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A physics-based earthquake simulator and its application to seismic hazard assessment in Calabria (Southern Italy) region

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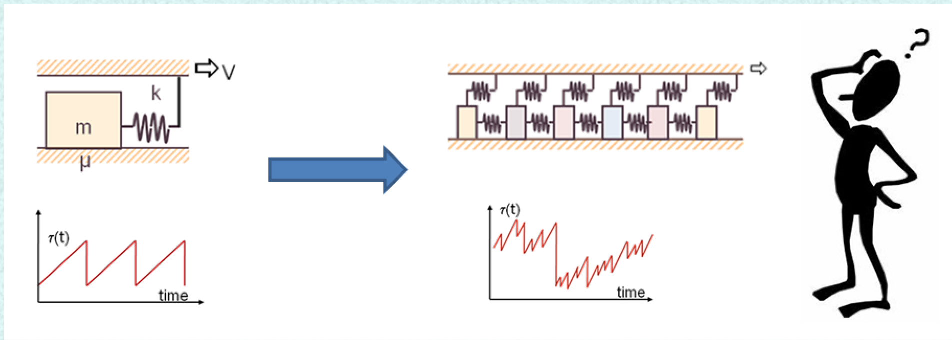
Introduction

The characteristic earthquake hypothesis, based on the elastic rebound theory, justifies a time and size predictable model for earthquake occurrence. However, the complex situation of real fault systems may lead to a more chaotic and (almost) unpredictable behaviour, often referred to as self organized criticality.



The characteristic earthquake hypothesis is not strongly supported by observational data because of the relatively short duration of historical and even paleoseismological records. For instance, in the Calabria (Southern Italy) region, historical information exists for at least two thousand years, but it can be considered complete for M > 6.0 only in the latest few centuries. As a consequence, characteristic earthquakes are seldom reported for individual fault segments, and hazard assessment is not reliably estimated by means of only minor seismicity reported in the historical catalogs.

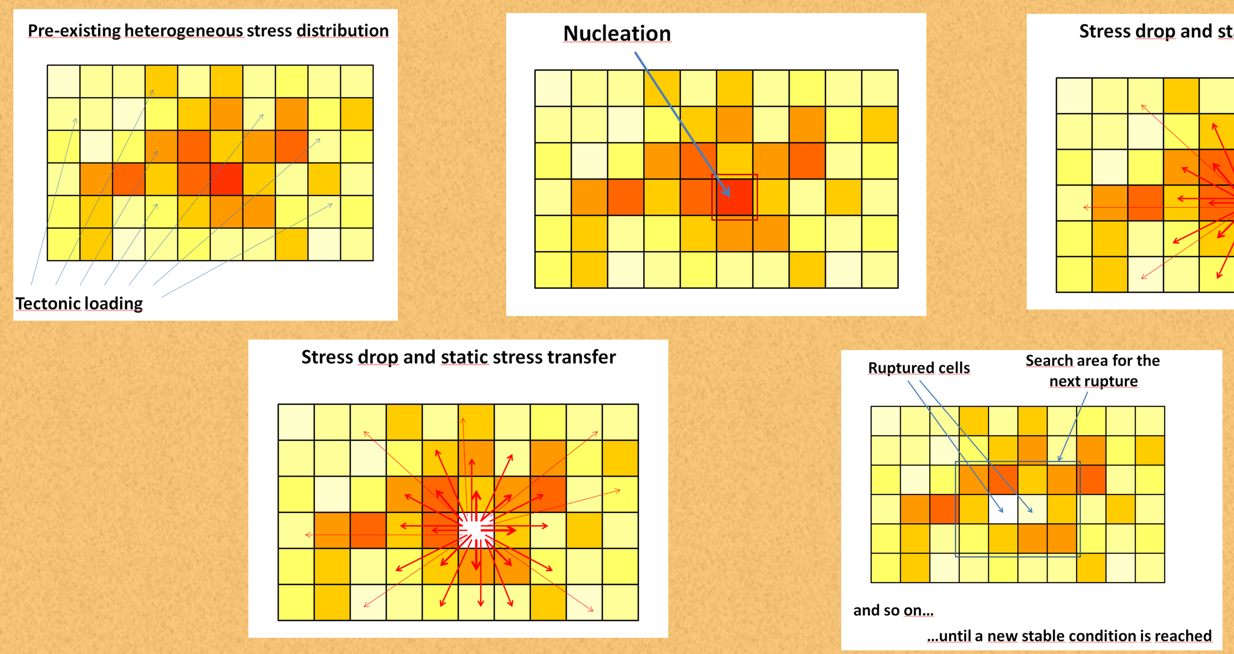
Even if they cannot substitute the information contained in a good historical catalog, physics-based earthquake simulators have become popular in the recent literature, and their application has been justified by a number of reasons. In particular, earthquake simulators can provide interesting information on which renewal models can better describe the recurrence statistics, and how this is affected by features as local fault geometry and kinematics.

A short outline of the algorithm adopted in our earthquake simulator

The seismogenic system is modeled by rectangular fault segments, each of which is composed by many rectangular cells of the same size.

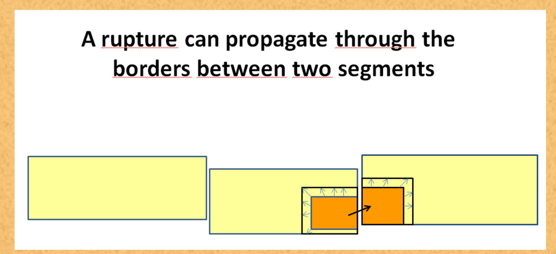
Each cell is initially given a stress chosen from a random distribution.

The stress on each cell is increased in time by the tectonic loading computed from a given slip rate, the value of which is uniform on each segment.



Empirical rules for nucleating and stopping a rupture:

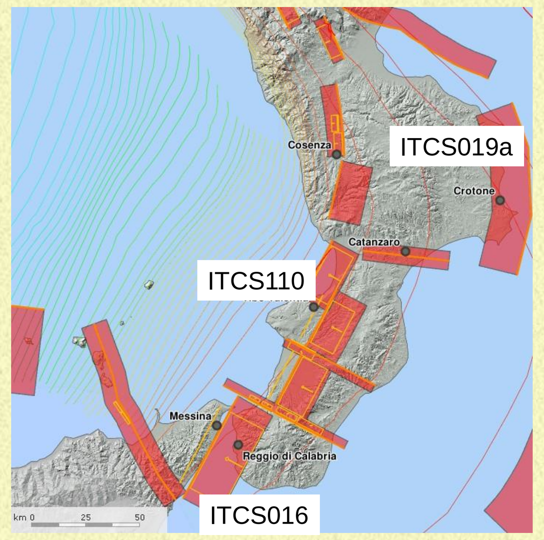
- a cell can nucleate a rupture if the stress reaches a value that exceeds its strength;
- after nucleation, the effective strength on the cells in the search area is reduced by a value proportional to the square root of the search area, encouraging the expansion of the rupture;
- the strength reduction is limited if the search area exceeds a given number of times the width of the rupturing segment, discouraging a further expansion of the rupture;
- a rupture stops when for no cells of the search area the stress exceeds the effective strength;
- a cell can rupture more than once in the same event.



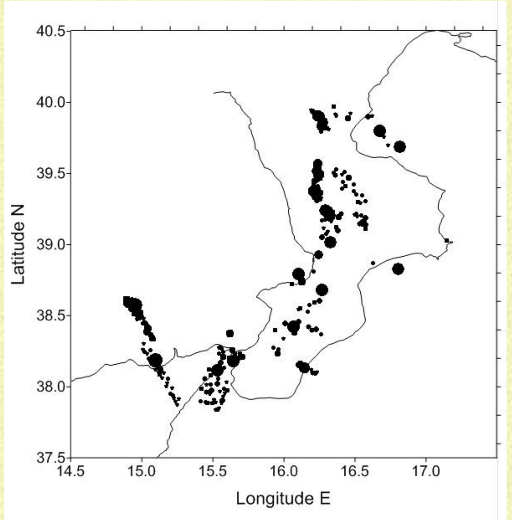
Application to the seismicity of the Calabria region

The fault model was obtained from the DISS 3.2.0 catalogue maintained by INGV with two different kinds of discretization (1 km x 1 km and 0.25 km x 0.25 km respectively).

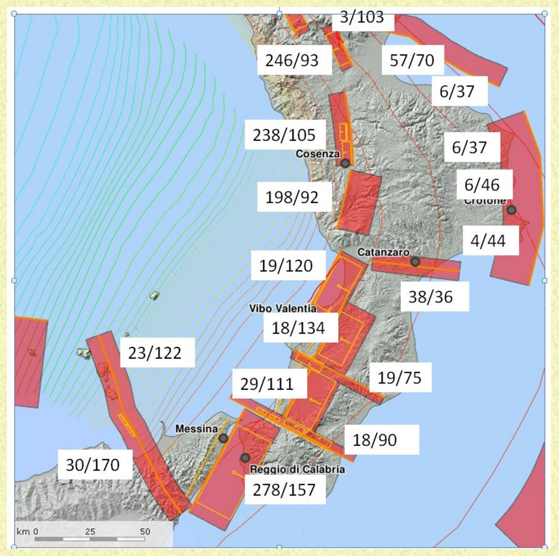
The use of the physics-based earthquake simulator has allowed the production of catalogs lasting 100,000 years and containing more than 100,000 events of magnitudes $\geq$ 4.5 by the (1 km x 1 km) discretization.



Seismic sources recognized by DISS 3.2.0 in the Calabria region.



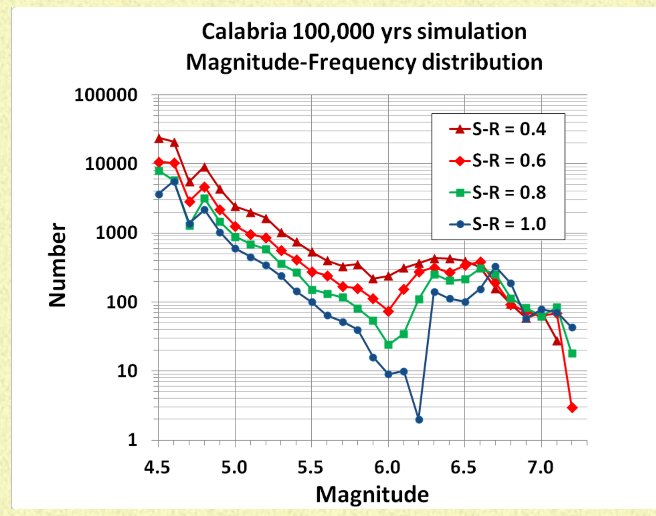
Epicentral map of the seismicity obtained by the earthquake simulator for the first 1000 years.

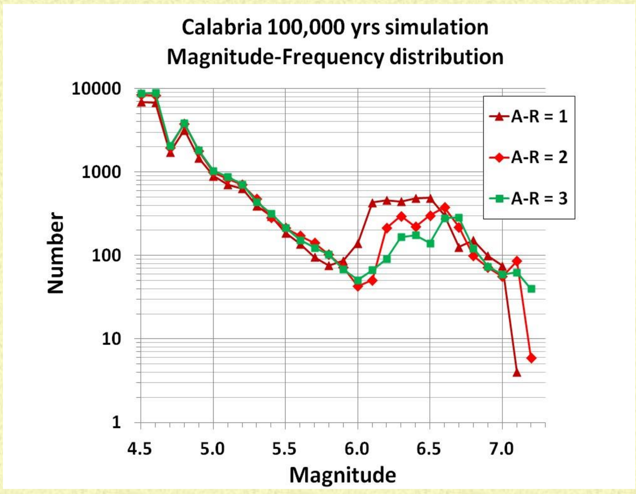


Number of M ≥ 6.0 events with unsegmented/segmented ruptures.

Main features of the catalogue obtained by the earthquake simulator for three seismogenic sources in Calabria

DISS code	Source name	Number of events M ≥ 4.5	Number of events M ≥ 6.0	Maximum magnitude
ITCS016	Aspromonte-Peloritani	5327	438	7.17
ITCS110	Sant'Eufemia	711	129	6.92
ITCS019a	Crotone-Rossano North	461	43	6.98





Frequency–magnitude distribution of the earthquakes in the synthetic catalogs obtained from the simulation algorithm with different combinations of two free parameters. Labels S-R and A-R refer to the values of parameters "strength reduction coefficient" and "fault aspect ratio", respectively. The combination adopted in this study is 0.7 (S-R) and 2.0 (A-R). The total seismic moment released by the events in all the synthetic catalogs is the same for all combinations.

This F-M distributions are different from the rectilinear trend hypothesized by the G-R law. This can be ascribed mainly to two facts:

- the magnitude can't exceed values depending on the thickness of the seismogenic layer through the A-R parameter;
- a lack of events exists for a magnitude range between those of the background seismicity and those close to the maximum magnitude of the sources (characteristic earthquake of M 6.4-6.7).

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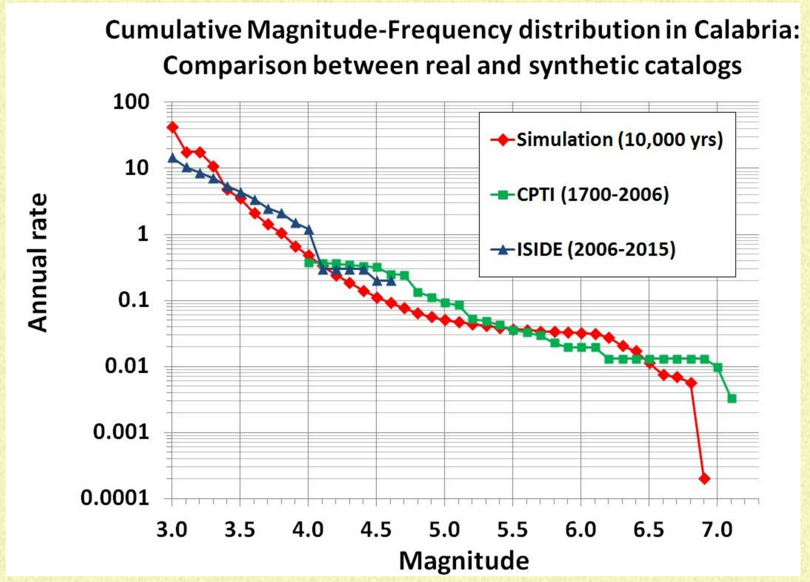
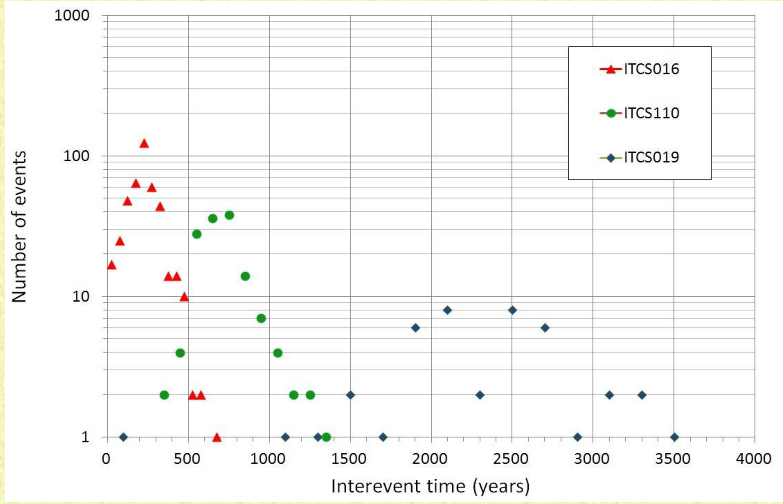


Inter-event time distribution of M ≥ 6.0 earthquakes for three seismogenic sources in Calabria: ITCS016, Aspromonte-Peloritani; ITCS110, Sant'Eufemia; ITCS019, Crotone-Rossano North.

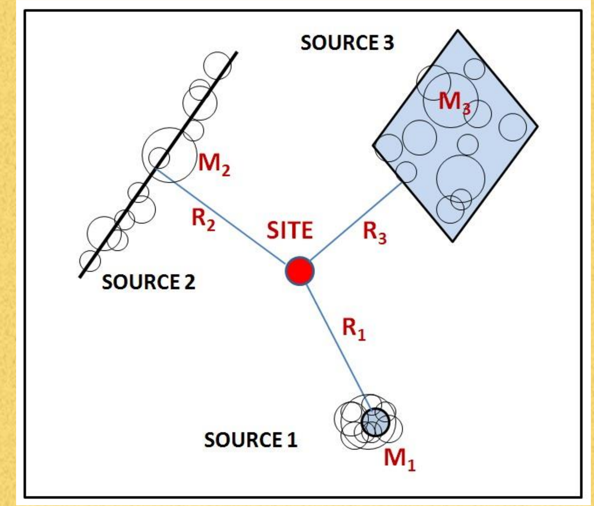


Parameters obtained from the analysis of the inter-event time distribution for three seismogenic sources in Calabria

DISS code	Source name	T_r(M ≥6.0) (years)	P_{100} (%)	σ (years)	C_v
ITCS016	Aspromonte-Peloritani	230.4	43.5	102.6	0.45
ITCS110	Sant'Eufemia	720.6	13.9	165.0	0.23
ITCS019a	Crotone-Rossano North	2312.6	4.3	616.6	0.27

The simulated catalogue applied to seismic hazard assessment

We adopted the Cornell method applied to the M ≥ 4.5, 100,000 years simulated catalogue.

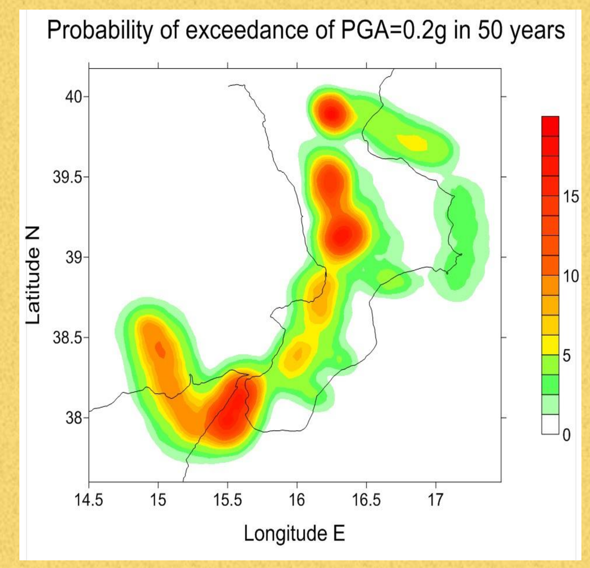


The PGA at a dense grid of points covering the territory of the Calabria region was estimated for each earthquake of the catalogue through a typical attenuation law (Sabetta-Pugliese, 1987):

$$\log(PGA) = -1.562 + 0.306M - \log\left(\sqrt{d^2 + 5.8^2}\right) + 0.169S_1 + 0.169S_2 \pm 0.173$$

where M is the earthquake magnitude, *d* is the epicentral distance, and S_1 and S_2 are parameters taking into account the soil dynamic features at the site.

At each node of the grid we obtained the distribution of the number of times that a given PGA was exceeded in 100,000 years, and from that, the probability of exceedance of the given PGA in 50 years. The results are shown in the map to the right, as an example of how the method can work.



Here at the bottom: two methods for earthquake forecasting.