Cracking the AQ Code

ADEQ Arizona Department of Environmental Quality
Air Quality Forecast Team

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Dust in Arizona and around the World

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Arizona is a unique state. With all of its deserts, mountains, forests, canyons, spectacular sunrises and sunsets, and climate, it's no wonder that Arizona is a popular place to live in or travel to. On the same token however, Arizona is susceptible to adverse air quality. This is where the ADEQ Forecast Team steps in. As a team of air quality meteorologists, we predict air pollution levels around the state based on the weather. This includes course particulate matter (dust), fine particulate matter (soot, smoke), and ozone. Overall, it is our goal to inform the public of any potential air quality concerns so they can make better decisions for the protection of their health and/or the environment. Since dust is relevant during the monsoon season, it is the focus of this issue of *Cracking the AQ Code*.

The Origin of Dust

Earth has a wide variety of climates. In fact, every continent has its own collection of different climates (see Figure 1). One climate that most continents share is the arid climate, commonly associated with deserts. Some arid climates are hot and others are cold. Some are on the interior of continents and others are coastal. However, all arid climates have one thing in common: they are characterized by a water deficit. In other words, more water is removed (e.g. evaporation, transpiration by plants) from arid climates than put into them (e.g. precipitation). This ultimately results in arid environments being very dry.

Because of their intrinsic dryness, arid climates undergo large temperature changes between day and night as well as throughout the year. This, in combination with winds, occasional heavy precipitation, and other meteorological and geological factors, erodes desert mountains and rocks over time and ultimately leads to the formation of fine-grained soils or sand, depending on the

About "Cracking the AQ Code"

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In an effort to further ADEQ's mission of protecting and enhancing the public health and environment, the Forecast Team has decided to produce periodic, in-depth articles about various topics related to weather and air quality.

Our hope is that these articles provide you with a better understanding of Arizona's air quality and environment. Together we can strive for a healthier future.

We hope you find them useful!

Upcoming Topics…

- Tropical Storms
- Arizona Tornadoes
- Prescribed Burns

composition of the rocks. Given strong enough winds, dust can then result from loose, fine-grained soils or sand becoming airborne.

In this issue of *Cracking the AQ Code*, we will explore and examine the dust of four arid regions around the world: Arizona, Australia, the Middle East, and Africa. First, we'll cover some basics about dust and why it is of interest. Then, we'll dive into each of these regions.

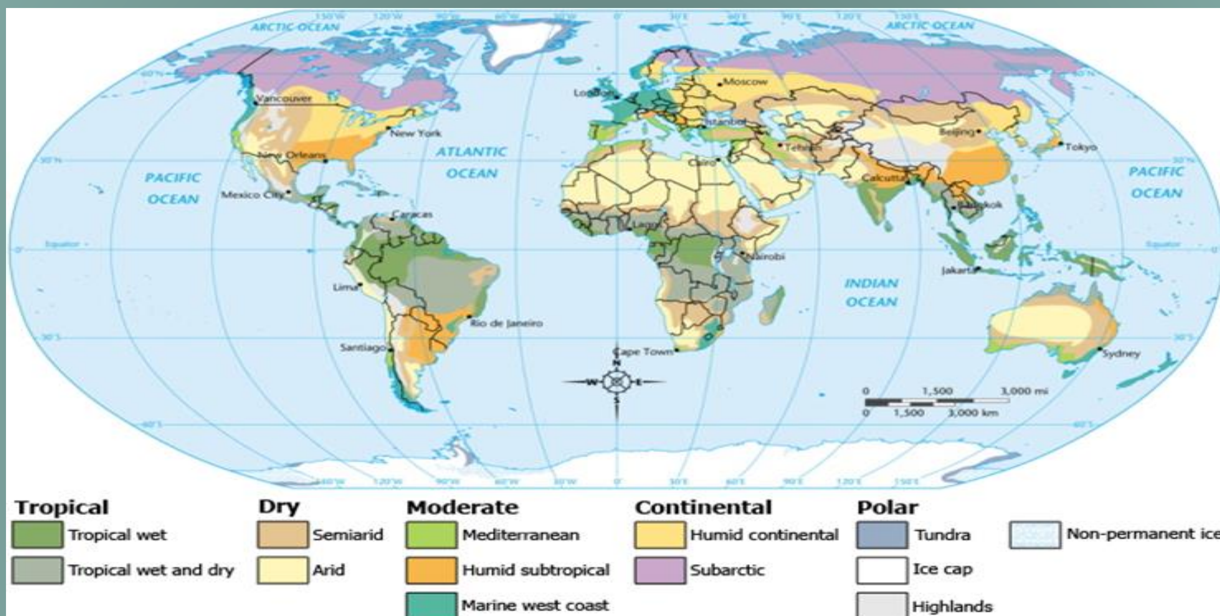

Figure 1: A map showing the basic climate classifications around the world. Deserts make up about one third of the earth's total landmass.

Source: Wikimedia Commons, user: Leqoktm (CC BY-SA 3.0)

Dust Basics

Atmospheric dust (not the dust collecting on your wood furniture at home) is ultimately the result of wind on loose, fine-grained soils or sand (see Figure 2). When wind blows over such soil, if it is strong enough, it can lift particles from the soil and suspend them in the air (suspension). Heavier particles will be lifted and fall back down to the ground. When these particles hit the ground, they force other particles to jump into the air. This ultimately leads to a chain reaction of jumping particles in the direction of the wind (saltation). Lastly, heavier particles that can't be lifted or suspended in the air will "creep" along the surface as they are blown by the wind or impacted by falling particles.

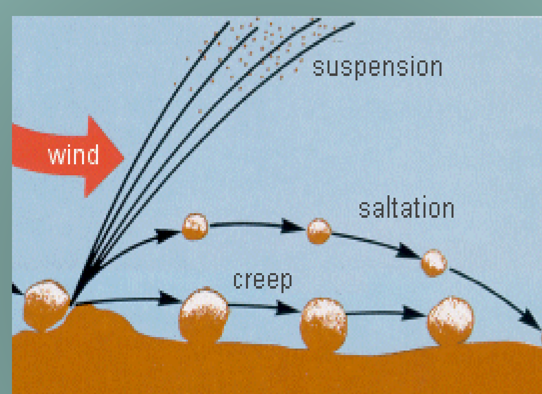

Figure 2: The basic processes of how soil particles are transported by the wind can create dust. The word "saltation" comes from the Latin word "saltus", which means "to leap".

There are various manifestations of atmospheric dust in arid environments. One of the most common is pockets of blowing dust, which result from locally gusty winds. These winds could be due to a nearby thunderstorm, or they could be associated with more regional-scale weather phenomena like cold fronts or strong pressure gradients. The pinnacle of blowing dust is the dust storm, a massive wall of dust initiated by strong winds transporting dust across large distances. Less severe and usually harmless is the common dust devil, a whirlwind made visible by the dust it picks up.

Dust Impacts

Unfortunately, even though a dust storm might be visually stunning, dust is more of a nuisance to society than something to admire. For one, visibility can be severely reduced, which negatively impacts drivers. Research shows that between 2001 and 2005, there were 614 traffic accidents in Arizona due to dust storms, and 15 were fatal.

Dust can also adversely affect people's health. Dust consists of particulate matter less than or equal to 10 micrometers (PM_{10}), which is small enough to penetrate into the lungs and damage lung tissue. Increased hospital visits, worsened heart and lung diseases, and premature death are all associated with exposure to PM_{10}. People most at risk for health problems associated with dust are those with respiratory illnesses (asthma, chronic lung disease, etc.), as well as the elderly and children.

Regardless of which continent you live on or in which arid environment you dwell in, dust will have the same basic impacts on visibility and human health. However, the scale of the impacts will differ, based on the size of the dust sources, the dominating weather patterns, the regional topography, the local agricultural activity, and the population distribution and density. Without further ado, let's travel the world and see how other people's lives are influenced by atmospheric dust. We'll begin our journey here in Arizona and then work our way around the globe.

Do you know what to do if you're suddenly caught driving in a dust storm?

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Arizona

Just as we will see with other parts of the world, desert regions of Arizona have their fair share of dust issues. We are in the arid Sonoran Desert after all. However, if many of our cities, from Yuma to Winslow to Tucson, are surrounded by seemingly endless tracts of desert, then why are we not constantly inundated with high levels of PM_{10} on a daily basis?

As is often the case with air quality, it once again comes down to both past and current weather. Under extended periods of dry conditions (when soil moisture need to stabilize surface dust gets depleted) there are three weather phenomena that the ADEQ Forecast Team searches for: 1) cold fronts, 2) thunderstorms, and 3) stagnation. All three have been responsible for PM_{10} exceedances of EPA's National Ambient Air Quality Standards (NAAQS) within our state.

Cold Frontal Passages

Arizona encounters cold frontal passages typically between October and May. Cold fronts follow the jet stream, which dictates the storm track through the United States. If the jet stream drops far enough south in latitude then low-pressure troughs and their surface cold fronts can march into the Desert Southwest. This is a problem for air quality at times. Generally, breezy winds would be considered ideal for pollutant dispersion, but there is a certain point when gusty winds become too much and can loft excessive amounts of dust into the air.

In a worst case scenario, a cold front without precipitation brings long duration (12-36 hours) gusty winds in excess of 25 mph over parched deserts. This usually points to an imminent and widespread blowing dust event here in Arizona, not only from local dust sources, but also through long-range transport of particulates from as far away as central California. An example of this is shown in Figure 3. Active dust events typically last no more than a day or two; however, a haze can linger in the wake of a passing cold

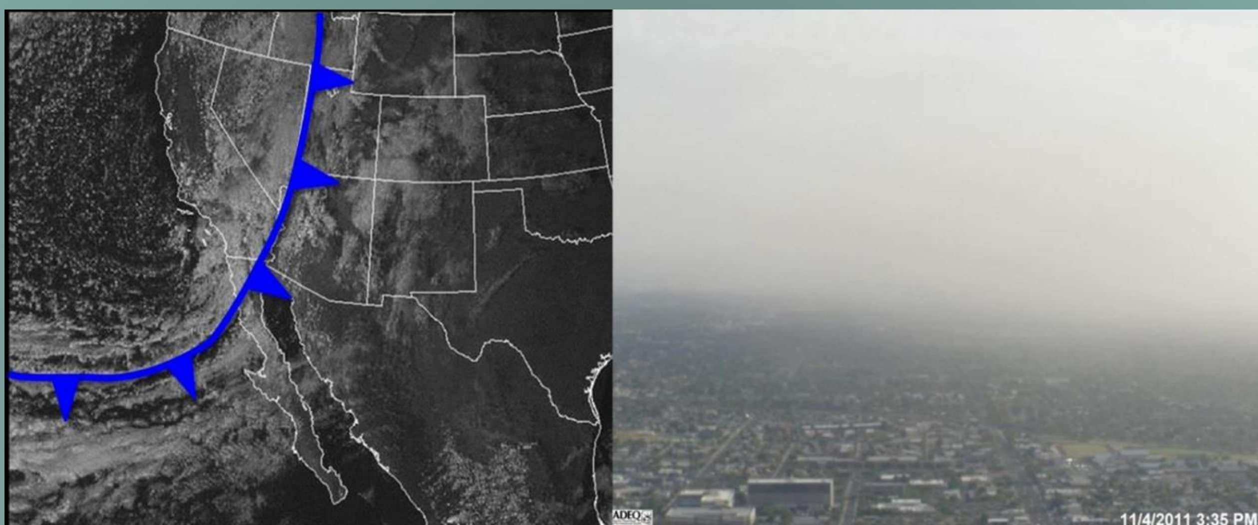

Figure 3: GOES visible satellite image (left) of low-pressure trough and associated cold front (blue line) that brought widespread gusty winds over 35 mph and blowing dust to the Desert Southwest on November 4, 2011. ADEQ camera image captures the suspended dust blanketing Metro Phoenix (right) during the afternoon hours. Numerous PM_{10} monitors throughout the Valley exceeded EPA's National Ambient Air Quality Standard (NAAQS) that day.

Source: NOAA. Image from ADEQ camera monitoring network

front before suspended dust gradually settles with calmer winds. During a high wind blowing dust episode, it's a good idea to avoid or limit long-term outdoor activity to reduce breathing in particulates.

Thunderstorms

Dust storms arise because of collapsing thunderstorms sending gusty downdraft winds toward and across the surface. Wind speeds can easily exceed 50 mph under favorable atmospheric conditions. The result is

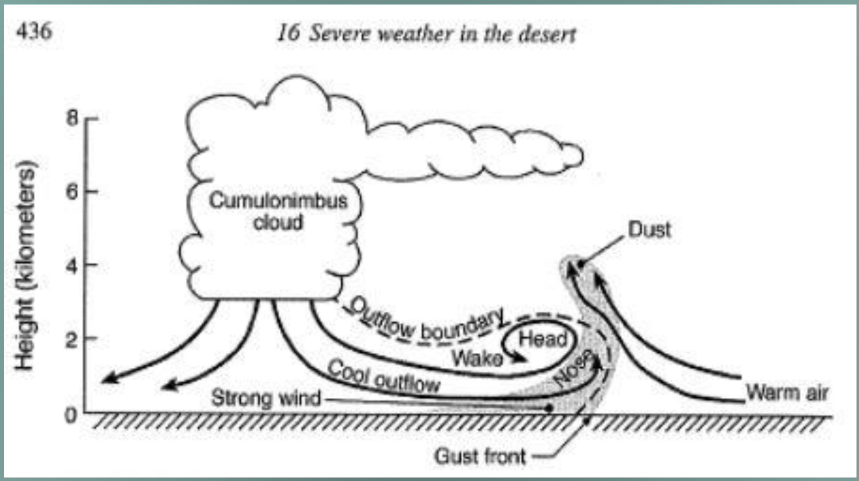

Figure *4*: A cross-section of thunderstorm creating an outflow boundary that could result in dust storm formation.

Source: Desert Meteorology. Thomas T. Warner. 2004)

rapidly expanding outflow boundaries (think of dropping a rock in a pond). Essentially, these can be thought of as mini cold fronts. A diagram of a thunderstorm outflow is shown in Figure 4.

The air quality effects with dust storms from thunderstorm outflows don't last nearly as long as traditional cold fronts that span hundreds of miles and take days to move through a region. The trouble is how extreme short-term PM_{10} concentrations can be with dust-laden outflows. Often, PM_{10} surges over thousands of µg/m^3 (micrograms per cubic meter) in the heart of a dust storm, as was the case in the Phoenix area on June 27, 2012 (Figure 5). Keep in mind that the day's 24-hour PM_{10} average needs to be kept at or below 150 µg/m^3 to avoid a NAAQS exceedance! It only takes a few hours of very high particulate levels to cause an exceedance of the 24-hour PM_{10} NAAQS. Because of the quick nature of dust storms, it's best to seek shelter and wait it out. For Arizona, even though thunderstorms and blowing dust could occur any time of the year, the threat is certainly heightened during our summer monsoon season. It can be quite difficult to forecast for dust storm strength, intensity, and location in terms of particulate concentration during the monsoon because of the spotty nature of thunderstorms and rainfall in the lower deserts. Every summer, there becomes an evolving patchwork of saturated versus parched soils. This is why the most severe dust storms tend to develop early in the monsoon season before rains are widespread enough to limit an outflow's ability to kick up dust. Click the following links to previous issues of Cracking the AQ Code for more details about what defines our monsoon, how a thunderstorm forms, or read a case study when a dust storm caused a PM_{10} exceedance in Metro Phoenix.

Figure 5: Dust storm impacting Metro Phoenix on June 27, 2012.

Image from ADEQ camera monitoring network

Stagnation

We don't necessarily need wind for PM_{10} air quality events to unfold. In fact, the lack of wind can be very problematic, too. Anywhere there are continuous dust generating activities, a threat for stagnation exceedances exist. Stagnation is actually quite common on a daily basis. We usually experience it during the overnight and early morning hours when radiation inversions form. Winds are either light or calm within these inversions, meaning whatever dust is produced locally, stays locally.

By daybreak, thermals from surface heating begin to mix the lower atmosphere, helping to disperse trapped pollutants. This is why our air quality monitors typically register higher particulate values in the morning and reduced concentrations in the afternoon. If your health is sensitive to particulates, you might want to consider shifting morning activity and/or exercise routines to later in the day instead.

Air quality concerns do come to the forefront if inversions are strong and long in duration, which are common during the winter months. Despite sunshine, a low sun angle may not generate enough heat to break a surface inversion (Figure 6). Consecutive days of inversions allows particulates to gradually accumulate. The rate of concentration increase becomes heavily dependent on daily industrial and public pollutant contribution. However, the presence of a low pressure system, cold front, or precipitation can eliminate an inversion, day or night. Consequently, we benefit from rapid improvements to our air quality.

There is summer stagnation as well. Surface heating wouldn't be lacking, yet pollutants can still become trapped by what is called a subsidence inversion layer. These inversions form under high-pressure systems and are the result of sinking air warming upon descending. Stronger high-pressure systems force subsidence inversions toward lower altitudes, which makes them that much more effective at containing dust toward the surface. Pair containment with light winds long enough and PM_{10} concentrations are bound to spike.

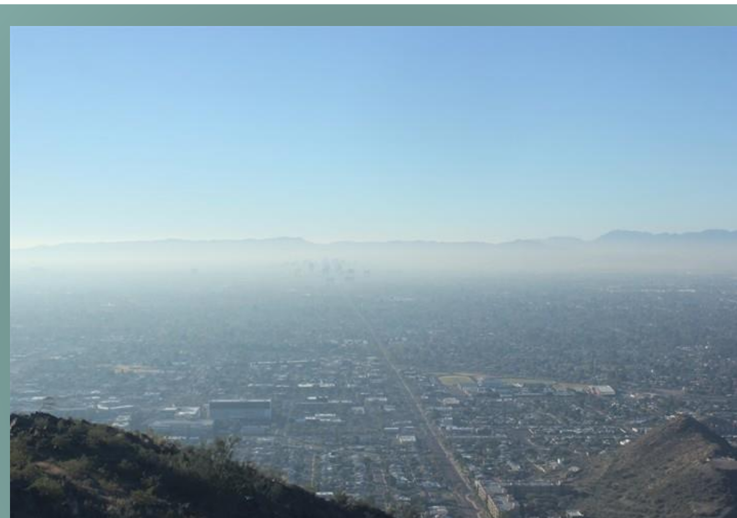

Figure 6: Inversion trapping pollutants, including particulates, close to the surface.

Image from ADEQ camera monitoring network

Australia

Our next stop around the world takes us to Australia. The second driest continent only to Antarctica, Australia is roughly 70% desert, so it's no wonder major dust storms occur there. Take away the health risks, the reduced visibility, and all the dangers of dust storms and it's amazing how spectacular they can be (see Figure 7). Australian dust storms can be especially stunning due to the reddish nature of some of the dust source regions. Unfortunately, we can't simply ignore the dangers, and Australia has seen their fair share of threatening conditions due to dust storms.

Ask anyone living in eastern Australia, “what dust storm sticks out to you the most?”, and if they’ve lived there a while, chances are they would say the September 2009 event. This dust storm was a monster! The dust originated from south-central Australia and ended up engulfing most of the eastern half of Australia (Figure 8).

Dust was even reported to have reached as far east as New Zealand. At the Bringelly monitor, west of Sydney, an hourly concentration of PM_{10} reached a staggering 15,366 $\mu g/m^3$. At the Wellsend monitor, north of Sydney, the 24-hr average PM_{10} concentration reached 2,150 $\mu g/m^3$. This is an incredible amount, especially given that exceeding the National Ambient Air Quality Standards (NAAQS) here in the U.S. only requires a 24-hr average above 150 $\mu g/m^3$.

So what caused the dust storm? Just like many of the dust events here in Arizona, it was a cold frontal system. On the morning of September 22, 2009, a cold front pushed through south-central Australia. The strong winds associated with the frontal system began to suspend dust as it passed over the dry desert regions. The next day, the front made it to the east coast (Figure 9) accompanied by a massive dust storm. Weather observations at the

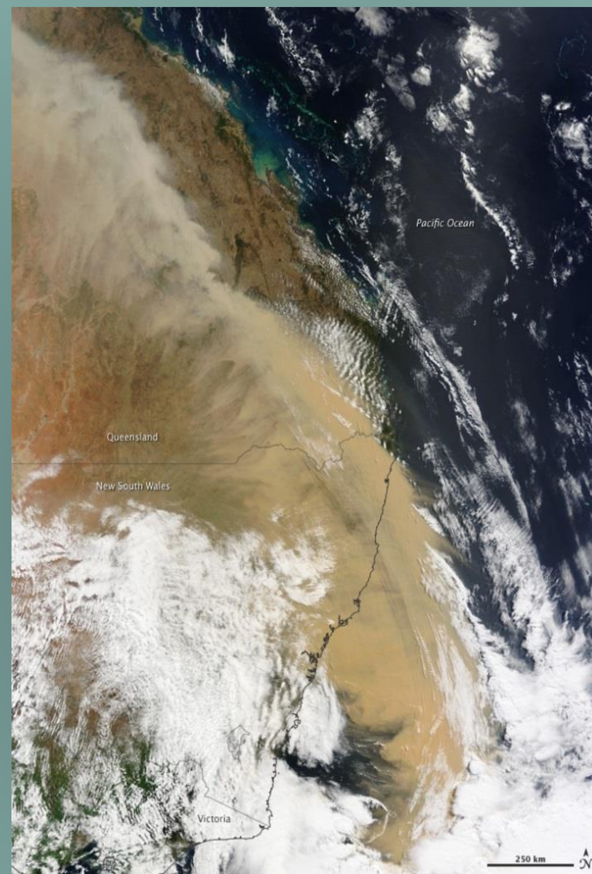

Figure 7: Satellite image of eastern Australia on September 23, 2009 during a major dust storm.

Source: NASA

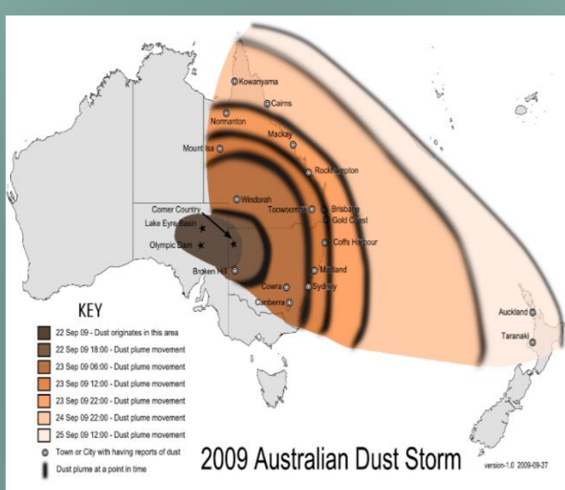

Figure 8: A graphic illustrating the extent of the dust storm from September 22, 2009 through September 25, 2009.

Source: Wikipedia user Advanstra

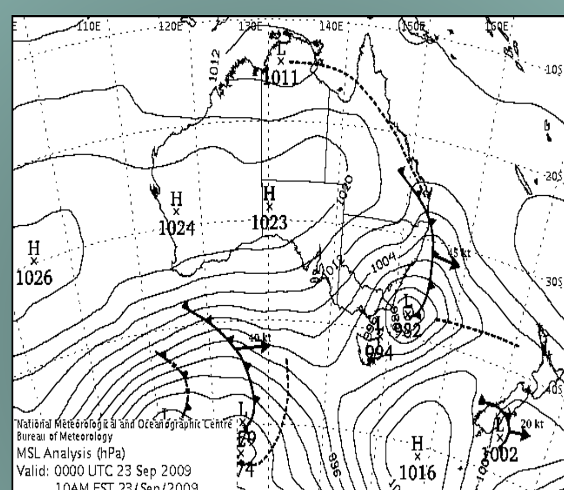

Figure 9: Surface weather chart depicting the cold front responsible for the dust storm over the east coast.

Source: Bureau of Meteorology Australia international airport in Sydney reported gusts over 50 mph and visibility down to nearly zero during the event.

Figure 10: Photo of the Sydney Opera House during the dust storm on September 23, 2009.

Source: REUTERS/Tim Wimborne

While the scene looked strangely ominous and spectacular at the same time (Figure 10), the potential health impacts were certainly serious. As we looked at earlier, the PM_{10} concentrations were dangerously high that day. Hospitals reported a large increase in asthma patients along with some increase in respiratory issues during the dust event (Merrifield et al.). Research by Merrifield et al. entitled, “Health effects of the September 2009 dust storm in Sydney, Australia: did emergency department visits and hospital admissions increase?” also concluded that, “…public health measures including specific warnings targeting asthmatics should be implemented during future dust storm events”. Bringing the discussion back to Arizona, informing the public of impending air quality events and actions to take for countering health effects is exactly what ADEQ’s Forecast Team aims to do. We provide forecasts, and when necessary, issue High Pollution Advisories (HPAs) and Health Watches (HWs) in order to inform the public so they can be proactive in protecting their health.

The Middle East

Now we head to the arid Middle East. The Middle East abounds with deserts, including the western-most portion of the Sahara Desert in northern Africa and several deserts throughout the Arabian Peninsula (see Figure 11). The Arabian Desert, which occupies most of the Arabian Peninsula, is the second largest, non-polar desert in the world. This desert is second only to the Sahara desert in northern Africa, with a surface area of 1 million square miles. It also contains the *Rub’ al Khali*, the largest sand desert in the world. The Syrian Desert, located in the northern portion of the peninsula, is the seventh largest, non-polar desert, lying at 190,000 square miles. For perspective, the Sonoran desert in North America covers 120,000 square miles in size.

Ultimately, it won’t take long to realize that this part of the world is rich with dust storm potential. In fact, the term “haboob” (Arabic for “to blow”) describes dust storms specifically in Sudan, but has since been used in reference to severe dust storms in Arizona, thanks to mainstream media. Compared to Arizonian dust storms, dust storms in the Middle East can get much, much larger. This is due to the Middle East itself being a much greater source of dust. The dust storm that occurred early September 2015 is a classic example of the scale of a Middle Eastern dust storm.

On the 6th of September 2015, a low pressure system over northern Iraq resulted in strong winds that were able to lift up dust and initiate a dust storm. The environment in Iraq was very hot (113°F) and dry (much like the lower deserts of Arizona in the summer), favorable for strong near-surface winds and thus, large dust storms. The bulk of the dust was then transported westward by the prevailing winds; dust even reached all the way to northern Egypt, 800 miles away (see Figure 12)!

Figure 11: Left: A map of the Middle East, with major deserts and the *Rub' al Khali* labeled. Other deserts in the Middle East that are not labeled include the Sinai Desert of the Sinai Peninsula and the Negev region of southern Israel. Top right: The Syrian Desert. Bottom right: Sand dunes in the *Rub' al Khali*, in the Arabian Desert.

Sources: Wikimedia Commons (Public Domain), Flickr, user: yeowatzup (CC-BY 2.0).

When all was said and done, the dust affected numerous countries in the region, with Syria, Lebanon, Jordan, and Israel receiving the brunt of it. Syrian military operations against terrorism were even stopped by the adverse weather conditions. Unfortunately, this dust storm proved to be an unprecedented event for

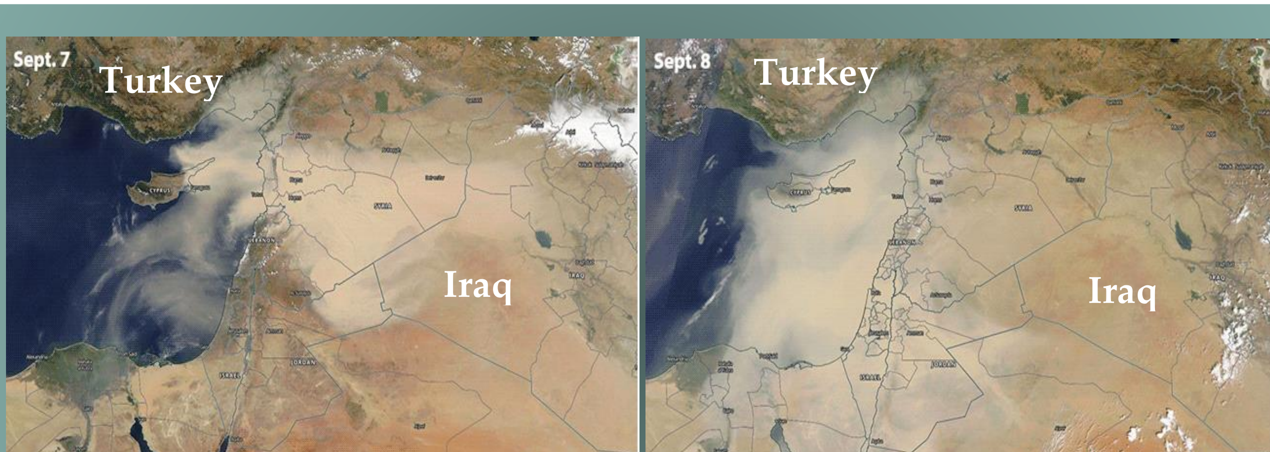

Figure 12: Satellite photos showing the overall westward expansion of the dust that was lifted by storms in northern Iraq, on September 7, 2015 (left) and on the 8th (right). Dust can be seen reaching Egypt on September 8th.

Source: NASA

these countries and resulted in thousands of people being hospitalized due to respiratory problems. Several deaths were also reported in Lebanon and Syria. The image in Figure 13 gives us a glimpse into what the dust storm looked like from the ground.

Although the Middle East is a large source of dust in and of itself, dust can also be transported into the Middle East. For example, mid-June this year, strong winds over the Sahara desert in Africa lifted dust high into the atmosphere and moved it all the way to Iraq. We experience dust transport here in Arizona too. Weather systems crossing the U.S. Southwest are capable of transporting dust from the southern California deserts to the lower deserts of Arizona. When this occurs, there is a noticeable haze present in the air, obscuring mountain vistas here in the Valley.

Figure 13: A view of the dust storm from the Homs countryside in Syria. The unusual amount of dust in the air severely reduced visibility at the ground and led to serious health implications.

Source: Qasioun News Agnecy EN

Africa

On our last stop, we explore the Sahara Desert (Figure 14), located in northern Africa. The Sahara Desert is the second largest desert in the world (about the size of the United States). However, it still retains the title as the largest hot desert in the world. While the Antarctic, the largest desert in the world, is cold and dry, the Sahara is subtropical, accompanied by hot temperatures and warm soils with very low precipitation. With an area of over 3.3 million square miles, it blankets almost all of the northern continent of Africa, stretching over 3,000 miles from the eastern Atlantic Ocean all the way to the Nile River and the Red Sea.

The Sahara is extremely dry, hot, and one of the most unforgiving regions in the world. Across the desert, the annual average rainfall is no more than a few inches, with much less in several locations. In fact, it's not uncommon for some parts of the Sahara to go without rain for several years! The reason for this desert's aridness is the prevailing winds, which blow from the northeast towards the equator throughout the year. As this air moves south, it warms and the moisture is dissipated, leaving behind just the hot, dry air. Because of this, temperatures can soar well above 120°F during the summer day. After the sun goes down, temperatures can fall nearly 40°F or more under clear skies. Once in a while during the winter, if temperatures reach freezing levels, snowfall can occur over some of the higher terrain in the Sahara. This vast range of climate makes the Sahara one of the more interesting places on the planet.

Due to a desert's natural tendency to be so dry most of the year, soils are usually primed and ready for dust activity. The key ingredient missing often times is wind. Occasionally, some breezy winds will loft a few patches of dust and sand over small distances. However, during times of weather activity, this effect can be magnified and give birth to a dust storm. The Arabic term for this is "haboob". During times of heavy wind activity, these strong, gusty winds, can kick up massive amounts of dust into the Saharan Air Layer (SAL), much like the same way we see dust storms in Phoenix. However, Saharan dust storms often dwarf those in Arizona and can easily be seen in satellite images (Figure 15).

The Saharan Air Layer is a layer of hot, dry air (usually less than 50% humidity), which exists over the Sahara Desert during the late spring, summer, and early fall. This moisture-starved air mass moves west towards the tropical North Atlantic Ocean every 3-5 days. The SAL is very dusty, composed of tiny aerosols such as dirt and sand that extend 5,000-20,000ft above sea level and is associated with strong winds (20-55 mph). On average, each year, hundreds of millions of tons of dust particles are blown across the Atlantic Ocean (Figure 16), which could lead to air quality or environmental issues around the world. It has been noted that the red sunset often seen in Miami, FL is due to reflection of sunlight by the dust particles present in the atmosphere from the Sahara Desert.

Figure 14: A satellite image of Europe, the Middle East, and Africa. The massive, un-vegetated area in northern Africa (denoted by the red circle) is the Sahara Desert.

Figure 15*:* An unmistakable view of dust being blown over the Atlantic Ocean via the Saharan Air Layer (SAL). Notice the vast distance covered by the SAL.

Source: ***NASA Soumi NPP***

Recent studies have also shown that the SAL can transport dust as far as the Amazon and the Caribbean, leading to fertilization of the soils in those regions. Furthermore, dust often provides the condensation nuclei for moisture droplets to wrap around, forming organized areas of clouds. Given enough moment, this collection of clouds often develop into Topical Storms and Atlantic Hurricanes. However, if the SAL is very active and prominent, then fewer tropical storms develop in the Atlantic due to the intrusion of dry hot air.

So, while not a lot of people might be affected by the Saharan dust locally due to the low number of people living in the region, it can have vast impacts for millions living thousands of miles away.

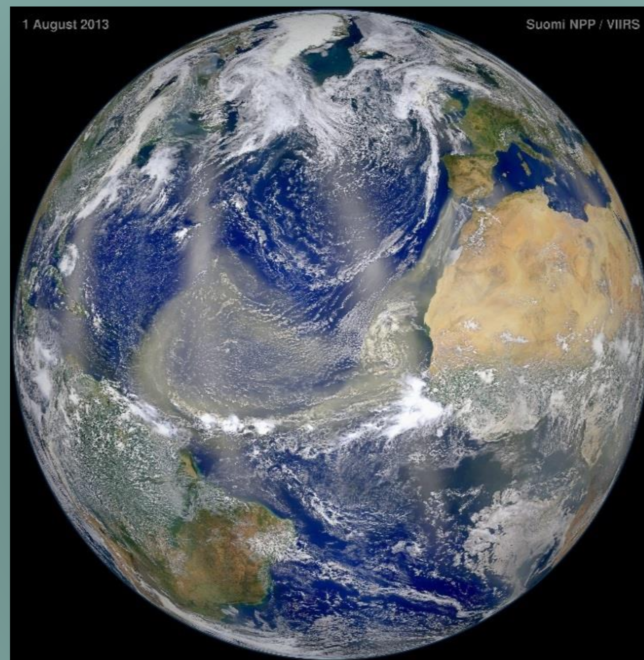

Figure 16*:* Another view of dust being transported over several thousand miles over the Atlantic from western Africa. This image was taken by the Suomi satellite operated by NASA.

Source: ***NASA Polar Orbiting Missions***

It all comes down to two things…

After our tour around the world, we have seen that atmospheric dust affects millions of people on multiple continents. It's quite amazing that the recipe for atmospheric dust is very simple: all you need is a source of dust and wind (or lack of wind). As we have seen, these two things typically come together in arid climates. As long as people live in arid climates, dust will continue to affect society, keeping the need for air quality forecasters.

We hope you have enjoyed this latest issue of *Cracking the AQ Code* on dust around the world!

For our next topic, the ADEQ Forecast Team will look at Tropical Storms.

Thanks for reading!

Sincerely,

The ADEQ Forecast Team

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If you haven't already, click HERE to start receiving your Daily Air Quality Forecasts (Phoenix, Yuma, Nogales)

In case you missed the previous Issues…

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Sept 2015: North American Monsoon
Oct 2015: The Genesis of a Thunderstorm: An Arizona Perspective
Dec 2015: Temperature Profiles, Inversions, and NO BURN DAYS
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Feb 2016: All About Fog
April 2016: Jet Streams and Fronts
May 2016: Consequences of the New Ozone Standard Change
June 2016: Tools of the Air Quality Forecasting Trade Part 2: Predicting and Tracking Wildfire Smoke

Here's a look at what we'll be discussing in the near future…

-Tropical Storms
-Arizona Tornadoes
-Prescribed Burns

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