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Impact of earthquake rupture extensions on parameter estimations of point-process models, *Bull. Seismol. Soc. Am.*, 2008

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Here we perform additional simulations to test the impact of a physically reasonable scaling of the d-parameter with earthquake magnitude. Furthermore, we test possible correlations between the magnitude of the largest earthquake in the analyzed earthquake catalog and the estimated α-value, and finally, we test the impact of inhomogeneous background activity.

Simulations

We assume a self-similar aftershock pattern, that is, we assume that in Eq.(2), the d-parameter scales according to $d = d_0 L$, where d_0 is a constant related to the aspect ratio between the characteristic width and length of the aftershock cloud. For the magnitude-dependence of the rupture length, we use again the empirical relation of Wells and Coppersmith (1994): $L = \sqrt{10^{-3.49+0.91\,M}}$ [km]. In the following, d_0 is set to 0.01.

We analyze Monte Carlo simulations of the ETAS model with pre-set α=1. The other parameters are chosen by fitting the ETAS model to the seismicity preceding the 1992 M7.3 Landers, California, earthquake in the region -119W to -115.5W and 32.5N to 36.5N and the time interval between t_1=1/1/1984 and t_2=6/27/1992. The data set included N=1537 earthquakes with magnitude $M \geq 3$. We optimized the parameters μ, K, c, p, q, q by maximum likelihood method and obtained: μ=0.06 [1/day]; K=0.007; c=0.006 days; p=1.08; and q=1.45.

The simulations are done for a 100 km x 100 km box and a time interval of 1 year. Earthquake magnitudes are randomly chosen from a Gutenberg-Richter distribution with b=1, within M_{min} and M_{max} which are specified below. To allow a targeted simulations, a mainshock with a magnitude of M_{max} is set in each simulation to occur at time 0 in the center of the box.

Parameter estimation

For each simulation, the estimation of all model parameters is performed again by the maximum likelihood method. To study the impact of taking the spatial distribution into account, we use the following three models for inversion:

1. the "no-space" model which uses only the time-sequence of earthquake occurrences (i.e. neglect the spatial information)
2. the "d=const" model which assumes that d is constant; that means, we use in this case a slightly wrong model for the spatial kernel.
3. the "d(M)" model which uses the true kernel $d = d_0 L(M)$ with the Wells & Coppersmith scaling.

Test 1: Results for the $d(M)$-model

For the first test, we used a constant magnitude range $M_{max} - M_{min}$=3.5 to ensure similar statistics, but change the size of the mainshock. In this way, we can test the effect of the relative size of the

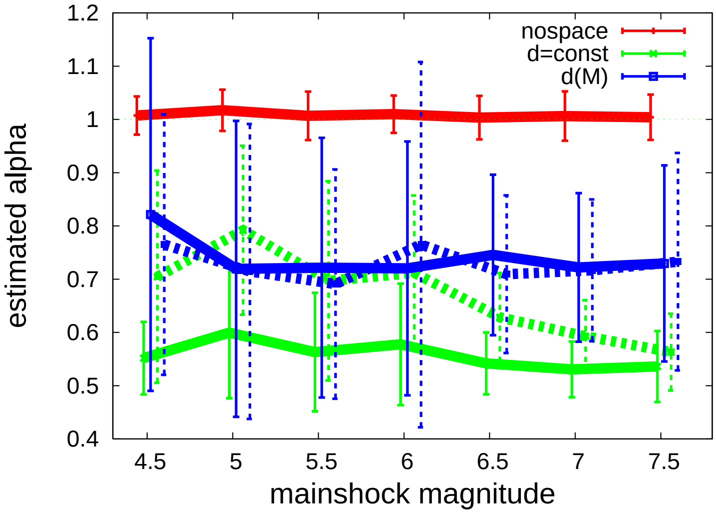

Figure 1: The α-estimations with their standard deviations for the space-dependent and space-independent models are shown with different colors (continuous lines: for earthquakes without location error; dashed lines: for earthquakes with realistic, Gaussian distributed, location errors). Here the magnitude interval is constant in all cases, in particular, the minimum magnitude is M_{max}-3.5.

mainshock with regard to total size of the region under consideration. Furthermore, it allows us to analyze the impact of epicenter location errors.

Figure 1 shows the estimated α-parameter for the three different inversion methods. It can be clearly seen that only the "no-space"-model is able to reproduce the input-value of α, whereas both models using the space-informations clearly underestimate the α-value. However, the underestimation is less pronounced for the model using the correct scaling of d.

Real earthquake catalogs will always consist of location errors. Theoretically, it can be expected that for mainshocks with a rupture length in the order of the location error, the apparent aftershock distribution will be almost isotropic in space and thus the bias of inversions using isotropic kernels should become smaller. Therefore we add realistic Gaussian distributed location errors on the true (simulated) epicenters and repeat the estimation. For a standard deviation of 1km, the results are shown in Fig. 1. The bias decreases slightly in the case of the "d=const"-model but does not vanish. For larger location errors, we find that the inversion with the space-dependent models becomes completely unstable and that the uncertainties of the α-estimations become huge. The likely reason is that the power-law kernel cannot fit the almost Gaussian distributed aftershock activity well. Finally, we add magnitude errors with standard deviation of 0.1 and repeat the parameter estimations. We find that this does not influence the results systematically.

Test 2: Dependence on M_{max}

Now we will test whether the estimation of the α-parameter depends on the magnitude range of our observation. For that, we analyze simulations where the minimum magnitude is set to M_{min}=3, whereas M_{max} is varying between 4.5 and 7. The resulting α-estimation based on the "no-space"-model is shown in Fig.2. We find that the true α-parameter can be reconstructed in all cases without any systematic error, however, the uncertainty is largely increased for smaller M_{max}. The

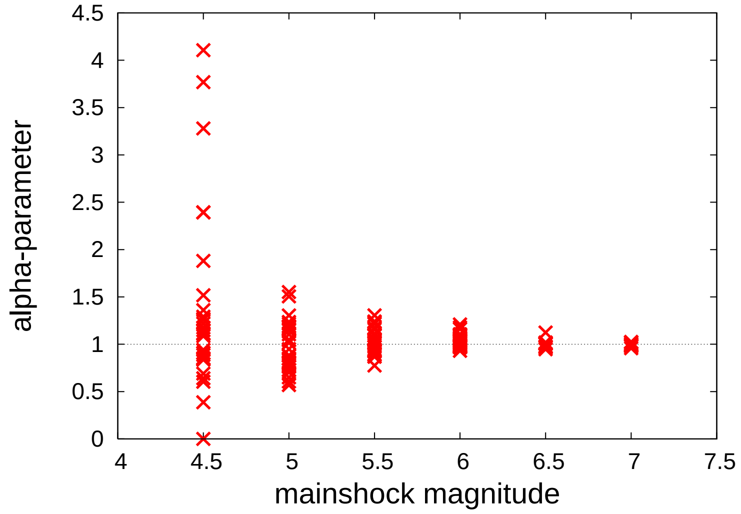

Figure 2: The figure shows the α-estimations based on the space-independent model as a function of the mainshock magnitude, where the minimum magnitude is fixed to 3.0, i.e. the magnitude interval is varying.

enlarged uncertainty is mainly related to the smaller number of events in the simulated catalogs with small M_{max}.

Test 3: Inhomogeneous background activity

Background activity is likely to be related to fault structures and thus cannot generally be expected to be uniform in space. This could be another reason for the underestimation of the α-parameter.

To test this, we modeled the probability distribution of the background seismicity by a fractal surface of dimension D (Turcotte, 1997), where we set the ratio between the absolute maximum and minimum to 1000. For the simulation, we neglected the anisotropy of aftershock clouds and used an isotropic kernel in order to analyze the possible effect of inhomogeneous background distributions separately. The "d(M)"-model is in this case the true model for the triggered activity but not for the description of the background activity. The results of the parameter inversion for the "d(M)"-model are shown in Fig.3. The estimations are scattering around the true values and the inhomogeneity seems to have no significant effect on the parameter estimation.

It is important to note that this is not an exhaustive test because of the large variety of possible model setups, in particular, alternative spatial distributions of the background seismicity. Thus our investigation is not conclusive, however, it seems to indicate that the spatial inhomogeneity of the background seismicity does not significantly influence the α-estimation.

References

Turcotte, D. L. (1997). *Fractals and Chaos in Geology and Geophysics*, Cambridge University Press, 1997.

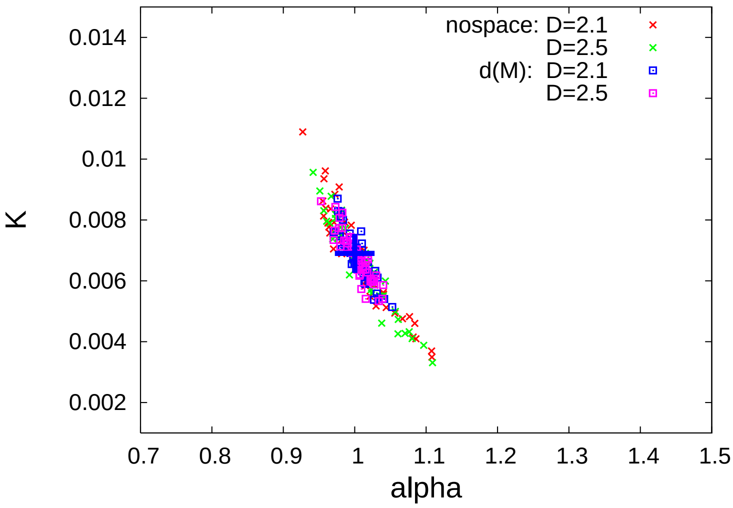

Figure 3: The estimated α and K-parameters for simulations with a fractal distribution (dimension D=2.1 and 2.5) of the background activity. The input value is shown as a big blue cross. In the simulations, an isotropic spatial kernel for aftershocks was used and the magnitude range was set to [3.5, 7.0].