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Studying aftershock sequences generated through a physics-based simulator

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The area of Central Ionian Islands, comprising Kefalonia and Lefkada Islands, consists the most active zone in the Aegean and the surrounding area, characterized by high seismic moment rate release and frequent occurrence of strong ($M \geq 6.0$) earthquakes. The last strong event (M_w6.5) occurred on 17 November 2015 at the south western part of Lefkada Island, in less than 2 years after the occurrence in 2014 of a doublet along the western part of Kefalonia Island (with M_w6.1 and M_w6.0), with the two main events being separated temporally by seven days and associated with adjacent fault segments (Karakostas *et al.*, 2015; Papadimitriou *et al.*, 2017).

The above agrees with the observation that one of the most important features of seismic activity is its tendency to clustering. It is widely recognized that the seismicity rate increases after a large earthquake for several years and at distances distinctly larger than the fault length. Since the area under study is characterized by remarkable temporal closeness of strong events, their tight clustering implies significant interaction on adjacent fault segments (Papadimitriou *et al*., 2017) and can be explained through stress transfer (Papadimitriou, 2002). Since strong events in the region have caused severe damage and numerous casualties, it is important to set up a real time evaluation of the evolution of aftershock activity.

Aiming to investigate short-term interactions and find seismicity patterns, even if the information contained in a good historical catalog cannot be substituted, physics-based simulators created with characteristics based on the Central Ionian Islands faulting properties can overcome the lack of long historical data and provide us reliable information. In order to investigate clustering features in a larger time window in comparison to the short duration of historical and instrumental records thus, the use of a newly developed earthquake simulator is proposed providing the opportunity of dealing with a catalog lasting 10kyr, i.e., of much larger duration (Console *et al.*, 2015, 2017, 2018a, b). The free parameters of the simulator are the strength reduction coefficient (S-R), which is a weakening mechanisms, the aspect ratio coefficient (A-R), which controls the rupture propagation, and $A\sigma$ related to the Rate and State Constitutive law. A synthetic catalog with time, space and magnitude behavior comparable to the observed seismicity is compiled, where substantial similarity is observed between the observed (magenta line) and the calculated annual rate (red line in Figure 1).

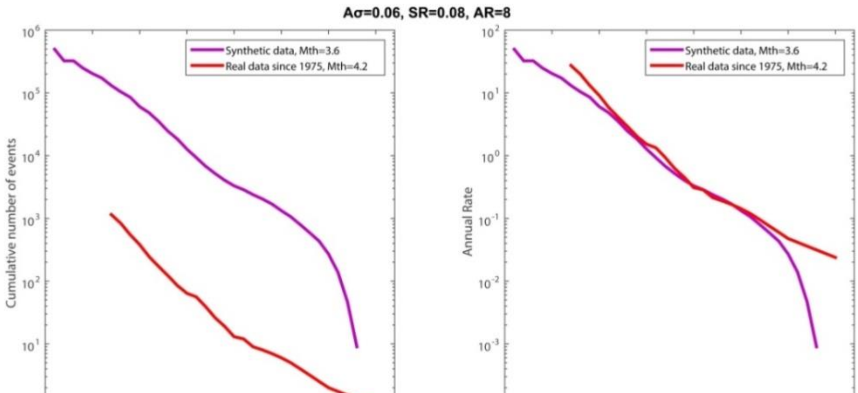

Figure 1. (left) The frequency magnitude distribution and (right) the annual rate of events using the synthetic data (magenta line) with Aσ=0.06, S-R=0.08 and A-R=8 and the real data since 1975 (red line).

A temporal feature obtained from the simulator algorithm can be explored by analyzing the statistical distribution of the time by which an event can precede or follow a strong earthquake. For that purpose a stacking technique is applied and all events with $M \geq 6.0$ included in the 10kyr catalog, are scanned for a time period of 0.5 years before and 0.5 years after the occurrence of the main shock. The total number of events with $M \geq 3.6$ preceding and following the mainshock in each bin for the whole time period considered is shown in Figure 2. A sudden raise is clearly observed soon after the occurrence of a large event, indicating the presence of a feature resembling the aftershock activity.

The clustering features and patterns of the synthetic seismicity are also investigated by means of the spatio-temporal Epidemic Type Aftershock Sequence (ETAS) branching model that has been widely and successfully applied to quantify earthquake interrelations (Console and Murru, 2001; Console *et al.*, 2003). The synthetic data are subdivided in smaller periods in order to test the performance of the model within periods of equivalent duration to the real case. Comparison is performed with the results provided by the application of the ETAS model in the Central Ionian Islands fault system, using as a learning period the period from 2008 until 2014, i.e. approximately 7 years. Although the synthetic data adequately match the real data as shown by statistical tests (Kolomogorov Smirnov test, Wilcoxon rank sum test), some discrepancy is observed between the estimated parameters when the ETAS model is applied. This could be explained by the fact that the study period in the real case is characterized by intense seismic activity with 3 strong events ($M_w \geq 6.0$) in a period of 2 years, which is not the case in the subdivided periods of 7 years in the simulated data.

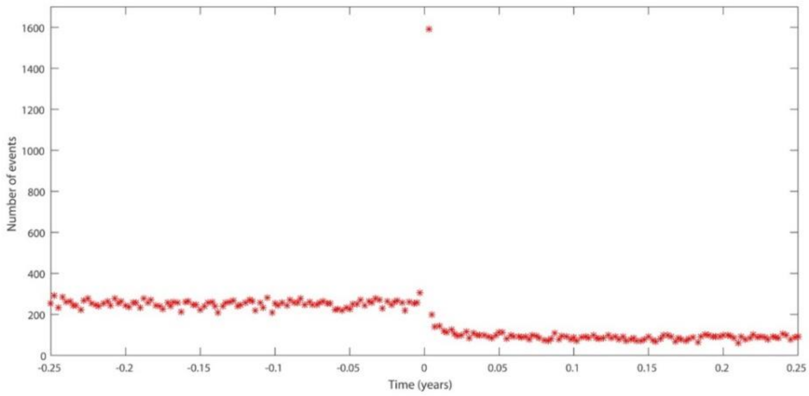

Figure 2. Stacked number of earthquakes with $M \geq 3.6$ preceding and following an M6.0 earthquake, obtained from the 10kyr simulation in a short-time scale, 0.5 years before and after the occurrence of the strong 2015 M_w6.5 Lefkada event.

Conclusions

Our preliminary results show that the spatial rather than the temporal features of the model are more stable. It is intriguing exploiting more deeply the performance of the clustering model using the synthetic catalog generated through the physics-based simulator in order to find features and patterns – both temporal and spatial – of short-term seismicity.

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