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21st century California drought risk linked to model fidelity of the El Niño teleconnection

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Greenhouse gas induced climate change is expected to lead to negative hydrological impacts for southwestern North America, including California (CA). This includes a decrease in the amount and frequency of precipitation, reductions in Sierra snow pack, and an increase in evapotranspiration, all of which imply a decline in surface water availability, and an increase in drought and stress on water resources. However, a recent study showed the importance of tropical Pacific sea surface temperature (SST) warming and an El Niño Southern Oscillation (ENSO)-like teleconnection in driving an increase in CA precipitation through the 21st century, particularly during winter (DJF). Here, we extend this prior work and show wetter (drier) CA conditions, based on several drought metrics, are associated with an El Niño (La Niña)-like SST pattern. Models that better simulate the observed ENSO-CA precipitation teleconnection also better simulate the ENSO-CA drought relationships, and yield negligible change in the risk of 21st century CA drought, primarily due to wetting during winter. Seasonally, however, CA drought risk is projected to increase during the non-winter months, particularly in the models that poorly simulate the observed teleconnection. Thus, future projections of CA drought are dependent on model fidelity of the El Niño teleconnection. As opposed to focusing on adapting to less water, models that better simulate the teleconnection imply adaptation measures focused on smoothing seasonal differences for affected agricultural, terrestrial, and aquatic systems, as well as effectively capturing enhanced winter runoff.

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INTRODUCTION

In response to anthropogenic climate change, climate models from the Coupled Model Intercomparison Project (CMIP) version 3 and 5 indicate a likely transition to a more arid climate over many land areas,[1] resulting in increased frequency and intensity of drought.[2,3] Severe and widespread drought during this century are of particular concern for southwestern North America, including California (CA).[4–8] This drying is a consequence of reduced precipitation in the subtropics, and a poleward expansion of the subtropical dry zones.[9–13] Moreover, in addition to reduced precipitation, warmer temperatures will lead to an increase in evapotranspiration[3] and a decrease in mountain snow mass.[6] All of this translates into reduced surface water availability, soil moisture and runoff,[14] implying significant stress on water resources. Future drought risk in southwestern North America may even exceed that during the driest centuries of the Medieval Climate Anomaly.[15,16]

However, despite the large body of literature suggesting an increase in drought under greenhouse gas forcing, uncertainty still remains. Overall, there is medium confidence that warming will increase the duration and intensity of droughts in some regions, including the Mediterranean, Central America and Mexico, north-east Brazil, southern Africa and central North America.[13,17] The only regions with a consistent increase in drought are those where precipitation decreases.[18] Furthermore, many of the above studies quantify drought using the Palmer Drought Severity Index (PDSI), which is calculated from a simple water balance model,[19] and may overestimate the increase in global drought[20] due to an oversensitivity to warmer temperatures.[21] Consistent with this uncertainty, a recent study suggests increased radiative forcing may lead to a decrease in the likelihood of CA agricultural drought.[22] This study, however, was based on a single model and did not focus on 21st century climate change.

An important component of drought is precipitation, and relatively large uncertainty exists for future CA precipitation projections.[23,24] Relative to CMIP3, however, CMIP5 CA precipitation projections tend to yield a more consistent increase.[25–27] This is related to a coherent extratropical response, involving a southeastward extension of the the upper level winds in the east Pacific,[25] an increase in storm track activity,[28] and an increase in CA moisture convergence,[29] all of which promote an increase in CA precipitation. Moreover, a robust dynamical response in the tropics also exists,[27] including an increase in central/eastern tropical Pacific divergence and a poleward propagating Rossby wave, both of which are reminiscent of an El Niño-like teleconnection. Combined with warming of the tropical Pacific sea surface temperatures (SSTs), CMIP5 models that better simulate the observed El Niño-CA precipitation teleconnection yield larger, and more consistent increases in CA precipitation through the twenty-first century.[27]

Using a multitude of models from the CMIP5[30] archive, we build off of prior work[27] and evaluate future CA drought risk using multiple metrics under business as usual warming. We primarily focus on annual drought to be able to compare our results to previous studies of future water availability in California and the Southwestern US from GCM simulations.[4,31] More importantly, the question of potential changes in seasonal versus annual (and

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