway to the ground level ozone monitors. National Weather Service and aircraft meteorological data demonstrate that afternoon mixing heights within the Maricopa nonattainment area were at approximately 3,000 meters, allowing for the downward mixing of any transported ozone and ozone precursors from the Lake Fire. Further evidence for this downward mixing event on June 20, 2015 is provided by observing the trend in ozone concentrations between high and low altitude ozone monitoring sites. The observed trend matches trends seen in other documented ozone mixing events.

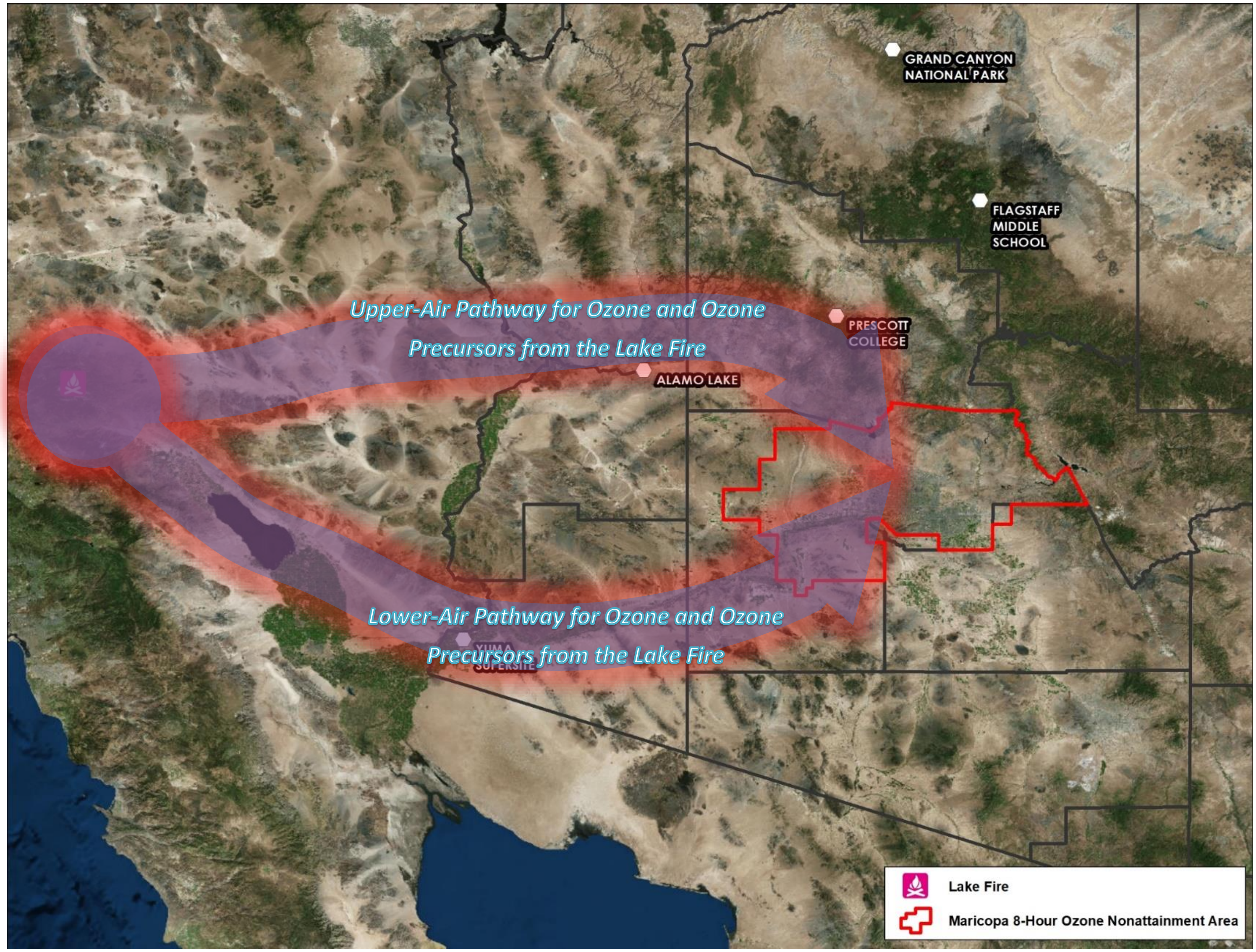
These additional analyses strengthen the link and clear causal relationship between the ozone and ozone precursors from the Lake Fire and the exceedances of the 2008 ozone standard on June 20, 2015 in the Maricopa nonattainment area.

## Upper-Air and Lower-Air Pathways for the Transport of Ozone and Ozone Precursors from the Lake Fire into the Maricopa Nonattainment Area

The additional analyses presented in this addendum provide evidence that ozone and ozone precursors from the Lake Fire were transported into the Maricopa nonattainment area through two distinct pathways: an upper-air pathway (approximately 1,500-3,000 meters above ground level, in the free troposphere) and a lower-air pathway (approximately 10-1,000 meters above ground level, within the boundary layer). Figure 1 displays the general location of these two pathways.

The upper-level pathway generally follows an east-northeast route from the Lake Fire to the Maricopa nonattainment area. Since there are no terrain features to alter the upper-air pathway, upper-level wind patterns are the main determinant for the directional flow of upper-level air. In contrast, the lower-level pathway is greatly affected by terrain features and other local meteorological features linked to specific times of the day. This produces an airflow pattern where smoke, ozone and ozone precursors from the Lake Fire first transported southeast to Yuma, Arizona and then transported northeast to the Maricopa nonattainment area. Evidence for these two pathways is presented in the following subsections.

**Figure 1. Upper-Air and Lower-Air Pathway for Transport of the Ozone and Ozone Precursors from the Lake Fire into the Maricopa Nonattainment Area.**



***Upper-Air Pathway***

The satellite photos and NOAA smoke maps presented in the original documentation provided to EPA show widespread smoke dispersion across Arizona on June 18-19, 2015 from the Lake Fire (see Figures 3–15, 3–16, 3–21, and 3–22 in original documentation). Further analysis of the transport across Arizona reveals that the satellite images of the smoke correspond well to upper-air (approximately 1,500-3,000 meters) forward HYSPLIT trajectories from the Lake Fire originating on June 18-19, 2015. Additionally, upper-air backward HYSPLIT trajectories from the Maricopa nonattainment area originating on June 20, 2015 also correspond well to visible satellite photos of the smoke dispersion and transport from the Lake Fire.

The forward trajectories from the Lake Fire reveal that on June 18, 2015, the upper-air pathway for smoke, ozone and ozone precursors traveled northeast and east from the Lake Fire. On June 19, 2015, the forward trajectories shift and reveal an upper-air transport pathway dispersing smoke, ozone and ozone precursors southeast and south from the Lake Fire. Multiple upper-air forward trajectories from the Lake Fire terminate within the Maricopa nonattainment area on June 20, 2015, providing clear evidence of a pathway for ozone and ozone precursors from the Lake Fire to reach the upper-air above the Maricopa nonattainment area on June 20, 2015.

Additionally, the forward trajectories that terminate within the Maricopa nonattainment area on June 20, 2015, terminate in a clockwise rotational pattern. This reflects the change in air movement that occurred on June 20, 2015 within the Maricopa nonattainment area, allowing the ozone and ozone precursors from the Lake Fire to recirculate within the nonattainment area on June 20, 2015 and cause the observed exceedances.

The upper-air forward trajectories for June 18, 2015 are shown in Figure 2. Figure 3 contains the upper-air forward trajectories for June 19, 2015. The HYSPLIT trajectories shown in both figures were performed at the 2,500-meter level. Based on these figures, the forward trajectories that most likely affected the Maricopa nonattainment area originated from the Lake Fire area starting at approximately 12:00 pm on June 18 and ending by 8:00 am on June 20, 2015. Backward upper-air trajectories (2,500 meters) from the nonattainment area also confirm that the air present above the nonattainment area on June 20, 2015 originated from the area near the Lake Fire. Figure 4 contains the upper-air backward trajectories from the nonattainment area on June 20, 2015.

While not discussed in detail in this addendum, the upper-air pathway also served as the horizontal pathway that transported ozone and ozone precursors to Alamo Lake, Grand Canyon and other rural Arizona monitors on June 18 and June 19, 2015, causing ozone concentrations to rise on those days to near exceedance levels. Rising ozone concentrations within these rural areas west and north of the nonattainment area provide support for the upper-air pathway and also suggest a significant non-anthropogenic source of ozone and ozone precursors generated outside of the Maricopa nonattainment area.

**Figure 2. Upper-Air Forward Trajectories on June 18, 2015.**

**Figure 3. Upper-Air Forward Trajectories on June 19, 2015.**

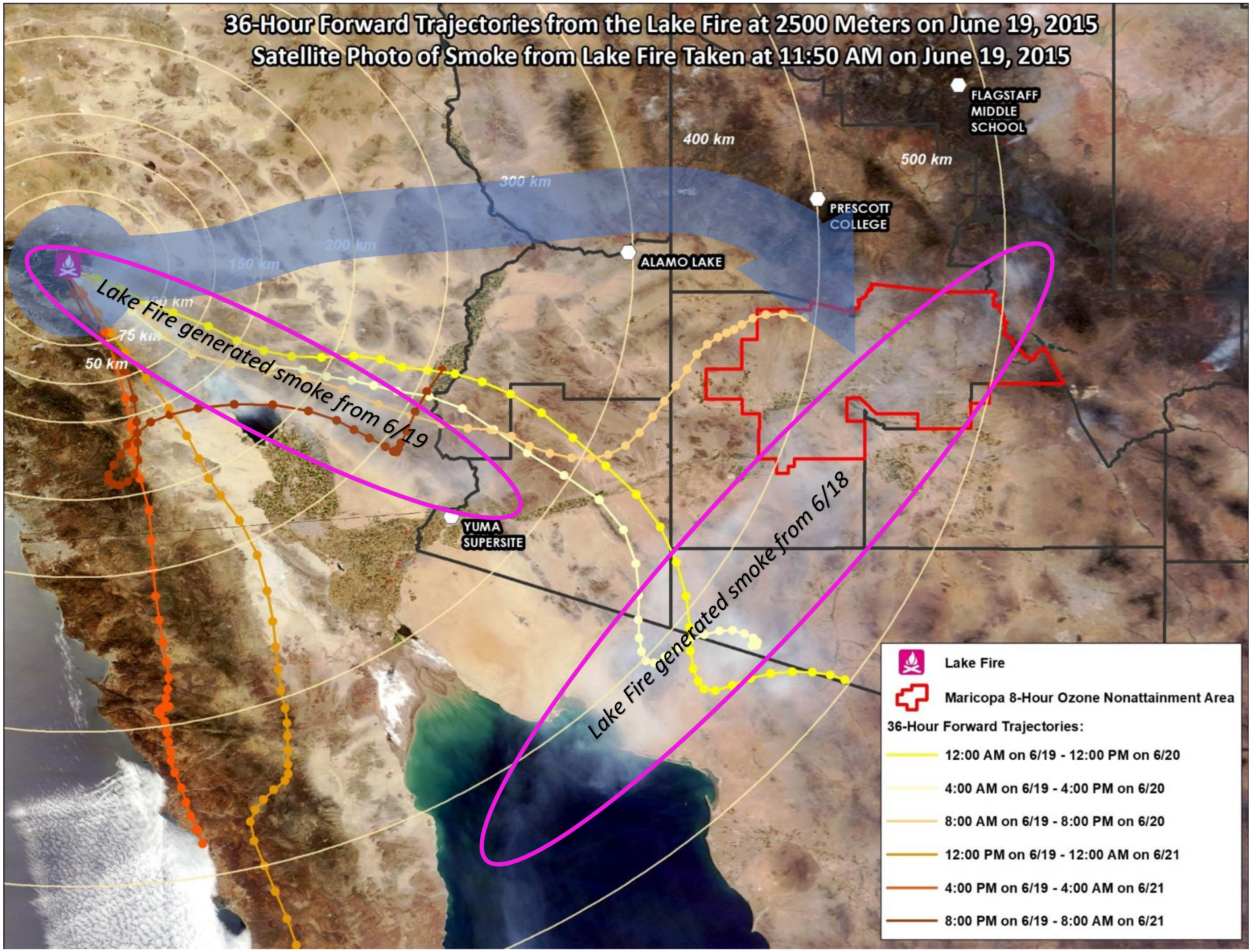
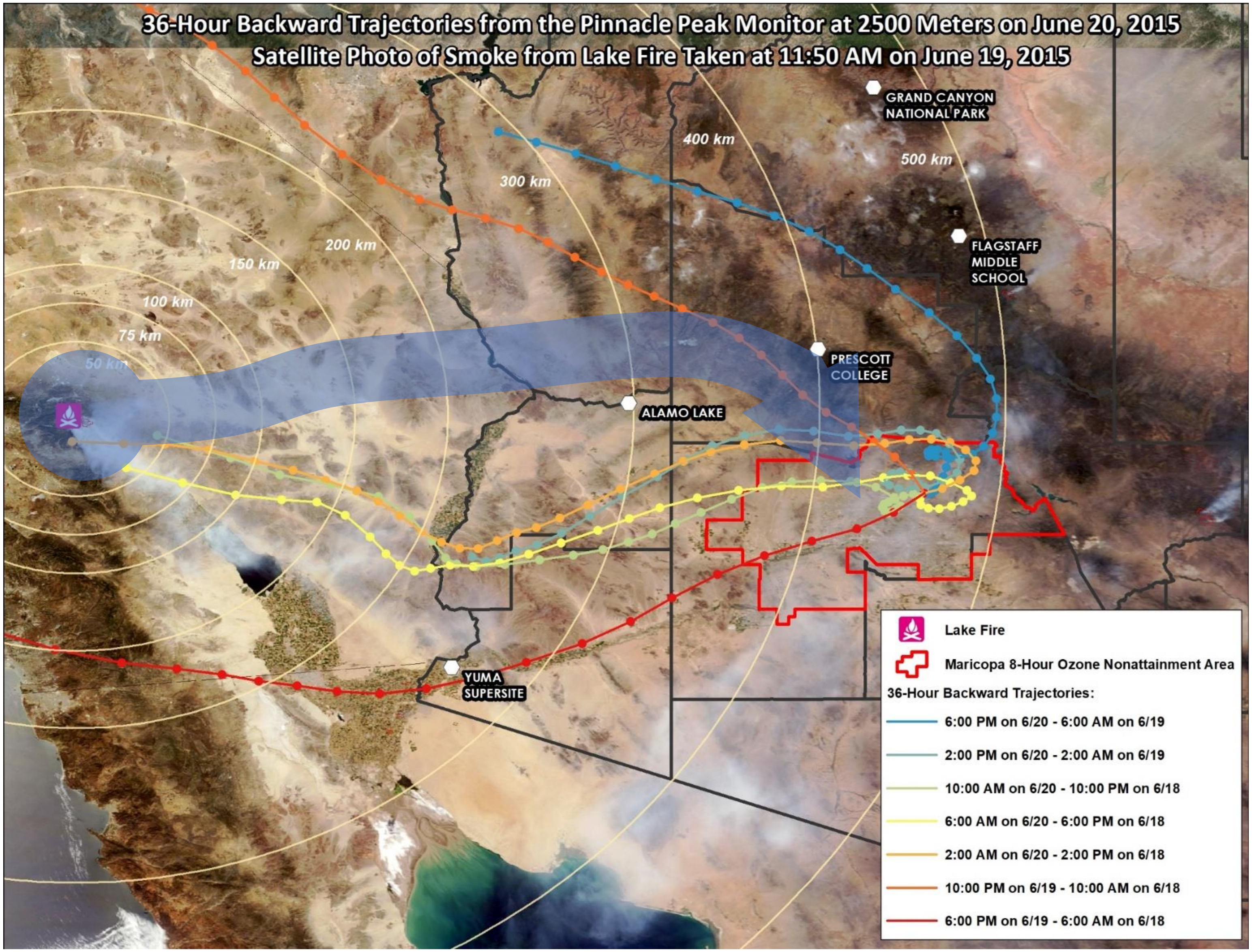


**Figure 4. Upper-Air Backward Trajectories on June 20, 2015.**



***Lower-Air Pathway***

In addition to the upper-air pathway described above, there is strong evidence for a lower-air pathway that is capable of transporting ozone and ozone precursors from the Lake Fire to the Maricopa nonattainment area. This evidence is based on backward HYSPLIT trajectories on June 19-20, 2015 performed at the 100-meter level. The lower-air pathway displayed in backward trajectories first begins at the Lake Fire, then disperses to Yuma on June 18-19, 2015, and then into the Maricopa nonattainment area on June 19-20, 2015.

On June 19, 2015, the ozone concentration at Yuma increased dramatically, exceeding the ozone standard with a maximum 8-hour average concentration of 0.084 parts per million. Many of the backward trajectories originating from Yuma on June 19, 2015 pass by the area near the Lake Fire. Additionally, vertical profiles of the backward trajectories from Yuma (See Appendix A), show that the air moved from higher elevations (approximately 1,500 meters) down to 100 meters as the air moved from the Lake Fire area to Yuma. This provides strong evidence that a pathway existed for the smoke, ozone and ozone precursors from the Lake Fire to reach Yuma on June 19, 2015, leading to the exceedance of the ozone standard seen at Yuma on June 19, 2015.

Figure 5 displays the lower-air backward trajectories from Yuma on June 19, 2015. Note that two of the backward trajectories from Yuma shown in Figure 5 indicate air from Mexico transporting up into Yuma. However, these two back trajectories start on June 18, 2015, a day when Yuma did not exceed, indicating that airflow from Mexico is unlikely to contribute to the increased ozone concentrations seen on June 19, 2015 in Yuma. Also, the ground level dew point data for Yuma and Phoenix discussed in later sections reveal very dry air on June 19-20, 2015, which is inconsistent with transport from Mexico as air from Mexico would be wetter due to the influence of the Gulf of California.

Similarly, backward trajectories from the nonattainment area at the 100 meter-level on June 20, 2015 show the transport of air from Yuma to the nonattainment area. This shows that the ozone and ozone precursors that caused the exceedance at Yuma on June 19, 2015 were then transported into the nonattainment area, causing the ozone exceedances on June 20, 2015. Figure 6 shows the lower-air backward trajectories from the Maricopa nonattainment area on June 20, 2015.

The backward trajectories from Yuma and the nonattainment area provide additional evidence for the transport of ozone and ozone precursors to the nonattainment area from the Lake Fire. The lower-air and upper-air pathways together provide clear transport pathways from the Lake Fire to the nonattainment area. The pathways also provide the most reasonable explanation for the unusual source of ozone that caused the ozone exceedances in the nonattainment area and support a clear causal relationship between the nonattainment area exceedances and ozone and ozone precursors from the Lake Fire.

**Figure 5. Lower-Air Backward Trajectories on June 19, 2015.**

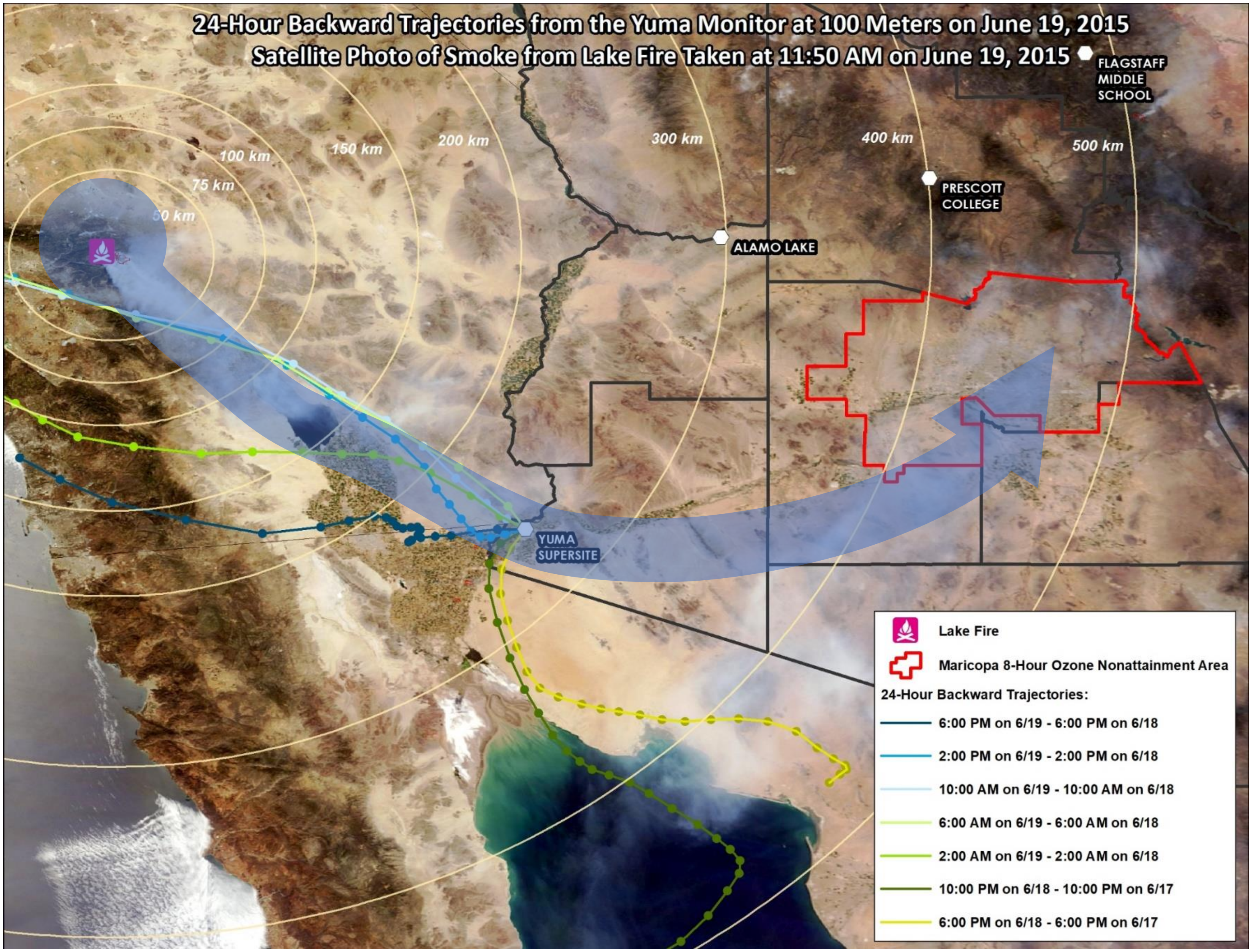
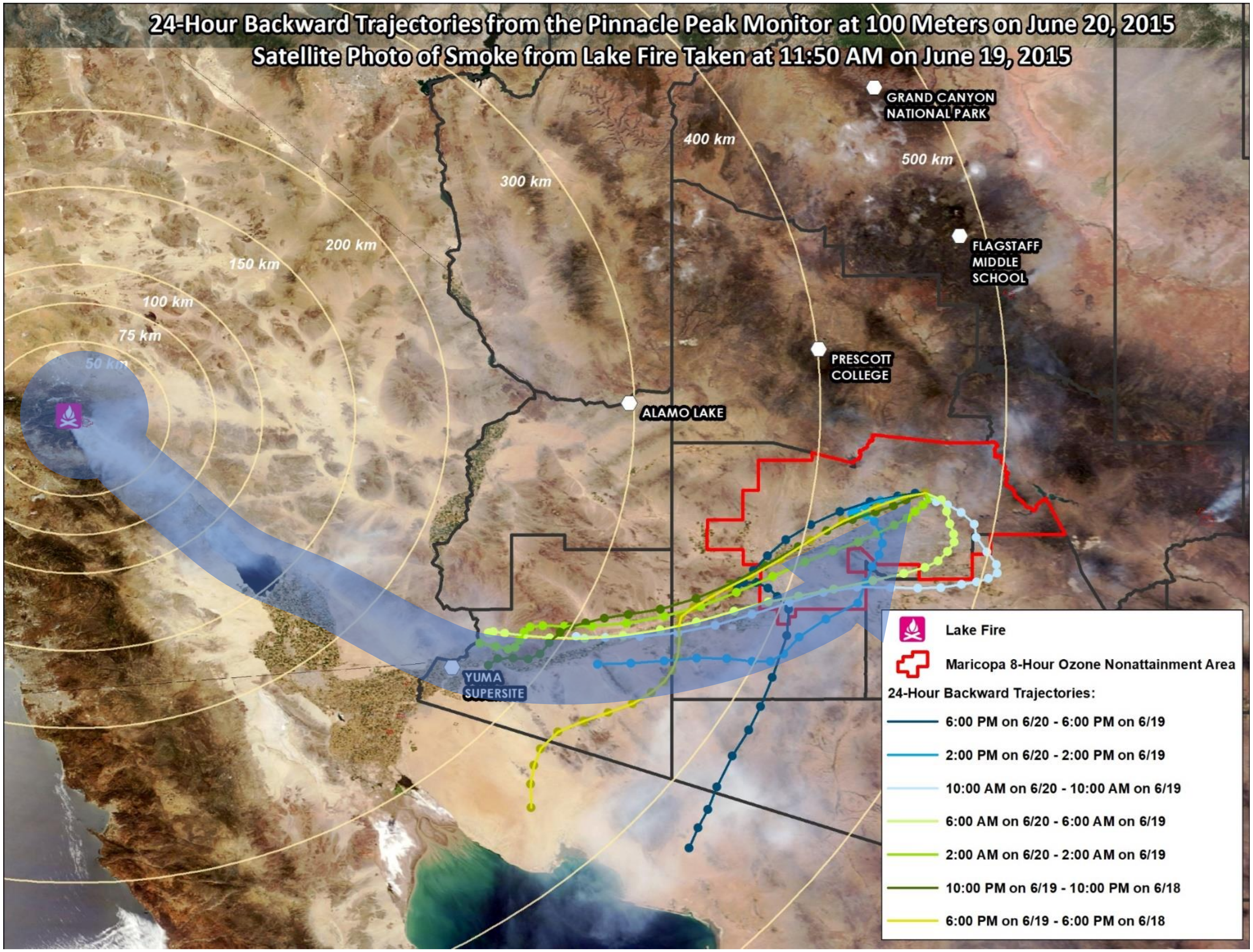


**Figure 6.  Lower-Air Backward Trajectories on June 20, 2015.**



## Dew Point and Water Vapor Analysis

***Dew Point and Water Vapor Measurements as a Tracer Mechanism for the Downward Movement of Air***

In the late afternoon and evening of June 19, 2015, an influx of very dry air was transported into the Maricopa nonattainment area as reflected in atypically low dew point measurements at Phoenix Sky Harbor International Airport. For a six-hour period on June 19, 2015, the measurable dew point was below the fifth percentile diurnal values for dew point in the month of June (based upon 2010-2015 data). Dew points remained below average for nearly all hours of June 20, 2015. Figures 7 and 8 show a graph of the dew point measurements at Sky Harbor from June 13-27, 2015 and a figure showing the measurements on June 19, 2015 were below the fifth percentile.

The analysis in this subsection shows that the very dry dew point and water vapor data observed at ground level in Phoenix, Arizona can also serve as a tracer for the downward movement of air on June 19, 2015 from heights of over 3,000 meters. This provides additional evidence that a pathway and mechanism existed for the movement of transported aloft ozone and ozone precursors from the Lake Fire down to the ground level ozone monitors within the Maricopa nonattainment area.

In order to examine the vertical distribution of water vapor and dew point in the atmosphere on June 19, 2015, the Weather Research and Forecasting Model (WRF) was run to visualize the hourly vertical distribution along a plane running through the Lake Fire area and the center of the Maricopa nonattainment area. Figure 9 shows the line of the vertical plane running through the Lake Fire area and the nonattainment area that was used to generate the vertical cross section of water vapor and dew point that are shown in the Figures 10-23. Figures 10-23 cover the hours of 10:00 am – 11:00 pm on June 19, 2015. The following information is contained within each of the hourly vertical distributions in Figures 10-23:

- The UTC time and local time are printed in the upper right hand corner.
- A red to blue color ramp represents the water vapor mixing ratio: On a relative scale, red represents drier air and blue represents wetter air.
- The contour lines depict dew point in degrees Fahrenheit, from -125 to 75 in five degree increments.
- The y-axis represents height above sea level in kilometers.
- The x-axis represents the grid cell location running from west to east. The Lake Fire area is approximately at grid cell 25 on the x-axis and the center of the nonattainment area is located at approximately 60 on the x-axis.
- The stair-step line near the bottom of the vertical distribution depicts terrain height.

Figures 10-23 show that the plunge in dew point measurements observed at the Phoenix Sky Harbor International Airport in the afternoon and evening of June 19, 2015 correspond to the downward movement of drier upper-level air. The water vapor and dew point data presented in the figures provide a means to visualize the movement of air from the 3,000-4,000 meter height down to the ground level within the Maricopa nonattainment area in the afternoon and evening of

June 19, 2015. As such, any ozone or ozone precursors aloft from the Lake Fire would also be transported down to the ground during the same period within the nonattainment area.

Earlier presented HYSPLIT forward trajectories (Figure 2) have shown that wind patterns on June 20, 2015 within the nonattainment area shifted from the west to a clockwise flow. This allows for the transported ozone and ozone precursors from the Lake Fire that occurred during the late afternoon and evening of June 19, 2015 (as shown in this analysis) to recirculate and cause the ozone exceedances observed on June 20, 2015 within the Maricopa nonattainment area.

The observed pattern of low dew points and downward movement of aloft dry air has also been shown to occur over Yuma, Arizona on June 19, 2015. This, in conjunction with the ground level HYSPLIT analysis presented in earlier sections, provides another mechanism where ozone and ozone precursors from the Lake Fire can reach down to the ground level at the Yuma monitor as well as the Maricopa nonattainment area monitor. As shown earlier in the lower-air pathway, those elevated ground level ozone concentrations observed in Yuma on June 19, 2015 then transported into the Maricopa nonattainment area on June 20, 2015 through ground level wind patterns. The dew point and water vapor analysis for Yuma is included in Appendix B of this addendum.

In summary, the information in this analysis provides evidence that an atmospheric mechanism existed in the afternoon and evening of June 19, 2015 to allow aloft ozone and ozone precursors from the Lake Fire to reach the ground level within the Maricopa nonattainment area, leading to the exceedances on June 20, 2015.

Figure 7. Surface Hourly Dew Point on June 13-27, 2015 at Sky Harbor International Airport.

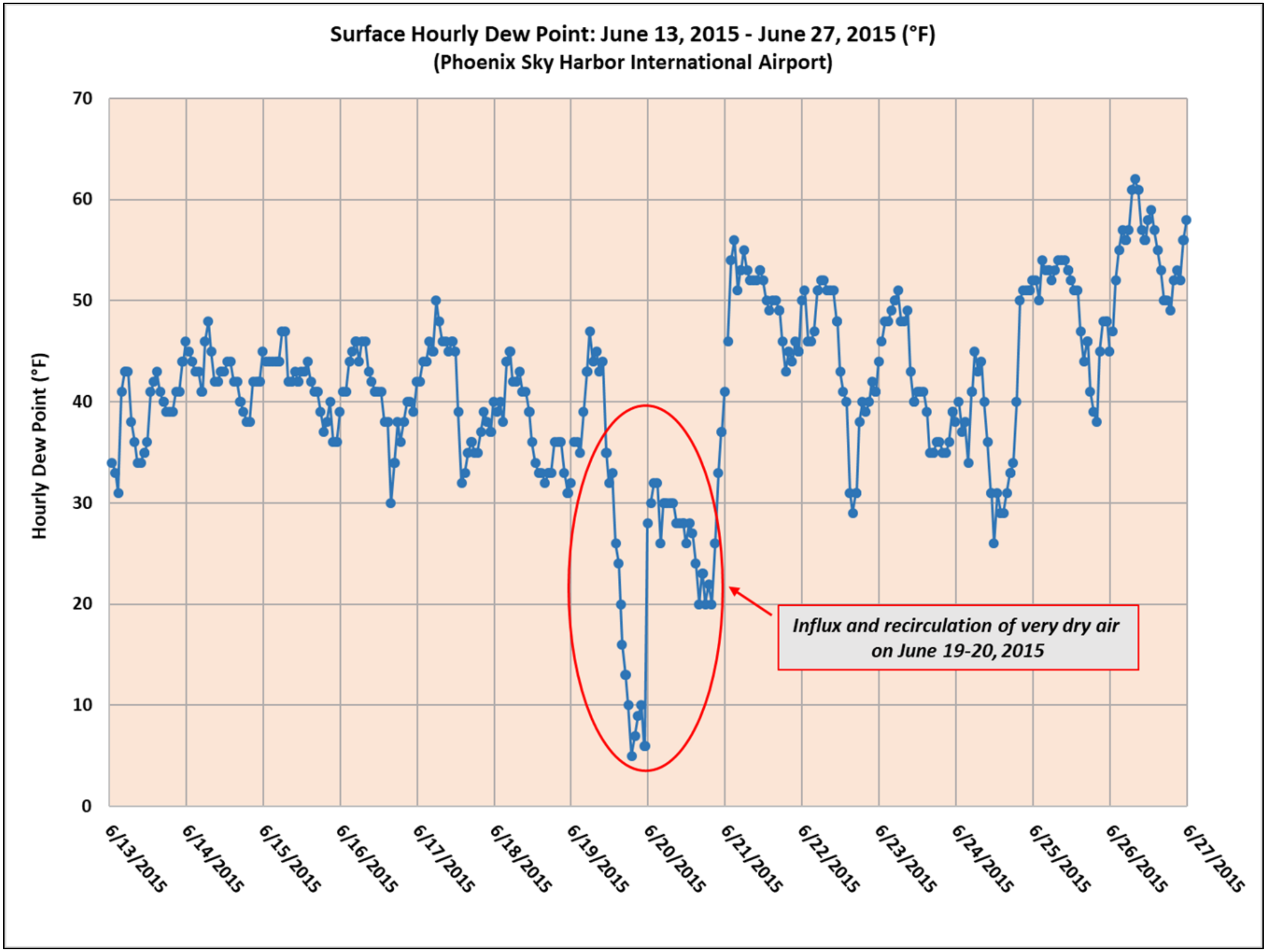



Figure 8. Comparison of Diurnal Dew Point Measurements on June 18-21, 2015 with Historical Percentiles.

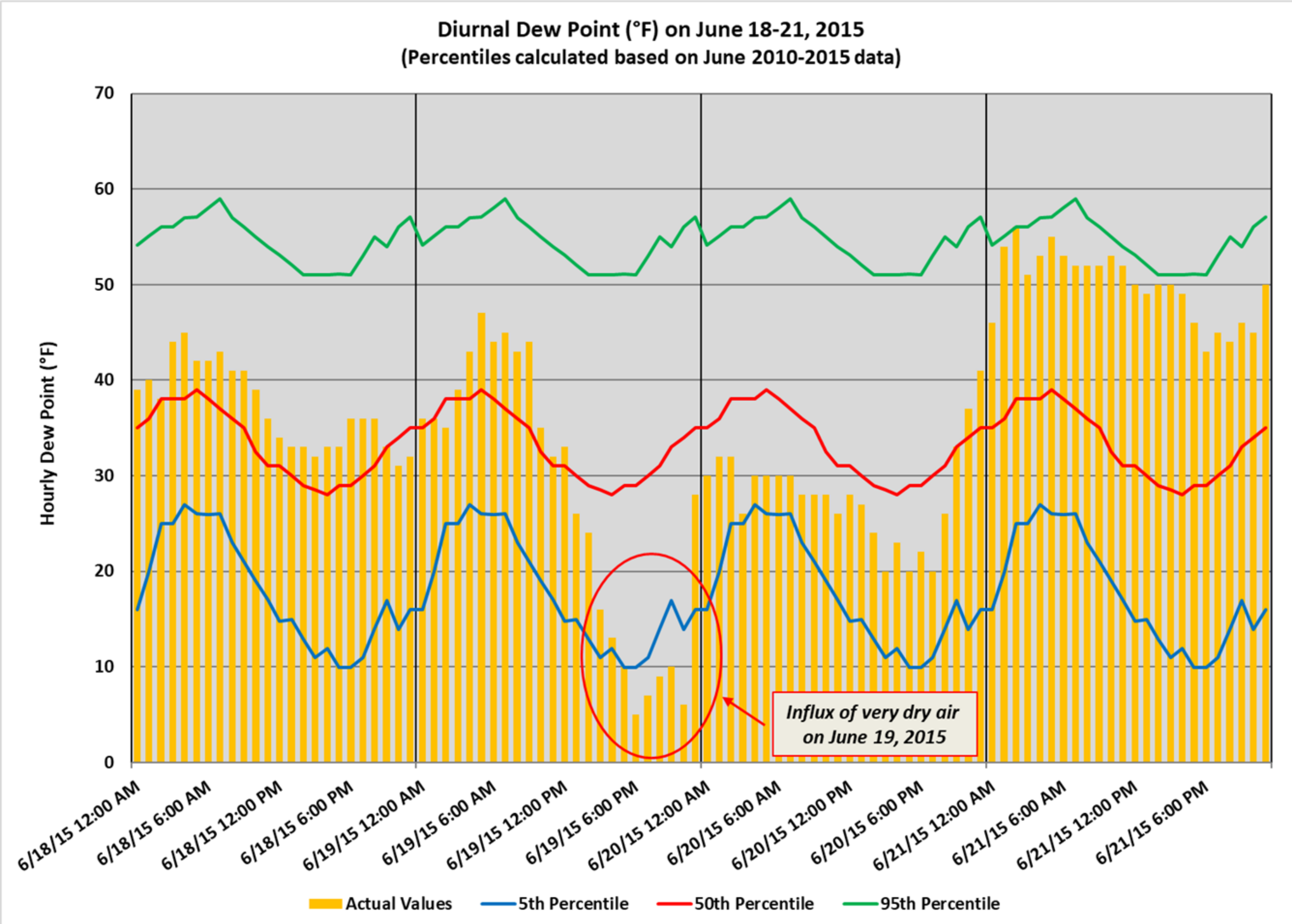

Diurnal Dew Point (°F) on June 18-21, 2015
(Percentiles calculated based on June 2010-2015 data)
Hourly Dew Point (°F)
0
10
20
30
40
50
60
70
Influx of very dry air on June 19, 2015
6/18/15 12:00 AM
6/18/15 6:00 AM
6/18/15 12:00 PM
6/18/15 6:00 PM
6/19/15 12:00 AM
6/19/15 6:00 AM
6/19/15 12:00 PM
6/19/15 6:00 PM
6/20/15 12:00 AM
6/20/15 6:00 AM
6/20/15 12:00 PM
6/20/15 6:00 PM
6/21/15 12:00 AM
6/21/15 6:00 AM
6/21/15 12:00 PM
6/21/15 6:00 PM
Actual Values
5th Percentile
50th Percentile
95th Percentile

**Figure 9. Vertical Plane Line (Running through the Lake Fire Area and the Maricopa Nonattainment Area) used to Generate the Vertical Distribution of Water Vapor and Dew Point on June 19, 2015.**

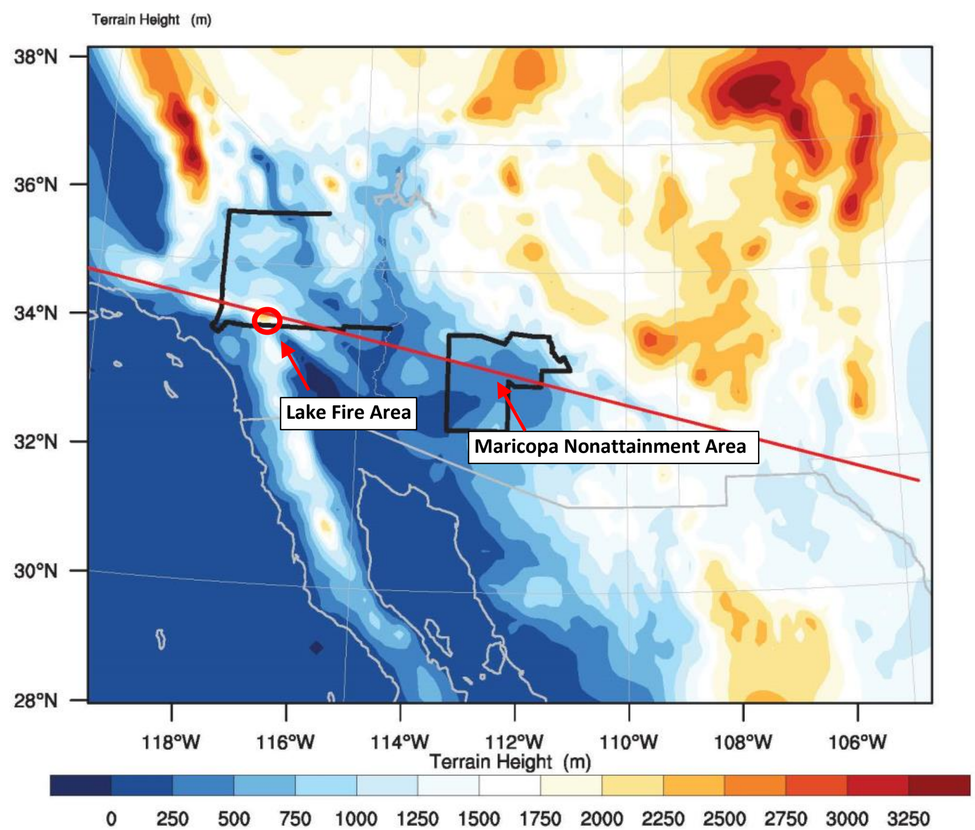
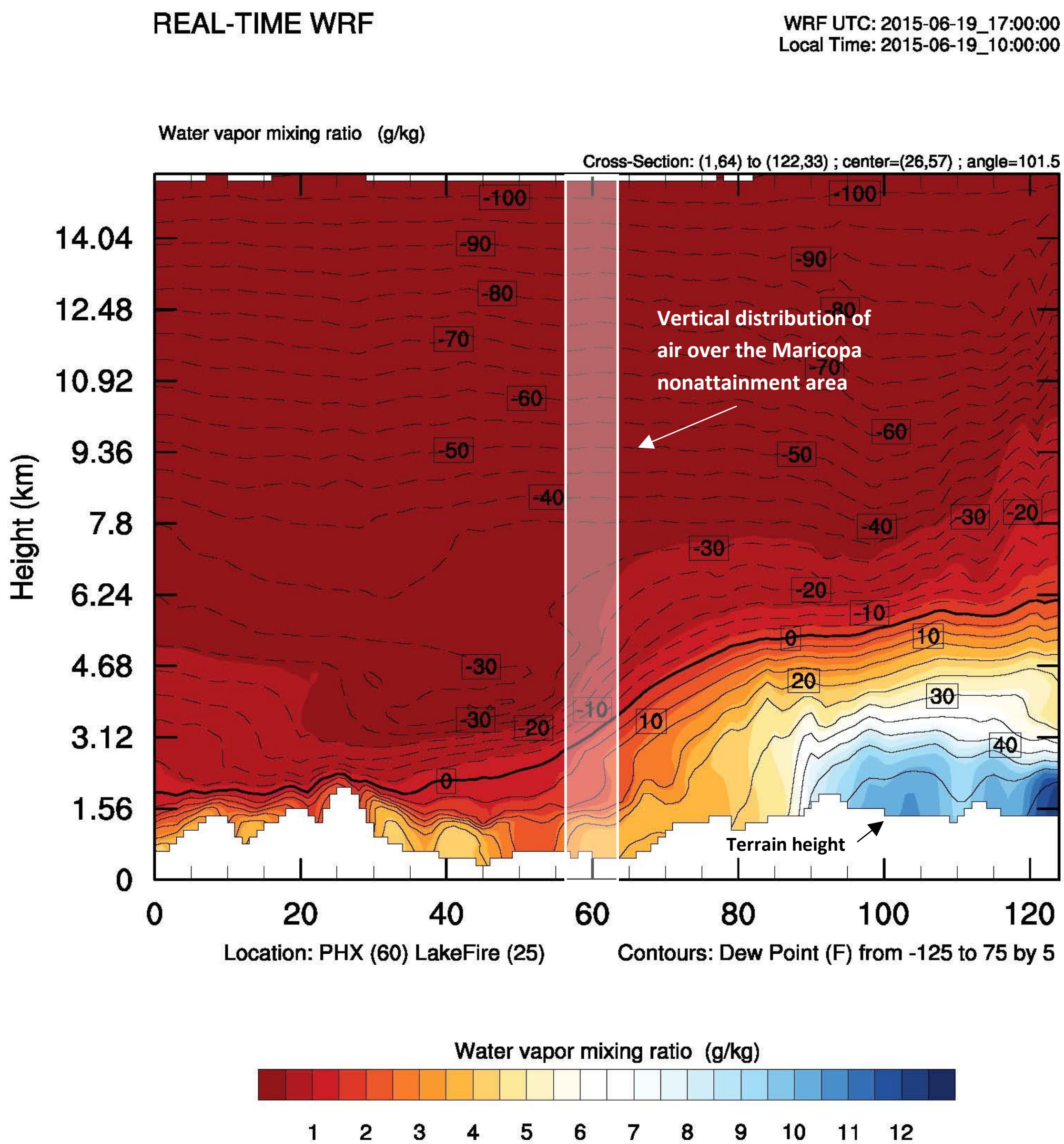
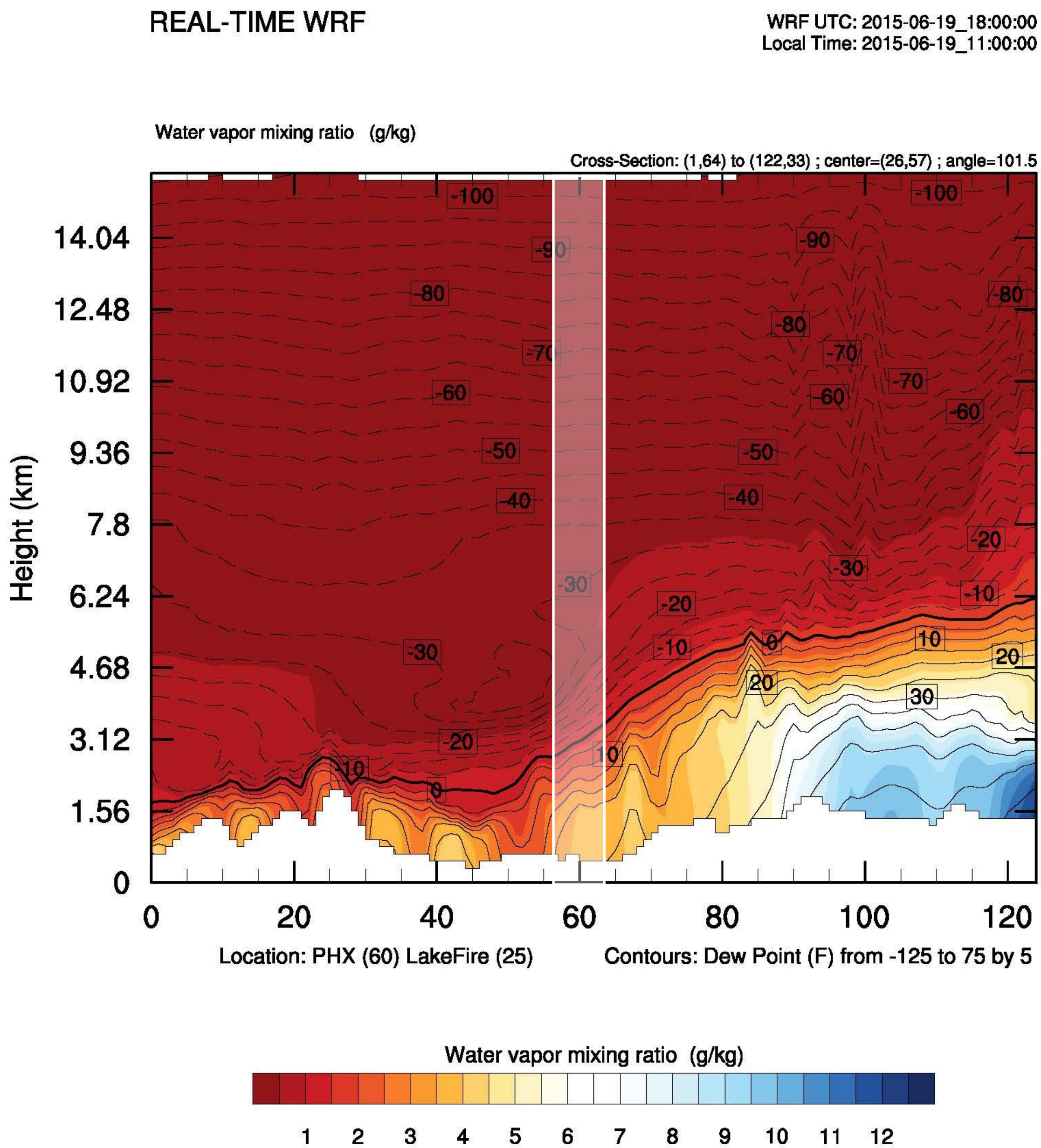


**Figure 10. Vertical Distribution of Water Vapor and Dew Point at 10:00 am on June 19, 2015.**



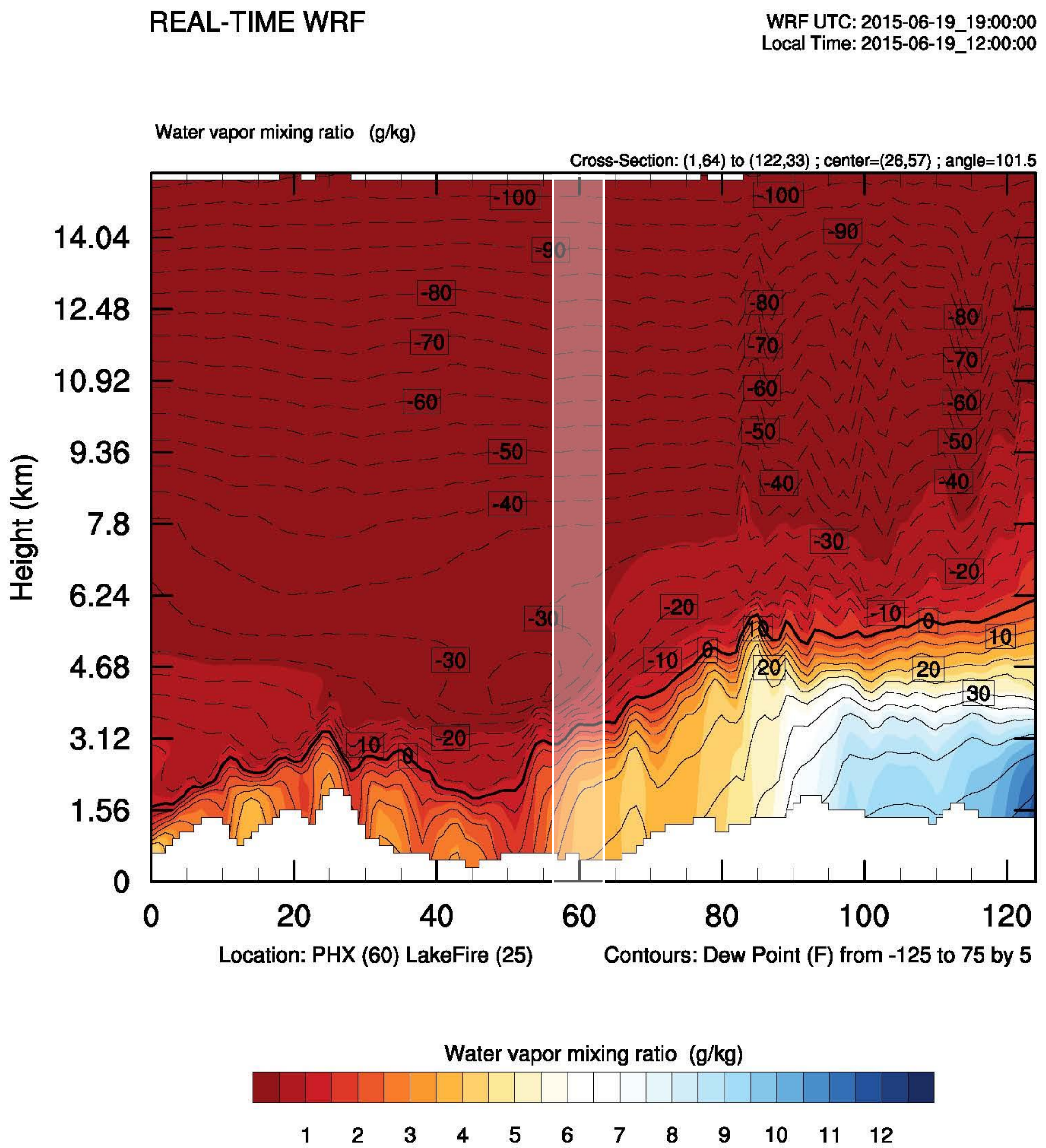

The rapid drop in dew points began at approximately 10:00 am on June 19, 2015. The figure above shows the dew point within the Maricopa nonattainment area to be between 25-30 degrees Fahrenheit at ground level. The dew point is 5 degrees at approximately 3,000 meters above the nonattainment area.

**Figure 11. Vertical Distribution of Water Vapor and Dew Point at 11:00 am on June 19, 2015.**



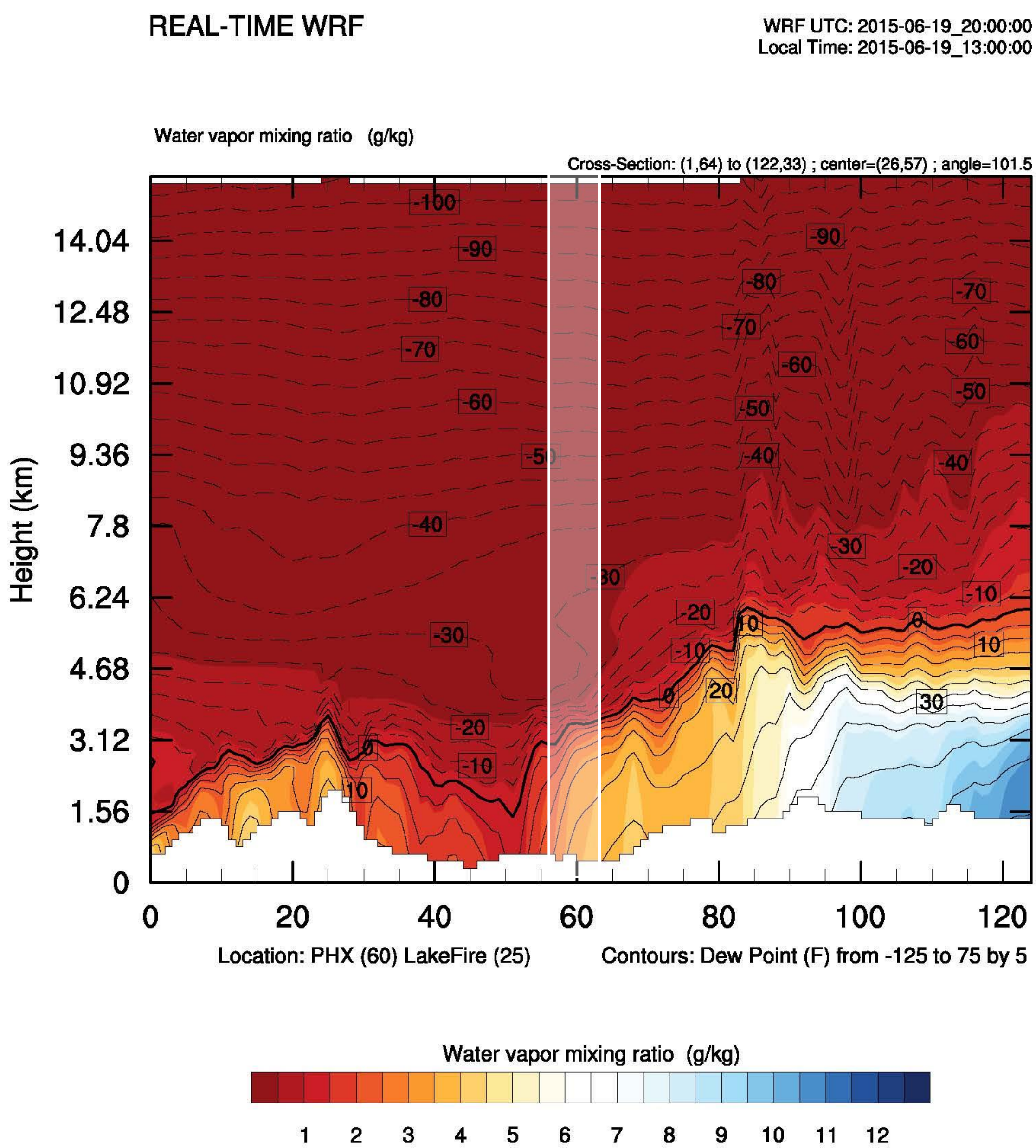

At 11:00 am, a noticeable "tongue" of drier air is beginning to form just west of the nonattainment area. The contour lines start to become more vertical as opposed to horizontal, indicating the beginning of the drier air from above mixing with the wetter, lower air.

**Figure 12. Vertical Distribution of Water Vapor and Dew Point at 12:00 pm on June 19, 2015.**



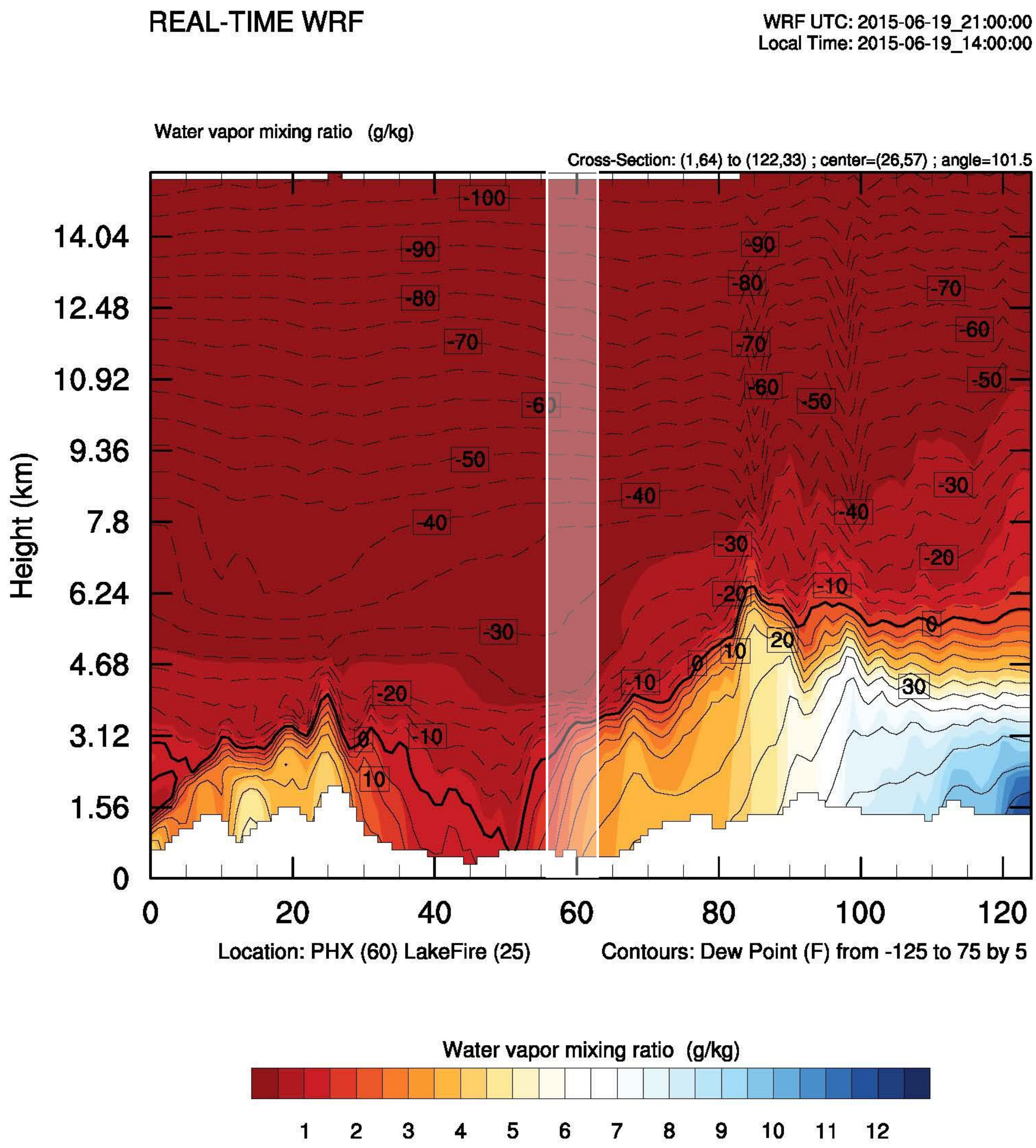

At 12:00 pm, the downward movement of air continues to form. Just west of the nonattainment area the dew point contours are nearly vertical between ground level and 2,500 meters, indicating rapid mixing of air.

**Figure 13. Vertical Distribution of Water Vapor and Dew Point at 1:00 pm on June 19, 2015.**



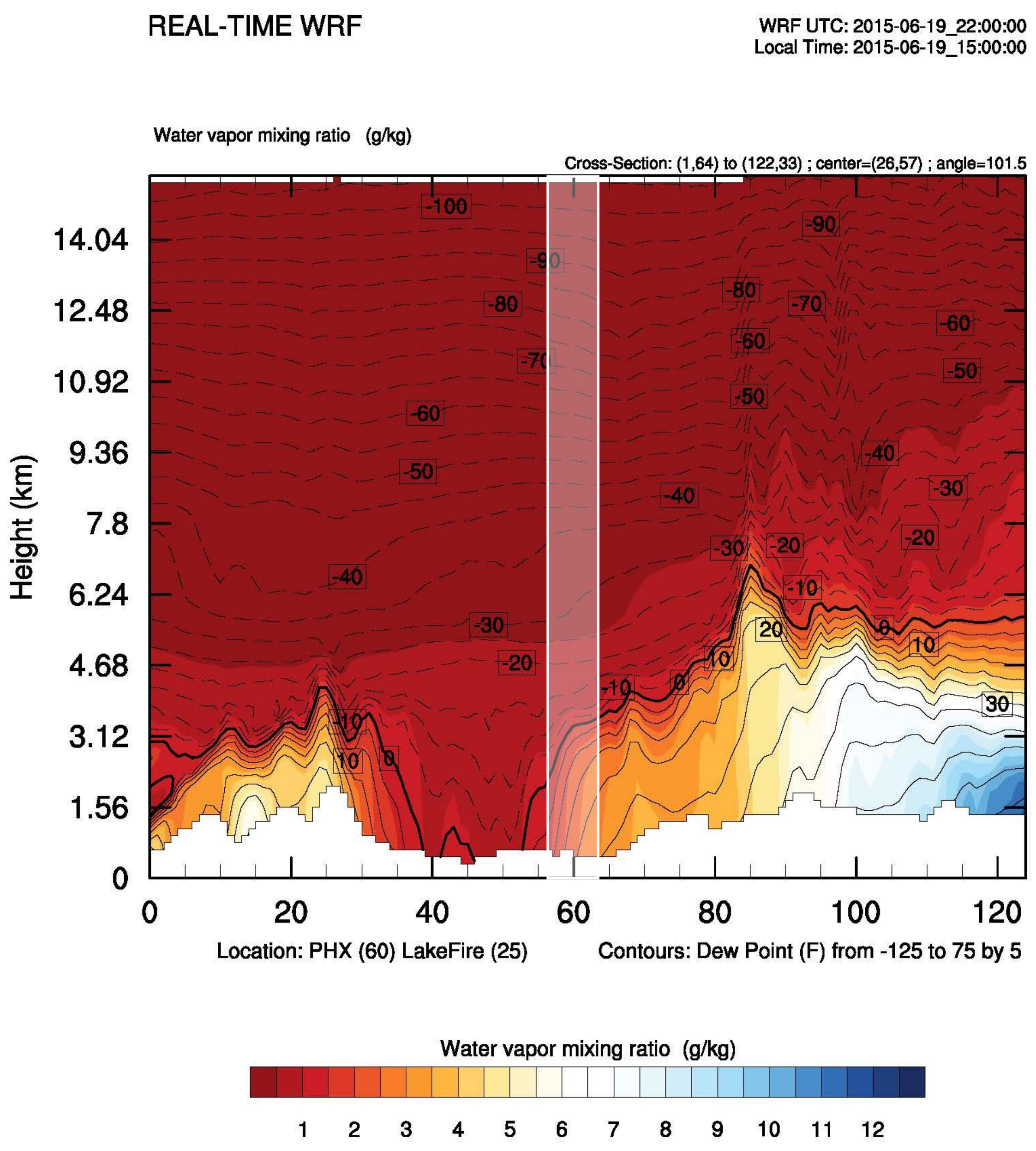

The tongue of dry air is more pronounced just west of the nonattainment area by 1:00 pm. Dew point contours from ground level to 3,000 meters are nearly vertical in the nonattainment area.

**Figure 14. Vertical Distribution of Water Vapor and Dew Point at 2:00 pm on June 19, 2015.**



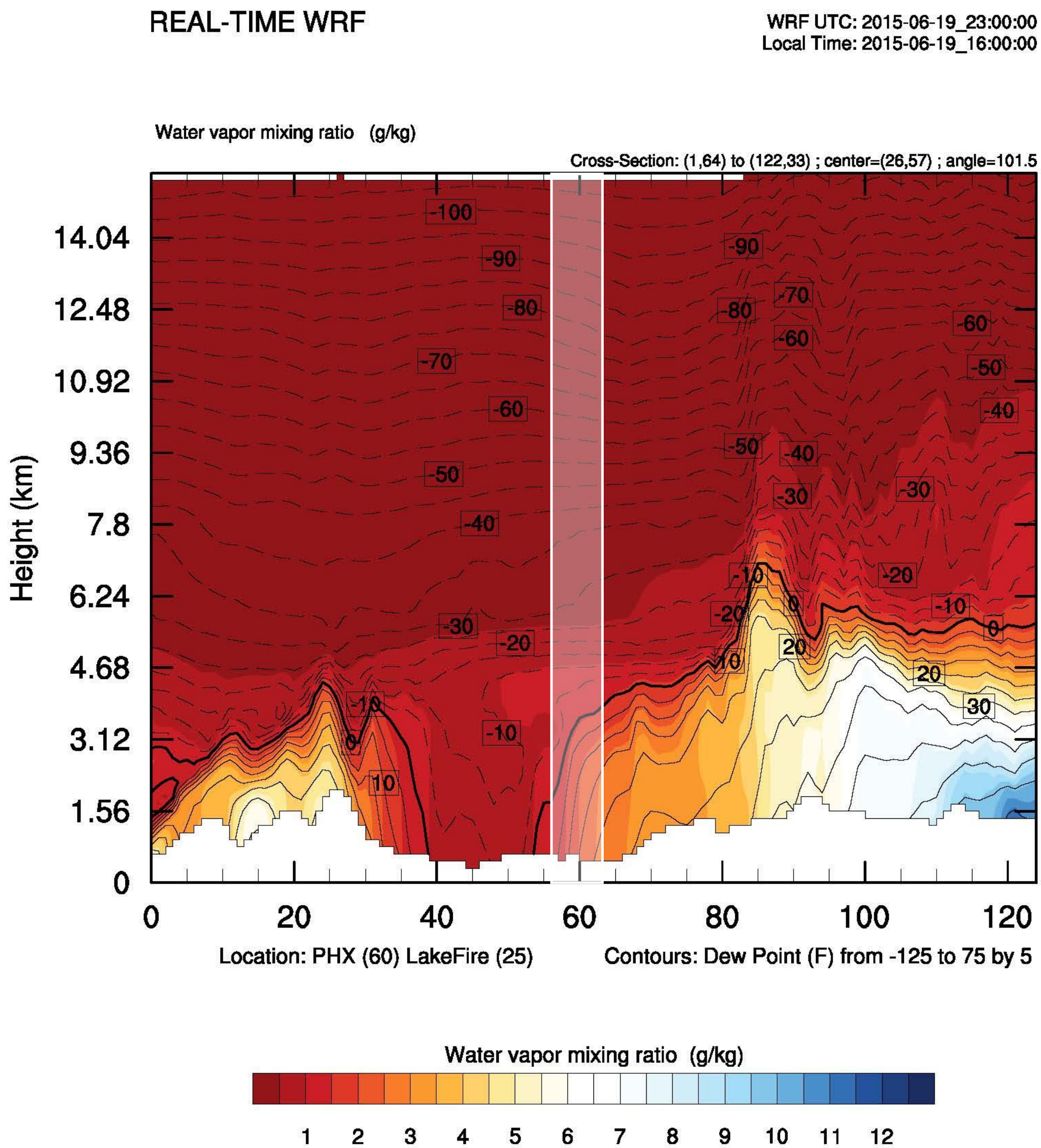

A very steep drop in the dew point contours occurs west of the nonattainment area at 2:00 pm, with dew points of zero degrees now present at ground level. The western most edge of the nonattainment area has dew points of 10-15 degrees at ground level.

**Figure 15. Vertical Distribution of Water Vapor and Dew Point at 3:00 pm on June 19, 2015.**



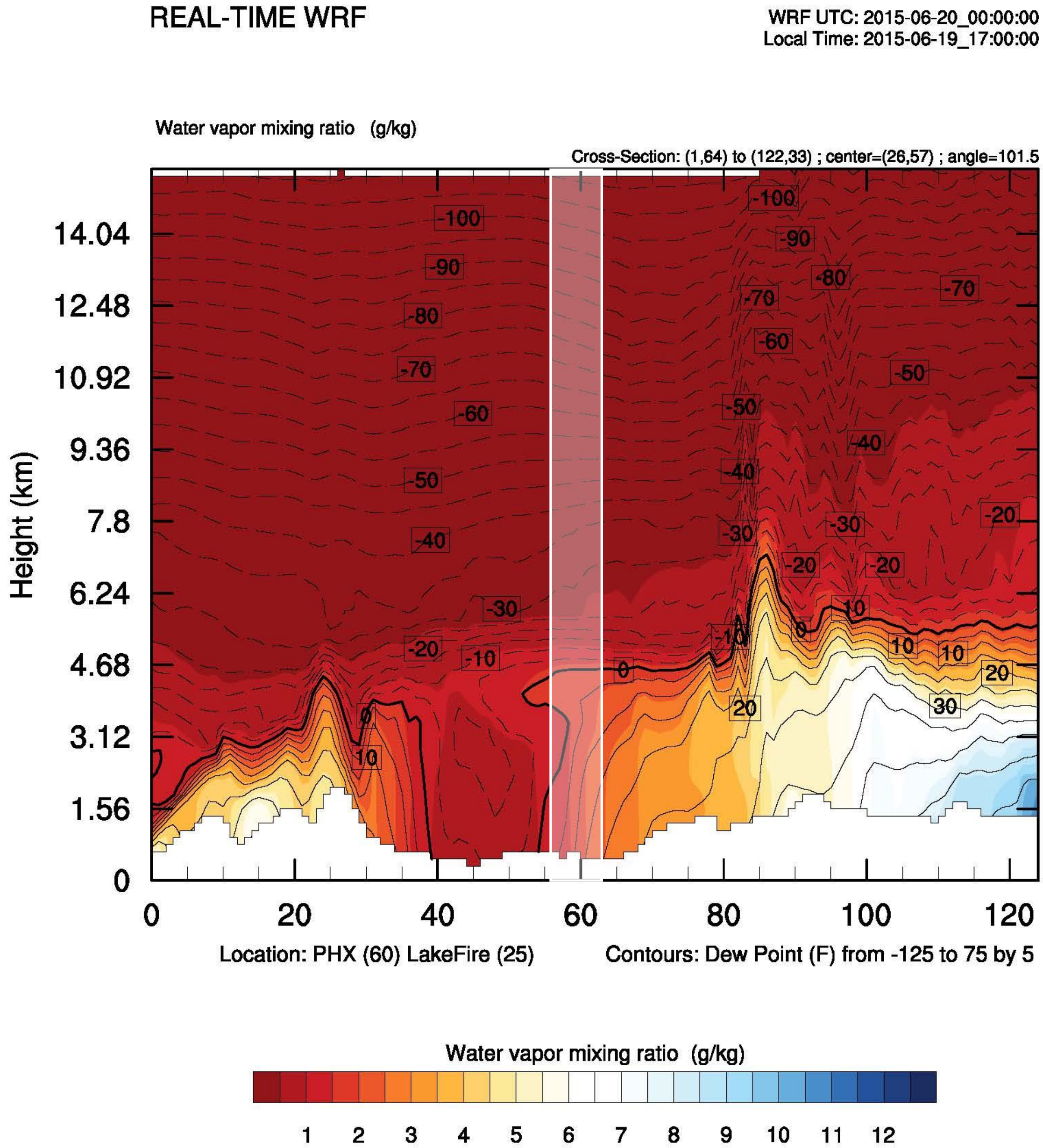

At 3:00 pm, the steep drop in dew point continues, with the tongue of dry air clearly visible and now present within the western part of the nonattainment area.

**Figure 16. Vertical Distribution of Water Vapor and Dew Point at 4:00 pm on June 19, 2015.**



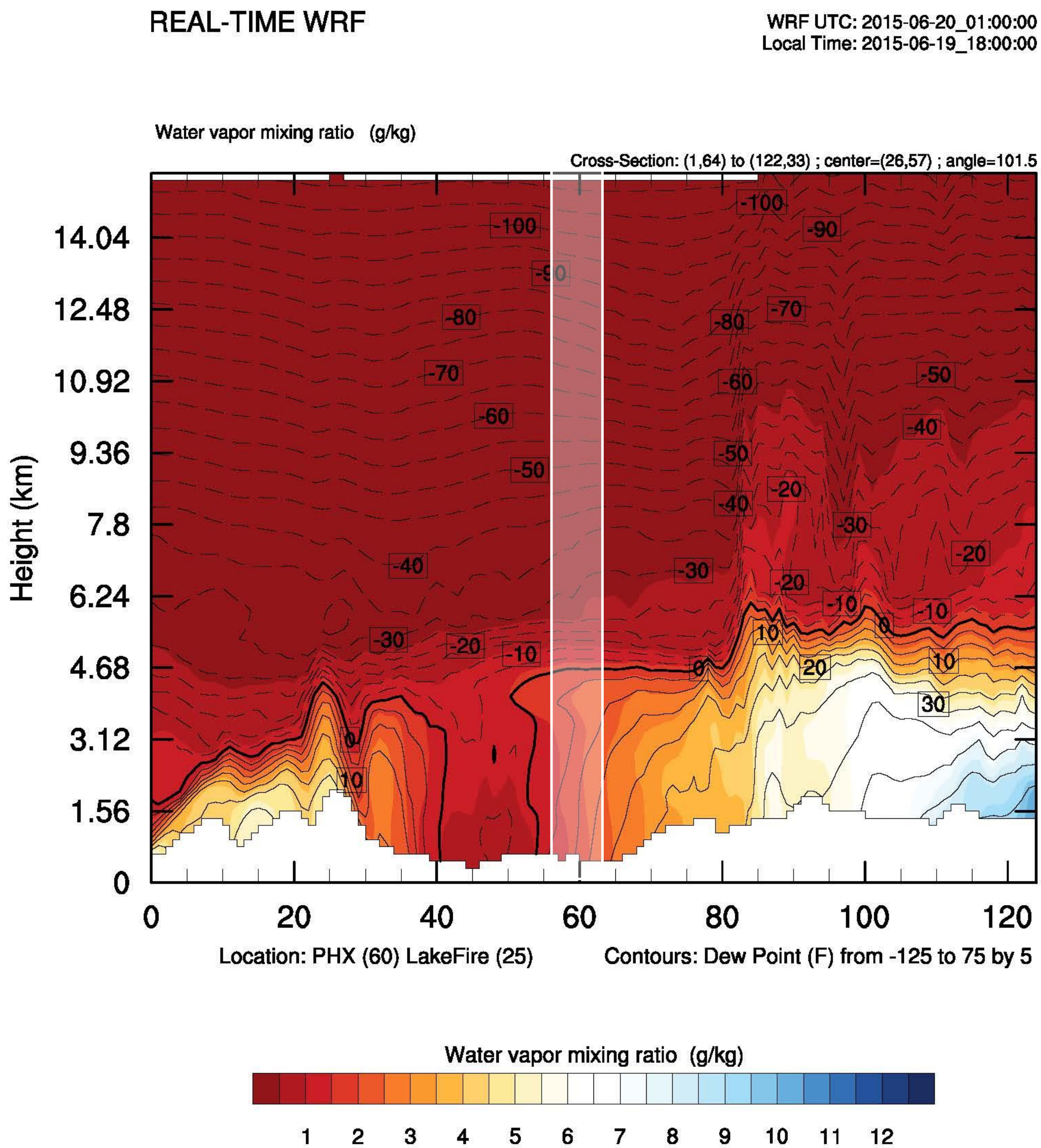

At 4:00 pm, the upper, drier air continues to descend. Dew points of -5 degrees Fahrenheit are present just west of the nonattainment area.

**Figure 17. Vertical Distribution of Water Vapor and Dew Point at 5:00 pm on June 19, 2015.**



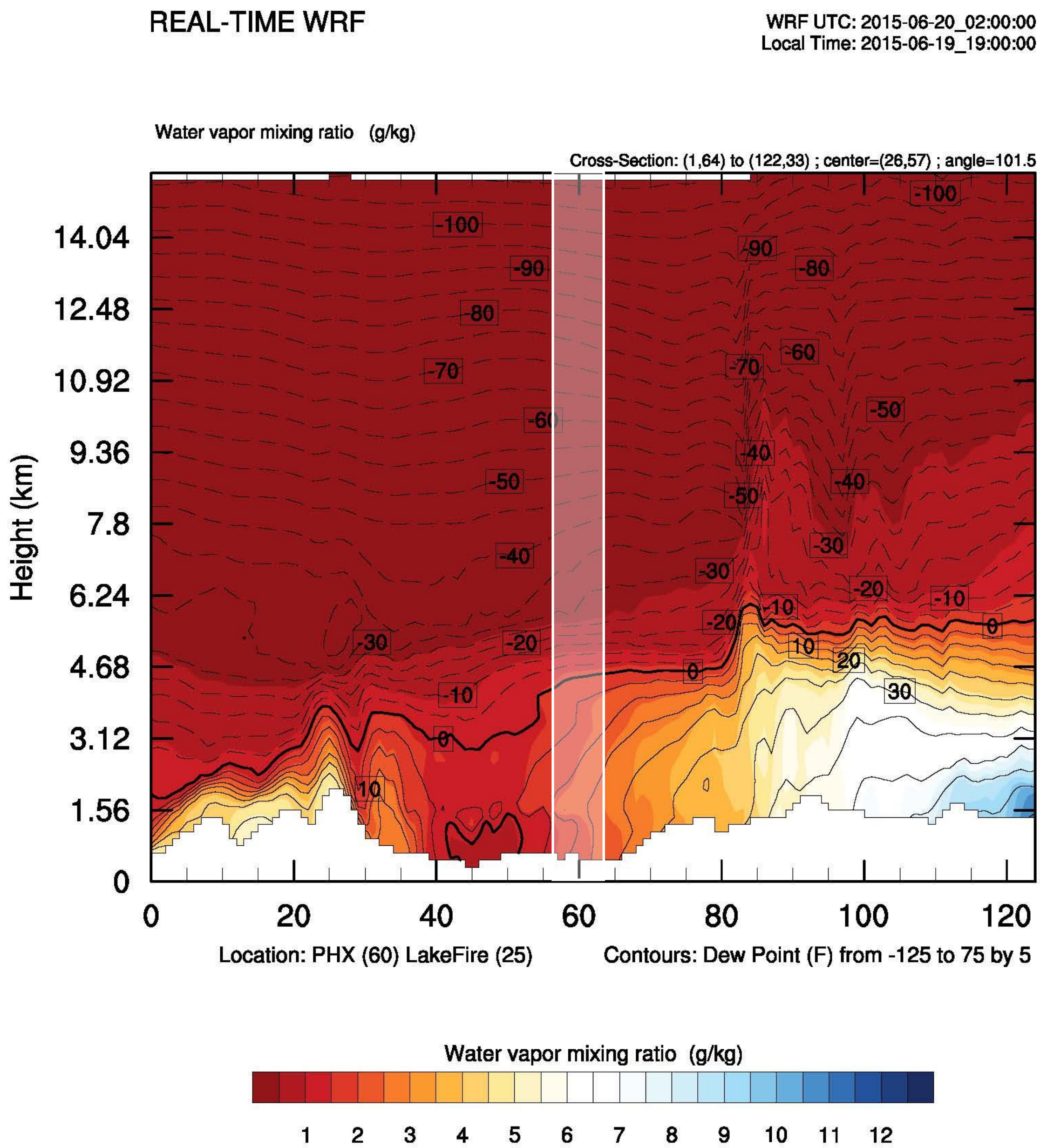

The tongue of dry air is fully formed from ground level to near 4,000 meters at 5:00 pm. Water vapor readings of near zero are present at ground level. The dew point contour lines are nearly vertical within the nonattainment area from ground level to 4,500 meters, indicating that the air is thoroughly mixed within this vertical distribution.

**Figure 18. Vertical Distribution of Water Vapor and Dew Point at 6:00 pm on June 19, 2015.**



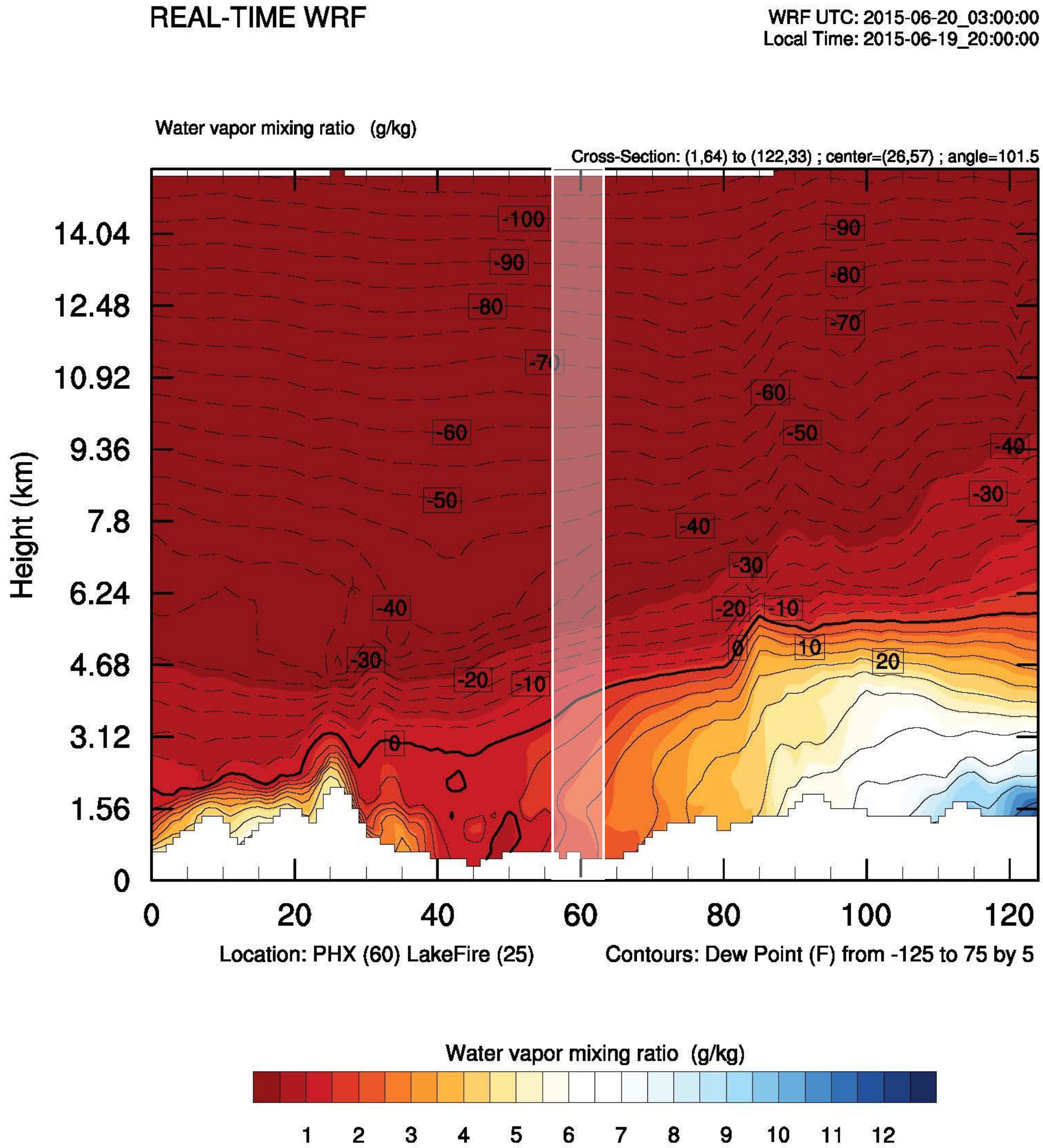

The trend from the 5:00 pm hour continues in the 6:00 pm hour with dew points constant from ground level to 4,500 meters within the nonattainment area.

**Figure 19. Vertical Distribution of Water Vapor and Dew Point at 7:00 pm on June 19, 2015.**



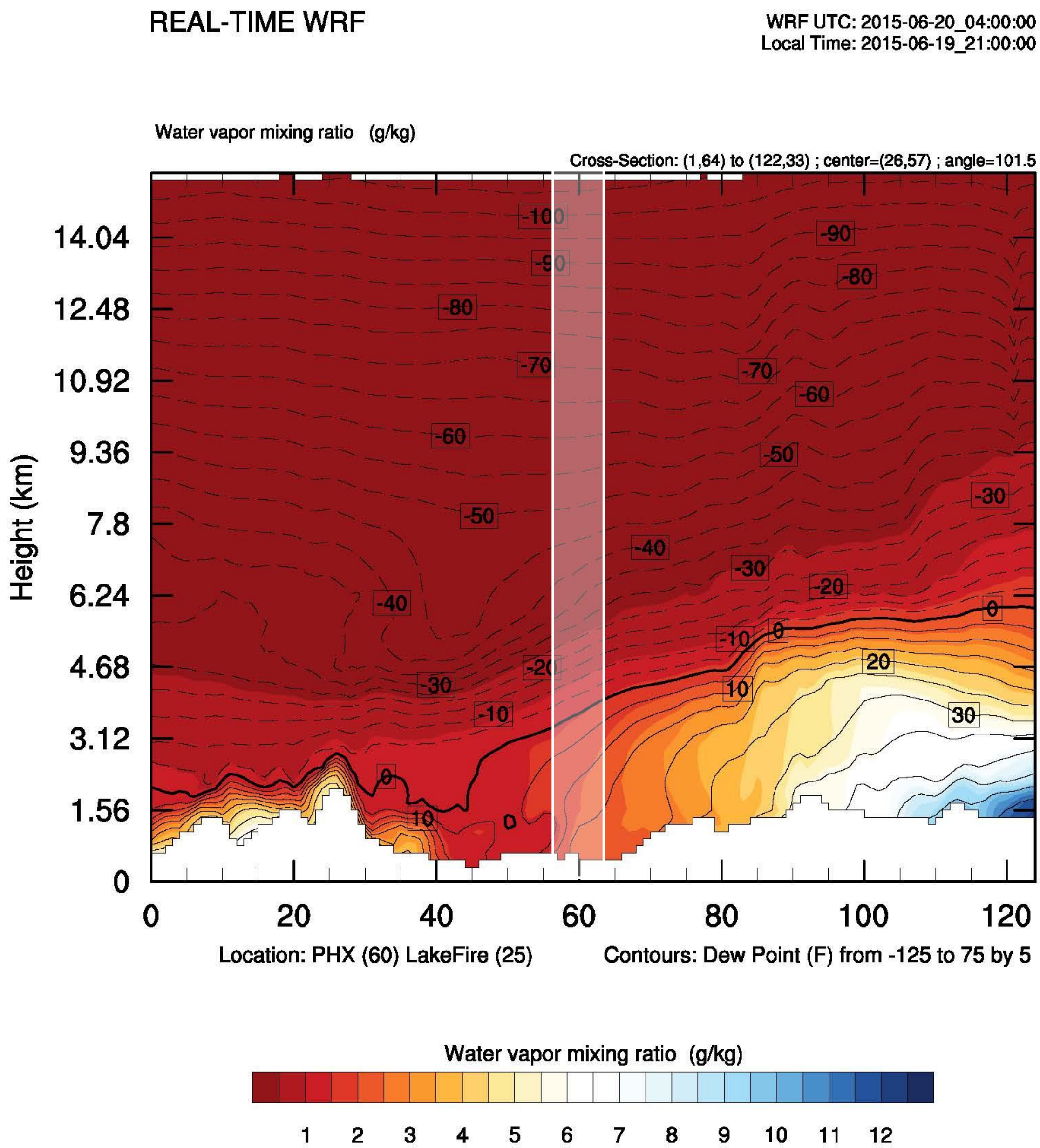

Very low dew points continue to be present at 7:00 pm at the ground level and vertical mixing continues. Drier air can also be seen moving horizontally from west to east into the nonattainment area just above the terrain height.

**Figure 20. Vertical Distribution of Water Vapor and Dew Point at 8:00 pm on June 19, 2015.**



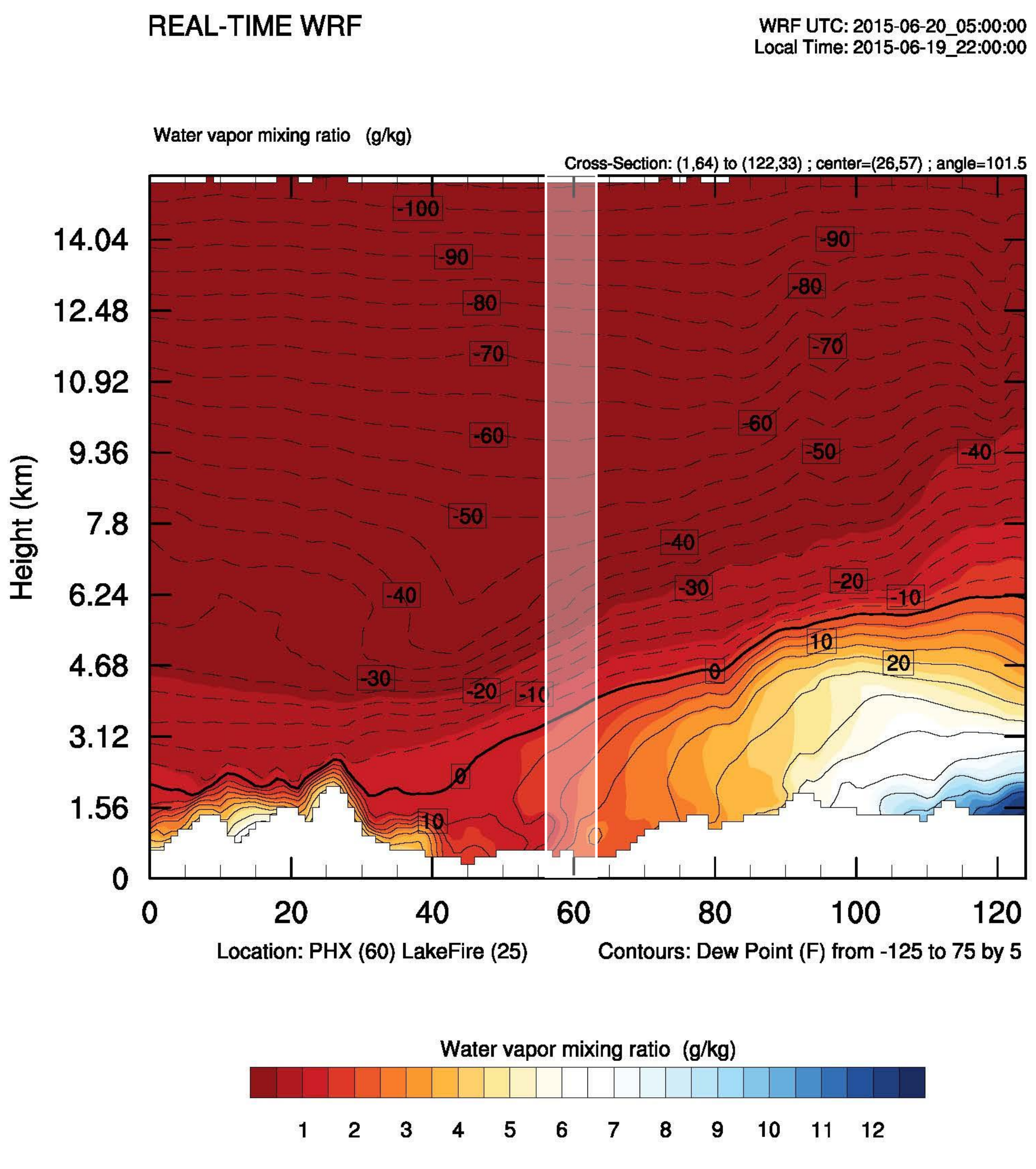

Dew points remain very low during the 8:00 pm hour, and very low water vapor content continues at the ground level within the nonattainment area.

**Figure 21. Vertical Distribution of Water Vapor and Dew Point at 9:00 pm on June 19, 2015.**



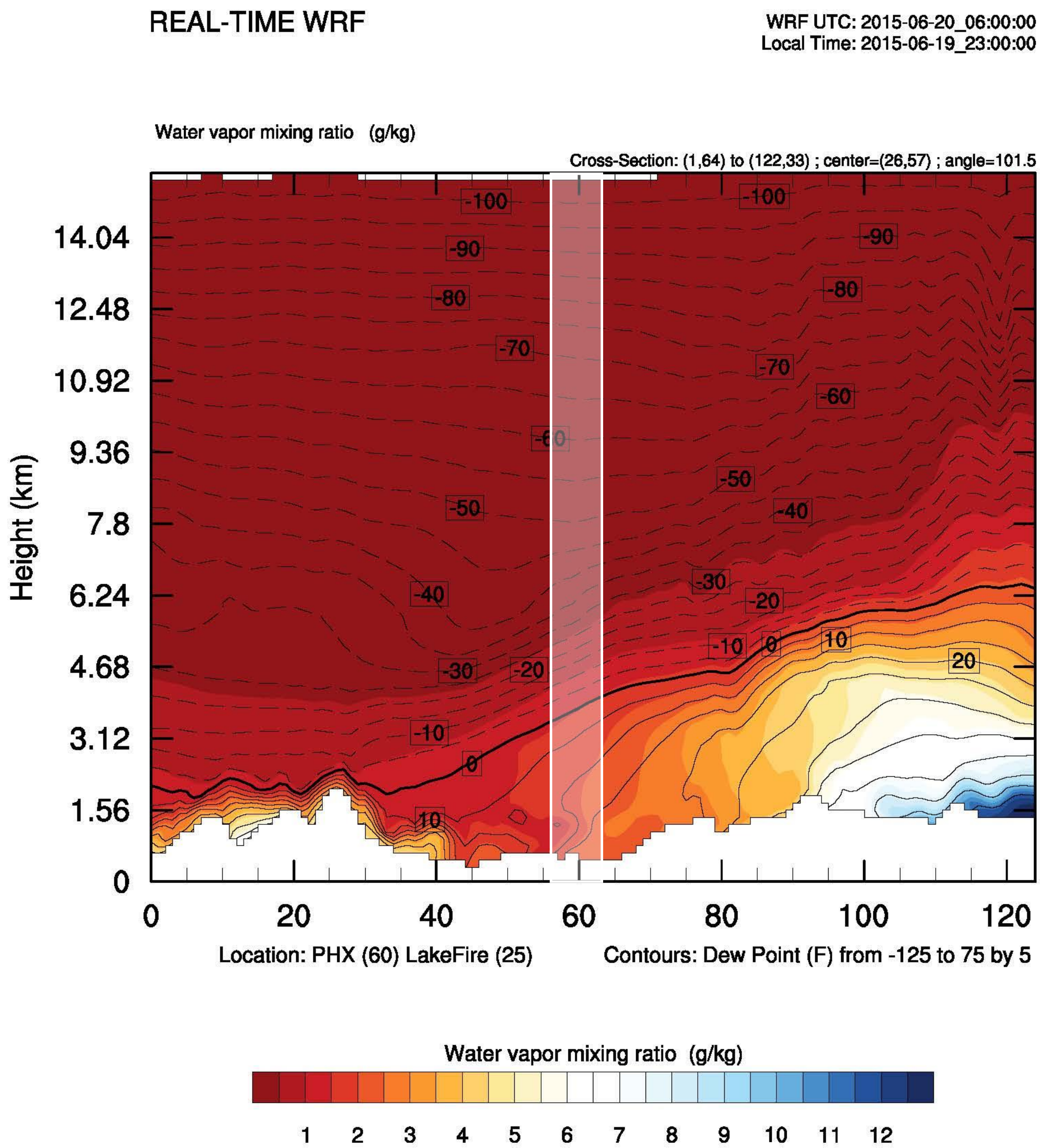

Dew points remain low during the 9:00 pm hour, and very low water vapor content continues at the ground level within the nonattainment area.

**Figure 22. Vertical Distribution of Water Vapor and Dew Point at 10:00 pm on June 19, 2015.**




Ground level dew points begin to rise a little bit in the 10:00 pm hour, and become more stratified as elevations increase. Very dry air as indicated by the water vapor mixing ratio remains present at ground level.

**Figure 23. Vertical Distribution of Water Vapor and Dew Point at 11:00 pm on June 19, 2015.**




By 11:00 pm the stratification of dew point contours continues. However, very dry air remains on the ground when examining the water vapor content, which now may be an indication of former upper air being trapped at lower elevations as the natural nightly inversion layer begins to form.

**Ozone and Ozone Precursor Fumigation (Down-Mixing) Event on June 20, 2015**

On June 20, 2015 the observed evolution of vertical atmospheric conditions in the Maricopa nonattainment area revealed an environment where transported wildfire smoke influenced ozone and ozone precursor emissions existing aloft would have been fumigated or mixed downward to contribute to surface ozone concentrations. According to the American Meteorological Society, fumigation is defined as the "mixing downward of an elevated plume of air pollution (often embedded in a layer of statically stable air such as a temperature inversion) into a turbulent mixed layer that has grown into and entrained the plume". Evidence for the meteorological mechanism allowing fumigation of ozone and ozone precursors is shown by reviewing vertical temperature measurement data taken over Phoenix at 5:00 am by National Weather Service weather balloon and later at 6:00 pm by Aircraft Meteorological Data Relay.

Specifically for mixing potential between the surface and higher altitudes, it is important to track changing surface mixing heights (layer where pollutants mix freely), which are restricted by temperature inversion altitude. An inversion occurs when temperature increases with height. The warm inversion layer acts as a cap and stops atmospheric mixing. Inversions therefore limit mixing between air masses not contained within the inversion layer. As noted by the red temperature line traces in Figure 5, early morning mixing height potential (Figure 24A) over Phoenix was below 1,500 meters (5,000 feet) while afternoon mixing heights (Figure 24B) approached approximately 3,000 meters (10,000 feet). Consequently, the extension of the surface mixed layer in altitude would have facilitated daytime fumigation of an air mass toward the surface that preexisted over the nonattainment area in the layer between 1,500 to 3,000 meters the day prior. That elevated atmospheric layer would include an air mass previously influenced and transported from the Lake Fire on June 18 and 19, 2015 based on previously discussed satellite data, HYSPLIT trajectories, and water vapor distribution data.

Further evidence of ozone and ozone precursor emissions aloft transferring to the surface during the daytime on June 20, 2015 is provided by an ozone mixing event signature recorded at the high elevation Humboldt Mountain monitoring site (1,582 meters) located within the nonattainment area. Explicitly, a rapid drop in ozone values at Humboldt Mountain after sunrise (Figure 25) is coincident with morning inversion breakup and vertical extension of the surface mixing height at lower elevations of the nonattainment area due to developing hot conditions. At the same time, lower elevation sites observed a rapid rise in ozone concentrations enhanced by ozone and ozone precursors aloft down-mixing. Diurnal ozone trends in the Maricopa nonattainment area match the relationship documented between paired high and low elevation sites experiencing ozone mixing events (e.g., VanCuren, 2015) (Figure 26).

This additionally provided evidence helps support that the Maricopa nonattainment area was impacted by Lake Fire ozone and ozone precursors on June 20, 2015 by an upper-air vertical pathway.

**Figure 24. National Weather Service 5AM Phoenix Weather Balloon Data (A) and 6 PM Aircraft Meteorological Data Relay data (B) on June 20, 2015.**

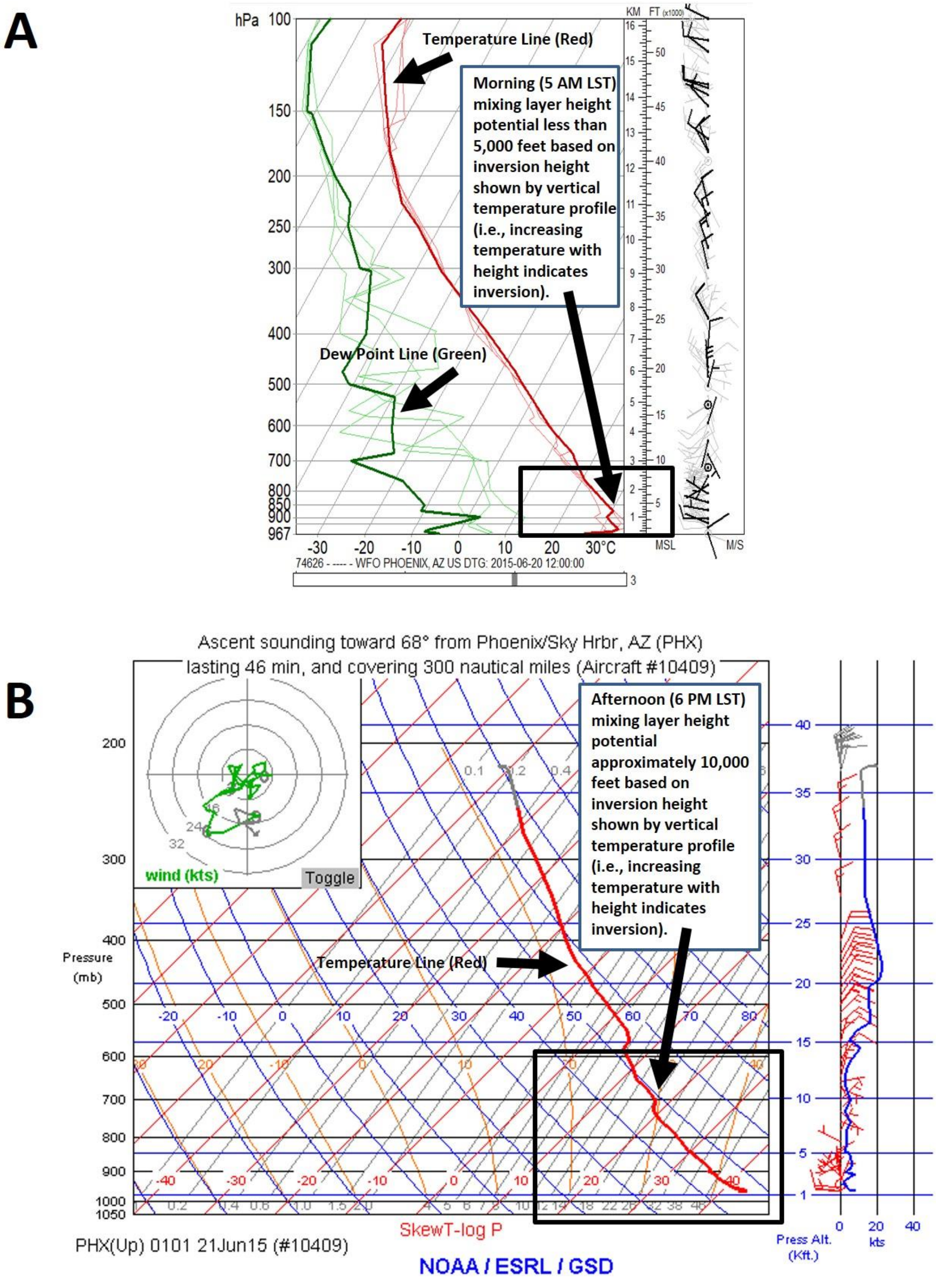


**Figure 25. Evidence for an Ozone Mixing Event in the Maricopa Nonattainment Area on June 20, 2015.**

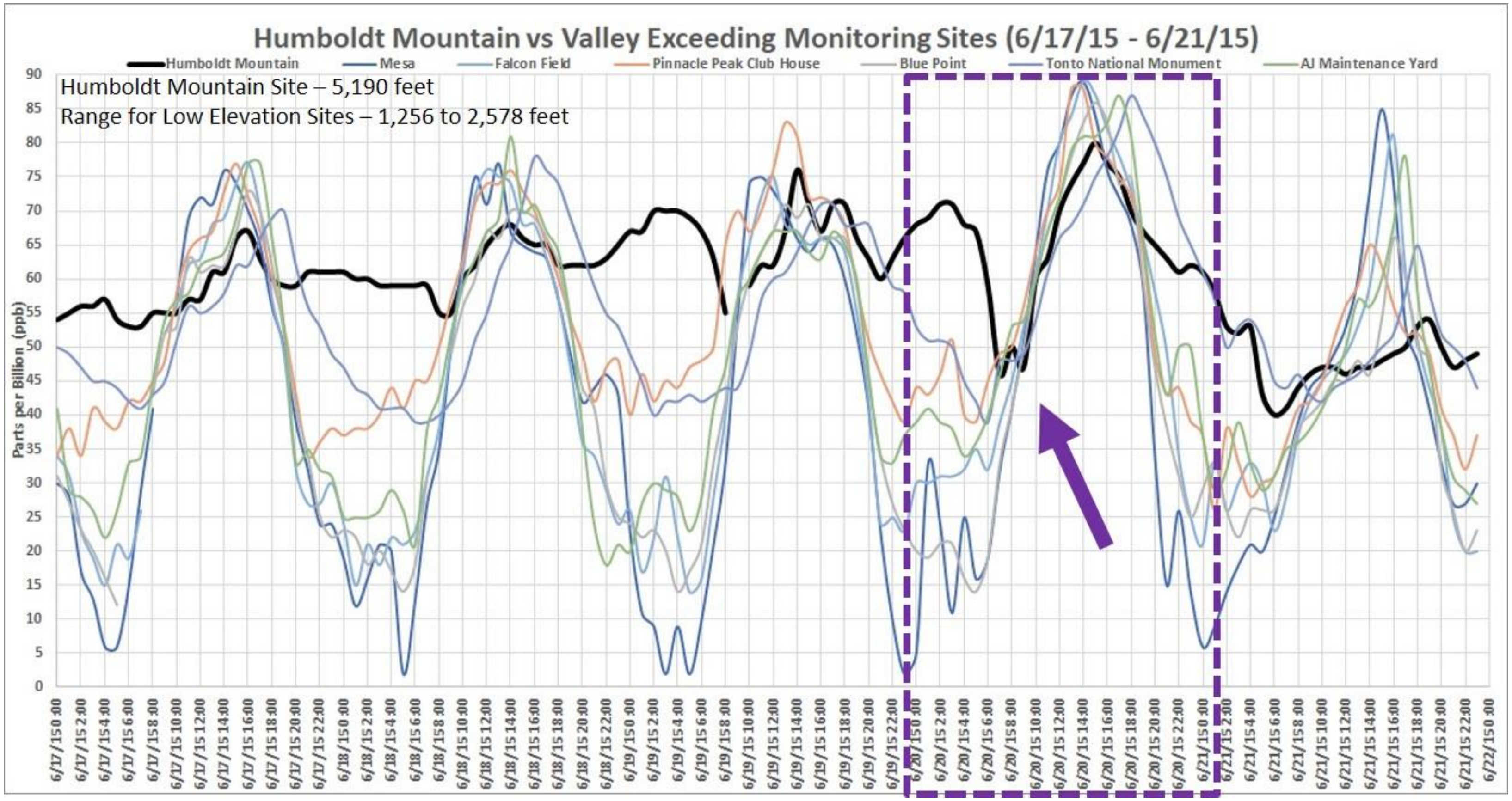


**Figure 26. Documented Ozone Mixing Event from Reference Literature (Van Curen, 2015).**

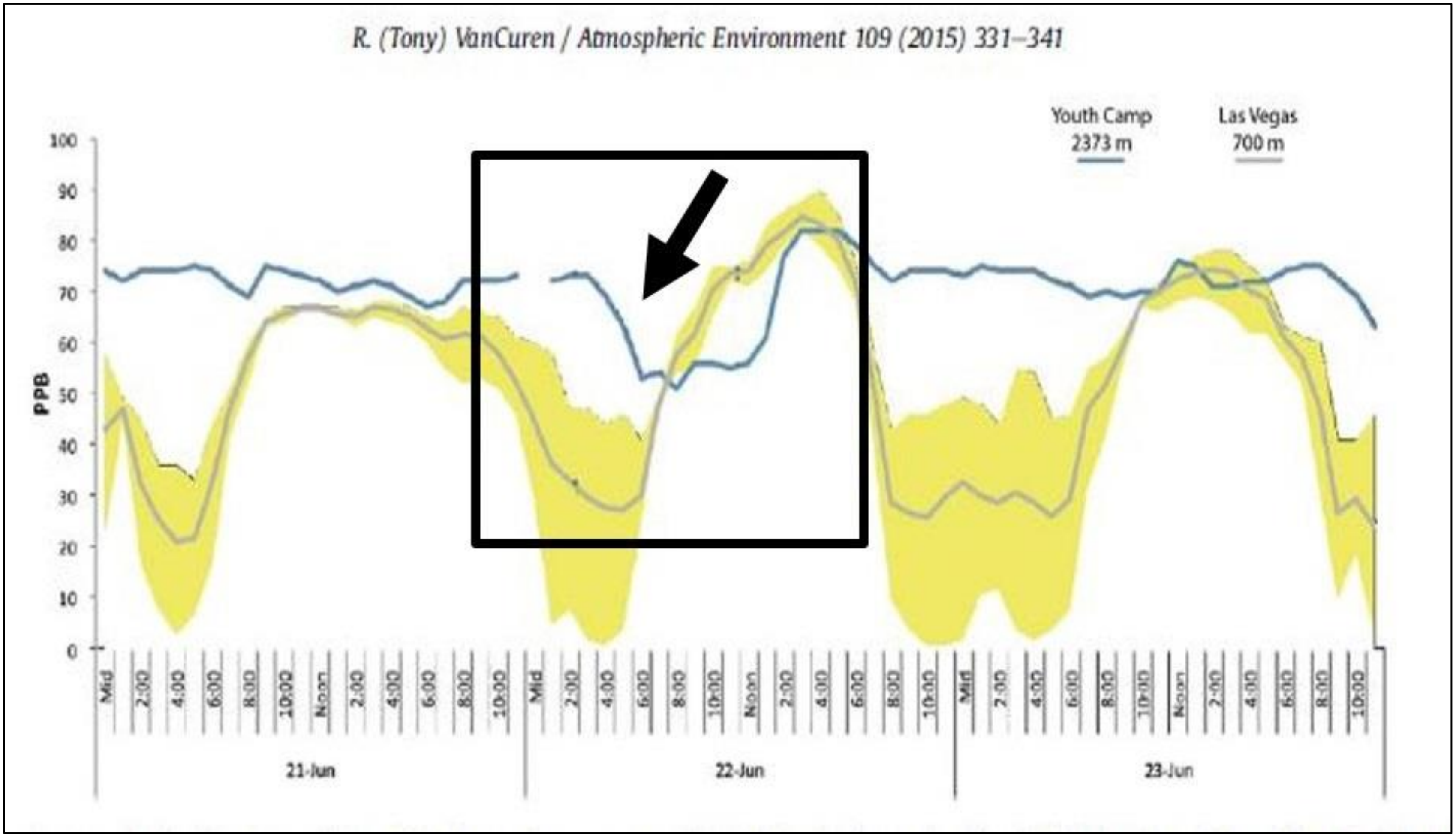



***Fig. 8.*** *Diurnal structure of ozone fumigation from aloft: a. Timelines of ozone at an elevated site in Spring Mts. (SMYC) and an urban valley site in Las Vegas, summer 2011 (Huys, 2012). Afternoon heating mixes ozone from aloft to surface, equalizing the concentrations in the late afternoon on June 22.*

Literature Cited From:

VanCuren, R., 2015. Transport aloft drives peak ozone in the Mojave Desert. *Atmospheric Environment*. 109, 331-341.

***Summary of Ozone Fumigation Event***

This meteorological mechanism allowing ozone and ozone precursor emissions aloft to the surface is fumigation or down-mixing. Available vertical meteorological measurements over the Maricopa nonattainment area on June 20, 2015 capture a relatively shallow surface mixing layer height over Phoenix under 1,500 meters that extended up to 3,000 meters through the daytime to include the altitude of an air mass aloft that was influenced by the Lake Fire on June 18 and 19, 2015. This created a meteorological upper-air vertical pathway for transported Lake Fire ozone and ozone precursor emissions to down-mix and reach the surface. Observed ozone concentration trends between high and low elevation monitoring sites for the nonattainment area on June 20, 2015 are consistent with the occurrence of an ozone mixing event discussed in prior research studies. Generally, these ozone mixing events are characterized by an initial early day rapid drop (rise) in high (low) elevation ozone monitoring sites that require the surface mixing layer to extend high enough in altitude to force daytime down-mixing (or fumigation) of non-local ozone and ozone precursors aloft that was initially separated from the surface by temperature inversion.

## CONCLUSION

The focus of the data and analyses presented in this addendum is to provide evidence (above and beyond what was submitted to EPA in the September 2016 documentation and the May 2018 addendum) that ozone and ozone precursors from the Lake Fire in Southern California reached and affected the monitors in the Maricopa nonattainment area. The additional analyses have been performed to expand upon the conceptual and narrative model of the wildfire event, providing new and additional evidence linking the ozone and ozone precursors from the Lake Fire with the exceedances of the 2008 ozone standard in the Maricopa nonattainment area on June 20, 2015.

The expanded conceptual model presented in this addendum demonstrated through multiple HYSPLIT analyses that both an upper-air and lower-air pathway for the horizontal transport of ozone and ozone precursors from the Lake Fire to the Maricopa nonattainment area existed on June 18-20, 2015.

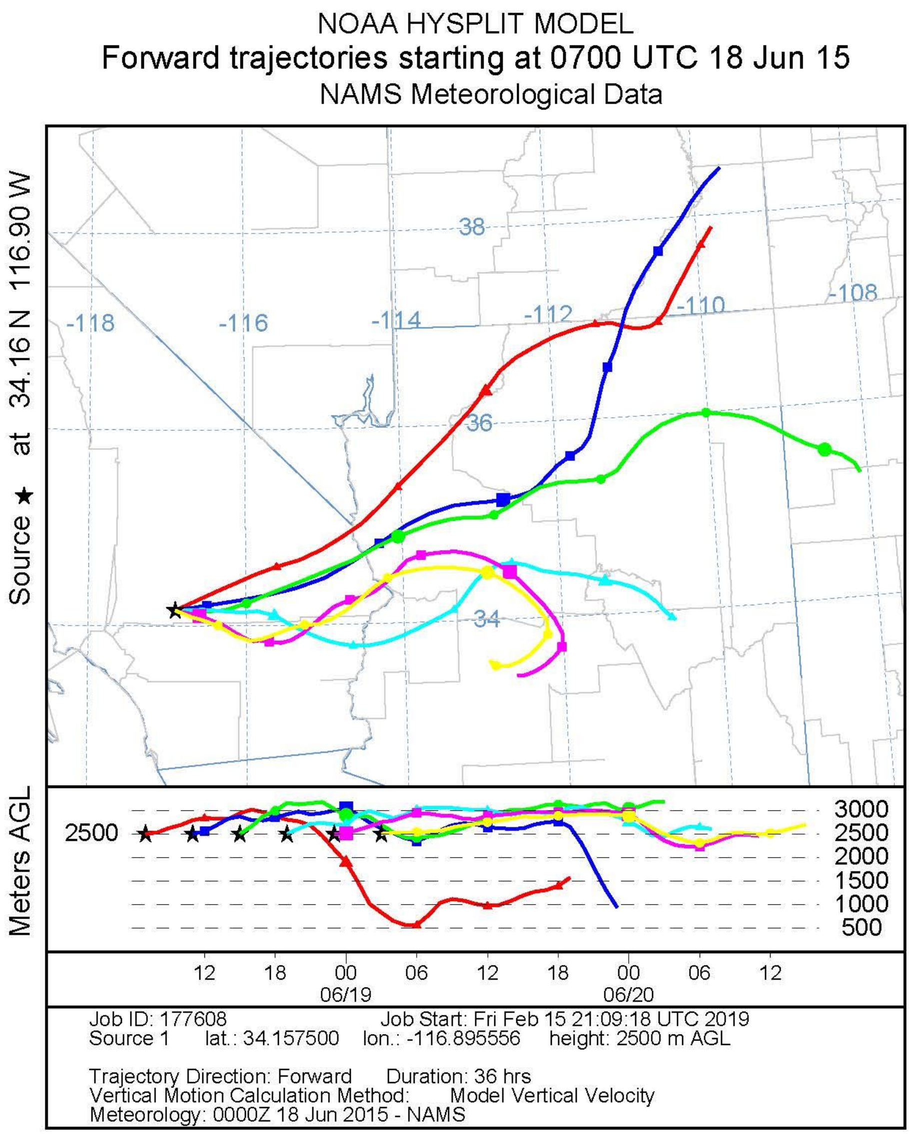
Additional analysis on the vertical distribution of dew point and water vapor content over the Maricopa nonattainment area confirms that the very dry air seen in the Maricopa nonattainment area on June 19-20, 2015 was the result of elevated (3,000 – 4,000 meter) dry air descending to the ground. As such, this analysis confirms that atmospheric transport and mixing processes existed that would allow for aloft ozone and ozone precursors from the Lake Fire to impact the ground level ozone monitors in Yuma, Arizona and the Maricopa nonattainment area, leading to the exceedances of the ozone standard on June 20, 2015.

Furthermore, available vertical meteorological measurements over the Maricopa nonattainment area on June 20, 2015 capture a relatively shallow surface mixing layer height over Phoenix under 1,500 meters that extended up to 3,000 meters through the daytime to include the altitude of an air mass aloft that was influenced by the Lake Fire on June 18 and 19, 2015. This created a meteorological upper-air vertical pathway for transported Lake Fire ozone and ozone precursors to down-mix and reach the surface. Additionally, observed ozone concentration trends between high and low elevation monitoring sites for the nonattainment area on June 20, 2015 are consistent with the occurrence of an ozone mixing event discussed in prior research studies.

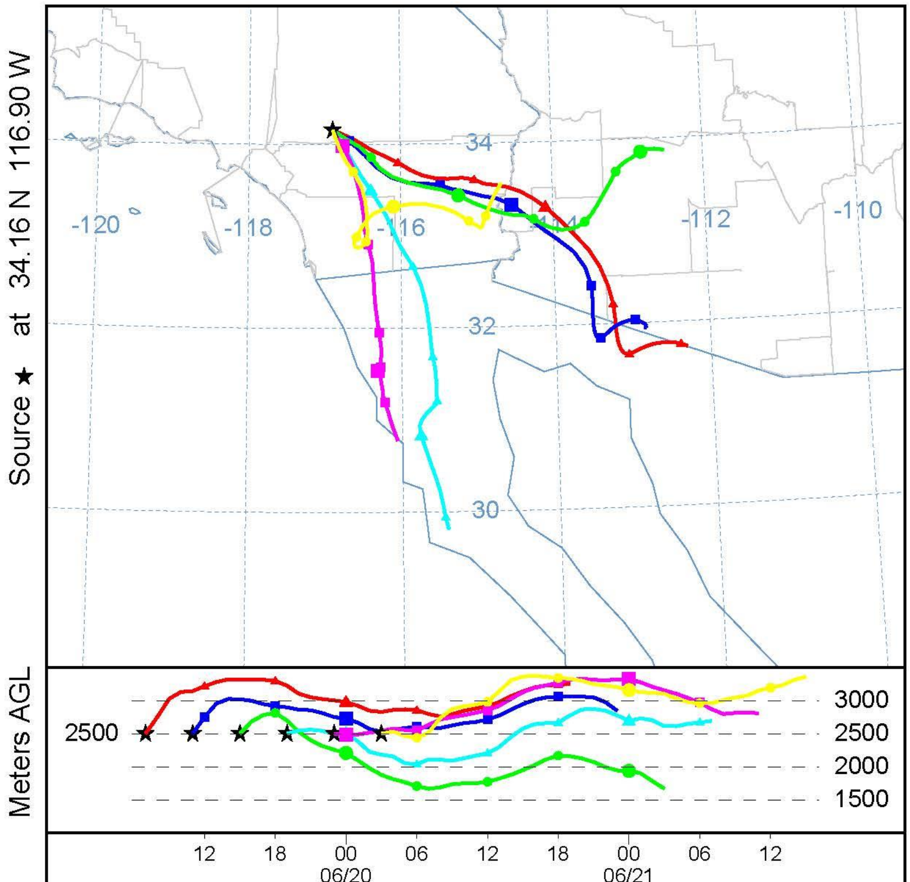
These additional analyses were provided to expand the conceptual and narrative model presented and submitted to EPA in prior documentation. Taken together, the analyses significantly strengthen the link and clear causal relationship between the ozone and ozone precursors from the Lake Fire and the exceedances of the 2008 ozone standard on June 20, 2015 in the Maricopa nonattainment area.

# APPENDIX A

# HYSPLIT OUTPUTS

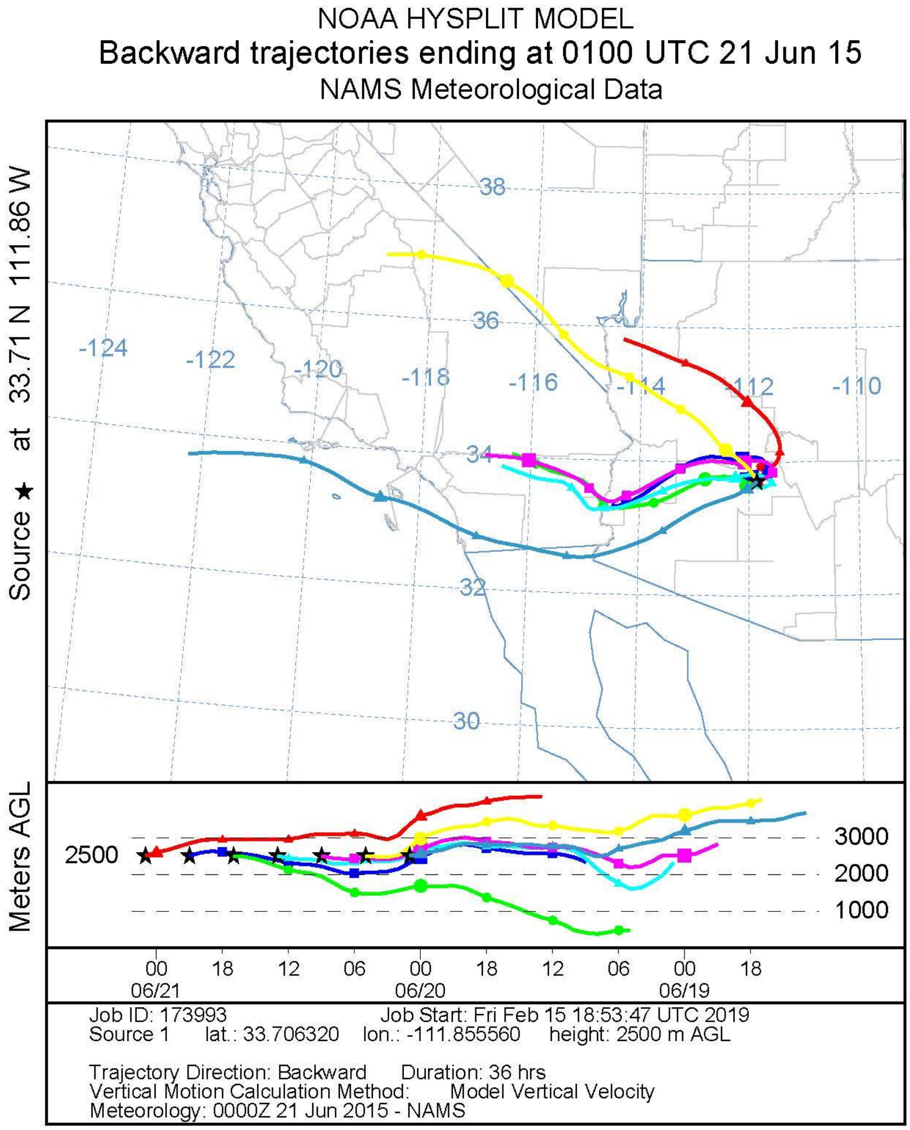

NOAA HYSPLIT MODEL
Forward trajectories starting at 0700 UTC 18 Jun 15
NAMS Meteorological Data
Source ★ at 34.16 N 116.90 W
38
36
34
-118
-116
-114
-112
-110
-108
Meters AGL
2500
3000
2500
2000
1500
1000
500
12 18 00 06 12 18 00 06 12
06/19
06/20
Job ID: 177608
Job Start: Fri Feb 15 21:09:18 UTC 2019
Source 1 lat.: 34.157500 lon.: -116.895556 height: 2500 m AGL
Trajectory Direction: Forward Duration: 36 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 18 Jun 2015 - NAMS

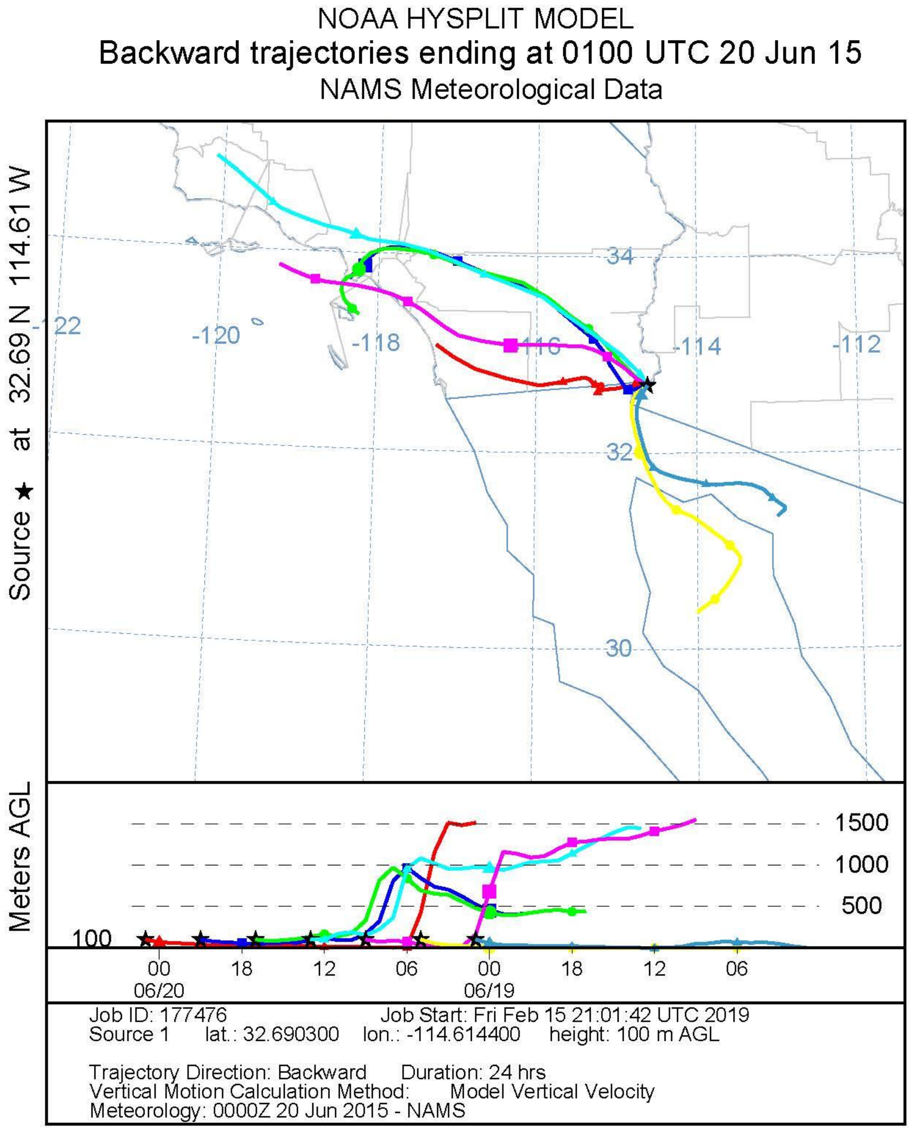
NOAA HYSPLIT MODEL
Forward trajectories starting at 0700 UTC 19 Jun 15
NAMS Meteorological Data

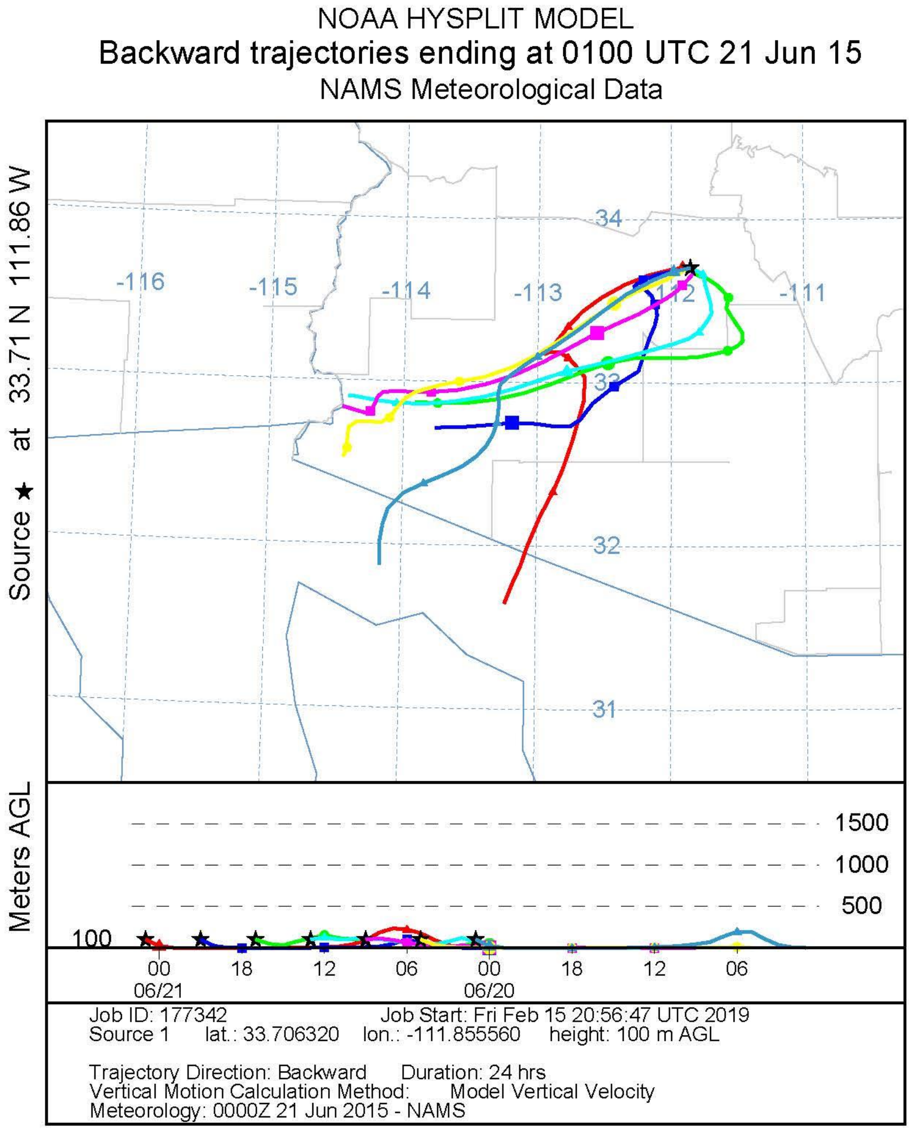



Job ID: 177581 Job Start: Fri Feb 15 21:06:57 UTC 2019
Source 1 lat.: 34.157500 lon.: -116.895556 height: 2500 m AGL

Trajectory Direction: Forward Duration: 36 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 19 Jun 2015 - NAMS


NOAA HYSPLIT MODEL
Backward trajectories ending at 0100 UTC 21 Jun 15
NAMS Meteorological Data
Source ★ at 33.71 N 111.86 W
38
36
34
32
30
-124
-122
-120
-118
-116
-114
-112
-110
Meters AGL
2500
3000
2000
1000
00 18 12 06 00 18 12 06 00 18
06/21
06/20
06/19
Job ID: 173993 Job Start: Fri Feb 15 18:53:47 UTC 2019
Source 1 lat.: 33.706320 lon.: -111.855560 height: 2500 m AGL
Trajectory Direction: Backward Duration: 36 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 21 Jun 2015 - NAMS


NOAA HYSPLIT MODEL
Backward trajectories ending at 0100 UTC 20 Jun 15
NAMS Meteorological Data
Source ★ at 32.69 N 114.61 W
34
-122
-120
-118
-116
-114
-112
32
30
Meters AGL
1500
1000
500
100
00
06/20
18
12
06
00
06/19
18
12
06
Job ID: 177476
Job Start: Fri Feb 15 21:01:42 UTC 2019
Source 1 lat.: 32.690300 lon.: -114.614400 height: 100 m AGL
Trajectory Direction: Backward Duration: 24 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 20 Jun 2015 - NAMS


NOAA HYSPLIT MODEL
Backward trajectories ending at 0100 UTC 21 Jun 15
NAMS Meteorological Data
Source ★ at 33.71 N 111.86 W
34
-116
-115
-114
-113
-112
-111
33
32
31
Meters AGL
1500
1000
500
100
00
06/21
18
12
06
00
06/20
18
12
06
Job ID: 177342
Job Start: Fri Feb 15 20:56:47 UTC 2019
Source 1 lat.: 33.706320 lon.: -111.855560 height: 100 m AGL
Trajectory Direction: Backward Duration: 24 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 21 Jun 2015 - NAMS

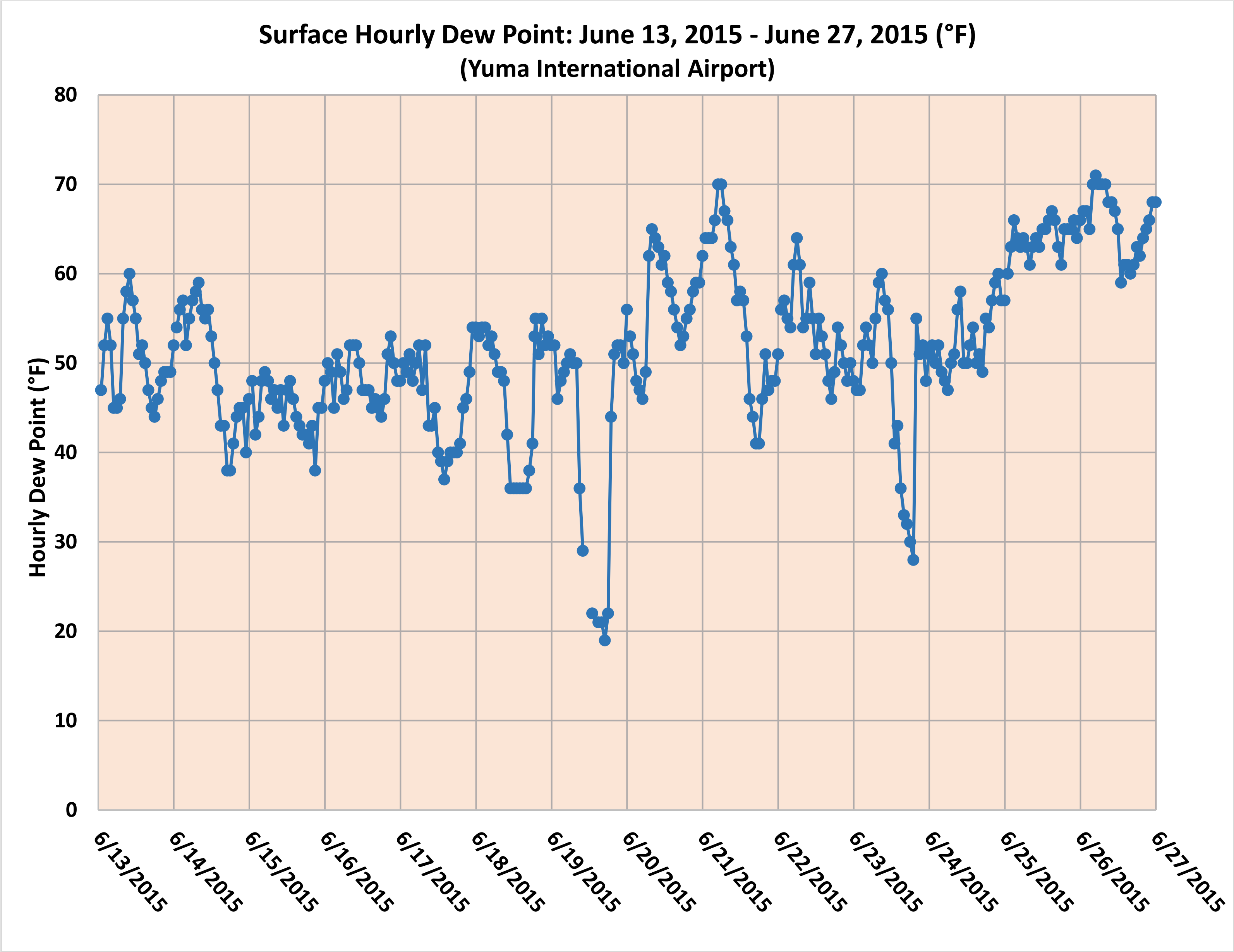
# APPENDIX B

# DEW POINT AND WATER VAPOR ANALYSIS
# FOR YUMA ARIZONA

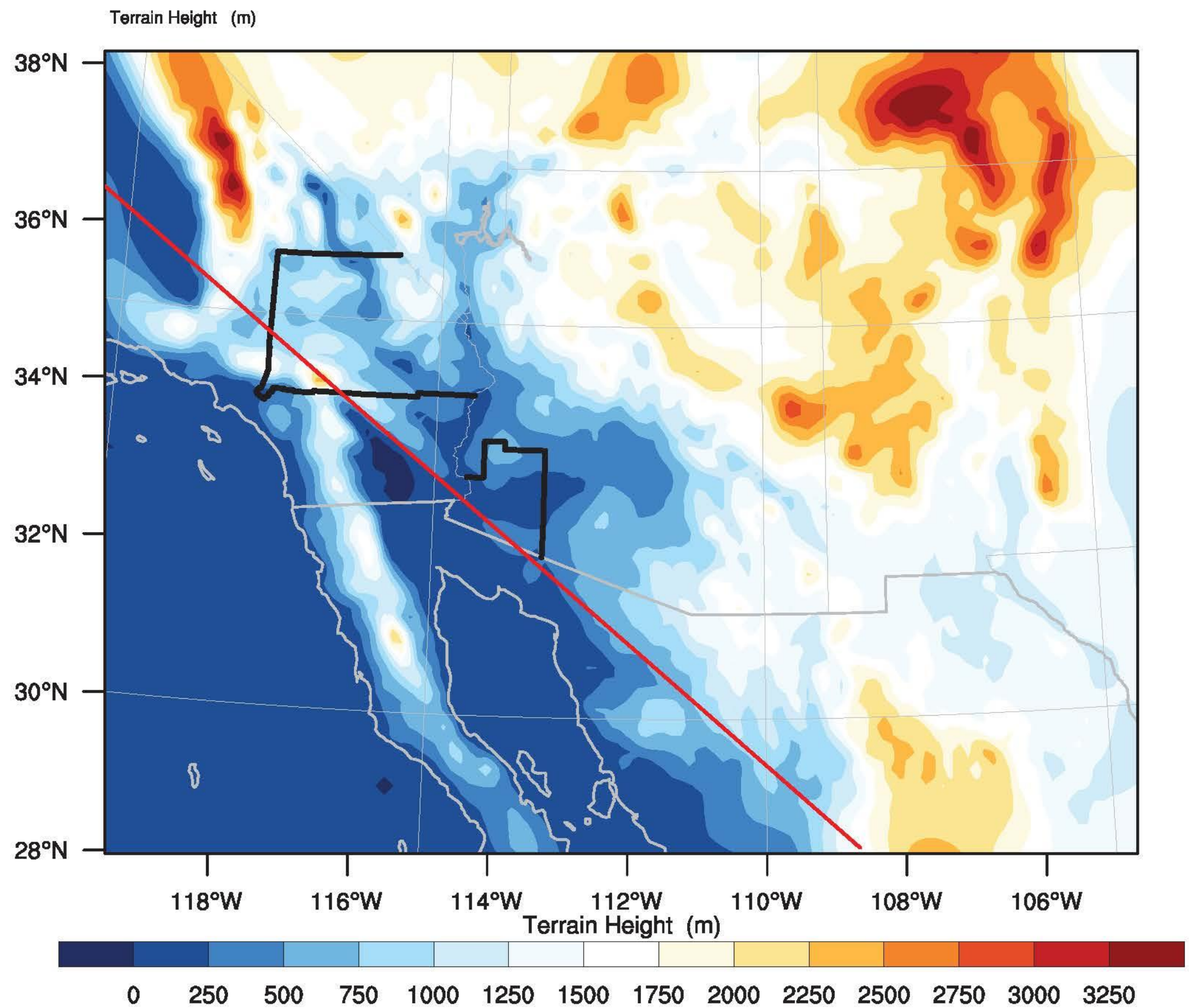
**Dew Point and Water Vapor Analysis for Yuma, Arizona**

Similar to the dew point analysis for the Maricopa nonattainment area provided in the main body of this addendum, low dew points and the descending of elevated dry air were also observed in Yuma, Arizona on June 19, 2015. The following figures show the observed ground level dew points at the Yuma NWS station and the WRF hourly modeled vertical cross section of dew point and water vapor over a line running through the Lake Fire and Yuma.

These figures provide additional evidence of a mechanism that existed which would allow for ozone and ozone precursors from the Lake Fire to descend to the ground level Yuma monitor on June 19, 2015.

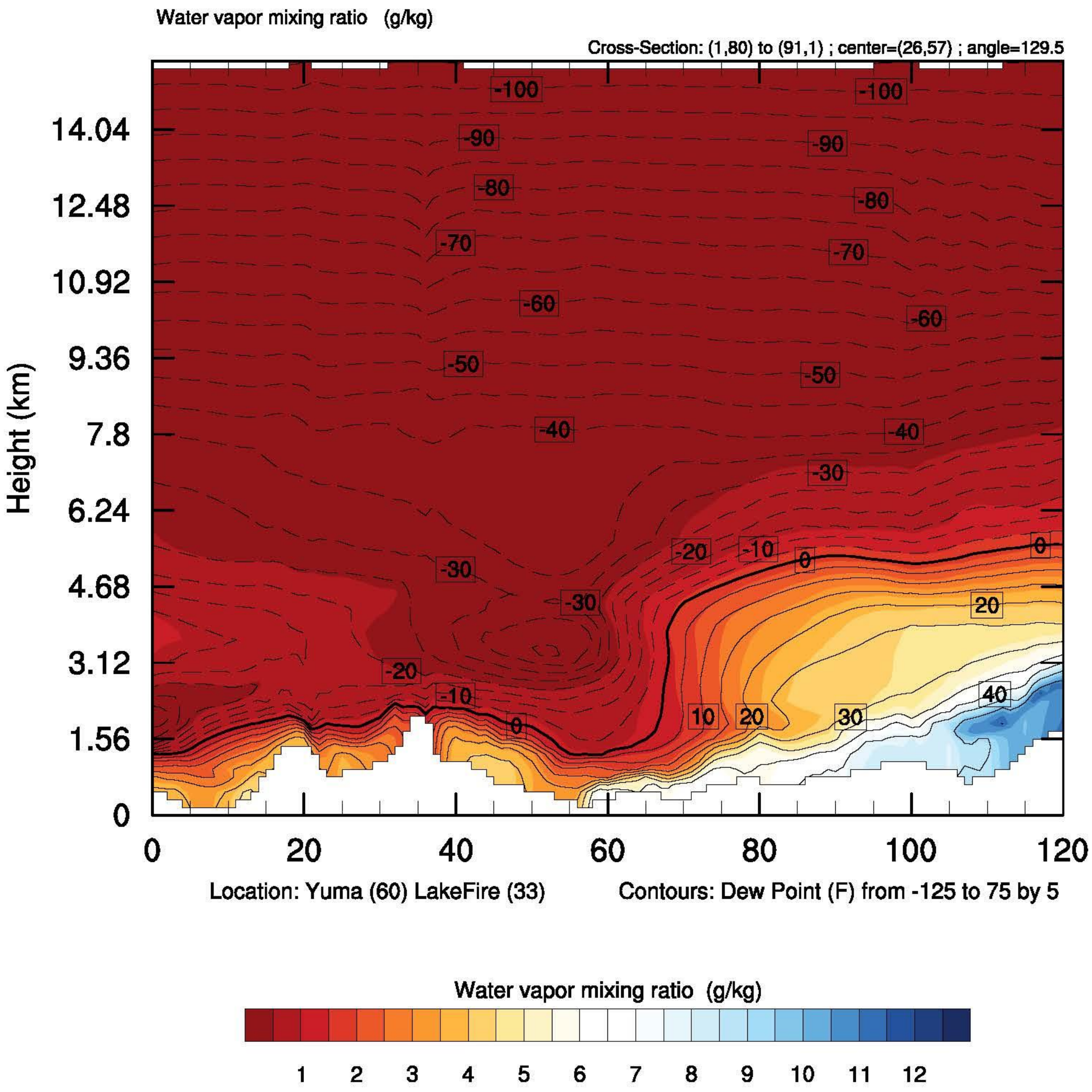


Surface Hourly Dew Point: June 13, 2015 - June 27, 2015 (°F)
(Yuma International Airport)
Hourly Dew Point (°F)
80
70
60
50
40
30
20
10
0
6/13/2015
6/14/2015
6/15/2015
6/16/2015
6/17/2015
6/18/2015
6/19/2015
6/20/2015
6/21/2015
6/22/2015
6/23/2015
6/24/2015
6/25/2015
6/26/2015
6/27/2015

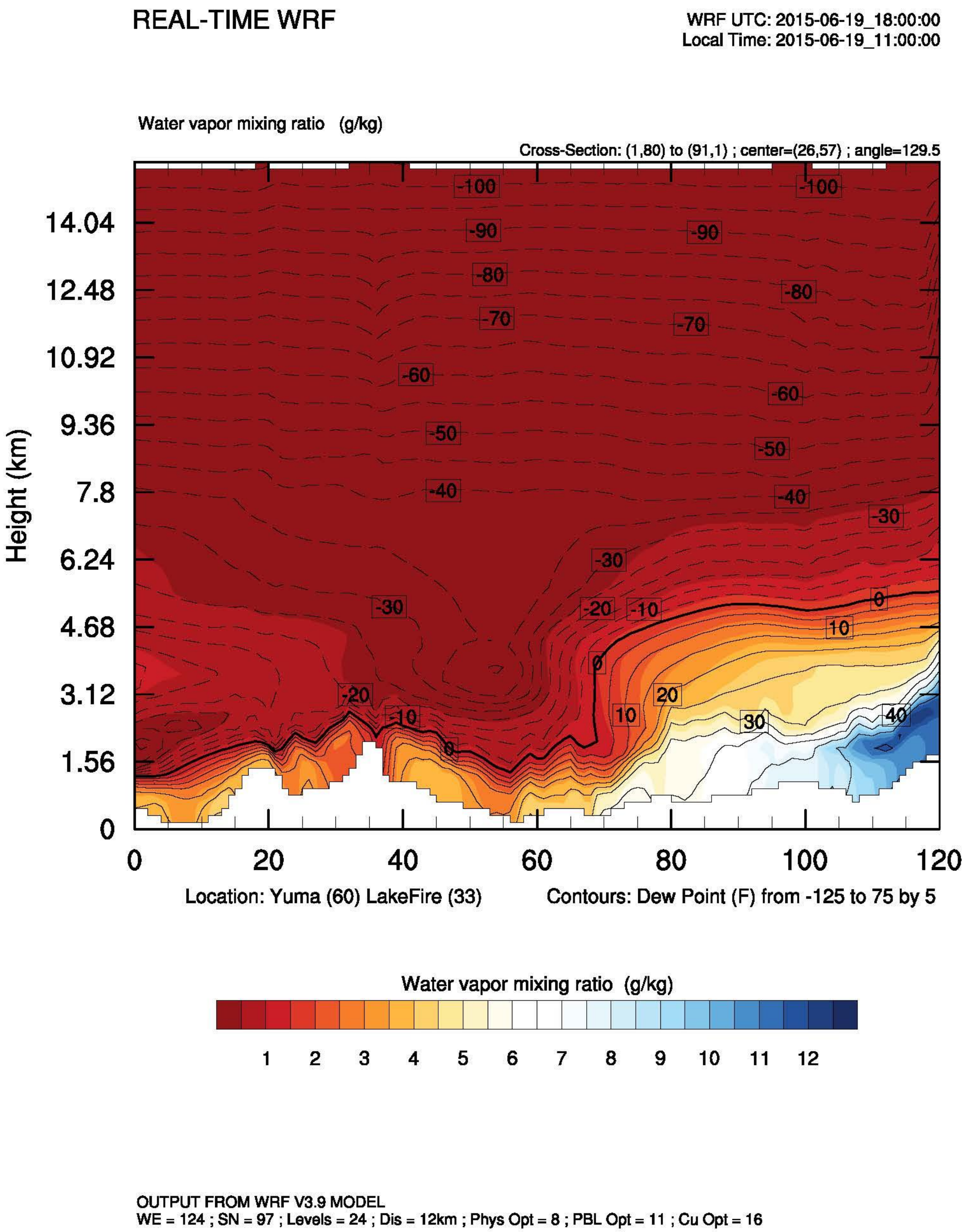

Terrain Height (m)
38°N
36°N
34°N
32°N
30°N
28°N
118°W
116°W
114°W
112°W
110°W
108°W
106°W
Terrain Height (m)
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
2750
3000
3250

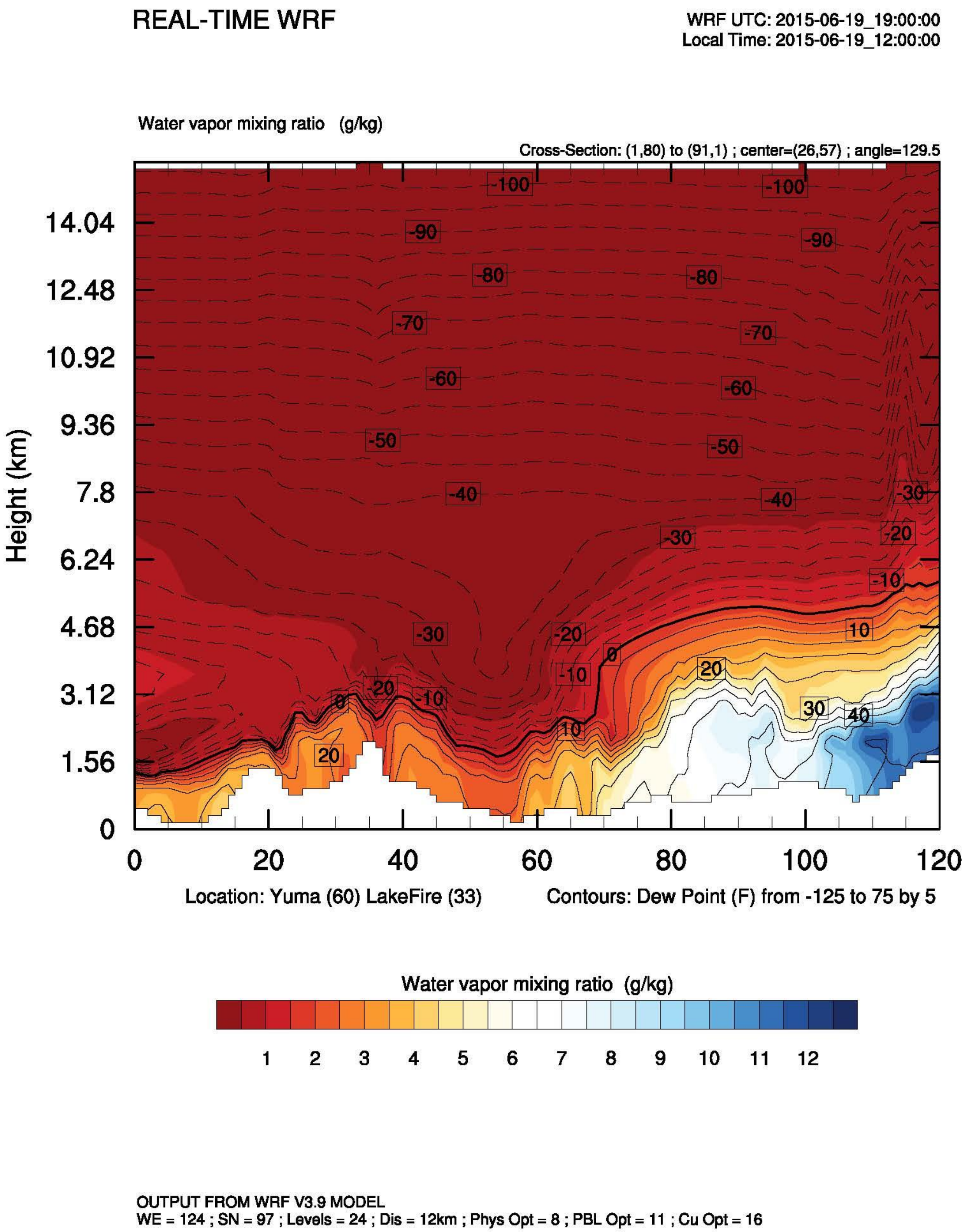
REAL-TIME WRF

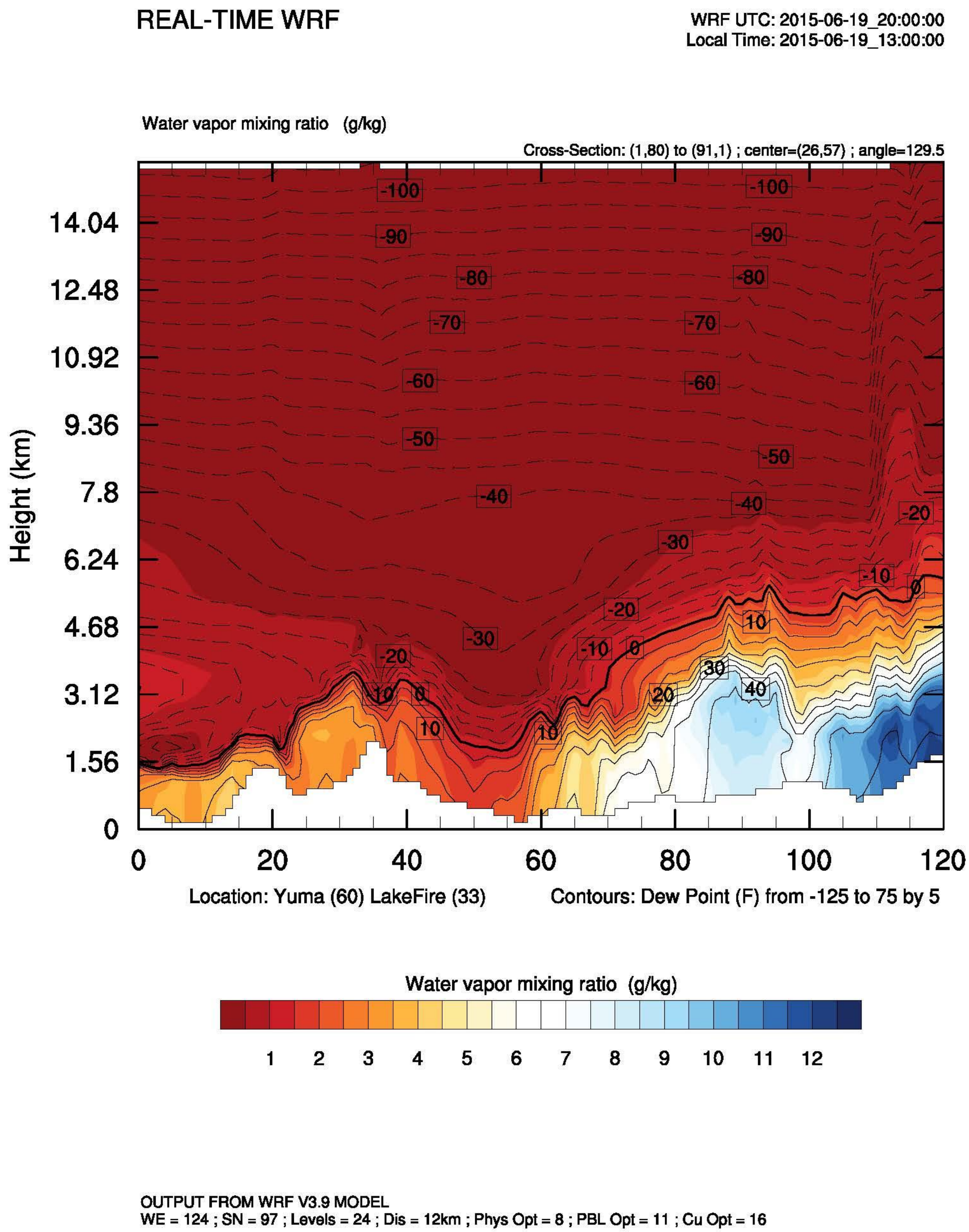
WRF UTC: 2015-06-19_17:00:00
Local Time: 2015-06-19_10:00:00

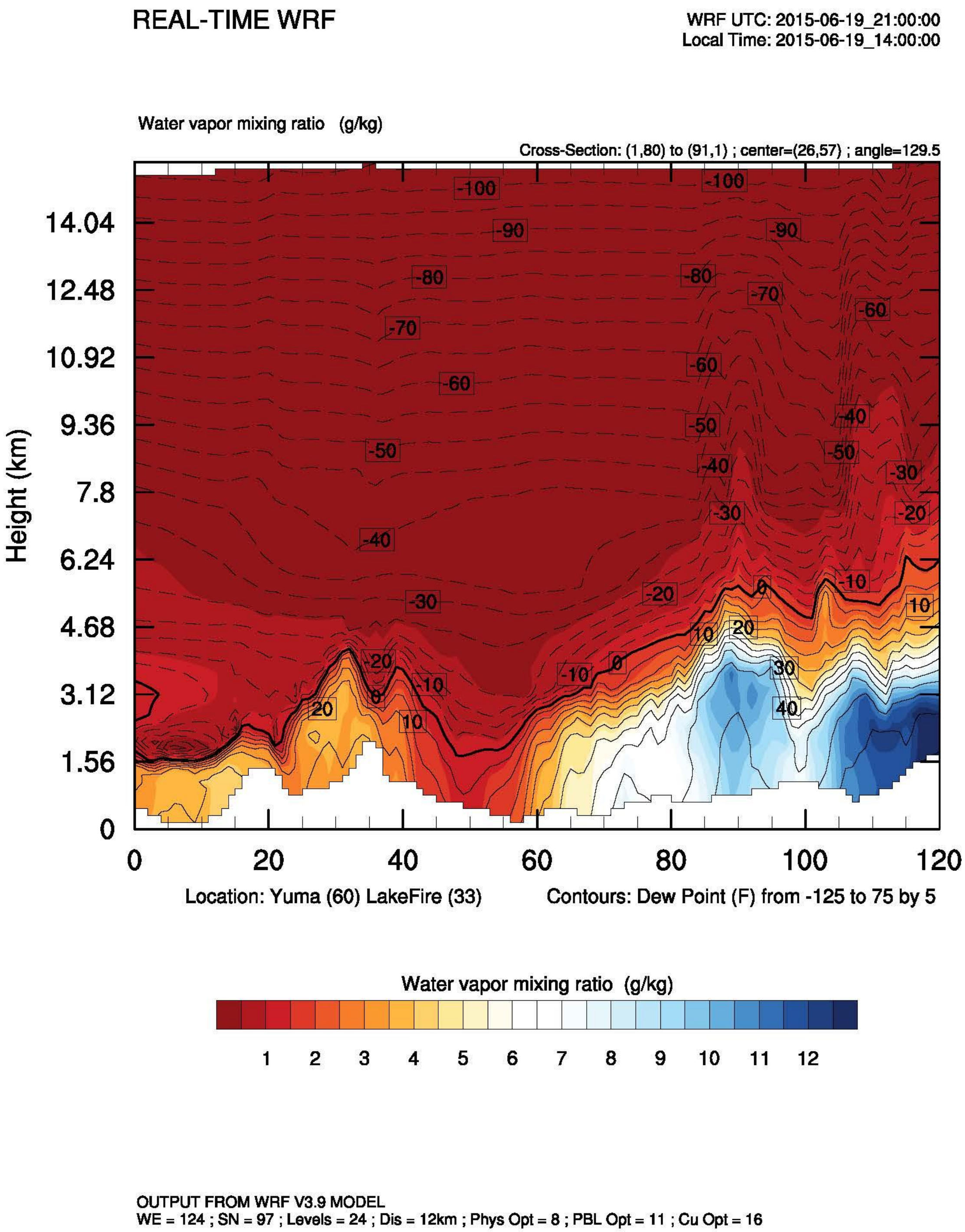


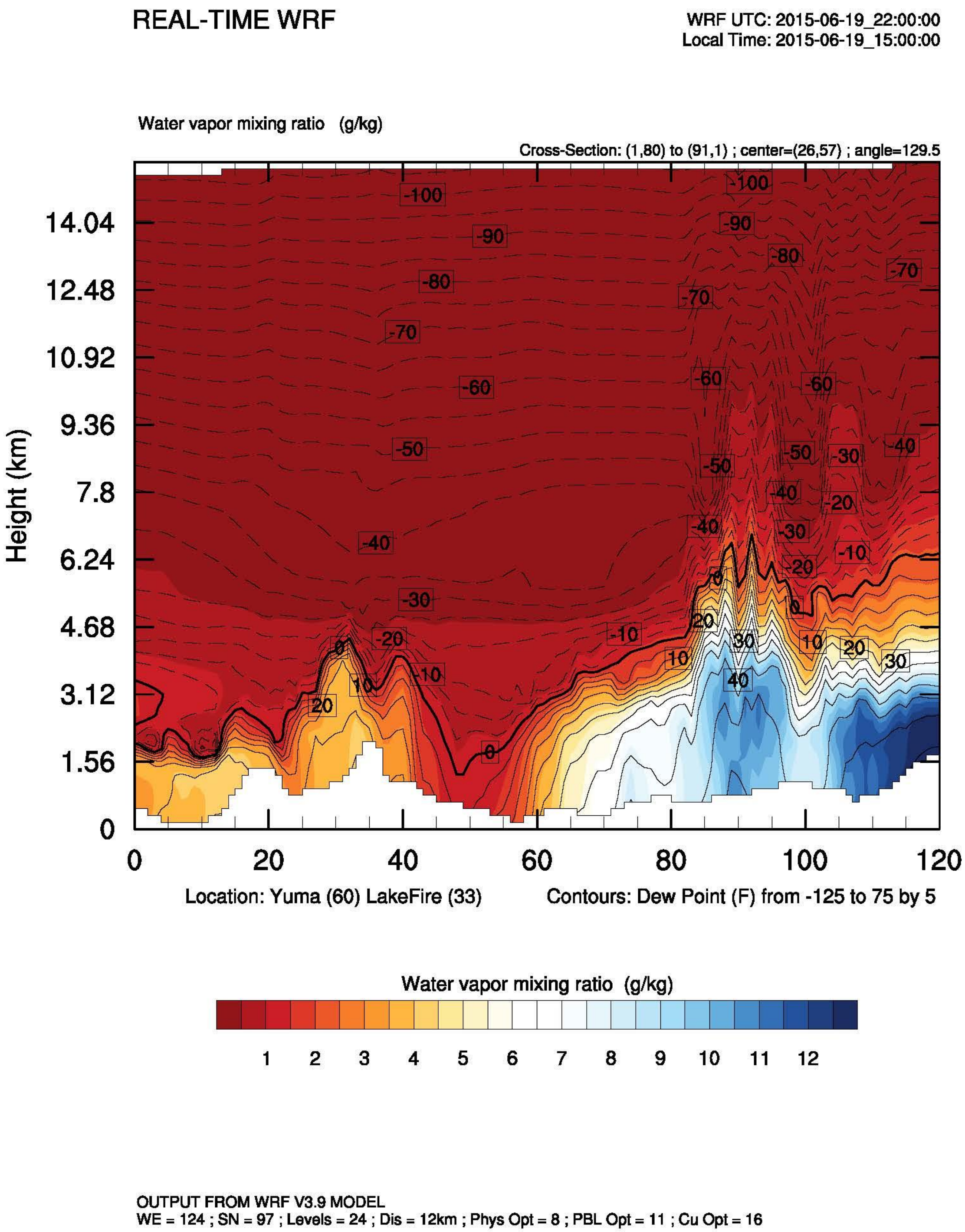

OUTPUT FROM WRF V3.9 MODEL
WE = 124 ; SN = 97 ; Levels = 24 ; Dis = 12km ; Phys Opt = 8 ; PBL Opt = 11 ; Cu Opt = 16

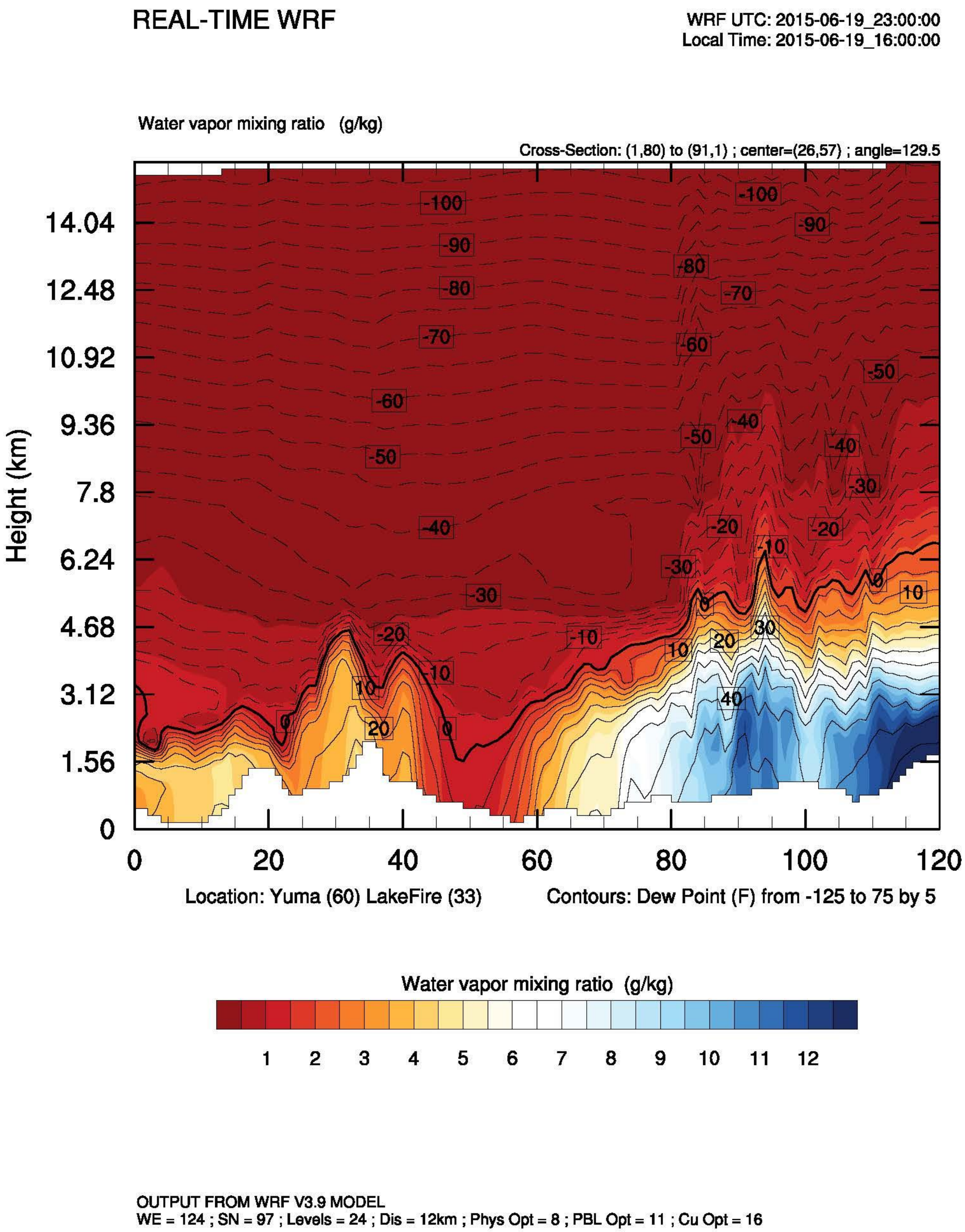

REAL-TIME WRF
WRF UTC: 2015-06-19_18:00:00
Local Time: 2015-06-19_11:00:00
Water vapor mixing ratio (g/kg)
Cross-Section: (1,80) to (91,1) ; center=(26,57) ; angle=129.5
Height (km)
Location: Yuma (60) LakeFire (33)
Contours: Dew Point (F) from -125 to 75 by 5
Water vapor mixing ratio (g/kg)
OUTPUT FROM WRF V3.9 MODEL
WE = 124 ; SN = 97 ; Levels = 24 ; Dis = 12km ; Phys Opt = 8 ; PBL Opt = 11 ; Cu Opt = 16

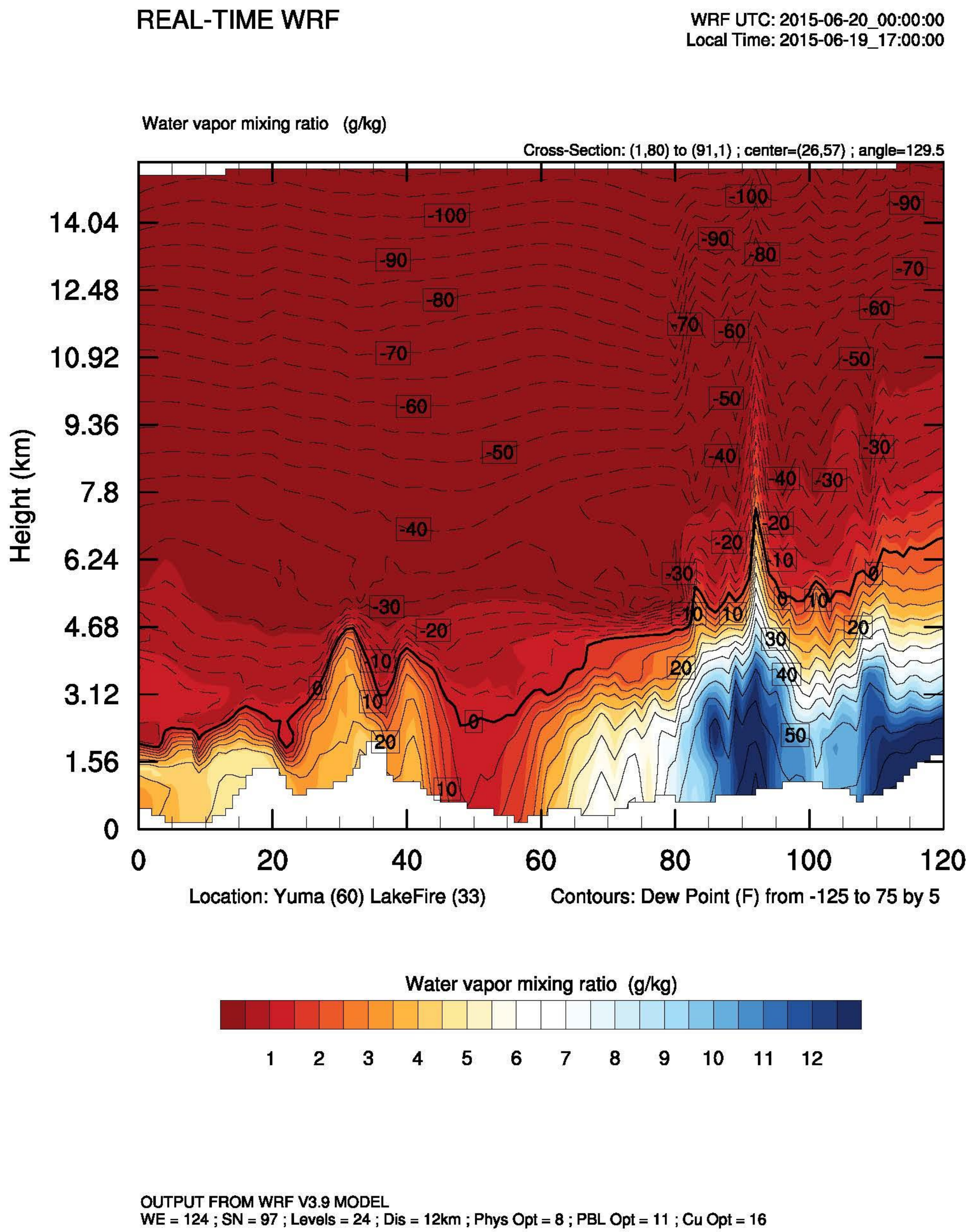

REAL-TIME WRF
WRF UTC: 2015-06-19_19:00:00
Local Time: 2015-06-19_12:00:00
Water vapor mixing ratio (g/kg)
Cross-Section: (1,80) to (91,1) ; center=(26,57) ; angle=129.5
Height (km)
14.04
12.48
10.92
9.36
7.8
6.24
4.68
3.12
1.56
0
0
20
40
60
80
100
120
Location: Yuma (60) LakeFire (33)
Contours: Dew Point (F) from -125 to 75 by 5
Water vapor mixing ratio (g/kg)
1 2 3 4 5 6 7 8 9 10 11 12
OUTPUT FROM WRF V3.9 MODEL
WE = 124 ; SN = 97 ; Levels = 24 ; Dis = 12km ; Phys Opt = 8 ; PBL Opt = 11 ; Cu Opt = 16

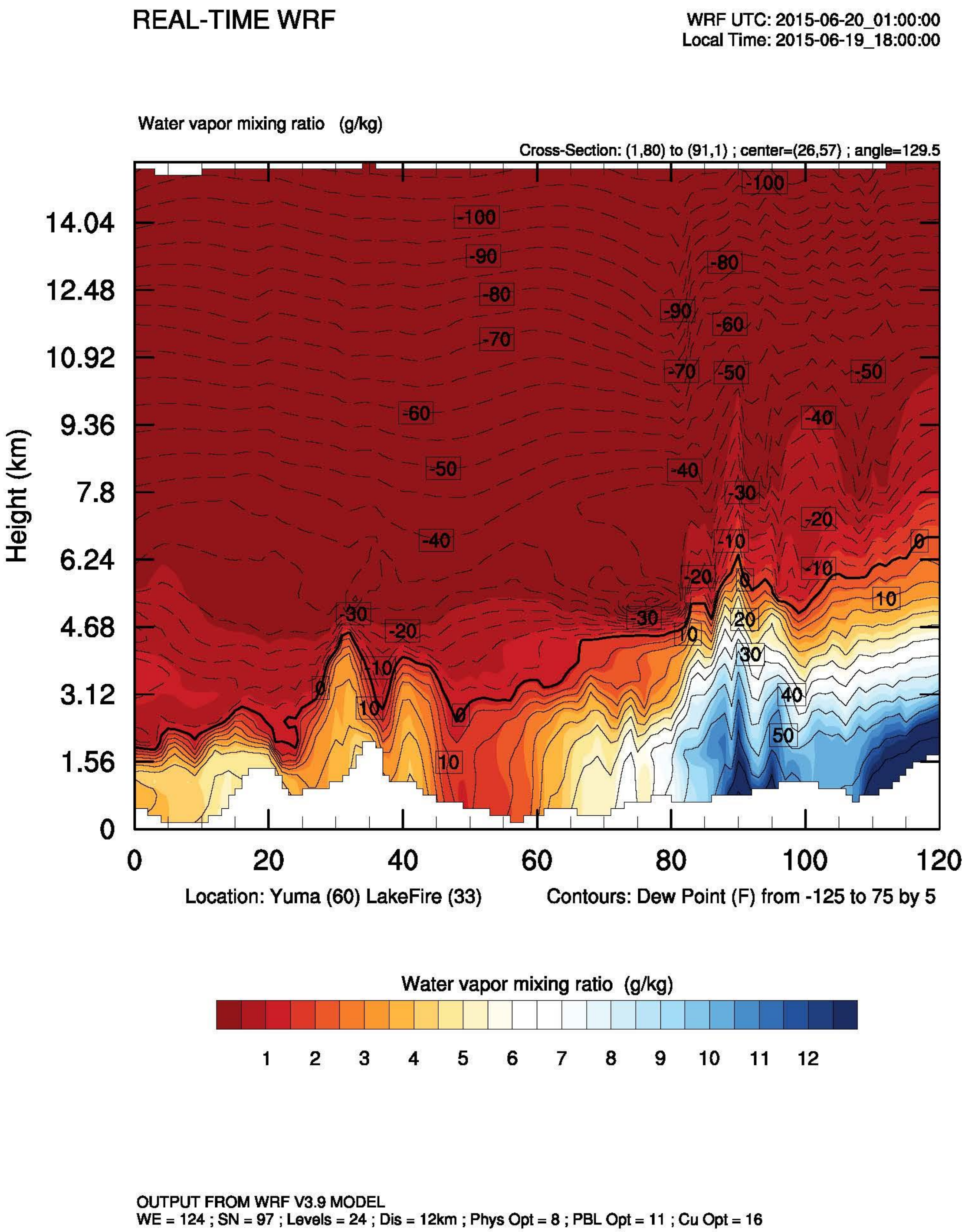

REAL-TIME WRF
WRF UTC: 2015-06-19_20:00:00
Local Time: 2015-06-19_13:00:00
Water vapor mixing ratio (g/kg)
Cross-Section: (1,80) to (91,1) ; center=(26,57) ; angle=129.5
Height (km)
14.04
12.48
10.92
9.36
7.8
6.24
4.68
3.12
1.56
0
0 20 40 60 80 100 120
Location: Yuma (60) LakeFire (33)
Contours: Dew Point (F) from -125 to 75 by 5
Water vapor mixing ratio (g/kg)
1 2 3 4 5 6 7 8 9 10 11 12
OUTPUT FROM WRF V3.9 MODEL
WE = 124 ; SN = 97 ; Levels = 24 ; Dis = 12km ; Phys Opt = 8 ; PBL Opt = 11 ; Cu Opt = 16

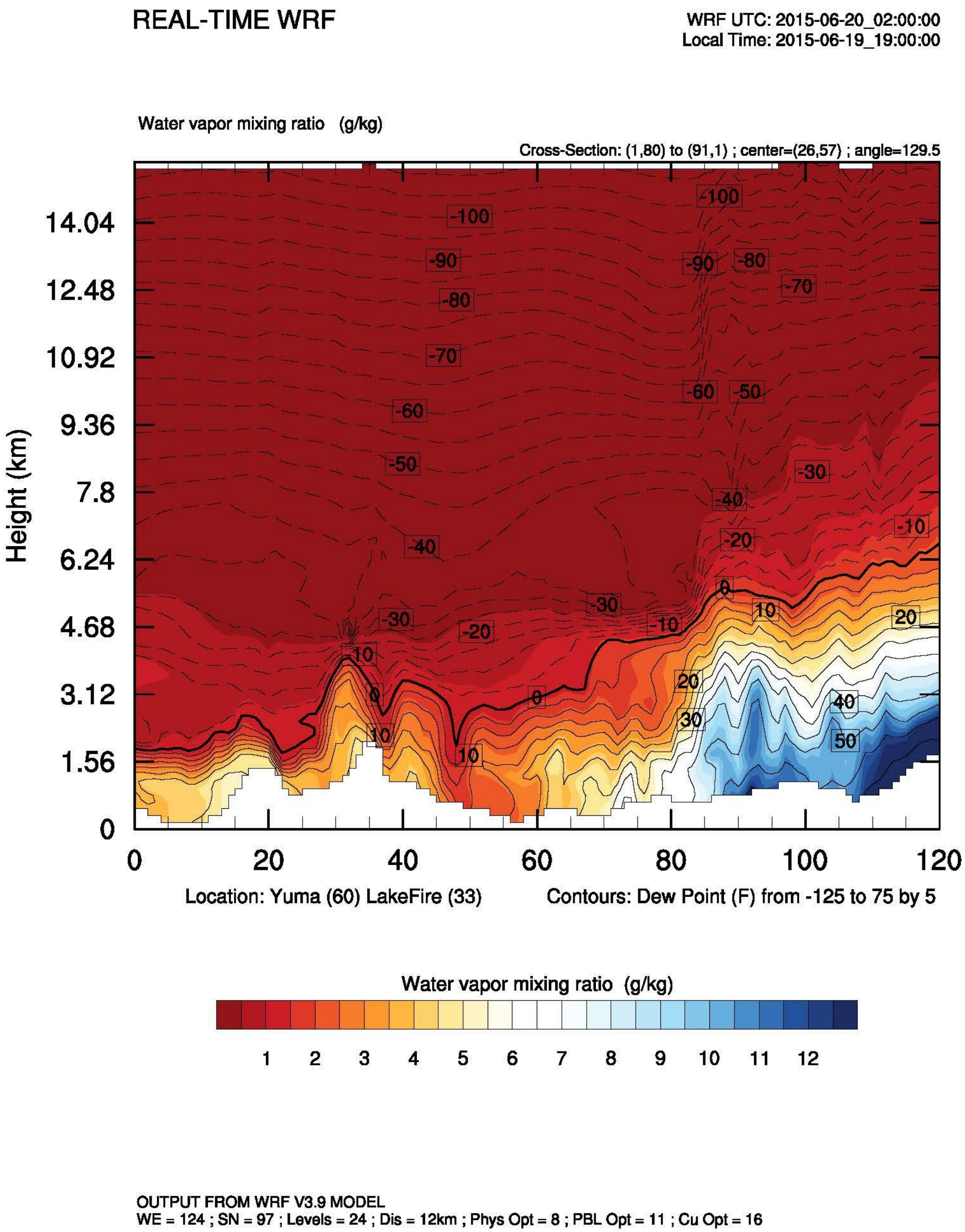

REAL-TIME WRF
WRF UTC: 2015-06-19_21:00:00
Local Time: 2015-06-19_14:00:00
Water vapor mixing ratio (g/kg)
Cross-Section: (1,80) to (91,1) ; center=(26,57) ; angle=129.5
Height (km)
14.04
12.48
10.92
9.36
7.8
6.24
4.68
3.12
1.56
0
0
20
40
60
80
100
120
Location: Yuma (60) LakeFire (33)
Contours: Dew Point (F) from -125 to 75 by 5
Water vapor mixing ratio (g/kg)
1 2 3 4 5 6 7 8 9 10 11 12
OUTPUT FROM WRF V3.9 MODEL
WE = 124 ; SN = 97 ; Levels = 24 ; Dis = 12km ; Phys Opt = 8 ; PBL Opt = 11 ; Cu Opt = 16

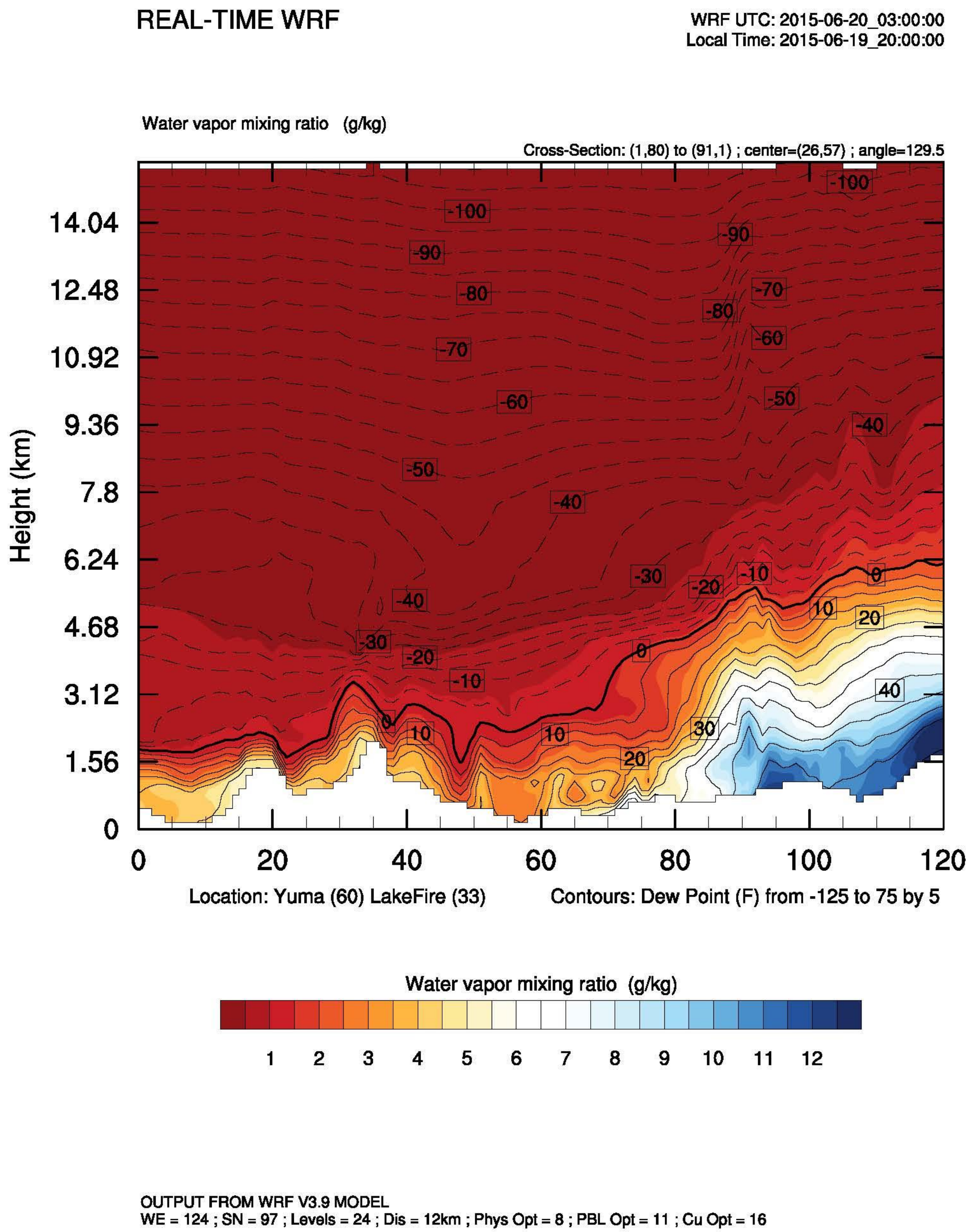

REAL-TIME WRF
WRF UTC: 2015-06-19_22:00:00
Local Time: 2015-06-19_15:00:00
Water vapor mixing ratio (g/kg)
Cross-Section: (1,80) to (91,1) ; center=(26,57) ; angle=129.5
Height (km)
Location: Yuma (60) LakeFire (33)
Contours: Dew Point (F) from -125 to 75 by 5
Water vapor mixing ratio (g/kg)
OUTPUT FROM WRF V3.9 MODEL
WE = 124 ; SN = 97 ; Levels = 24 ; Dis = 12km ; Phys Opt = 8 ; PBL Opt = 11 ; Cu Opt = 16


REAL-TIME WRF
WRF UTC: 2015-06-19_23:00:00
Local Time: 2015-06-19_16:00:00
Water vapor mixing ratio (g/kg)
Cross-Section: (1,80) to (91,1) ; center=(26,57) ; angle=129.5
Height (km)
14.04
12.48
10.92
9.36
7.8
6.24
4.68
3.12
1.56
0
0
20
40
60
80
100
120
Location: Yuma (60) LakeFire (33)
Contours: Dew Point (F) from -125 to 75 by 5
Water vapor mixing ratio (g/kg)
1
2
3
4
5
6
7
8
9
10
11
12
OUTPUT FROM WRF V3.9 MODEL
WE = 124 ; SN = 97 ; Levels = 24 ; Dis = 12km ; Phys Opt = 8 ; PBL Opt = 11 ; Cu Opt = 16


REAL-TIME WRF
WRF UTC: 2015-06-20_00:00:00
Local Time: 2015-06-19_17:00:00
Water vapor mixing ratio (g/kg)
Cross-Section: (1,80) to (91,1) ; center=(26,57) ; angle=129.5
Height (km)
14.04
12.48
10.92
9.36
7.8
6.24
4.68
3.12
1.56
0
20
40
60
80
100
120
Location: Yuma (60) LakeFire (33)
Contours: Dew Point (F) from -125 to 75 by 5
Water vapor mixing ratio (g/kg)
1
2
3
4
5
6
7
8
9
10
11
12
OUTPUT FROM WRF V3.9 MODEL
WE = 124 ; SN = 97 ; Levels = 24 ; Dis = 12km ; Phys Opt = 8 ; PBL Opt = 11 ; Cu Opt = 16


REAL-TIME WRF
WRF UTC: 2015-06-20_01:00:00
Local Time: 2015-06-19_18:00:00
Water vapor mixing ratio (g/kg)
Cross-Section: (1,80) to (91,1) ; center=(26,57) ; angle=129.5
Height (km)
14.04
12.48
10.92
9.36
7.8
6.24
4.68
3.12
1.56
0
0
20
40
60
80
100
120
Location: Yuma (60) LakeFire (33)
Contours: Dew Point (F) from -125 to 75 by 5
Water vapor mixing ratio (g/kg)
1
2
3
4
5
6
7
8
9
10
11
12
OUTPUT FROM WRF V3.9 MODEL
WE = 124 ; SN = 97 ; Levels = 24 ; Dis = 12km ; Phys Opt = 8 ; PBL Opt = 11 ; Cu Opt = 16


REAL-TIME WRF
WRF UTC: 2015-06-20_02:00:00
Local Time: 2015-06-19_19:00:00
Water vapor mixing ratio (g/kg)
Cross-Section: (1,80) to (91,1) ; center=(26,57) ; angle=129.5
Height (km)
14.04
12.48
10.92
9.36
7.8
6.24
4.68
3.12
1.56
0
0
20
40
60
80
100
120
Location: Yuma (60) LakeFire (33)
Contours: Dew Point (F) from -125 to 75 by 5
Water vapor mixing ratio (g/kg)
1
2
3
4
5
6
7
8
9
10
11
12
OUTPUT FROM WRF V3.9 MODEL
WE = 124 ; SN = 97 ; Levels = 24 ; Dis = 12km ; Phys Opt = 8 ; PBL Opt = 11 ; Cu Opt = 16


REAL-TIME WRF
WRF UTC: 2015-06-20_03:00:00
Local Time: 2015-06-19_20:00:00
Water vapor mixing ratio (g/kg)
Cross-Section: (1,80) to (91,1) ; center=(26,57) ; angle=129.5
Height (km)
14.04
12.48
10.92
9.36
7.8
6.24
4.68
3.12
1.56
0
0 20 40 60 80 100 120
Location: Yuma (60) LakeFire (33)
Contours: Dew Point (F) from -125 to 75 by 5
Water vapor mixing ratio (g/kg)
1 2 3 4 5 6 7 8 9 10 11 12
OUTPUT FROM WRF V3.9 MODEL
WE = 124 ; SN = 97 ; Levels = 24 ; Dis = 12km ; Phys Opt = 8 ; PBL Opt = 11 ; Cu Opt = 16

# APPENDIX C

# PUBLIC COMMENT PERIOD

# THE ARIZONA REPUBLIC

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**STATE OF WISCONSIN**
**COUNTY OF BROWN** } SS.

I, being first duly sworn, upon oath deposes and says: That I am the legal clerk of the Arizona Republic, a newspaper of general circulation in the counties of Maricopa, Coconino, Pima and Pinal, in the State of Arizona, published weekly at Phoenix, Arizona, and that the copy hereto attached is a true copy of the advertisement published in the said paper on the dates indicated.

Sworn to before me this
25 TH day of
MARCH 2019

VICKY FELTY
NOTARY PUBLIC
STATE OF WISCONSIN

Notary Public

My Commission expires: 9-19-21

**Request for Public Comments on Addendum to an Exceptional Event in the Maricopa County (Greater Phoenix) O3 Nonattainment Area**

In 2005, Congress identified a need to account for events that result in exceedances of the National Ambient Air Quality Standards (NAAQS) that are exceptional in nature (e.g., not expected to reoccur or caused by acts of nature beyond man-made controls.) In response, EPA promulgated the Exceptional Events Rule (EER) to address exceptional events in 40 CFR Parts 50 and 51 on March 22, 2007 (72 FR 13560). On November 20, 2015, EPA released guidance on the preparation of exceptional events demonstrations for wildfire events that may influence ozone concentrations to State, tribal and local air agencies for review. The EER allows for states and tribes to "flag" air quality monitoring data as an exceptional event. If flagged, these data can be excluded from consideration in air quality planning if EPA concurs with the demonstration submitted by the flagging agency documenting that all procedural and technical requirements have been met.

Pursuant to 40 CFR 50.14(c)(3)(i), the Arizona Department of Environmental Quality (ADEQ) is soliciting comments on its second addendum to a previously submitted demonstration for an event that caused elevated concentrations of Ozone (O3) in the Maricopa County (Greater Phoenix) O3 Nonattainment area on June 20, 2015. ADEQ has decided to flag exceedance concentrations based on these analyses. A copy of this addendum is available for review beginning Monday, March 25, 2019, on the ADEQ website at http://azdeq.gov/PN/o3_NAA. Interested parties can submit written comments throughout the comment period which will end at 5:00 p.m. on Wednesday, April 24, 2019. Any comments received will be responded to and forwarded to EPA with the final demonstration.

Written comments should be addressed or E-mailed to:

Air Assessment Section, Arizona Department of Environmental Quality, 1110 W. Washington Street, Phoenix, AZ 85007, E-mail: exceptionalevents@azdeq.gov.

In addition to being available on-line, a copy of the analysis is available for review, Monday through Friday, 8:30 a.m. to 4:30 p.m., at the ADEQ Records Management Center 1110 W. Washington St., Phoenix, AZ, 85007, Attn: Records Center (602) 771-4380 ...

ADEQ
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Center, (602) 771-4380, E-mail: recordscenter@azdeq.gov.

To request an auxiliary aid or service for accessible communication, please contact (602) 771- 2215 or at ej2@azdeq.gov or dial 7-1-1 for TTY/TTD Services.

Pub: Mar 25, 2019