

Climate change and California drought in the 21st century

Michael E. Mann^{a,1} and Peter H. Gleick^b

^aDepartment of Meteorology, Pennsylvania State University, University Park, PA 16802; and

^bPacific Institute for Studies in Development, Environment, and Security, Oakland, CA 94612

Climate science has advanced over decades from an initial focus on the development and use of numerical models of Earth's climate and compilation of rich networks of observational data, to now being in a position to "detect" and "attribute" specific impacts and events to anthropogenic climate change. Recent analyses have thus established the "fingerprint" of anthropogenic climate change in an increasingly diverse array of meteorological and hydrological phenomena around the world, from heat waves to coastal damages during extreme tides and storms, flooding from more intense precipitation events, and severe drought (1). In a new study published in PNAS, Diffenbaugh et al. now add weight to the accumulating evidence that anthropogenic climatic changes are already influencing the frequency, magnitude, and duration of drought in California (2). The authors show that the increasing co-occurrence of dry years with warm years raises the risk of drought despite limited evidence

of a trend in precipitation itself, highlighting the critical role of elevated temperatures in altering water availability and increasing overall drought intensity and impact.

Golden State Goes Brown

California's nickname is the Golden State, a name that owes as much to the golden hue of its landscapes during the dry summer season as to the 19th century Gold Rush or the fields of golden poppies. The grasses green up again in late fall when the mid-latitude storms and rainfall return. What happens if those rains come late, come little, or in some cases don't come at all? Such has been the case in recent years.

California is experiencing extreme drought. Measured both by precipitation and by runoff in the Sacramento and San Joaquin river basins, 10 of the past 14 y have been below normal, and the past 3 y have been the driest and hottest in the full instrumental record. A plot of temperature and precipitation anomalies over the full instrumental record from

1895 through November 2014 shows that the 3-y period ending in 2014 was by far the hottest and driest on record (Fig. 1). As of the publication of this commentary, the state appears headed into a fourth consecutive year of water shortfall, leading to massive groundwater overdraft, cutbacks to farmers, reductions in hydroelectricity generation, and a range of voluntary and mandatory urban water restrictions.

As drought has taken hold, the Golden State is slowly becoming a more arid, brown state, where constraints on water availability threaten a large and growing population (up nearly 80% since the severe drought of 1976–77), unique ecological resources, a major source of agricultural produce, and one of the largest economies in the world. What a sadly ironic destiny that would be for the state currently led by one Governor Brown: The growing threat of climate change to California is one of the drivers for extensive efforts under the Brown (and prior Schwarzenegger) administration to understand the risks to the state and develop strategies to reduce greenhouse gas emissions and implement adaptation strategies (3). Of course, we're not just talking about whether or not the grass is green. There are growing concerns about whether California can continue to meet its tremendous demand for water for industrial use, growing food, sustaining ecosystems, and expanding cities in the face of drought (4).

As part of the effort to understand the influence of climate change on extreme regional events, there has been a robust scientific debate over the role of climate change on California's current drought. Some studies (5–7) have argued that we cannot yet discern a link between storm tracks (and the Pacific Ocean surface temperature patterns that influence their behavior) and drought in the western United States. Others (8) do, however, see a relationship in the form of observational data, physical analysis of possible

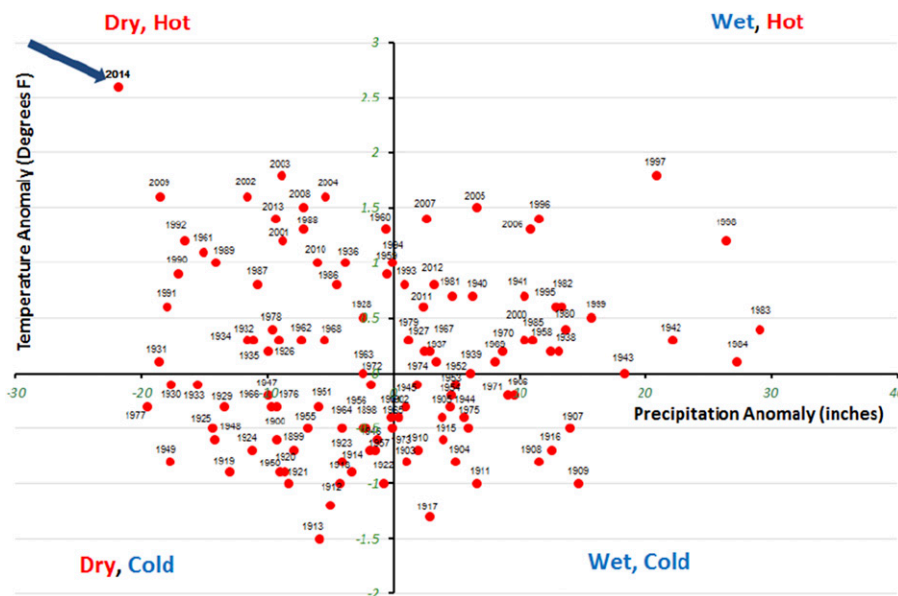


Fig. 1. California temperature ($^{\circ}$ F) and precipitation (inches) anomalies from January 1895 to November 2014, plotted as 3-y anomalies relative to 1901–2000 mean. Data from the National Climatic Data Center nClimDiv dataset.

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¹To whom correspondence should be addressed. Email: mann@psu.edu.

