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Improving 3D Velocity Models and Catalogs: Reliability of Hypocenters and 3D Vp and Vp/Vs Models

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Introduction

One source of uncertainty in seismic hazards estimates arises from seismologists having inadequate knowledge about where the earthquakes occur in relationship to the nearby geologically mapped fault and the lack of knowledge about the fault structures itself. In this study we address the following basic research questions: Do earthquakes occur on the primary mapped fault surface or in the surrounding fault zone on subsidiary faults? Is the relation dependent on the magnitude of the earthquake?

To reduce the uncertainties in estimates of seismicity parameters and to make progress in understanding the relationship between earthquakes and late Quaternary faults, we used the high-precision waveform relocated earthquake catalogs for Southern California (1981-2005) and the Community Fault Model (CFM, Ver. 2.5). We used the 3D euclidian distances from the hypocenters to the CFM fault segments for deterministic analysis to associate earthquakes with faults. We also applied and extended a probabilistic approach based on Bayesian inference approach to compute association probabilities between seismicity and mapped faults (Wesson et al., 2003).

Deterministic approach

We used the computed 3D euclidian distances from the hypocenters to the SCEC CFM fault segments (Figure 1) to obtain insight into the first order characteristics of the data set. We analyzed the occurrence of earthquakes as function of the distance from the fault, selecting the earthquakes inside swaths of increasing width around the fault segments and additionally in different magnitude bands. The cumulative distribution functions in Figure 2 illustrate that the larger earthquakes tend occur with a much larger percentage close to the faults, whereas the smaller earthquakes tend to occur further away and distributed over a large area. While for the increasing cut-off magnitude, the percentages at short distances increase, the percentages decrease when using only smaller magnitude earthquakes. For example, at the d=2km distance, 40% of all events occur inside the swath (red line, Fig. 2A and B), for $M \geq 3.5$ this percentage is at 45% and for $M \geq 5$ at 50% (Fig. 2A), while for magnitude $M \leq 1$, the percentage is at 28% (Fig. 2B). Although the CDFs in Fig. 2B might be biased by completeness issues and larger location errors for the smaller magnitude earthquakes ($M \leq 2$), we find the tendencies to be real that smaller earthquakes in southern California are distributed across the whole region. The tendency for the larger magnitude events to occur close to the faults is robust, although number of earthquakes to be analyzed decreases.

We also determined the seismicity parameters for the fault segments of the CFM. In summary, we found that b-values tend to decrease when using smaller width swaths (Figure 3), which is in agreement with Figure 2. However, this is a subtle signal and it is arguable if the small amount of events used may influence the analysis.

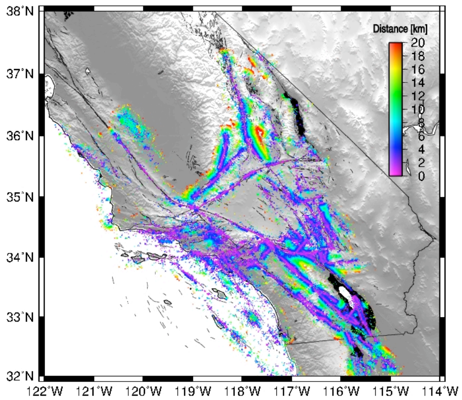

Figure 1: 3D hypocentral distances from relocated hypocenters to SCEC-CFM Ver. 2.5 fault segments.

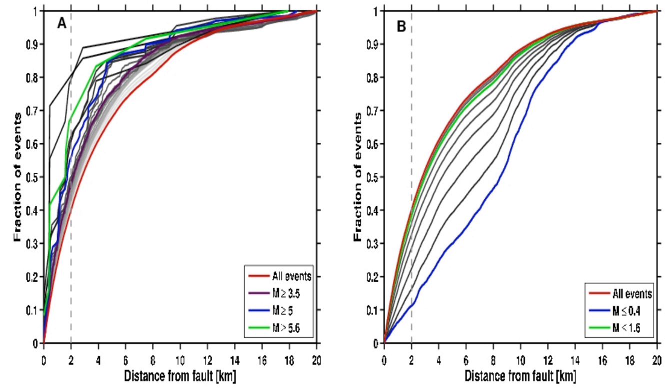

Figure 2: Fraction of events inside swaths with a fault perpendicular distance d as a function of distance (A) using only earthquakes with magnitudes larger than a cut-off magnitude M=0,0.2...,6, (B) using earthquakes only below a cut-off magnitude M=6,5.8,...,0.4.

For quality insurance, we limited the determination of the parameters to at least N=100 events, thus we are confident that the signal exists. In contrast to the WGCEP (2002), we find that the b-value for the background, i.e. using seismicity not associated with faults, ranges at a stable level of $0.9 \leq b \leq 1$ when using a lower cut-off range between $2.2 \leq Mc \leq 2.8$ for the seismicity relocated catalog in the period 1981-2005. This result suggests that the hazard from the background seismicity is currently overestimated due to the smaller b-value used by WGCEP (2002).

From the same analysis we found that smaller faults tend to have higher productivity values, or *a-values*, than larger faults (Figure 4). This argument is supported by the fact that seismicity along larger fault segments, like the Garlock and the San Andreas segments in the CFM, is less abundant than along the relatively smaller segments of the San Jacinto fault system. This could be explained by the evolutionary state of the specific fault system and we hypothesize that the maturity of the fault system governs the properties.

Bayesian Association

We applied a Bayesian inference approach to associate earthquakes with faults based on the approach by Wesson et al (2003). This method provides quantitative estimates of the probabilities that earthquakes occur on nearby faults. In addition, this technique provides: 1) determination of a probabilistic frequency-magnitude relationship for a fault segment; 2) estimation of the probability of background earthquakes; and 3) calculation of the part of the seismic moment released by earthquakes less than the characteristic magnitude.

We applied this approach with different prior information, using only the number of faults as information (equal priors) or including the information about slip-rates for faults (slip-weighted prior), with the slip-rates taken from the fault database used in the National Seismic Hazard Maps and the SCEC Fault Information System (FIS)(Figure 5a and b). We find that the equal prior approach resembles better the association of earthquakes with faults, relying on the measured distances from hypocenters to faults as the governing parameter.

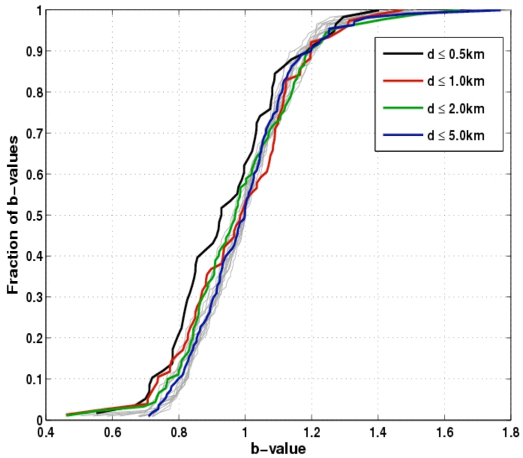

Figure 3: Cumulative distribution functions of fault scale b-values for different distance cut-offs. Highlighted are CDFs of four distances. The black line indicates the shift of the CDF when using only very close to the fault events at distances d<0.5km.

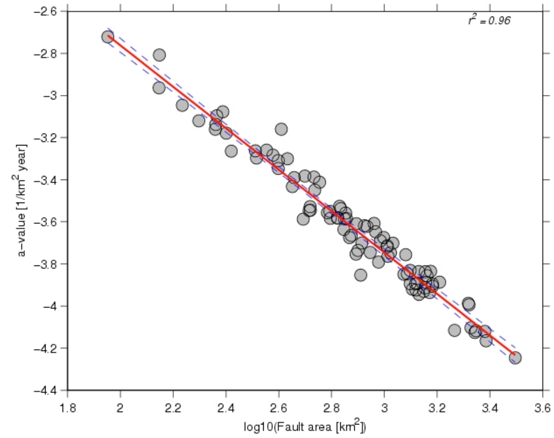

Figure 4: Double logarithmic plot of a-values as a function of fault area normalized to the square kilometer for seismicity in a swath of 2km width.

Using slip-rates as additional information for the definition of the prior introduces a more physical basis, however, the uncertainties and lack of exact knowledge about these values also introduces a large uncertainty. The introduction affects the association in the way that earthquakes along faults with abundant seismicity and large slip-rates (Banning, San Jacinto) get larger probabilities, while the ones with less seismicity have still few earthquakes associated. However, for faults with very small long-term slip rates, e.g. the faults thast ruptured in the Landers earthquake, the association probabilities are very small. Therefore, it is necessary to include additional parameters, like prevailing style of faulting or post-seismic slip-rates, as information resource for the Bayesian prior to obtain a more realistic estimate of the association probabilities.

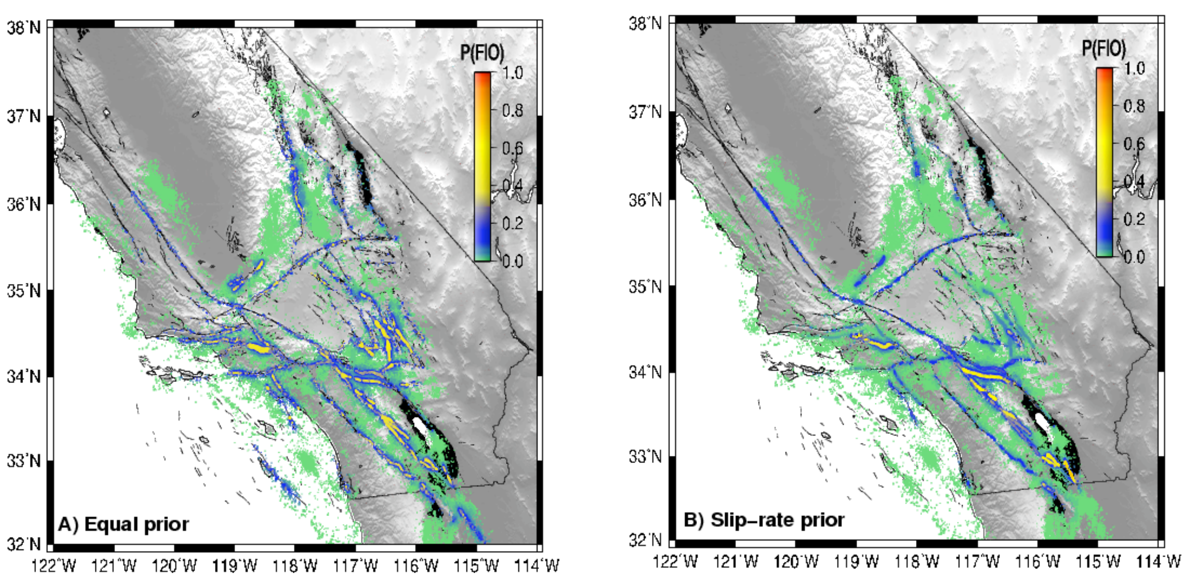

Figure 5: Probabilistic association of earthquakes with faults using Bayesian inference applying different prior probabilities: A) equal prior probabilities and B) slip-rate weighted prior probabilities.

References

Hauksson, E., J. Woessner, and P. Shearer, Associating Seismicity to Late Quaternary Faults in Southern California (abstract), Fall. Ann. Meeting, American Geophys. Un., Eos Trans. AGU, 87, (52), 2006.

Wesson R. L., H. W. H. Bakun, and D. M. Perkins, Association of earthquakes and faults in the San Francisco Bay area using Bayesian Inference, Bull. Seismol. Soc. Am., 93 (3), 1306-1332, 2003.

Working Group on California Earthquake Probabilities, Documentation for the 2002 Update of the National Seismic Hazard Maps, U. S. Geol. Surv. Open File Rep., 02-420, 2002.

J. Woessner, E. Hauksson, R. Wesson, A. Plesch, J. Shaw: Associating Southern California Seismicity with Late Quaternary Faults, Seismological Society of America, San Francisco, 2006.

Woessner J. and E. Hauksson, Associating Southern California Seismicity with Late Quaternary Faults: Implications for Seismicity Parameters, 2006 SCEC Annual Meeting, Proceed. of the Southern California Earthquake Center, 16, page 181, 2006.