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A physics-based simulator application in Southern Thessaly Fault System, Greece

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The development of fault-based long-term earthquake models is one of the key components of probabilistic hazard assessment. The main input parameter of such models is the recurrence time of strong earthquakes above a predefined magnitude threshold (e.g. $M \geq 6.0$) on specific faults or fault segments. These earthquakes, so called characteristic (Schwartz and Coppersmith, 1984), are considered to be identical for a given fault segment, that is to rupture the majority of the fault area, resulting in events with similar physical mechanism. Using the determined recurrence time of each segment on a given region, then one can develop an Earthquake Rupture Forecast (ERF), which returns the likelihood of the occurrence of a characteristic event in a specific time span. This forecast model can be considered either a memoryless Poisson or a renewal one, constraining the occurrence time of a future event with the date of the last one. That latter kind of models represent an elastic rebound motivated forecast (Field, 2015), in accordance with Reid's theory (Reid, 1911). The real situation in fault zones is much more different leading the recurrence time to a complex behavior due to the interactions among fault segments due to the permanent and temporal stress perturbations (Dieterich, 1994; Stein *et al.*, 1997), which is a potential factor that can move a fault towards or away from a future rupture.

According to this conclusion, the study of recurrence time should be treated with the application of statistical approaches, rather than deterministic ones, which require the compilation of as many as possible strong earthquakes occurred in individual fault segments from all possible records, including historical, paleoseismological and instrumental catalogs. In fact, these observational data are limited because of the large interevent times between successive strong earthquakes in a given segment and consequently the related catalogs are short and incomplete. The development of earthquake simulators, introduced and applied in California (Tullis, 2012) is one powerful tool to overcome these difficulties and limitations, and can provide information on earthquake occurrence combining approximations of the known physics concerning the stress transfer, frictional properties, fault parameters and kinematics. This concept became very popular over the years due to its ability to model and reproduce long earthquake occurrence records (starting from thousands to millions of years). Following this concept, Console *et al.* (2015) have developed a physics-based simulator algorithm based on the modeling of the rupture growth, taking into account the long-term slip rate constrains on fault segments and without using any rheological parameter. Over the years, the simulation algorithm had an evolutionary improvement. These improved versions of the algorithm were successfully applied to simulate the Italian seismicity (Console *et al.*, 2017, 2018a, b). In this study, a new version of the above mentioned simulation algorithms is applied, embodying in the physical processes the effect of the Rate and State Constitutive law proposed by Dieterich (1994), that contributes in the resembling of stress transfer and fault interaction in short time scales. The current version is applied in Southern Thessaly Fault Zone (Figure 1), which consists in the southern margin of Thessaly basin and belongs to the extensional back-arc Aegean region, that formed due to the subduction of Eastern Mediterranean oceanic lithosphere under Aegean Sea. The regional stress field is characterized by a N-S extension with relatively moderate slip rates (about 4.1 – 4.6 ± 0.5 mm/yr) as derived from GPS measurements (Muller *et al.*, 2013; among others). The stress is mainly accumulated on and released by six normal faults with an E-W to WNW-ESE strike as obtained from geodetic studies, fault plane solutions and field observations (Papadimitriou and Karakostas, 2003 and the references therein).

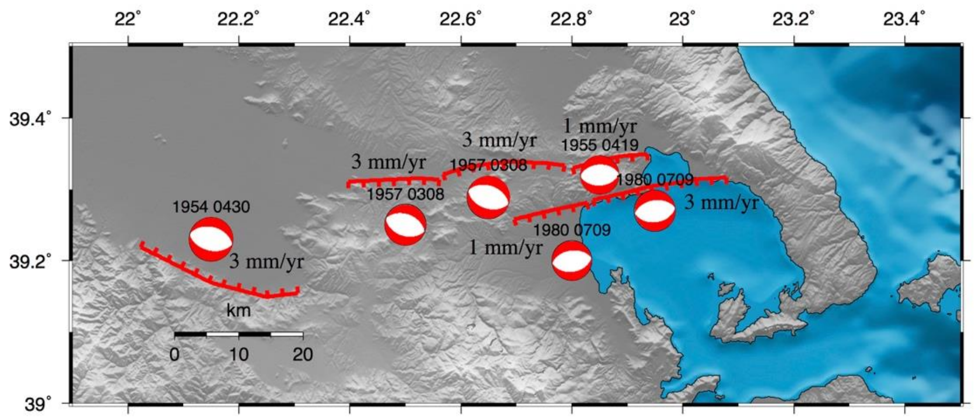

Figure 1. The six major segments of Southern Thessaly Fault System. Focal mechanisms are taken from Papadimitriou and Karakostas (2003) and plotted as lower-hemisphere equal-area projections. The occurrence date of each event is annotated on the top of focal spheres. Slip rates are taken from Muller *et al.* (2013).

Several strong earthquakes $M_w \geq 6.0$ have occurred in the past as inferred from both historical and instrumental earthquake catalogs. Historical information related with strong earthquake occurrence are available since the 16th century (Papazachos and Papazachou, 2002). As revealed from this information, a sequential pattern of active and inactive clustering periods is observed over the years. Focusing on the latest one during the 20th century, Papadimitriou and Karakostas (2003) showed that the stress transfer dominates the occurrence of strong earthquakes. This fact provokes the detailed study of both short and long term behavior of strong earthquakes by the application of the simulation algorithm.

The simulation is implemented by modeling each one of the six fault segments as rectangular source, considered as a grid of 0.75x0.75 km squared cells. The thickness of the seismogenic layer, which is equal to 3-15 km (Hatzfeld *et al.*, 1999), is constrained by the long-term slip rate. Taking into account that only the 60% of the total slip is released coseismically (Davies et al., 1997) the corresponding slip rate of each segment is calculated and given in Figure 1. Additionally, three free parameters must be specified before the simulation processes. These are the product $A\sigma$ of Rate and State law, the Strength Reduction (S-R) coefficient, which refers to the fault weakening and the Aspect Ratio (A-R), which discourages the rupture propagation over long distances. The selection of the three parameters is made by the application of the algorithm multiple times with different combinations among them and the comparison of each resulting catalog with a real one using the two sample Kolmogorov-Smirnov goodness of fit test. The duration of each simulation is 10kyr with a warm up period of 2kyr. The minimum magnitude generated by a two cell rupture is selected to be equal to 4.0. Based on these results, the best fitted synthetic catalog is built and used for the investigation of the strong earthquakes recurrence behavior and the renewal model was tested whether it performs better than the Poisson one. The interactions and possible triggering behavior between adjacent fault segments is studied and compared with the observed episodic occurrence of strong events. For modeling the recurrence times of each segment as a renewal process the Brownian Passage Time (BPT) distribution (Matthews *et al.*, 2002) is adopted against the memoryless exponential one. The comparison between the models is made in terms of their log-likelihood values.

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