



Southwestern drought regimes might worsen with climate change

Will long-term drought in the Southwest be the rule or the exception as the global climate warms? That's a tough question, because the answer requires a long-range projection based on a climate change that has not yet fully manifested. But there are indications that drought and other extreme events will become more common in a warming world—even if precipitation in the Southwest actually increases, as arguably could be expected.

The global warming trend that climatologists and physicists have long predicted because of a build-up of greenhouse gases began in earnest in the past quarter of a century, and evidence indicates it will accelerate (see sidebar on page 3).

Just how the warming might influence drought regimes was the topic of a workshop discussion that drew about 60 scientists to Tucson in mid-November. Although the group noted that our existing level of understanding prevents accurate predictions of expected precipitation changes by region, they agreed there was much cause for concern because of the global implications.

"Global warming contributes to more drying and heat stress. Going along with the consequences of drought in summer are heat waves and wildfires," noted Kevin Trenberth, a senior scientist who heads the Climate Analysis Section for the National Center for Atmospheric Research.

Trenberth co-organized the drought workshop along with Jonathan Overpeck, the director of the Institute for the Study of Planet Earth (ISPE) in Tucson. While Trenberth focuses on understanding climate processes using computer models and in providing a conceptual framework for observations of drought, Overpeck specializes in using past climates to reveal patterns of climate variability.

"The more we look, the more we find megadrought," noted Overpeck. Like drought, megadrought doesn't have one specific definition, but typically it refers to droughts that persist for decades in one region. "From the perspective of the past, we know that droughts in excess of even 20 years have occurred, so that's a possibility in the future."

Based on workshop discussion and other input, there are two main ways in which global warming could affect drought regimes:

- 1) Greater heating leads to higher evaporation rates and higher temperatures that boost the atmosphere's ability to hold moisture. This speeds up the hydrological cycle, leading to more drying as well as more high-intensity rainfall and snowfall events.
- 2) More importantly but less predictably, changes in sea surface temperatures affect the oceanic cycles, such as El Niño, that apparently dictate where the large-scale drought events predominate.

Ramped-up water cycle

Changes in evaporation rates with temperature are fairly predictable. More incoming solar radiation is used up in evaporation than in warming the Earth's surface, Trenberth noted, and the atmosphere's water-holding capacity increases by roughly 4 percent for each rise of 1 degree Fahrenheit.

All those sunny southwestern days lead to high evaporation rates here in winter as well as summer. Even higher evaporation rates might jeopardize the recharging of groundwater, and also make southwestern forests even more susceptible to catastrophic wildfires.

Surface water supplies could also suffer, although that is less predictable because of the expectation for more precipitation in a warmer world. Higher evaporation rates over the ocean translate to more precipitation over land as well as sea, although the effect will surely vary by region. In addition, climatologists expect to see more high-intensity events that do not necessarily soak into the soils, but could help rivers flow more often.

Summer monsoon rain events in the Southwest often fall into the intense category, with sudden downpours that can fill rivers and even streets in the short term. But the effect is so short-lived that monsoon rains generally do little to boost groundwater supplies. Winter precipitation—with

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snowfall being particularly important to Southwest water supplies—tends to involve less-intense several-day events over larger areas than the splashy, localized summer rainfall.

Even if the Southwest does receive more precipitation overall, there's still a chance of getting more droughts because of the other changes. In fact, workshop participant Russell Vose presented evidence that the higher temperatures may already be impacting drought incidence in the Southwest.

"Temperature, in theory, could have a very significant impact on the extent of area under drought," he said. Jay Lawrimore, Vose, and some of their colleagues at the National Climatic Data Center (NCDC) in North Carolina decided to test the theory by comparing the actual U.S. area under drought from 1998 through 2002 to the theoretical area that would have been under drought if temperatures had not risen as abruptly as they did during the last few decades of the 20th century.

In an analysis applying the Palmer Modified Drought Index to the Four Corner states identified as the Southwest (Arizona, New Mexico, Colorado and Utah), they estimated that about one-fifth less of the land area would have experienced severe to extreme

drought from 1998 through 2002 if temperatures had remained on its pre-1976 track. As it was, about three-fifths of the Four Corners land area fell under severe to extreme drought at some point during that five-year time period.

Vose and his colleagues also noticed a national trend for increased precipitation during the last 50 years of the past century. Further, they reported that other NCDC analyses indicated that extremely wet months were increasing even more than extremely dry months in six of the nine regions of the United States, including the Four Corners region.

In addition to spawning more precipitation, a warmer climate likely produces more rainfall relative to snowfall, while warmer spring seasons could cause more rapid snowmelt. So along with drought, floods could well become more frequent as the world warms.

In fact, a 1,000-year climate reconstruction for the Southwest supports the old adage that droughts end with floods, reported Malcolm Hughes of the University of Arizona's Laboratory of Tree-Ring Research (LTRR).

"Please notice that in all of these periods, sustained drought is followed by

a sustained wet period," Hughes instructed, referring to the half a dozen intense, prolonged southwestern droughts scattered throughout the millennia in the climate reconstruction he prepared with LTRR colleague Fenbiao Ni and others. (CLIMAS provides reconstructions for Arizona and New Mexico climate divisions at <http://www.ispe.arizona.edu/climas/research/paleoclimate/product.html>.)

Oceanic influences

While the atmosphere moves lithely around the globe, discharging moisture within about nine days of its capture, the ocean moves on slower time scales that can be measured in years, decades, even millennia. But scientists are still working out numerous details involving the ocean's role in climate.

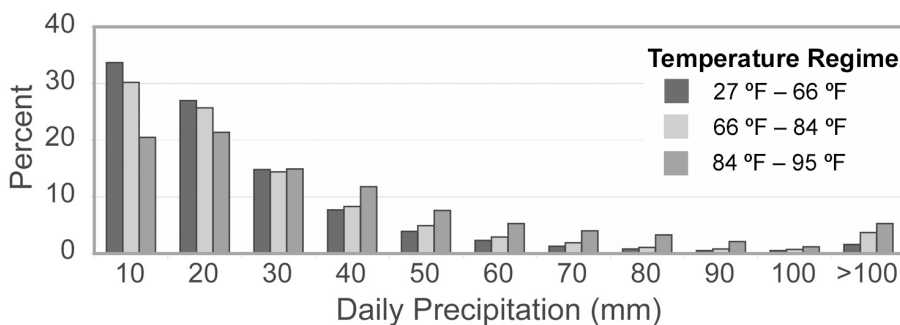
El Niños, which are particularly important for Southwest winter precipitation, typically occur every three to seven years, but evidence indicates that the frequency of El Niños can vary through time.

El Niño tends to bring periods of above-average precipitation to the Southwest, while its counterpart, La Niña, brings dry spells even more predictably. El Niño conditions occur when a warm tongue of surface water reaches the eastern tropical Pacific, while La Niña conditions describe times when the warm pool remains particularly concentrated in the western tropical Pacific.

Although our understanding of the El Niño phenomenon has grown enough to allow prediction of its arrival months ahead of its influence, the details remain uncertain for what to expect with a warmer climate.

"I think it's clear that El Niño will be changed as the climate changes," Trenberth said. "And our observations of El Niño suggest that it has changed in the past 20 years. However, our climate models, which we like to use to

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Precipitation events tend to come in more intense bursts in warmer climate, as illustrated by this bar graph from 100 weather stations around the world. Seasonal precipitation for all locations averages about 9 inches (230 millimeters). Yet precipitation in the warmer locales was more likely to arrive in heavy (greater than 40 millimeter) or extreme (greater than 100 millimeter) events compared to the cooler locales. Temperature ranges were converted from Celsius and are approximate values only. Source: Karl, T., and K. Trenberth. 2003. *Science*, 302:1719–1723. Reprinted with authors' permission.

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verify that these two things are related, are really not up to the task at the moment.”

“Coupled” computer models try to recreate the atmospheric-ocean link, but with limited success. For instance, changing atmospheric temperature even in coupled computer models is not enough to reproduce some of the decades-long droughts of the past. Modelers must instead specify observed sea surface temperatures as well to recreate these droughts. This highlights the importance of the ocean but also signals our lack of understanding about what causes sea changes.

An increase in intense El Niño events in the past quarter century, along with an expectation of more frequent and stronger El Niños in the future, supported a conclusion by a regional panel that climate change would bring more precipitation to the Southwest. The Southwest Regional Assessment Group, co-chaired by then-ISPE Deputy Director William Sprigg, used this premise to predict other future changes in their 2000 report (available online at <http://www.ispe.arizona.edu/swassess/>). However, some climate models show an increased frequency of El Niño during cooler time periods.

The question is further complicated by evidence that all of the world’s oceans have been warming since about the middle of the 20th century, as reported in a March 24, 2000, *Science* article by Sydney Levitus and colleagues at the National Oceanographic Data Center in Maryland. Their finding indicates that the ocean warming preceded the atmospheric warming trend that began in full swing in the mid-1970s.

This indication that oceanic warming preceded atmospheric warming makes perfect sense to Trenberth, who suspects the high sea surface temperatures measured during the strong El Niño of 1997–1998 helped put 1998 down in the books as the hottest year

Evidence Of Global Warming

The 1990s and some of the years that followed contained an abundance of exceptionally hot years, as judged by both the instrumental record and longer records reconstructed from tree rings, corals, ice cores, and other natural archives of temperature.

By all accounts, global mean annual temperatures since about the mid-1970s have been above average. Since about 1976, the rate of atmospheric warming has tripled the 20th century average global rate of about 1 degree Fahrenheit per century, as captured by analyses by Russell Vose and his colleagues at the National Climatic Data Center.

And given the continuing input of greenhouse gases entering the atmosphere from industry, vehicles, and deforestation, scientists expect the warming trend to continue and even accelerate throughout the 21st century. Greenhouse gases like carbon dioxide and methane basically trap some of the sun’s heat that would otherwise escape from the atmosphere out into space.

The Intergovernmental Panel on Climate Change projects the influx of greenhouse gases will spur a rise in global temperatures by roughly 2 to 10 degrees Fahrenheit by 2100.



on record, as the heat moved from the ocean to the air. Interestingly, this high-magnitude event quickly switched into a high-intensity La Niña event from 1998–2002, which contributed to drought conditions in the Southwest.

Martin Hoerling, another workshop participant, published a paper in the January 31, 2003, issue of *Science* attributing the severity of the 1998–2002 drought—which spanned southern Europe and Southwest Asia as well as the southwestern United States—to persistently warm sea surface temperatures in the western Pacific and Indian oceans during this time frame.

If warm temperatures in the Pacific can strengthen both sides of the El Niño cycle, the theory that a warming climate will bring more extreme events gains strength. The uncertainty about how ocean cycles might

change with the continued warming, in turn, fuels concerns that the global climate could make an “abrupt” shift to a new state—a quantum leap that would force scientists to re-evaluate the current system of knowledge about climate.

“In terms of abrupt climate change, we now think that it’s the wild card of global warming or future climate change,” Overpeck said. “There is good reason to suspect that with climate change, the tropical Pacific system could change abruptly in ways that we can’t yet anticipate.”

—Melanie Lenart, CLIMAS

Next month, the newsletter will address how other oceanic trends, the Atlantic Multidecadal Oscillation and the Pacific Decadal Oscillation, can influence Southwest climate.

