Weather Tutor Archive
Flood Warning Branch
Meteorological Services Program

MARICOPA COUNTY
FLOOD CONTROL DISTRICT

Photo: Jonny W. Malloy

Flood Control District of Maricopa County

Preface

The following are a collection of brief discussions about different aspects of the weather and climate affecting the Desert Southwest, including Maricopa County. The presented catalogue of *Weather Tutor* topics is meant for both general hydrometeorological educational purposes and to serve as a reference for understanding common weather terminology highlighted in our daily *Weather Outlook* forecasts. Additional content will be added, so check back for updates!

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What is Virga?

Virga is simply the appearance of rain streaks originating from a cloud base but evaporates before reaching the ground. Virga is common when the mid and/or upper levels of the atmosphere are sufficiently moist for saturation and precipitation generation yet a much drier air mass near the surface evaporates (or "consumes") any falling liquid or frozen precipitation. The "streakiness" appearance in the sky is related to both wind shear and changing terminal velocity of falling precipitation as vaporization occurs. Excessive virga and evaporative cooling may promote windier conditions similar to how thunderstorms create gusty outflow winds when relatively colder air above arrives at the surface and spreads out.

What is Wind Shear?

Wind shear is an important forecasting consideration for assessing the potential severity of thunderstorms. Wind shear comes in two forms: 1) difference in wind speed with height and 2) difference in direction with height. Having greater environmental wind shear helps support longer-lived thunderstorms by tilting the storm. A storm that is "stacked" vertically top-down quickly dissipates when cool rain begins to fall cutting off warm and moist updrafts initiating storm growth (30 to 60 minute lifespans are typical). When sufficient wind shear is present, the rain cooled downdraft becomes separated from updrafts feeding the storm, hence a longer maturity phase is possible and a greater chance for the storm to become severe. Rotating "supercell" thunderstorms occurring in "Tornado Alley", located in the Midwest of the U.S., are an example of severe thunderstorms supported by atmospheric wind shear linked to frequent large-scale low pressure systems and passing frontal boundaries. On the other hand, supercells are much less common during the monsoon in Arizona given the weak wind shear typical under the monsoon high pressure ridge.

What is a Pressure Gradient?

You'll hear us mention at times in our discussions a "tightening" or "relaxing" pressure gradient influencing local wind speeds. Wind speed is driven by the spatial difference in relative low and high pressure. In general, air wants to flow directly from areas of high pressure towards low pressure. In reality, though, observed large-scale air flow trajectories are complicated by a rotating planet causing the Coriolis effect. Even so, a tightening pressure gradient simply refers to a greater contrast in low and high pressure over a shorter distance and, hence, faster wind speeds. Tight pressure gradients and associated gustier winds develop in response to an incoming weather disturbance, such as low pressure troughs or approaching cold frontal boundaries. On weather maps, this is shown by closely packed isobar lines that represent lines of equal pressure. As the weather disturbance or frontal boundary either weakens or passes by (and with it the area of greatest spatial pressure contrast), the local pressure gradient begins to relax allowing for local winds to weaken until the next weather disturbance arrives.

What is a Mountain-Valley Circulation?

Why are winds typically westerly/southwesterly during the daytime and northerly/easterly overnight? You've likely noticed this very common daily wind shift living in the County. In meteorology, what is being observed can be called a mountain-valley wind circulation pattern. The key here is the elevation contrast between lower valleys and adjacent higher mountains. It's amazing that elevations in the County can range from under 1,000 feet near Gila Bend to well over 5,000 feet at points along the northern and eastern borders. This complex topographic configuration is ideal to create uneven heating and cooling of the landscape throughout the day. Consequently, during the daytime sloped mountains facing the sun quickly heat up. Hot buoyant air rising from the mountains are replaced by air from surrounding lower elevations, hence a tendency for air to flow upslope towards higher terrain when the sun is out. At night exposed mountains cool off more rapidly than valley locations. Since colder air is more dense, downslope air flow now drains into the valleys, reversing the prevailing surface wind direction.

Why do Dry Air Masses have Greater Diurnal Temperature Ranges?

Why do drier air masses cause greater diurnal temperatures ranges? Here in the Desert Southwest, we are no stranger to dry air masses. In fact, the world's subtropical desert latitudes (found near 30°N and 30°S of the equator) may experience wildly fluctuating temperatures on a daily basis. For example, the Sahara Desert in Africa can reach well above 100°F only to fall below freezing overnight. Quite the contrast! Closer to home in the Sonoran Desert, a 30°F to 40°F degree difference between afternoon highs and morning lows are not uncommon, especially in rural desert landscapes. The reason for intense temperature fluctuations in dry environments is the lack of water. Water, whether in your pool, at nearby lakes, or in the air as water vapor, has a powerful moderating effect on the local climate. Essentially, water's high specific heat capacity relative to other substances means water is slow to warmup, but also slow to cool down! Therefore, wetter/moist climates in general have tighter diurnal and seasonal temperature ranges compared to arid or semi-arid environments.

What is Instability and Upper-Level Forcing?

What is “upper-level forcing”? Concerning weather forecasting, we are always on the lookout for ways to lift moisture up in the atmosphere to cool and condense into clouds. An approaching upper-level weather disturbance (e.g., a low pressure trough or short-wave trough) helps with vertical moisture transport throughout the atmospheric column by increasing the temperature contrast between the surface and higher altitudes. In other words, more robust rising motion occurs when the upper-levels are very cold while near-surface temperatures are warm. But, it really is about the contrast in vertical temperatures that generates forced ascent. This is why scattered “instability” showers or virga may still erupt behind a passing cold frontal boundary (even if only briefly) as lingering moisture continues to rise under the broader area of upper-level forcing associated with the larger low pressure trough passing overhead.

When is the Hurricane Season?

We are familiar with our monsoon season running between June 15th – September 30th; however, did you know that the hurricane season for our part of the world extends until November 30th! Likely everyone at this point is feeling the change in seasons as cooler autumn temperatures become more apparent, even over the Desert Southwest (no complaints!). The summer season is now over and the worst of the heat behind us, yet you may continue to hear about tropical systems developing in the open waters of the East Pacific by Mexico and out in the Atlantic Ocean. The monsoon season shuts down when we lose intense landmass surface heating as daily sun angles lower and potential heating energy to warm the land decreases. For the surrounding oceans, though, heat energy accumulates throughout the summer and is slower to “cool off” with the changing seasons versus land given water’s relative high heat capacity. The result is the Pacific and Atlantic Oceans able to support tropical system development deep into the autumn season, as long as sea surface temperatures are near 80°F or warmer.

What Causes Blue Skies?

The “Valley of the Sun” often hosts beautiful blue skies throughout the year. Perhaps you may be wondering why the sky is blue? This is probably one of the top asked weather questions! The answer really comes down to what our atmosphere is made of. In short, the atmosphere contains a lot of very tiny gas molecules, such as oxygen and nitrogen, that due to their relatively small molecular sizes can scatter incoming sunlight. This physical process is called “Rayleigh scattering”. Pure white sunlight is actually comprised of red, orange, yellow, green, blue, indigo, and violet wavelength energies (i.e., the classic

ROYGBIV acronym). Importantly, the wavelengths of bluish light are smaller than reddish light. This is significant. Since the size of gas molecules in our atmosphere are much smaller than any of the visible light wavelengths but closer to the wavelength of bluish light, that end of the visible light spectrum is more easily scattered upon entering the top of the atmosphere, hence a dominant bluish color for the daytime sky!

How does Air Density Affect Baseball Home Runs?

Can the atmosphere play a role in the score of a baseball game? Yes! Specifically, when it comes to the long ball (i.e., the "home run") different factors such as elevation, temperature, and moisture may hurt or help your chances for hitting the ball over the fence.

First thing to note about our local Arizona Diamondbacks is they, perhaps surprisingly, have the second highest stadium above sea level in Major League Baseball (around 1,100 feet). The highest stadium belongs to the Colorado Rockies at a mile high (5,280 feet). The takeaway here is that the atmosphere becomes less dense with increasing altitude, which provides less air resistance to a hit ball, hence a greater potential traveling distance when holding everything else on paper equal. The aspects of temperature and moisture also deal with air density and resistance to a ball in flight. I believe it is common for folks to think of a hot and humid air mass feeling "heavy" or "stifling"; however, increased temperature and/or higher water vapor content in the atmosphere (represented by dewpoint temperature) lowers air density!

So, ideal weather conditions for home runs would be a hot and humid air mass at higher elevations. Of course, a tailwind behind the baseball in flight wouldn't hurt either! Another option is for a baseball player to just muscle through any weather obstacles to get that home run!

How does Summer and Winter Precipitation Affect Drought?

Forecasting the next heavy rain event is always on the mind here at the FCDMC. However, from a drought monitoring perspective, when during the year heavy rain events occur are significant concerning longer-term benefit for the environment. The atmosphere, unless saturated (humidity 100%), is always "soaking" up available water vapor through evaporation. Evaporation stresses plant life, water reservoir levels, and soil moisture to name a few. Evaporation replenishing the atmosphere's water vapor holding capacity is then removed from the local region by prevailing winds to then later rain out somewhere downwind. The nearly constant daily high atmospheric demand (i.e., hot temperatures with low relative humidity) during the summer months can easily (and quickly!) reduce any benefit provided by intense isolated to scattered thunderstorm rains. During the late autumn, winter, and early spring months, precipitation (rain and snow) tends to be more widespread and longer duration events. The lower temperatures and higher relative humidity associated with these cool season large-scale weather systems reduces overall atmospheric demand to better preserve precipitation that does fall. So, it really is a different story from a drought monitoring perspective whether an inch of rain falling in the Phoenix area occurs in January versus July.

What are the Westerlies and Other Global Circulation Patterns?

As we look in the rearview mirror of the summer monsoon each year and march closer to the winter season, our mechanism for heavy precipitation shifts from daytime thunderstorm potential to tracking large-scale weather disturbances (i.e., low pressure troughs and cold fronts) following the prevailing Westerlies. What are the Westerlies? This topic can be broken down into multiple future tutor sessions that cover general planetary wind circulation patterns.

For an introduction today, it is important to know that there are three main latitudinal confined planetary circulation belts (or “cells”) of rising and sinking motion between the equator and poles (this is true for both the Northern and Southern Hemisphere). The Westerlies are found in the “Ferrel Cell” that tends to occupy the region bounded by 35N and 60N (for context, Phoenix is ~33.5N and the Canadian border with the U.S. is ~49N latitude). Therefore, the Westerlies are a major influence on the daily weather across the United States Lower 48, including AZ. Embedded in the Westerlies are a narrow corridor of very fast jet stream winds circumnavigating the globe. These jet stream winds essentially serve as an ever evolving upper-level storm track highway for both low pressure troughs (southern dips in the jet stream) and high pressure ridges (northward bulges in jet stream winds) progressing in a general west-to-east manner, as seen on satellite and weather charts.

Dips in the jet stream over the Desert Southwest region are what we are looking for to usher in cold air intrusions, increase atmospheric instability/lift, and bring enhanced precipitation potential. Location and strength of jet stream winds are not stable. Large-scale spatial and temporal variability in the storm track can be challenging to forecast!

How does Annual Solar Energy Potential Affect the Changing Seasons?

Our Daily Weather Outlook product has a “Workday Almanac” section which is useful information for tracking daily sunset, sunrise, daylight hours, and the lunar cycle. As benchmarks, our longest daylight length of the year occurs on the summer solstice around June 20th-21st each year. After the summer solstice, we’ll continue to shed daylight length every day until after the winter solstice passes on December 20th-21st (our day with the least amount of sunlight).

The perpetual oscillating gradual loss/gain of daily potential solar energy received by Earth’s surface between the summer and winter solstices is significant over time and helps drive large-scale seasonal weather pattern shifts. Additionally, peak daily sun angles are highest near the summer solstice and lowest around the winter solstice. A higher sunlight angle in the sky translates to more focused solar energy per unit land area. Therefore, the summer season has more energy (and heating) potential from both longer daylight lengths and a more directly overhead positioned Sun.

Visually you can use a flashlight to highlight this effect by shining the flashlight over a spherical surface like a basketball to mimic our planet. First, pick a spot on the “basketball” and shine directly overhead and close enough so the light is contained on the surface. Notice how much area the light occupies on the surface. Next, shine the flashlight at a “lower sun angle” from the same distance away and still pointed at the same spot on the sphere. Now you can see all the light becomes spread out over a larger surface area. So, lower sun angle energy is diffused compared to when the Sun was directly overhead. Basically, you get more bang for your buck solar energy wise across the landscape when the Sun is overhead than lower on the horizon.

Putting the lower sun angle and decreasing daylength concepts together, you’d expect our long-term average climatological normal high and normal low temperature data found in the “Today’s Climate Context” section to also steadily cool getting closer to the winter solstice, which we do observe in Phoenix, AZ.

What are Shortwave and “Inverted” Low Pressure Troughs?

You’ll likely hear us reference a “shortwave” trough in many of our Weather Outlooks. That is a good thing! Precipitation formation relies on the combination of moisture, lift, and instability. Shortwave troughs, as the name hints, is a smaller scale and often faster moving atmospheric disturbance that is 1) embedded either in the main Pacific midlatitude storm track (i.e., the Northern Hemisphere’s Polar jet stream), 2) as part of existing larger longwave troughs, or

3) rotating clockwise around the peripheries of high pressure systems such as during the summer monsoon (often called “inverted troughs” due to an atypical east-west movement and poleward bulge appearance on weather pressure charts).

Shortwave weather disturbances help provide lift by their inherent lower pressure and atmospheric instability aided by cooling temperatures aloft and wind shear they bring into a region. The influence on local weather tied to a passing shortwave can be quite variable depending on its potency. Additionally, without a decent moisture tap the primary weather trends observed are limited to increased breeziness and a general cooldown. Importantly, multiple shortwaves may exist or develop around a larger slowly propagating longwave low pressure trough to provide distinct unsettled weather periods as they individually cross a region. The same can be said for a series of “inverted troughs” being steered by a persistent monsoon high pressure circulation. Given their smaller scale of impact and faster progression, shortwave low pressure disturbances are more challenging to forecast than much larger longwave low pressure troughs.

What Creates Daytime Breeziness?

Why do daytimes tend to be breezier than overnights? There are plenty of meteorological concepts that could be unpacked with this question, but we can focus today’s tutor discussion on what helps drive atmospheric mixing. Reviewing a typical vertical wind profile over a location would likely show an increase in wind speed with height. Friction aids in causing this vertical wind speed shear since surface roughness (vegetation, buildings, etc.) tends to impede air flow closer to the surface.

One mechanism to bring faster winds aloft to the surface is to introduce turbulence into the lower atmosphere for vertical energy momentum transfer. The sun is key here as everyday sunlight heats the ground to generate rising air currents or thermals. This is very much like turning on the heat to a pot of water! Pockets of warm, buoyant air rising from the surface, especially by the afternoon hours, effectively disrupts prevailing faster flow aloft, allowing momentum transfer towards the ground. We feel/observe this effect through periodic wind gusts.

After sunset it’s like now turning off the heat on the stove. Heat continues to radiate upwards from the landscape, but in general rising thermals become much weaker, hence surface winds begin to calm down while prevailing winds aloft continue to blow faster. The daily wind cycle repeats following the rising and setting sun.

Keep in mind that active weather systems in the region (e.g., low pressure troughs, frontal boundaries, and thunderstorms) can alter this idealized diurnal wind pattern!

What are "Dry Slots"?

Do moist precipitable water values always lead to rainfall? You'll often here us refer to "precipitable water" values (or "PW") when discussing rain chances. Precipitable water is the available liquid water depth that could condense out of the atmospheric column overhead (bounded by the surface and the top of the troposphere) given a certain quantity of available water vapor. Generally, a PW value over an inch is what we are looking for to get excited about rain chances. However, a relatively "wet" atmosphere corresponding to high PWs does not mean the entire vertical air column above you is supportive of rain. Weather is complex and there are many moving parts to account for when forecasting! One such variable is tracking dry air intrusions aloft or "dry slots". Very dry air can still be transported through the atmospheric column at varying altitudes to prevent deeper cloud development ideal for precipitation generation, despite compelling PWs that could otherwise facilitate heavier rain amounts. We monitor dry slots using water vapor satellite imagery and regional weather balloon data. Both sources of data are valuable when assessing rain probability!

What is a Lapse Rate?

Is there a "back of the envelope" calculation to anticipate temperatures when traveling between lower valleys and higher elevations throughout the County? Yes! The atmosphere naturally tends to cool going higher in altitude due to less atmospheric pressure. The rate of cooling is the lapse rate and is dependent on how moist the environment is. As a useful rule of thumb, for a dry atmosphere (i.e., unsaturated and cloud free), the cooling rate is around 5.5°F per thousand feet, while a saturated air mass (e.g., fog, active precipitation, low clouds), the rate is around 3.0°F per thousand feet. So, if the skies are sunny and the temperature at Phoenix Sky Harbor with elevation around 1,150 feet is 60 degrees than a nearby mountain of elevation 5,150 feet could reasonably be expected to have a temperature in the upper 30s to near 40°F (4,000-foot climb with a ~22 degree difference). Better pack that jacket!

How do Mountains both Enhance and Limit Precipitation Potential?

You’ll likely hear us on a regular basis note an elevation precipitation forecast disparity (amounts and probabilities) for the County during winter storms. A lifting mechanism is essential to force air masses higher in altitude to cool and condense! Prevailing wind flow perpendicular to significant terrain can do the trick to start generating clouds for precipitation, if sufficient moisture is present. It’s important to know that upslope (rising) motion can cool an air mass to saturation, while downslope (sinking) motion compresses, heats, and dries an air mass.

This conceptual model is the reason for wet, cool windward slopes and the corresponding warm, dry rain shadow effect. In a region of complex topography, such as south-central AZ, the local spatial difference in precipitation amounts during a winter storm passage can be drastic ranging from getting nothing at all in the lower valleys to exceeding well over an inch falling over favored windward higher terrain features. Assessing moisture profiles and wind direction/speed relative to terrain alignment add to our forecasting challenge!

How do Temperature Trends Evolve during a Pacific Storm Passage?

Why do the coldest morning temperatures typically occur a day or two after a winter storm passage? You’ll notice there are different general temperature phases that accompany a Pacific winter storm system passage. Ahead of a Pacific storm’s arrival stronger southerly flow usually brings warm air (sometimes moist) due to the counterclockwise flow around low pressure systems in the Northern Hemisphere. As the Pacific storm approaches, a cold front (with or without precipitation) sweeps through the local region and changes the prevailing wind direction from southerly to northwesterly. Behind the cold front (as the name implies) cooler and drier air is immediately ushered in that may abruptly end the precipitation threat, but temperatures continue to stay temporarily moderated by higher humidity, mixing breezes, and any lingering cloud cover. Once skies fully clear, winds diminish, and air mass dewpoint temperatures continue to dry, overnight temperatures may then plummet, especially when combined with evaporative cooling from wet soils.

What do Relative Humidity (Rh) and Dewpoint (Td) represent?

What's the difference between relative humidity (RH) and dewpoint temperature (Td)? These are two very common meteorological variables used to assess moisture in the atmosphere. Relative humidity is expressed as a percentage (0-100%) and truly is "relative" to the temperature of an air mass. In a nutshell, the water vapor carrying capacity of air is not fixed, but rather is dependent on how hot or cold an air mass is. Warmer versus colder air masses have greater water vapor carrying capacity, so the RH percentage simply tells you how much water vapor capacity has been "filled" at a given temperature. This is why RH can vary significantly throughout the day, even in a dry desert environment. From a diurnal perspective, RH is often the highest during the cooler overnights and much lower during hot, dry afternoons.

Let's jump to dewpoint temperatures (denoted as "Td"). Dewpoint, unlike RH, is a better measurement of how much water vapor is actually present. A higher Td always indicates a moister environment and vice versa. Now we can link both RH and Td! The observed Td is the trigger temperature that the air would have to be chilled for saturation to occur (i.e., RH reaches 100% and water vapor capacity is maxed out). Because of this relationship, a reported dewpoint can equal but not exceed the observed temperature. Importantly, any further cooling of the air mass and/or increased moisture mixing with the air mass would continue to force the conversion of excess water vapor to condense into liquid droplets or deposit as ice. The water vapor phase change to liquid and/or ice is what we see as clouds in the sky or fog near the ground!

How does High Pressure affect Air Quality (Winter)?

As we head towards the winter season, bouts of high pressure systems not only affect our weather but air quality, too. Haze can be a common sight in and around major population centers under the influence of stable weather patterns. High pressure typically brings light winds and clear skies. Pollutant dispersion becomes difficult under light wind regimes in general, while clear skies allow efficient overnight radiational cooling that leads to pollutant trapping temperature inversions at valley locations. Surface inversions act as "lids" above the ground by having a relatively warm temperature layer above cooler temperatures found closer at the surface. Such a stable vertical profile greatly limits the mixing potential of the cooler air mass, hence pollutants may build over time and degrade local air quality. Lower sun angles, less daytime heating potential, and shorter daytimes during the winter months collectively make it more difficult to breakup morning inversions. Additionally, the physical geography of the County plays a significant role for pollution buildup due to a recurring mountain-valley wind circulation that becomes prominent under large-scale stable weather patterns. The repeating daytime upslope followed by nighttime downslope winds help recirculate pollutants. The good news is that passing low pressure troughs, wet or dry, can reset the airshed by either bringing beneficial precipitation or even just stronger clearing winds into the region.

What is the Significance of “Red Skies in the Morning”? – Weather Lore

Knowing common weather lore can be a useful way to help anticipate weather pattern changes in your local area. One example (you may have heard this before) is “red sky at night, sailors’ delight; red sky in the morning, sailor take warning”. There is some forecasting merit here when applied to the latitudes affected by the Westerlies (~30-60 north and south). The main consideration here has to do with the prevailing west-to-east flow of passing low and high pressure systems in the planetary Westerlies. The brief science rationale behind this weather lore is that when sunlight is low on the horizon it can better be scattered by pollution and dust particulates, which favors red light scattering. Dust and pollution tend to buildup during stable weather patterns, such as with high pressure systems. Any available clouds reflect the scattered reddish sunlight. So, if the sun rises in the east and a brilliant red morning is visible, the area of high pressure that resulted in the dust/pollution buildup is likely pressing further east away from you to be replaced by low pressure approaching from the west (i.e., unsettled weather might be coming soon), hence the adage “red sky in the morning, sailor take warning”. You can see how the opposite could be inferred for red sky at sunset (now an air mass with increased dust and pollution with high pressure approaching from the west)!

What is Wind Chill?

Part of winter weather hazard awareness is knowing and protecting yourself and pets against “wind chill”. What is the science behind wind chill, though? An important aspect about the atmosphere to be mindful of is that it is constantly seeking equilibrium from an energy and moisture standpoint. The inherent spatial and temporal imbalance of temperatures and water vapor across the planet forces constant air mass energy transfers and water phase changes (e.g., condensation and evaporation). Everyday weather is the product of that perpetual battle in an environment seeking equilibrium! Now to why wind chill can be a significant health hazard. When I say air mass, that also means the modified micro air mass your body generates. Just like the atmosphere’s constant pursuit of equilibrium, your body desires the same! The air in motion has a certain temperature and if something in the environment is warmer (like you!) than heat is transferred to the air. Under cool, calm conditions your body may be able to keep up with the energy being lost to the surrounding air; however, faster cold winds is like a never ending reset button on your body’s attempt to gradually “warm” the air in contact with your skin. It’s a losing battle. Furthermore, dry and cold winds interacting with any sweat you have adds to your temperature deficit through evaporative cooling effects. Bottom line, bundle up if in cold and windy weather!

What are Airsheds?

The smell of woodsmoke after sunset from heating and recreational use often becomes more prominent in the Phoenix Valley during the autumn, winter, and spring months thanks to cooler overnight temperatures. Why is that and where does all the woodsmoke come from and then go? Well, our airsheds over complex topography has a lot to say about where air quality from woodsmoke may deteriorate the most. There’s a reason that airshed boundaries follow very closely to watershed boundaries. Watersheds capture and funnel rainfall/streamflow, while in a similar fashion airsheds “capture” and “funnel” entrained pollutants, including woodsmoke.

Both hydrology and air quality conceptual models are based on terrain gravity-fed influences. Water wanting to flow downhill is intuitive. Air movement behaves likewise when the air mass at the surface is relatively cool and dense compared to the air above. Essentially, cool/dense air (and the pollutants it contains) becomes restricted to the surface under a nocturnal temperature inversion. Such trapped pollutants caught in overnight downslope air currents will tend to “fill” valley locations through the night. This is why air quality from woodsmoke is usually at its worst near sunrise before sufficient heating of the surface has had a chance to break up the morning temperature inversion and dilute surface pollutants. Unfortunately, stable weather patterns and light dispersing winds typically still allow day-to-day pollutant carryover to steadily degrade air quality over time.

A key takeaway message is that our local topography, watersheds, and airsheds are intricately linked, so be mindful that the overnight journey of woodsmoke sources, even from your backyard, may impact the air quality many miles downslope.

What is “Black Frost”?

As opportunities for freezing air masses increase in the County throughout the winter and early spring months, it’s necessary to check local weather forecasts and monitor current temperature trends to protect sensitive vegetation and pets. Specific to vegetation, the combination of freezing temperature potential and available moisture in the air is another important consideration. Once an air mass cools to its dewpoint temperature, gaseous water vapor either condenses into liquid dew droplets (if saturation occurs above the freezing mark) or deposits directly as ice crystals leading to frost buildup (if saturation continues below the freezing mark).

Unlike evaporative cooling, the water vapor phase changes resulting in either dew or frost formation release heat back into the environment that may provide a protective microclimate around plant life! That’s why cold and moist weather conditions are more ideal to protect vegetation, while cold and very dry environments may never be able to reach saturation. Under such cold and dry conditions, a dangerous dry freeze can kill sensitive vegetation. Vegetation with dry freeze damage may take on a black appearance, hence the term “black frost”.

What are the Origins of the Expression “Socked In”?

If you have had conversations with a meteorologist, the phrase “socked in” may have come up from time to time when discussing the threat of tempestuous weather. This informal weather jargon actually has its roots in aviation. A common sight at airports is the windsock that serves as a simple low-tech but effective visual cue of monitoring the prevailing wind direction. During inclement weather like fog, heavy rain, and blowing snow the windsock would be lost from view or said to be “socked in” the stormy weather!

What are Ideal Conditions for Fog?

Idea weather conditions for fog begin with having abundant moisture at the surface. Surface conditions across the lower deserts of south-central AZ are typically dry and unsaturated. In other words, there is usually not a surplus of soil moisture available to evaporate into the atmosphere, at least on a large-scale. We really had a unique setup for foggy conditions here in the County after the latest wet winter storm impacted the local region and brought widespread 0.50”-1.50” of rainfall to the lower deserts. As colder air settled in behind the exiting winter storm, air mass saturation near the ground became possible when ongoing soil evaporation “filled” the water vapor capacity of the colder ambient air mass (cooler temperatures have a lower water vapor capacity). Excess evaporation at that point leads to condensation and fog formation. Clear skies and light winds are ideal for ground fog as it promotes stronger surface radiational cooling overnight. This is why fog is usually most pronounced near sunrise when temperatures are at their coldest. Fog dissipation then occurs throughout the morning hours when temperatures rise and evaporation rates are no longer able to saturate the warming air mass with increasing water vapor capacity.

How are Clouds Classified?

We'll often point out expected sky conditions in our Weather Outlooks. You'll hear discussion on whether "low", "middle", or "high" clouds may be seen in the upcoming forecast period. What does that mean? Concerning cloud classification, "low" clouds, such as fair weather cumulus or stratus, generally develop below 6,500 feet above ground. The "middle" clouds are found between around 6,500-20,000 feet and may include altocumulus formations that produce a "mackerel sky" appearance, which are fantastic for creating beautiful painted sunsets and sunrises. Lastly, "high" clouds (over ~20,000 feet) are home to the wispy cirrus cloud variety. During the advance of a dynamic and moist Pacific storm system, the typical progression of high, middle, and then low clouds is common as upper-level moisture tends to outpace near-surface moisture advection due to stronger winds aloft. There's a lot more discussion we can have about cloud classification in future Weather Tutor sessions!

Are Distant Moisture Sources Important for Local Precipitation?

Sometimes it's not enough to have a low pressure circulation passing through to get precipitation! The three key ingredients for wet weather are having a sufficient combination of moisture, lifting mechanism(s), and atmospheric instability. Often times it's tough for the environment to have all three aspects in play at once over a local region. For example, a lack of deep subtropical moisture over the East Pacific (often detected by water vapor imagery) available to tap into for passing Pacific low pressure troughs can be a significant obstacle limiting a widespread precipitation threat here in Arizona. Forecasting the local weather requires you to zoom out to see all the moving parts upstream that have potential to intersect over you in the future. For Arizona, that includes keeping tabs on prevailing weather conditions far out in the Pacific Ocean!

How can a Cold Front Help Cloud Development?

One way to track cloud base height is knowing the environment's "lifted condensation level" or LCL. The LCL is an important altitude marker for how high up in the atmosphere the surface air mass would need to rise vertically to allow enough cooling of that air mass to reach saturation for cloud generation. A cold front is a natural (and often very effective) lifting mechanism since advancing cold/dense air across the surface forces the warm/less dense air mass to rise ahead of the frontal boundary and possibly achieve the LCL altitude to trigger cloud development. Therefore, the strength of a cold front is an important forecast consideration when evaluating precipitation potential. Also, keep in mind that not all cold fronts are able to generate deep clouds and precipitation if moving through a particularly dry air mass because the drier the air mass the higher the LCL altitude becomes.

What is an Inversion Layer and how to Temperatures Fluctuate in the Vertical?

You may notice regularly that a wide range in observed early morning temperatures in the County are possible. Natural versus urbanized landscapes play a significant role in creating microclimates. As you would expect, urbanization tends to keep temperatures warmer overnight compared to outlying rural zones due to persistent heat release from abundant asphalt, concrete, and other society activities. For this topic, though, I wanted to focus on local vertical temperature disparities. Within the Valley and on tranquil winter mornings, you find that temperatures observed at higher elevation monitoring sites can be warmer than surrounding lower rural valleys by several degrees at times!

A few concepts are at work here. First, cold air is dense. This means cold overnight air behaves very much like flowing water running downhill and filling lower valleys. Second, the ground is more effective at losing heat than air. In other words, air is a good insulator, while the surface can heat or cool at a much more rapid rate. So, heat radiated from the ground at night rises above the surface and collectively forms a relative warm layer at some altitude aloft. Tying it together, what has developed between the cooling surface and warmer air above is a stable temperature inversion layer that resists mixing of the two different air masses.

Depending on the evolving depth of the cold air trapped near the surface through the night and early morning hours, a higher elevation monitoring site may have fluctuating temperature readings by being located at times either 1) in the colder air mass below the inversion layer altitude (point when temperatures start increasing with height), 2) within the warmer inversion layer, or 3) possibly isolated above the nocturnal inversion layer where the free atmosphere is not significantly influenced by the dynamics of a cooling overnight surface!

What is Mixing Fog?

It may sound odd at first, but you can generate a cloud when mixing two unsaturated air masses! What makes this possible in nature is the fact that the water vapor carrying capacity for an air mass at a certain temperature is not linear, but increases as temperatures increase. As two different air masses mix together, temperature and moisture properties eventually equilibrate for a new combined air mass. Because of the inherent nonlinear temp-water vapor carrying capacity relationship, it is possible that the combined water vapor content of the original two air masses exceeds the new dewpoint of the modified air mass leading to saturation and visible cloud material! Where do you see this in action? Well, some good examples at work are during Lake Effect snow events (e.g., evaporation from relatively warm waters mixing with drier arctic air masses), opening your freezer door, and even seeing your breath on a cold winter’s day!

How does Cloud Cover Effect Surface Winds?

Do cloudy skies influence surface winds? Yes, they can! A source of local wind variability in complex terrain is the uneven heating of valleys and mountains throughout the daytime hours as the sun progresses across the sky. Exposed surfaces and changing mountain aspects facing the sun warm to create localized rising motion (low pressure). Air tends to flow from high to low pressure. The air movement seeking environmental equilibrium is what we observe as wind. Differential heating over the course of a day can be a strong driver of mountain-valley wind circulations. Block the sun with passing cloud cover and you lose or diminish that terrain differential heating responsible for tighter spatial pressure gradients, hence, weakening wind flow when thicker clouds are present. A caveat to this discussion is when regional pressure waves are in play, such as a passing cold front (wet or dry). Such unsettled synoptic scale atmospheric features tend to temporarily override any predominate local mountain-valley wind circulation patterns typical under otherwise fair weather conditions.

What are “Arroyos”? – Flash Flooding

Have you heard of the term “arroyo”? An arroyo is a geological feature commonly found in semi-arid desert climates. They may also be referred to as dry streambeds or washes. These typically dry water channels seemingly carved into desert landscapes are a natural hydrological mechanism directing excessive runoff and flash flooding when intense rains do occur overhead or upstream. For Arizona, the flash flood threat is heightened during the summertime North American Monsoon when torrential thunderstorm rainfall is possible over a short time. The high energy associated with flash flood events are capable of reshaping the landscape, including the width and depth characteristics of affected arroyos. The desert landscape is constantly evolving in this sense. Be mindful of the increased flash flooding risk while traveling, camping, or hiking near arroyos when heavy rain is forecast in the local region!

What is Cumulus Turret Succession?

Growing cumulus clouds are a fantastic sight during the thunderstorm monsoon season. If you were to look at a looping animation of cumulus cloud development during a hot and moist period, especially over a mountain, you’ll likely notice a repeating daily pattern. Small cumulus clouds start developing by early/midmorning as stronger surface heating thermals start lifting moisture higher into the cooler atmosphere aloft to condense into clouds (heat exchange process called convection). Often, early day cumulus clouds initially struggle to become thunderstorms; however, ongoing cumulus cloud development are still playing a vital role in progressively moistening the atmosphere above the surface and decreasing the effect of dry air entrainment on future cloud formation. This is why throughout a hot and moist monsoon day vertical cumulus cloud turrets are eventually better able to penetrate higher in altitude later in the day to more likely become mature thunderstorms. In other words, nature can put in a lot of work after sunrise before finally yielding a classic afternoon monsoon storm!

Why do Low and High Pressure Systems Spin?

Why do low and high pressure systems spin? There are a couple general concepts to point out. First, in nature airflow prefers to move directly from regions of highest to lowest pressure in order to balance the spatial pressure gradient, but if you were to look at weather charts, you’ll notice winds tend to circulate *around* high and low pressure centers. Second, airflow becomes complicated on a rotating body. The rotation of Earth creates an apparent deflection for airflow trajectories moving in any direction (to the right in the Northern Hemisphere and to the left in the Southern Hemisphere). This is the Coriolis effect! With both concepts in mind, consider air *leaving* in all directions from a high pressure center over the United States and being deflected to the right throughout its exit journey. When viewed from above winds take on a clockwise circulation pattern. On the other hand, air moving *inwards* toward a low pressure center and being deflected to the right translate to a counterclockwise wind pattern.

Why does Snowpack Linger on the Landscape?

Arizona's high country can receive significant snowfall during the winter and spring months. Snowpack is often stubborn to leave the landscape once established, which can be a good thing in terms of water resource management. Why does snow cover linger for so long even after the winter storm has passed and full sunshine returns?

There are a few considerations here. First, the albedo value of fresh snow is very high (~95%) given its light color and often smooth surface. This means that nearly all incoming solar radiation that would otherwise aid heating the landscape is instead reflected back up into the atmosphere. Second, snowpack is an excellent "heat sink" due its high efficiency at absorbing existing longwave radiation emitted from the surrounding environment (what we feel as a temperature). Third, water in all phases (vapor, liquid, ice) have inherently high specific heat capacities meaning that the amount of energy needed to raise the temperature of snowpack is greater than for other substances in the environment such as the air above or any exposed dirt/rocks. Consequently, snowpack can 1) reduce solar radiation reaching the surface, 2) continuously remove heat from the environment, and 3) absorb a lot of thermal energy before warming past the melting point. All three of these physical properties of snow collectively serve as a positive feedback that cools the environment to help preserve snow cover on the landscape!

How is Probability of Precipitation ("PoP") Determined?

What comes to mind when you hear there's a 10%, 50%, or 90% chance of rainfall? Perhaps you dismiss a 10% chance of rain in your daily planning but would be more inclined to bring your umbrella should 90% be forecast. It's likely such a range in forecast values are interpreted differently by those not knowing more context about the weather situation. So, what does "probability of precipitation" mean? Here's the breakdown!

When meteorologists provide a probability of precipitation (or "PoP") forecast they are actually accounting for two different percentages that are then mathematically multiplied together. The final result is expressed as a single forecast PoP value ranging from 0%-100%. Alright, let's unpack that!

The two aspects under consideration to derive a forecast PoP value are 1) the likelihood that any spot in a designated forecast zone receives measurable rain (at least 0.01 inches) during the forecast period and 2) the expected spatial extent of measurable rain within that forecast zone. In other words, a PoP considers both “likelihood” and potential “coverage” of measurable rain! As an example, a forecaster having very high confidence that measurable rain will occur in a forecast zone (100%) yet the expected aerial extent of measurable rain in the forecast zone is ultimately to be minor (10%) would communicate a final PoP of 10% (from 1.00 multiplied by 0.10).

This forecast scenario is actually quite common during our summer thunderstorm season. Importantly, such monsoon days (or any day of the year) with a seemingly low PoP may still have locally impactful heavy rainfall. A PoP value does not convey forecast precipitation intensity! This is why it is critical that those relying on precipitation forecasts also review associated forecast/outlook discussions to better understand the level of forecast confidence and consider any forecast uncertainties that may exist.

What is a Cutoff Low Pressure Circulation?

Although a vast majority of large Midlatitude cyclones generally move west-to-east steered by the Polar jet stream, occasionally an area of low pressure gets separated from the upper-level Westerlies flow regime. This can happen when cyclonic flow at the base of a deep low pressure trough becomes pinched off at lower latitudes after a quick northward realignment of the prevailing jet stream. Once cutoff, the area of low pressure may persist over a local region for several days or even slowly retrograde westwards. From a forecasting perspective, cutoffs can pose an enhanced flooding threat if the sluggish moving weather disturbance entrains excessive subtropical moisture that interacts with mountainous terrain (orographic lift) or is associated with enough atmospheric instability to generate heavy rain from thundershowers. After several days, it is not uncommon for cutoff lows to eventually be absorbed back into the main Pacific storm track as the Polar jet stream is continuously shifting north and south when circumnavigating the Northern Hemisphere.

What is “Precipitable Water”?

Let’s revisit briefly what is meant by “precipitable water”. Precipitable water (“PW” or “PWAT”) is a critical forecast consideration as the measurement indicates how much water vapor in the atmosphere is available to precipitate out over a local area under ideal environmental conditions. A PW value is often expressed with units of inches during a forecast discussion (e.g., “relatively dry PW less than 0.50 inches” or “a moisture rich subtropical air mass with PW exceeding 1.00-1.50 inches). Although a PW value does not guarantee you will see that amount of rainfall during any one storm event, there is generally a good correlation between moist air masses having higher rainfall amounts observed. In other words, fluctuations in PW can affect rainfall potential but should not be confused with how much rainfall is actually forecast to occur as this is dependent on both atmospheric lift and instability present to allow the available water vapor in the air to condense/freeze into deeper cloud generation necessary for precipitation in the first place. Therefore, it’s possible for a humid air mass overhead having very high PW content (i.e., a subtropical air mass); however, forecast probability of precipitation is low or absent!

Why are Spring Season Temperatures a Rollercoaster?

You have likely noticed the rather wild temperature swings occur during our spring season. For instance, a quick review of the daily high temps in Phoenix for the month of March (2024) shows there were six days in the 60s, 12 days in the 70s, and 13 days in the 80s. This is not too unexpected even though when referring to climatological “normal high” values it may seem that daily temperatures should be more consistent than what they have been. Remember any average climate value can be derived from a highly variable dataset!

From an energy balance perspective, the spring season for the Northern Hemisphere across the midlatitudes (inclusive of our region) is often quite dynamic due to increasing surface heating potential from the sun getting higher in the sky that at times must compete with bouts of cold air intrusions from the higher latitudes being forced southward along an active Polar Jet (i.e., the Pacific storm track). The net result is still a general rising temperature trend as the spring season progresses (as indicated by long-term climatological values) that for any given year is periodically interrupted by breezy winds, sharp dips in temperatures, and possible mountain snow/valley rain when low pressure systems do cross the Desert Southwest. The spring months can be a challenging period to forecast the weather!

How does Soil Moisture Affect a Flood Threat?

Is soil moisture important when forecasting a flood threat? Absolutely! Soil moisture is a vital component to a weather forecast addressing flooding and runoff potential, especially when the next storm arrives! Having initially dry or unsaturated soils can be significant for “soaking” in heavy rain to limit or prevent runoff. However, should additional rain fall on already saturated watersheds then the flooding/runoff risk increases, even if lighter amounts are in the forecast. This is why communicating a flooding threat is a fluid process (pun intended!) needing to be evaluated situationally. Overall, flooding and runoff risks are dependent on precipitation event frequency, duration, amount, rainfall rate, and antecedent soil moisture conditions. Urbanized areas have an inherently higher risk of runoff given that impervious surfaces such as concrete, asphalt, and roofing essentially act as “saturated” soils.

When does It Typically Rain in Maricopa County?

Seasonally, the Desert Southwest tends to have two distinct wet periods that for the Phoenix area combine to account for the typical 7-8 inches of average annual rainfall. Statistically, these two wet seasons show up in Arizona climate data graphs as a “bimodal distribution” indicating two pronounced peaks or, in other words, two favorable times in the year to observe rainfall or higher elevation snow.

One favorable timeframe is between winter and early spring with the passage of large-scale Pacific low pressure disturbances steered along the upper-level Westerlies storm track (i.e., the Polar Jet Stream). Rainfall and higher elevation snow with such weather systems tend to be more widespread but tamer in terms of precipitation rates compared to the second warm rainy season being the summer North American Monsoon when atmospheric instability combines with deep subtropical moisture leading to isolated torrential downpour potential. As a result, flash flooding is more common in the summer; however, flooding concerns do still happen during the cool wet season, especially when the weather pattern becomes ideal for sending frequent moist low pressure systems into the Desert Southwest.

Frequent wet weather disturbances help keep soils near saturation lowering infiltration rates to increase runoff efficiency compared to soils that have a chance to dry out. A similar situation can occur during the monsoon as locations can be impacted by multiple heavier thunderstorm events throughout the season. Interestingly for the Phoenix area, there is a fairly even split between cool and warm wet season contributions to the long-term average annual rainfall total, despite two very different weather pattern regimes.

Do Passing Solar Eclipses Affect the Weather?

Yes, temporarily on a local scale, at least! Suddenly blocking out the sun using the moon ultimately alters temperature, humidity, wind trends on Earth's surface. How? First thing to note is solar radiation from the Sun upon entering materials like asphalt, rocks, and trees is reradiated back to the environment as infrared radiation (what we feel as a temperature). The more solar radiation the hotter the environment can be.

The shadow of the eclipse acts in a similar manner to a sunset when sunlight ends and decreasing temperature trends are observed. If temperatures fall and water vapor content in the air stays constant, then relative humidity must increase since cooler air masses have less water vapor carrying capacity than warmer ones.

As for winds, typically during the heart of an eclipse winds likely decrease given less active surface heating thermals (i.e., convection). Think of shutting off the heat for a boiling pot of water, which allows the water surface to become less turbulent. The overall changes to your weather will be most pronounced if you happen to be in the eclipse's "path of totality". In other words, a partial eclipse does not yield as dramatic of an effect on influencing weather conditions. Also, overcast skies or presence of a weather disturbance during an eclipse would tend to prevent or "wash out" any noticeable eclipse specific related impacts.

How can You Be "Heat Aware"?

What does it mean to be "heat aware"? The following are helpful to keep in mind as spring season temperatures start to ramp up:

Keep Hydrated: Drink plenty of water before you start feeling thirsty to stay ahead of hydration.

Stay Cool and Protected: Wear loose-fitting, light-colored clothing and use sunscreen. Avoid strenuous activity when outdoors during excessive heat periods.

Protect Kids and Pets: Remember to never leave kids and pets unattended in vehicles. Keep feet and paws off hot sidewalks and pavement.

These tips will help you beat the heat!

Why does Lightning Exist?

Defining a thunderstorm, lightning is both beautiful and dangerous! Lightning serves as a natural mechanism to rebalance cloud-to-cloud and cloud-to-ground charge separation that are instigated by the turbulent motion associated with vigorous thunderstorm updrafts and downdrafts. Specifically, collisions between tumbling and rising of a mixture of frozen and liquid precipitation have been linked to an accumulation of electrons at the bottom of thunderstorms, which creates a negatively charged zone. As the negatively charged zone is created so too are relative positively charged zones towards both the top of the storm and also near the ground under the thunderstorm.

Air is a very good insulator, but eventually there is a tipping point in the building environmental electrical field when connections start developing allowing excess electrons to flow either to positive regions found within the cloud or near the ground. When a connection or channel does manifest the rapid and dazzling display of electron transfer rebalancing is apparent as lightning! Knowing when and where lightning strikes will precisely occur remain impossible, so when thunderstorms are forecast to develop or seen/heard moving into your area remember the following lighting safety tips to protect yourself and others from harm!

What are some Lightning Safety Tips?

Let’s talk a bit about lightning safety. Whether it’s an imminent severe thunderstorm outbreak or a seemingly benign pop-up stray thunderstorm, the lightning that is generated in either scenario and the inherent danger it poses to you is all the same. When any thunderstorms are forecast in your area keep in mind these outdoor safety tips:

1) Monitor the latest forecast ahead of time and consider having a Doppler radar app on your phone to keep track of developing storms and receive pertinent weather warnings/forecast updates.

2) If you hear thunder, you are already close enough to a thunderstorm to be struck by lightning! Move to an indoor shelter and wait at least 30 minutes after the last sound of thunder to return outside. Continue to watch for more developing storms. It’s possible for a location to be impacted by multiple thunderstorms through the day, especially during the summer monsoon.

3) If you are caught in a storm event outside, avoid exposed higher terrain areas, move off of or away from water bodies such as ponds and lakes,

don’t be near conductive infrastructure (e.g., powerlines, barbed wire fences, etc.), and don’t seek shelter under isolated trees.

What are Kelvin-Helmholtz (Wave) Clouds?

Kelvin-Helmholtz wave clouds! These wave looking clouds develop when there is vertical wind speed shear occurring at the interface of two separate air mass layers in the atmosphere. The faster winds on the top layer occasionally mix with slower winds in the layer below and lose momentum, hence the wave breaking appearance like what is observed on the ocean surface when faster winds are blowing. Atmospheric wave breaking becomes visible when clouds are entrained in the process.