National Weather Service

Southeast Arizona Monsoon Progression

No two years are ever alike weather-wise, and the same can certainly be said about the monsoon. However the monsoon ebbs and flows in a relatively predictable cycle each year across Arizona, with five broadly-defined phases. These phases depend heavily on where the subtropical (monsoon) ridge is located, and how strong it is.

Many tools are used to track these trends, but the single best method is to monitor the height of the 500mb atmospheric pressure. This 500mb height, usually expressed in meters above sea level, indicates how strong the monsoon ridge is, where it is centered, and how warm it is underneath. A height above 5950m is indicative of a strong monsoon ridge with hot temperatures underneath. It also tends to lead to stronger easterly flow aloft south of the ridge. A height below 5880m is indicative of a weak monsoon ridge, with slightly cooler temperatures underneath. It also means weaker easterly winds south of the ridge, and the tendency for the high to shift south and allow drier westerly winds aloft to penetrate into the monsoon region.

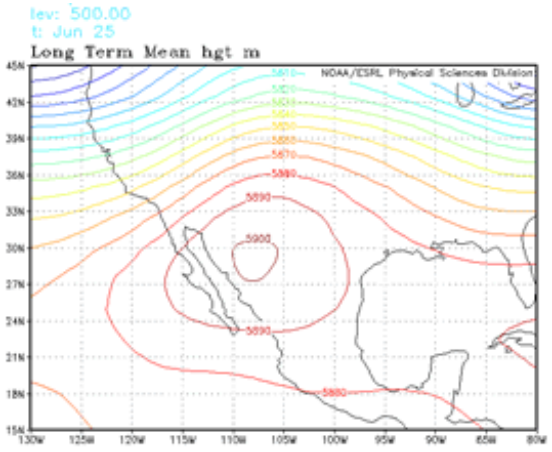
Ramp-Up: Mid June through early July

By mid June, the flow of tropical moisture has begun into the Sierra Madres in southern Chihuahua, Durango and Sinaloa, Mexico. The monsoon ridge has formed, is strengthening, and is expanding north into the Rio Grande Valley. This causes upper level winds over southeast Arizona to turn from the southwest or west to the southeast or east. The shift begins to spread upper level subtropical moisture from the Gulf of Mexico into northwest Mexico and the southwest U.S. Isolated thunderstorms develop, mainly during the hottest part of the day in late afternoon. The lower levels of the atmosphere remain dry, though, so most of the rain from these mainly mountain thunderstorms evaporates before reaching the ground. Instead, the storms produce strong, gusty and highly variable winds, and dry lightning. By this time, the mountain forests have not received precipitation since April, so both live and dead vegetation is at its driest. Thus the risk of wildfires is at its highest as well.

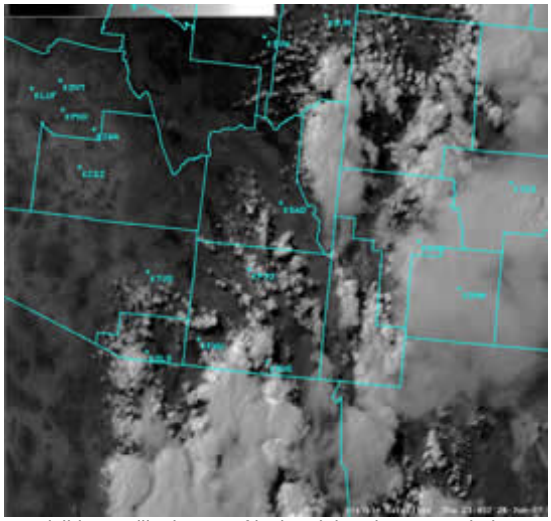
A few of these weakening thunderstorms may be pushed by the winds aloft into the lower deserts during the early evening hours. As the rain from these thunderstorms evaporates into the hot, dry desert air, it cools and accelerates downward to the surface. This is known as a microburst. Microbursts, while only a mile or two across, can be accompanied by damaging wind gusts exceeding 70 mph. As these gusts strike the desert and valley floors, a dust storm, or haboob, can occur. Dust storms like this can reach great heights and travel dozens of miles away from the thunderstorm. Within the dust storm, visibilities can drop to near zero.

In this ramp up phase, the monsoon ridge can shift back to the south, and cause a temporary return to hot, dry, early summer weather. This “false start” can be problematic

if wildfires have been ignited, since the return to very low humilities is usually accompanied by stronger winds. Once every few years, though, the low level moisture does not lag behind the upper level moisture. Instead, the low level moisture surges into Arizona from the subtropical rain forests of the southern Sierra Madres, up the Rio Grande Valley, or up the Gulf of California. If that happens, we can entirely skip this phase and jump to the Onset Phase.



Mean 500mb heights, June 25 (monsoon ramp up)

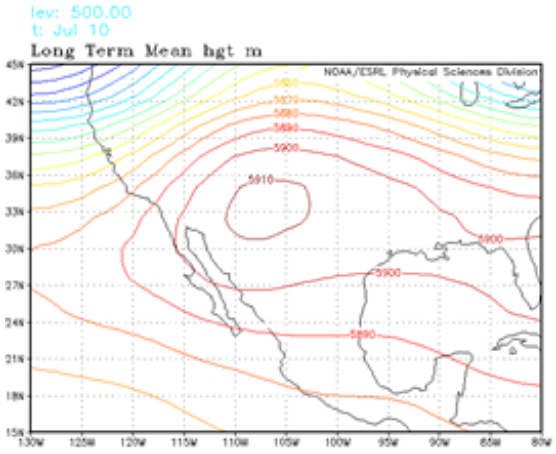


Visible satellite image of isolated thunderstorms during monsoon ramp-up, June 28, 2007

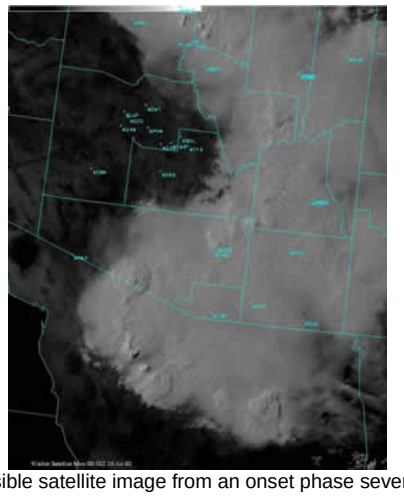
Onset: late June through mid July

As moisture increases over northern Mexico, and thunderstorms become a daily occurrence over the Sierra Madres just south of the Arizona border, dramatic changes take place in the mountain landscape. Areas that were brown and dry in spring and early summer rapidly green up as semitropical trees begin to soak up recently-fallen monsoon rains and sprout canopies of leaves. These trees, shrubs and grasses, combined with the wet soils, put considerable moisture into the atmosphere through evapotranspiration. Meanwhile, the monsoon ridge continues to strengthen and move northward into the southern Plains of the U.S. By now, winds aloft over southeast Arizona are solidly out of the east or southeast. Moisture spreads into the region not only aloft, but also at the surface. Surface dewpoints are usually the last weather parameter to reach critical values as the monsoon arrives in earnest.

At this stage, the deserts are still relatively hot and dry. However, the thunderstorms become much more organized, more numerous, and produce more rain. They start developing earlier in the afternoon, and may continue to grow and organize into the evening hours as they move west or northwest more easily. Severe weather becomes an even greater concern as the damaging winds being to affect larger areas. Dust storms and microbursts may still occur, especially as the storms spread north and west toward Phoenix and the low deserts. However, as the first heavy rains begin to fall on the deserts, dust storms become less common as the risk of flash flooding increases.



Mean 500mb heights, July 10 (monsoon onset)

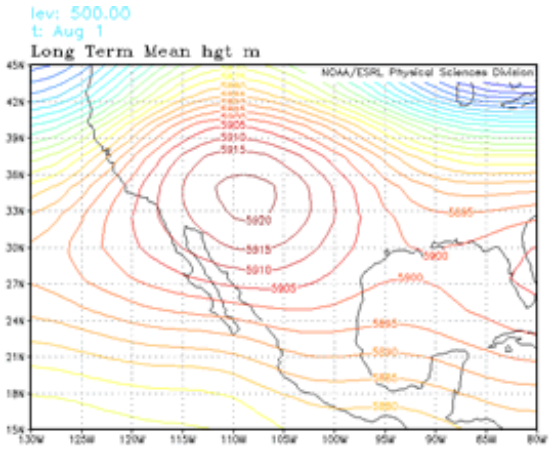


Visible satellite image from an onset phase severe thunderstorm outbreak over southeast Arizona, July 14, 2002.

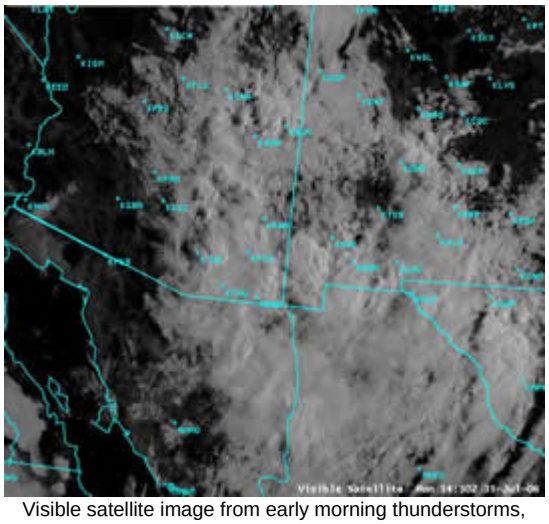
Peak: mid July through mid August

This is monsoon prime-time in southeast Arizona. The monsoon high is at its strongest and northernmost extent in the four corners region of the U.S. This high can meander over the region, and at times may even shift into the Great Basin. Steering winds aloft are persistently out of the east over southern Arizona, and may even turn to the northeast. If the monsoon ridge is unusually weak or is pushed south by an unseasonably strong storm in the Pacific Northwest, monsoon "breaks" can occur as the upper level winds weaken and fail to bring additional moisture into the region.

Two particular phenomena can also take place and cause heavy "burst" periods of rainfall. First, there are occasional low-level moisture surges from the Gulf of California, which by now has water temperatures approaching 90° F. These Gulf Surges travel up the Colorado River Valley and low deserts of Arizona, sometimes even reaching Utah and Nevada. Second, upper level disturbances rotating around the subtropical high pass rather regularly across southern Arizona and Sonora. These create a more favorable atmospheric environment at upper levels for thunderstorm development. When one or both of these conditions occur, thunderstorms moving westward off the mountain ranges and into the low deserts may continue to grow and organize, instead of decaying. The favorable upper level environment can also affect the timing of thunderstorm development. Instead of the typical development in the afternoon, thunderstorms can occasionally develop in the middle of the night, early in the morning, or redevelop repeatedly over the same general area. With the increased moisture, and more focusing mechanisms in the upper atmosphere, flash flooding becomes the main concern. Dry microbursts are unusual during this time, but the rain can be so heavy (sometimes falling at the rate of 4 inches per hour) that the down-rushing, cold rain and even hail can produce damaging winds on their own.



Mean 500mb height, August 1 (monsoon peak)

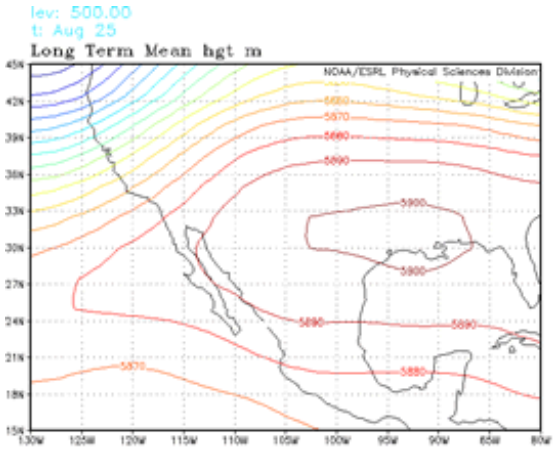


Visible satellite image from early morning thunderstorms, 0730am MST July 31, 2006, during the peak of the 2006 monsoon. Many of these thunderstorms produced 1-2 inches of rain per hour.

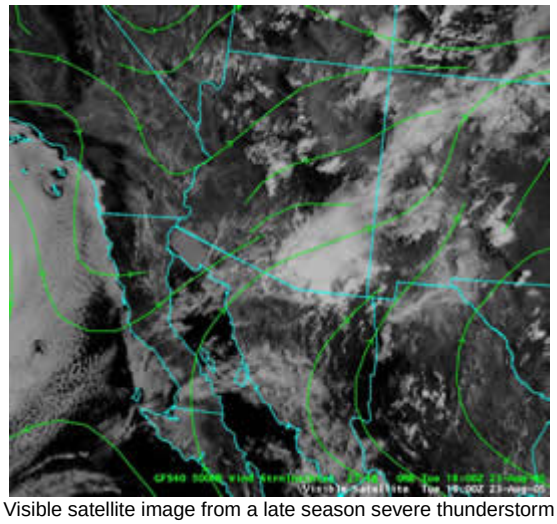
Late Monsoon: mid August through early September

It is unusual for the monsoon to end abruptly. By mid August, the increasingly lower sun angle in the northern hemisphere becomes less effective in maintaining the monsoon ridge. The high begins to retreat southeast into the southern Plains and can even breaks into pieces as the polar jet stream begins to shift south from Canada. Upper level winds become more variable, and sometimes turn to the south or even southwest. Breaks become longer between thunderstorm events. However, the combination of wet soils and continued rain over Mexico usually keeps low level moisture in place over Arizona. Because steering winds become more variable and sometimes light, thunderstorms can still be slow-moving and pose a serious flash flood threat, particularly in places where it has been wet all summer.

This is the time of year where the tropical eastern Pacific becomes a concern. Very warm water temperatures support tropical storms and hurricanes west of the Mexican coast. Most of these hurricanes move harmlessly west into the open Pacific. However as the monsoon ridge shifts south, moisture from these systems can be steered toward Arizona. When this happens, thunderstorm rains can be enhanced and lead to flash flooding.



Mean 500mb height, August 25 (late monsoon)



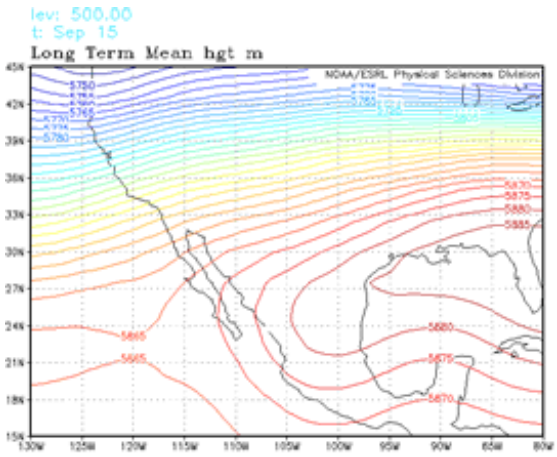
Visible satellite image from a late season severe thunderstorm and flash flood event, August 23, 2005. Note southwest flow aloft and weak trough near the lower Colorado River.

Decay: late August-late September

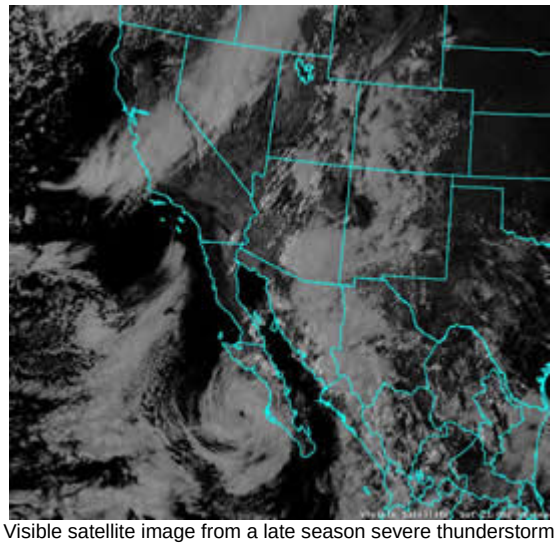
By September, the subtropical ridge has weakened considerably, while the jet stream continues to strengthen and shift deeper into the U.S. Winds aloft begin to blow more consistently from the southwest and work their way to the surface. Unless a tropical system is captured, this southwest flow disrupts both the upper and lower level moisture feed into Arizona. The soils begin to dry out, and temperatures begin to cool while remaining relatively warm aloft. The lack of low level moisture and a more stable atmosphere causes thunderstorm activity to diminish and the monsoon to fade.

In this decay phase, though, the weather can still turn active. Moisture lingering from earlier in the summer remains over Mexico until early October. If any incoming cold fronts from the Pacific tap into this moisture, thunderstorms will redevelop. This can be a dangerous time since the cold fronts are usually accompanied by colder air and stronger winds aloft. This situation, which is more typical for the Plains states, can lead to rotating, supercell storms. Although Arizona only sees a few tornadoes a year, they are most likely to occur during this transition period.

Once every 2 to 3 years, an east Pacific tropical storm or hurricane is steered into Arizona, either by an incoming Pacific storm system, or by the weakening subtropical high over Mexico. Most of the time, these systems dissipate before reaching the border. However, they can induce moisture surges into Arizona and support larger areas of heavy rain. About once every 10 years, a system survives long enough to actually cross into Arizona as a minimal tropical storm. In either case, torrential rains and flooding can result as the monsoon winds down.



Mean 500mb height, August 25 (late monsoon)



Visible satellite image from a late season severe thunderstorm and flash flood event, August 23, 2005. Note southwest flow aloft and weak trough near the lower Colorado River.

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