Understanding the southwestern monsoon

Rain, lightning, fire and what is in store for the future

By Zack Guido

While hikers on Mount Lemmon witness the clouds coalescing, pedestrians in downtown Tucson wisely dodge the sun in the shade of buildings and street-lined trees. People high in the mountains feel a nervous tinge in their stomach with the first thunderous rumble while those in the valleys wish for the splash of rain.

The monsoon season is a showcase of dramatic weather that brings relief and danger. It suppresses the hot summer temperatures and resuscitates vegetation, but it also delivers intense rain, large hail, powerful winds, whirling dust, and a startlingly high number of lightning strikes.

The monsoon is highly anticipated each year, yet experts see no clear-cut trends in monsoon activity over the last 100 years. This begs the question: will the monsoon strengthen or weaken in the future?

The Nuts and Bolts of the Monsoon

The engine of the monsoon is the sun. As summer progresses, solar radiation warms the land and Pacific Ocean at different rates, inciting a tug-of-war with the winds. Until the land sufficiently warms, air flow maintains a westerly flow. When the winds do an about-face, the monsoon begins.

The monsoon first begins in northern Mexico in May. The summer sun evaporates water from the Gulfs of Mexico and California and creates humid conditions over the land which produce rain. Vegetation begins to grow and moves water from the soils back to the air in the form of vapor in a process called evapotranspiration. Humidity rises, fueling more rain and more transpiration. Then a pressure difference between the hot, parched southwestern air and cooler Mexican air pulls the moisture-laden air north to Arizona and New Mexico.

In Arizona and New Mexico, monsoon storms typically begin in early July after several complex and dynamic weather phenomena collide. By July, the Four Corners region has baked in the sun for months. Air has risen like a helium balloon, creating a low pressure trough in the lower atmosphere. Off the coast of Baja California, the sun's energy has boosted ocean temperatures to around 85 degrees Fahrenheit. But the ocean has a moderating effect on the air and has kept it at temperatures below those over the deserts of the Southwest. This temperature imbalance becomes large enough that a change in the high and low altitude atmospheric movement occurs. The winds high over the Southwest, near an altitude of 30,000 feet, take a U-turn westward, opposite their trajectory for nine months. They carry with them moisture from the Gulf of Mexico. At approximately the same time, the near-surface air over the Gulf of California rushes northward into Arizona and New Mexico, carrying with it moisture from the gulf.

The moist air flowing into Arizona and New Mexico hits the mountains and rises. As the air ascends, it expands and cools. The air temperature decreases, falling below the dew point temperature—the temperature below which the air can not hold all the moisture and condenses to form rain. Thunderstorms begin, vegetation grows, and humidity increases over land. Then more rain falls, creating a cycle that continues until the temperature difference between the land and sea is reduced, sometime in early fall.

The Monsoon in the Southwest

Until this year, the National Weather Service (NWS) declared that the monsoon season began on the first of three consecutive days when the average dew point temperature was greater than 54 degrees Fahrenheit in Tucson and 55 F degrees in Phoenix. The average monsoon start date in Tucson was July 3, according to statistics compiled by the NWS for 1949 to 2007. The earliest onset occurred in 2000 on June 17. In Phoenix, the average start date was July 7 and the earliest onset similarly occurred on June 17, 2000. Unlike Arizona, New Mexico has not quantitatively defined the onset of the monsoon.

The dew point temperature, however, is just one of several indicators of the monsoon, and it is typically the last index to suggest that the monsoon has arrived, said Eric Pytlak, science and operations manager at the NWS in Tucson.

In June, for example, numerous monsoon storms occurred around Tucson while the dew point remained below 54 degrees F. For this reason, and to allow the media to more effectively communicate to the public when the monsoon storms are likely to form, the NWS in Arizona has designated June 15 as the official monsoon start date.

Arizona and New Mexico receive up to half of their annual precipitation during the monsoon season. The monsoon's wild winds and driving rains are most dramatic in Tucson and in western New Mexico, tapering off in Phoenix and Yuma (Figure 1). On average, the monsoon delivers approximately 6.1 inches of rain a year to Tucson compared to 2.8 inches to Phoenix.

But the monsoon is variable. Everything from the timing of storms to the production of lightning, changes from region to region and from year to year. If the amount of rainfall is the basis for judging a summer, then it is common to have good summers and bad summers within the same city.

The character of the monsoon has not changed in the past 100 years, said

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Pytlak. The monsoon in the 1930s and 1940s is just as variable as it is today.

Similarly, the Las Cruces region "has not seen any trends in the precipitation of the North American Monsoon," said Dave Novlan, meteorologist for the NWS in El Paso.

A close look at the monsoon precipitation in Tucson and Phoenix supports Pytlak's assertions (Figure 2). Since 1895, precipitation has neither generally increased nor decreased.

Despite no clear-cut trends in precipitation, people often claim that the monsoon is either weakening or strengthening. People still cite the 2006 monsoon season, in which rain fell in near records amounts, as evidence that the monsoon rains are intensifying. But people tend to remember more vividly extreme years, said Pytlak.

How is the monsoon shaping up this summer?In June, rains were below average in both Tucson and Phoenix. It is too early to judge the monsoon season, however, and predicting it is difficult. This year may be especially tricky because two monsoon-enhancing and two monsoon-damping forces are at work.

La Niña, although weakening, is still at hand, said Tom Evans, Warning Coordination Meteorologist at the NWS in Tucson. A La Niña event increases easterly air flow, which tends to bring more moisture from the Gulf of Mexico, Evans said. In addition, the tropical Pacific Ocean has heightened convection, known in the meteorology world as an active Madden-Julian Oscillation (MJO). This year's energetic MJO can help push more moisture into the Southwest from the Gulf of California. However, the Midwest has not been hot and the Rocky Mountains have seen an above-average snowpack this past winter; both factors act to decrease monsoon activity. Which of these forces will ultimately win out has yet to be seen.

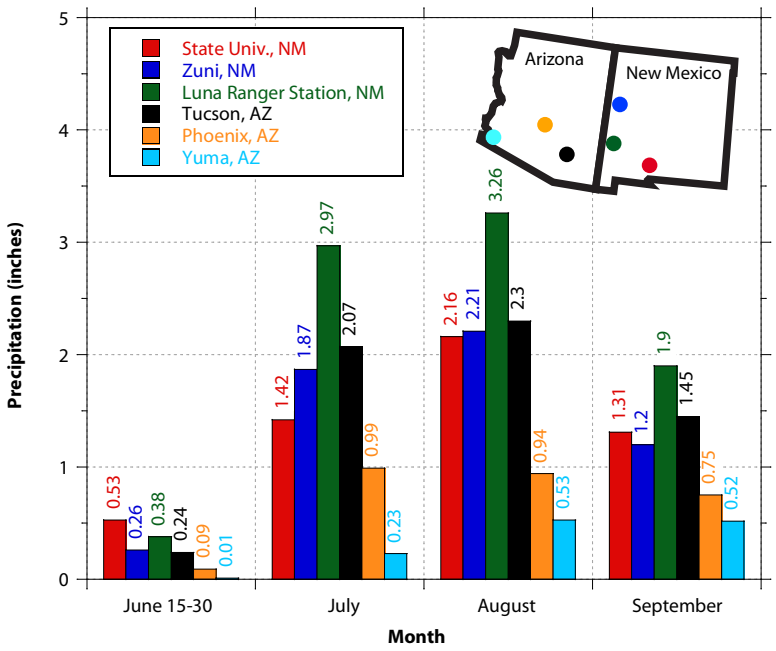

Figure 1. Monsoon precipitation in the Southwest. The data for Arizona was obtained from the NWS Tucson; New Mexico data was compiled from the Western Regional Climate Center.

Monsoon Lightning

Regardless of which monsoon shows up this summer, one thing is for certain: dangerous weather will leave its mark. In the Southwest, flash floods, dust storms, strong winds, hail, excessive heat, and fires injure people and property, said Evans. Of these, lightning has the potential to cause the greatest damage.

For most of the Southwest, the monsoon season is also the fire season. On June 21, lightning zapped Pima County 46 times, shooting electromagnetic pulses for each strike more than 400 miles across the landscape. Each pulse passed through a network of sensors that pinpointed where the lightning touched down. For one strike, sensors were not needed, as smoke began billowing from the Rincon Mountains east of Tucson. The blaze, called the Distillery Fire, burned more than 8,500 acres in eight days before monsoon rains helped extinguish it. A day later, Pima County lit-up with another 218 strikes, a large fraction of the 928 cloud-to-ground strikes that occurred on June 22 in the entire state of Arizona. Two of these ignited the Apache-Sitgreaves National Forest near Clifton and Alpine, starting the Hot Air and Bear Mountain fires that charred more than 10,000 acres. In New Mexico, the eastern half of the state was bombarded with 8,024 ground strikes on June 24. Fortunately, only one ignited a fire.

In the ramp-up phase of the monsoon, from mid-June to early July, the landscape is more susceptible to large and uncontrollable fires because little precipitation has typically fallen since April and vegetation is desiccated. According the Tucson NWS website, isolated thunderstorms develop over the mountains in the afternoon. But because moisture from the Gulf of California has yet to flow into Arizona and New Mexico, the lower levels of the atmosphere are dry and the rain evaporates as it falls to the Earth. Lightning, however, reaches the ground, sometimes igniting wildfires, and the storms often bring gusty winds that fan the fires.

In the Southwest, lightning has ignited more than 2,300 fires annually since

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2001, burning on average approximately 277,000 acres per year. Those figures, however, represent a mere fraction of the number of lightning strikes.

Between 1996 and 2005, an average of 673,320 lightning bolts touched down in Arizona each year, according to Ron Halle, meteorologist and consultant for Vaisala Inc., a company that monitors lightning.

During July and August, Arizona receives a similar number of lightning strikes as Florida, Halle said. With a lightning season that stretches more than six months—at least twice as long as Tucson's—Florida is considered the lightning capital of the United States.

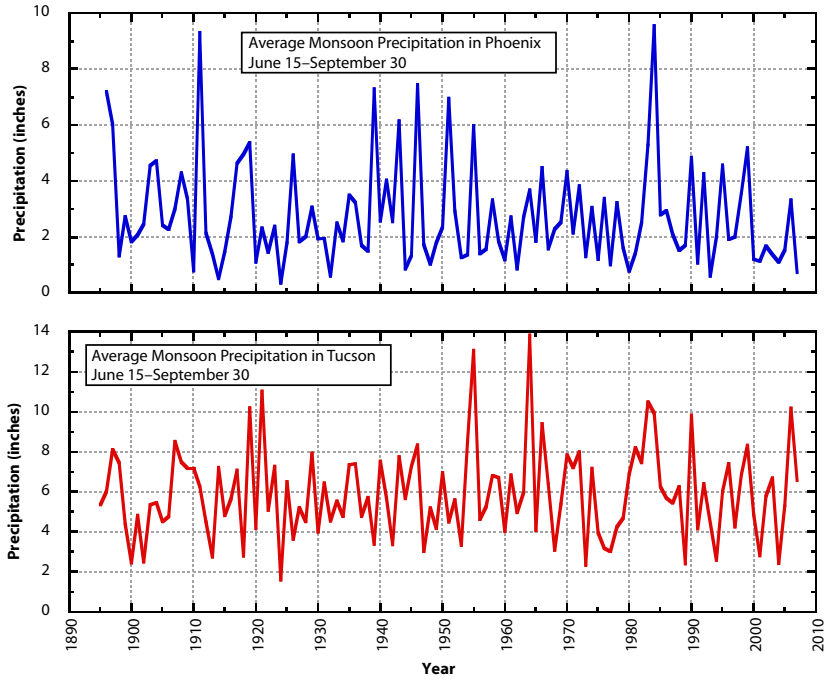

Figure 2. Average monsoon precipitation (June 15 through September 31) since 1895 for Tucson and 1896 for Phoenix. This data was obtained from the National Weather Service in Tucson.

A look ahead

Will the monsoon respond in a predictable manner to higher future temperatures? The monsoon rains, in conjunction with winter precipitation, are vital for sustaining the unique Sonoran vegetation. It also helps replenish water supplies and aids agricultural production. Changes in the monsoon can have dramatic effects, especially given rapid population growth in the region.

In the Southwest, climate and society are tightly connected, said Joellen Russell, assistant professor of biochemical dynamics at The University of Arizona.

"We're living in one of the fastest growing populations in one of the most vulnerable ecosystems," she said.

At the moment, researchers do not know how the monsoon will respond to future temperature changes. The best educated guesses come from 19 general circulation models, or GCMs, used in the 2007 Intergovernmental Panel on Climate Change Fourth Assessment Report. These models, however, are not very good at capturing the monsoon. Only two of the models simulate monsoon precipitation, and one predicts an increase in future rains while the other predicts a decrease.

One reason that most of the models fail to capture the monsoon is because they grid the globe into squares with an area of roughly 4,900 square miles. Each grid is assigned an average elevation. This eliminates small scale topography, such as Mount Lemon, and in the process eliminates the important role mountains play in generating thunderstorms.

Why do the two models that generate monsoon rains simulate it differently? Russell's group hypothesizes that for the model with enhanced future monsoon activity, the dominant climatic influence is a larger temperature gradient between the Four Corners region and the tropical east Pacific Ocean. For the model with suppressed monsoon activity, the controlling influence may result from higher air temperatures that reduce the number of days in which the air temperature falls below the dew point temperature.

To this point, the observed increase in global temperature, for which humans bear some responsibility, has not had a clear impact on the monsoon. Russell added, however, that if she had to bet on the character of the future monsoon, she'd gamble that it will strengthen.

The Southwest may get bigger monsoons because the temperature difference between the land and the Pacific Ocean will be greater, she said. But, she continued, it may take 10 to 15 years to understand the links between increasing temperatures and the monsoon activity.

Come September

Earth moves farther from the sun each day. With every 24 hours, solar radiation strikes the Southwest at more of an obtuse angle. The temperature difference shrinks between the waters off the coast of Baja California and the land in the Four Corners region. The winds aloft change direction and flow east. Soils dry. Humidity drops. Thunderstorms and lightning become rare. The dramatic and powerful monsoon wanes, officially ending on September 30. And hiking on Mount Lemmon or on the other Sky Islands in the afternoon becomes a safer, drier outing.