Warming temperatures implicated in recent California droughts

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A photograph of a farmer showing his affected plot due to drought in Karnataka, India, 2012. Credit: Pushkarv/Wikipedia

California has experienced more frequent drought years in the last two decades than it has in the past several centuries. That observed uptick is primarily the result of rising temperatures in the region, which have climbed to record highs as a result of climate change, Stanford scientists say.

In a new study, published in the March 2 issue of the journal of the *Proceedings of the National Academy of Sciences*, researchers led by Stanford professor Noah Diffenbaugh, examined the role that temperature has played in California droughts over the past 120 years. They also examined the effect that human emissions of carbon dioxide and other greenhouse gases are having on temperature and precipitation, focusing on the influence of global warming upon California's past, present, and future drought risk.

The team found that the worst droughts in California have historically occurred when conditions were both dry and warm, and that global warming is increasing the probability that dry and warm years will coincide. The findings suggest that California could be entering an era when nearly every year that has low precipitation also has temperatures similar to or higher than 2013-2014, when the statewide average annual temperature was the warmest on record.

"Of course low precipitation is a prerequisite for drought, but less rain and snowfall alone don't ensure a drought will happen. It really matters if the lack of precipitation happens during a warm or cool year," Diffenbaugh said. "We've seen the effects of record heat on snow and soil moisture this year in California, and we know from this new research that climate change is increasing the probability of those warm and dry conditions occurring together."

Diffenbaugh and his team reached their conclusions by analyzing historical observations and computer climate change simulations. They took advantage of a recently released trove of monthly precipitation, temperature, and drought data for California that stretches back to 1895. Using this 120-year observed dataset, the scientists calculated the probability of drought years occurring in different temperature and precipitation conditions.

Their analysis revealed that the years that were both warm and dry were about twice as likely to produce a severe drought as years that were cool and dry. The scientists were also surprised to find that during the early and mid-20th century, temperature and precipitation were largely "uncoupled"-that is, they occurred more or less independently of one another.

"Imagine having two coins-one controls temperature, and the other precipitation," Diffenbaugh said. "In the past, when you flipped the coins, they each came up tails half the time, meaning that a quarter of the time both coins came up tails, representing a warm and dry year."

In the past two decades, however, nearly all of the years in California have been either warm or hot. "Now the temperature coin is coming up tails most years," Diffenbaugh said. "So, even though the precipitation coin is still coming up tails only half the time, it means that over the past two decades we have gotten two tails-warm and dry-in half the years, compared with only a quarter of years in the preceding century."

"When we look at the historical record, not only do we see a doubling of the odds of a warm-dry year, but we also see a doubling of the frequency of drought years," said Danielle Touma, a graduate student in Diffenbaugh's Climate and Earth System Dynamics research group and a coauthor on the study. "Warm conditions reduce snowfall, increase snowmelt, and increase water loss from soils and plants."

The team also used climate models to investigate the role of global warming in driving the observed warming trend, and the associated increase in drought. They analyzed simulations of California's temperature and precipitation levels over the 20th century both with and without human greenhouse gases in the atmosphere.

The results were clear: even though climate change to date has not

substantially reduced yearly precipitation, human emissions are clearly implicated in California's statewide warming, and in the increased probability that dry years are also warm.

Assessment of climate model simulations that projected into the future also led the team to conclude that the risk of co-occurring warm and dry years will continue to increase in the coming decades. "We found that essentially all years are likely to be warm-or extremely warm-in California by the middle of the 21st century," said study coauthor Daniel Swain, who is also a graduate student in Diffenbaugh's lab. "This means that both drought frequency-and the potential intensity of those droughts which do occur-will likely increase as temperatures continue to rise."

More frequent warm years also increase the likelihood of multi-year droughts in the future. According to team's analyses, the current California drought, now entering its fourth year, is one of the longest consecutive periods in the historical record during which conditions were both severely dry and severely warm. The climate models also indicate that such conditions will become even more common if global warming continues in the future, as the state enters a regime in which there is nearly 100 percent risk that every year is warmer than conditions experienced during the 20th century.

The Stanford researchers say their findings could help California water managers and state officials plan for the future. "While our findings don't provide any particular recommendations," Diffenbaugh said, "they do provide very strong evidence that global warming is already making it much more likely that California experiences conditions that are similar to what we have experienced during the current severe drought."

More information: Anthropogenic warming has increased drought risk in California, *Proceedings of the National Academy of Sciences*, www.pnas.org/cgi/doi/10.1073/pnas.1422385112

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