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The Importance of Small Aftershocks for Earthquake Triggering

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Earthquakes occur in response to changes in the crust's stress state, however, the full picture of the causative process for earthquake triggering remains unclear. Many researchers have employed Coulomb stress change theory, which quantifies the changes in static Coulomb stress from nearby ruptures. This theory seems to at least partly explain the spatial patterns of triggered earthquakes, in particular during aftershock sequences and along faults.

Several assumptions are needed to facilitate the calculation of stress changes. Here, we challenge the typical neglect of stress changes induced by the small but numerous and strongly clustered aftershocks during the evolution of the sequence. Both empirical observations and a simple scaling law suggest that this neglect may not be justified.

We estimate the evolution of Coulomb stress changes during the 1992 Mw 7.3 Landers earthquake sequence by including the effect of the detected aftershocks using the focal mechanisms from the recently updated Southern California catalog. This estimation is hampered by that only 62% of located events from our study window have a focal mechanism, by the neglect of events that are too small to be detected and by the unreliability of near-field stress change estimations. As a consequence, we are limited to analyzing only a part of the full stress change signal imparted by small events.

Despite these shortcomings, our calculations suggest that small to moderate events strongly dominate static stress redistribution in dense secondary aftershock clusters. However, their relative importance varies over space and is, on average, smaller than the main shock contribution.

Furthermore, we find that aftershocks – with their reported relative orientations and positions - impose more often positive than negative stress changes, which is what would be expected if they were actively involved in triggering processes. However, this effect appears to be limited to event pairs with inter-event distances of at least one source length and with cumulative stress change amplitudes of above 0.01MPa. While the former limitation can be explained by the unreliability of the near-field stress estimations, the latter is a controversial observation that has also been reported in main shock stress change studies (e.g. Hardebeck et al., 1998). We assess the statistical significance of the observed fraction of events with positive stress changes with three different null hypotheses. Although designing meaningful null hypotheses for this particular problem is difficult, our results indicate that the observed fractions are unlikely be found by chance or due to random fluctuations. Furthermore, we use an iterative procedure to compile catalogs where >98% of events receive positive stress changes from earlier aftershocks and then perturb these catalogs with realistic focal mechanism uncertainties. This experiment indicates that the observed fraction of events with positive stress changes is around the maximum observable fraction with current focal mechanism quality.