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: Weather Forecast Models

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Try to imagine what life was like in the early twentieth century, before multiple-day weather forecasts were a possibility. How would you make weather-dependent decisions? Would you ever dare to plan something a few days in advance and just hope for tolerable weather? Fortunately, this is not our reality today. Weather forecasts—and air quality forecasts—are readily available, *every day*. And for many of us, they are just a tap away on our smartphones (Figure 1). But how does this information come about? In large part, we can attribute it to weather forecast models.

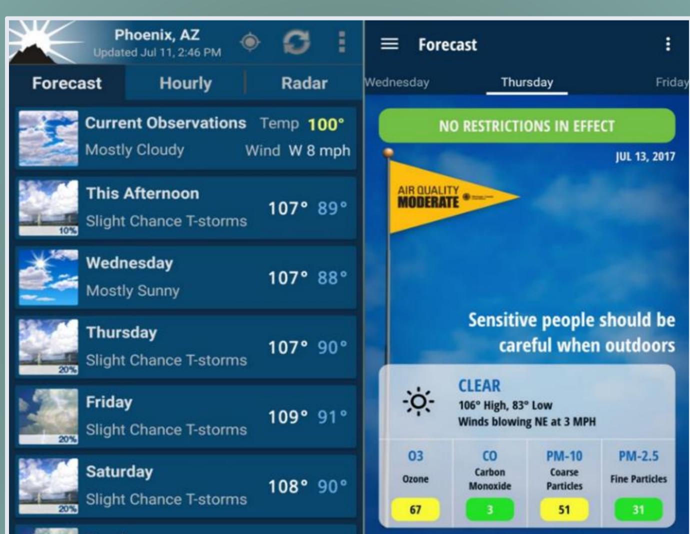

Figure 1: Smartphone apps displaying weather forecast (left) and air quality forecast (right) information for Phoenix, AZ.

Source: Granite Apps (left); Clean Air Make More app (right)

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…

- Organized Thunderstorm Systems
- Chaos Theory

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In this issue of *Cracking the AQ Code*, we will explore the world of weather forecast models and how we use them to forecast air quality in Arizona.

The Weather Model Process

At the center of weather model prediction is the idea that we can describe the movement of the atmosphere through a set of mathematical equations. We won't get into the tangle of all the numbers and variables—all you need to know is that these equations take in current weather information and produce projected pressure, temperature, moisture, winds, rainfall, etc. (Figure 2). Values for these weather conditions are calculated at regularly-spaced grid points throughout a set geographical domain (see Figure 3), at various levels up through the atmosphere, and at regular time increments

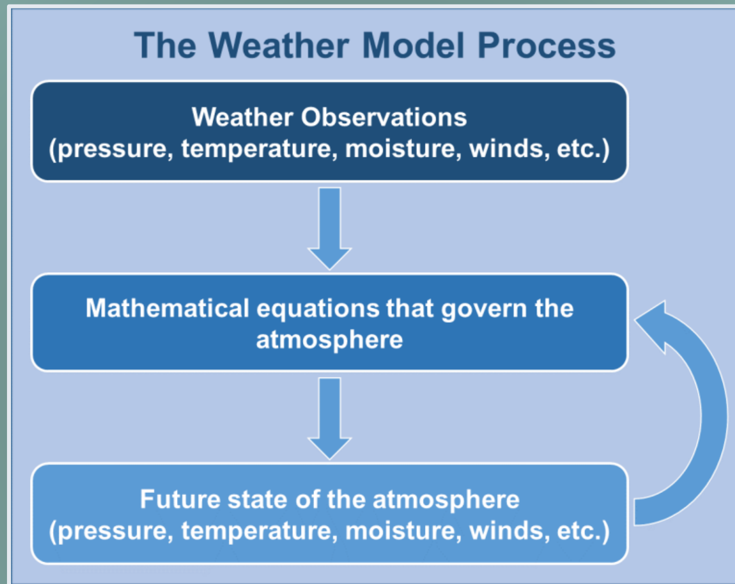

Figure 2: A simple diagram of the weather model process. Once the model produces a forecast for the future state of the atmosphere, the new forecast values are reinserted into the equations to yield another forecast, but slightly further in time. This process repeats itself until the model reaches its end time.

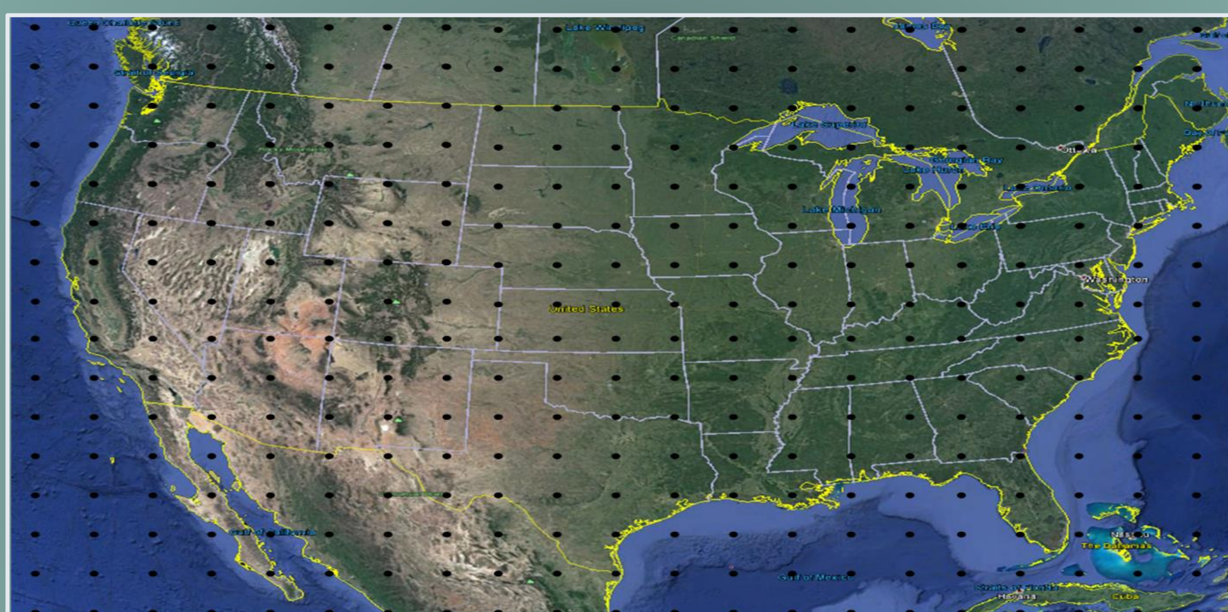

Figure 3. A general illustration of grid points in a domain encompassing the U.S. (this not an actual model). The mathematical equations that govern the atmosphere would be calculated at each grid point.

Source: Google Earth, grid points added

into the future, up to a desired forecast time. The end result is a picture of how the atmosphere is changing in both time and three-dimensional space.

Not Perfect, But Useful

Now, before we become gung-ho over weather forecast models, we should take to heart what a famous statistician once said: “All models are wrong, but some are useful” (George E. P. Box). Weather models, amazing as they may seem, are essentially wrong. This stems from the fact that imperfections permeate the whole forecast weather model process (Figure 4). Consequently, weather forecasts become more and more inaccurate the further they go out in time (we’ll expound upon this subject in a future issue of *Cracking the AQ Code*).

Weather Forecast Model Limitations

- **Weather observations going into models can have errors**
- **Models have to guess current weather conditions where observations are sparsely located**
- **The models’ equations don’t perfectly describe atmospheric processes**
- **The way the equations are solved has inherent error**
- **Smaller atmospheric or terrain features can be missed when they fall in between grid points on which calculations are made**

Figure 4: A list of limitations intrinsic to weather forecast models. Each item in the list results in a degree of error in the model. The last item can be visualized by looking at Figure 3 again. Notice how there is quite of bit of space in between grid points; much meteorological and geographical detail would thus go unrepresented by a given model.

However, when observations going into a model are available and reliable, a weather model could potentially make a useful prediction up to a week. Of course, during actively changing weather, this period may be much less (Figure 5). It ultimately takes an experienced meteorologist to know how much of a model’s results are sufficiently accurate and how much should be disregarded. Overall, weather models are only tools, *sometimes* useful, and should always be taken with a grain of salt.

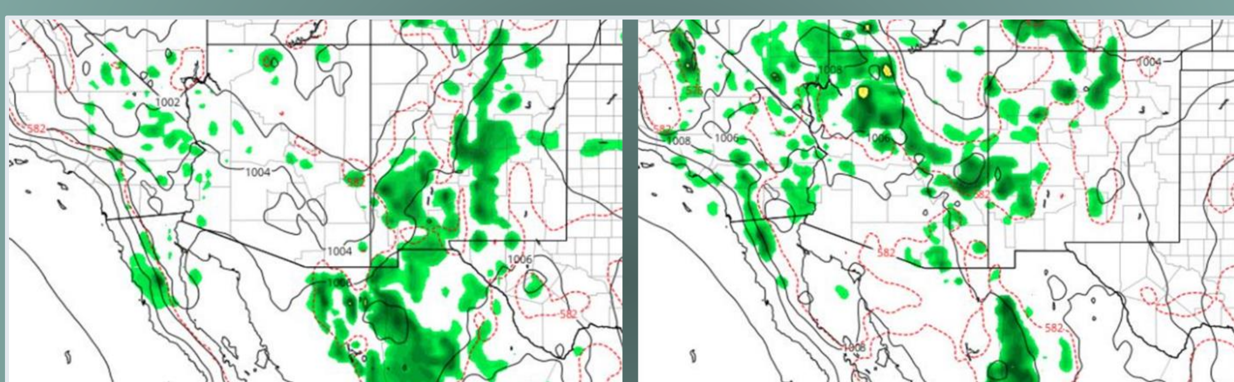

Figure 5: Two precipitation forecasts by the same model for the U.S. Southwest, valid at 5 PM (Arizona time) July 24, 2017. On the left is the model’s forecast when it was run at 5 AM July 20, on the right, at 5 AM July 21. Notice the difference in precipitation over northern Arizona and northern Mexico. This contrast shows how active weather can be difficult for models to handle. This kind of “flip-flop” introduces uncertainty into a weather or air quality forecast.

Source: Tropical Tidbits

Types of Weather Forecast Models

Before we dive into how weather forecast models can be applied to air quality forecasting, let's meet several of the models themselves. There are two main types of weather forecast models that we use: low-resolution models that cover large geographical areas such as countries or continents, and high-resolution models that focus more on regions, such as the Southwest, or states, such as Arizona. In general, high-resolution models are better at capturing small-scale weather features such as individual thunderstorm cells and dust storms, while low-resolution models can be used to project general weather patterns over the continent. The most common low-resolution models are the Global Forecast System (GFS) model and the North American Mesoscale (NAM) model. An example of a high-resolution model is the Arizona Regional Weather Research and Forecasting (AZ-WRF) model.

Weather Forecast Models in Action!

Now that we have a better idea on how weather forecast models work and are familiar with several of the models, let's explore how they can be used to forecast air quality on an active [monsoon](#) day! The following examples are weather model forecasts for weather conditions at different times on Tuesday, July 18, 2017.

5 AM Tuesday: Upper Atmospheric Flow Forecast

One of the most important things we consider when forecasting for the weather and air quality is the predominant wind flow pattern within the upper levels of the atmosphere. This can be seen in such maps as to the right, which shows a GFS model forecast for wind speed and direction in the upper levels of the atmosphere (approx. 18,000 ft.) for 5 AM on Tuesday. Winds flow parallel to the black contour lines. Areas where contour lines curve northward are called "ridges" and mark areas of high pressure; areas where they curve southward are called "troughs" and mark areas of low pressure.

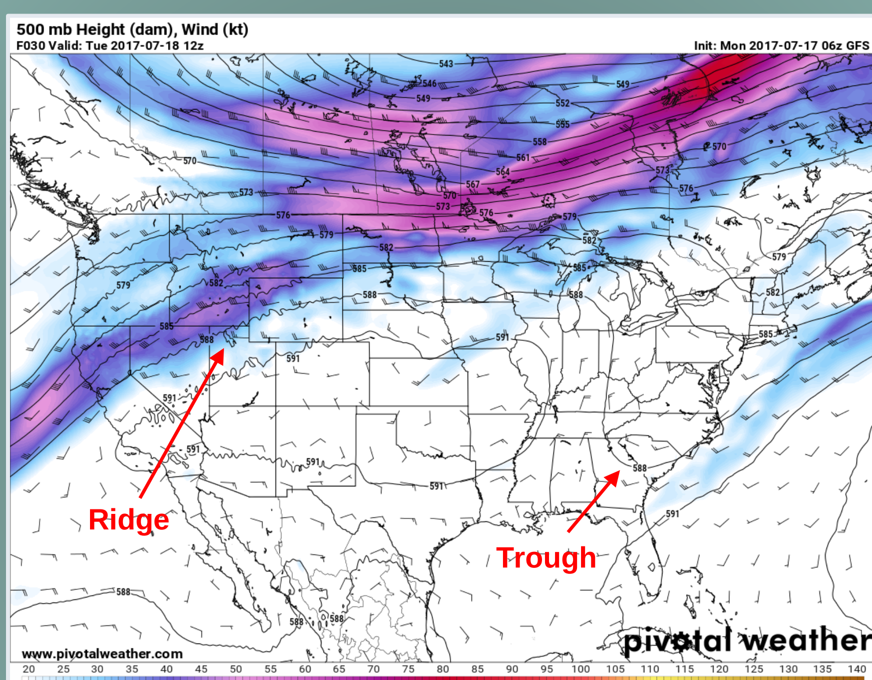

Figure 6. A GFS forecast map of the wind flow pattern in the upper levels of the atmosphere (~18,000 ft.) for 5 AM Tuesday.

Source: [Pivotal Weather](#)

In Figure 6, a large ridge of high pressure is forecast to continue dominating over the Southwest and southern Plains states on Tuesday (broad ridges are often slow-moving). The wind pattern over Arizona—winds out of the east—is a common signature of the monsoon, which helps to bring in moisture from the Gulf of Mexico and northern Mexico. This means we would expect another active day of thunderstorm development over the higher terrain in southeast Arizona and in the high country to the north. We would key into this meteorological setup since it is often favorable for thunderstorm outflows affecting the Valley, particularly from the south/southeast. As a result, blowing dust may be a potential threat in the late afternoon/evening hours. However, before making that determination, let's look at moisture to see if thunderstorms themselves could potentially reach the Valley.

8 AM Tuesday: Dewpoint Temperature Forecast

One of the primary ways we examine moisture in the atmosphere is by looking at the surface dewpoint temperature (we'll just call it the dewpoint henceforth). The dewpoint is basically the temperature at which air can no longer hold in any more water vapor (it would condense into a cloud at that air temperature). The dewpoint is useful because it is an indication of the amount of moisture in the atmosphere—the higher the dewpoint, the more moisture that is present. Furthermore, moisture is important because the greater it is, the more fuel there is for thunderstorms.

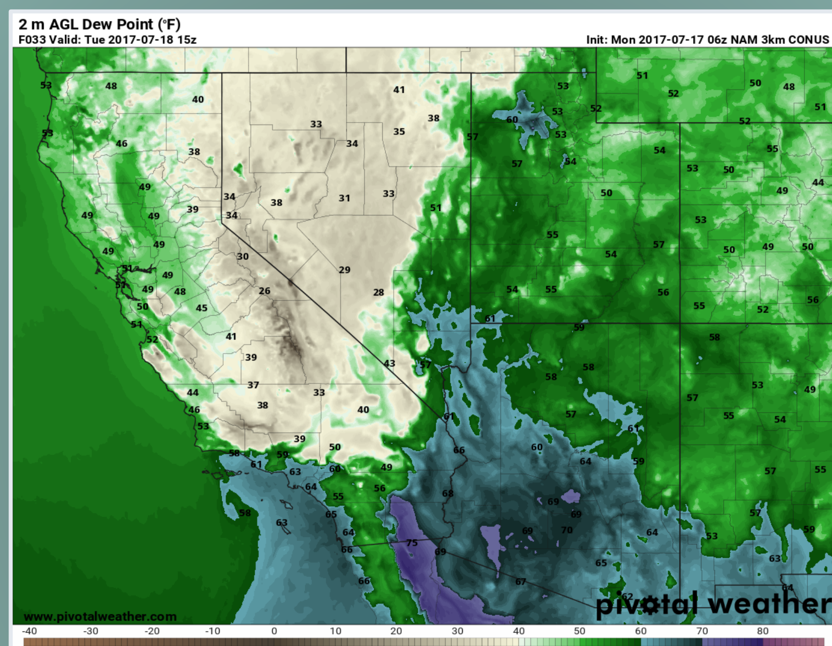

Figure 7. A high-resolution NAM forecast of the surface dewpoint temperature, focused on the U.S. Southwest, for 8 AM Tuesday. Note: Sometimes, the NAM model is used with even a higher resolution than its more common, low-resolution counterpart, as seen here.

Source: Pivotal Weather

The map in Figure 7 is a dewpoint forecast produced by a high-resolution model for Tuesday morning for 8 AM; the blue and purple colors indicate higher dewpoints. This forecast tells us that there would be plenty of moisture available to fuel thunderstorms throughout central and southern Arizona. If the model's conditions verify, outflows from thunderstorms that form over higher terrain would have a better chance at triggering new thunderstorms further away. This would be good news air quality-wise, as there would be a better chance for heavy rains to follow dust-bearing thunderstorm outflows.

2PM Tuesday: Cloud Cover Forecast

Another consequence of a lot of thunderstorm activity is cloud cover. For one, as thunderstorms reach towering heights, they block out sunlight. Then, once thunderstorms run through the course of their lives, they leave behind “debris clouds”, potentially resulting in an overcast sky. Clouds are of interest to air quality forecasters because they can interrupt the process of ozone formation (which requires sunlight). However, the timing and duration of cloud cover matters. Cloud cover from overnight thunderstorms lingering long enough in the morning can delay the ozone formation process; also, cloud cover early enough in the afternoon can shorten the daily ozone formation cycle. This gets tricky, though, as there is often uncertainty surrounding the arrival time of thunderstorms and/or cloud cover.

Figure 8 shows a cloud cover forecast for Tuesday afternoon at 2 PM by the GFS weather model. Greater cloud cover is represented by the white colors. The “BKN” (“broken” clouds) over Phoenix in the early afternoon hours indicates mostly cloudy skies. Unfortunately, new ozone formation would still be possible under such sky conditions since sunlight can still have a chance of interacting with ozone precursors near the ground. In fact, it could be possible for one side of the Valley to have higher ozone than the other side, depending on the distribution of clouds. Cloud cover is just one factor affecting potential ozone concentrations; for a more complete picture, we would explore other model forecasts, such as simulated radar reflectivity.

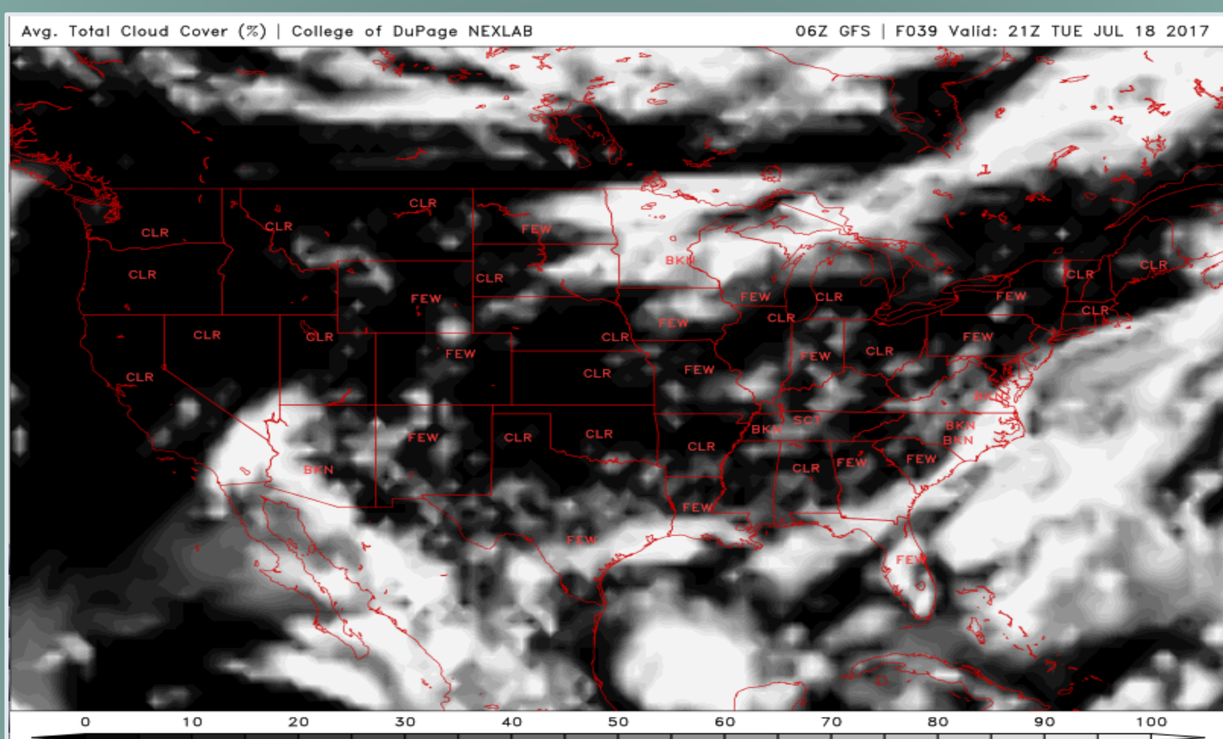

Figure 8. A GFS forecast map of the average cloud cover across the U.S. for 2PM Tuesday. Greater cloud coverage corresponds with brighter white on the color scale.

Source: College of DuPage

7 PM Tuesday: Radar Reflectivity Forecast

Radar reflectivity is simply what you would see in a radar image on your local TV weather or perhaps on the internet. The colors are generally associated with precipitation, where the greens correspond with lighter precipitation and the yellows and reds with heavier precipitation. Simulated radar reflectivity is a model's take on what the Doppler radar may look like in the future. This product is helpful for identifying potential future areas of rain and thunderstorms.

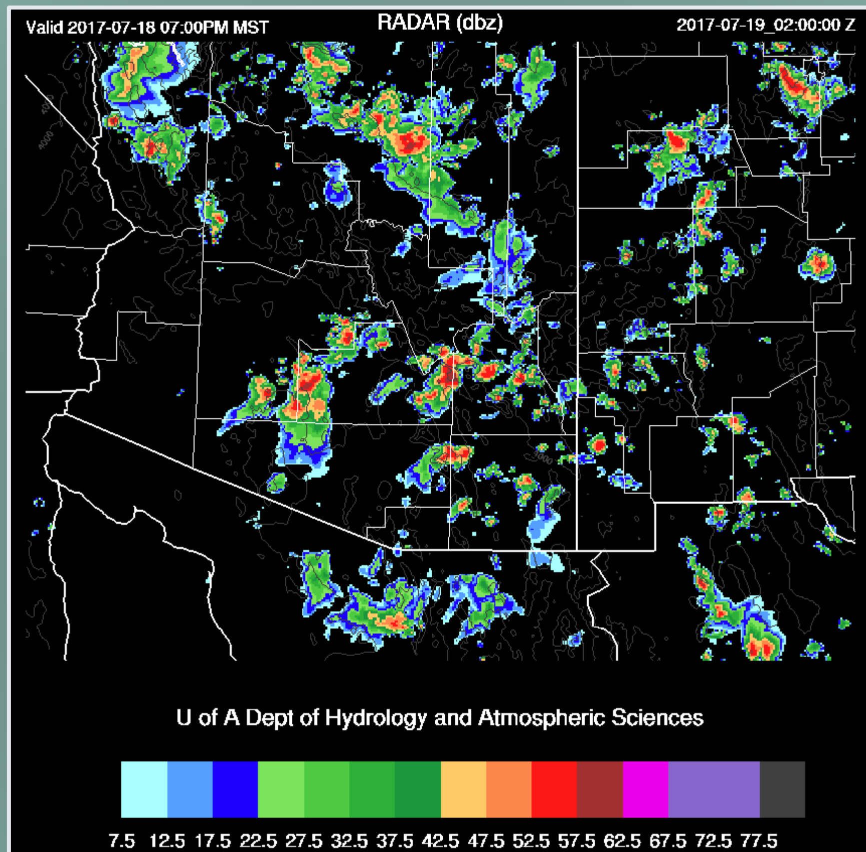

Figure 9. A high-resolution AZ-WRF forecast of radar reflectivity across Arizona for Tuesday 7 PM. This is a projection of what we might see on the radar in the future. Colors represent precipitation intensity. The main colors from weakest to strongest are: light blue, blue, green, yellow, red, and reddish brown.

Source: [University of Arizona]

In Figure 9, thunderstorms, indicated by the red and yellow features, can be seen throughout Arizona Tuesday evening at 7 PM (notice the cluster of thunderstorms in Maricopa and Pinal Counties). Air quality-wise, thunderstorms can both help and hurt air quality. Rain from thunderstorms is always welcome as it helps to wash pollutants out of the air. However, the rain is often preceded by strong, gusty outflows, which can pick up and move dust. Thunderstorm outflows can also be beneficial in that they increase ventilation and thus, disperse ozone. For a closer look at the potential impact of outflows, we then consult forecast winds near the ground.

7 PM Tuesday: Near-surface Wind Forecast

Winds near the ground are one of the most important things to examine when forecasting for air quality in Arizona. These winds have a direct impact on all air pollutants (ozone, PM_{10}, and $PM_{2.5}$) as they either help to reduce stagnation and disperse pollutants or deteriorate air quality through causing local or regional blowing dust. During the monsoon season, model forecasts of near-surface winds can help us anticipate the risk for dust storms.

Below in Figure 10, we have a high-resolution model forecast of winds 10m (~33 ft.) off the ground across most of Arizona Tuesday evening at 7 PM. This forecast includes both wind speed (colors) and direction (black wind barbs). The strongest winds are represented by yellows and reds. In this map, the model forecasts strong and gusty thunderstorm outflow winds to pass through the Valley from the south in the evening. The "arc" shape in the leading edge of the strongest winds is a signature often associated with dust storms. If we compare these forecast winds with the radar forecast above, we can see that rain may quickly follow any blowing dust, which would improve air quality.

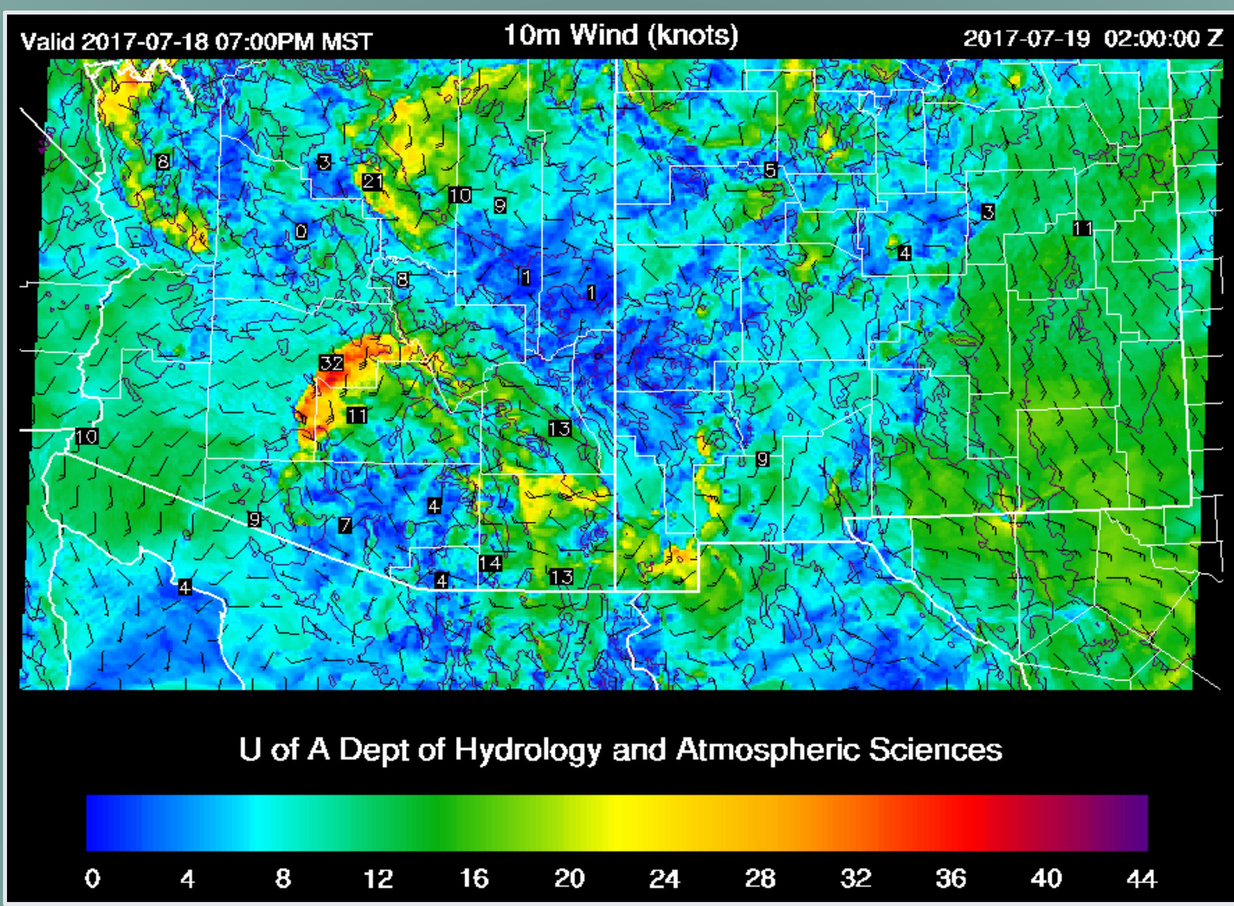

Figure 10. A high-resolution AZ-WRF forecast of 10m (~33ft) winds for 7 PM Tuesday. These winds are roughly equivalent to what we would experience at the ground. Colors represent wind speed. The main colors from weakest to strongest are: blue, light blue, green, yellow, and red. Black wind barbs point to where the wind is blowing to.

Source: University of Arizona

Every Model Tells a Story

We have now reached the end of this brief journey through the world of weather forecast models. In all, it's quite amazing that we can have a glimpse into the "future", at least in regards to the weather and air quality. However, these glimpses are not perfect. Every forecast model tells a story of what the atmosphere *might* look like in the hours or days to come. It's the meteorologist's job to confirm whether those stories are plausible or not.

We hope you enjoyed learning about weather forecast models!

Sincerely,

The ADEQ Forecast Team

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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…

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
June 2017: Patterns in Phoenix Air Pollution
For Full Archive (2015-2017): Click Here

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

-Organized Thunderstorm Systems
-Chaos Theory

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