Cracking the AQ Code

ADEQ Arizona Department of Environmental Quality
Air Quality Forecast Team

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All About Fog

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Do you remember the anticipation for the 2015 Super Bowl in Phoenix? Surely nothing would have put a damper on the big day. But then, Valley residents awoke to a dense blanket of fog in the morning. The heavy shroud caused dozens of flight cancellations and delays at Sky Harbor. Digital road signs on freeways advised motorists to drive with caution as well. Fortunately for Phoenix, fog is pretty rare. But, in other parts of Arizona, fog is more likely to be observed several times a year. In this topic, we will explore fog in Arizona and how it relates to air quality.

Figure 1. Fog filling up the Grand Canyon during a total cloud inversion.
Photo by: Erin Huggins (Grand Canyon National Park Service/flickr.com (license)).

Fog Formation

First of all, to understand fog in Arizona, we have to understand how fog forms. Fog is simply a cloud in contact with the ground. Just like other clouds, fog is made up of tiny water droplets that are suspended in the air.

About "Cracking the AQ Code"

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…

- The Jet Stream, Cold Fronts, etc.
- Air Quality Trends, Standards Changes, and Comparisons
- Wildfires

These water droplets form when water vapor (moisture in the air) condenses into liquid water. You might recall from science class that in order for condensation to occur, there needs to be cooling. Figure 2 illustrates this process.

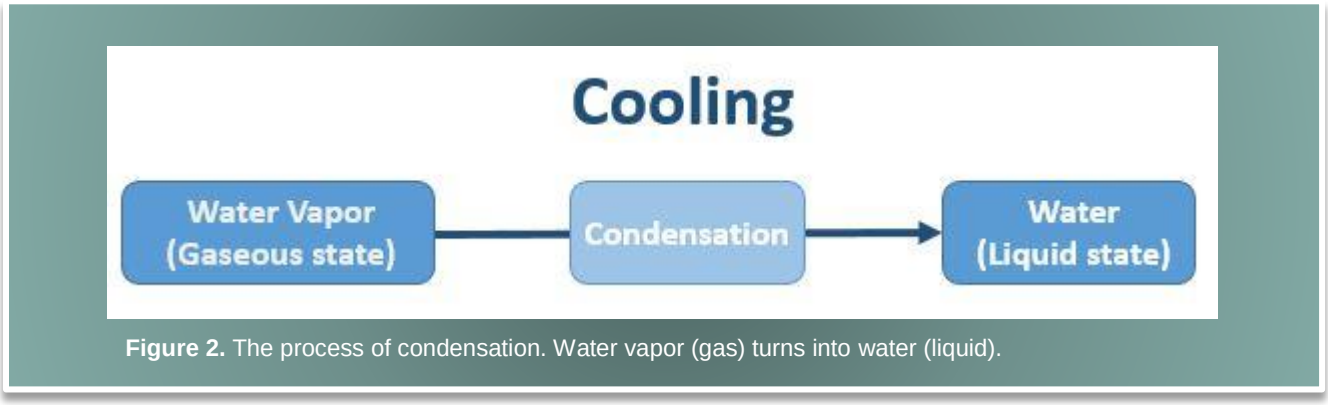
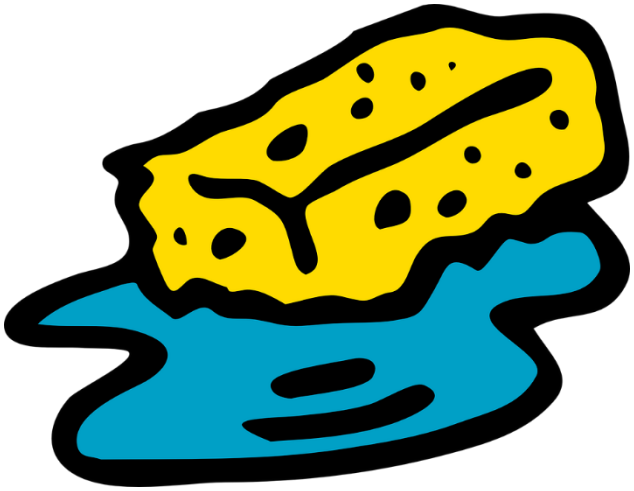


Figure 2. The process of condensation. Water vapor (gas) turns into water (liquid).

Condensation occurs when the temperature of the air cools enough to reach the point at which it can no longer hold any more water vapor. This threshold is known as the "dewpoint temperature." Think of the air as a sponge that is saturated and unable to take in any more water. When the air becomes saturated, a cloud forms.



Types of Fog

There are two ways to saturate the air: by adding moisture to the air or by cooling the air (or both). The way in which this is accomplished determines the type of fog. Two common types of fog that occur in Arizona are discussed below.

Radiation Fog

The most common type of fog is "radiation fog" (Figure 3). This type of fog forms overnight or in the early morning hours. At night, the ground radiates (gives off) heat and cools the surface. If there is enough moisture near the ground, fog forms once the air cools to its dewpoint. Radiation fog is then able to last throughout the night and into the morning hours because of the nocturnal inversion (see one of our previous "Cracking the AQ Code" topics for more information on inversions). The inversion acts as a lid, trapping the moist, cool air close to the earth's surface.

An impressive image slide show of the foggy Super Bowl Sunday 2015 can be found at AzCentral.com

Figure 3. Radiation fog engulfing downtown Phoenix the morning of March 3, 2015. ***Source: 12 News***.

Ideal weather conditions for radiation fog are a clear night with light winds. These conditions help to maximize the cooling at the ground and keep the fog in place. Light winds can actually help stir the fog layer and make it thicker. A moist ground is also favorable for fog formation. This moisture can come from vegetation releasing water vapor into the air, nearby bodies of water, or from a wet ground due to a recent rain. In Arizona, rainfall is often a key factor in allowing radiation fog to form during the winter. Figure 4 shows an example of this.

Figure 4. A visible satellite image showing a broad area of fog enveloping most of the Little Colorado River Valley and extending to the Mogollon Rim on December 10, 2014. This region experienced several days of continuous fog after a heavy rain event.

Source: National Oceanic and Atmospheric Administration (NOAA)

Precipitation Fog

This type of fog may form when heavy rain from a thunderstorm falls into drier air near the ground. As this occurs, the rain evaporates in the drier air, cooling the air and adding moisture to it. If enough rain is present, the air near the ground could cool enough to reach its dewpoint and become saturated, forming fog. Overall, since the rain drives the saturation of the air, it also drives the fog. Precipitation fog is thus very localized and brief, lasting until the rain ceases to keep the air saturated.

If you are interested in learning about other types of fog that may occur, click here.

Fog in Arizona

Arizona is unique…

Out of all the states in the United States, Arizona has the least amount of dense fog days per year. Most of Arizona averages less than 5.5 dense fog days per year; portions of north-central Arizona and the northeast corner of the state average slightly more (see Figure 5 below). This is due to Arizona's dry climate. Compared to the rest of the country, the conditions for fog formation do not occur very often in Arizona.

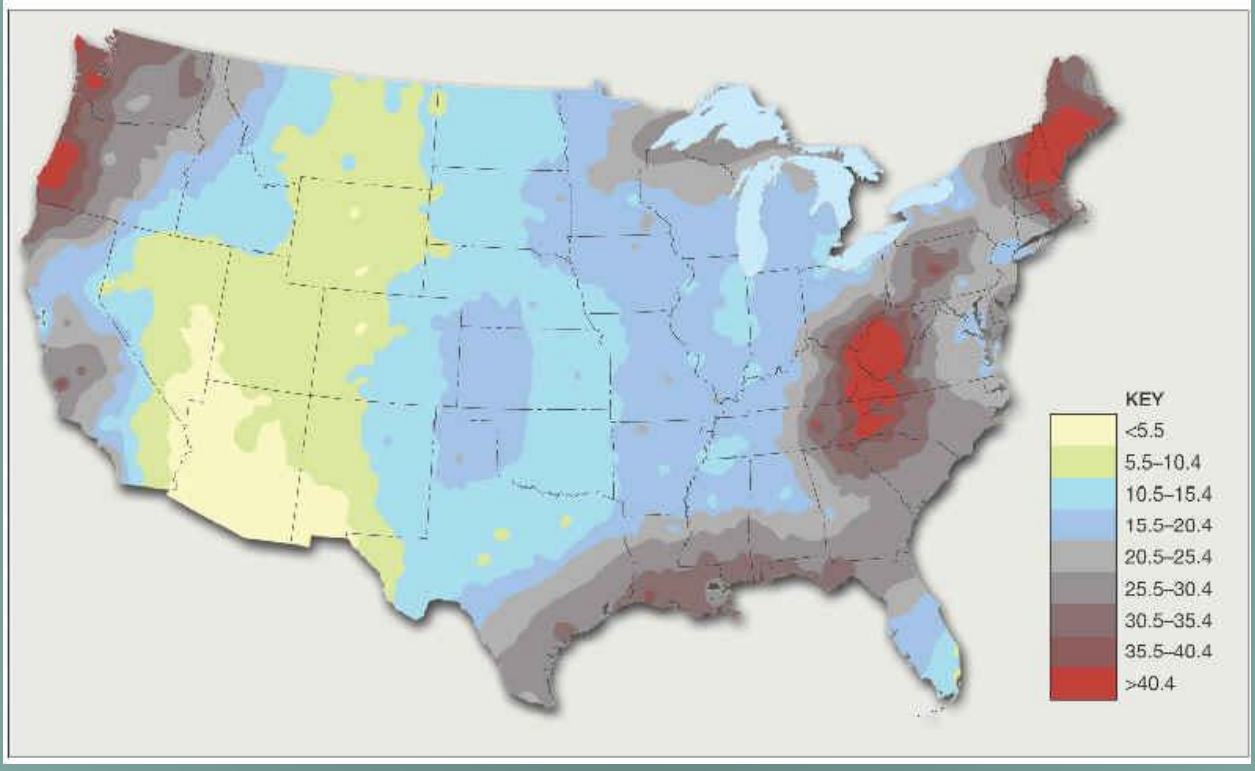


Figure 5. A map showing the average number of days of dense fog per year in the United States. ***Source: NOAA***

Warm season vs. cold season

When fog does form in Arizona, it is most often during the colder months. But, there are some locations where fog occurs relatively frequently in the summer as well.

In the colder months (December through February), the potential for fog formation is greater because:

1) Temperatures are colder
2) Nights are longer (more time for cooling near the surface)
3) The atmosphere is more stable
4) Inversions are more frequent and stronger
5) Precipitation-producing storm systems are more frequent

Ultimately, storm systems from the Pacific play a pivotal role in fog formation. For one, as a storm system impacts Arizona, it typically brings in colder air and increased moisture. Provided that a storm's track is far enough south, it can tap into moisture from the Pacific Ocean or the Gulf of California. This would then result in an increase in the dewpoint temperature at the ground and increase rain chances. Once a storm passes through, the cold and stable air mass following the storm and the leftover moisture from rain provide favorable conditions for fog.

For example, consider the Super Bowl radiation fog event on February 1, 2015. This fog event was driven by a Pacific storm system. The map on the left in Figure 6 shows this system centered over southern California during the early morning hours on January 30. First of all, this storm increased moisture levels in Phoenix. The map on the right shows moisture (green lines) being transported northward by south-southeasterly winds (blue arrows) into Arizona at the same time.

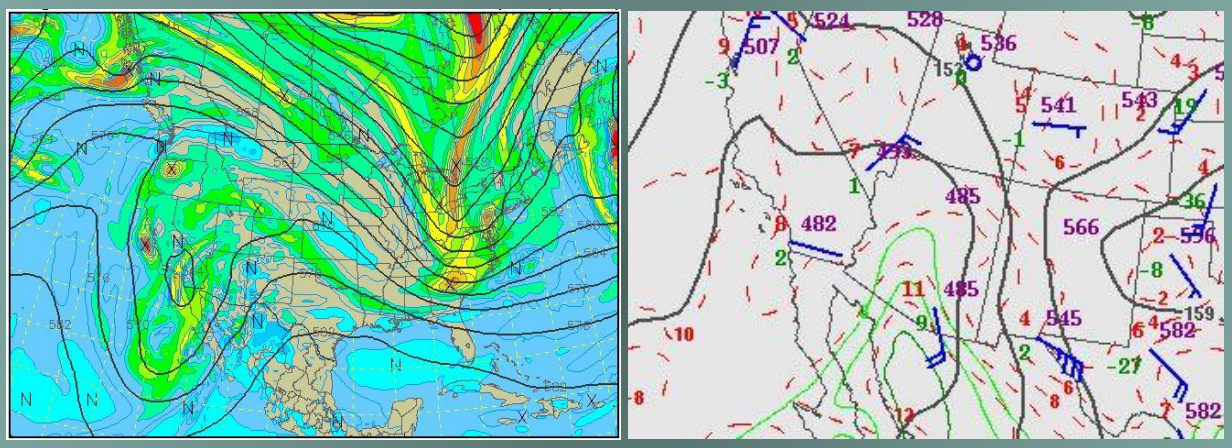


Figure 6. Left: A map of the wind flow in the upper-levels of the atmosphere at 5AM on January 30, 2015. Right: a map of the low-level winds (blue arrows) and moisture (green lines) at the same time.

Sources: left: UCAR; right: NOAA.

This paved the way for rain: between the afternoon of the 29th and the afternoon of the 30th, light rain was observed during almost every hour at Sky Harbor. Second, colder air was brought into the region. The high temperature at Sky Harbor dropped by about 12°F between the 29th and 30th. Once the sky began to clear up overnight from 31st to the 1st, temperatures were able to cool further and eventually reach the dewpoint. This resulted in widespread, dense fog in the Phoenix area. Figure 7 below gives a good perspective on how thick this fog was.

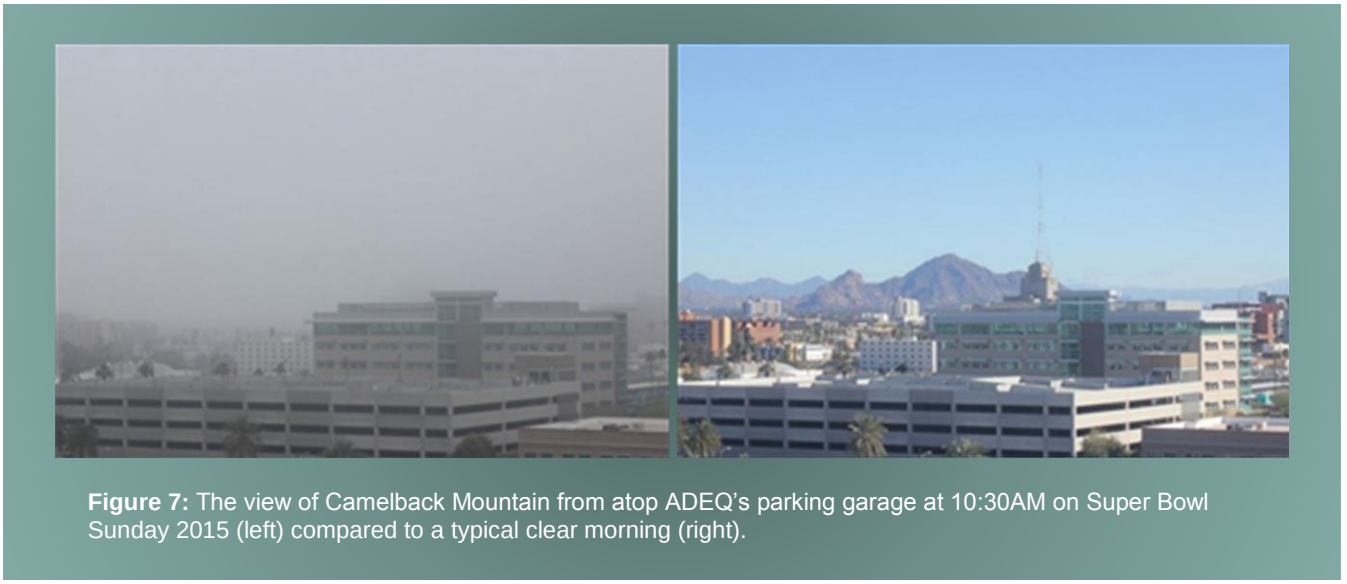


Figure 7: The view of Camelback Mountain from atop ADEQ's parking garage at 10:30AM on Super Bowl Sunday 2015 (left) compared to a typical clear morning (right).

In the warmer months, the desert climate of Arizona is too hot and too dry for widespread, dense fog to form. However, thanks to the monsoon, brief fog is possible. Moisture for fog becomes available through the combination of two things:

1) Higher overall moisture during an active monsoon phase
2) Heavy thunderstorm rain

During an active monsoon period, the wind flow pattern brings moisture into Arizona from the Gulf of California, the Pacific Ocean, and/or northwestern Mexico (learn more about the monsoon here). This establishes a higher baseline of moisture, elevating the dewpoint temperature. The extra moisture is noticeable by how humid it feels outside. Then, when a storm develops and produces heavy rainfall, the evaporation of the rain cools the air and moistens it even further. Precipitation fog forms if there is a sufficient amount of rain to saturate the air.

Geography matters…

The frequency of fog varies greatly across Arizona. Over the past decade, both Flagstaff and the Grand Canyon have averaged more than 25 calendar days of fog per year. However, much of the rest of the state has only averaged 0-5 fog days per year. Phoenix and Yuma have averaged only 1 or less fog days each year. In general, fog is most common in the high country and least common in the lower deserts. The disparity in the number of fog days between these two geographic regions is evident in the map of Arizona in Figure 8. Flagstaff has the most fog days in the last decade with 322 calendar days on which fog was observed; Phoenix came in last with only seven.

Some of the foggiest places on earth

Grand Banks, Newfoundland

San Francisco, CA, USA

London, United Kingdom
(not in the top 10)

Figure 8. Total fog days for 10 locations around Arizona between January 2005 and December 2015. Note: Fog events may span multiple calendar days. "Fog" is defined when the visibility is observed to be less than 5/8 of a mile.

Arizona basemap source: NordNordWest [CC BY-SA 3.0], via Wikimedia Commons. Text added.

Time of year matters…

The months during which fog typically forms also vary across Arizona. For northern Arizona locations such as Flagstaff, the Grand Canyon, and Winslow, fog is most common in the colder months and least common in the warmer months. This is shown in the left-hand column of Figure 9 below. Since Pacific storm systems drive fog in the colder months, radiation fog events likely make up an overwhelming majority of all fog events in northern Arizona in the winter. Fog can still occur in the summer, but it is much more uncommon.

On the other hand, for lower desert locations including Tucson, Nogales, and Douglas, fog has a stronger presence in the warmer months. This is shown in the right-hand column of Figure 9 below. Since thunderstorms drive fog in the warmer months, precipitation fog makes up a large portion of fog events in the lower deserts. This makes sense because the lower deserts are closer to the core area of the monsoon and thus, experience more thunderstorms during the monsoon season. Each lower desert location, however, still has a signature of fog in the colder months. This means that radiation fog is also present in the lower deserts.

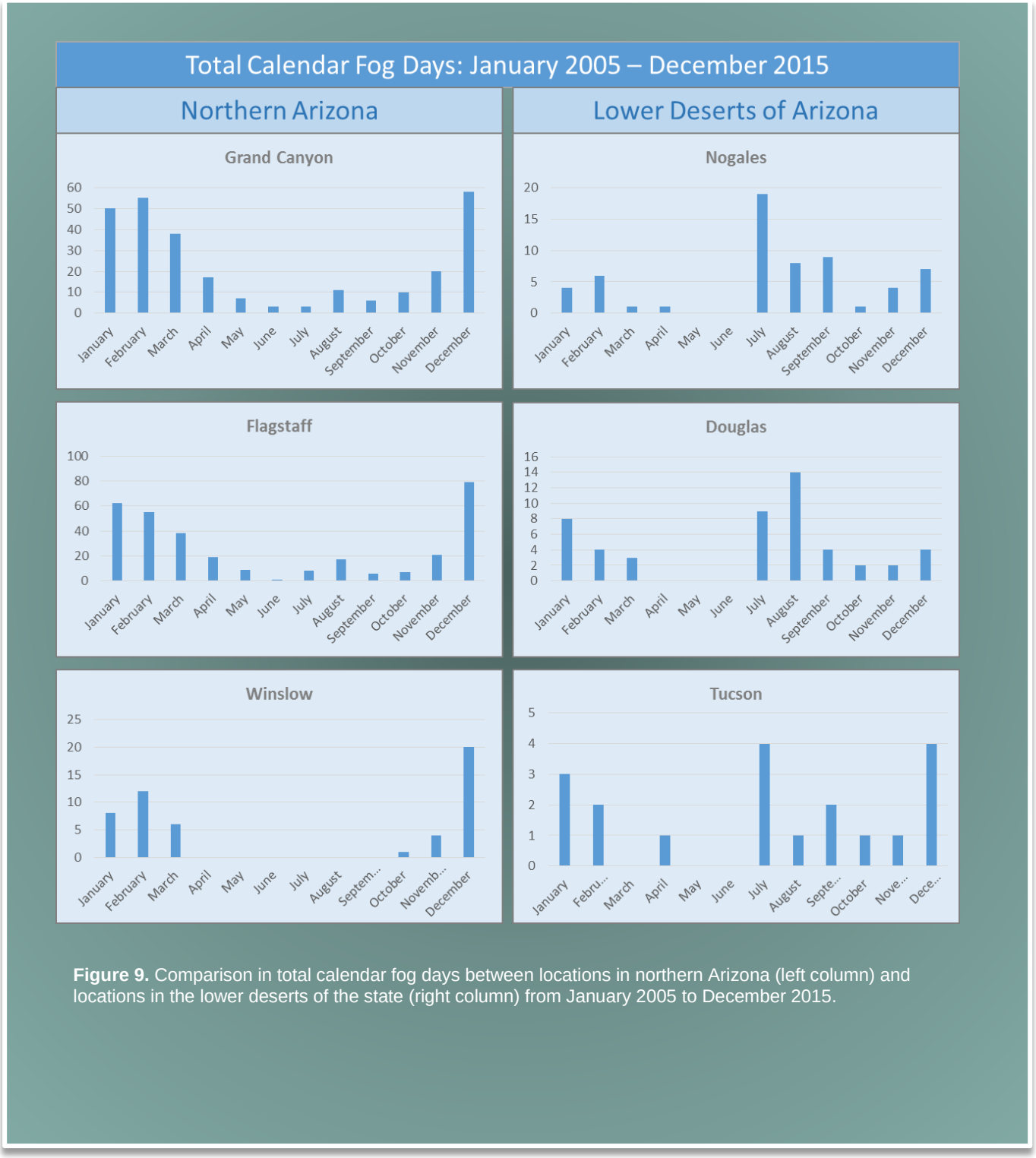


Figure 9. Comparison in total calendar fog days between locations in northern Arizona (left column) and locations in the lower deserts of the state (right column) from January 2005 to December 2015.

Fog and Air Quality

In general, local atmospheric conditions drive both fog and air quality. So, if we can deduce the state of the atmosphere by the presence of fog, we might be able to use that information to help forecast air quality. However, fog can play a small role in influencing $PM_{2.5}$ (fine particulate) levels.

Type of fog and air quality…

Weather conditions associated with a certain type of fog can give us a clue to how good or bad the air quality is at a given time. Take for instance radiation fog. Recall that radiation fog is associated with light winds and inversions, which imply relatively stagnant conditions. Stagnant conditions are also favorable for pollutant accumulation near the surface. So, winter radiation fog could coincide with deteriorating air quality due to $PM_{2.5}$, PM_{10} (coarse particulates), and other locally produced pollutants becoming trapped by inversions. This actually happened Super Bowl Sunday 2015 in Phoenix, which saw elevated $PM_{2.5}$ levels throughout the morning.

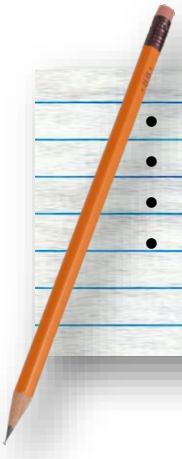
Now consider precipitation fog. Precipitation fog requires heavy rain, which is produced by thunderstorms. Rain washes particulates and ozone precursors out of the air; rain also stabilizes soils. Moreover, clouds associated with thunderstorms block out sunlight, which is necessary for local ozone production. If this type of fog is observed, it would coincide with locally good air quality as PM_{10}, $PM_{2.5}$, and ozone levels are decreased.

Fog and $PM_{2.5}$…

The only time fog might directly impact air quality would be in the winter time, during a radiation fog event. Though $PM_{2.5}$ typically comes from fuel combustion activities (such as motor vehicles, power plants, and wood burning), $PM_{2.5}$ can also form through interactions between gases from burning fuels and water vapor in the air. Therefore, moisture within the fog can interact with gases from burning fuels and increase $PM_{2.5}$ levels. Also, moisture in the air can act as a surface on which fine particulates can accumulate. This would then result in a slight increase in $PM_{2.5}$ levels.

Summary

When it comes to fog (or lack thereof), Arizona stands out from the rest of the United States. However, fog still has a presence thanks to winter storms and the monsoon. Fog can even become very dense in Arizona, namely in the colder season. Also, depending on the fog type, we can have an idea of what the local air quality might become. Overall, winter radiation fog is of most interest due to its adverse impact on transportation and its potential impact on fine particulate matter. The following are a few fog safety tips to consider:



Fog Safety Tips:

- Be aware of your local weather conditions; know if fog is in the forecast
- Avoid driving if you can; if you do drive, drive slowly
- Use low-beam headlights and/or fog lights if your vehicle has them
- Allow extra distance between your vehicle and other vehicles

For our next topic, the ADEQ Forecast Team will look at the Jet Stream, Cold Fronts, etc.
Thanks for reading!

Sincerely,

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In case you missed the previous Issues…

June 2015: Tools of the Air Quality Forecasting Trade: Capturing Dust Storms on Doppler Radar
July 2015: Ozone: An Invisible Irritant
Sept 2015: North American Monsoon
Oct 2015: The Genesis of a Thunderstorm: An Arizona Perspective
Dec 2015: Temperature Profiles, Inversions, and NO BURN DAYS
Jan 2016: El Niño Southern Oscillation

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

–The Jet Stream, Cold Fronts, etc.
-Air Quality Trends, AQI Standard Changes and Comparisons
-Wildfires

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