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California: Indications for Continued Groundwater Depletion after Drought and Causes of Drought Variety

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ABSTRACT

California's Central Valley is undergoing a groundwater drilling boom amid one of the most severe droughts in state history from 2012~2015. Within California's Central Valley, home to one of the world's most productive agricultural regions, drought and increased groundwater depletion occurs almost hand-in-hand but this relationship appears to have changed over the last decade. Data derived from 497 wells as variations of groundwater level (GW) have revealed a continued depletion of groundwater about one year after drought, a phenomenon that did not exist prior to year 2000 from the sliding correlation between PDSI and GW with a 15-year running window (Fig. 1). Possible causes include (a) lengthening of drought associated with amplification in the 4-6-year drought frequency since the late 1990s (Fig. 2), that drought conditions in California have become increasingly more intense and lasted longer (Cayan *et al.*, 2010; MacDonald, 2010; Diffenbaugh *et al.*, 2015), and (b) intensification of drought and increased pumping that enhances depletion, that Famiglietti (2014] noted that drought is the leading contributor to groundwater behavior, rather than changes in reservoir storage. Altogether, the implication is that groundwater storages in the Central Valley will likely continue to diminish even further in 2016, regardless of the drought status. This work has been accepted in Journal of Hydrometeorology (Wang *et al.*, 2016).

Furthermore, as we know, upper-troposphere ridges play an important role to influence the

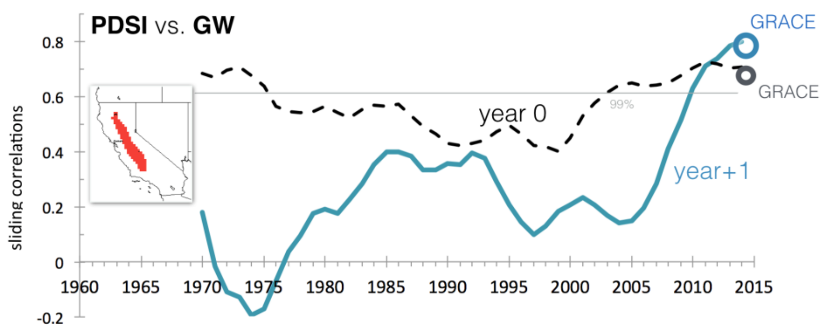

Fig. 1 Sliding correlations between the Central Valley PDSI and the groundwater level (GW) in the following year (year+1; solid line) and in the same year (year 0; dashed line), computed with a 15-year running window (one-sided). The LWET correlations with PDSI are indicated by thick circles for 2002-2014. Gray horizontal lines indicate the 99% confidence interval.

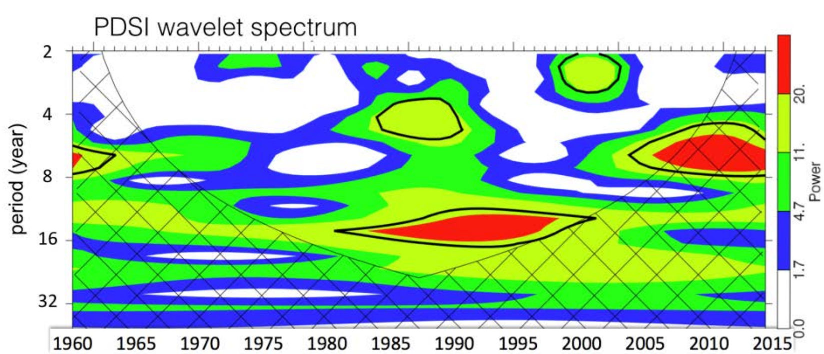

Fig. 2 Wavelet spectrum of the PDSI using the Morlet param-6 approach, in which the contour levels are chosen so that 75%, 50%, 25%, and 5% of the wavelet power are respectively above each level.

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drought in California (Wang *et al.* 2014), but each drought year has different climate regime. To understand the circulation variations within dry years, we applied the empirical orthogonal function (EOF) to depict the variation(s) of the Nov.~Mar. 250mb geopotential (Z250mb) high within the selected 18 dry winters. The results show that the first mode (Fig. 3a) and its Z250mb regression pattern with PC1 (Fig. 4a) is relative to the teleconnection varieties of Pacific North American (PNA) pattern (Fig. 4b) and the second mode (Fig. 3b) and its Z250mb regression pattern with PC2 (Fig. 4b) is relative to the negative North Pacific Oscillation (NPO) pattern (Fig. 4d). By comparing Z250mb (Figs. 4b and 4d) and PDSI (Figs. 5a and 5b) regression patterns with PNA and negative NPO, the variations of two dominated circulation patterns over Pacific Ocean, PNA and NPO, modulate the drought conditions in California. Nevertheless, the PNA and NPO variations do not directly cause the droughts.

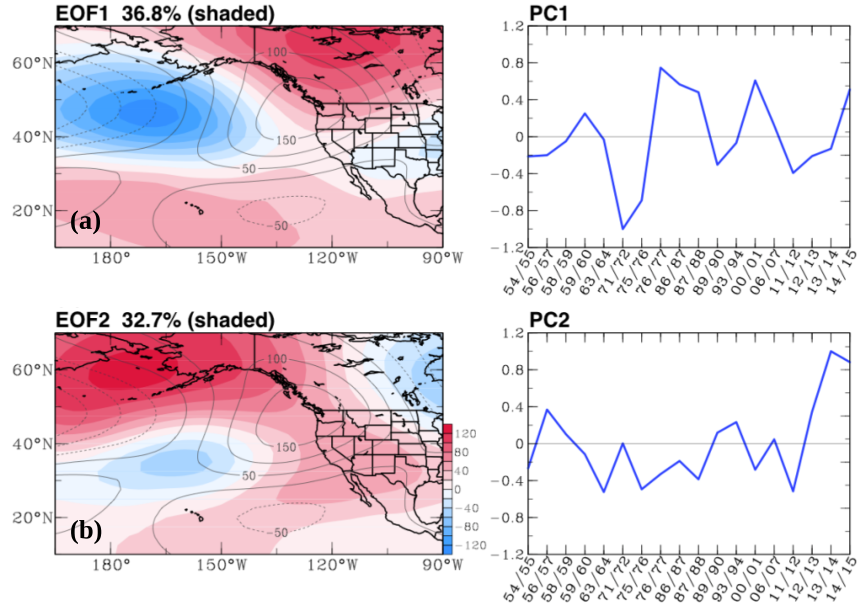

Fig. 3 (a) The first mode of EOF1 (shaded) of winter (Nov~Mar) $Z_{(250mb)}$ in 18 California dry years and its relative PC1, superimposed with these18 years' mean $Z_{E(250mb)}$. (b) The second mode.

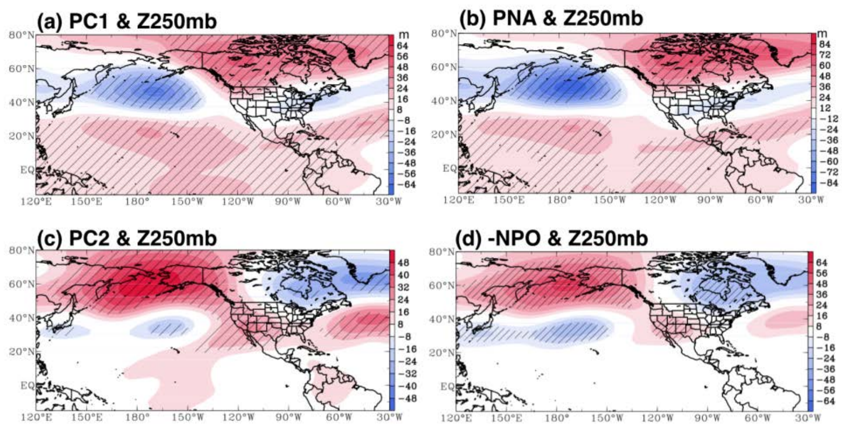

Fig. 4 The Z_{250mb} regression patterns in 18 California dry years with: (a) PC1 index (b) PNA index, (c) PC2 index, and (d) negative NPO index, superimposed with 95% significant test.

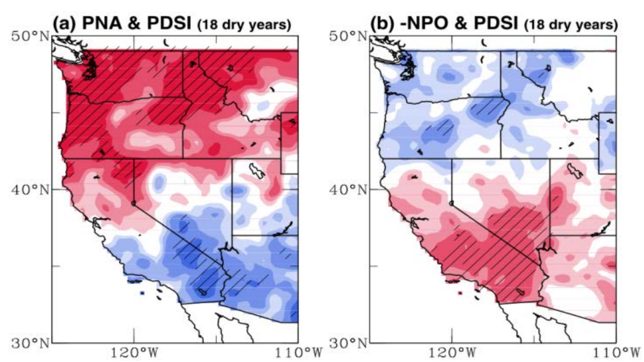

Fig. 5 The boreal winter (Nov~Mar) PDSI regression patterns with (a) PNA and (b) negative NPO in 18 California dry years, superimposed with 95% significant test (hatch).

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