Monsoon could strengthen as climate warms

Broad-scale influences imply more summer rain, but many caveats apply

by Melanie Lenart

Editor's Note:
This is the first in a two-part series about how the monsoon might change with global warming. This article focuses on some of the broad-scale factors that could influence monsoonal strength while next month's article will consider atmospheric influences on the North American monsoon.

The mystery continues about how global warming might impact the North American monsoon, which lofts summer thunderstorms into the Southwest. Some circumstantial evidence suggests future monsoons could strengthen as temperatures rise, but the investigation has barely begun.

It's an important case considering that collectively New Mexico and Arizona receive about a third of their annual precipitation during the peak months of the monsoon, July and August (Figure 1). A major challenge is picking out the most influential suspects in the line-up, especially since they differ somewhat for the two states. Sea surface temperature (SST) definitely has some role in starting things off, while atmospheric response appears to determine where monsoonal rains will strike next.

Considering how climate change might affect the monsoon requires thinking out of the box. The Intergovernmental Panel on Climate Change projects that the world's average annual temperature will rise at an average rate of about 0.2 to 1 degree Fahrenheit per decade this century. But computer programs designed to consider the impacts of this warming model precipitation at grid scales that don't match regional monsoons.

Also, such models typically have 18 or more atmospheric layers, but they have only one land elevation for each grid cell measuring hundreds of square kilometers. This flattens the mountains that are so important to monsoon dynamics, with their slopes angling to take the full force of the summer sun's rays.

Besides North America, monsoons contribute summer precipitation in South America, Africa, Australia, and, of course, Asia. The North American Monsoon actually centers on Mexico, with Central America as well as Arizona and New Mexico receiving only fringe benefits from the main event. The southwestern U.S. region typically affected by the monsoon can expand or contract somewhat depending on seasonal monsoon strength and pattern.

The first fact in the case is that rising sea surface temperatures tend to promote precipitation. At least that's what witnesses have observed, although the physical reasoning for this remains unclear. Global warming will continue to raise sea surface as well as air temperatures. In fact, data provided by the National Climatic Data Center (NCDC) shows that surface temperatures of the world's oceans already rose on average during the second half of the 20th century (Figure 2).

Another line of evidence involves the role of land heating in luring summer wind and rain to parched lands. Land temperatures fluctuate faster than ocean temperatures with a given heat input (Figure 2), and this operates at the scale of decades, as well as seasonally and even daily.

As for exhibit number three: As air temperatures go up, so does the atmosphere's ability to pick up and hold moisture. This well-documented factor leads climate change specialists to predict with confidence that precipitation rates as well as evaporation rates will increase with a warming climate—at the global scale. Regionally, it will vary, and there's little confidence regarding specifics.

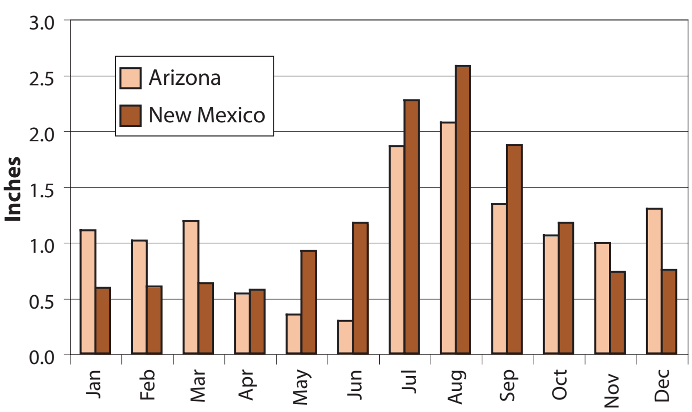

Figure 1. Average monthly values for July, August and September rainfall illustrate the monsoon's substantial contribution to Arizona and New Mexico precipitation. Data is provided by the Western Regional Climate Center, http://www.wrcc.dri.edu/htmlfiles/avgstate.ppt.html.

No smoking gun

There is no clear verdict on how the North American monsoon will fare in a warming world. However, circumstantial evidence suggests monsoons in general will strengthen as global warming heats up ocean and land surfaces and increases air moisture.

All three factors suggest stronger monsoons with a warmer climate—but they also come with complexities. As might be expected, generalities drawn at such a broad scale have limitations for local or regional applications. Still, they're worth considering, with caveats in mind.

Sea surface temperatures

One of the more compelling reasons to suspect an increase in monsoonal strength with time involves the role played by sea surface temperatures in spawning thunderstorms and other convective systems.

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Convection relates to surface heating. A pot of boiling water on a stove demonstrates a form of convection, with the heat from the stovetop being lifted up as bubbles float to the top. This is somewhat analogous to how the atmosphere works when it comes to convective processes.

Rising sea surface temperatures in the Gulf of California contribute to the convective processes that hail Arizona's monsoonal rains, according to research by atmospheric scientist David Mitchell and some colleagues (*Journal of Climate,* September 1, 2002).

Based on their temperature estimates from satellite observations, the sea surface in the gulf must warm up to 26 degrees Celsius (about 79 degrees Fahrenheit) to launch thunderstorms along the Sierra Madre mountains of northwestern Mexico into Arizona. This is also the minimum sea surface temperature required to spawn hurricanes, and for tropical convection in general.

"It's a very interesting number. That's when we get convection started along the coast of Mexico, and all over the world really," Mitchell noted. He cited an October 1993 *Journal of Climate* paper by Chidong Zhang for support.

An even more interesting number, at least for monsoon prediction purposes, is 29 degrees Celsius (about 84 degrees Fahrenheit). Relatively heavy rainfall from the monsoon in Arizona typically begins within days of the northern Gulf's sea surface reaching this temperature, the researchers found.

"We have been monitoring the monsoon since we wrote that paper, and so far the monsoon seems to be consistent with what we'd expect," Mitchell reported by phone. Although he has developed a model to use May conditions to predict this monsoon onset, he was unable to test it this year because he's working off-site on a project to improve the treatment of clouds in climate models.

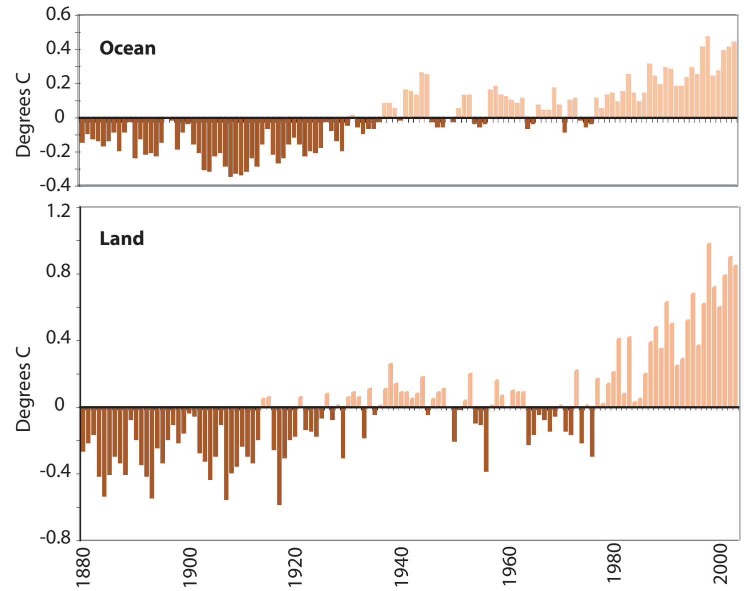

Figure 2. Global mean temperatures compiled by the National Climatic Data Center show an ongoing warming of the planet, with land temperatures heating up faster than ocean temperatures. The annual differences are shown in comparison to the average temperature for 1961–1990. Details about how the data were calculated as well as the data are available at http://lwf.ncdc.noaa.gov/oa/climate/research/anomalies/anomalies.html.

Mitchell's finding that Gulf of California temperatures trigger Arizona's monsoonal rains is supported by another independent study. University of Arizona researchers led by William Wright used oxygen isotopes in tree rings to pinpoint Arizona's monsoonal moisture as coming from the Gulf of California and the eastern Pacific Ocean (*Geophysical Research Letters,* March 1, 2001).

Although Mitchell said he prefers relating northern Gulf sea surface temperatures to monsoon onset rather than strength, he has also found that a late arrival of warm water in the northern Gulf typically means a weaker monsoon for Arizona. If these sea surface temperatures don't reach about 84 degrees Fahrenheit by mid-July, the state's summer rainfall tends to fall below average, he indicated.

A connection between monsoon onset and strength was identified as well by Arizona state climatologist Andrew Ellis and colleagues (*International Journal of Climatology,* February 2004). Their analysis of monsoon seasons from 1950–2001 indicated that early onsets tend to mean longer—and thus wetter—seasons.

The relationships between Gulf of California sea temperatures and monsoon onset do not appear to translate to New Mexico, noted University of New Mexico researcher David Gutzler.

"It's less obvious that that sort of influence maintains its strength, as you move east toward and over the Continental Divide," Gutzler said.

Monsoon strength in Arizona and New Mexico often differ within the same year, leading him (and others) to suspect different influences for the two states. New Mexico's moisture source for monsoonal rains appears to be largely the Gulf of Mexico, although the tropical eastern Pacific also contributes.

Gulf of Mexico sea surface temperatures seem to vary less than those in the Gulf of California, Gutzler said. Meanwhile, eastern Pacific trends vary with El Niño fluctuations, which influence Arizona less consistently than Mexico, explained Wayne Higgins, a Climate Prediction Center researcher and leader of the

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North American Monsoon Experiment. In general, El Niño tends to suppress monsoon activity, especially in Mexico, Higgins noted.

Now for the caveats: Some speculate El Niño events could increase as climate warms (although others suspect the opposite). Sea surface temperatures at a specific location also depend on ocean currents, which may change as climate changes. Along coastlines, upwelling of cooler water from below the surface potentially could temper some sea surface warming.

Even the relationship between tropical convection and sea surface temperatures of 26 degrees could change as the atmosphere warms. (For more on the latter, see the July 1, 2004, *Journal of Climate* paper by Chia Chou and J. David Neelin.) Gutzler noted that scientists still are working to unravel the physical reasons for the 26-degree-Celsius threshold for tropical convection.

"The fact that we see this threshold doesn't mean we understand it," he pointed out.

Land heating

Back in 1884, H.F. Blanford observed that the monsoon in India seemed to be weaker during years when there was abundant snow on the Tibetan Plateau (*Proceedings of the Royal Society of London*). His proposed mechanism—that heating the mountainous land pulls winds and rains landward—is still considered relevant.

Basically, the summer sun heats the land, causing air to rise. This creates a slight vacuum, compelling offshore air to rush in and fill it. The result is a landward shift in prevailing wind direction. As is often the case, with wind comes rain—especially when the wind is seaborne.

The connection between snow cover, and the cooling moisture it imparts, is not the only factor influencing monsoon dynamics, to be sure. But it's potentially important to pin down because most climatologists expect global warming to exacerbate the ongoing trend toward earlier western U.S. snowmelt documented by researcher Daniel Cayan and others (*Bulletin of the American Meteorological Society,* March 2001).

Arizona State University researcher Timothy Hawkins and colleagues found relatively low summer snow cover in the northwestern United States linked at the broad scale to higher summer rainfall in the Southwest. Similarly, University of New Mexico's Gutzler has found relatively low April snowpack in the Rocky Mountains tended to correlate with strong monsoon seasons in New Mexico, but less so for Arizona (*Journal of Climate,* November 15, 2000).

Even in New Mexico, the year-to-year variability was more predictable in some decades than others. Gutzler suspects the drought that began in the mid-1990s suppressed the relationship that held for the previous three decades, he explained in a follow-up telephone conversation earlier this month.

The potential for large-scale drought patterns to blur the relationship also adds uncertainty to predictions about what will happen to the monsoon with global warming. Some climatologists suspect western drought will become more frequent with global warming.

The investigation continues into how snowcover and drought factors relate to Southwest monsoon seasons, and whether the link involves land heating itself or the atmospheric processes that influence snow cover and drought variability.

Atmospheric moisture

A warmer atmosphere can hold more moisture, based on a physical relationship known as the Clausius-Clapeyron equation. This relationship is among the reasons given in an article by Kevin Trenberth and colleagues on how precipitation could be expected to increase and occur in more extreme events as climate warms (*Bulletin of the American Meteorological Society,* September 2003).

However, a projected increase in global precipitation does not necessarily translate into an increase in regional or local precipitation—especially effective precipitation, which is the moisture that remains to nourish plants and fill streams after evaporation has taken its toll.

First of all, the warming atmosphere's increasing ability to hold moisture means evaporation rates will climb. Rates could increase by about 5 percent for a rise of about 4 degrees Fahrenheit, based on calculations by Paul Brown of the Arizona Meteorological Network. So even with an increase in rainfall, there can be a drop in effective precipitation.

On top of that, atmospheric conditions vary daily, with dozens of interacting varieties possessing different modus operandi. Given the myriad of atmospheric combinations that contribute to climate variability, some areas and regions are sure to see a drop in effective precipitation, while other areas will get more than they can handle, at least at some scales.

So, will global warming strengthen the North American monsoon? It's not an open-and-shut case. But it doesn't take Sherlock Holmes to conclude that climate variability will continue to be an accomplice in any long-term changes in monsoon behavior related to global warming.

Next month's article will delve into some of the atmospheric processes affecting North American monsoon strength.

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