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Including time dependent Coulomb stresses in Coulomb-Rate-and-State seismicity models: effect of afterslip and aftershocks

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The original Coulomb stress triggering model, as well as several more recent models based on stress transfer, consider only the mainshock and the few largest events as a source of stress changes, and assume that the stress field remains constant after each large event. This assumption can be reconciled with the observed time dependent (Omori-type) seismicity by considering a time dependent frictional response: in the rate-and-state framework, the earthquake nucleation process following a single stress step gives rise to an Omori decay.

However, the role of postseismic processes in triggering aftershocks is subject of debate: in particular, the similarity between aftershock and afterslip decay, and the observed spatial relation between them, has led several authors to suggest that aftershocks are governed by afterslip. A second aspect to consider is the redistribution of stresses due to aftershocks: the importance of secondary clustering is supported both by the success of statistical models which model secondary aftershocks (such as ETAS) and by theoretical considerations (Marsan, 2005).

In this work, we investigate the role of these two processes in the framework of Coulomb-Rate-and-State models. We model aftershock seismicity in 250days following the $M_w = 6.0$ Parkfield earthquake. In order to take into account the uncertainty due to the choice of receiver faults on which to resolve Coulomb stresses, we perform Monte Carlo simulations in which the stress tensor is resolved on planes drawn from the local catalog of past focal mechanisms (1970-2004). Rate-and-state parameters ($A\sigma$, t_a and r) are simultaneously inverted using the maximum Likelihood approach.

To assess the impact of afterslip in the forecasts, we test three types of model: one including only stresses from the coseismic slip, one with only the stresses imparted by afterslip, and one including both processes. We find that both models incorporating afterslip perform significantly better in terms of Akaike Information Criterion (AIC=-3201, AIC=-4647, AIC=-4466 respectively), indicating that afterslip plays an important role in aftershock triggering. On the other hand, we find that the model which does not include coseismic stresses severely underestimates seismicity at short times after the mainshock and performs most poorly in the time domain. In terms of spatial distribution, however, this model is the most successful: a large number of aftershocks in fact occur on a fault region of large coseismic slip, which was successively reloaded by afterslip. We observe that the forecasted seismicity in the model combining coseismic and postseismic stresses is very sensible to the relative location of coseismic and postseismic stress changes, and it suffers significantly from slip model uncertainties and resolution limits.

Finally, we assess the impact of including aftershocks as stress sources. Events for which focal mechanisms are available are included directly, using a uniform slip model derived from focal mechanisms information and empirical relations between magnitude, rupture size and average slip; events for which focal mechanisms are not available are included using a stochastic approach.