JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 114, B05309, doi:10.1029/2008JB006011, 2009

Aftershock modeling based on uncertain stress calculations

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Received 12 August 2008; revised 2 March 2009; accepted 19 March 2009; published 28 May 2009.

[1] We discuss the impact of uncertainties in computed coseismic stress perturbations on the seismicity rate changes forecasted through a rate- and state-dependent frictional model. We aim to understand how the variability of Coulomb stress changes affects the correlation between predicted and observed changes in the rate of earthquake production. We use the aftershock activity following the 1992 M7.3 Landers (California) earthquake as a case study. To accomplish these tasks, we first analyze the variability of stress changes resulting from the use of different published slip distributions. We find that the standard deviation of the uncertainty is of the same size as the absolute stress change and that their ratio, the coefficient of variation (*CV*), is approximately constant in space. This uncertainty has a strong impact on the forecasted aftershock activity if a rate-and-state frictional model is considered. We use the early aftershocks to invert for friction parameters and the coefficient of variation by means of the maximum likelihood method. We show that, when the uncertainties are properly taken into account, the inversion yields stable results, which fit the spatiotemporal aftershock sequence. The analysis of the 1992 Landers sequence demonstrates that accounting for realistic uncertainties in stress changes strongly improves the correlation between modeled and observed seismicity rate changes. For this sequence, we measure a friction parameter $A\sigma_n \approx 0.017$ MPa and a coefficient of stress variation $CV = 0.95$.

Citation: Hainzl, S., B. Enescu, M. Cocco, J. Woessner, F. Catalli, R. Wang, and F. Roth (2009), Aftershock modeling based on uncertain stress calculations, *J. Geophys. Res.*, *114*, B05309, doi:10.1029/2008JB006011.

1. Introduction

[2] Aftershocks are commonly seen as the delayed response of a fault population to static Coulomb stress changes (ΔCFS) induced by a main shock [see, e.g., *Harris*, 1998; *Stein*, 1999; *Steacy et al.*, 2005a; M. Cocco et al., Sensitivity study of forecasts based on Coulomb stress calculation and rate- and state-dependent frictional response, submitted to *Journal of Geophysical Research*, 2009, hereinafter referred to as Cocco et al., submitted manuscript, 2009]. By joining the coseismic stress changes with the rate- and state-dependent frictional response of a population of nucleating patches [*Dieterich*, 1994], both the spatial distribution of aftershocks and their temporal decay can be modeled. In particular, it explains the empirical Omori-Utsu law

$$\lambda(t) = \frac{K}{(t+c)^p} \quad (1)$$

where t indicates the elapsed time since the main shock; K, c and p are constants where c is typically found to be much less than 1 day and the p value is between 0.8 and 1.2 for most cases [*Utsu et al.*, 1995]. For a population of faults in the nucleation regime, a sudden stress jump leads to a nonlinear response of earthquake nucleation times which matches the Omori-Utsu law with $p = 1$ until the seismic activity returns to the background level [*Dieterich*, 1994; Cocco et al., submitted manuscript, 2009]. Applications of this model to empirical data provided a good explanation of the observations [*Dieterich et al.*, 2000; *Toda et al.*, 2002, 2005; *Hainzl et al.*, 2006], and reasonable estimations for the regional stressing rate [*Gross and Kisslinger*, 1997; *Gross*, 2001].

[3] However, the observation of aftershocks occurring in stress shadows, i.e., in regions where the calculated stress change becomes negative, $\Delta CFS < 0$, seems to contradict the stress triggering mechanism [*Hardebeck et al.*, 1998; *Catalli et al.*, 2008]. Regions of reduced activity, as predicted by the static stress triggering model for stress shadows, are hardly found in real data and might even not exist [*Marsan*, 2003]. Indeed, it has been recently demonstrated that accounting for the small-scale slip variability that might not be accessible to direct measurement, can explain the absence of regions of quiescence in the first period of the aftershock activity [*Helmstetter and Shaw*, 2006; *Marsan*, 2006].

[4] All applications of the stress-triggering model rely on the determination of the induced stress changes. However,

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0148-0227/09/2008JB006011$09.00