Cracking the AQ Code

ADEQ Arizona Department of Environmental Quality

Air Quality Forecast Team

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Tools of the Air Quality Forecasting Trade Part 3: Satellite Imagery

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Have you ever imagined what it would have been like to have never seen a picture of the earth or know what it looked like from outer space? Considering the whole of mankind that has walked the earth over the ages, we are a minority in that we do know what the earth looks like, thanks to satellite and space technology. The first ever photos of earth from space were taken in the late 1940s by cameras attached to rockets. Later, accelerated by its space race with the Soviet Union during the Cold War, the United States developed and launched its first successful weather satellite on April 1, 1960. This satellite, the TIROS-1 (Television InfraRed

Figure 1. The first photo ever taken of earth by a weather satellite. The TIROS-1 snapped this image of the earth on April 1, 1960. A large mass of clouds can be seen in the bottom-right quadrant of the photo.

Source: NASA

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…

- You Ask, We Answer
- Stratospheric Intrusions: Ozone Transport from Above
- Fitness and Air Quality

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Observational Satellite), provided the next step in obtaining images and video of the earth from outer space (see Figure 1). Even though the TIROS-1 had a brief life, operating only for about 80 days, it was the initial spark that would expedite further advancements in weather satellite technology throughout the 20th century (space.com). We still continue to improve our weather satellites today.

The advent of the weather satellite proved to be a wonderful boon for meteorologists. Now with a view from above, meteorologists could better detect, track, and forecast weather systems and their cloud formations. Weather satellites would also become a vital piece in improving severe weather forecasting and result in more accurate and timely weather information for the public. Additionally, satellite technology would enable scientists to observe and/or measure global temperature and precipitation trends, changes in vegetation and soil moisture, ocean temperatures and circulations, atmospheric dust, smoke, and a myriad of other weather and climate variables. In this issue of *Cracking the AQ Code*, we will explore a variety of weather phenomena as they appear from space and see how these images can benefit air quality forecasting here in Arizona.

Types of Satellite Imagery

The three foundational types of satellite imagery include visible light imagery, infrared imagery, and water vapor imagery. Most satellite applications in weather and air quality forecasting involve these imageries. Each are briefly discussed below:

Visible Light Imagery

Visible light imagery is simply what the satellite sees by visible light, which originates from the sun. In other words, it is what the naked eye would see from space. Since this type of imagery relies on sunlight, it is not available during nighttime hours. Visible light imagery is useful for tracking weather systems, tracking atmospheric dust, locating snow and fog, and finding smoke from wildfires.

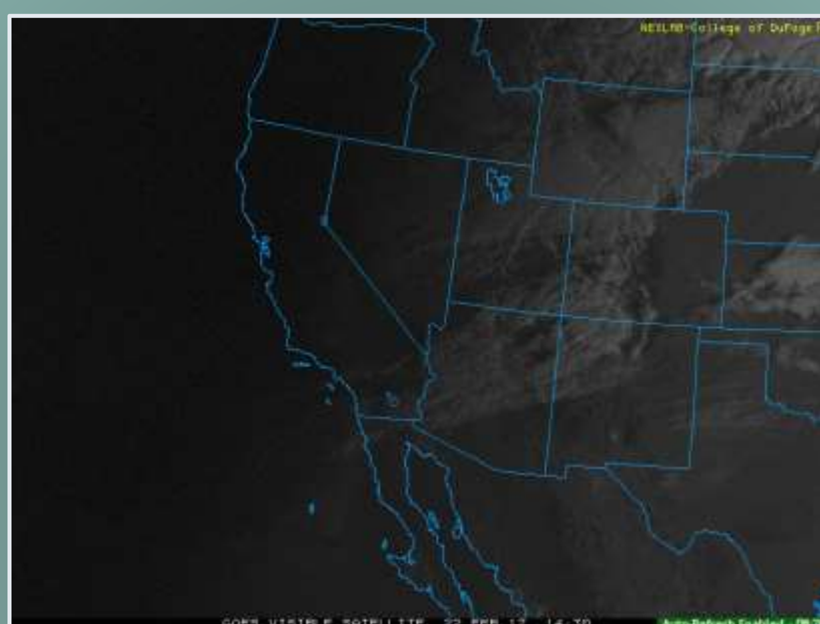

Figure 2. An example of a visible light satellite image taken over the western half of the U.S. at 7:30 AM MST on February 22, 2017. The sunrise line can be seen roughly from southern California, across central Nevada and through Idaho and western Montana. Much of the white over the Rockies is snow.

Source: College of DuPage

Infrared Imagery

Weather satellites also detect infrared radiation (IR), which is emitted into space by the earth's surface and clouds.

The amount of IR emitted into space by an object on earth is directly proportional to the object's temperature. For interpretation, relatively warm objects appear darker while relatively cold objects appear brighter. Since temperature decreases with altitude, clouds higher in the atmosphere will appear brighter than those closer to the ground. The tops of thunderstorms have the brightest returns, implying that they reach very high into the atmosphere. Often, IR images are "enhanced" with colors to help in highlighting certain features such as thunderstorms. Since IR is invisible to the human eye and does not depend on sunlight, it can be used during both the day and night. IR imagery is useful for tracking thunderstorms and weather systems.

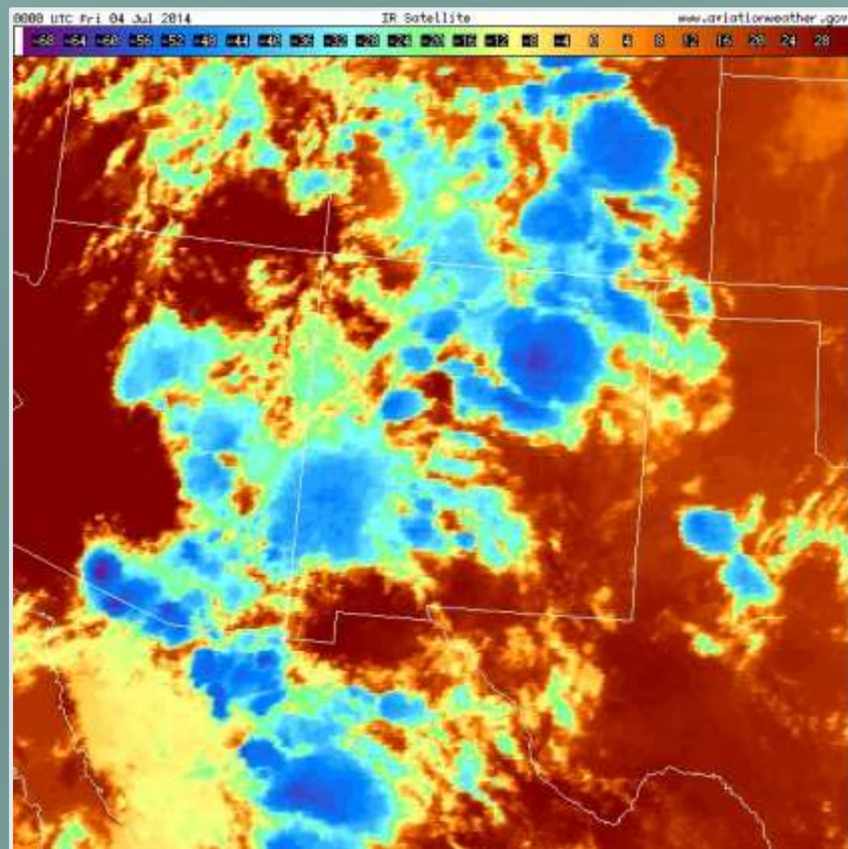

Figure 3. An example of an enhanced IR satellite image taken over the Southwest at 5:00 PM on July 4, 2014. In this image, thunderstorms have developed over the higher terrain in eastern and southern Arizona, central and northern New Mexico, and eastern Colorado. The darkest blues represent the coldest (highest) clouds and thus, the strongest thunderstorms.

Source: NOAA

Water Vapor Imagery

Lastly, weather satellites also have the capability to sense the presence of water vapor (the gaseous phase of water) in the upper levels of the atmosphere. This is possible because water vapor emits IR in a particular range of wavelength; if a satellite sensor is tuned into this wavelength range, it can detect atmospheric water vapor. Water vapor imagery is useful as it allows meteorologists to see patterns in air movement, the transportation of moisture, and the locations of jet streams in the upper levels of the atmosphere. This ultimately enables meteorologists to have a better understanding of the bigger picture of the atmosphere, which ultimately trickles down to weather at the surface. Like IR imagery, water vapor imagery is available during both the day and night.

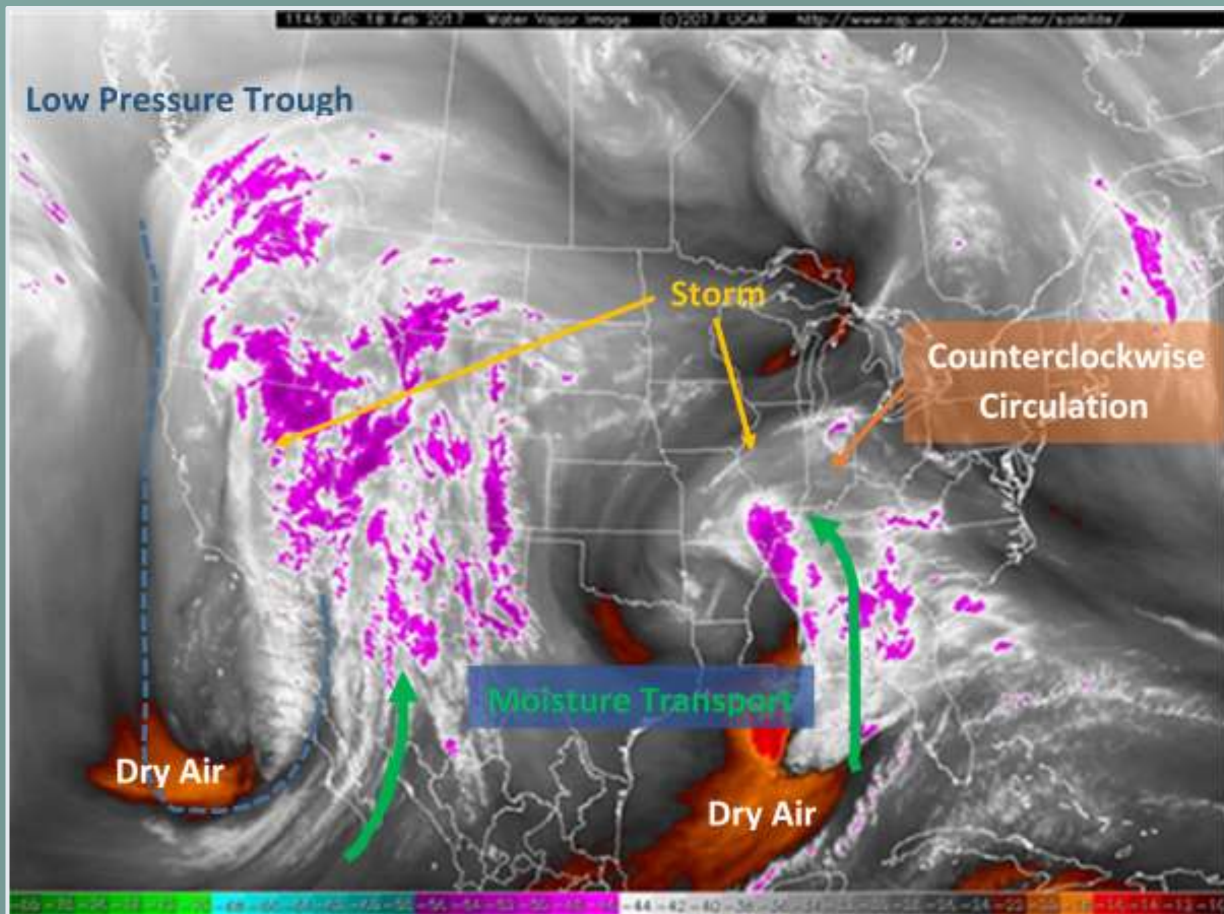

Figure 4. An example of an “enhanced” water vapor image taken over the United States near 5 AM on February 18, 2017. The purple colors in the water vapor image represent areas with the highest moisture content; white and grays are next on the scale; blacks, browns, and reds represent the driest air. There are two winter low pressure systems or storms in this image. Notice how both storms are drawing in moisture: the eastern storm drawing from the Gulf of Mexico and the western storm from the Pacific Ocean and Gulf of California. Pockets of very dry air also follow to the south of each storm.

Source: UCAR

You Ask, We Answer

For an upcoming issue of *Cracking the AQ Code*, we are opening up the floor to our readers. What would you like to know about air quality or weather here in Arizona? Your question just might be featured in this next topic!

Email us your question at: ForecastTeam@azdeq.gov

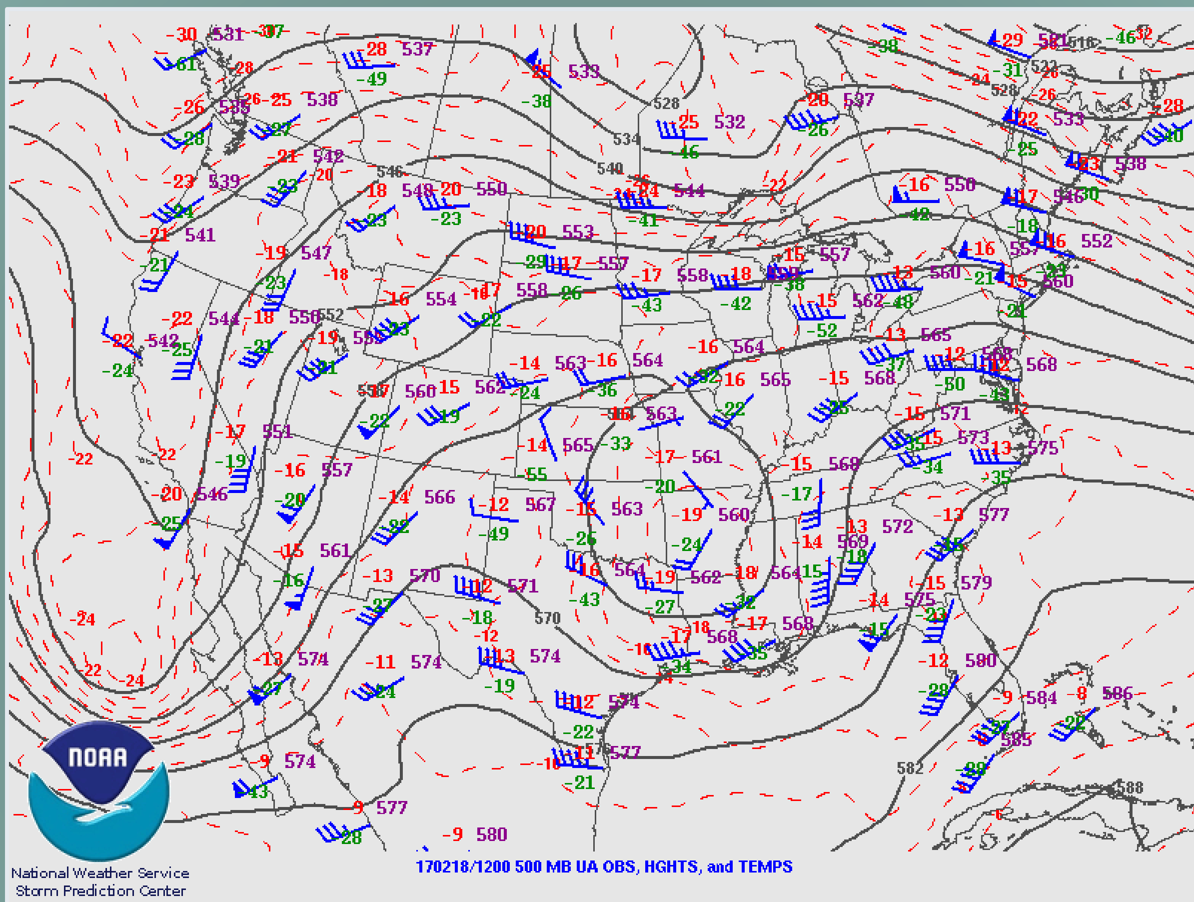

Figure 5. The upper-atmospheric weather map that corresponds in time with the water vapor image. This map shows the flow of winds approximately 18,000 ft. up in the atmosphere. Notice how the counter-clockwise circulation in the water vapor centered over northwestern Arkansas matches with the circulation in upper-atmospheric winds on the map. You can also see the shape of the deep low pressure trough located west of the Baja Peninsula in both the water vapor image and the map.

Source: NOAA

Satellite Imagery Online

All of these types of satellite imagery are readily available to the public online. Two good sources include: the National Weather Service and NOAA.

Weather and Air Quality Satellite Images

Now that we have an understanding of the basic types of satellite imagery, let's use them to explore what various weather and air quality phenomena look like from above.

Phoenix Dust

The photo below (Figure 6) is a natural color satellite image (like a visible light image) taken over central Arizona on July 6, 2011, the day after Phoenix experienced one of its largest dust storms ever (see insert photo). This image shows leftover dust (in blue circle) still lingering in and near the Valley. Dust levels are highest in north-northeast Phoenix. This is a good example of how satellite imagery can help air quality meteorologists monitor and predict the movement of dust.

Phoenix Dust

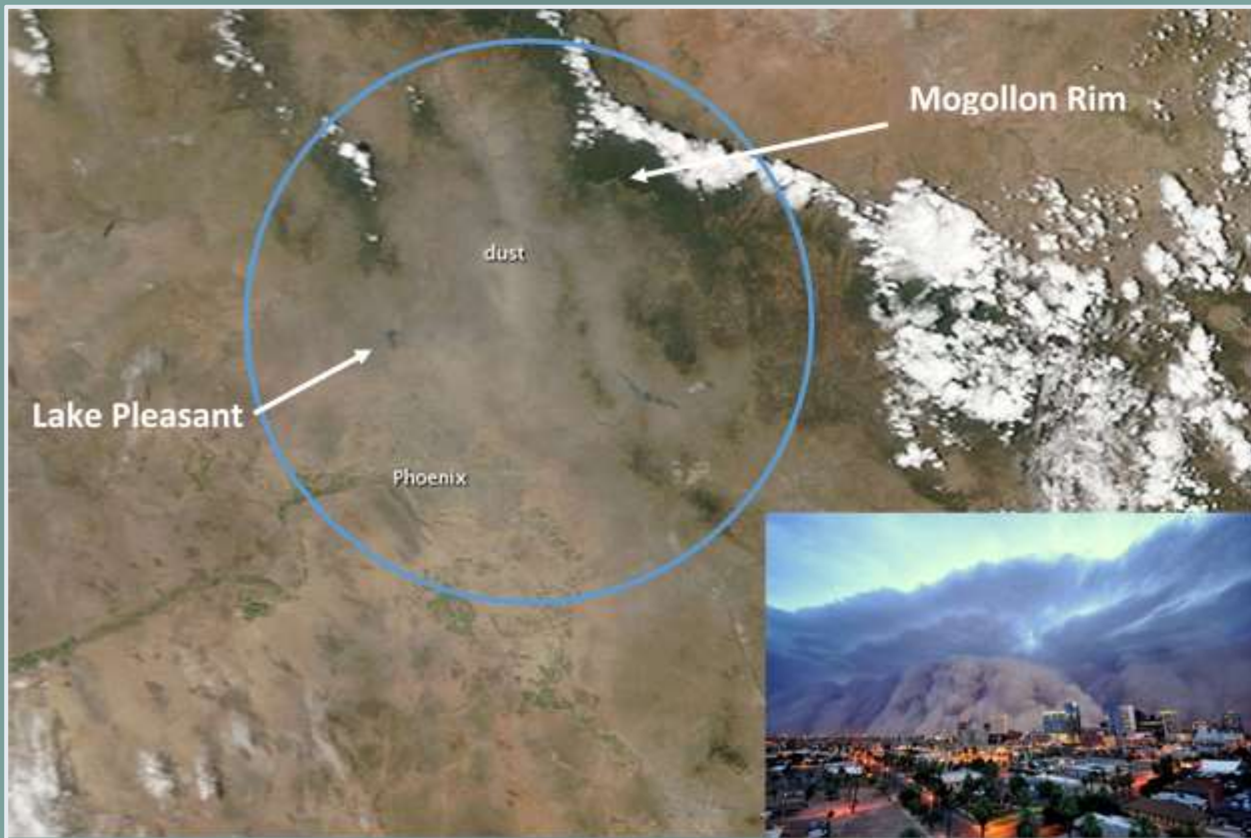

Figure 6

Source: NASA, Photo: Daniel Bryant

Australia Dust

The next photo (Figure 7) is a natural color satellite image (visible light image) taken over eastern Australia on September 23, 2009. This image shows a dust storm reaching the eastern coast of the continent, with its movement denoted by blue arrows. This was one of the region's worst dust storms. In a case like this, satellite imagery can help air quality meteorologists alert the public of an approaching dust storm and estimate how long dust is expected to stick around once it arrives. Of course, they will have constantly updated images to monitor the progression of the storm. Learn more about the event here.

Southwest Wildfire

Visible light satellite images can also show the spatial extent of smoke from large wildfires. The following two photos in Fig. 8 are two visible light images of wildfire smoke that impacted California and Arizona. The top image shows the Lake Fire burning in San Bernardino National Forest, California. This wildfire burned about 31,359 acres in total, beginning on June 17, 2015, and being completely contained by July 1, 2015. This satellite image helps to reveal the transport of the smoke from the fires into central Arizona.

Smoke, which contains ingredients for ozone, can play a role in increasing ozone levels in the Valley; air quality meteorologists can thus use satellite imagery to anticipate the potential for increased ozone levels in the Valley. Smoke also consists of PM-2.5 (fine particulates), which can cause breathing problems for the general public in heavy quantities, but especially for sensitive populations. In the bottom image, the Wallow Fire burns in east-central Arizona. This wildfire consumed a total of 538,049 acres in Arizona and New Mexico, beginning on May 11, 2011, and being fully contained on July 8, 2011.

Australia Dust

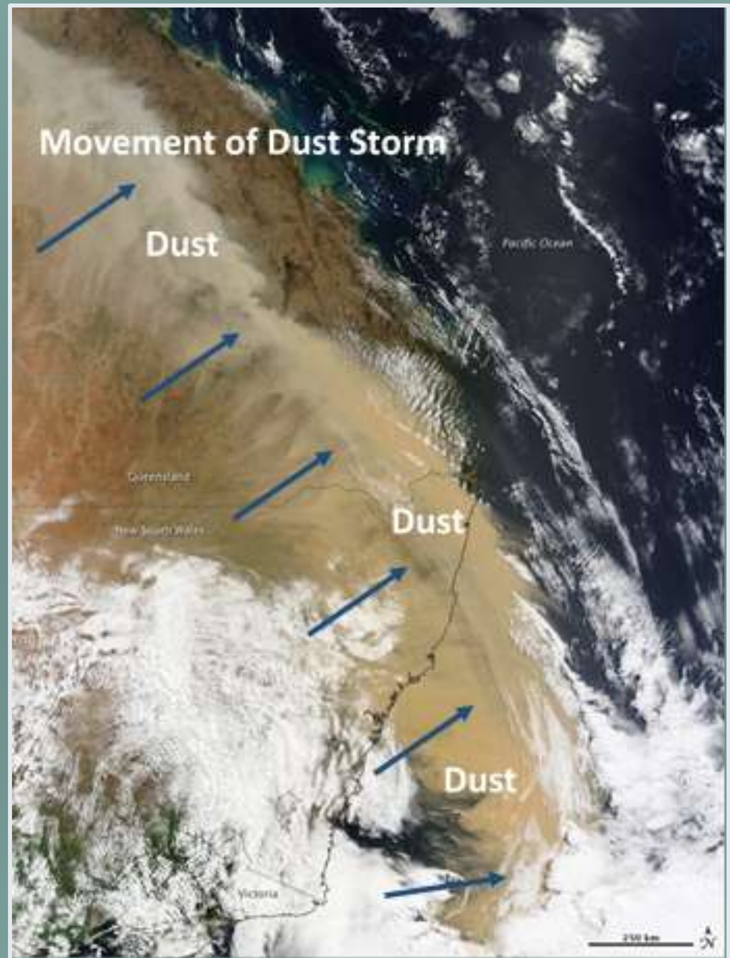

Figure 7

Source: NASA

Southwest Wildfires

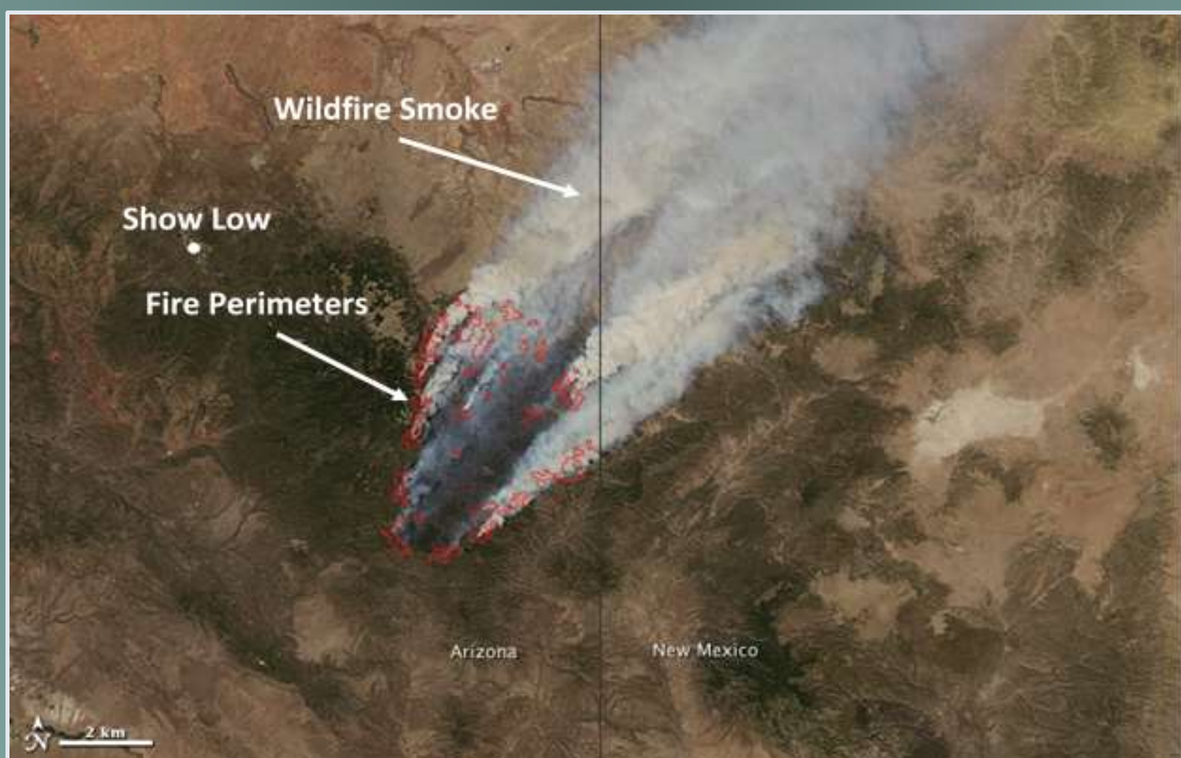

Figure 8

Source: NASA (MODIS)

Pacific Storms and Cold Fronts

Another benefit of satellite imagery is that it can aid meteorologists in analyzing surface weather conditions. In the image box below (Figure 9), the photo on the left is an infrared (IR) satellite image showing the cloud structure of an incoming Pacific storm and its cold front around 2 PM on February 9, 2017. On the right, a surface weather map elucidates the location of the Pacific storm and its cold front (blue line with spikes). Notice how the clouds in the satellite image and the cold front on the map have a very similar orientation. A red “L” has been added to the satellite image to mark the center of the low pressure system.

Pacific Storms and Cold Fronts

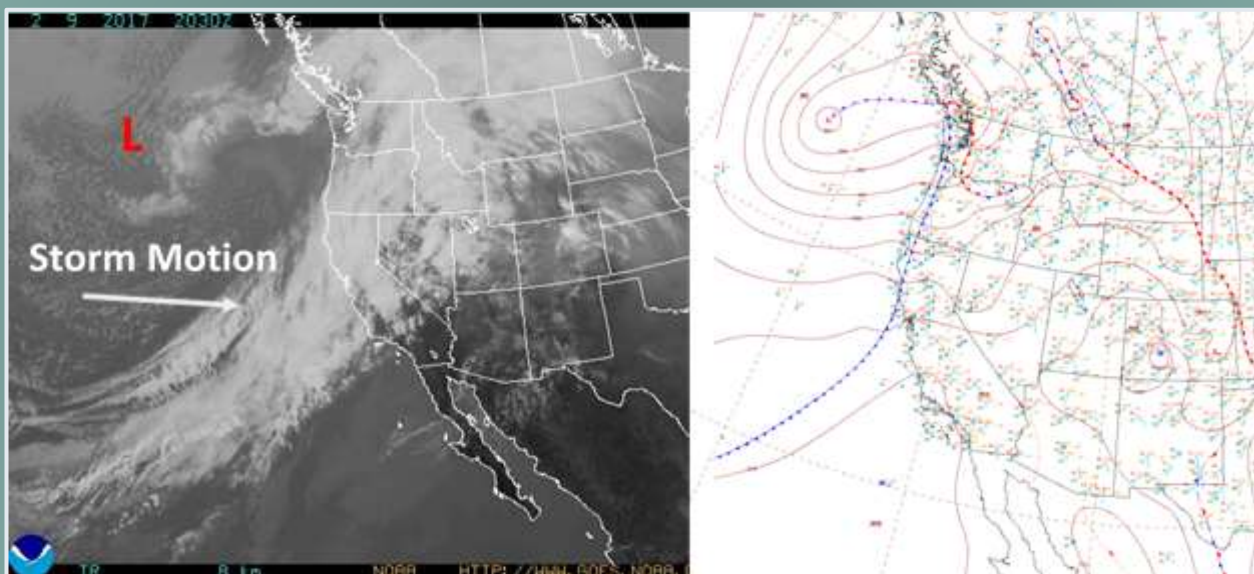

Figure 9

Source: NOAA

Air quality meteorologists can use this information to estimate the timing of weather systems and therefore, the timing of their impact on air quality. For this particular system, it was anticipated several days out that air quality would improve due to forecast winds and rain. Sure enough, the front passed through the Valley on the afternoon of the 12th and particulate levels (both PM-10 and PM-2.5) decreased.

Thunderstorms – Night

Fig. 10 is a combination of an enhanced IR image (top left), a visible light image (top right), a water vapor image (bottom left), and a radar image (bottom right) visually detailing thunderstorms over Arizona between 9:30 and 10:00 PM, July 20, 2013. The enhanced IR satellite image shows the presence of thunderstorms over central, northern, and northwestern Arizona at 9:45 PM. The darker oranges represent the areas where the thunderstorms are the highest and therefore, most intense. The visible light satellite image was taken at the same time. Since it is night, the visible light sensor does not pick up on anything. This is where IR imagery has an advantage over visible light imagery.

Thunderstorms - Night

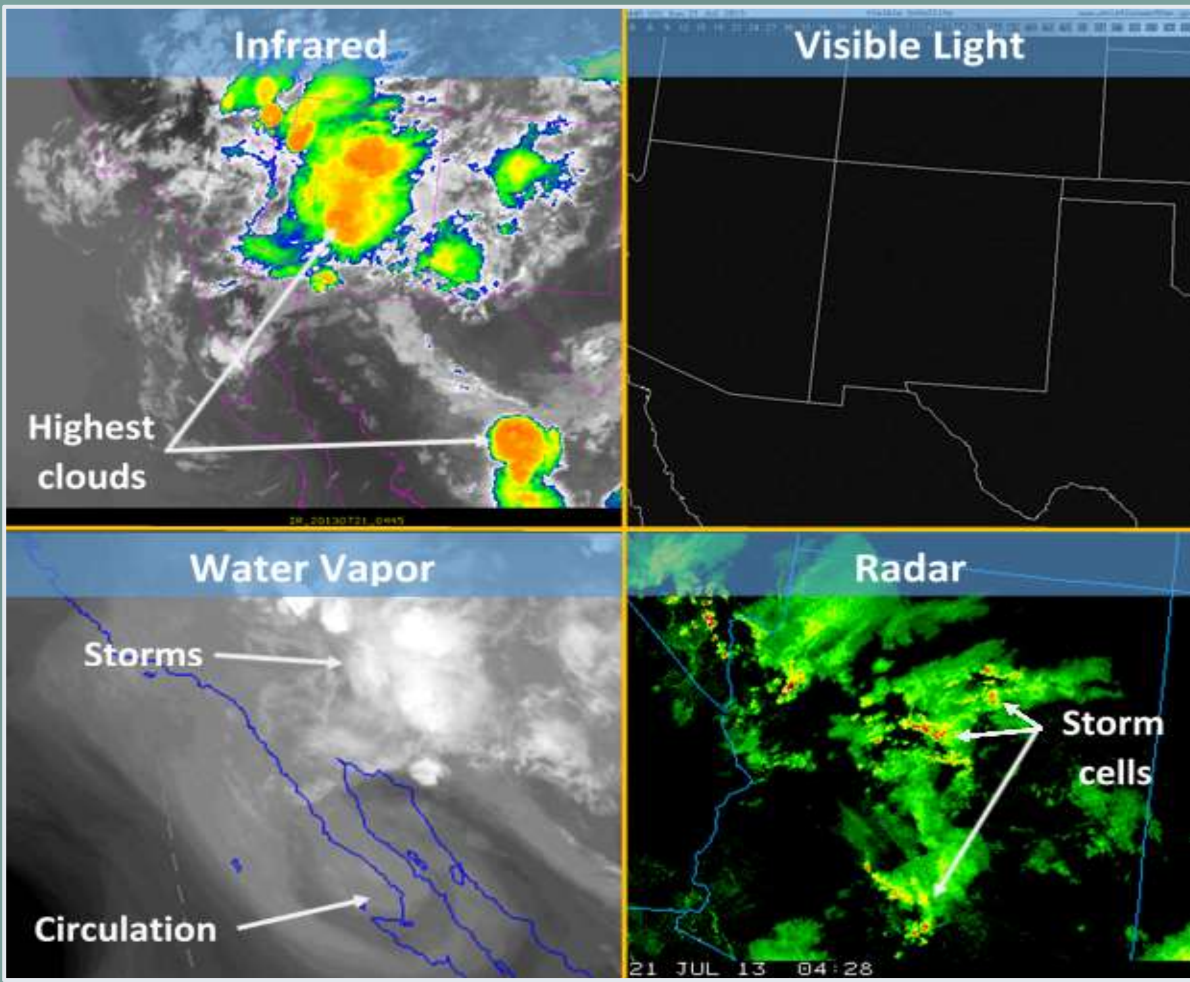

Figure 10

Sources: NOAA GOES, UCAR, UW Online Weather Data Archive

The water vapor image shows the upper-level moisture associated with the storms at 10:00 PM. It is clear that moisture is greatest in the storms. Notice the circulation of moisture centered over the Baja Peninsula, which is not readily apparent in the IR image. The radar image is a snapshot of the storms at around 9:30 PM. Notice how the storm cells on the radar (reds, oranges) fall under the most intense areas on the IR image. For air quality purposes, IR and water vapor imagery can help reveal where cloud cover left over from thunderstorms may linger overnight and into the morning hours. If such cloud cover remains into the next day, it can delay both local ozone production and thunderstorm development, depending on how long it sticks around.

Thunderstorms – Day

Often during the monsoon season, thunderstorms move slowly due to weak winds in the middle levels of the atmosphere. However, winds higher up in the atmosphere are stronger. These stronger winds blow the “anvils” or tops of thunderstorms out ahead of the storms. This ultimately provides cloud cover for locations a distance away from the storms themselves. In the next image

Thunderstorms - Day

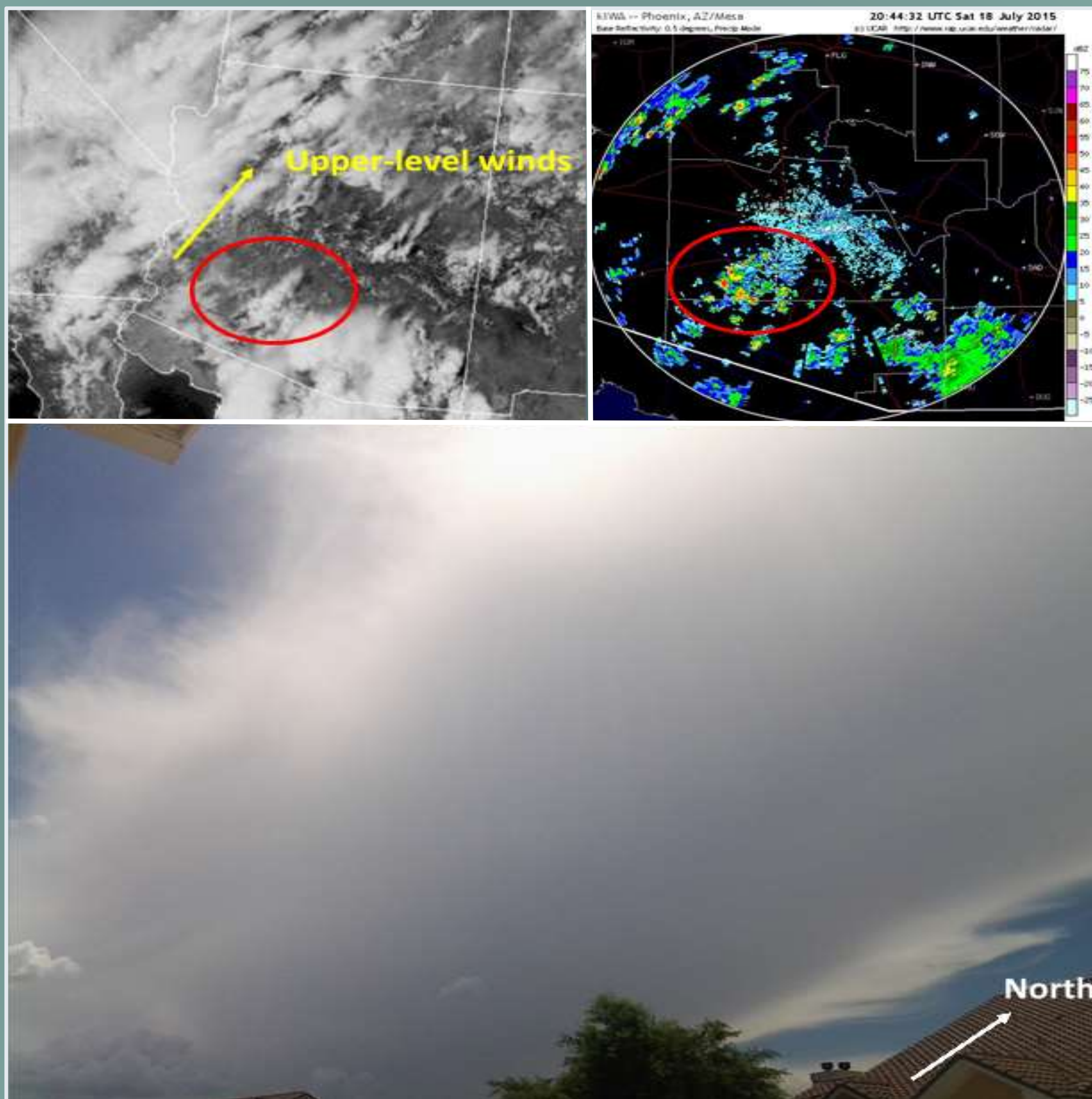

Figure 11

Sources: UCAR; photo: Michael Graves

box (Figure 11), the top left image is a visible satellite image showing high-level clouds streaming over the Valley from storms in southern Maricopa County (in red circle) at 2:45 PM on July 18, 2015. The direction of the strong, upper-level winds is denoted by the yellow arrow. The top right image is a snapshot of the radar display at the same time revealing the location of the storms over southern Maricopa County.

The photograph on the bottom is a ground observation in Ahwatukee of the extensive band of high-level clouds expanding across the sky. Air quality-wise, such extensions of clouds over the Valley can help reduce local ozone production as they block out sunlight. A satellite image would help to reveal the extent of the clouds and thus, where local ozone might be reduced.

Atmospheric Rivers

Another atmospheric phenomenon for which satellites are useful to see are “atmospheric” rivers, or streams of water vapor that can stretch for thousands of miles across the Pacific Ocean. Sometimes this phenomenon is dubbed, “The Pineapple Express” since it can originate from near the Hawaiian Islands. The next two images in Fig. 12 are water vapor satellite images (the top one enhanced) showing examples of atmospheric rivers.

Atmospheric Rivers

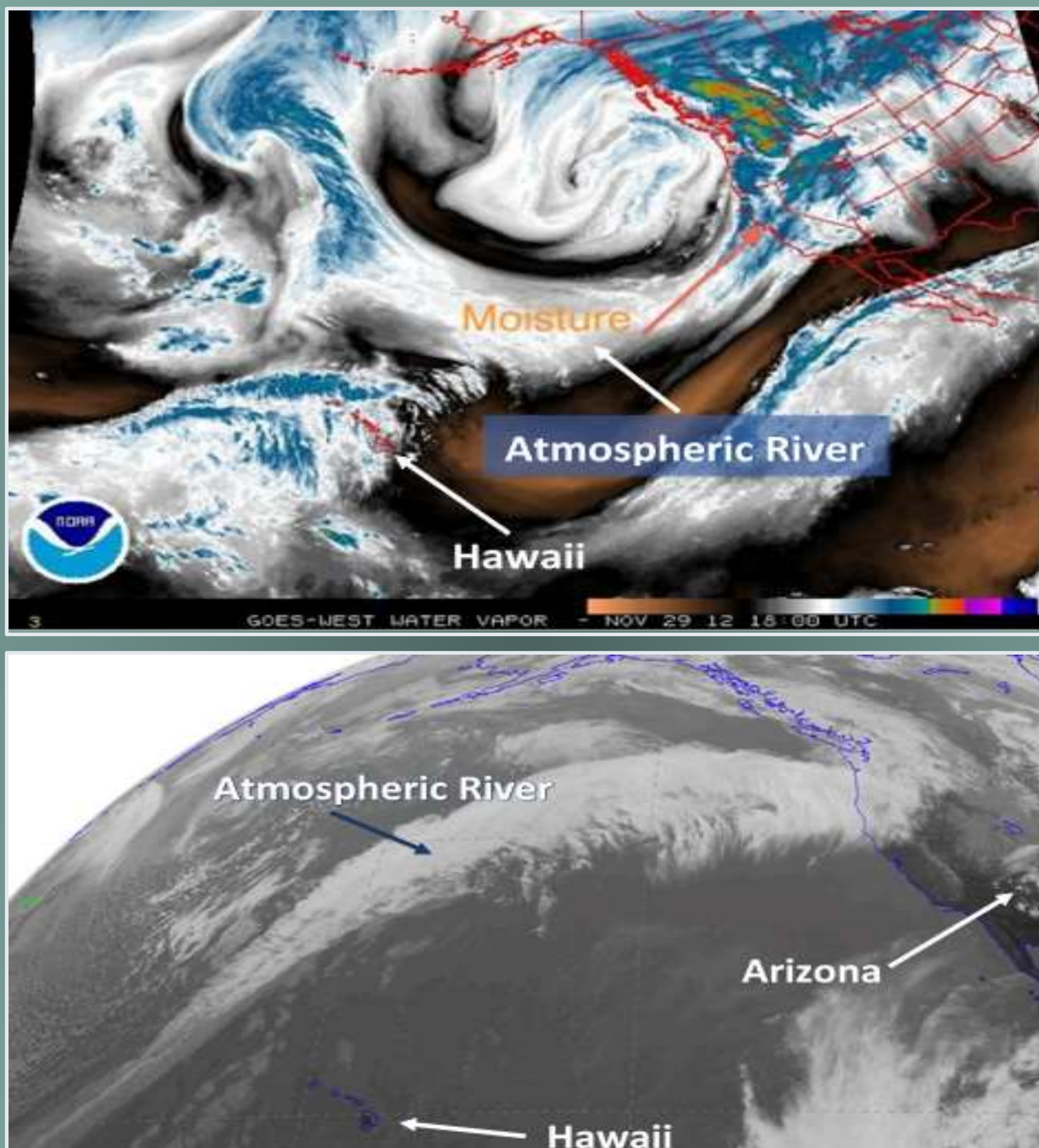

Figure 12

Sources: NOAA. UW Online Data Archive

Atmospheric rivers are of interest to meteorologists because they can transport copious amounts of moisture into the U.S. mainland. As they run into the mountains of California, moisture is squeezed out and heavy rain results. These are known to cause persistent heavy rains in California and can lead to flooding. Furthermore, atmospheric rivers can provide moisture for storm activity and precipitation in Arizona. If a winter storm on course to affect Arizona can tap into the moisture of an atmospheric river, air quality meteorologists can expect the potential for rain and therefore good air quality.

Fog

Below in Fig. 13 is a visible light satellite image showing a widespread fog event over northern Arizona on November 30, 2013. Rain fell across northern Arizona between November 20 and 24 due to a large and strong winter storm that slowly moved over the state. Behind this system, high pressure developed over the region. The combination of wet soils from the rain, colder air, and stagnant conditions resulted in widespread fog. Satellite imagery helps to reveal the extent of the fog as well as imply stagnant conditions across the state. Stagnant conditions are favorable for higher particulate (PM-2.5) levels. Learn more about Arizona [fog](#) here.

Fog

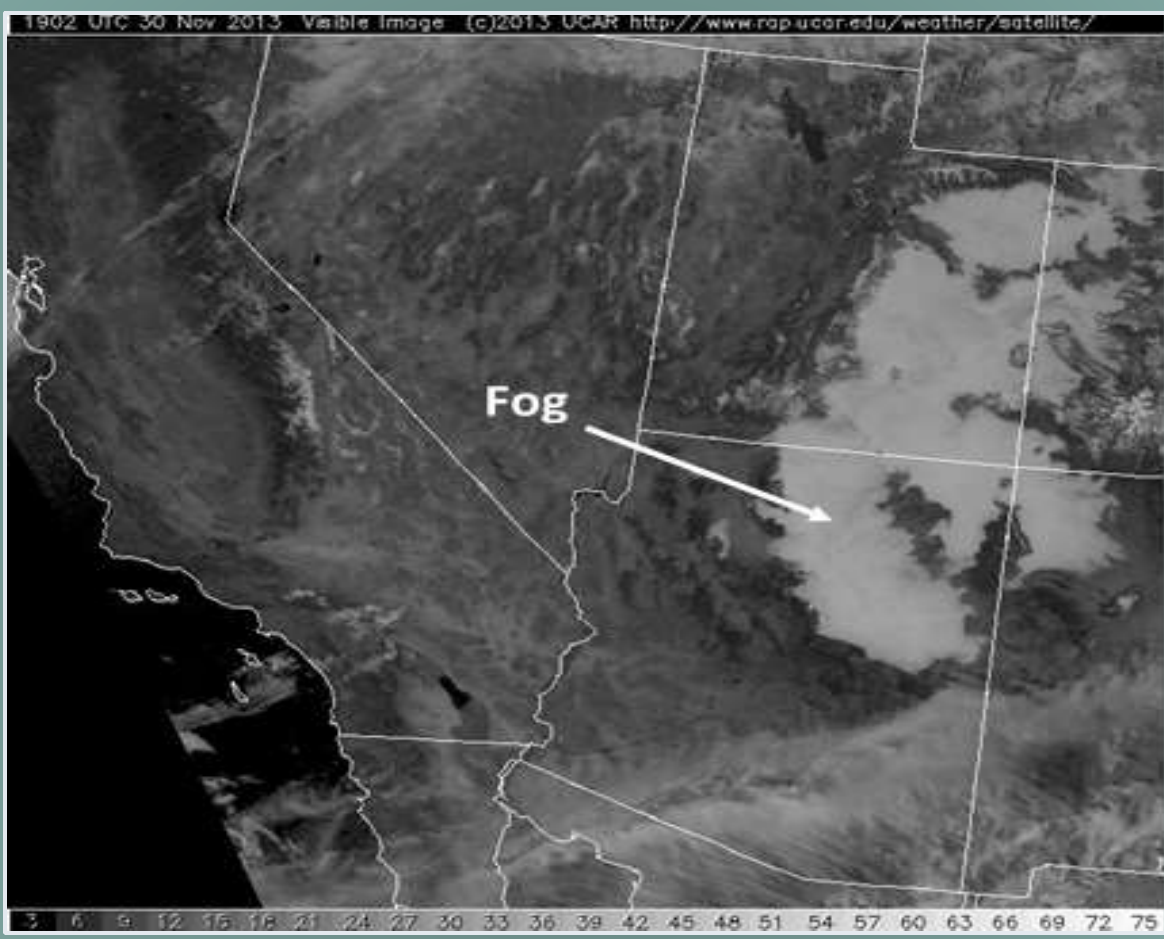

Figure 13

Source: UCAR

Summary

One of the first steps of the scientific method is observation—if you want to learn more about something in nature, you have to observe it first. As we have seen from the above examples, satellite imagery is an extremely useful tool when it comes to studying, learning about, and predicting what goes on in the earth's atmosphere. Air quality is no exception. Satellite imagery has proven to be indispensable in giving air quality meteorologists a bird's eye view of various phenomena that impact society's air quality. Consequently, air quality forecasts can be more accurate and the public can make more informed decisions.

We hope you have enjoyed our exploration into satellite imagery and its usefulness for weather and air quality forecasting!

Also, don't forget to send in your questions about air quality or weather in Arizona!
Email us at the address below.

Sincerely,
The ADEQ Forecast Team
ForecastTeam@azdeq.gov

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…

February 2016: All About Fog
April 2016: Jet Streams and Fronts
May 2016: Consequences of the New Ozone Standard Change
July 2016: Tools of the Air Quality Forecasting Trade Part 2: Predicting and Tracking Wildfire Smoke
August 2016: Dust in Arizona and Around the World
September 2016: Tropical Cyclones
October 2016: Arizona Tornadoes
November 2016: Arizona Prescribed Burns
December 2016: $PM_{2.5}$ in Arizona and around the World
February 2017: Outdoor Carbon Monoxide: the Pollutant of Yesteryear
For Full Archive (2015-2016): Click Here

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

-You Ask, We Answer
-Stratospheric Intrusions: Ozone Transport from Above
-Fitness and Air Quality

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