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Can earthquake simulators improve our understanding of the physics of earthquake preparation process?

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Outline

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- Magnitude-frequency distribution
- Spatiotemporal patterns
- Mapping of stress variations
- Application to seismic hazard assessment
- Discussion
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Introduction

Earthquake simulators have gained popularity to produce synthetic (simulated) catalogs of a huge number (even millions) of events. In this way, statistical analyses of simulated catalogs are by far more robust than those achievable by real ones.

Nevertheless, criticism has been expressed against the effective utility of simulated catalogs. For instance, some seismologists have remarked that the algorithms employed in earthquake simulators are based on oversimplified physical models, and intrinsically contain arbitrary assumptions that constitute serious obstacles for a reliable representation of the real seismicity.

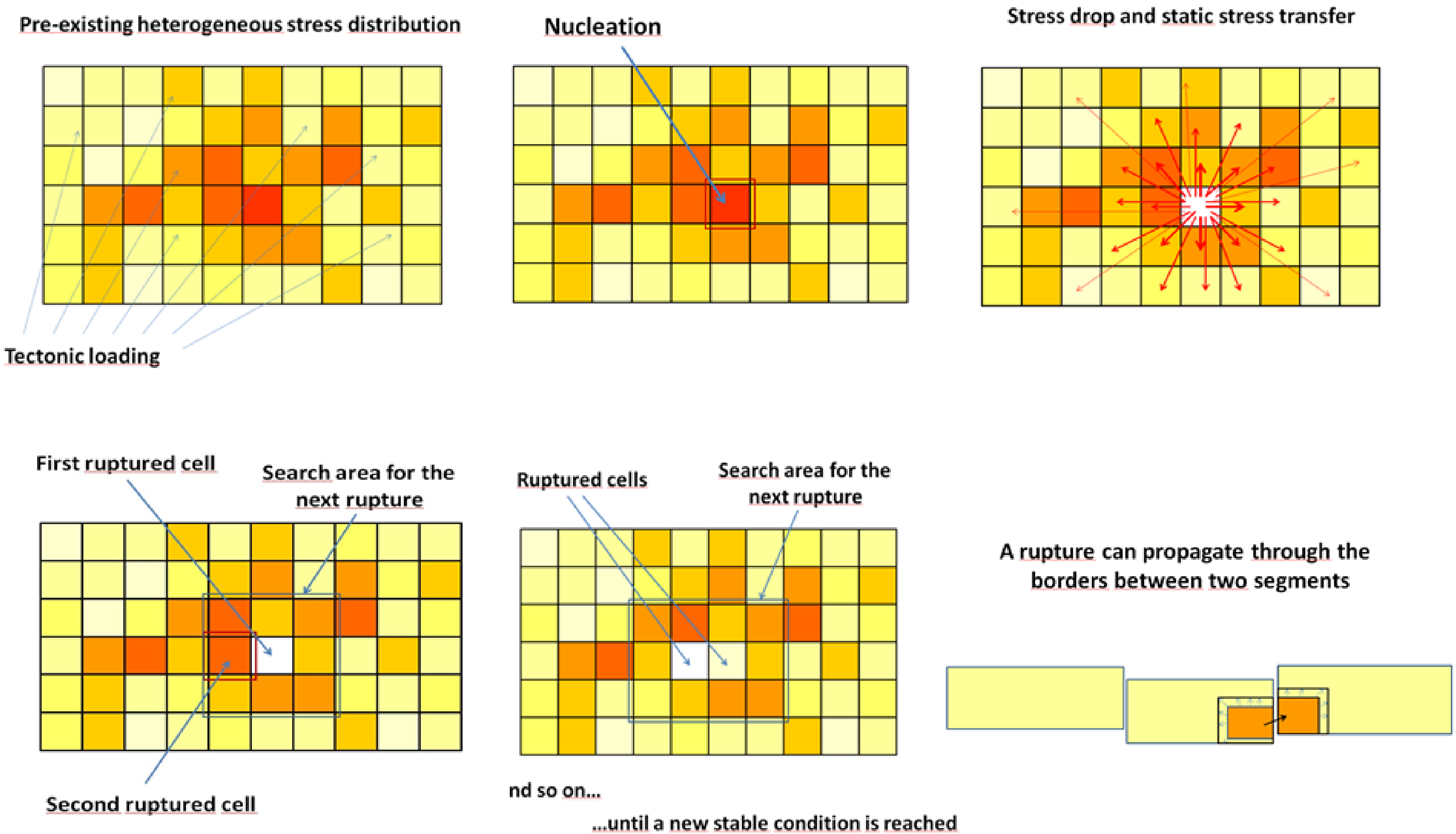
Despite some criticism, it is commonly retained that simulation models can be useful in developing hypotheses to explain earthquake observations, such as well-known spatiotemporal patterns and statistical relationships. The following question arises:

Does an EQ simulator work well?

This question is still debated. Here we try to get some insights based on the experience collected with the application of our earthquake simulators to seismic areas in Italy, Greece, California and Japan, and the comparisons between the respective simulated and real catalogues.

We present an overview of possible advantages and drawbacks in the application of earthquake simulators for the comprehension of earthquake preparation process and pertinent applications to

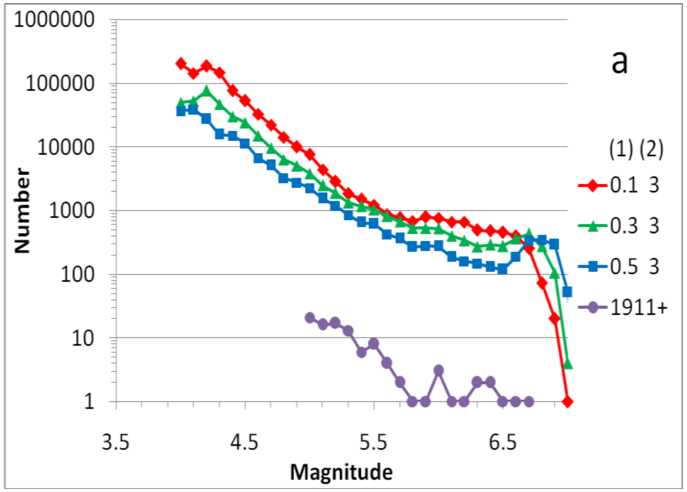
Earthquake Process Simulation

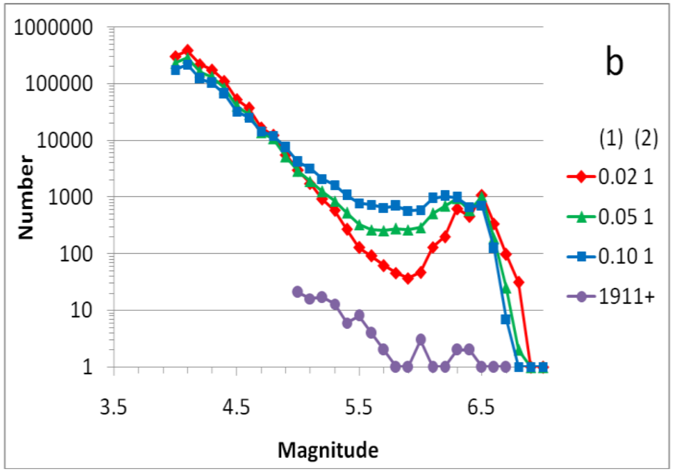


A mix of phyisics-based ingredients and empirical rules are applied to set up the basic features of the nucleation, expansion and stopping of ruptures in the simulation algorithm. The statistical properties of the output catalogue are conditioned by selecting appropriate values of free parameters in the model.

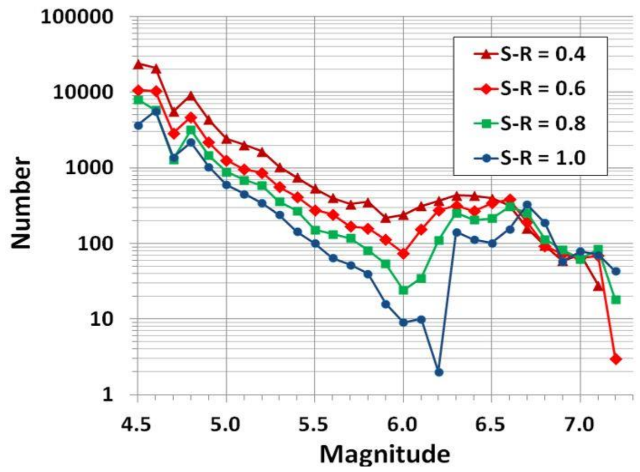
Magnitude-frequency distribution

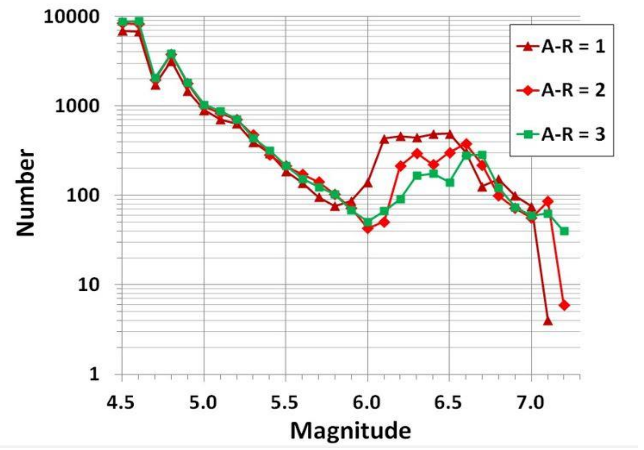
Corinth Gulf
JGR 2015





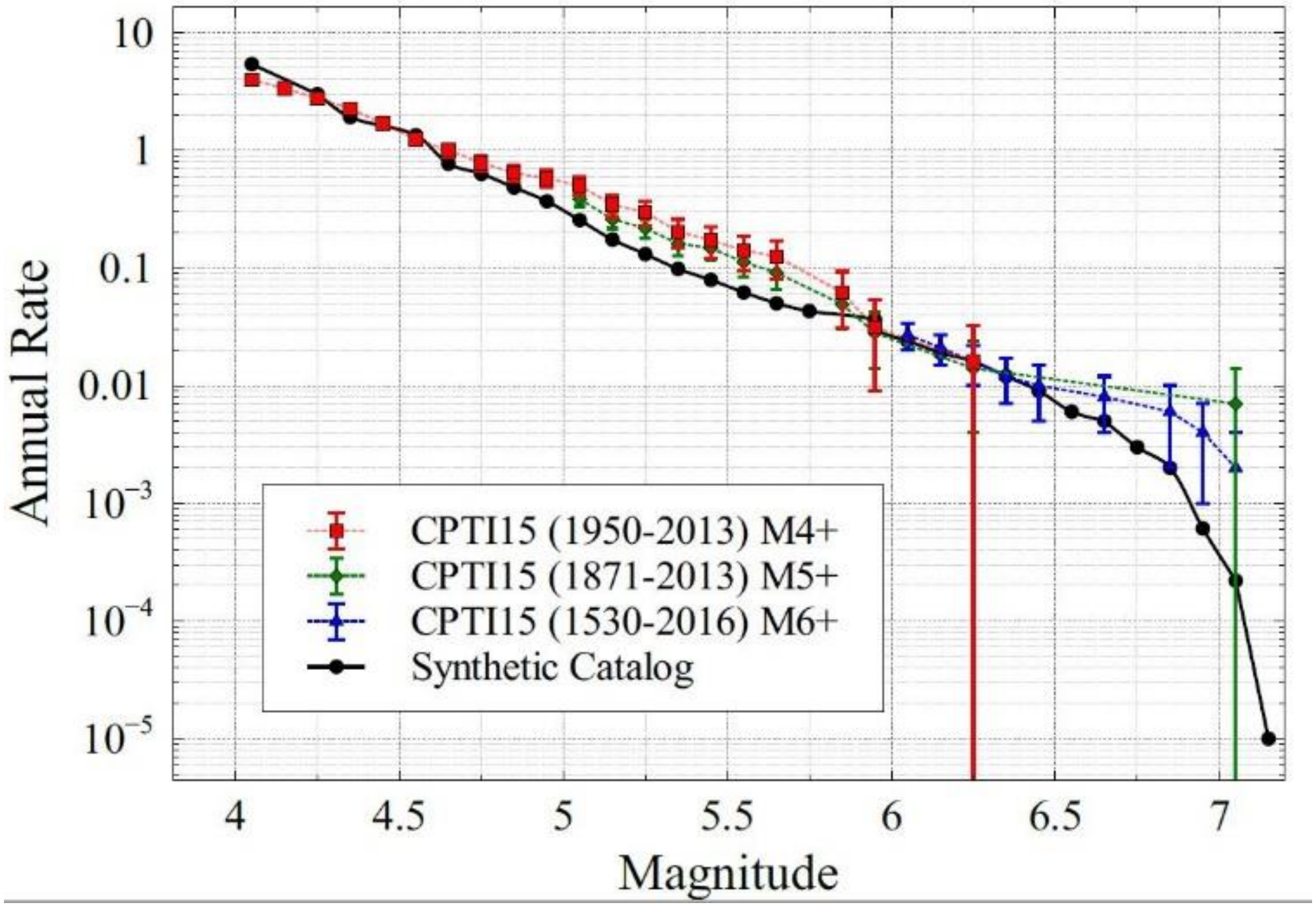
Calabria
AG 2017





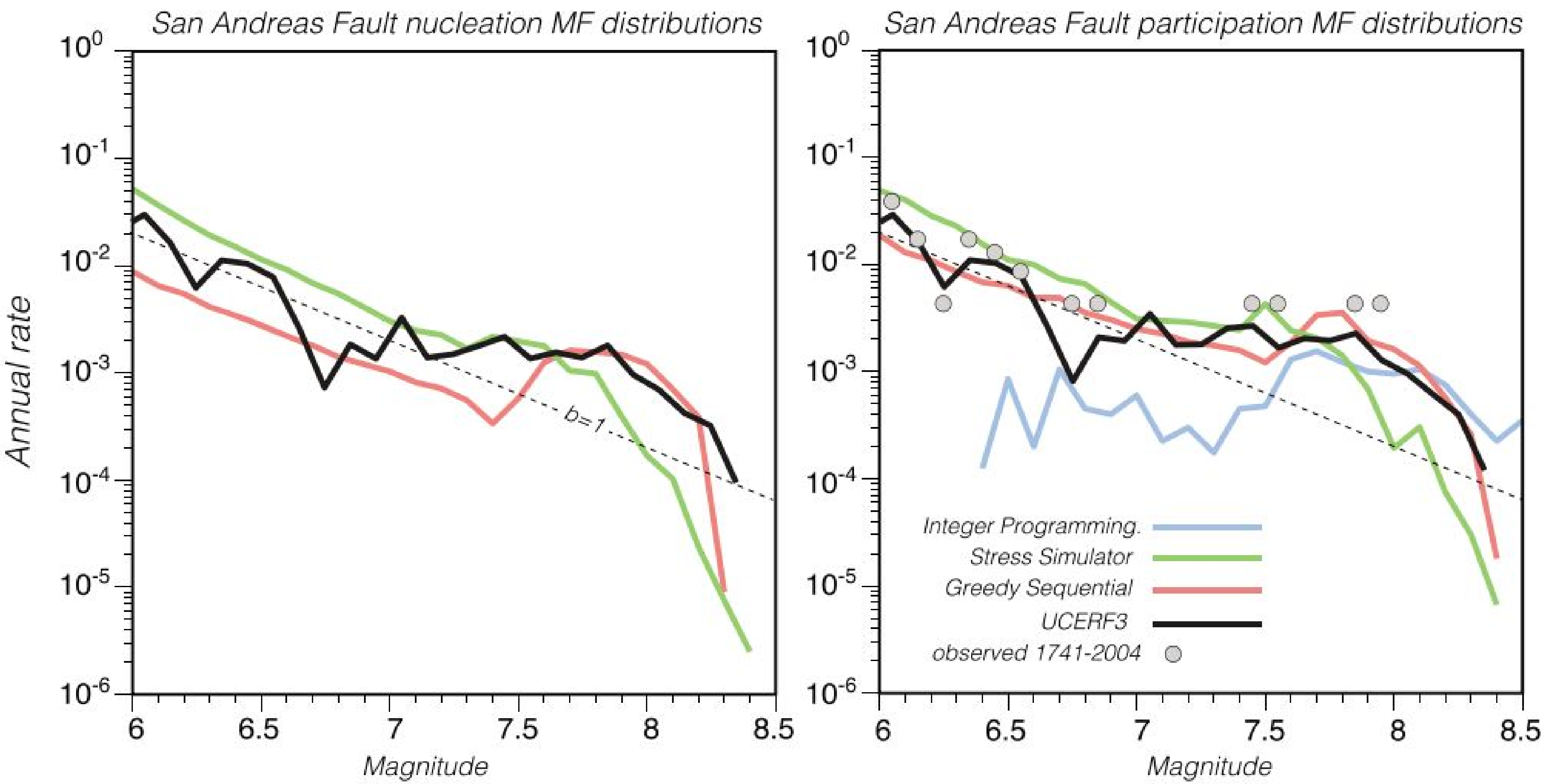
Magnitude-frequency distribution of the earthquakes in the synthetic catalogs obtained from the simulation algorithm with different combinations of free parameters

Simulated *vs* observed MF distribution - I



Cumulative magnitude-frequency distribution of the earthquakes in the 100,000 yrs simulated catalog compared with observations in the central Apennines GJI 2018

Simulated *vs* observed MF distribution - II

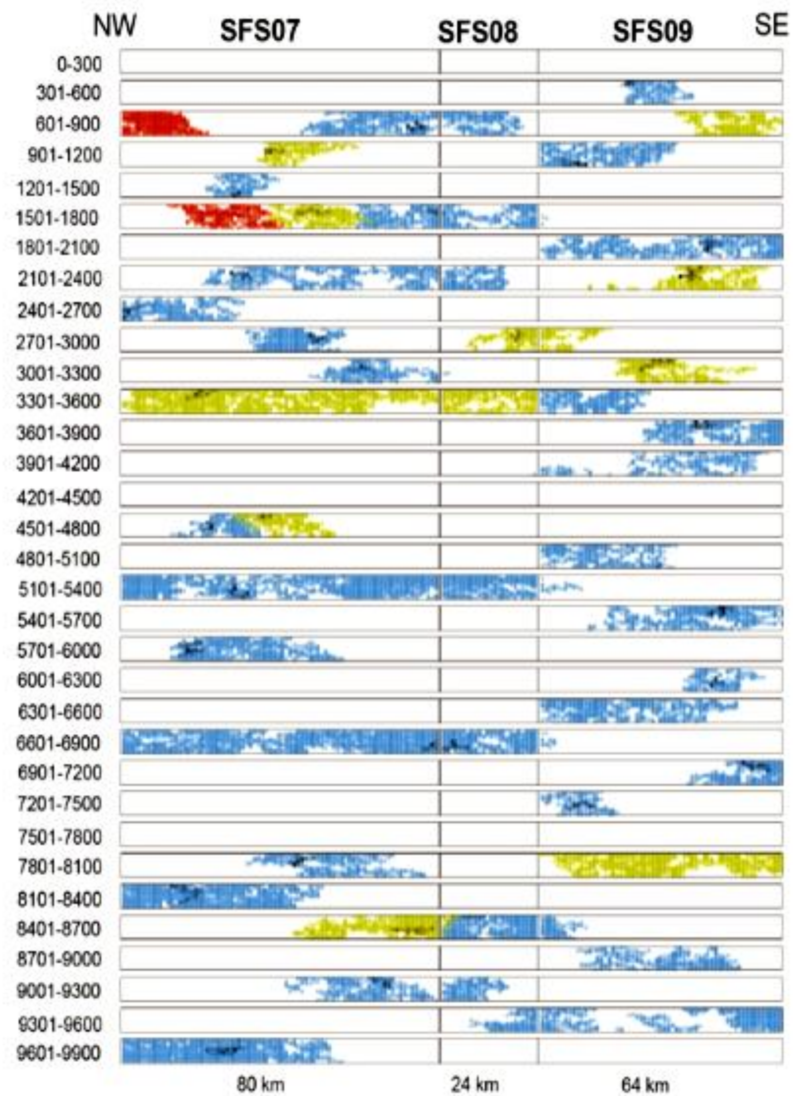


Four calculated incremental magnitude frequency distribution solutions averaged from multiple runs by UCERF3 (black curve), as well as integer programming (optimal results; blue curve), stress simulator (green curve), and greedy sequential methods (red curve). Observed earthquakes located within ±5 km of the San Andreas surface trace are shown by gray dots. A Gutenberg-Richter line extrapolated from the observed M = 5.5 rate is plotted (dashed line). JGR 2018

Seismic gap hypothesis verified!

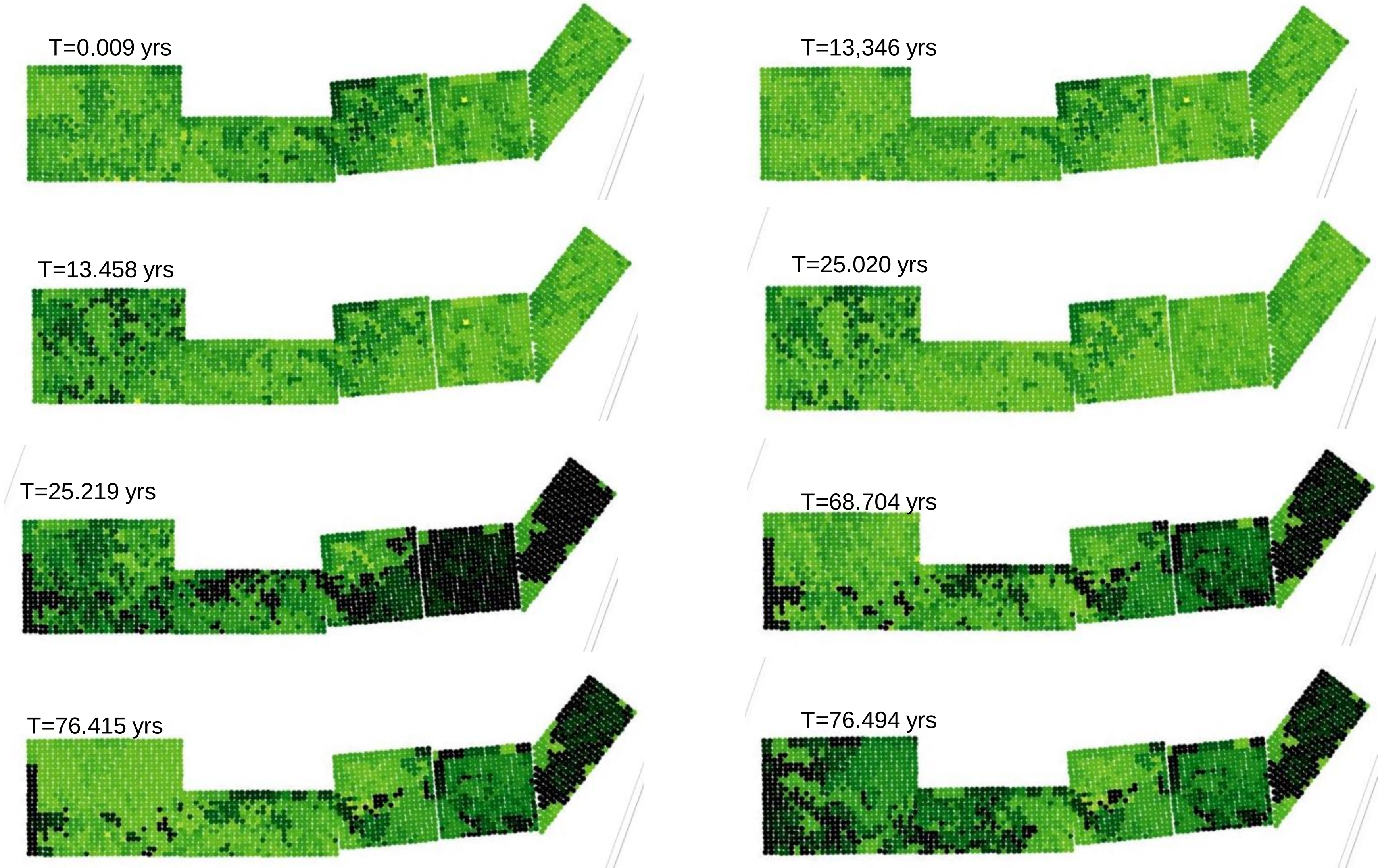
Map of ruptures for M ≥ 6.0 earthquakes on the joint set of three fault segments (central Apennines, Italy) in 33 time windows of 300 years.

The 170 km-long fault system is displayed in each panel from left to right moving from NW to SE. On any panel, the blue, yellow and red colors represent the temporal order of earthquake occurrence, and the darker tone of the respective colors represent the amount of slip on multiply ruptured cells.



GJI 2018

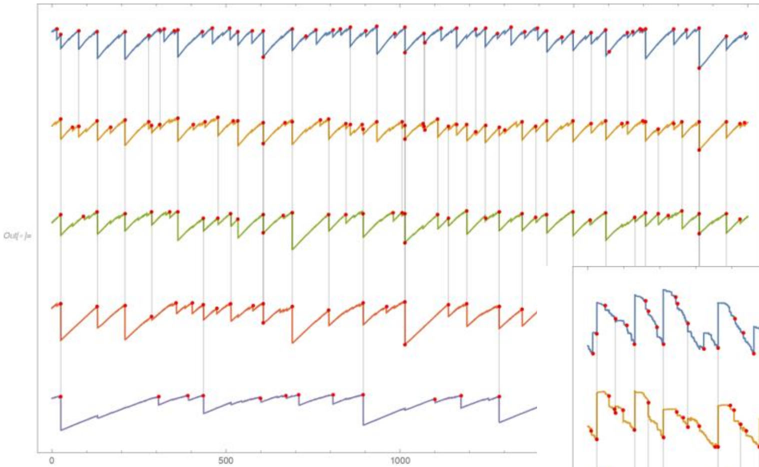
Stress variations on a Japan seismogenic structure



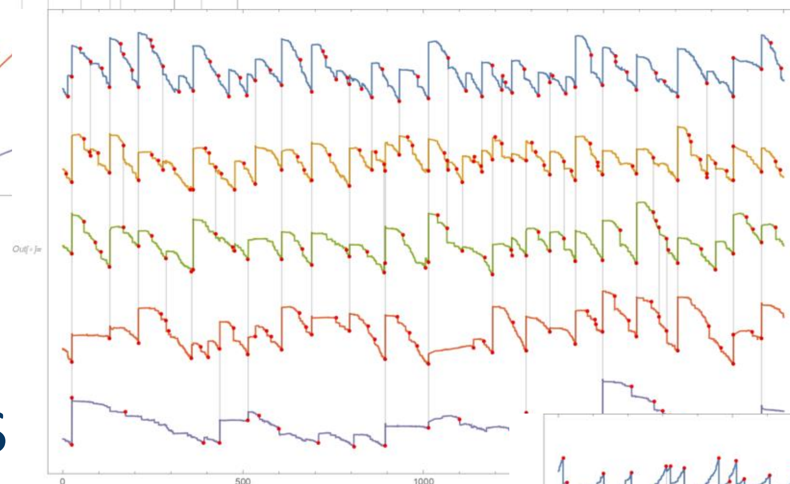
Simulated time history of stress on the Nankai Trough in 77 yrs ISTE 2021

Stress variations on 5 fault segments of the Nankai Trough seismogenic zone

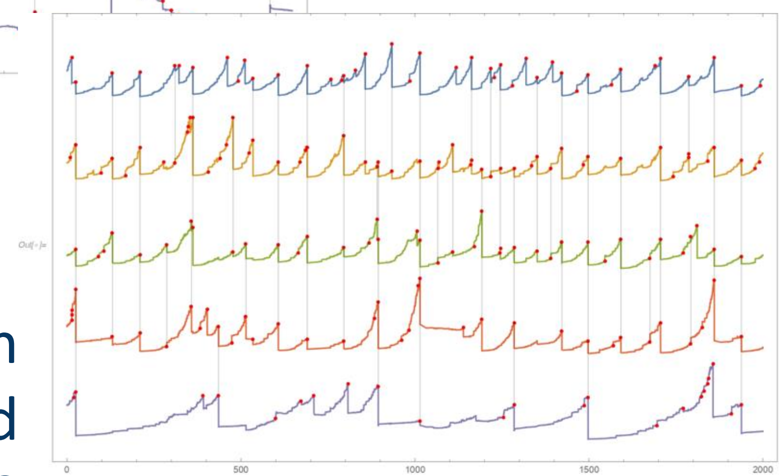
Average stress



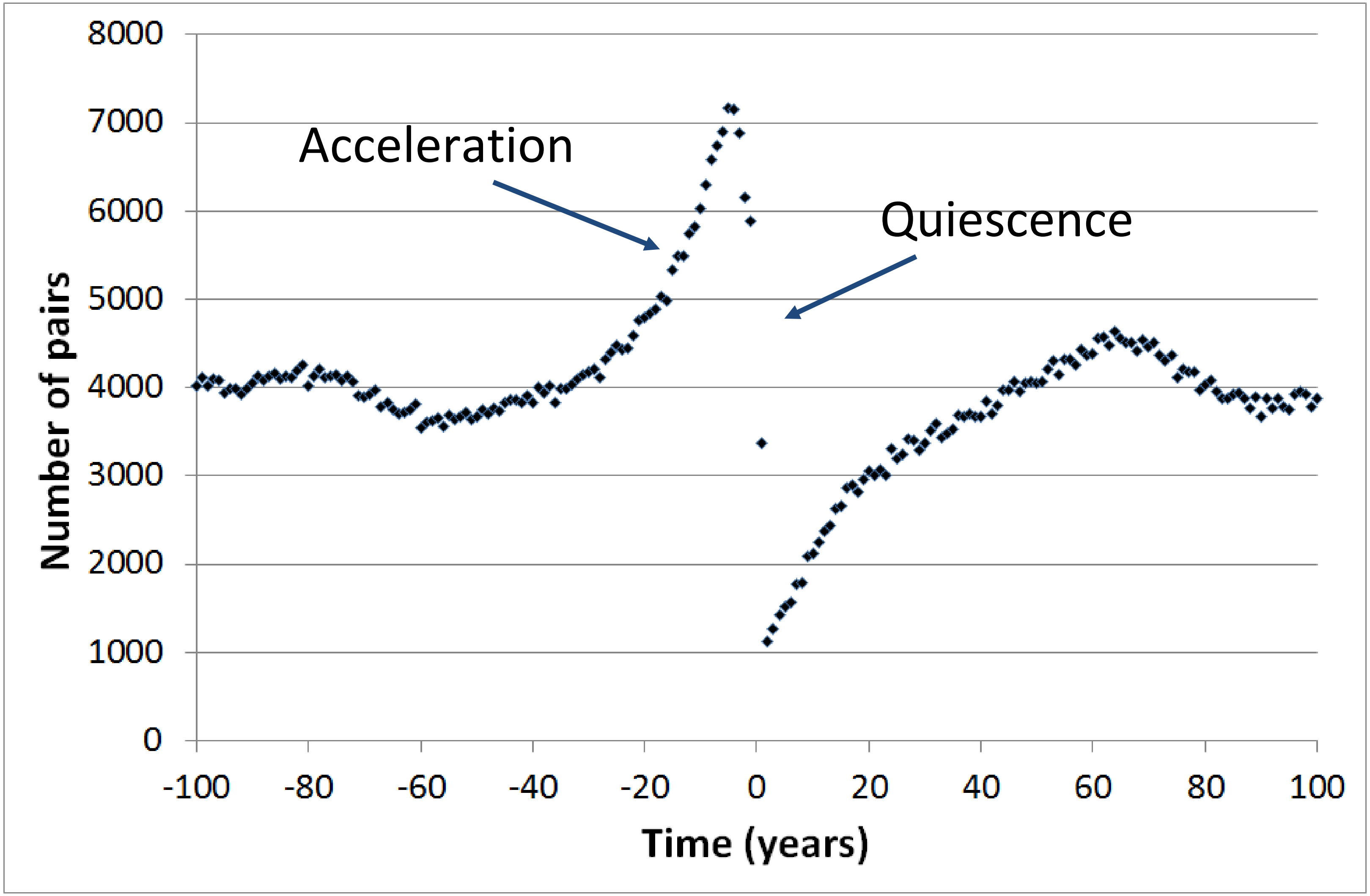
Stress RMS



Ratio between average stress and stress RMS



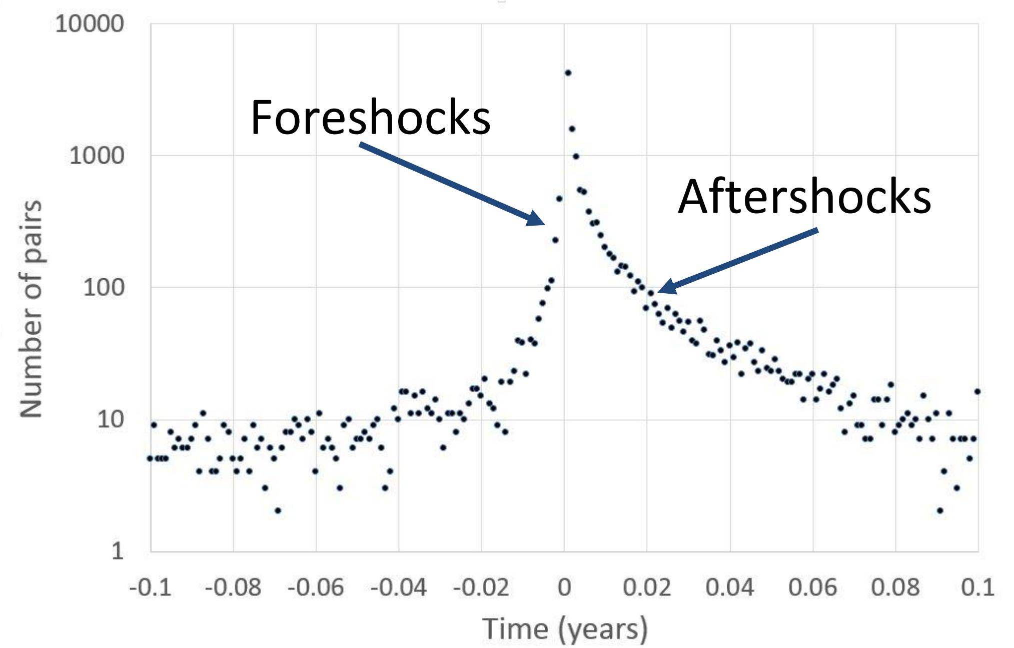
Long-term performance



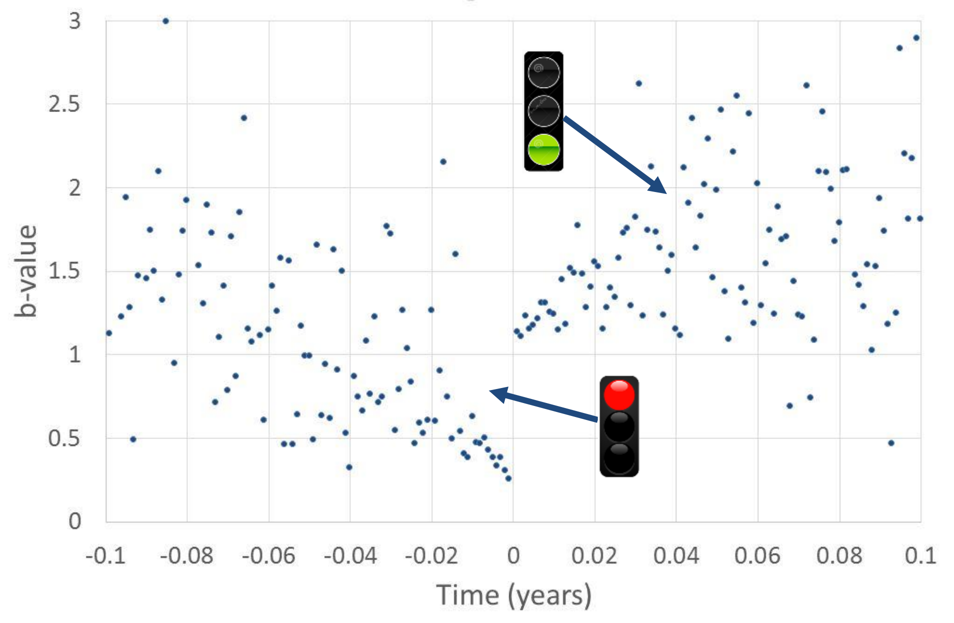
Stacked number of M ≥ 4.2 events in the 50 yrs period in bins of 1 yr before and after an M ≥ 6.0 mainshock and within a radius of 20 km, in the 100,000 yrs simulated catalog of the Corinth Gulf fault system. BSSA 2021

Short-term performance

A clear foreshock and aftershock pattern of the duration of some weeks before and after an M ≥ 6.0 event is visible in the stacking plot.

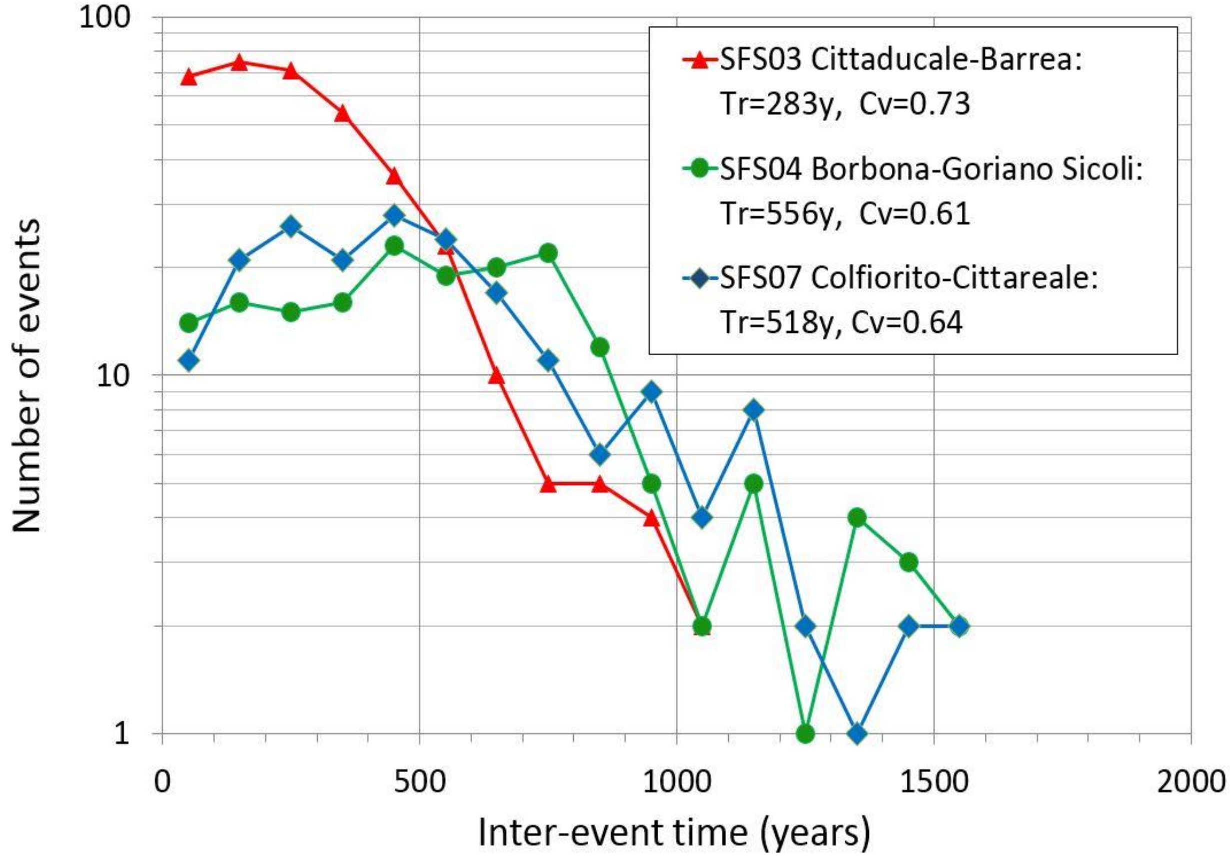


With the same time scale, this plot shows a clear trend of b-value decreasing before a mainshock of M ≥ 6.0, and recovering to the average value just after it.



Inter-event time distribution

for three faults in Central Apennines

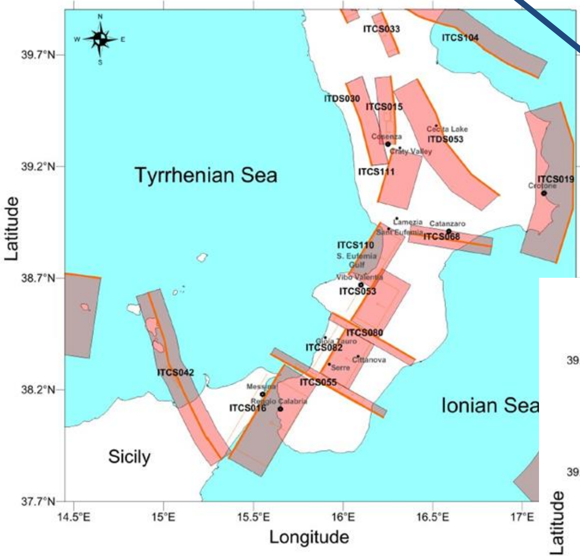


The time-dependent 50 years occurrence probability of a $M \geq 6.0$ earthquake on the *Colfiorito-Cittareale* fault system, under a renewal BPT model, could be estimated before the Amatrice, 24 August 2016 earthquake as 13%, against a probability of 9% obtained under a time-independent Poisson model. GJI 2018

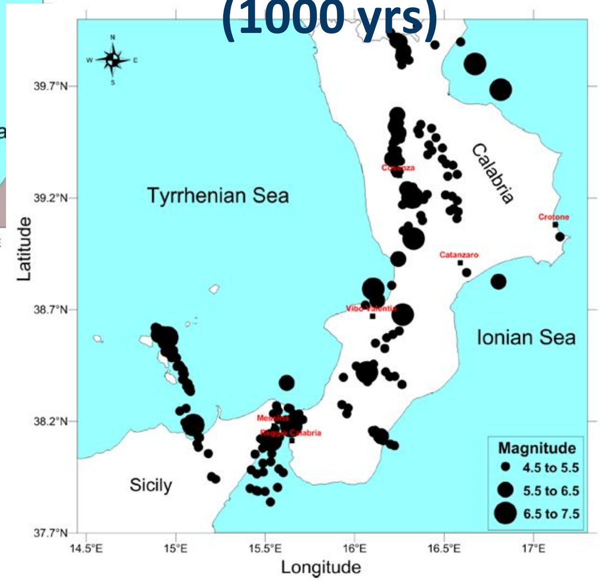
Application to earthquake hazard assessment in Calabria

Acta Geophysica 2017

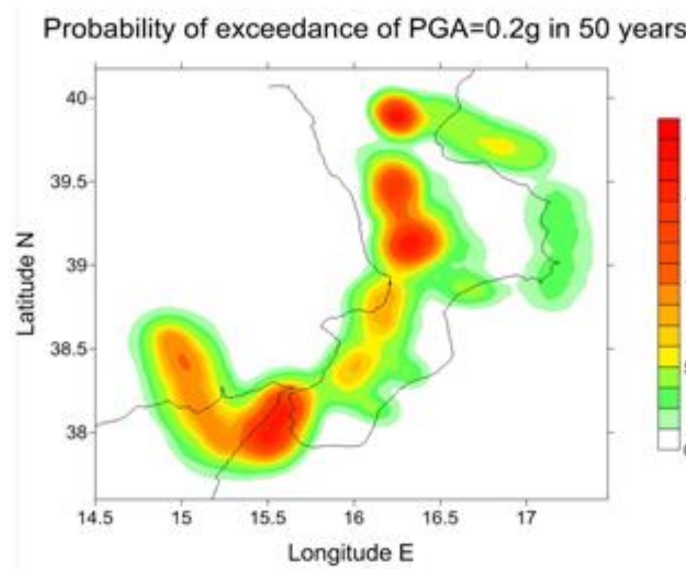
Fault model



Synthetic catalogue (1000 yrs)



PGA estimate



The simulation over 100,000 years allows robust statistics up to large magnitude (characteristic) earthquakes

Discussion - I

Our study is based on the application of an earthquake simulation algorithm based on relatively simple hypotheses, which can differ from actual earthquake processes *(e.g.* the assumption of uniform slip rate on a fault segment).

As it is true of any earthquake simulation algorithm, our model relies on some hard to test assumptions.

Nevertheless, models can be useful in developing and testing hypotheses to explain earthquake observations, such as well-known statistical relationships.

Discussion - II

The best fit of the free parameters of our model is based on the comparison of the magnitude-frequency distribution between the synthetic and real catalogs. This procedure can be regarded as a somewhat arbitrary process.

Testing the models against real seismicity through the comparison of the simulated and observed MF relation appears a problematic task due to the very long inter-event time of large-magnitude events with respect to the duration of reliable observations.

Possible improvements

- Improve source modeling both in geometry and variability of slip-rate

- Consider aseismic slip and its effect of stress transfer on neighboring faults

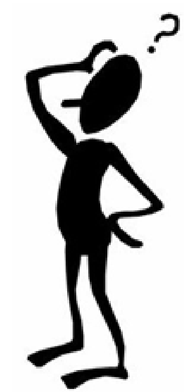
- Include off-fault seismicity

CONCLUSIONS

The reliability of the earthquake simulator results depends on:

- The validity of the physical model adopted in the simulator algorithm (epistemic uncertainty);
- An appropriate choice of the free parameters adopted in the application of the algorithm to the specific seismogenic area;
- The validity of the seismogenic model adopted in the input to the simulator (fault geometry, tectonic stressing rate, seismic coupling, etc.).

Two ways of predicting the future



Thank you for your attention!