Cracking the AQ Code

ADEQ Arizona Department of Environmental Quality
Air Quality Forecast Team

September 2015 Volume 1, Issue 3

The North American Monsoon

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The North American Monsoon has a major influence on Arizona's weather. "Monsoon" is a common term used in Arizona and the greater southwestern United States, but it is often used incorrectly. Our hope is that this discussion will increase your understanding of what a monsoon is and the crucial part it plays in shaping not only the region's weather, but also its air quality.

What is (and isn't) a monsoon?

Much like the hurricane season, the North American Monsoon also has specific start and end dates. The monsoon season officially runs from June 15 through September 30, although the monsoon pattern can set up earlier or end later than this period. Technically speaking, a monsoon is a seasonal shift in the prevailing wind pattern which results in a significant change in precipitation. In the case of the North American Monsoon, the typical southwesterly (blowing **from** the southwest) synoptic flow shifts southeasterly, driving mid-level moisture from the Gulf of Mexico into Arizona. A common misconception associated with the monsoon is that a single thunderstorm or heavy rain event in the summer is a "monsoon," but this is not the case. Rain and thunderstorms are simply more prominent as a *result* of the seasonal shift in winds known as the monsoon.

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 Genesis of a Thunderstorm
- Tropical Cyclones (A.K.A Hurricanes)
- ENSO (A.K.A El Niño)

Publication No. N-15-39

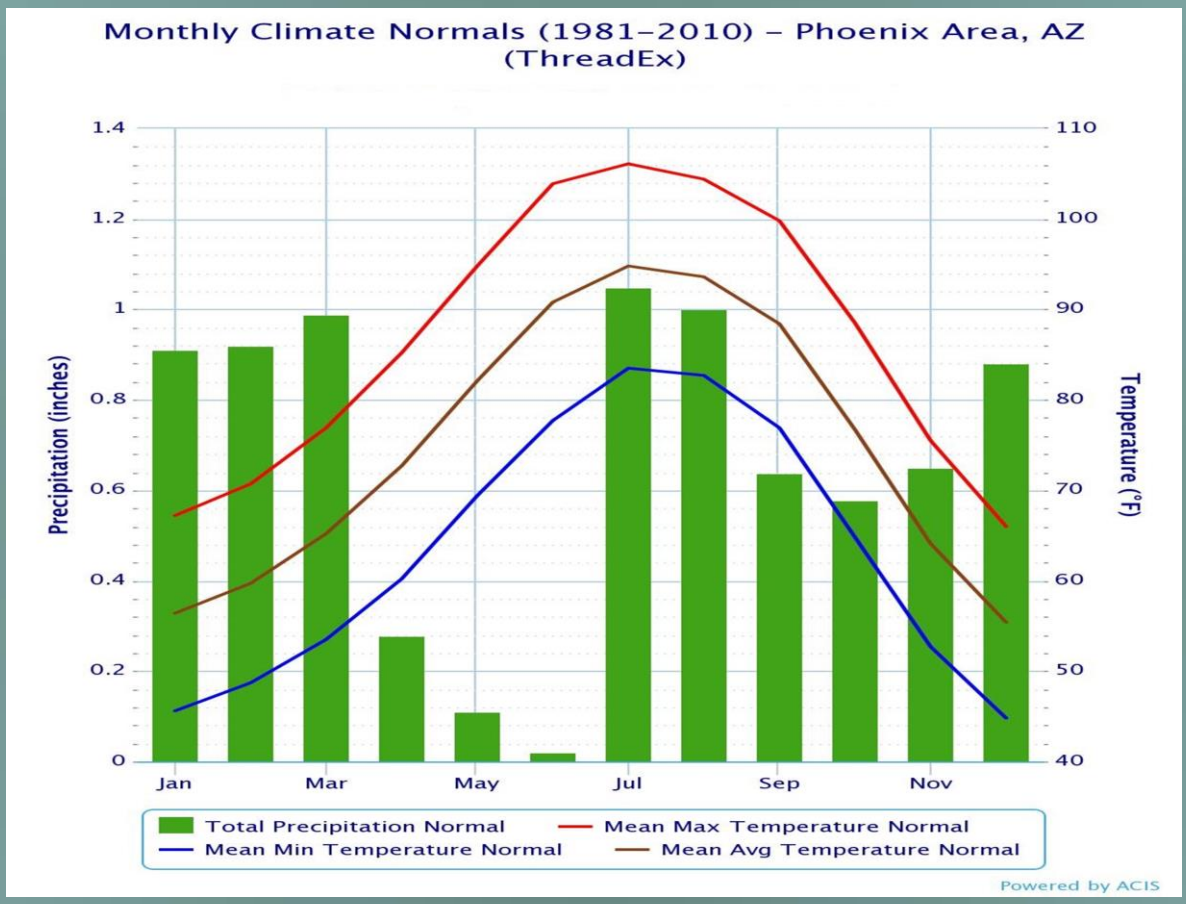

Figure 1: This National Weather Service graphic depicts the normal temperature and precipitation throughout the year for Phoenix. Notice the sharp increase in precipitation from June to July indicating the start of the monsoon.

Let's dive in...

There are two primary changes to the wind patterns that result in the return of much needed rain to the desert: a low-level flow pulling moisture up from the Gulf of California, and mid-level flow (around 18,000 feet) drawing moisture from the Gulf of Mexico. Let's begin with the moisture transport from the Gulf of Mexico. Generally, areas of subsiding (sinking) air are located near latitudes 30˚N and 30˚S resulting in semi-permanent regions of high pressure, also known as subtropical ridges. One such ridge is typically present over North America, and is often times called the Monsoon Ridge. Due to the tilt of the Earth, and the subsequent changes in the orientation of the Sun and Earth throughout the year, the subtropical ridge slowly moves north in the summer and south in the winter. During the cooler months, this ridge is located to the south over Mexico, creating generally southwesterly mid-level flow over Arizona. On the other hand, during the summer, mid-level winds shift more southeasterly as this ridge moves northward (Figure 2). Thus, the moisture transport from the Gulf of Mexico is initiated, kicking off the North American Monsoon.

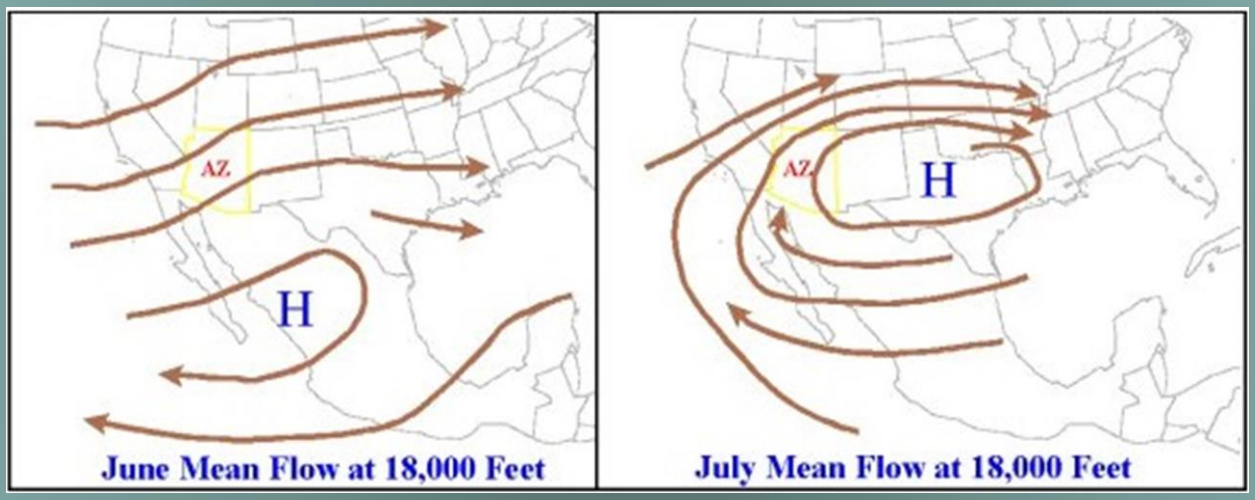

Figure 2: Here we see the typical position of the subtropical ridge before and after the onset of the monsoon. In June, the prevailing wind pattern over Arizona is still generally out of the southwest (left). By July, the flow has shifted out of the southeast, pulling moisture from the warm Gulf of Mexico. Photo: www.theweatherprediction.com

In addition to mid-level moisture, low-level moisture transport is also essential for the development of significant weather during the monsoon season. The interaction between the thermal trough and moisture from the Gulf of California satisfy this requirement. A thermal trough - commonly referred to as a heat low or thermal low - is an area of low pressure created by intense surface heating. This is a common phenomenon in the Southwest during the summer. Just as air descends in a high pressure system, air ascends within a low pressure system. This causes the surrounding low-level winds to converge inwards towards the center. The component of this flow from the Gulf of California draws more moisture into Arizona. You may also commonly hear the term “gulf surge” during the monsoon season. A gulf surge is an exceptionally strong push of moisture from the Gulf of California. Moisture has a profound effect on the weather and is one of the key ingredients for thunderstorms. Therefore, any increase in moisture over the state becomes an important factor in determining the coverage and severity of thunderstorms.

Speaking of the key ingredients for thunderstorms, let’s dig in a little deeper and discuss the basic process by which thunderstorms can occur here in Arizona. There are three primary ingredients needed to produce a thunderstorm. As we have already discussed, moisture is one crucial element. The other two are instability and lift.

Instability during the monsoon is typically provided by the thermal trough, and by extension, the strong surface heating. Naturally, warm air rises and cool air sinks. With such intense surface heating, the air temperature cools rapidly with height, creating a very unstable atmosphere. This is a result of the near surface air becoming less dense than the air above it and, therefore, rising. You can see this in action when you boil water on a stove. The water is stable with little to no movement at first, but after the stove has added sufficient heat, air bubbles begin to rise to the surface. Simultaneously, relatively cooler water from above begins to sink. Eventually, this movement intensifies, resulting in a very unstable, turbulent environment. This is similar to what happens in our atmosphere on a grand scale.

The last ingredient, lift, can be provided in many ways. Surface heating alone can and does generate the needed lift for thunderstorms during the summer, but mountainous terrain can also provide an additional orographic effect to greatly enhance the lift. This creates various thunderstorm-prone areas within Arizona such as the White Mountains, Grand Canyon region, Mogollon Rim, as well as the “Sky Islands” of southeastern Arizona. As these storms collapse and generate outflows, they can provide additional lift for the development of new thunderstorms. This process continues throughout the day with each new thunderstorm developing further into the lower deserts. This is why the lower deserts, such as the Phoenix area, have a heightened risk for thunderstorm activity in the late afternoon and evening. While many people enjoy the rain and thunderstorms during the monsoon, they can unfortunately pose a significant threat as well.

Lightning and Winds and Hail, Oh my!

It is incredible that a simple shift in the wind direction can cause such a significant change in the weather. The southwestern United States experiences some of its most severe weather of the year during the monsoon season. The relatively benign weather much of the year quickly shifts to frequent thunderstorms, capable of producing damaging winds, hail, flooding, and of course lightning.

Lightning is an inherent danger with all thunderstorms, since you technically cannot have a thunderstorm without lightning. Lightning is caused by the buildup of electrically charged regions in the atmosphere, and the electric discharge can cause power outages, start wildfires, and endanger anyone nearby. If you are close enough to hear the thunder, then it is a good idea to head inside. Click here for more tips and information on lightning safety.

Outflow winds from thunderstorms pose another potential danger. These winds can be strong enough to cause structural damage to buildings, while blowing debris and dust can be dangerous to anyone caught outside. In a dust storm, visibility can drop to near zero in a matter of seconds, causing road travel to be extremely dangerous. If caught in a dust storm, remember: “Pull Aside, Stay Alive.”

> *"WE HAVE OVERTURNED PLANES. WE HAVE PLANES THAT JUST GOT MOVED… WE'VE GOT A HUGE AMOUNT OF DAMAGE."*
>
> -Battalion Chief Keith Welch of the Chandler Fire, Health and Medical Department
>
> Source: Associated Press. "Monsoon Storm Packing High Winds Flips Planes at Chandler, Arizona, Airport Snaps Power Poles". FoxNews.com, 12 Aug. 2015

Strong thunderstorms also have the potential to create hail, which results when a thunderstorm updraft suspends water droplets high within the storm long enough for them to freeze. The stronger the updraft, the longer the hail stays aloft and the more time it has to accrue more water. This causes the hail stone to grow in size until it either moves out of the updraft or simply becomes too large for the thunderstorm updraft to keep it suspended. The National Weather Service has determined that a thunderstorm producing hail with a diameter of at least one inch is considered severe. Across the United States, hail is consistently one of the costliest weather phenomena in terms of property damage. During a hail storm the best thing you can do is seek shelter immediately.

Thunderstorms can also precipitate copious amounts of water in a short amount of time, resulting in flash flooding that can cause widespread destruction. Because the deserts of Arizona receive very little rain throughout the year, the soil is extremely hard below the surface. Since these short bursts of heavy rain can't easily seep into the ground, fast flowing rivers and streams quickly appear in what were previously bone-dry washes or city streets. People can be knocked off their feet with only six inches of fast-flowing water, and two feet of water can turn your car into a boat, so it's advisable to avoid walking or driving through a flash flood. Instead, "Turn Around, Don't Drown®."

Thunderstorms can, indeed, be dangerous, but other hazards exist during Arizona summers even on days without any significant weather. For example, heat is always a concern during the warm months in Arizona, especially during the monsoon season. The increase in moisture makes sweat less effective, which allows for a quicker onset of heat exhaustion and, in extreme cases, a heat stroke. Whether rain or shine, know the dangers and stay safe!

How does the monsoon affect air quality?

The monsoon season has a large impact on Arizona's air quality, and the impact can be both good and bad. For instance, ozone pollution typically has higher concentrations during the summer months primarily due to the higher sun angle and longer days. The more intense solar radiation in the summer months is more effective at converting volatile organic compounds (VOCs) and nitrogen oxides (NOx) into ozone. While ozone concentrations are certainly elevated during the summer, the concentrations are also more sporadic. During a thunderstorm outbreak, ozone concentrations will typically improve due to gusty winds

dispersing accumulated ozone along with an increase in cloud cover. In addition, rain will help “drag” pollutants out of the air. For a more in-depth look at ozone, be sure to check out our ozone discussion.

Another pollutant influenced by monsoonal weather is PM_{10}. PM_{10} stands for particulate matter with a diameter less than 10 microns (10^{-6} meters), which is far less than the width of a human hair. Dust is the most common form of PM_{10}. As was discussed in the June issue of *Cracking the AQ Code*, strong, gusty winds associated with thunderstorms can generate dust storms that can lead to unhealthy levels of PM_{10}, but rain, on the other hand, helps suppress dust and clear out the air. Thus, typical monsoon weather can have both a negative and positive influence on our air quality. Consequently, it can make the job of air quality forecasting more difficult because we must weigh each of these meteorological factors.

Hopefully by now you are able to see how spectacular and complex the North American Monsoon’s effect is on the weather. And just think - the primary factor driving all of this change is a shift in the prevailing wind pattern. Exciting weather phenomena, like those associated with the monsoon, is a major reason why I became a meteorologist. Hopefully you now have a better appreciation and understanding of the North American Monsoon and its affects here in the great state of Arizona.

For our next topic, the ADEQ Forecast Team will look in depth at the thunderstorm development process. Thanks for reading!

Sincerely,

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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…

June 2015: Tools of the Air Quality Forecasting Trade: Capturing Dust Storms on Doppler Radar
July 2015: Ozone: An Invisible Irritant

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

– The Genesis of a Thunderstorm
– Tropical Cyclones (A.K.A Hurricanes)
–ENSO (A.K.A El Niño)

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