June 2, 2021

Re: Cannabis Cultivation Ordinance

Attachments:

Round Valley County Water District letter
Round Valley County Water district spring well levels
Anthropogenic warming has increased drought risk in California
A tale of two California droughts: Lessons amidst record warmth and dryness in a region of complex physical and human geography.

Dear County Supervisors,

Seeing a lack of data in the packets, I wanted to make sure the potential impacts to our community of Round Valley are better understood. Below is some math I did to calculate the potential cultivation on AG land in Round Valley. Please take this very seriously, as it represents a HUGE jump in cultivation allowance, which is a major concern for our community and our Water District.

I also request that for any and all cannabis cultivation permits being considered, there needs to be an adequate hydrologic study to assess the impacts that cultivation will have on the aquifer as a whole, including cumulative impacts of all anticipated future projects as well as existing water uses. These studies should be designed in partnership with the respective local Water Districts, as they know their aquifers best. No permit should be issued without getting the approval of the Water District, after they have been able to determine there will not be adverse impacts to the community's water supplies, including that which is need for future growth and much needed housing development.

It is also crucial for the Water Districts to be fully informed as to location and use of all permitted cannabis farms so they can identify problems that may arise in the future and, if any such negative impacts to the aquifer are noted, cultivation should be halted immediately until the concerns are addressed, so that we can prevent irreversible impacts such as chemical pollutants contaminating our aquifer or subsidence that reduces the holding capacity of the aquifer.

As Climate Change is leading to a more unpredictable future, that will undoubtedly have more extreme drought years, as we are seeing currently, there needs to be a mechanism within the permitting process that reduces or halts cultivation during drought emergencies, to protect the water resources that are needed for health and safety and for cultivating food crops, which should be given priority for water use.

In order to assure all of the protections put in place are effective, the County's Code Enforcement division needs to be increased to a capacity that can realistically oversee and proactively address situations that may pose threats to the public, including our collective water resources, in a timely manner.

Using parcel data from the Planning department, I did a little math on cultivation potential on AG land here in and Round Valley. Please note this is just for AG zoned land that is greater than 10 acres within the Round Valley area. RL calculations would take more tools than I have on hand, but that too would allow for some increased acreage that is not included in the info below. The image attached is a zoning map of the area.

AG Parcels > 10 acres: 226 parcels
Total acreage of AG parcels > 10 acres: 11,183 acres

If the max cultivation permit currently allowable is 10,000 Square Feet, that means there could be a max of 226 permits at that size, which would total 52 acres of cultivation on AG land.

Under the 10% of acreage cultivation allowance on AG land, that would equal 1,118 acres on AG land alone in Round Valley. That's adding a potential of 1,066 additional acres of allowable cultivation on AG land alone in Round Valley!! The 10% acreage expansion would allow a 2,155% increase of allowable cultivation on AG land in Round valley, or nearly 22 times more than what is currently allowed on AG land.

Considering the Planning Commission recommendations of a 2+ acre cap (for 2 acres outdoor plus other permit types) that would still allow for 452+ additional acres of potential cultivation on AG land in Round Valley, which is still an 870% increase, allowing 9 times more cultivation than what is currently allowed to be permitted, which would of course be in addition to the RL zoning districts that would also allow some cultivation in existing agriculture footprints. This all of course would be in addition to all the unpermitted cultivation which the Sheriff estimates to include 1 million unpermitted cannabis plants in Round Valley alone, which he states will take at least 3-5 years to adequately address.

Do we have enough water for this level of increased cultivation? Our local Round Valley County Water District doesn't seem to think so and has expressed concerns in multiple letters sent to the Planning Commission & Board of Supervisors. And if not, does that mean we're going to allow this expansion for all those who can prove they have water until we're out of water?

The Round Valley County Water District has also expressed concern with this high level of development potential being proposed in Round Valley and has asked that no such expansion be allowed without a full EIR to assure the community water resources aren't negatively and permanently impacted. We are ALL on wells here, we have no municipal water system to help meet the needs of the community when the water table begins to drop below the level of some of our wells, which we are

ALREADY seeing happen here. Looking at the spring well level data for the test wells monitored by the Round Valley County Water District, it's clear that the levels are at exceptionally low levels. (See 2 attachments from RVCWD 1) April 30th letter to the Board of Supervisors and 2) Spring Well levels).

The Covelo CalFire well is already showing signs that it will soon run dry, as stated during the April 12th BOS meeting on water shortages, and the CalFire Chief expressed concerns that when the well runs dry and no longer has water pressure, the aquifer could subside and water storage capacity could be lost forever, as we've seen over the years in other parts of CA. Meanwhile water trucks are continuously hauling water from the valley aquifer to cannabis cultivation sites. This issue has been discussed at several Round Valley Water District meetings.

All of this water use, water hauling, and proposal to increase cultivation of a water-intensive crop, by hundreds or ever 1,000 acres plus, just in Round Valley alone, is happening against a backdrop of a record-breaking drought, a situation that we can foreseeably understand to be a recurring event in our future, according to climate scientists (see 2 attachments: 1) Anthropogenic warming has increased drought risk in California and 2) A tale of two California droughts: Lessons amidst record warmth and dryness in a region of complex physical and human geography).

While the County is refusing to conduct environmental analysis on this the level of expansion they are proposing allowing with this ordinance, it's clear that the cumulative and long-term impacts are very likely significant.

The level of water use in Round Valley MUST be looked and made at to assure that we don't end up drawing down our aquifer in irreparable ways.

This expansion is not desired by our community either. The Round Valley Area MAC has held several public meetings with the topic of cannabis cultivation expansion on the agenda and 100% of those who attend the meetings express very strongly that they are against large-scale expansion as currently proposed, for a vast array of reasons.

Please, slow down and consider expansion more wisely and carefully, including preparing a full EIR on the ordinance before any such expansion is considered, for the well being of all the communities within Mendocino County, including those of us in Round Valley. Our very livelihood is at stake, as without adequate water supplies, our community will suffer in dramatic ways.

Thank you for your thoughtful consideration,

Jessica Stull-Otto

Anthropogenic warming has increased drought risk in California

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Edited by Jane Lubchenco, Oregon State University, Corvallis, OR, and approved January 30, 2015 (received for review November 22, 2014)

California is currently in the midst of a record-setting drought. The drought began in 2012 and now includes the lowest calendar-year and 12-mo precipitation, the highest annual temperature, and the most extreme drought indicators on record. The extremely warm and dry conditions have led to acute water shortages, groundwater overdraft, critically low streamflow, and enhanced wildfire risk. Analyzing historical climate observations from California, we find that precipitation deficits in California were more than twice as likely to yield drought years if they occurred when conditions were warm. We find that although there has not been a substantial change in the probability of either negative or moderately negative precipitation anomalies in recent decades, the occurrence of drought years has been greater in the past two decades than in the preceding century. In addition, the probability that precipitation deficits co-occur with warm conditions and the probability that precipitation deficits produce drought have both increased. Climate model experiments with and without anthropogenic forcings reveal that human activities have increased the probability that dry precipitation years are also warm. Further, a large ensemble of climate model realizations reveals that additional global warming over the next few decades is very likely to create ∼100% probability that any annual-scale dry period is also extremely warm. We therefore conclude that anthropogenic warming is increasing the probability of co-occurring warm–dry conditions like those that have created the acute human and ecosystem impacts associated with the "exceptional" 2012–2014 drought in California.

drought | climate extremes | climate change detection | event attribution | CMIP5

The state of California is the largest contributor to the economic and agricultural activity of the United States, accounting for a greater share of population (12%) (1), gross domestic product (12%) (2), and cash farm receipts (11%) (3) than any other state. California also includes a diverse array of marine and terrestrial ecosystems that span a wide range of climatic tolerances and together encompass a global biodiversity "hotspot" (4). These human and natural systems face a complex web of competing demands for freshwater (5). The state's agricultural sector accounts for 77% of California water use (5), and hydroelectric power provides more than 9% of the state's electricity (6). Because the majority of California's precipitation occurs far from its urban centers and primary agricultural zones, California maintains a vast and complex water management, storage, and distribution/conveyance infrastructure that has been the focus of nearly constant legislative, legal, and political battles (5). As a result, many riverine ecosystems depend on mandated "environmental flows" released by upstream dams, which become a point of contention during critically dry periods (5).

California is currently in the midst of a multiyear drought (7). The event encompasses the lowest calendar-year and 12-mo precipitation on record (8), and almost every month between December 2011 and September 2014 exhibited multiple indicators of drought (Fig. S1). The proximal cause of the precipitation deficits was the recurring poleward deflection of the cool-season storm track by a region of persistently high atmospheric pressure, which steered Pacific storms away from California over consecutive seasons (8–11). Although the extremely persistent high pressure is at least a century-scale occurrence (8), anthropogenic global warming has very likely increased the probability of such conditions (8, 9).

Despite insights into the causes and historical context of precipitation deficits (8–11), the influence of historical temperature changes on the probability of individual droughts has—until recently—received less attention (12–14). Although precipitation deficits are a prerequisite for the moisture deficits that constitute "drought" (by any definition) (15), elevated temperatures can greatly amplify evaporative demand, thereby increasing overall drought intensity and impact (16, 17). Temperature is especially important in California, where water storage and distribution systems are critically dependent on winter/spring snowpack, and excess demand is typically met by groundwater withdrawal (18–20). The impacts of runoff and soil moisture deficits associated with warm temperatures can be acute, including enhanced wildfire risk (21), land subsidence from excessive groundwater withdrawals (22), decreased hydropower production (23), and damage to habitat of vulnerable riparian species (24).

Recent work suggests that the aggregate combination of extremely high temperatures and very low precipitation during the 2012–2014 event is the most severe in over a millennium (12). Given the known influence of temperature on drought, the fact that the 2012–2014 record drought severity has co-occurred with record statewide warmth (7) raises the question of whether long-term warming has altered the probability that precipitation deficits yield extreme drought in California.

Significance

California ranks first in the United States in population, economic activity, and agricultural value. The state is currently experiencing a record-setting drought, which has led to acute water shortages, groundwater overdraft, critically low streamflow, and enhanced wildfire risk. Our analyses show that California has historically been more likely to experience drought if precipitation deficits co-occur with warm conditions and that such confluences have increased in recent decades, leading to increases in the fraction of low-precipitation years that yield drought. In addition, we find that human emissions have increased the probability that low-precipitation years are also warm, suggesting that anthropogenic warming is increasing the probability of the co-occurring warm–dry conditions that have created the current California drought.

Author contributions: N.S.D., D.L.S., and D.T. designed research, performed research, contributed new reagents/analytic tools, analyzed data, and wrote the paper.

The authors declare no conflict of interest.

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Results

We analyze the "Palmer" drought metrics available from the US National Climatic Data Center (NCDC) (25). The NCDC Palmer metrics are based on the Palmer Drought Severity Index (PDSI), which uses monthly precipitation and temperature to calculate moisture balance using a simple "supply-and-demand" model (26) (*Materials and Methods*). We focus on the Palmer Modified Drought Index (PMDI), which moderates transitions between wet and dry periods (compared with the PDSI) (27). However, we note that the long-term time series of the PMDI is similar to that of other Palmer drought indicators, particularly at the annual scale (Figs. S1 and S2).

Because multiple drought indicators reached historic lows in July 2014 (Figs. S1–S3), we initially focus on statewide PMDI, temperature, and precipitation averaged over the August–July 12-mo period. We find that years with a negative PMDI anomaly exceeding –1.0 SDs (hereafter "1-SD drought") have occurred approximately twice as often in the past two decades as in the preceding century (six events in 1995–2014 = 30% of years; 14 events in 1896–1994 = 14% of years) (Fig. 1*A* and Fig. S4). This increase in the occurrence of 1-SD drought years has taken place without a substantial change in the probability of negative precipitation anomalies (53% in 1896–2014 and 55% in 1995–2014) (Figs. 1*B* and 2 *A* and *B*). Rather, the observed doubling of the occurrence of 1-SD drought years has coincided with a doubling of the frequency with which a negative precipitation year produces a 1-SD drought, with 55% of negative precipitation years in 1995–2014 co-occurring with a –1.0 SD PMDI anomaly, compared with 27% in 1896–1994 (Fig. 1 *A* and *B*).

Most 1-SD drought years have occurred when conditions were both dry (precipitation anomaly < 0) and warm (temperature anomaly > 0), including 15 of 20 1-SD drought years during 1896–2014 (Fig. 2*A* and Fig. S4) and 6 of 6 during 1995–2014 (Fig. 2*B* and Fig. S4). Similarly, negative precipitation anomalies are much more likely to produce 1-SD drought if they co-occur with a positive temperature anomaly. For example, of the 63 negative precipitation years during 1896–2014, 15 of the 32 warm–dry years (47%) produced 1-SD drought, compared with only 5 of the 31 cool–dry years (16%) (Fig. 2*A*). (During 1896–1994, 41% of warm–dry years produced 1-SD droughts, compared with 17% of cool–dry years.) The probability that a negative precipitation anomaly co-occurs with a positive temperature anomaly has increased recently, with warm–dry years occurring more than twice as often in the past two decades (91%) as in the preceding century (42%) (Fig. 1*B*).

All 20 August–July 12-mo periods that exhibited a –1.0 SD PMDI anomaly also exhibited a –0.5 SD precipitation anomaly (Fig. 1*B* and 2*E*), suggesting that moderately low precipitation is prerequisite for a 1-SD drought year. However, the occurrence of –0.5 SD precipitation anomalies has not increased in recent years (40% in 1896–2014 and 40% in 1995–2014) (Fig. 2 *A* and *B*). Rather, these moderate precipitation deficits have been far more likely to produce 1-SD drought when they occur in a warm year. For example, during 1896–2014, 1-SD drought occurred in 15 of the 28 years (54%) that exhibited both a –0.5 SD precipitation anomaly and a positive temperature anomaly, but in only 5 of the 20 years (25%) that exhibited a –0.5 SD precipitation anomaly and a negative temperature anomaly (Fig. 2*A*). During 1995–2014, 6 of the 8 moderately dry years produced 1-SD drought (Fig. 1*A*), with all 6 occurring in years in which the precipitation anomaly exceeded –0.5 SD and the temperature anomaly exceeded 0.5 SD (Fig. 1*C*).

Taken together, the observed record from California suggests that (*i*) precipitation deficits are more likely to yield 1-SD PMDI droughts if they occur when conditions are warm and (*ii*) the occurrence of 1-SD PMDI droughts, the probability of precipitation deficits producing 1-SD PMDI droughts, and the probability of precipitation deficits co-occurring with warm conditions have all been greater in the past two decades than in the preceding century.

These increases in drought risk have occurred despite a lack of substantial change in the occurrence of low or moderately low precipitation years (Figs. 1*B* and 2 *A* and *B*). In contrast, statewide warming (Fig. 1*C*) has led to a substantial increase in warm conditions, with 80% of years in 1995–2014 exhibiting a positive temperature anomaly (Fig. 2*B*), compared with 45% of years in 1896–2014 (Fig. 2*A*). As a result, whereas 58% of moderately dry years were warm during 1896–2014 (Fig. 2*A*) and 50% were warm during 1896–1994, 100% of the 8 moderately dry years in 1995–2014 co-occurred with a positive temperature anomaly (Fig. 2*B*). The observed statewide warming (Fig. 1*C*) has therefore substantially increased the probability that when moderate precipitation deficits occur, they occur during warm years.

The recent statewide warming clearly occurs in climate model simulations that include both natural and human forcings ("Historical" experiment), but not in simulations that include only natural forcings ("Natural" experiment) (Fig. 3*B*). In particular, the Historical and Natural temperatures are found to be different at the 0.001 significance level during the most recent 20-, 30-, and 40-y periods of the historical simulations (using the block bootstrap resampling applied in ref. 28). In contrast, although the Historical experiment exhibits a slightly higher mean annual precipitation (0.023 significance level), there is no statistically

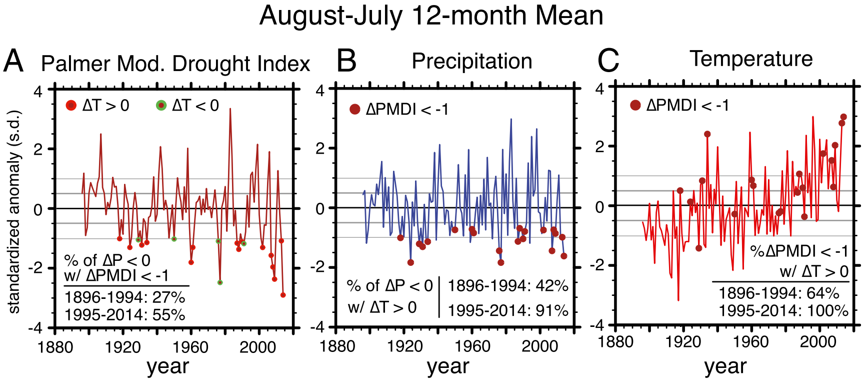

Fig. 1. Historical time series of drought (*A*), precipitation (*B*), and temperature (*C*) in California. Values are calculated for the August–July 12-mo mean in each year of the observed record, beginning in August 1895. In each year, the standardized anomaly is expressed as the magnitude of the anomaly from the long-term annual mean, divided by the SD of the detrended historical annual anomaly time series. The PMDI is used as the primary drought indicator, although the other Palmer indicators exhibit similar historical time series (Figs. S1 and S2). Circles show the years in which the PMDI exhibited a negative anomaly exceeding –1.0 SDs, which are referred to as 1-SD drought years in the text.

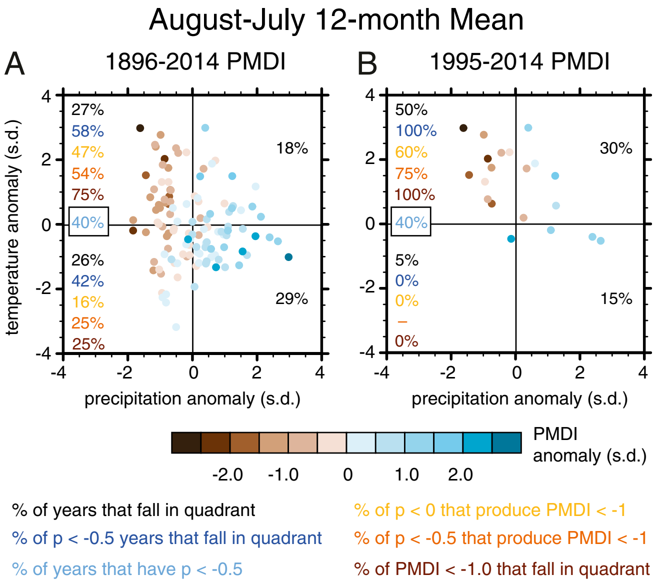

Fig. 2. Historical occurrence of drought, precipitation, and temperature in California. Standardized anomalies are shown for each August–July 12-mo period in the historical record (calculated as in Fig. 1). Anomalies are shown for the full historical record (*A*) and for the most recent two decades (*B*). Percentage values show the percentage of years meeting different precipitation and drought criteria that fall in each quadrant of the temperature–precipitation space. The respective criteria are identified by different colors of text.

significant difference in probability of a –0.5 SD precipitation anomaly (Fig. 3 *A* and *C*). However, the Historical experiment exhibits greater probability of a –0.5 SD precipitation anomaly co-occurring with a positive temperature anomaly (0.001 significance level) (Fig. 3*D*), suggesting that human forcing has caused the observed increase in probability that moderately dry precipitation years are also warm.

The fact that the occurrence of warm and moderately dry years approaches that of moderately dry years in the last decades of the Historical experiment (Fig. 3 *B* and *C*) and that 91% of negative precipitation years in 1995–2014 co-occurred with warm anomalies (Fig. 1*B*) suggests possible emergence of a regime in which nearly all dry years co-occur with warm conditions. We assess this possibility using an ensemble of 30 realizations of a single global climate model [the National Center for Atmospheric Research (NCAR) Community Earth System Model (CESM1) Large Ensemble experiment ("LENS")] (29) (*Materials and Methods*). Before ~1980, the simulated probability of a warm–dry year is approximately half that of a dry year (Fig. 4*B*), similar to observations (Figs. 1*B* and 2). However, the simulated probability of a warm–dry year becomes equal to that of a dry year by ~2030 of RCP8.5. Likewise, the probabilities of co-occurring 0.5, 1.0 and 1.5 SD warm–dry anomalies become approximately equal to those of 0.5, 1.0, and 1.5 SD dry anomalies (respectively) by ~2030 (Fig. 4*B*).

The probability of co-occurring extremely warm and extremely dry conditions (1.5 SD anomaly) remains greatly elevated throughout the 21st century (Fig. 4*B*). In addition, the number of multiyear periods in which a –0.5 SD precipitation anomaly co-occurs with a 0.5 SD temperature anomaly more than doubles between the Historical and RCP8.5 experiments (Fig. 4*A*). We find similar results using a 12-mo moving average (Fig. 4*C*). As with the August–July 12-mo mean (Fig. 4*B*), the probability of a dry year is approximately twice the probability of a warm–dry year for all 12-mo periods before ~1980 (Fig. 4*C*). However, the occurrence of warm years (including +1.5 SD temperature anomalies) increases after ~1980, reaching 1.0 by ~2030. This increase implies a transition to a permanent condition of ~100% risk that any negative—or extremely negative—12-mo precipitation anomaly is also extremely warm.

The overall occurrence of dry years declines after ~2040 (Fig. 4*C*). However, the occurrence of extreme 12-mo precipitation deficits (–1.5 SD) is greater in 2006–2080 than in 1920–2005 (<0.03 significance level). This detectable increase in extremely low-precipitation years adds to the effect of rising temperatures and contributes to the increasing occurrence of extremely warm–dry 12-mo periods during the 21st century.

All four 3-mo seasons likewise show higher probability of co-occurring 1.5 SD warm–dry anomalies after ~1980, with the probability of an extremely warm–dry season equaling that of an extremely dry season by ~2030 for spring, summer, and autumn, and by ~2060 for winter (Fig. 4*D*). In addition, the probability of a –1.5 SD precipitation anomaly increases in spring ($P < 0.001$) and autumn ($P = 0.01$) in 2006–2080 relative to 1920–2005, with spring occurrence increasing by ~75% and autumn occurrence increasing by ~44%—which represents a substantial and statistically significant increase in the risk of extremely low-precipitation events at both margins of California's wet season. In contrast, there is no statistically significant difference in the probability of a –1.5 SD precipitation anomaly for winter.

Discussion

A recent report by Seager et al. (30) found no significant long-term trend in cool-season precipitation in California during the 20th and early 21st centuries, which is consistent with our

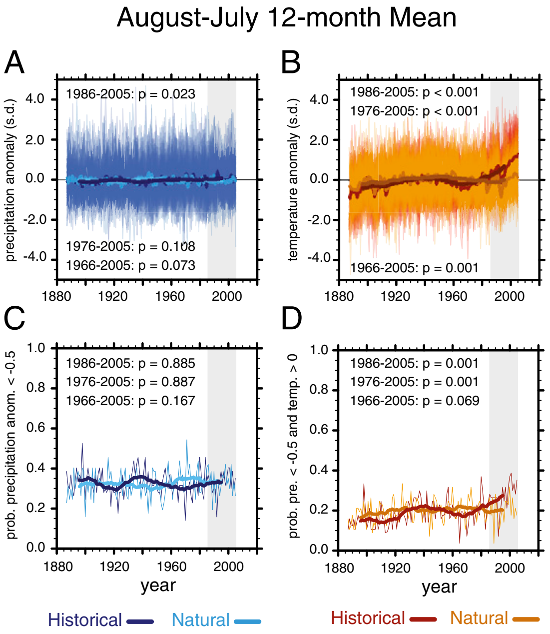

Fig. 3. Influence of anthropogenic forcing on the probability of warm–dry years in California. Temperature and precipitation values are calculated for the August–July 12-mo mean in each year of the CMIP5 Historical and Natural forcing experiments (*Materials and Methods*). The *Top* panels (*A* and *B*) show the time series of ensemble–mean standardized temperature and precipitation anomalies. The *Bottom* panels (*C* and *D*) show the unconditional probability (across the ensemble) that the annual precipitation anomaly is less than –0.5 SDs, and the conditional probability that both the annual precipitation anomaly is less than –0.5 SDs and the temperature anomaly is greater than 0. The bold curves show the 20-y running mean of each annual time series. The CMIP5 Historical and Natural forcing experiments were run until the year 2005. *P* values are shown for the difference between the Historical and Natural experiments for the most recent 20-y (1986–2005; gray band), 30-y (1976–2005), and 40-y (1966–2005) periods of the CMIP5 protocol. *P* values are calculated using the block bootstrap resampling approach of ref. 28 (*Materials and Methods*).

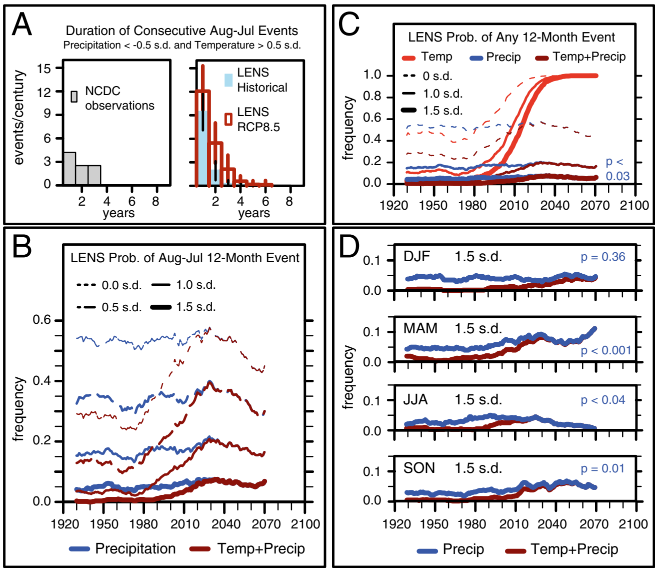

Fig. 4. Projected changes in the probability of co-occurring warm–dry conditions in the 21st century. (*A*) Histogram of the frequency of occurrence of consecutive August–July 12-mo periods in which the 12-mo precipitation anomaly is less than –0.5 SDs and the 12-mo temperature anomaly is at least 0.5 SDs, in historical observations and the LENS large ensemble experiment. (*B*) The probability that a negative 12-mo precipitation anomaly and a positive 12-mo temperature anomaly equal to or exceeding a given magnitude occur in the same August–July 12-mo period, for varying severity of anomalies. (*C*) The probability that a negative precipitation anomaly and a positive temperature anomaly equal to or exceeding a given magnitude occur in the same 12-mo period, for all possible 12-mo periods (using a 12-mo running mean; see *Materials and Methods*), for varying severity of anomalies. (*D*) The unconditional probability of a –1.5 SD seasonal precipitation anomaly (blue curve) and the conditional probability that a –1.5 SD seasonal precipitation anomaly occurs in conjunction with a 1.5 SD seasonal temperature anomaly (red curve), for each of the four 3-mo seasons. Time series show the 20-y running mean of each annual time series. *P* values are shown for the difference in occurrence of –1.5 SD precipitation anomalies between the Historical period (1920–2005) and the RCP8.5 period (2006–2080).

findings. Further, under a scenario of strongly elevated greenhouse forcing, Neelin et al. (31) found a modest increase in California mean December–January–February (DJF) precipitation associated with a local eastward extension of the mean subtropical jet stream west of California. However, considerable evidence (8–11, 31–33) simultaneously suggests that the response of northeastern Pacific atmospheric circulation to anthropogenic warming is likely to be complex and spatiotemporally inhomogeneous, and that changes in the atmospheric mean state may not be reflective of changes in the risk of extreme events (including atmospheric configurations conducive to precipitation extremes). Although there is clearly value in understanding possible changes in precipitation, our results highlight the fact that efforts to understand drought without examining the role of temperature miss a critical contributor to drought risk. Indeed, our results show that even in the absence of trends in mean precipitation—or trends in the occurrence of extremely low-precipitation events—the risk of severe drought in California has already increased due to extremely warm conditions induced by anthropogenic global warming.

We note that the interplay between the existence of a well-defined summer dry period and the historical prevalence of a substantial high-elevation snowpack may create particular susceptibility to temperature-driven increases in drought duration and/or intensity in California. In regions where precipitation exhibits a distinct seasonal cycle, recovery from preexisting drought conditions is unlikely during the characteristic yearly dry spell (34). Because California's dry season occurs during the warm summer months, soil moisture loss through evapotranspiration (ET) is typically high—meaning that soil moisture deficits that exist at the beginning of the dry season are exacerbated by the warm conditions that develop during the dry season, as occurred during the summers of 2013 and 2014 (7).

Further, California's seasonal snowpack (which resides almost entirely in the Sierra Nevada Mountains) provides a critical source of runoff during the low-precipitation spring and summer months. Trends toward earlier runoff in the Sierra Nevada have already been detected in observations (e.g., ref. 35), and continued global warming is likely to result in earlier snowmelt and increased rain-to-snow ratios (35, 36). As a result, the peaks in California's snowmelt and surface runoff are likely to be more pronounced and to occur earlier in the calendar year (35, 36), increasing the duration of the warm-season low-runoff period (36) and potentially reducing montane surface soil moisture (37). Although these hydrological changes could potentially increase soil water availability in previously snow-covered regions during the cool low-ET season (34), this effect would likely be outweighed by the influence of warming temperatures (and decreased runoff) during the warm high-ET season (36, 38), as well as by the increasing occurrence of consecutive years with low precipitation and high temperature (Fig. 4*A*).

The increasing risk of consecutive warm–dry years (Fig. 4*A*) raises the possibility of extended drought periods such as those found in the paleoclimate record (14, 39, 40). Recent work suggests that record warmth could have made the current event the most severe annual-scale drought of the past millennium (12). However, numerous paleoclimate records also suggest that the region has experienced multidecadal periods in which most years were in a drought state (14, 39, 41, 42), albeit less acute than the current California event (12, 39, 41). Although multidecadal ocean variability was a primary cause of the megadroughts of the last millenium (41), the emergence of a condition in which there is ~100% probability of an extremely warm year (Fig. 4) substantially increases the risk of prolonged drought conditions in the region (14, 39, 40).

A number of caveats should be considered. For example, ours is an implicit approach that analyzes the temperature and precipitation conditions that have historically occurred with low PMDI years, but does not explicitly explore the physical processes that produce drought. The impact of increasing temperatures on the processes governing runoff, baseflow, groundwater, soil moisture, and land-atmosphere evaporative feedbacks over both the historical period and in response to further global warming remains a critical uncertainty (43). Likewise, our analyses of anthropogenic forcing rely on global climate models that do not resolve the topographic complexity that strongly influences California's precipitation and temperature. Further investigation using high-resolution modeling approaches that better resolve the boundary conditions and fine-scale physical processes (44–46) and/or using analyses that focus on the underlying large-scale climate dynamics of individual extreme events (8) could help to overcome the limitations of simulated precipitation and temperature in the current generation of global climate models.

Conclusions

Our results suggest that anthropogenic warming has increased the probability of the co-occurring temperature and precipitation conditions that have historically led to drought in California. In addition, continued global warming is likely to cause a transition to a regime in which essentially every seasonal, annual, and multiannual precipitation deficit co-occurs with historically warm conditions. The current warm–dry event in California—as well as historical observations of previous seasonal, annual, and multiannual warm–dry events—suggests such a regime would substantially increase the risk of severe impacts on human and natural systems. For example, the projected increase in extremely low precipitation and extremely high temperature during spring and autumn has substantial implications for snowpack water storage, wildfire risk, and terrestrial ecosystems (47). Likewise, the projected increase in annual and multiannual warm–dry periods implies increasing risk of the acute water shortages, critical groundwater overdraft, and species extinction potential that have been experienced during the 2012–2014 drought (5, 20).

California's human population (38.33 million as of 2013) has increased by nearly 72% since the much-remembered 1976–1977 drought (1). Gains in urban and agricultural water use efficiency have offset this rapid increase in the number of water users to the extent that overall water demand is nearly the same in 2013 as it was in 1977 (5). As a result, California's per capita water use has declined in recent decades, meaning that additional short-term water conservation in response to acute shortages during drought conditions has become increasingly challenging. Although a variety of opportunities exist to manage drought risk through long-term changes in water policy, management, and infrastructure (5), our results strongly suggest that global warming is already increasing the probability of conditions that have historically created high-impact drought in California.

Materials and Methods

We use historical time series of observed California statewide temperature, precipitation, and drought data from the National Oceanic and Atmospheric Administration's NCDC (7). The data are from the NCDC "nClimDiv" divisional temperature–precipitation–drought database, available at monthly time resolution from January 1895 to the present (7, 25). The NCDC nClimDiv database includes temperature, precipitation, and multiple Palmer drought indicators, aggregated at statewide and substate climate division levels for the United States. The available Palmer drought indicators include PDSI, the Palmer Hydrological Drought Index (PHDI), and PMDI.

PMDI and PHDI are variants of PDSI (25–27, 48, 49). PDSI is an index that measures the severity of wet and dry anomalies (26). The NCDC nClimDiv PDSI calculation is reported at the monthly scale, based on monthly temperature and precipitation (49). Together, the monthly temperature and precipitation values are used to compute the net moisture balance, based on a simple supply-and-demand model that uses potential evapotranspiration (PET) calculated using the Thornthwaite method. Calculated PET values can be very different when using other methods (e.g., Penman–Monteith), with the Thornthwaite method's dependence on surface temperature creating the potential for overestimation of PET (e.g., ref. 43). However, it has been found that the choice of methods in the calculation of PET does not critically influence the outcome of historical PDSI estimates in the vicinity of California (15, 43, 50). In contrast, the sensitivity of the PET calculation to large increases in temperature could make the PDSI inappropriate for calculating the response of drought to high levels of greenhouse forcing (15). As a result, we analyze the NCDC Palmer indicators in conjunction with observed temperature and precipitation data for the historical period, but we do not calculate the Palmer indicators for the future (for future projections of the PDSI, refer to refs. 15 and 40).

Because the PDSI is based on recent temperature and precipitation conditions (and does not include human demand for water), it is considered an indicator of "meterological" drought (25). The PDSI calculates "wet," "dry," and "transition" indices, using the wet or dry index when the probability is 100% and the transition index when the probability is less than 100% (26). Because the PMDI always calculates a probability-weighted average of the wet and dry indices (27), the PDSI and PMDI will give equal values in periods that are clearly wet or dry, but the PMDI will yield smoother transitions between wet and dry periods (25). In this work, we use the PMDI as our primary drought indicator, although we note that the long-term time series of the PMDI is similar to that of the PDSI and PHDI, particularly at the annual scale considered here (Figs. S1 and S2).

We analyze global climate model simulations from phase 5 of the Coupled Model Intercomparison Project (CMIP5) (51). We compare two of the CMIP5 multimodel historical experiments (which were run through 2005): (*i*) the Historical experiment, in which the climate models are prescribed both anthropogenic and nonanthropogenic historical climate forcings, and (*ii*) the Natural experiment, in which the climate models are prescribed only the nonanthropogenic historical climate forcings. We analyze those realizations for which both temperature and precipitation were available from both experiments at the time of data acquisition. We calculate the temperature and precipitation values over the state of California at each model's native resolution using all grid points that overlap with the geographical borders of California, as defined by a high-resolution shapefile (vector digital data obtained from the US Geological Survey via the National Weather Service at www.nws.noaa.gov/geodata/catalog/national/html/us_state.htm).

We also analyze NCAR's large ensemble ("LENS") climate model experiment (29). The LENS experiment includes 30 realizations of the NCAR CESM1. This large single-model experiment enables quantification of the uncertainty arising from internal climate system variability. Although the calculation of this "irreducible" uncertainty likely varies between climate models, it exists independent of uncertainty arising from model structure, model parameter values, and climate forcing pathway. At the time of acquisition, LENS results were available for 1920–2005 in the Historical experiment and 2006–2080 in the RCP8.5 (Representative Concentration Pathway) experiment. The four RCPs are mostly indistinguishable over the first half of the 21st century (52). RCP8.5 has the highest forcing in the second half of the 21st century and reaches ~4 °C of global warming by the year 2100 (52).

Given that the ongoing California drought encompasses the most extreme 12-mo precipitation deficit on record (8) and that both temperature and many drought indicators reached their most extreme historical values for California in July 2014 (7) (Fig. 1 and Figs. S1 and S2), we use the 12-mo August–July period as one period of analysis. However, because severe conditions can manifest at both multiannual and subannual timescales, we also analyze the probability of occurrence of co-occurring warm and dry conditions for multiannual periods, for all possible 12-mo periods, and for the winter (DJF), spring (March–April–May), summer (June–July–August), and autumn (September–October–November) seasons.

We use the monthly-mean time series from NCDC to calculate observed time series of statewide 12-mo values of temperature, precipitation, and PMDI. Likewise, we use the monthly-mean time series from CMIP5 and LENS to calculate simulated time series of statewide 12-mo and seasonal values of temperature and precipitation. From the time series of annual-mean values for each observed or simulated realization, we calculate (*i*) the baseline mean value over the length of the record, (*ii*) the annual anomaly from the baseline mean value, (*iii*) the SD of the detrended baseline annual anomaly time series, and (*iv*) the ratio of each individual annual anomaly value to the SD of the detrended baseline annual anomaly time series. (For the 21st-century simulations, we use the Historical simulation as the baseline.) Our time series of standardized values are thereby derived from the time series of 12-mo annual (or 3-mo seasonal) mean anomaly values that occur in each year.

For the multiannual analysis, we calculate consecutive occurrences of August–July 12-mo values. For the analysis of all possible 12-mo periods, we generate the annual time series of each 12-mo period (January–December, February–January, etc.) using a 12-mo running mean. For the seasonal analysis, we generate the time series by calculating the mean of the respective 3-mo season in each year.

We quantify the statistical significance of differences in the populations of different time periods using the block bootstrap resampling approach of ref. 28. For the CMIP5 Historical and Natural ensembles, we compare the populations of the August–July values in the two experiments for the 1986–2005, 1976–2005, and 1966–2005 periods. For the LENS seasonal analysis, we compare the respective populations of DJF, March–April–May, June–July–August, and September–October–November values in the 1920–2005 and 2006–2080 periods. For the LENS 12-mo analysis, we compare the populations of 12-mo values in the 1920–2005 and 2006–2080 periods, testing block lengths up to 16 to account for temporal autocorrelation out to 16 mo for the 12-mo running mean data. (Autocorrelations beyond 16 mo are found to be negligible.)

Throughout the text, we consider drought to be those years in which negative 12-mo PMDI anomalies exceed −1.0 SDs of the historical interannual PMDI variability. We stress that this value is indicative of the variability of the annual (12-mo) PMDI, rather than of the monthly values (compare Fig. 1 and Figs. S1 and S2). We consider "moderate" temperature and precipitation anomalies to be those that exceed 0.5 SDs ("0.5 SD") and "extreme" temperature and precipitation anomalies to be those that exceed 1.5 SDs ("1.5 SD").

ACKNOWLEDGMENTS. We thank the editor and two anonymous reviewers for insightful comments; Deepti Singh for assistance with the block bootstrap resampling; the National Oceanic and Atmospheric Administration's NCDC for access to the historical temperature, precipitation, and drought data; the World Climate Research Program and Department of Energy's Program for Climate Model Diagnosis and Intercomparison for access to the CMIP5 simulations; and NCAR for access to the LENS simulations. Our work was supported by National Science Foundation Award 0955283 and National Institutes of Health Award 1R01AI090159-01.

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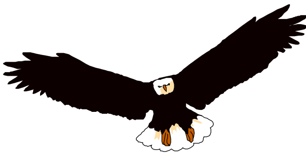
Round Valley County Water District



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April 30, 2021

Mendocino County Board of Supervisors
501 Low Gap Road, Room 1010
Ukiah, CA 95482

Re: Regarding exclusion of Round Valley from cannabis expansion, pending completion of EIR that includes hydrological study and likely cumulative impacts.

Dear Supervisors:

In our letter to you of March 15, 2021, we raised concerns about the vast increase in groundwater usage, chemical usage, and sanitation issues that could result if the proposed ordinance is adopted. It is our firm belief that a comprehensive environmental impact review of the proposed ordinance should be performed by the county, including an in-depth study of possible cumulative effects on groundwater supplies, to mitigate any potentially irreversible damage to the Round Valley aquifer.

Of great concern is that the Round Valley aquifer is a closed aquifer. Groundwater collects in the valley like a bowl and, unlike the flowing aquifers in other areas of the county, does not flow outside of this confined area. As you know, fertilizers, chemicals, herbicides and poisons, some of which originate in Mexico and are banned here in the United States, have been found at cannabis grow sites. Pollutants released in the watershed surrounding Round Valley are transported into the valley by surface water and permitted to enter the aquifer via the alluvial fans at each of the five major streams entering the valley. The alluvial fans are major recharge areas for the aquifer as they are virtually solid gravel from the surface, extending down into the aquifer and allowing water to flow into it. If the aquifer is drawn down far below the surface, the chemicals may perk through the soil and deep into the aquifer. Any pollution entering the aquifer will stay in the aquifer and likely spread throughout the valley.

The risk for ground subsidence is another issue that needs to be evaluated. When excessive aquifer pumping and depletion have occurred in other areas, ground subsidence has occurred, with a permanent loss of groundwater storage capacity. The risk of subsidence in Round Valley should be studied, and mechanisms for limiting cultivation during drought years should be implemented, prior to allowing expansion.

There has never been a comprehensive study of Round Valley's unique aquifer, making its supply, structure, and vulnerability to impacts largely unknown. The cost of such study is far too high for the Round Valley County Water District to execute, and it is unreasonable to expect it would be performed within the site-specific CEQA process of individual cannabis permit applicants. Therefore, the Round Valley County Water

District requests Round Valley be excluded from the dramatic expansion of cannabis cultivation allowed in the currently proposed Phase 3 ordinance, until such time as the county completes a comprehensive groundwater study as part of an environmental impact review of likely cumulative impacts. If the county does not honor this request, we ask that, at a minimum, professional hydrological studies be conducted before issuing individual permits, and that Round Valley County Water District be included in developing study protocols and reviewing study findings prior to permit approval.

We also urge the county to budget sufficient funds to adequately monitor and enforce provisions of any adopted ordinance. We understand the legal cannabis framework is intended to prohibit use of dangerous chemicals and other destructive behaviors, but we have not seen this reflected in practice. There must be sufficient tax revenue generated from cannabis activity within the county to support vigorous ongoing monitoring and enforcement. Failure to do so will result in an ordinance that encourages expansion and provides no concomitant limitation.

Sincerely,

Denis L. Moore, Chairman
Round Valley County Water District

Coordinates	Owner	Altitude	3/22/2013	4/13/2014	5/8/2015	5/3/2016	3/23/2017	3/21/2018	3/22/2019
	Helmholz	1331'	0.0'	0.0'	2.1'	artisian	artisian	artisian	artisian
N39`46.371' W123`12.052'									
	Crawford/Foothill	1407'	17.5'	15.5'	21.9'	n/a		n/a	10.1'
N39`47.745' W123`15.758'									
	Proschold	1348.4'	0.0'	0.6'	.2'	artisian	n/a	artisian	artisian
N39`47.517' W123`12.342'									
	Karel	1401.5'	n/a	16.2'	14.2'	n/a	n/a	n/a	
22N12W12R00M State ID									
	YukiTrails	1409'	8.4'	10.4'	12.4'	5'	2.0'	9.4'	1.4'
N39`48.288' W123`16.035'									
	Kinney	1344.3'	0.8'	0.0'	0.0'	n/a	n/a		
N39`46.372' W123`12.872'									
	Fugman	1328.3'	9.2'	10.5'	11.3'	10.5'	9.6'	7.9'	9.7'
N29`45.365' W123`12.262'									
	Library	1409'	10.0'	9.2'	11.3'	8'	6.6'	6.4'	
N39`47.633 W123`15.005									
	Crwfd/Mill	1409.6'	13.8'	15.7'	17.6'	13.4'	11.0'	14.4'	12.8'
23N12W36C003 State ID									
	Airport	1420'	10.5'	5.5'	15.1'	7.5'	5.7'	5.8'	5'
22N13W01N001M State ID									
	H162/Ea Lane	1395'	5.1'	5.7'	6.8'	4.1'	2.8'	4.6'	2.8'
N39`47.430' W123`14.515'									
	Cemetary/Grist	1395'	6.9'	9.6'	9.3'	5.1'	4.5'	7.2'	5.1'
N39`48.426' W123`15.917'									
	ShrtCrk/EastLane	1352'	n/a		n/a	n/a	n/a		
22N12W04B001M State ID									
	M&M	1386'		8.7'	n/a	n/a	n/a		
N39`46.746' W123`11.393'									
	H162/Shrt. Crk.	1424'		10.6'	16.0'	13.4'	12.2'	12'	12.4'
N39`49.209' W123`12.071'									
	Wyre								

4/20/2020	4/29/2021
0.9	n/a
19.7	20.4
artisian	artisian
	n/a
15.1	15.7
	n/a
	13.5
	n/a
	n/a
9.2	11.8
6.3	7.2
10.4	10.2
	n/a
	n/a
15.2	n/a
	4.2

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Geophysical Research Letters

COMMENTARY
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A tale of two California droughts: Lessons amidst record warmth and dryness in a region of complex physical and human geography

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Key Points:
- California has experienced the worst drought in its historical record during 2012–2015
- Effects of this event have been relatively mild in some sectors but very severe others
- El Niño presents the simultaneous prospect of drought relief but also an increased risk of flooding

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Abstract The state of California has experienced the worst drought in its historical record during 2012–2015. Adverse effects of this multiyear event have been far from uniformly distributed across the region, ranging from remarkably mild in most of California's densely populated coastal cities to very severe in more rural, agricultural, and wildfire-prone regions. This duality of impacts has created a tale of two very different California droughts—highlighting enhanced susceptibility to climate stresses at the environmental and socioeconomic margins of California. From a geophysical perspective, the persistence of related atmospheric anomalies has raised a number of questions regarding the drought's origins—including the role of anthropogenic climate change. Recent investigations underscore the importance of understanding the underlying physical causes of extremes in the climate system, and the present California drought represents an excellent case study for such endeavors. Meanwhile, a powerful El Niño event in the Pacific Ocean offers the simultaneous prospect of partial drought relief but also an increased risk of flooding during the 2015–2016 winter—a situation illustrative of the complex hydroclimatic risks California and other regions are likely to face in a warming world.

California's extraordinary and ongoing drought of 2012–2015 provides a fascinating example of complex interactions between the atmosphere, ocean, and land surface playing out in region of great geographic and socioeconomic diversity. From a meteorological perspective, the present California drought is unparalleled in the more than century-long instrumental record [*Griffin and Anchukaitis*, 2014; *Robeson*, 2015] (Figure 1a); the paleoclimate record suggests that the event is remarkable even in a millennial context [*Griffin and Anchukaitis*, 2014; *Robeson*, 2015]. At the same time, natural and human systems across California have experienced a wide range of drought impacts—ranging from the barely perceptible to the profound. The ongoing situation in California holds the potential to become an important case study both for scientists interested in understanding the causes of underlying temperature and precipitation anomalies and also for decision makers responsible for long-range planning and on-the-ground response to extreme climate events.

The California drought has garnered considerable attention in the scientific community: its complex evolution has highlighted gaps in the collective knowledge regarding processes governing extreme, persistent, and recurring atmospheric circulation patterns in the midlatitudes. The proximal cause of California's enormous multiyear precipitation deficit—a recurring northward shift in the Pacific storm track during California's rainy season associated with a prominent region of high pressure known as the "Ridiculously Resilient Ridge" (Figure 2)—has already been characterized extensively [*Swain et al.*, 2014; *Wang et al.*, 2014; *Seager et al.*, 2015]. Yet partitioning the relative contributions to this highly anomalous atmospheric feature by potential geographically remote influences—including tropical and midlatitude ocean warming [*Wang et al.*, 2014, 2015; *Hartmann*, 2015; *Seager et al.*, 2015; *Lee et al.*, 2015], declining Arctic sea ice [*Lee et al.*, 2015], internal atmospheric variability [*Seager et al.*, 2015], and anthropogenic radiative forcing [*Swain et al.*, 2014; *Wang et al.*, 2014, 2015; *Lee et al.*, 2015]—remains a considerable challenge. The hypothesized importance of complex interactions between various Earth systems across a wide range of spatial and temporal scales reinforces the notion that understanding the physical causes of extreme events like the current drought will require an integrated, cross-disciplinary approach. Given California's location near the climatological winter mean position of the Pacific storm track and its large interannual precipitation variability, such investigations are likely to yield substantial insights into the broader mechanisms underlying regional climate variability and change in the midlatitudes.

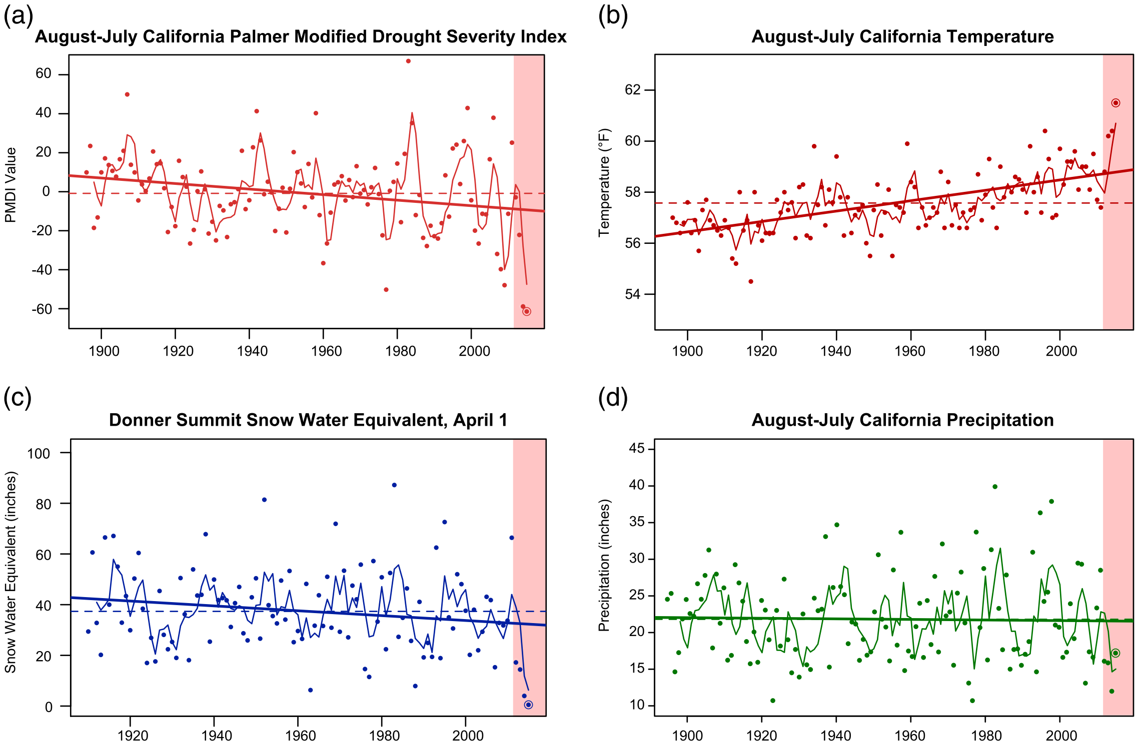

Figure 1. California's record-breaking 2012–2015 drought in historical context. Time series include (a) annually averaged (August–July) Palmer Modified Drought Severity Index, which integrates the net effect of precipitation and temperature, (b) annually averaged (August–July) mean temperature (Fahrenheit), and (d) annually averaged (August–July) precipitation (inches). (c) The time series depicts 1 April snow water equivalent (inches) for Donner Summit in the northern Sierra Nevada Mountains (2103 m above mean sea level). In each respective time series, annual data are plotted as points, the long-term mean value is represented by a horizontal dashed line, the 3 year right-sided moving average is represented by a thin solid curve, and the fitted least squares linear mean trend is represented by a heavy solid curve. The 2015 values are emphasized using concentric circles around each 2015 point, and the 4 year duration of the drought is highlighted with red light shading.

Indeed, the meteorological character of California's multiyear drought has already prompted new questions for physical scientists and policymakers alike. Precipitation, of course, has been far below the long-term mean—and the current drought has featured the driest consecutive 3 year period in California's history (Figure 1d). But even more impressive than these large accumulated precipitation deficits have been the astonishingly warm temperatures with which these dry years have cooccurred (Figure 1b). Record warmth has pervaded all corners of the state during both winter and summer, amplifying already severe drought impacts. The combination of well-above freezing temperatures and low precipitation in the Sierra Nevada Mountains—even in the heart of winter—resulted a snowpack during 2015 that was fully 95% below average [*California Department of Water Resources*, 2015] (Figure 1c). California, like the rest of the planet, has experienced a substantial long-term warming trend over the past century that can be attributed to the human emission of greenhouse gases into the atmosphere [*Diffenbaugh et al.*, 2015]—a trend that very likely contributed to the severity of California's worst drought on record [*Williams et al.*, 2015; *Shukla et al.*, 2015; *AghaKouchak et al.*, 2014] and to the observed overall increase in California drought [*Diffenbaugh et al.*, 2015; *Williams et al.*, 2015]. The increasing occurrence of "hot droughts" is a hallmark of global warming [*Overpeck*, 2013], and the current situation in California illustrates the sometimes dramatic effects of such events in a world with rising greenhouse gas concentrations.

It is a remarkable testament to the Golden State's resilience that for urban residents, the worst drought of California's statehood has been—for the most part—a modest inconvenience. Brown lawns abound, recreational opportunities on regional lakes and rivers have been curtailed, and short showers are now the norm. California's vast water conveyance system has kept thirsty cities quenched, transporting what relatively little water has been available away from the mountains where most of California's precipitation falls to the drier, more densely populated coastal areas. With the exception of occasional images of shrinking reservoir levels on

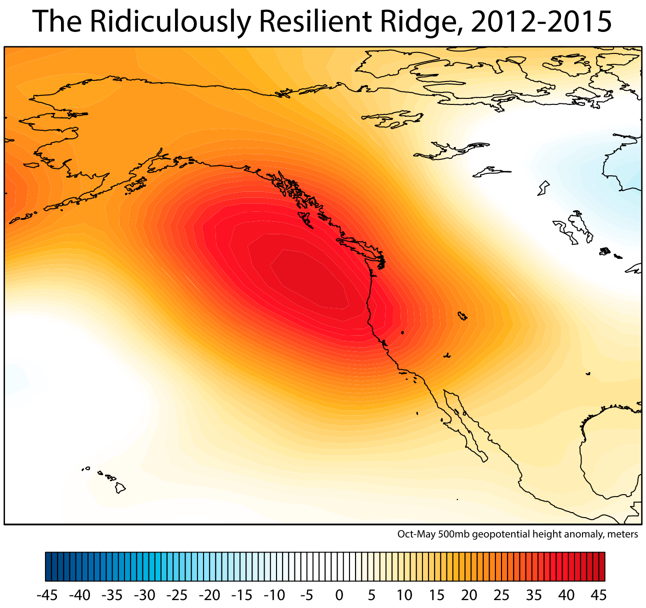

Figure 2. The proximal cause of California's multiyear drought is the remarkable persistence of a region of midtropospheric high pressure known as "The Ridiculously Resilient Ridge." The plotted quantity is the mean cool season 500 mbar geopotential height anomaly (meters) over four consecutive years (i.e., October–May 2012, 2013, 2014, and 2015).

the evening news, California's record-breaking drought has been largely out of sight—and out of mind—for a majority of the state's residents.

But the relatively mild effects in California's urban areas have masked much deeper and more troubling drought impacts elsewhere in the state. Hundreds of thousands of acres of the most productive farmland in North America has been fallowed due to the lack of water, resulting in multi-billion dollar losses [*U.S. Department of Agriculture* (*USDA*), 2014]. Those farms which have managed to stay afloat have done so by pumping tremendous quantities of groundwater out of the Central Valley at a rapid and highly unsustainable rate, leading to increasingly severe overdraft of critically stressed aquifers [*U.S. Geological Survey* (*USGS*), 2015]. This groundwater overdraft has not only led to infrastructure-threatening land subsidence but also caused taps to run dry in smaller, mostly low income agricultural communities dependent on local wells for domestic and drinking water supplies [*Howitt et al.*, 2015; *Fresno Bee*, 2015].

Effects upon California's natural environment, too, have steadily worsened with each passing warm and dry year. Low or nonexistent streamflows and unusually warm waters have threatened local extirpation of fish species [*San Francisco Chronicle*, 2015; *Sacramento Bee*, 2015]. Widespread forest mortality—potentially as high as 20% of all trees in the state [*Los Angeles Times*, 2015]—has occurred even among California's native and relatively drought resistant species, helped along by opportunistic bark beetle infestations encouraged by extreme drought stress [*USDA*, 2014]. Drought-killed or weakened trees, coupled with consecutive years of relentlessly warm temperatures, have led to explosive wildfire risk across most of California's millions of forested acres. This dangerous potential has unfortunately been realized during the 2015 fire season: multiple deadly and destructive wildfires have burned hundreds of thousands of acres and destroyed thousands of homes as they raced across the northern part of the state with "unprecedented" speed and intensity [*CAL FIRE*, 2015; *Capital Public Radio*, 2015]. And the fire-scorched, newly hydrophobic soils in these regions hold the potential to cause even more misery once the rains finally do return to California by preventing the absorption of heavy precipitation, increasing runoff and the subsequent risk of flash floods and debris flows.

Federal, state, and local actions have been successful in making California's drought a largely "invisible" disaster for those living in major cities. This relatively optimistic picture, though, does not hold for the residents of Porterville who have gone without running water for over a year; or for the (former) residents of fire-ravaged Middletown, whose entire community was devastated by the Valley Fire; or for San Joaquin Valley farmworkers, who have endured growing hunger and homelessness as their livelihoods turn to dust. Theirs is a very different drought reality than the one facing urban dwellers, but is representative of the challenges faced by tens of thousands of Californians living in smaller, poorer, or more rural communities throughout the state [*Fresno Foundation*, 2015]. This, combined with the essentially unmitigated adverse effects of the drought upon the region's forest and riverine ecosystems, suggests that systems at the socioeconomic and environmental margins of California remain vulnerable—even in a part of the world that is exceptionally wealthy by global standards. The disproportionate burden of extreme climate events borne by those with the least capacity and fewest resources to cope with them represents a key challenge in adapting to a changing climate [*Intergovernmental Panel on Climate Change*, 2012], both in California and across the globe.

California's precipitation predicament in late 2015 is further complicated by the emergence in the tropical Pacific Ocean of one of the most powerful El Niño events of the modern observational era. While El Niño does not always bring increased precipitation to Pacific Southwest—particularly in inland and mountainous parts of northern California, which are critically important regions for snowmelt-fed reservoir storage—top-tier El Niño events are more reliably associated with above-average winter precipitation throughout the state. Adding further uncertainty to the overall climatological picture is the presence of record oceanic warmth well to the north of the canonical El Niño region in the tropics, extending across a vast expanse of the eastern North Pacific. This observationally unprecedented combination of very warm tropical and extratropical conditions suggests that California may be facing an increased risk of extreme precipitation—and associated geophysical hazards, such as flooding and mudslides—despite the likely long-term persistence of its deeply entrenched multiyear drought

Recent evidence suggests that California's undoubtedly warmer future may also be characterized by an increased frequency of extremely dry and extremely wet years [*Berg and Hall*, 2015; *Yoon et al*., 2015]—despite relatively modest changes in mean precipitation [*Neelin et al*., 2013; *Seager et al*., 2015]. An increased risk of both drought and flood will require very different climate adaptation measures than those needed in a warming and gradually wetting California, underscoring the critical importance of clearly communicating these climatological nuances to decision makers. Ultimately, the successes (and failures) of California's response to the current drought—and its management of potentially competing flood risks associated with the evolving El Niño event—may offer a preview of challenges the state will face in decades to come.

Collectively, the body of research already published on the ongoing California drought points to an urgent need to better understand extreme events in the climate system. Studies motivated by the California drought have yielded more broadly generalizable findings regarding the physical processes responsible for changing regional climate extremes [*Swain et al*., 2014; *Wang et al*., 2014, 2015; *Lee et al*., 2015; *Berg and Hall*, 2015; *Yoon et al*., 2015]. Case studies focused on California have demonstrated that causes of trends in meteorological extremes are not necessarily inferable from those underlying regional mean trends, reiterating the importance of using quantitative metrics capable of accounting for nonstationary variability in observational and model-based analyses in a global context [*Xie et al*., 2015]. Ultimately, actions taken in response to lessons learned in the science, policy, and management realms during the present drought have to the potential to improve resilience—both by increasing our understanding of the relevant geophysical risks and by optimizing our adaptation strategies to future climate extremes.

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