Inquiry into monsoon and global warming continues

Troublesome twist: Atmospheric variables make prediction tough for summer rain

by Melanie Lenart

Editor's Note:
This is the second in a two-part series about how the monsoon might change with global warming. This article focuses on some of the atmospheric influences on the North American monsoon. For last month's article visit http://www.ispe.arizona.edu/climas/forecasts/articles/monsoon_June2005.pdf.

Some circumstantial evidence points to the possibility that global warming will yield stronger monsoons. Increases in sea surface temperatures, land heating, and air temperatures suggest the potential for an increase in summer rainfall.

Mystery solved? Not quite. There's a plot twist: Atmospheric variability remains elusive when it comes to the North American monsoon, which funnels summer rainstorms into the Southwest. Because the description of atmospheric variability remains sketchy, climatologists are seeking more clues before they will guess how the monsoon will respond to climate change.

"There's not much out there in terms of climate change and the monsoon," noted Arizona State Climatologist Andrew Ellis, alluding to the scientific literature on the North American monsoon. "I don't think people have a great feel out there how (atmospheric) flow would be affected by climate change."

Figure 1. The U.S. region affected by monsoon is restricted to the Southwest. Graphic courtesy of Andrew Ellis.

The North American monsoon has remained unresponsive to warming—at least where it reaches into the southwestern United States (Figure 1). Ellis finds no evidence of a trend toward more rainfall during the southwestern U.S. monsoon season (Figure 2), even though the Earth's surface has been warming for many decades.

Lack of data complicates efforts to unravel the mystery behind North American Monsoon variability. In a way, the southwestern U.S. is akin to a mere bystander—the main monsoon action centers on Mexico's Sierra Madres. While reliable U.S. data describing atmospheric activity exists from about the mid-20th century, comparable data in Mexico remains sparse to this day.

Since early 2004, researchers with the North American Monsoon Experiment (NAME) have been launching weather balloons, analyzing data, and studying monsoonal thunderstorms in intensive bursts of coordinated activity in both Mexico and the Southwest, explained NAME project leader Wayne Higgins. The project runs through 2008.

Meanwhile, satellites help fill in some of the missing puzzle pieces, but they provide only a few decades of data—a short time frame compared to some of the decades-long fluctuations that can influence monsoon strength. Even U.S. climate station data is considered short by these standards.

Although climatologists traditionally turn to computer modeling for insight on future changes, the General Circulation Models (GCMs) used to represent global climate are not yet up to the challenge for the North American monsoon. "The current generation of models doesn't do a good job of representing the monsoon, for a whole variety of reasons," said Andrew Comrie, a Climate Assessment for the Southwest (CLIMAS) researcher. GCMs have trouble modeling clouds, convection, and precipitation in general, he noted, in addition to using a spatial scale with no relevance to the monsoon. "It's a recipe for not getting it right in the GCMs."

Thinking outside the box

From a process perspective, global warming may affect some of the underlying drivers of the monsoon—sea surface temperatures, land heating, and atmospheric moisture—as discussed last month. The circumstantial evidence regarding the response of these drivers to global warming suggests a strengthening of monsoons around the world.

Long-term records support such an interpretation, showing the Asian monsoon tended to strengthen during warm episodes of the past, and weaken during cool periods (For example, see *Nature*, January 23, 2003). On the other hand, the immense size and height of the Tibetan Plateau make the Asian monsoon somewhat more predictable than the North American monsoon.

The sheer number and inherent variability of the factors affecting the North American monsoon make climatologists leery of predicting how it will respond to global warming. Comrie rattled off half a dozen influences on the North American monsoon during a July 14 interview in Tucson, when residents were still waiting for this year's monsoon to begin. The list includes sea surface temperature and land heating, but also the influence of mid-latitude westerly wind patterns, tropical easterly trade winds, and global-scale descent of tropical air.

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"They're all connected and it's all fluid, so it's not like you're moving cogs in a machine. There are just too many feedbacks," Comrie said. "It may be that there will be a dramatic change in one of these that overrides everything else. We don't know."

Changes in El Niño regimes could impact the monsoon, for instance. El Niño tends to suppress monsoon strength in Mexico, Higgins said. El Niño's dampening of Arizona's monsoon season is less noticeable but still detectable statistically, noted Klaus Wolter, a meteorologist with the Climate Diagnostics Center in Boulder.

Still, the El Niño advantage in making skillful predictions of winter precipitation falls short when it comes to forecasts of summer rainfall, at least for the U.S. Southwest. What's more, climatologists are still debating how global warming might affect El Niño regimes.

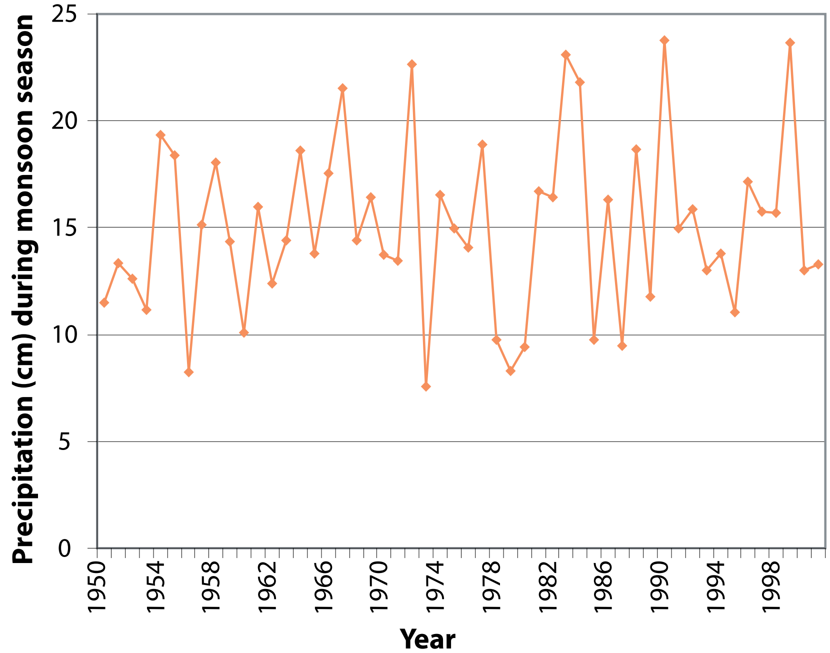

Figure 2. Annual precipitation in the monsoon region during the monsoon season fluctuates widely by year, but the fluctuations show no ongoing trend toward an increase in seasonal rainfall in recent years. Graphic based on 1950–2001 dataset accessible from Andrew Ellis' website at http://geography.asu.edu/azclimate/monsdat.htm.

Too many leads to follow

Predicting monsoon behavior on a seasonal scale poses a major challenge to climatologists, although experimental predictions by both Wolter and Ellis for a relatively dry season in Arizona this year seem to be panning out.

True, it's almost certain the seasonal cycle will kick in at some point with its accompanying thunderstorms. But rainfall rates fluctuate widely from year to year. In the southwestern U.S. dataset compiled by Ellis (Figure 2), average monsoon-season rainfall ranged from about 3 inches (8.3 cm) in 1975 to more than 9 inches (23.8 cm) in 1990.

Further, within that region, the distribution of rainfall typically ranges from abundant to sparse in the same year. In particular, New Mexico and Arizona often seem to follow different leads.

Tropical dynamics

Suspects in the investigation include anything that might influence the position of the signature monsoon "anticyclone" (Figure 3), including the climate features on Comrie's list of factors affecting monsoon variability. Year-to-year variability in southwestern summer rainfall relates in large part to the location and size of this anticyclone.

The anticyclone itself goes by a variety of aliases, including the Four Corners High. The high-pressure anticyclone is easier to define on weather maps (Figure 3), but its presence means a surface low exists below. The combination of a surface low and an upper-level high defines monsoon circulation.

These terms relate to how air flows in the atmosphere. Air may be invisible like a gas, but it flows in currents and moves in waves like fluid. While water will flow from mountaintop ridges to the low-lying valleys on the landscape, air will flow from areas of high pressure—often called atmospheric ridges—to "troughs" of low-pressure.

Surface lows allow moisture to rise more freely in the atmosphere, increasing their odds of forming the towering thunderclouds that can reach into the cooler heights needed to produce rainfall. Meanwhile, the descending air that characterizes highs generally limits precipitation.

At the global scale, heated air rises in the equatorial region and nearby tropics that take the brunt of the sun's incoming punch. The rising air loses steam and begins to descend by the time it reaches the subtropics—and to dry out as it warms on its way down, as descending air does. Climatologists call these global-scale ups and downs Hadley cell circulation.

This circulation pattern helps imprison the subtropics in dryness, as Hadley cell highs tend to suppress precipitation. It's no coincidence that the world's deserts—including the Southwest's Sonoran Desert—tend to be located in the subtropics, centered at around 30 degrees latitude North and South.

Those clear skies that distinguish the subtropics can cloud up during the

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monsoon season, though. In monsoon circulation, subtropical surface air "balloons" up into higher reaches, mimicking the tropic's usual approach to promoting convective activity such as thunderstorms, Ellis explained.

"It just opens the door for some very light flow and accompanying moisture from the south," he added. As discussed last month, moist air tends to rush in from the Gulf of California to Arizona, and from the Gulf of Mexico to New Mexico.

Wrong side of the storm tracks

When mid-latitude weather patterns reign, as often happens during El Niño years, westerly winds can delay the dynamics that usher in the monsoon.

Going back to the water analogy, the westerlies act as a river of airflow that speed along several miles above the Earth's surface. The jet stream speeds along in their core, like swift-flowing water in the center of the river. Sometimes the westerlies follow a straight course, staying mostly in line from west to east. Other times they can meander from Alaska down to Arizona, trailing cool air in their wake.

Although refreshing in the short term, the latter pattern restricts the formation of the anticyclone. Basically, it takes the stifle out of the summer heat needed to draw in warm, moist air from the south.

"That is a really killer for the monsoon," Ellis said.

The absence of sweltering stillness may be welcome by humans and other life forms—until the lack of seasonal relief from the monsoons creates its own problems. The July fire that raged through Tucson's Santa Rita Mountains is one example of how society pays for a sputtering monsoon that doesn't quite catch. Hundreds of hotshot firefighters battled the blaze, mostly in vain, at high personal and financial cost. Meanwhile, air quality in the greater Tucson area also suffered during the event.

When westerly winds shift north, or surface heating manages to override their interference, the anticyclone can take shape. Although the anticyclone brings rainfall to those under its domain, its presence often signifies dry spells for those outside its province, especially the areas falling north and east of its sway.

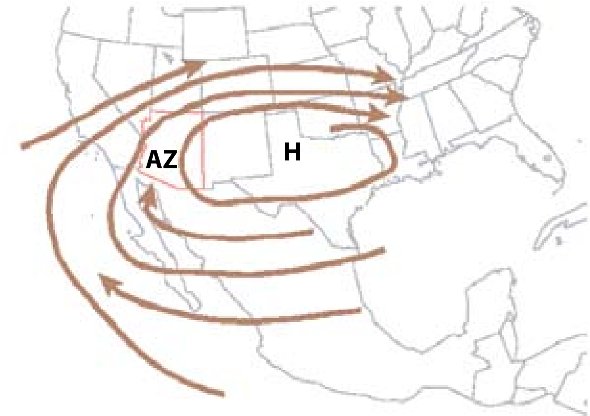

Figure 3. The air circulation patterns at 18,000 feet show the signature "anticyclone" that helps define the North American monsoon. Graphic courtesy of the National Weather Service, http://www.wrh.noaa.gov/twc/monsoon/mexmonsoon.php

"That monsoon anticyclone is huge, and it tends to suppress precipitation in the Great Plains," explained Higgins, whose October 1997, *Journal of Climate* research paper with colleagues first documented the see-saw action between the Southwest and Great Plains rainfall.

For the 30 years of data they averaged, the southwestern U.S. increase in rainfall coincided with a decline in summer rainfall in the Great Plains area between about 105 degrees and 85 degrees West. Monsoon circulation puts the Great Plains in the path of air descending from the heights of the anticyclone, creating a high pressure zone of dry air at the Earth's surface.

The correlation between summer rainfall in the Southwest vs. the Great Plains seems to indicate that stronger monsoon seasons do not represent an increase in overall U.S. rainfall, but merely a redistribution of regional rainfall. So it seems likely that whichever way the wind blows in a climate change scenario, some region of the country will suffer from a lack of moisture.

No solution in sight

Just how will the North American monsoon fare with global warming? It seems this case will be relegated among the great unsolved mysteries until more clues turn up to produce a coherent explanation for year-to-year monsoon variability.

Although global warming seems destined to affect some of the drivers influencing monsoons around the world, such as warming of land and sea, the atmospheric response to these drivers remains unclear when it comes down to considering the regional scale of the Southwest.

At this point, the plentiful cast of characters exerting influence on the monsoon and its characteristic anticyclone resembles the early stages of a game of Clue, when half a dozen or more suspects could be the culprit. Unlike this form of child's play, the real-world solution will probably involve a host of influences working together in a complex scheme that defies detection for many years, perhaps even decades.

One thing's certain: It will take continued dedicated effort by the many investigators now working diligently to solve the mystery. Until they do, the solution remains up in the air.

Melanie Lenart is a postdoctoral research associate with the Climate Assessment for the Southwest.