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Nonlinear Processes in Geophysics Discussions

Interactive comment on "Conditions for the occurrence of seismic sequences in a fault system" *by* Michele Dragoni and Emanuele Lorenzano

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Response to Reviewer 1

1) The reviewer suggests that we give more details on the 2012 Emilia sequence.

We agree to his request and shall include more details on the data and on their sources in Table 1 and two new figures (numbered as 4 and 5 in the revised version):

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a map showing the location of the events and a plot of their seismic moments.

2) The reviewer also suggests that we expand the discussion of the model assumptions, in particular assumptions 4, 5 and 6.

These assumptions are suggested by the features of the sequences we are describing, as recorded in seismic catalogues (e.g. Rovida et al., 2011). Assumptions 4 and 5 follow from the observation that sequences are made of distinct events, each one associated with the failure of a distinct fault in the system, and there is no reactivation of the same fault during a sequence. Assumption 6, stating that the sequence duration is short versus the intersequence time, is justified by seismic history, showing that intersequence intervals are in the order of centuries, while sequence durations are in the order of weeks or months. These comments will be added in section 2.

3) The reviewer finds that the abstract is unclear and favors technical details rather than focusing on the general conclusions of the paper.

The abstract will be rewritten and we shall stress that the key point of the model is to show that the knowledge of the order of activation of faults in a seismic sequence yields information on the state of the fault system before and after the sequence. The concept of permutation is crucial to this aim, because the evolution of the system can be expressed as a sequence of permutations and the order of activation can be described by a particular permutation of the n faults.

4) The reviewer suggests revising the text, particularly the results and conclusions, to make it clear what is new and innovative and/or interesting and significant about this research.

As stated in the Introduction, the aim of the paper is to answer some basic questions concerning seismic sequences. When we observe a sequence, we acknowledge that it is due to a system of n faults that fail one after the other. However, we do not know why the faults fail in that particular order. The order must be a consequence of the initial stress state of the fault system and of the mutual interaction between the faults of the system during the sequence. We show that the knowledge of the order of activation of faults in the sequence yields information on the state of the fault system before and after the sequence. To this aim, we introduce the concept of permutation of the n faults, ranking the faults according to the magnitudes of their Coulomb stresses. Such a permutation describes the state of the system at a given time and changes whenever a fault is activated. The order of activation itself can be described by a particular permutation of the faults. These considerations will be added in the Conclusions of the paper.

5) The reviewer notices that the paper is missing references concerning the subject of fault interaction and triggering.

Following this suggestion, we shall add references to Stein et al. (1992), Harris (1998), Stein (1999), Gomberg et al. (2000), Belardinelli et al. (2003). We shall also add a reference (Love, 1927) for the double-couple point source solution.

6) The reviewer considers that the figures are not detailed well enough, and their motivation or use is not clear: this applies, in particular, to Figure 2.

Figure 2 is a graphical illustration of the evolution of a system made of three faults (n = 3). This case is considered because it can be illustrated graphically, owing to the

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small number of variables involved. Cases with n > 3 would require higher dimensional spaces. The graphical representation allows a better understanding of the evolution of the state of the fault system during a seismic sequence. This explanation will be added at the beginning of section 7. The captions of figures 2 and 3 will be rewritten and more details will be added in the other captions.

Response to Reviewer 2

1-2) The reviewer suggests a discussion of some results obtained by other authors with regard to the 2012 Emilia sequence.

We agree with his request, though the aim of the present work is not to reproduce the details of any particular seismic sequence, but to show how the knowledge of the activation order of faults can give information on the stress state of a fault system. Convertito et al. (2013) suggest that dynamic triggering may have had a role in influencing the seismic sequence, in addition to the variation in permeability and pore-pressure effects due to a massive presence of fluids in the Po Plain basin. We neglected the effect of pore fluid diffusion, on the basis of general considerations in Appendix B, and did not consider dynamic triggering. If these effects are relevant and are introduced in the calculations, they may alter the sequence of permutations and yield a final permutation different from (64). However, they will not change the general conclusions of the paper. A mention of the possible role of pore fluids will be added in section 2, when the argument is introduced. A short discussion will be added in section 8 and will be recalled at the end of the Conclusions.

3) The reviewer mentions results obtained by Castro et al. (2013) from seismic spectra, suggesting that the events of the Emilia sequence generated relatively low stress drops.

We shall mention this paper in section 8 and show that our model yields values ranging between 0.9 and 1.9 MPa, within the range obtained in that study.

4) As suggested by the reviewer, references will be included in Table 1.

References

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