

# Cracking the AQ Code



Air Quality Forecast Team

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## Patterns in Phoenix Air Pollution

By: ADEQ Forecast Team (ADEQ Air Quality Meteorologists)

When is the best time to go outside? Will I be okay if I take a walk in the morning? Where are ozone levels highest in the Valley? These are the types of questions the ADEQ Forecast Team often receives from the public. Just like the weather, air quality affects people's decisions. If people know how air pollutants behave, they can take steps to minimize their exposure to them and therefore, protect their health (Figure 1). In this issue of *Cracking the AQ Code*, we'll explore the general behavioral patterns of air pollutants around the Valley and how both people and nature play a role.



Figure 1: The benefit of knowing how air quality changes ultimately helps people protect their health and well-being.

Source: Phoenix, AZ from the sky by [Shawn](#) on Flickr (CC-BY-SA 2.0)

## 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...

- Numerical Modeling
- Mesoscale Convective Systems (MCS)

## The Air Quality Index

Here in Arizona, particulate matter small enough to penetrate the lungs (PM<sub>10</sub> and PM<sub>2.5</sub>), and ozone, are common outdoor pollutants we can inhale. To understand how different levels of these air pollutants are tied to specific health impacts, one can refer to the [Air Quality Index \(AQI\)](#). Most of the time, these pollutants remain in either the Good or Moderate AQI categories, but on occasion, they can reach the Unhealthy for Sensitive Groups (USG) category. If any pollutant reaches this category or higher, it exceeds the federal health standard (referred to as an *exceedance* hereafter). Both the Moderate and USG categories are defined with sensitive people in mind (people with heart or lung disease, the elderly, children, those active outdoors, etc.). On rare occasions, we have seen Unhealthy or higher AQI levels; when air quality gets this bad, the general public will begin to be more affected.

## Air Quality in Space and Time

Unfortunately, anticipating which AQI category will be reached by a given pollutant is not always easy. This is because air pollutant levels are constantly changing in both *space* and *time*. In fact, pollutant levels have both daily and seasonal patterns in how they change, and even these patterns can vary. So, what drives changes in air pollution? Why is one pollutant more of a concern for our health at *this* time or during *that* season? It really comes down to three factors: weather, topography, and human activity. Below, we'll explore the typical ways in which [ozone](#), [PM<sub>10</sub>](#) (dust), and [PM<sub>2.5</sub>](#) (soot) change in both space and time in Phoenix and its surrounding areas. Although we focus on Phoenix, many of the key concepts affecting pollutant levels apply to other areas in Arizona as well.

### Winter (December – February)

Winter marks a period of shorter day lengths and colder temperatures. This season is also characterized by frequent, and at times, long-lasting [inversions](#). Now consider that Phoenix is situated at a lower elevation rimmed by higher terrain on nearly all sides (Figure 2).

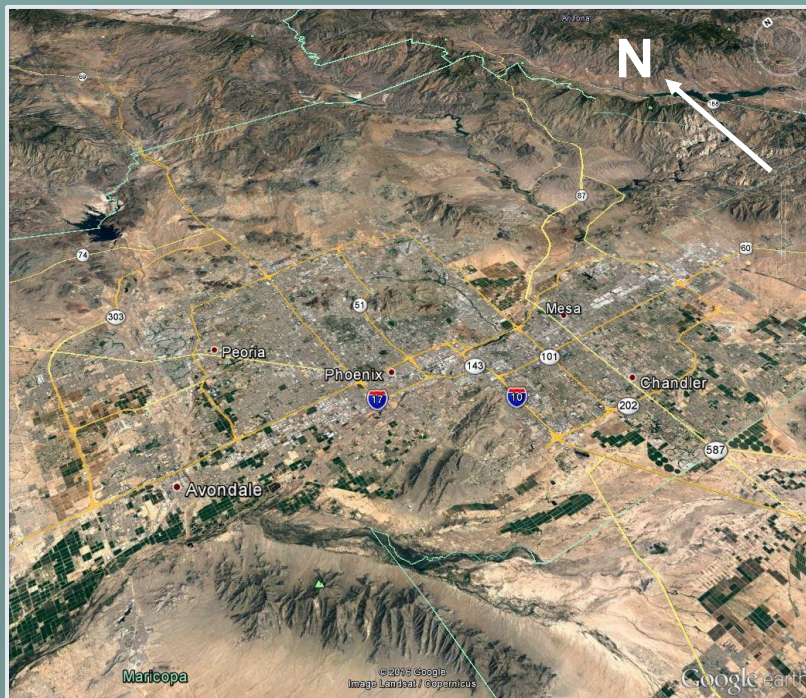
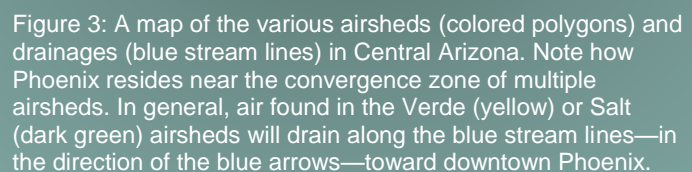


Figure 2: This image gives a 3D look at the local terrain in and around Phoenix, with North oriented toward the top-left of the image. Notice how Phoenix resides in a bowl, sandwiched between mountainous regions. During wintertime, this geography plays a crucial role for air quality. When temperature inversions set up, air is trapped near the ground between the mountains, allowing a buildup of PM<sub>2.5</sub> concentrations.

Source: Google Earth

The interior and downtown areas of Phoenix experience the greatest frequency of Moderate AQI days, whether it be PM<sub>10</sub> (Figure 5) or PM<sub>2.5</sub> (Figure 6). The main reason for this is the combination of the inversion and the pooling of particulates along the drainages towards the lowest parts of the metro area (as shown in Figure 3). This area also has heavy traffic and industrial activities that contribute to localized pollution levels. Active dust and combustion activities early in the morning hours, coinciding with when temperatures are coolest under the inversion, result in the day's highest observed particulate concentrations (Figure 7).



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## Proportion of Air Quality Index Categories for PM<sub>10</sub> during the Winter in Phoenix

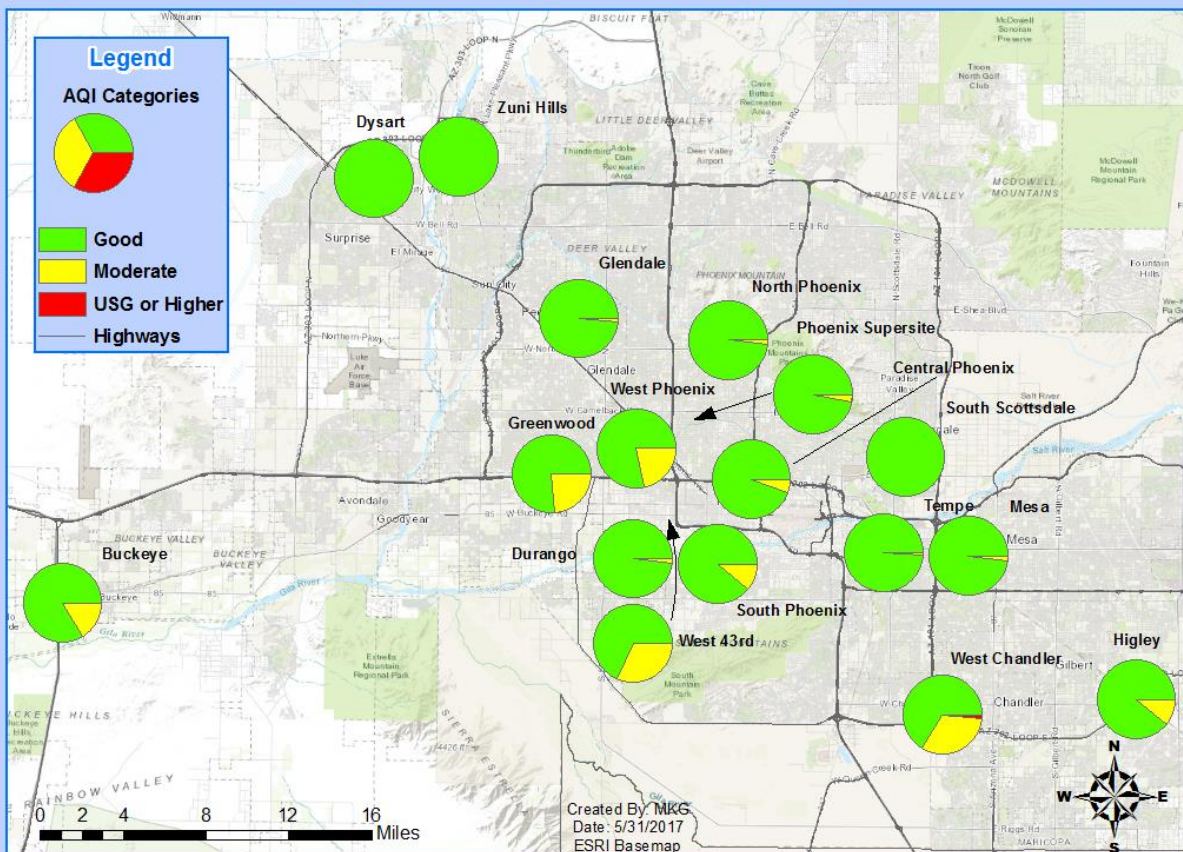


Figure 5: A map showing the PM<sub>10</sub> monitoring network in the Phoenix metro area and surrounding cities. Each pie chart shows the proportion of Good, Moderate, and USG or higher AQI categories that occurred at each PM<sub>10</sub> monitor location during the months of December, January, and February, between 2005 and 2016.

Source: ESRI Basemap

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## CLEAN AIR MAKE MORE

## Proportion of Air Quality Index Categories for PM<sub>2.5</sub> during the Winter in Phoenix

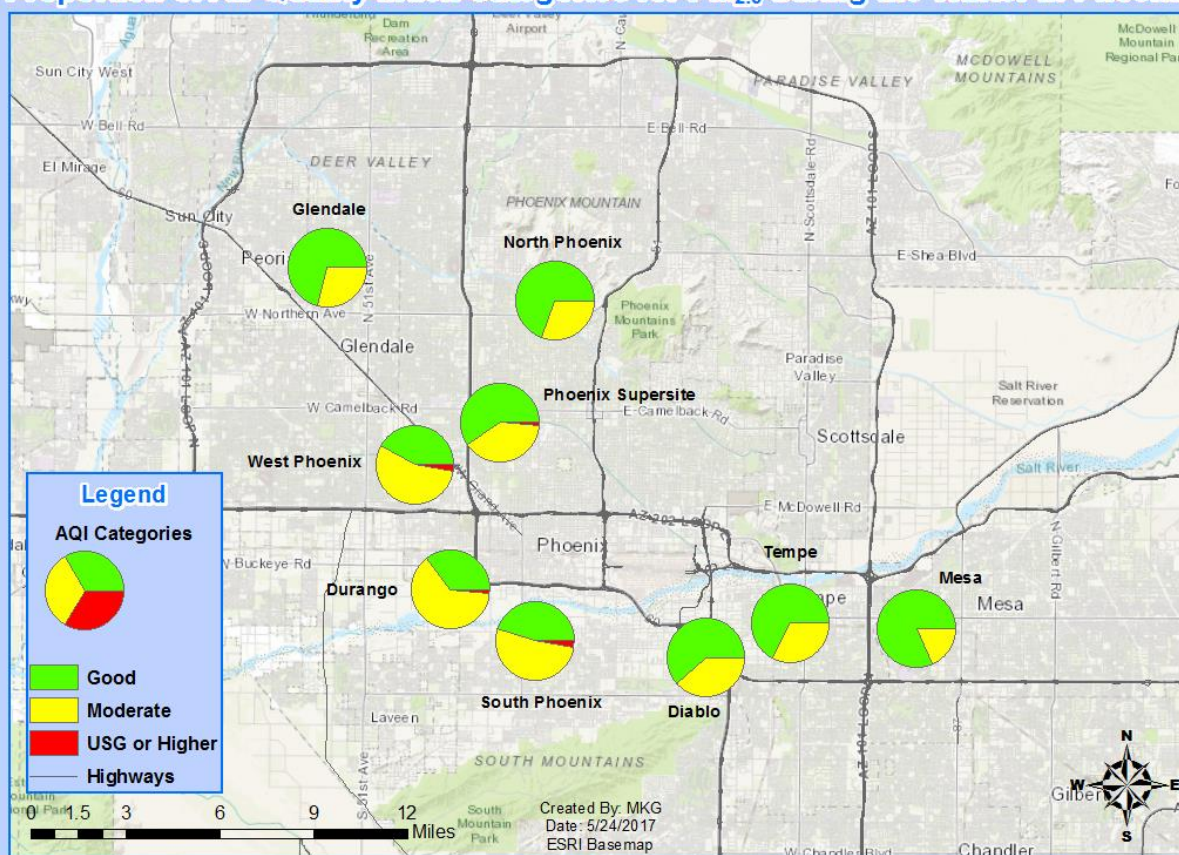


Figure 6: A map showing the PM<sub>2.5</sub> monitoring network in the Phoenix metro area and surrounding cities. Each pie chart shows the proportion of Good, Moderate, and USG or higher AQI categories that occurred at each PM<sub>2.5</sub> monitor location during the months of December, January, and February, between 2010 and 2016.

Source: ESRI Basemap

**Interested in seeing the proportion maps  
for each pollutant for every season?  
Click here to learn more!**

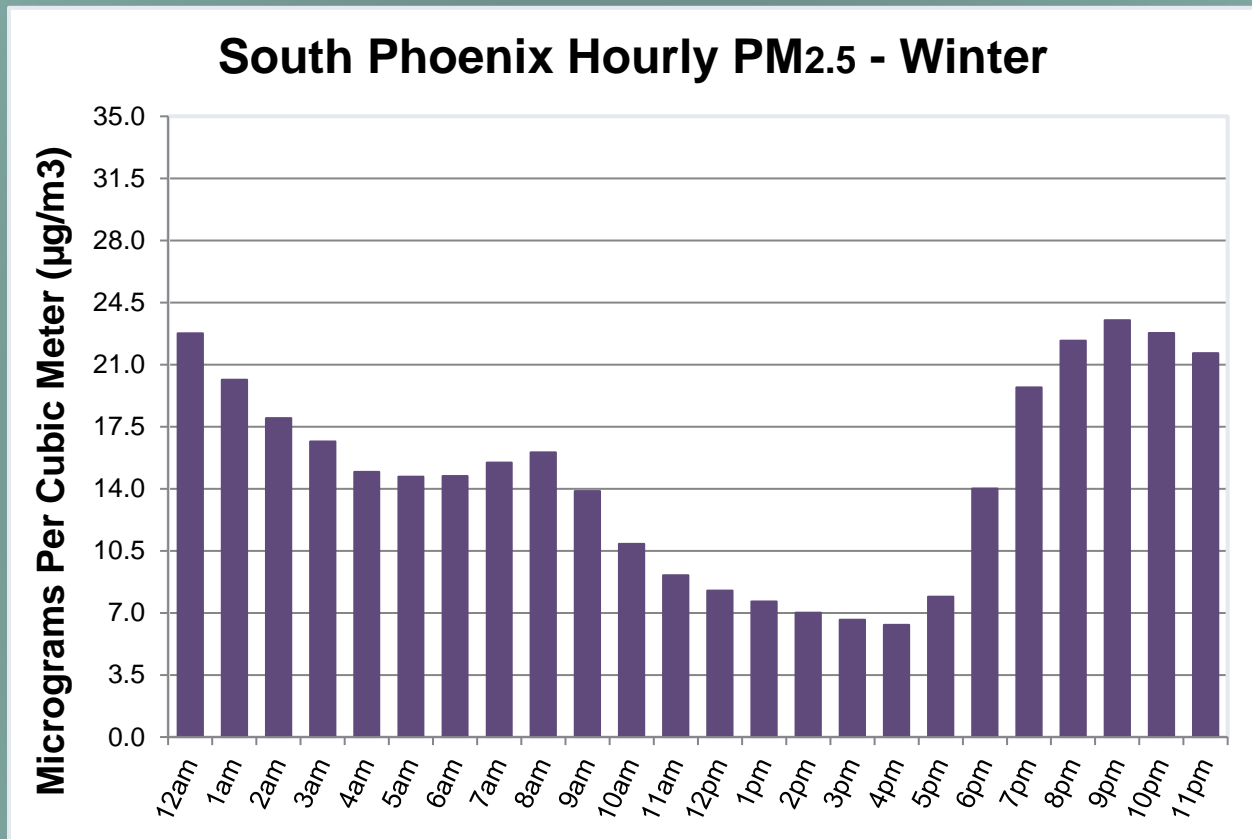


Figure 7: Graph showing the average hourly trend of PM<sub>2.5</sub> during the winter months (December, January, February) at Maricopa County's South Phoenix monitor. Data for this graph was collected from 2010 to 2015.

Generally, improvement for everyone arrives on a daily basis when surface heating from the sun breaks up the [inversion](#). This is why particulate levels are typically lower during the afternoon. Moreover, stronger winds and rain associated with passing Pacific storm systems can help to clear out the Brown Cloud. Rapid and welcome improvement to air quality is typical with this kind of weather.

It is worth mentioning that particulate readings can reach extreme levels during the Holidays because of people partaking in recreational burning (Figure 8). The appeal to have a fireplace lit or igniting fireworks does have a pronounced effect on our air quality. Eventually, there is a tipping point. Concentrations accumulate, approach, and then finally exceed the allowable limit between what is considered acceptable air quality and when the health of many becomes negatively impacted.

The basic fact, proven time and time again, is that thousands of fireplaces and fireworks lit at once overwhelm the state of the air quality in the Phoenix area. Although the downtown monitors have the greatest frequency of Moderate AQI and exceedance days (see Figure 6), all burning activities in the Phoenix metro area would be contributing to those poor air quality days by way of the drainage flow patterns (see Figure 3) in the Valley.

We do not always have the luxury of strong winds to clean out the local air. However, even in the absence of winds, we can take matters into our own hands at any time to avoid unhealthy air. Retrofitting indoor and outdoor fireplaces to natural gas are excellent alternatives that would result in considerably less emissions into the air. Other cleaner selections to decide from are Environmental Protection Agency (EPA) certified woodstoves, pellet stoves, oil furnaces, or going electric (Figure 9).

There is not a lot to discuss about ozone during the winter months. No exceedances of the current health standard have occurred in the past and there have only been a handful of Moderate AQI days. Ozone is largely kept in check by shorter day lengths and less intense solar radiation.

### Spring (March – May)

The spring season can be a turbulent one for air quality. The full spectrum of Good, Moderate, and exceeding AQI days are possible anywhere and for any pollutant. The same atmospheric conditions negatively affecting particulates in winter (e.g., inversions and stagnation) still apply, with the addition now of more frequent windy episodes. The problem is when Pacific storms drive dry [cold fronts](#) through the Desert Southwest. If drought conditions have been present, then gusty winds can easily pick up dust from the open deserts. As would be expected, the PM<sub>10</sub> monitors nearest the open deserts have had the greatest number of exceedances (Figure 10). Timing-wise, windblown dust and haze can occur at any hour of the day.

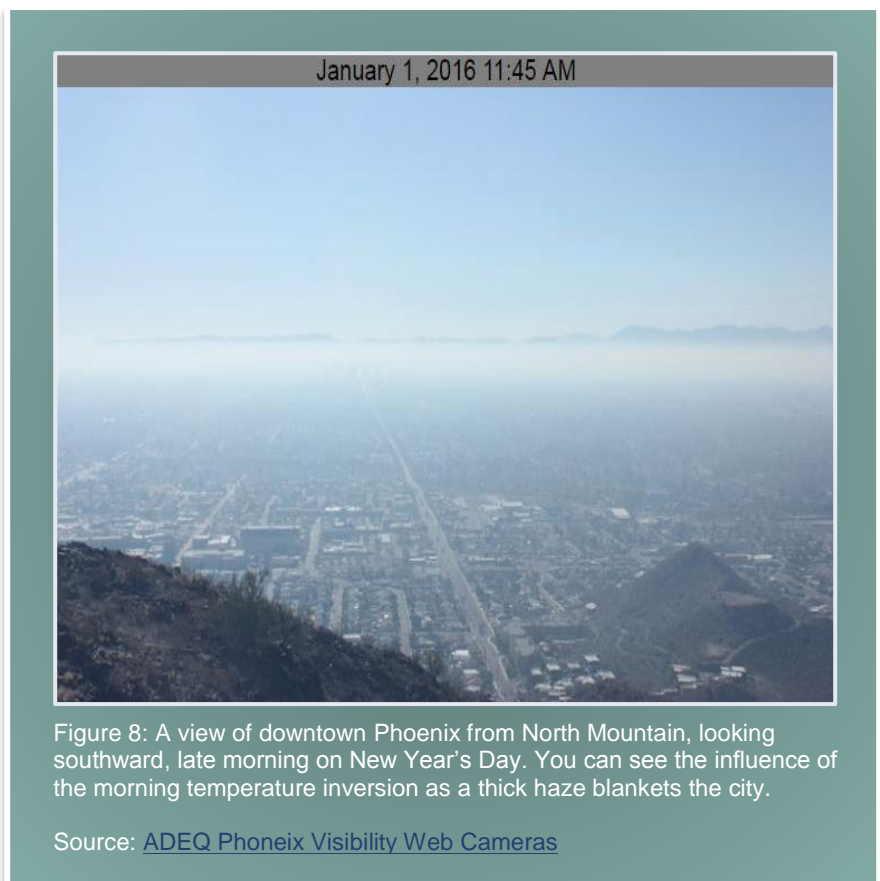


Figure 8: A view of downtown Phoenix from North Mountain, looking southward, late morning on New Year's Day. You can see the influence of the morning temperature inversion as a thick haze blankets the city.

Source: [ADEQ Phoenix Visibility Web Cameras](#)

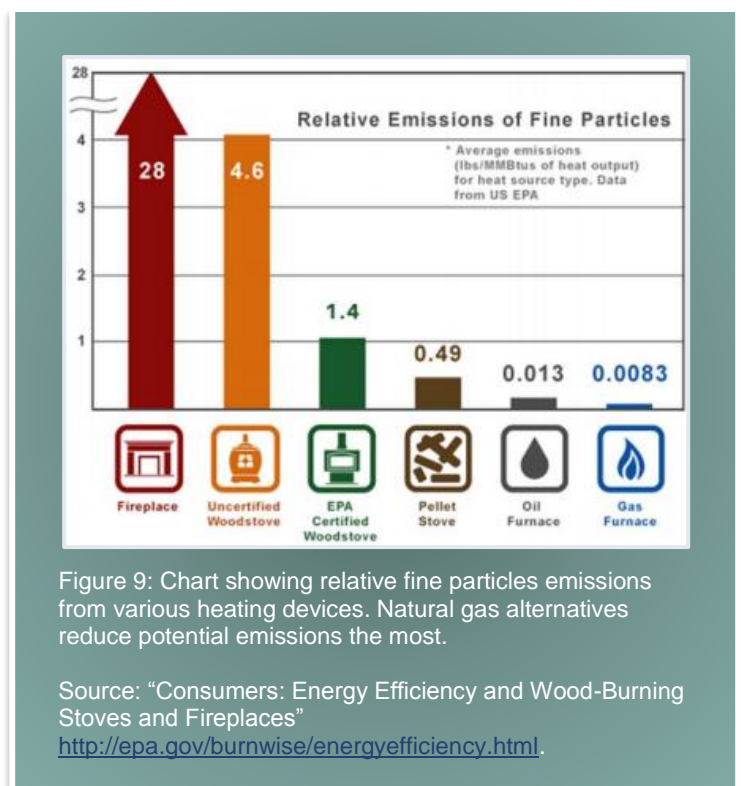


Figure 9: Chart showing relative fine particles emissions from various heating devices. Natural gas alternatives reduce potential emissions the most.

Source: "Consumers: Energy Efficiency and Wood-Burning Stoves and Fireplaces"  
<http://epa.gov/burnwise/energyefficiency.html>.

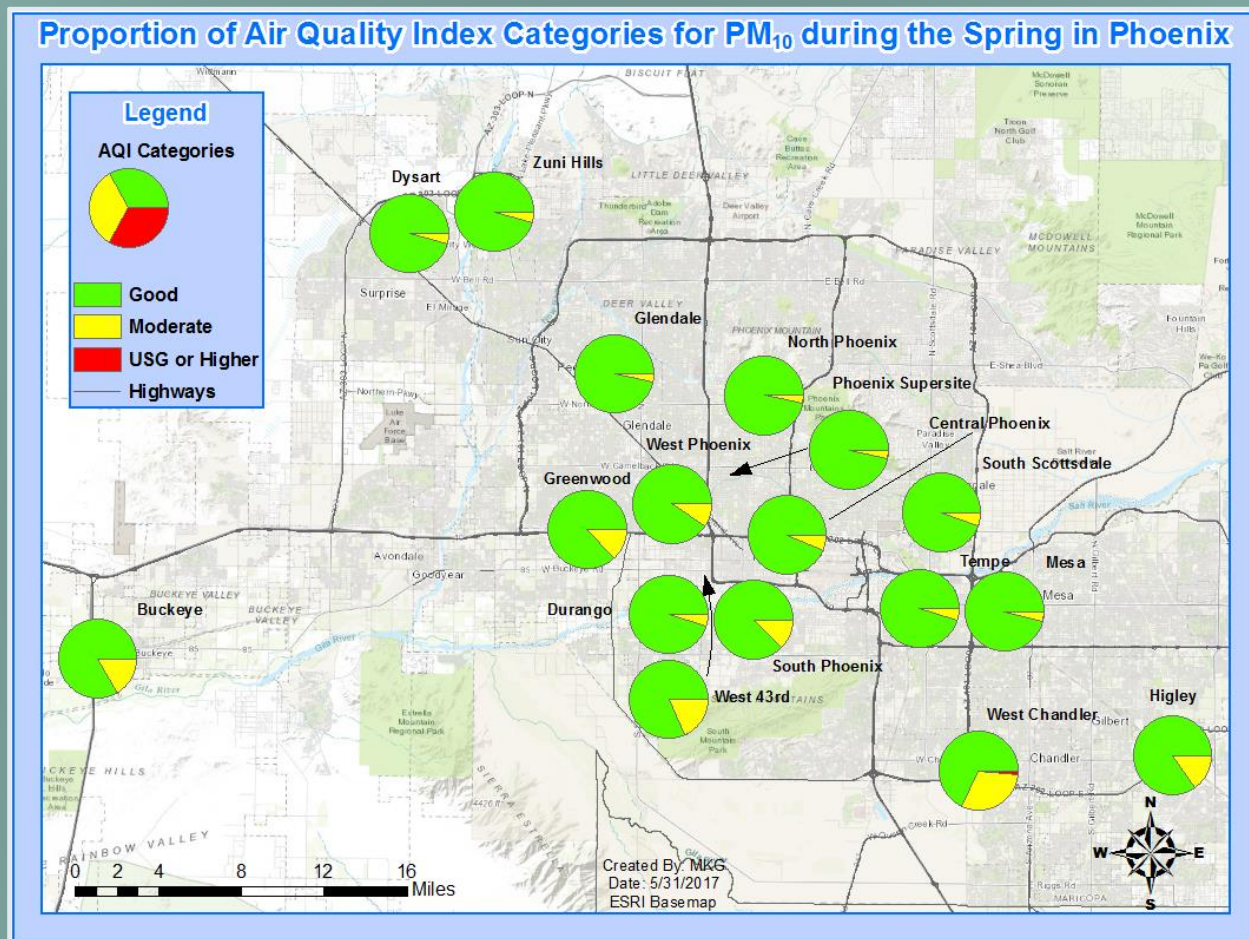


Figure 10: A map showing the PM<sub>10</sub> monitoring network in the Phoenix metro area and surrounding cities. Each pie chart shows the proportion of Good, Moderate, and USG or higher AQI categories that occurred at each PM<sub>10</sub> monitor location during the months of March, April, and May, between 2005 and 2016.

Source: ESRI Basemap

Contrary to winter, ozone does become a greater concern by spring, especially since the EPA recently lowered the ozone standard ([see this previous issue for more information](#)). The spring season represents a time when ozone concentrations begin to ramp up network-wide (Figure 11). Furthermore, exceedances are possible as early as late March, but typically begin in April.

So, why do we start seeing a ramp-up in ozone beginning in spring? Well, longer day lengths is the main reason for increased ozone production. Ozone is not strictly temperature dependent, it just needs sunlight to get the ball rolling. Longer stretches of daylight mean more accumulation of ozone. Another factor for increased ozone levels is the transport of ozone and [ozone precursors](#) from the ozone-rich environment of southern California. The frequent Pacific storm passages that often bring winds out of the west are ideal for carrying additional ozone and ozone precursors toward the Phoenix metro area. This adds to the preexisting, local ozone, resulting in higher AQI values.



Now let's fast forward to the afternoon hours. As the mountains to the east begin to heat up, the prevailing easterly winds start to weaken. Eventually, the prevailing winds reverse to a southerly and westerly direction. Once the winds switch, the ozone plume is steered toward the northeast Valley; ozone still continues to form along the way, until sunset. This whole process has been

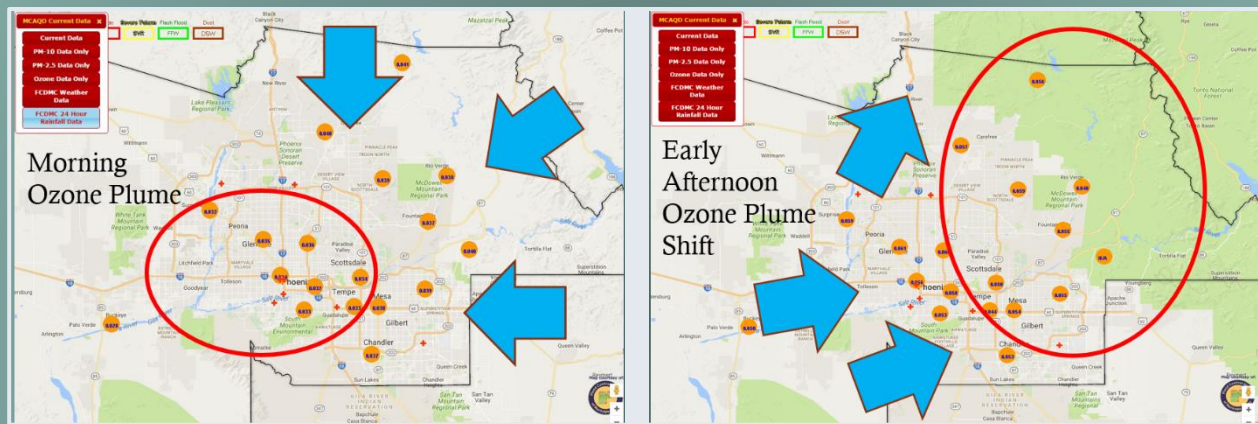


Figure 12: This graphic illustrates the “sloshing effect”. During the morning hours (left image), the mountains in the west are heated the most, resulting in easterly winds pushing ozone to the western parts of the Valley. By the afternoon (right image), the mountains in the east begin to be heated the most, resulting in westerly winds pushing ozone to the eastern and northeastern parts of the Valley. This back and forth movement of ozone in the Valley has been dubbed the “sloshing effect”.

Source: [Maricopa County Air Quality Department](#)

called the “sloshing effect” (Figure 12) and helps explain the maximum of Moderate and exceeding AQI days being focused in the northeastern parts of the Valley (see Figure 11). After sunset, ozone experiences a sudden drop due to a process called “titration”, in which ozone is broken down by nitrogen oxides into oxygen and nitrogen dioxide (Figure 13). Nitrogen oxides are ozone precursors, necessary for ozone formation. But, without the presence of sunlight, nitrogen oxides present from the day's pollution will instead remove ozone from the air and cause ozone levels to decrease substantially. Because nitrogen oxide emissions are more prevalent in

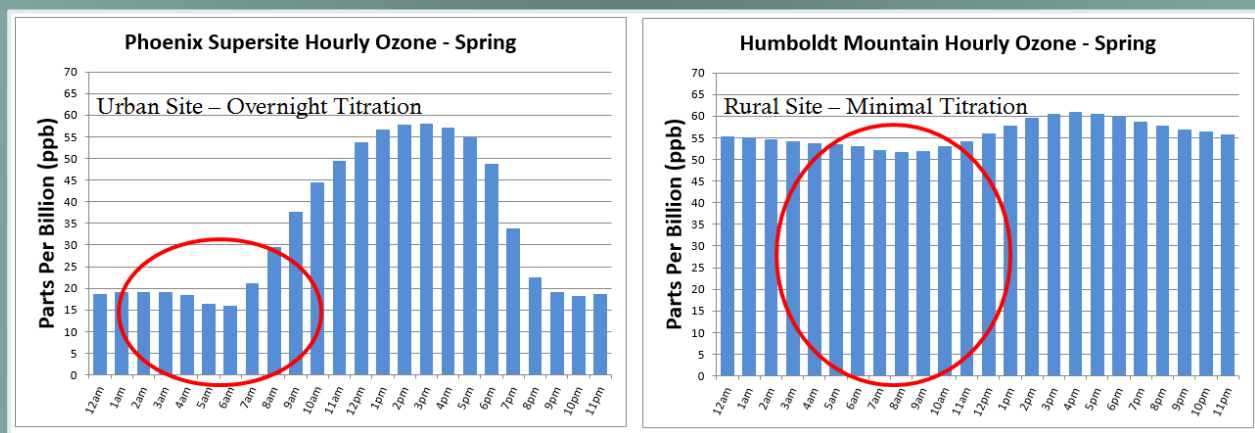
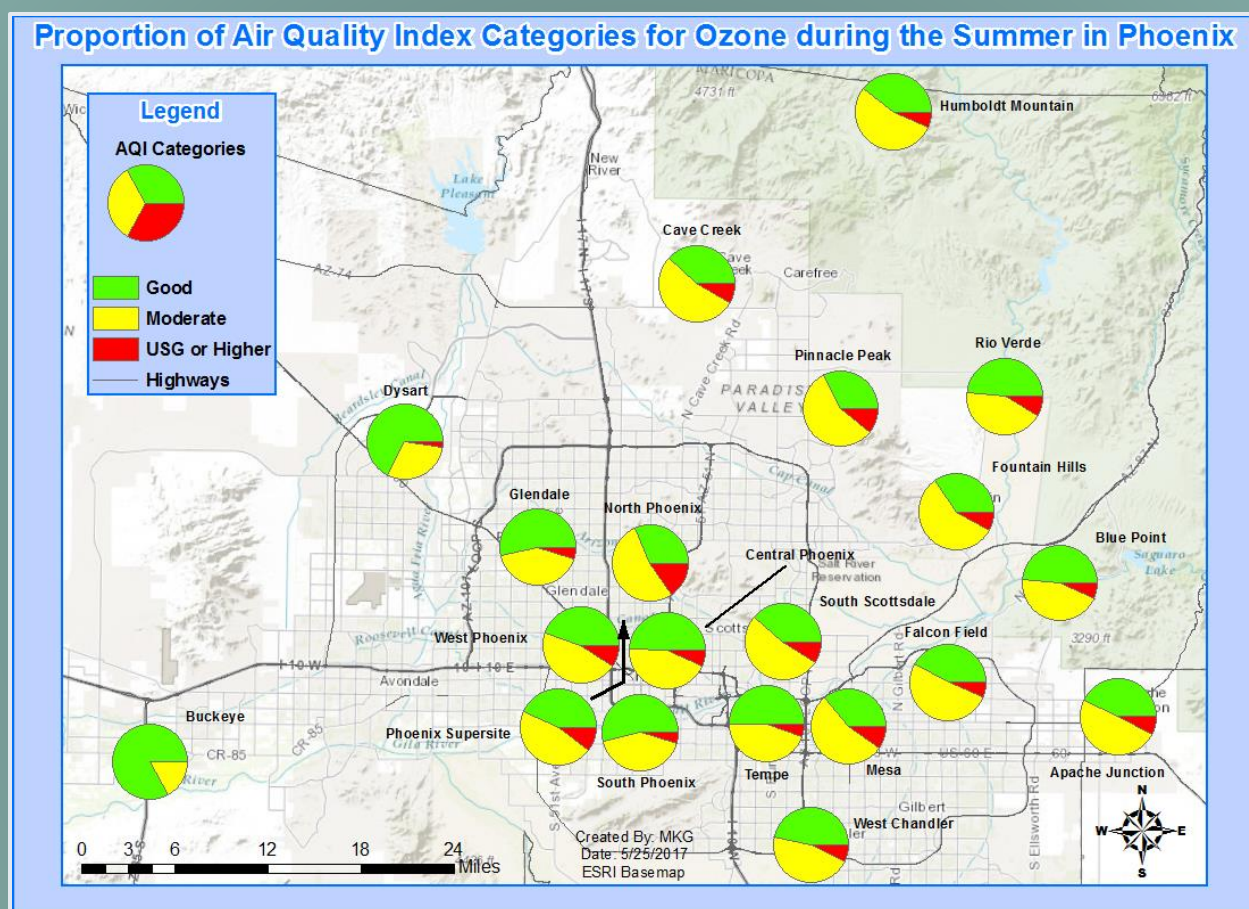


Figure 13: Two graphs showing the difference in average hourly ozone concentrations between urban sites (left) and rural sites (right). Ozone levels at urban locations experience a noticeable drop during the evening through morning hours due to titration, while rural locations show far less variation throughout the day.

urban areas than rural locations, titration is more noticeable in the city. Ozone concentrations can even approach near zero at times over interior Phoenix, before the ozone cycle repeats itself the next day.

## Summer (June – August)

When it comes to summer here in the Valley, ozone tracking remains at the forefront. The daily ozone pattern discussed above in the spring section also holds true for the summer. However, the focus for ozone exceedance potential expands, now including the central metropolitan area and even western portions of the Valley as well (Figure 14).



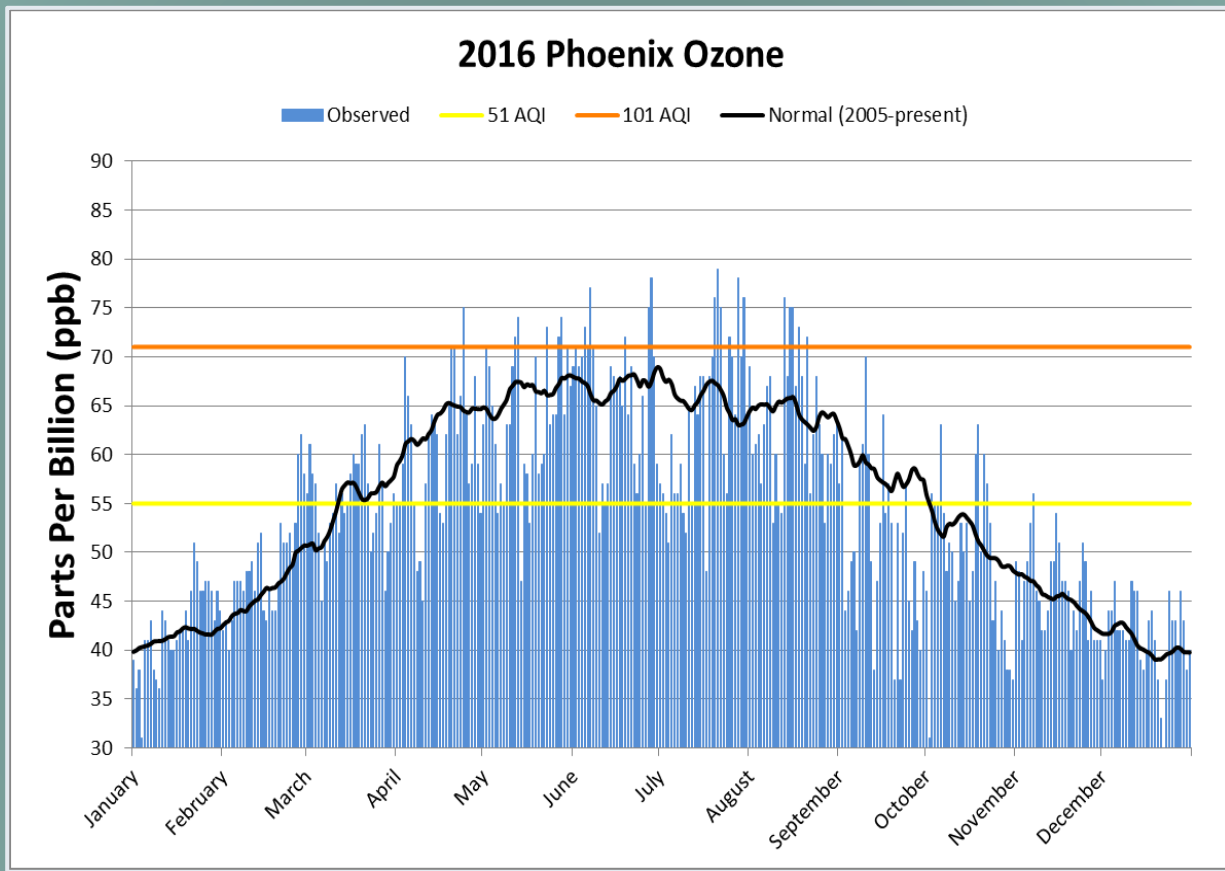


Figure 15: Graph showing the daily maximum 8-hour average ozone across the Phoenix monitoring network for 2016. Notice the increase in ozone levels during the warmer months due to more daylight hours and frequent calm weather patterns. The black line is rolling weekly average of historical ozone data (2005-2016). The yellow and orange lines are Air Quality Index (AQI) category breakpoints.

The monsoon season also brings [thunderstorms](#). Where there are thunderstorms over open deserts, there are bound to be gusty outflow winds and [dust storms](#). The southern and western outskirts of the Valley are particularly vulnerable to dust storms and rather drastic short-term jumps in  $PM_{10}$  are common as dust storms plow through. This shows up in the historical record when reviewing the monitors' percentage of Moderate and exceeding days (Figure 16). Thunderstorms affecting Phoenix are usually observed in the late afternoon or early evening, but keep in mind that sudden drops in visibility and blowing dust impacts can impact the Valley at any point in the day during the monsoon season.

Moreover, coarse particulates ( $PM_{10}$ ), such as dust, are more prominent in the summer than fine particulates ( $PM_{2.5}$ ). The excessive heat, weak surface inversions, and general lack of recreational burning by the public all help to keep  $PM_{2.5}$  levels minimal. A caveat would be [wildfire smoke](#) temporarily finding its way into the Phoenix metro area. However, these instances are rare.

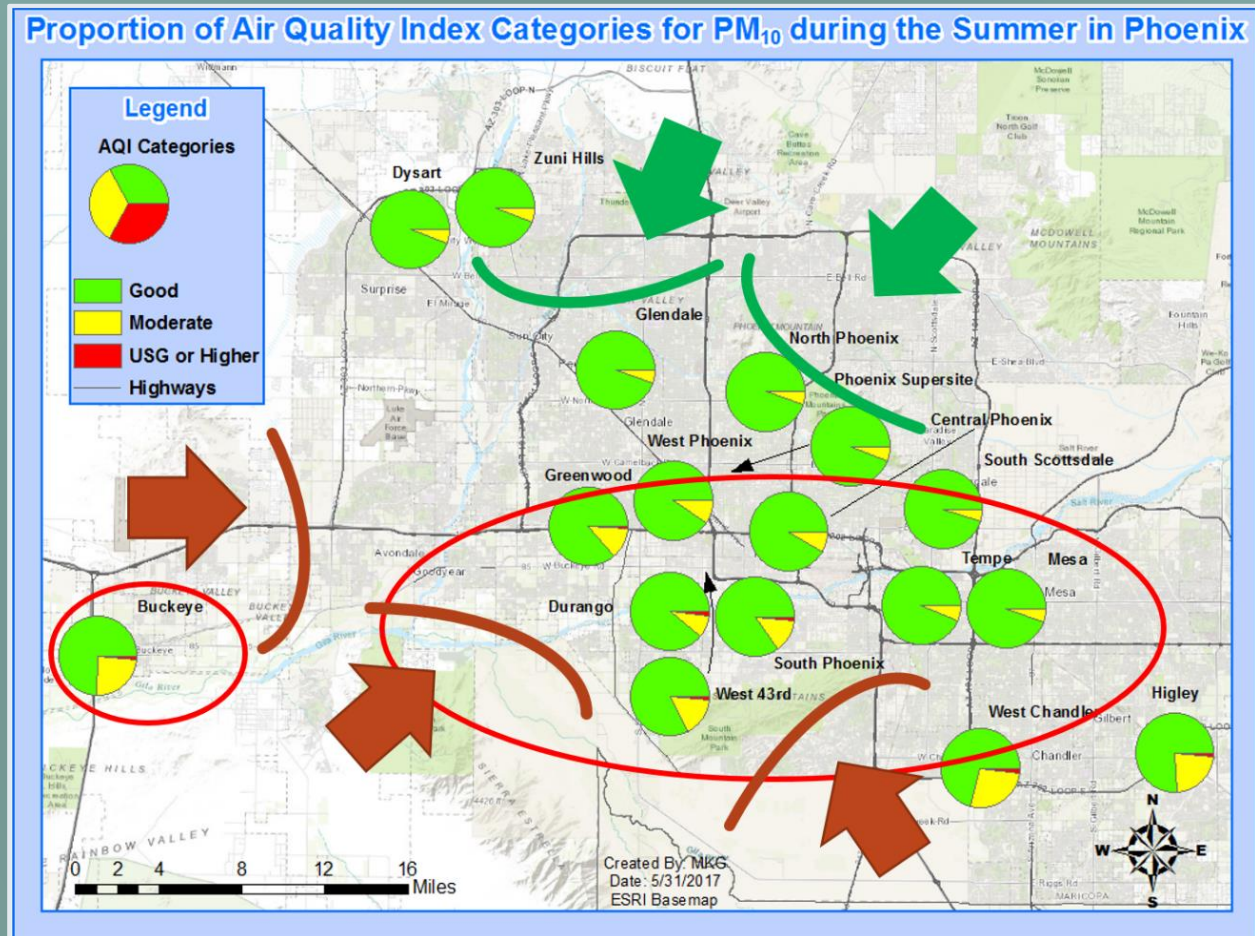


Figure 16: A map showing the PM<sub>10</sub> monitoring network, as in Figures 4 and 9, but for the months of June, July, and August. This map shows favorable directions where thunderstorm outflows may loft excessive amounts of particulates from open desert dust sources southeast and west of the Phoenix metro area (red arrows and boundaries). Outflows originating from the north and northeast (green arrows and boundaries) usually pass over more vegetated landscapes, making them less dust-laden and a minimal threat to the PM<sub>10</sub> federal health standard. The contrast in exceedance day frequency is evident between the northern and southern PM<sub>10</sub> monitors. The most powerful dust storms can be an air quality issue anywhere in the urban area, while recent and widespread heavy rainfall would all but eliminate blowing dust potential.

Source: ESRI Basemap

## Fall (September – November)

The monsoon season officially ends September 30<sup>th</sup>. That date on the calendar, though, doesn't always mean an abrupt halt in the weather and air quality relationships associated with the summer period. When the monsoon does end, the fall season mimics closely the weather and air quality patterns found in spring. Regarding ozone, moderate and exceedance ozone days tail off as sunlight decreases. Regarding particulates, concentrations begin to rise once again in the urban areas downstream of the drainages (see Figure 3) as cooler weather gets a better grip over the state. Widespread windblown dust enters the picture once again, too, as the frequency of Pacific storms and cold frontal boundaries affecting the Desert Southwest increases.

## In Summary

From winter to fall, we have now made it through the whole year, getting a glimpse into the daily and seasonal lifecycles of Phoenix's common air pollutants: ozone, PM<sub>10</sub>, and PM<sub>2.5</sub>. Overall, we have seen that, when it comes to pollutant behavior, the time of the year matters, the time of the day matters, and one's location in the Valley matters. Below is a table summarizing the times of day when one can expect these pollutants to be highest throughout the year, arranged by season. Of course, air pollution is not always confined to predictable patterns. This is rather a very general summary, not taking into account all special cases, as well as differences throughout the Valley. Regardless, armed with this knowledge, people can be better equipped to make more informed decisions and therefore, protect their health and well-being.

Table 1: A very general summary of when to expect the highest ozone, PM<sub>10</sub>, and PM<sub>2.5</sub> concentrations during each season. Note that both ozone and PM<sub>2.5</sub> are typically of minimal concern in the winter and summer, respectively. Elevated levels in PM<sub>10</sub> are possible throughout the year but are highly dependent on the frequency of weather storm systems from the Pacific, thunderstorms, and amount of precipitation. Special cases such as ozone transport from California and differences in ozone across the Valley are not fully represented here.

### When to Expect Highest Pollutant Concentrations during Each Season

Pollutant	Winter	Spring	Summer	Fall
Ozone	Minimal Concern	<ul style="list-style-type: none"><li>• Late morning through early evening</li><li>• Increasing through the season</li></ul>	<ul style="list-style-type: none"><li>• Late morning through early evening</li><li>• Highest this time of year</li></ul>	<ul style="list-style-type: none"><li>• Late morning through early evening</li><li>• Decreasing through the season</li></ul>
PM <sub>10</sub>	<ul style="list-style-type: none"><li>• Morning stagnation</li><li>• Wind events/blowing dust possible anytime</li></ul>	<ul style="list-style-type: none"><li>• Morning stagnation</li><li>• Wind events/blowing dust possible anytime</li></ul>	<ul style="list-style-type: none"><li>• Morning stagnation</li><li>• Wind events/blowing possible anytime; monsoonal dust storms</li></ul>	<ul style="list-style-type: none"><li>• Morning stagnation</li><li>• Wind events/blowing dust possible anytime</li></ul>
PM <sub>2.5</sub>	Overnight through late morning	<ul style="list-style-type: none"><li>• Overnight through late morning</li><li>• Decreasing through the season</li></ul>	Minimal Concern Monsoonal dust storms*	<ul style="list-style-type: none"><li>• Overnight through late morning</li><li>• Increasing through the season</li></ul>

\* Though PM-2.5 is not typically an issue during the summer, it can sometimes reach elevated concentrations with the passage of strong monsoonal dust storms; in fact, PM-2.5 exceedances are even possible.

We hope you enjoyed learning about the nature of air pollution here in Phoenix. If you would like to see the AQI proportion maps for each pollutant in every season, [click here](#).

Sincerely,  
The ADEQ Forecast Team  
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## In case you missed the previous Issues...

December 2016: [PM<sub>2.5</sub> in Arizona and around the World](#)

February 2017: [Outdoor Carbon Monoxide: the Pollutant of Yesteryear](#)

March 2017: [Tools of the Air Quality Forecasting Trade Part 3: Satellite Imagery](#)

May 2017: [You Ask, We Answer: Part 1](#)

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

- Numerical Modeling
- Mesoscale Convective Systems (MCS)

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