

# Cracking the AQ Code



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## ***The Genesis of a Thunderstorm: An Arizona Perspective***

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Cumulonimbus clouds exist as the pinnacle of all cloud formation. They can rise to the heights of 30,000-50,000 feet or higher on occasion. They are also capable of generating large amounts of energy, manifested by some of the most violent weather phenomena experienced on earth. Once a cumulonimbus cloud produces lightning, it is considered a thunderstorm. But how does a thunderstorm form in the first place? And how do thunderstorms affect air quality in Arizona? In this edition of *Cracking the AQ Code*, we explore the genesis of thunderstorms in central Arizona and their impacts on air quality.



**Figure 1:** Cumulonimbus clouds behind mountains in Tucson, Arizona. Notice how the clouds flatten and spread out at their top as they reach the upper limit of the troposphere.

*Photo by: Cindy Devin*

## *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...

- Temps/Inversions/  
No Burn Days
- ENSO (A.K.A El Niño)
- All About Fog

## Thunderstorm Ingredients

Have you ever heard someone say, “I think a storm is brewing!” upon observing a darkening sky in the middle of the afternoon? Meteorologically-speaking, this statement is not far from the truth. Similar to when you make your preferred pot of coffee or tea, a thunderstorm is simply the result of several ingredients coming together in the same place, at the same time, and given enough time to interact. There are three necessary ingredients for thunderstorm formation: instability, moisture, and a source of lift. Each is discussed in this section.

### *Instability*

For a thunderstorm to come to life, air needs to be able to rise. An air parcel (an invisible volume of air) rises when it is warmer (less dense) than the air around it and sinks when it is colder (more dense). For an air parcel to rise upward through the atmosphere, it must remain warmer than its surrounding environment, much like a hot air balloon as it gains altitude. When an air parcel is able to continually rise, the atmosphere is considered “unstable.” In other words, instability is present.

Instability increases in the atmosphere when the earth’s surface is heated by solar energy, when low-level moisture increases, and/or when the temperature in the upper-levels of the atmosphere decreases. During Arizona’s summer monsoon season, instability increases over the lower deserts as low-level moisture increases in the presence of intense solar heating. In the winter, instability is often provided by Pacific upper-level troughs that bring in cooler air aloft (see Figure 6). Overall, greater instability enables ordinary cumulus clouds to grow into their cumulonimbus form.



**Figure 2:**

It takes instability for cumulus clouds to achieve this kind of vertical development. This photo was taken from atop ADEQ’s parking garage, looking south toward South Mountain on July 6, 2015.

***Photo by: Michael Graves***

## Moisture

This ingredient is probably the most intuitive, because you can't have clouds without moisture. Suppose the atmosphere has enough moisture and instability for thunderstorms. An air cools as it begins to rise. Eventually it cools to its dewpoint, the temperature at which it can no longer hold any more water vapor. As a result, its water vapor condenses onto very small particles already present in the atmosphere, forming cloud droplets. Now imagine countless cloud droplets forming and then rising further into the atmosphere. Sooner or later these cloud droplets climb high enough to freeze and eventually become ice crystals.

The primary sources of moisture for Arizona include the eastern Pacific Ocean and the Gulf of California. During the fall, winter, and early spring, low pressure systems draw moisture from these sources and make it available for precipitation and sometimes thunderstorms. In the summer months, the monsoon flow pattern draws moisture from these sources, but also from additional places, including upper-level moisture from the Gulf of Mexico, and low-level moisture from the vegetated Sierra Madre Occidental Mountains in western Mexico. Figure 3 shows a map of the various possible sources of moisture for the monsoon.



**Figure 3:** Sources of low-level moisture for the North American Monsoon. Moisture from the Southern Plains is possible when crop fields have received enough rain **Source: National Weather Service**

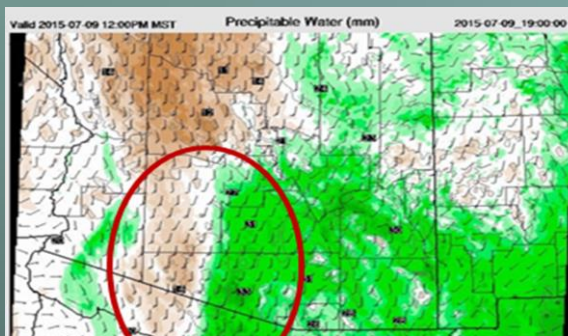


## Source of Lift

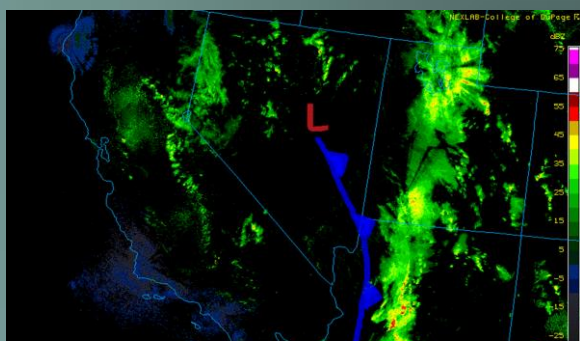
The ingredient necessary for a thunderstorm is a source of lift. This refers to any physical or meteorological mechanism that can initiate the rising motion of air parcels. Sources of lift that lead to thunderstorm development in Arizona include: mountains/terrain, outflows from preexisting/dying thunderstorms, atmospheric waves, locally strong winds in the jet stream, cold fronts, unequal heating at the surface, and a dry line (i.e., a sharp boundary between moist and dry air masses). Figure 4 illustrates some of these sources of lift.



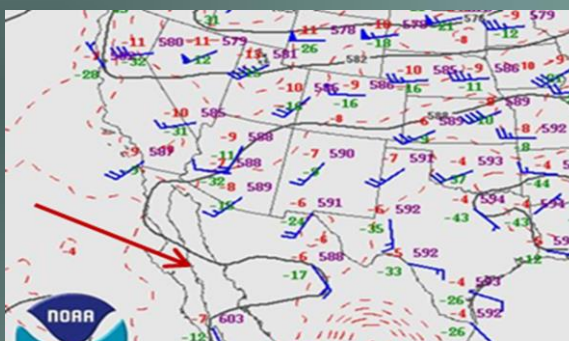
A. Mountains/terrain (Chiricahua National Monument)



B. Dry line (boundary of monsoon moisture)



C. Cold front (associated with Pacific trough)



D. Upper-level wave (see caption)

**Figure 4:** Common sources of lift in Arizona that can act as focus points for thunderstorm development, provided sufficient moisture and instability. In panel d, a small trough is analyzed over northwestern Mexico at 5 AM, Saturday, July 18, 2015. This wave moved northward and provided lift for storms that caused flash flooding in Wickenburg, AZ later in the afternoon.

**Sources:** panel A - photo by Ken Bosma; panel B - University of Arizona; panel C - NEXLAB College of DuPage; panel D - NOAA.

## Thunderstorm Life Cycle

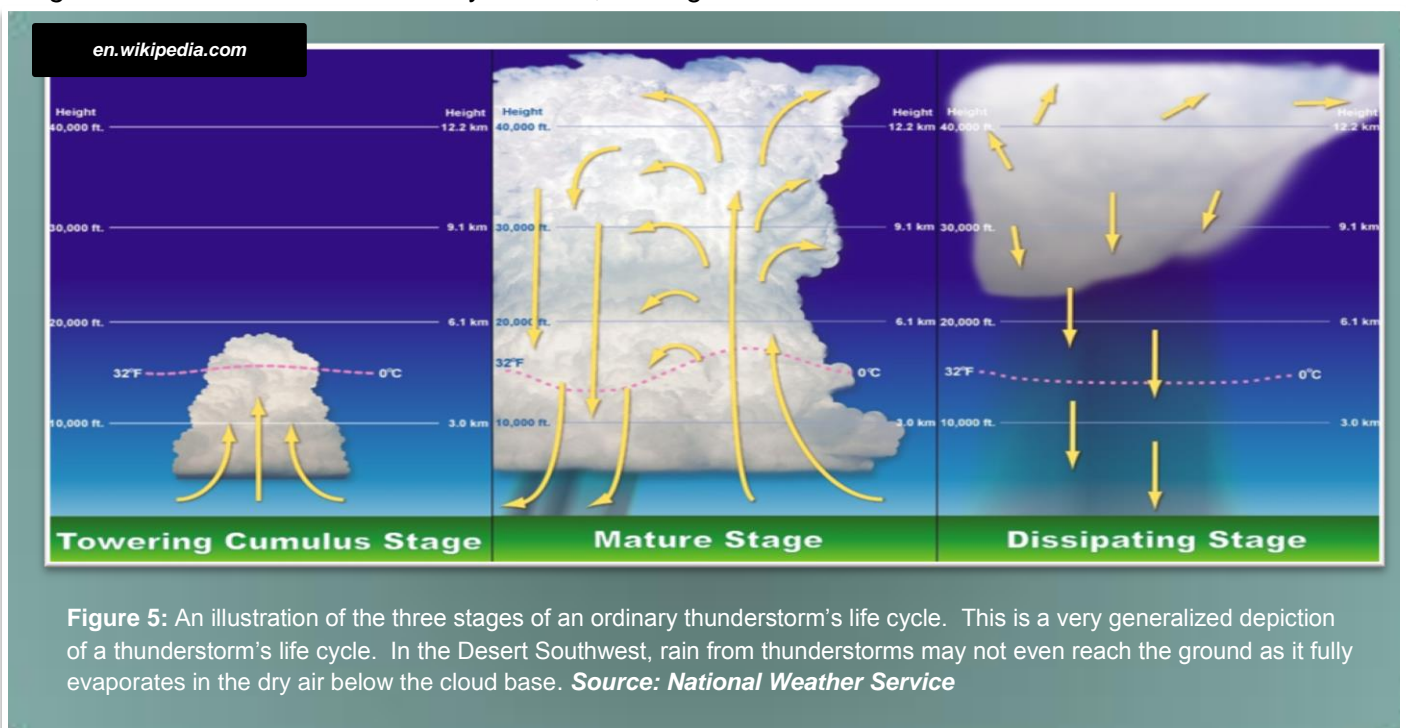
If each of these three ingredients is forecast to be present in an area, then there is a potential for thunderstorm formation. As a thunderstorm forms, it undergoes three distinctive stages:

- 1) The towering cumulus stage
- 2) The mature stage
- 3) The dissipating stage

The *towering cumulus stage* is characterized by a vertically growing cumulus cloud in an unstable environment. The lifeline of the cumulus tower is the “updraft” that forms within the cloud due to the rising motion of air parcels, which feeds warm, moist air into the cloud. As long as the updraft is pumping warm, moist air into the cloud, it will be sustained.

Eventually, water droplets within the cloud become heavy enough to escape the hold of the updraft and begin to fall as precipitation. The downward momentum of the precipitation then results in the development of a “downdraft” which is a plume of downward-moving air. Once the downdraft leaves the cloud base, it is further strengthened by cooling below the cloud base as rain evaporates. The downdraft eventually reaches the ground. The *mature stage* is marked by the presence of both the updraft and downdraft within the cloud. In this stage, the cloud continues to grow, eventually reaching the tropopause (the top of the troposphere,) about 7.5 miles above the ground. Since air above the tropopause is very stable, it acts as a cap, preventing further vertical development. This causes the cloud to spread out horizontally, creating a distinctive anvil shape. It is also during this stage that lightning, hail, and strong winds at the surface can occur.

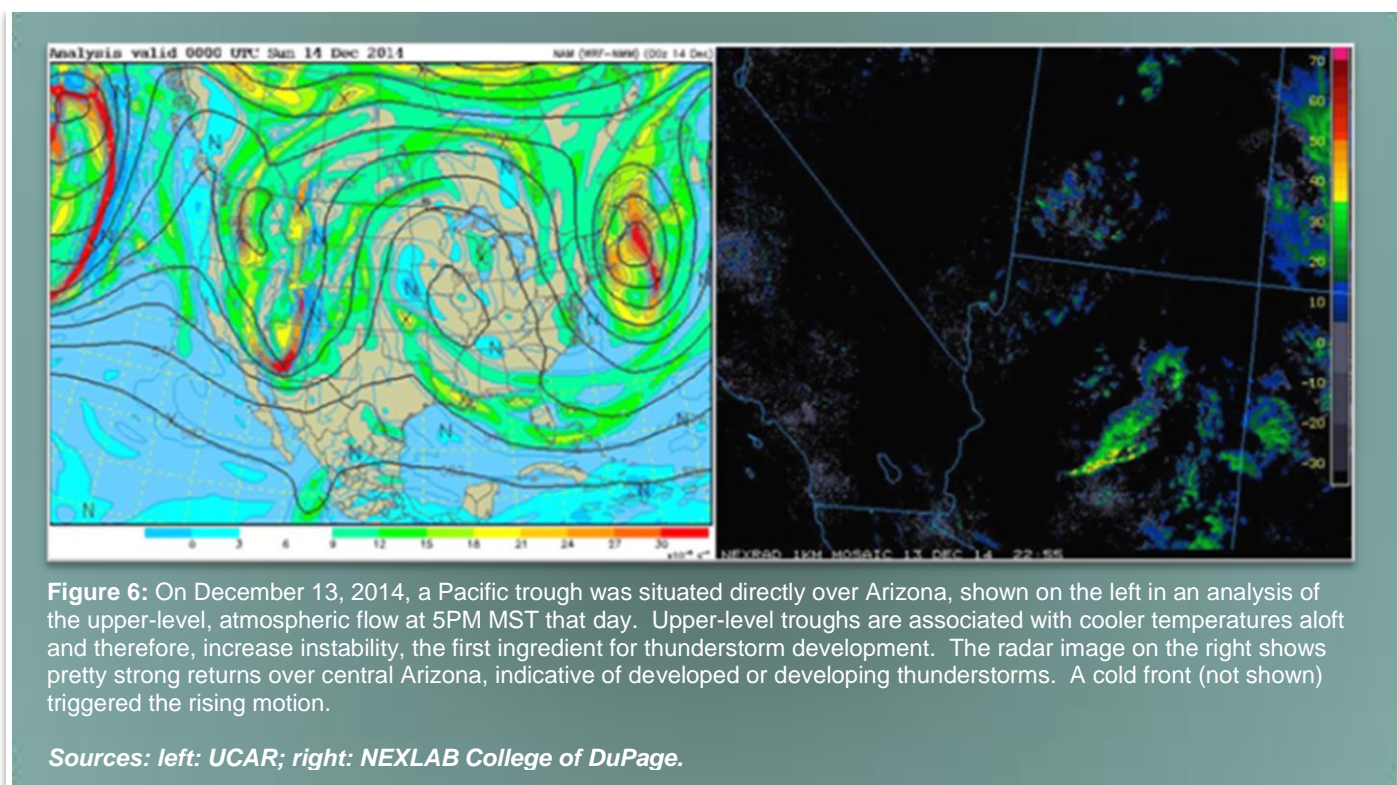
As the cool downdraft hits the ground, it spreads out in all directions. Eventually the “pool” of cold air at the surface cuts off the storm’s life-giving updraft. This ultimately ushers in the thunderstorm’s *dissipating stage* in which it weakens and finally dies out, leaving a remnant anvil.



## Thunderstorm Seasonality for Arizona

Thunderstorms can form during any time of the year if all the necessary ingredients are in place. In Arizona, these ingredients tend to come together most often during the summer monsoon season (learn more about the North American Monsoon [here](#).) Because of the combination of both strong solar heating and moisture during an active monsoon period, towering cumulus and cumulonimbus clouds can be seen developing over the higher terrain of north, east, and southeastern Arizona almost on a daily basis. The lower deserts of Phoenix and Tucson can see their own thunderstorms if enough moisture makes its way to these areas or if large scale winds blow thunderstorms from higher terrain to the valleys.

Thunderstorms are typically less common during the colder months since the atmosphere lacks instability due to the colder air at the surface. The best chance for thunderstorms to develop in the colder months is when an upper-level wave or Pacific trough moves over the Southwest (Figure 6). Troughs increase instability, initiate a low-level flow that taps into the Gulf's moisture, and are usually accompanied by a cold front at the surface.



## Impacts of Thunderstorms on Air Quality

Thunderstorms have a direct impact on the Valley's air quality. Let's look at how storms affect ozone and particulate pollution.

### *Particulate Matter (PM<sub>10</sub> and PM<sub>2.5</sub>)*

Thunderstorms cause dust storms. Recall from [our first publication](#) how a storm's powerful downdraft crashes to the surface and spreads out along the ground. The leading edge of this pool of cold air is essentially a front (called a "gust front"). If a gust front traverses the open desert, it can pick up large amounts of dust and transport it into the Valley. Dust storms often result from the consolidation of multiple gust fronts from several storms. This is why the development of thunderstorms over the open desert



south and southeast of the Valley is of interest to air quality forecasters at the Arizona Department of Environmental Quality.

The threat of dust storms is greatest during the onset of the monsoon (late June into mid-July) when the lower deserts emerge from the driest stretch of the year (April through June.) Gusty winds produced by nearby or overhead thunderstorms generally result in localized pockets of blowing dust, depending on how dry the soils are. This threat diminishes with the monsoon rainfall, which helps to stabilize soils and decrease the intensity of blowing dust as the season goes on.

Summertime thunderstorms also can result in higher concentrations of finer particles, reaching Moderate to Unhealthy levels on the Air Quality Index when dust concentrations intensify. Impacts of thunderstorms on finer particles such as soot are more often to occur in the cooler winter months, when soot is more of a public health concern because of increased wood burning and stronger inversions. In this case, however, thunderstorms actually improve air quality by helping to disperse accumulated soot concentrations with gusty winds or by filtering the air with rain.

### Ozone

Ozone levels typically improve when thunderstorms are present. Sunlight is necessary for ozone to form, and the towering cloud cover that comes with thunderstorms obstructs sunlight and reduces ozone production. Also summer wind intensity tends to be weak in the mid-levels of the troposphere, and thus thunderstorms move slowly and block sunlight for a longer period of time. Even if thunderstorms do not end up reaching the Valley, stronger winds higher in our atmosphere can blow the tops/anvils of distant storms over the Valley, blocking out sunlight (see Figure 7 for an example of this). [Read more about ozone production in detail here.](#)



**Figure 7:** Thunderstorms in southern Maricopa County are shown at 2:45PM on July 18, 2015 (left). Visible satellite imagery at that time (middle) reveals the tops of the storms being blown northward toward the Valley. Ground observation in Ahwatukee, AZ (right) shows an extensive band of high-level clouds expanding across the sky, beginning to block out the sun, which is at the top of the photo.

**Sources:** left and middle panels - UCAR; right panel - photo by Michael Graves.

Gustiness produced by nearby or overhead storms can also aid in mixing and dispersing ozone. Rain helps too, which acts to clean the air of ozone precursors (nitrous oxides and volatile organic compounds). However, timing of thunderstorms matters: it is possible to have storms and rain in the morning and still have high ozone levels in the afternoon if the rains and clouds have moved out. It's also possible for one part of the Valley to have clouds and/or storms and lower ozone levels while another part of the Valley is cloud-free and experiencing soaring ozone levels.

Thunderstorms: Pros and Cons	
PM-10 and PM-2.5	Ozone
<ul style="list-style-type: none"><li>• Rain stabilizes soils, reducing dust</li><li>• Gusty winds can generate blowing dust</li><li>• Outflows can generate blowing dust and dust storms</li></ul>	<ul style="list-style-type: none"><li>• Tall clouds block sunlight, reducing ozone production</li><li>• Gusty winds disperse ozone concentrations</li><li>• Rain washes air of ozone precursors</li></ul>

In this topic, we uncovered how thunderstorms form and how they affect air quality across Arizona. Overall, thunderstorms can both improve and worsen air quality, depending on the pollutant of interest. With a better understanding of thunderstorms and their effects on air quality, people sensitive and vulnerable to poor air quality can make more informed decisions regarding their outdoor activity.

See the helpful tips below for ways you can stay one step ahead of thunderstorms and their impact on air quality. We hope you have enjoyed learning about one of nature's most fascinating and powerful phenomena!

### Proactive things you can do:

- Stay informed with air quality forecasts from the Arizona Department of Environmental Quality
- Know the risk of thunderstorms each day, especially during the monsoon season
- Check the local radar (internet, smart phone apps, TV, etc.) for storms in/around your area
- Go indoors when storm outflows are approaching your location



For our next topic, the ADEQ Forecast Team will look temperature profiles of the atmosphere, surface inversions, and NO BURN DAYS.

Thanks for reading!

Sincerely,

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Help us by taking  
this survey.

Your feedback is  
appreciated!



## 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](#)



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

- Atmospheric Temperature Profile/Inversions/No Burn Days
- ENSO (A.K.A El Niño)
- All About Fog

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