Impact of the receiver fault distribution on aftershock activity

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INTRODUCTION

Aftershock models are usually based either on purely empirical relations ignoring physical mechanism or on deterministic calculations of stress changes on a predefined receiver fault orientation. Here we investigate the effect of more realistic interacting fault systems in aftershock models based on static Coulomb stress changes. For that purpose, we perform earthquake simulations with elastic half-space stress interactions, rate-and-state dependent frictional earthquake nucleation and extended ruptures with heterogeneous (fractal) slip distributions. We investigate the effect of more realistic distributions of receiver fault orientations and earthquake interactions on the characteristics of spatiotemporal aftershock occurrence.

I. MODEL

Fault system: Faults of different orientations are assumed to exist in all sub-volumes where the background earthquake nucleation rate on each fault plane is assumed to be proportional to the CFS-loading rate on that plane.

Earthquake nucleation: Earthquake nucleation rate R is determined by rate-and-state dependent frictional behavior (Dieterich, JGR 1994): $R = r/\gamma\dot{\tau}$ and $d\gamma = (dt - \gamma d\tau)/(A\sigma)$ with state variable γ. We assume an undisturbed state (background activity) in the beginning, i.e. $R(0) = r$. According to the state-evolution law, the event rate is increased/decreased after positive/negative stress jumps.

Slip distribution: The slip distribution is assumed to be fractal. The sizes of aftershocks are randomly taken from a Gutenberg-Richter probability distribution.

Earthquake interactions: For each earthquake, we calculate the static Coulomb-Stress changes in an elastic half-space for all locations and receiver orientations (Okada, BSSA 1992). Each of these stress changes affects the local activity rate (see above).

CASE STUDY: Aftershock sequences induced by a M7 strike-slip mainshock: Monte-Carlo simulations, or, if aftershock interactions are ignored, analytical results → see **Table** for model parameters

Table: Summary of model parameters used for the presented analysis

receiver fault distribution	mean values: $strike$=0^o; dip=90^o; $rake$=180^o Gaussian distribution in strike and dip std= (i) 0^o (*fixed*); (ii) 10/30^o; (iii) ∞ (*uniform*)
friction coefficient Skempton coefficient	μ=0.75 B=0.5
slip distribution	Hurst-Exponent = 0.7
half-space model	$v_p = 6.0km/s$; $v_s = 3.46km/s$; $\rho = 2600kg/m^3$
spatial grid magnitude	$100 \times 100 \times 15km^3$ with $\triangle x = \triangle y = \triangle z = 1km$ 4.0 to 7.5 with $b = 1$
mainshock	t=0; $M_{main} = 7.0$ extended rupture with central point at x=y=0
Rate-State model	r= 1 event per year (uniform in space) $A\sigma = 0.02MPa$ $\dot{\tau}$ = 1.25 kPa/y (strike=0^o; dip=90^o; rake=180^o)

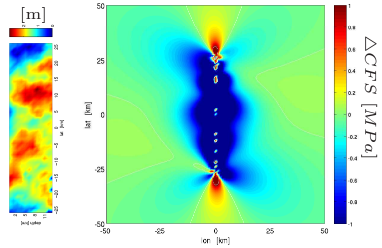

Fig.1: Example of a mainshock slip model with corresponding stress changes on receiver faults with the same mechanism as the mainshock at 10 km depth. The white line defines the locations with zero stress change.

II. RESULTS

Mainshock slip variability leads to activation on and close to the fault.

Existence of different receiver fault orientations leads to the disappearance of significant *stress shadows*

→ see Fig. 2: activation zones enclosed by white lines

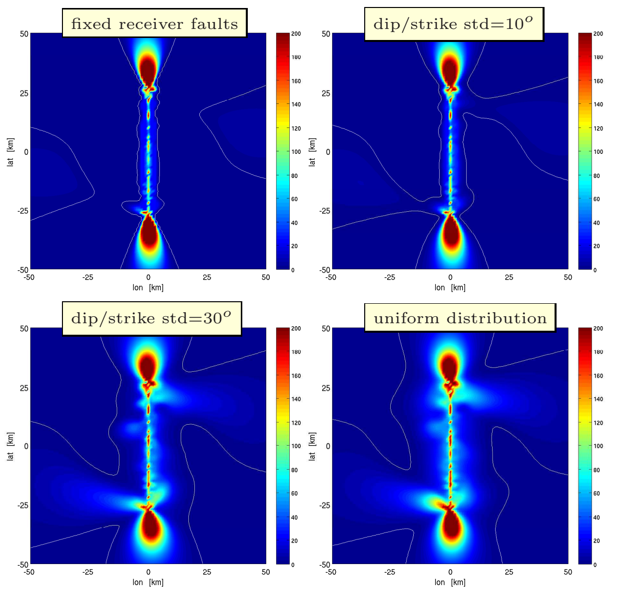

Fig.2: Normalized first year aftershock activity R/r for different receiver fault distributions (aftershock interactions are ignored). The underlying mainshock is that shown in Fig.1.

Aftershock interactions do not significantly change the temporal & spatial decay

→ see Fig. 3

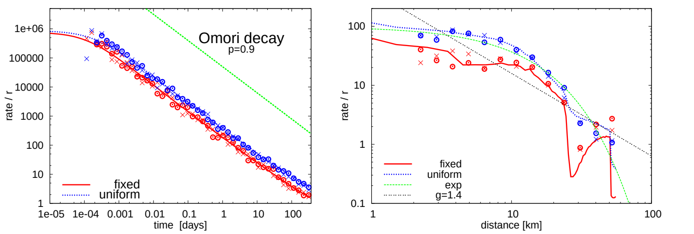

Fig.3: Simulation results with (circles) and without (crosses) interactions between aftershocks: the temporal (left) and distance (right) decay of the aftershock activity. The results are based on averaged activity of 100 stochastic simulations. Bold lines indicate the analytical results ignoring interactions.

SUMMARY

The explicite consideration of earthquake nucleation on a distribution of fault plane orientations shows that quiet zones which are expected when resolving stresses on only one fixed orientation cannot be anymore expected in a broad belt around the mainshock rupture. Thus our modeling indicates that regions of deactivation can be hardly detected in empirical data which is in agreement with observations. The simulated aftershock density decay can be approximately described by an exponential function of distance to the mainshock rupture plane, if the background rate is constant in space. We find that aftershock interactions do not change neither the temporal Omori-like decay nor the overall spatial patterns significantly. Thus, the analytical results can be used, in a good approximation, to estimate the integrated seismic activation occurring on the different depth layers and receiver fault orientations. For the fault distribution, constraints from geological and seismological observations should be used, if available. The resulting comprehensive earthquake activation maps consist of much more information than conventional stress maps calculated only for one receiver mechanism at a specific depth.