Climate modulated water storage, the deformation, and California earthquakes

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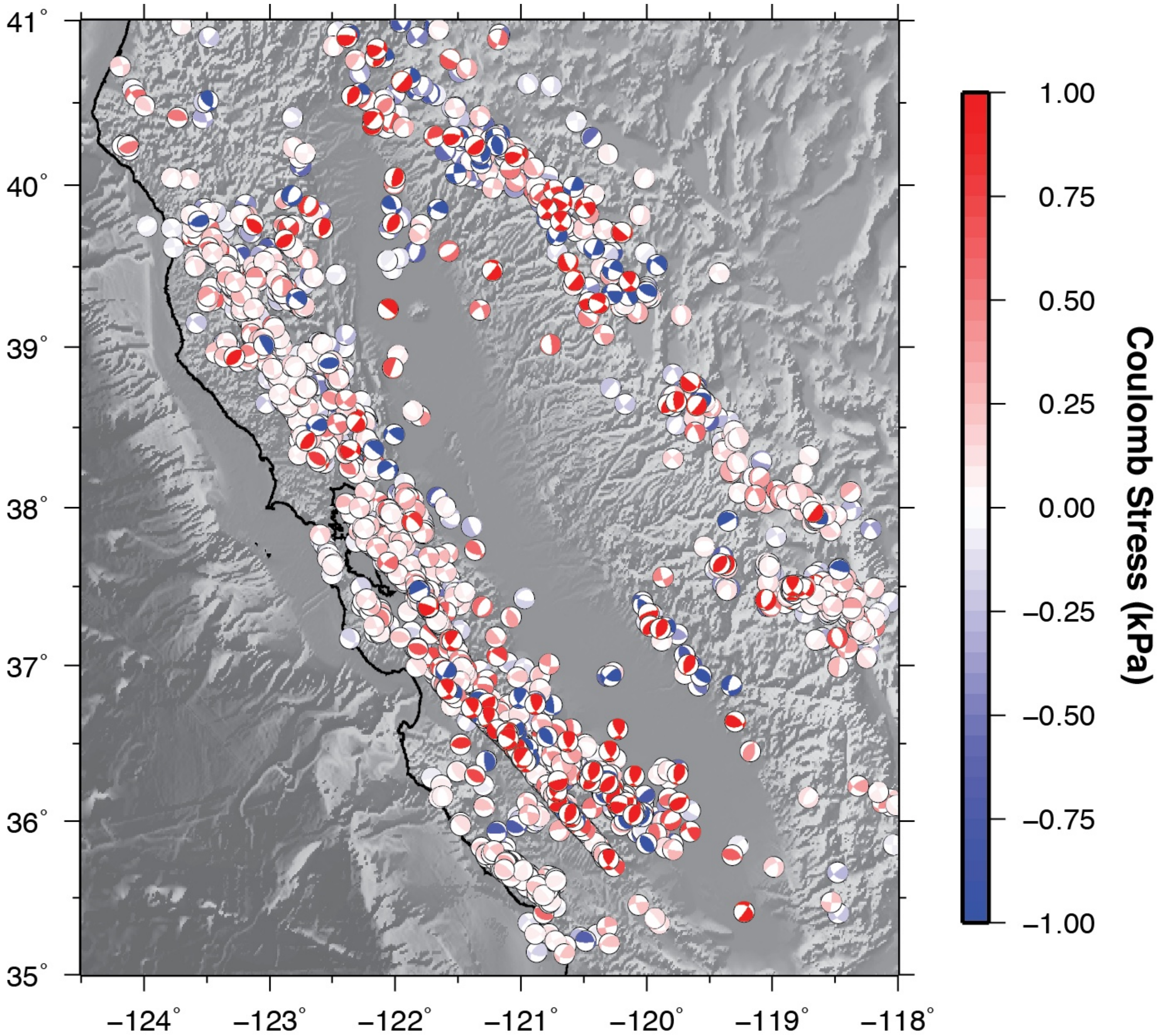
Establishing what controls the timing of earthquakes is fundamental to understanding the nature of the earthquake cycle and critical to determining time-dependent earthquake hazard. Seasonal loading provides a natural laboratory to explore the crustal response to a quantifiable transient force. In California, the accumulation of winter snowpack in the Sierra Nevada, surface water in lakes and reservoirs, and groundwater in sedimentary basins follow the annual cycle of wet winters and dry summers. The surface loads resulting from the seasonal changes in water storage produce elastic deformation of the Earth’ s crust. Previous studies posit that temperature, atmospheric pressure, or hydrologic changes may strain the lithosphere and promote additional earthquakes above background levels. Depending on fault geometry the addition or removal of water increases the Coulomb failure stress. We use 9 years of global positioning system (GPS) vertical displacement time series (2006 –2015) to constrain models of monthly hydrospheric loading and compute the resulting stress changes on fault planes of small earthquakes throughout northern California, which can exceed 1 kPa. Additionally, we model the seasonal stress changes in California for tidal, thermal, and atmospheric loading sources with annual periods to produce an aggregate stressing history for faults in the study area. Our modeling shows that the annual water loading, atmosphere, temperature, and Earth pole-tides are the largest loading sources and should each be evaluated to fully describe seasonal stress changes. In California, we find the hydrological loads are the largest source of seasonal stresses. The largest stress amplitudes are occurring on dipping reverse faults in the Coast Ranges and along the eastern Sierra Nevada range front. We analyze 9 years of M>=2.0 earthquakes with known focal mechanisms in northern and central California to resolve fault-normal and fault-shear stresses for the focal geometry. Our results reveal 10% more earthquakes occurring during slip-encouraging fault-shear stress conditions and suggest that earthquake populations are modulated at periods of natural loading cycles, which promote failure by stress changes on the order of 1-5 kPa. When projecting the seasonal stresses into the background stress orientation we find the timing of microseismicity modestly increases from a ˜8 kPa seasonal mean-normal-stress perturbation. The results suggest faults in California are optimally oriented with the background stress field and respond to subsurface pressure changes, possibly due to processes we have not considered in this study. We infer that California seismicity rates are modestly modulated by natural hydrological loading cycles. At any time a population of faults are near failure as evident from earthquakes triggered by these slight seasonal stress perturbations.

Keywords: Earthquake triggering, Seasonal loading cycles, Deformation from surface loading processes


41°
40°
39°
38°
37°
36°
35°
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−120°
−119°
−118°
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
Coulomb Stress (kPa)