HARVARD COLLEGE REVIEW OF ENVIRONMENT & SOCIETY

RUNNING DRY

WEATHERING THE GREAT CALIFORNIA DROUGHT

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ABOUT THE REVIEW

A publication at Harvard University that seeks to provide a platform for connecting students, researchers, business and political leaders, and the public to enable integrative discussion that is paramount to developing successful solutions to our current environmental issues. While much of the contemporary discourse on environment and society have been focused on either one or the other, this publication provides a robust multidisciplinary discussion on the full gamut of competing pressures and interests relating to the environment.

MASTHEAD

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LETTER FROM THE EDITOR

This publication, the third issue of the Harvard College Review of Environment & Society, focuses on the massively publicized topic of the California drought. Although certain areas of the state have received rain of late, California remains to be drought-ridden. As some officials state that the drought will continue for many years, the importance of understanding and solving its varied problems begins in this issue.

To first get a sense of the beginnings of the drought, Professor Richard Seager of the Palisades Geophysical Institute introduces the science behind the drought, with consideration towards any potential connections to the even greater issue of climate change. From here on, the reader has a foundation to approach the topic with a more informed and discerning eye.

Next, Professor Jay Lund discusses how, though destructive forces of nature, droughts have also driven innovative solutions to water management problems. His extensive article also describes the advancement of the drought-resistant economy in California, alongside lacking improvements to ecosystem management and preparation.

Approaching the conclusion of the issue, we turn towards issues often overlooked in the drought's discourse. Rory Stewart and Erika Eitland discuss its hidden mental health consequences. Researchers and professors from Harvard University shed light on the industrial and agricultural stresses on California's water system, as well as their implications on public health.

Bringing together this diversity of perspectives, we hope that our examination of nuclear energy expands the understandings of our readers. We hope this issue illuminates the intricate and multifaceted complexities of this controversial topic, and sparks new awareness about the impacts and proposed solutions to the Golden State's greatest water problem.

Sincerely,

Jahred Liddie

Editor-in-Chief
Harvard College Review of the Environment and Society

PHOTOCREDITS

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PHYSICAL MECHANISMS OF THE CALIFORNIA DROUGHT

Richard Seager

Palisades Geophysical Institute/Lamont Research Professor
Lamont Doherty Earth Observatory of Columbia University

At the time of writing in February 2016, California has enjoyed some heavy rain and snow, as expected given the massive El Nino of 2015 and 2016. However, California experienced less-than-normal precipitation in each of the previous four winters and, despite some relief, almost the entire state remains in drought. As a four-winter average, 2011-15 was the driest California has experienced since statewide records, as reported by the National Oceanic and Atmospheric Administration (NOAA), which began recording in 1895. There is no long-term trend, either wetting or drying, in California precipitation, but instead a tremendous amount of variability both year-to-year and decade-to-decade. For example, a silar multiyear drought occurred in the late 1980s to the early 1990s while the 1920s were an overall dry decade and the 1990s an overall wet decade. Evidence from tree rings and lake levels also indicate truly long, multi-decadal, droughts during the medieval era (Stine 1994, Cook et al. 2010).

So, given how variable California precipitation is, what caused this particular drought? Also, was human-driven climate change caused by rising greenhouse gases (GHGs) in any way involved? The results reported here largely follow from a study conducted by the NOAA Drought Task Force, a multi-institution group, and uses analysis of the instrumental record, simulations with atmosphere models forced by the observed sea surface temperature (SST) history and model simulations of the climate system response to changing atmospheric composition (e.g. GHGs) conducted for IPCC Assessment Report Five (Seager et al. 2014, 2015).

Climate variability that brings droughts and floods can arise in two fundamental ways. The first is by internal atmospheric variability in which the chaotic flow of the atmosphere can give rise to long periods of drier or wetter, or warmer or colder, than normal weather. The second method is via anomalies in the SST around the world which cause changes in the flux of heat between the ocean and atmosphere that force changes in atmospheric circulation. SST anomalies in the tropics are most effective in this regard—the El Niño-Southern Oscillation is a prime example. Coupled atmosphere-ocean interactions lead to changes in heat transport by ocean currents that generate SST anomalies that alter the intensity and location of tropical rain systems. This induces atmospheric circulation anomalies across the globe, including over North America.

Seager et al. (2014, 2015) found that the ocean exerts only a modest influence on California winter precipitation variability. While wet California winters tend to be favored by moderate to strong El Niño events, dry winters in California are typically related to internal atmosphere variability. Despite this, there was a strong indication that the 2011-2014 drought was, unusually, forced by the ocean. All of the seven models used in the study simulated drier than normal winters in California when forced by the observed SST anomalies. However, the simulated decline in precipitation was only about a third of that which actually occurred. Hence while the ocean state was conducive to dry conditions, the extremity of the drought probably required some additional influence from internal atmospheric variability also acting to reduce precipitation.

Based on the analysis in Seager et al. (2014. 2015), Hartmann (2015), and follow-up work (Seager and Henderson 2016), it appears that SST anomalies in the tropical oceans were an important cause of the drought-generating atmospheric circulation anomalies. Modeling results connect the high pressure ridge at the west coast to a dipole of warm SST anomalies in the tropical west Pacific and cool anomalies in the central to eastern tropical Pacific. The SST anomaly pattern is neither an El Niño nor a La Niña pattern. This warm western tropical Pacific pattern, coupled with cool waters to the east, prevailed during winters 2012-2013, 2013-2014 and then in early 2015 too.

So what caused this SST anomaly? Researchers found that the warm tropical west Pacific SST anomaly was associated with an anomalous flux of heat from the ocean to the atmosphere while the cool SST anomaly to the east had an anomalous heat flux into the ocean. This is only possible if ocean currents are providing an anomalous convergence (divergence) of heat into the warm (cold) anomaly with the surface flux exchange providing a damping. Hence there is likely to be an active role of the ocean in creating the SST anomalies that drive the drought. It appears as if this pattern's existence in recent winters was not unique but has occurred before (e.g. during the late 1980s-early 1990s drought). Further understanding of the SST anomaly is not available at this point. ENSO is the dominant mode of SST variability in the tropical Pacific and typically SST anomalies alternate between short lived but strong El Niños and longer but weaker La Niñas. It is not clear if the warm west-cool central tropical Pacific pattern of recent winters arises as an occasional part of the ENSO cycle or whether it a distinct phenomena. Only more research will provide the answers.

Is human-driven climate change in any way responsible for the drought? In terms of the precipitation loss, which was the main driver of the drought, it is hard to make a case that it was. Climate models forced by observed and projected increases in GHGs simulate that midwinter precipitation should increase at the west coast from central California northward and decline in late winter, with little change in the total winter precipitation. While this might be overestimated by the models (Simpson et al. 2015), there is no model-based evidence for rising GHGs to cause all-winter drops in precipitation like those that occurred during the drought.

Temperature is another story. As shown by Williams et al. (2015), there has been a long-term warming trend in California. Warming increases the potential evapotranspiration, the amount of water that would be lost by the surface via evaporation and transpiration if there was no limit on the water available within the surface layers. High temperatures can therefore dry soils and reduce runoff and exacerbate a drought initiated by a decline in precipitation. Measuring the drought via the Palmer Drought Severity Index, an index of upper level soil moisture, Williams et al. (2015) estimated that about ¾ of the drought was caused by the precipitation drop and about ¼ from the high temperatures. However the same high pressure ridge that caused the precipitation drop also, in some years, caused high temperatures so only some portion of the ¼ of the drought intensity that was due to temperature can be attributed to a GHG-driven warming trend.

There are some caveats to this work. The conclusion that rising GHGs is not leading to a reduction in winter precipitation in California is based on climate models that, with considerable agreement, predict midwinter precipitation will modestly increase. However, there is some reason to be skeptical of the models. The projected wetting is aided by a pattern of model-simulated tropical SST change with the largest warming in the eastern Pacific Ocean. However, over the entire period of instrumental records of SST (which began extensively in 1856), the western tropical Pacific Ocean has warmed by more than the eastern tropical Pacific Ocean. Such a pattern of SST change – which is vaguely La Nina-like – favors dry conditions over southwest North America. The observed trend could deviate from the model predicted one either because natural variability is obscuring the response to the rise in GHGs or because the models are wrong. Clement et al. (1996) and Cane et al. (1997) suggested that upwelling in the equatorial cold tongue of the eastern tropical Pacific should lead to less warming there than in the west. If they are right, and the observed record to date does not contradict them, then the SST response to rising GHGs would favor the pattern that to an important degree forced the California drought.

Secondly, the Palmer Drought Severity Index evaluated by Williams et al. (2015) is a measure of near surface moisture which is sensitive to atmospheric warming. Deeper soil moisture might respond differently to climate change and be more sensitive to precipitation changes in winter, when evapotranspiration is low, than to summer surface temperature warming (e.g. Cheng et al. 2016). Finally, fundamental to California water resources is the spring and early summer runoff from snow and rainfall into reservoirs for use by municipalities and agriculture. To assess how that changed during the drought would require a much more complex analysis examining the phase, timing, magnitude and detailed location of precipitation and runoff into streams.

In summary, the four year California drought was primarily the result of a record-breaking shortfall of precipitation forced to an important degree by a pattern of tropical Pacific and Indian Ocean SST anomalies. This drought-forcing SST anomaly pattern had not been recognized before but offers some potential seasonal predictability of California precipitation. The drought was intensified to a modest degree by long-term warming likely caused by rising GHGs. As of now, there is no evidence that the precipitation drop was influenced by GHG-driven climate change. However the sensitivity of California and southwest precipitation to patterns of tropical SST change strongly motivates more research into the latter and how it will influence circulation. Even if the future will not look like the recent drought, continued warming, less snow, and a potentially shorter wet season will all stress California water resources in the future and adaptation to that future climate is already overdue.