STOCHASTIC AND FULL-WAVEFIELD FINITE-FAULT GROUND-MOTION SIMULATIONS OF THE M7.1, MESSINA 1908 EARTHQUAKE (Southern Italy)

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Introduction

On December 28th 1908, Europe's largest earthquake shook southern Italy causing almost total destruction of the city of Messina.

This earthquake marks the beginning of seismic hazard studies that initiated modern strong-motion prediction in Italy. Today, the central challenge of engineering seismology is the prediction of entire strong-motion time series in future earthquakes based on detailed studies of seismogenic sources.

Here we use the Messina 1908 earthquake to establish a methodology to map ground-motion in Italy from the Italian Seismogenic Sources Database, DISS (http://www.ingv.it/DISS/, (Basili et al. 2008)), combining low and high frequency (LF and HF) motion to generate broadband waveforms (Mai and Beroza, 2003). The hybrid broadband seismograms comprise the reflect the short-scale variability of the earthquake rupture process as well as the scattering properties of heterogeneous Earth crust.

In our approach LF-waveforms are deterministic (computed with the software COMPSYN, Spudich and Xu, 2003) while HF-waveforms are stochastic (computed with the software EXSIM, Motazedian and Atkinson, 2005).

Database of Seismogenic Individual Sources

The Database of Individual Seismogenic Sources (DISS) is a repository of geologic, tectonic, and active-fault data for the Italian territory (DISS Working Group, 2007; left panel). "Individual Seismogenic Sources" (ISS) are characterized by a full set of geometric (strike, dip, length, width, and depth), kinematic (rake), and seismological parameters (single event displacement, magnitude, slip rate, recurrence time). They have a minimum moment magnitude of 5.5. This threshold was adopted for the DISS because the expected size of a fault generating an Mw 5.5 earthquake is close to the limit of the resolving power for geological–geophysical methods and can be considered a minimum to produce significant structural damage. The initial fault model used in this work (right panel) was based on an updated ISS of the Messina 1908 earthquake from Valensise et al. (2008).

Finite fault rupture modeling

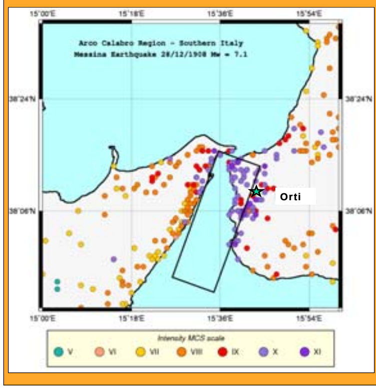
We use a fault model, in this work, based on an updated ISS of the Messina 1908 earthquake from Valensise et al. (2008).

The kinematic earthquake rupture considers variable slip over the rupture plane as well as constant rise time and rupture velocity. The slip is modeled as a spatial random field with magnitude dependent correlation lengths and a Van Karman correlation function (Mai and Beroza, 2002).

The bottom of the fault is assumed to be at 15 km due to computational limitations of the HF wavefield. The hypocenter locations are derived according to empirical findings on their distance to the high-slip asperities (Mai et al., 2005).

Rupture parameters							Correlation Function		
L (km)	W (km)	D_{mean} (cm)	D_{Max} (cm)	M_0 (N m)	τ_r (s)	v_r	a_x km	a_v km	H
40	15	253.12	805.17	5.0e+019	1.5	0.8	13	5	0.6

Source parameters.
We use a left-lateral strike-slip faulting mechanism and select 4 slip maps (ME1, ME2, ME3, ME4, Fig. 1) after 30 different stochastic realizations (Mai an Beroza, 2002) on fixed fault dimensions and correlation functions.
L=Length; W=Width; D_{mean}, D_{max} = slip; M_o = seismic moment; τ_r = rise time; v_r = rupture velocity ratio; a_x,a_y,H are correlation lengths and Hurst exponent of the von Karman correlation function.



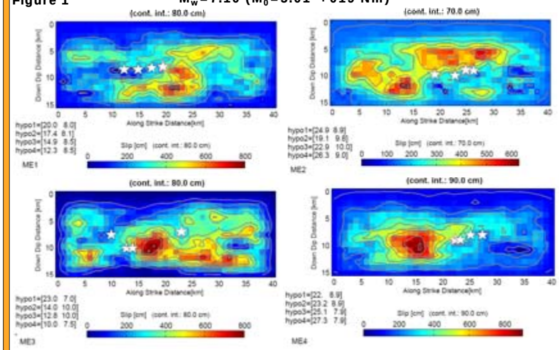
The map displays colour-coded observed MCS Intensities (DBMI04, Stucchi et al., 2007). We examine single-site statistics at Point A, in Orti superiore (X-XI MCS).

Since no seismic recordings are available, we use observed Intensities (MCS, Mercalli-Cancani-Sieberg scale) as a constraints for shake maps. GPS data are not considered here.

We derive IMM as a function of PGA (Wald et al., 1999). Although only qualitative comparison between IMM and MCS Intensity can be drawn we remark that the equivalence is roughly MCS=IMM +1.

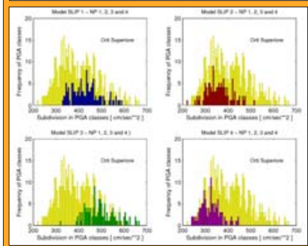
Single-site statistic analysis

Figure 1 M_w=7.10 (M_0=5.01°+019 Nm)



We compute HF waveforms at site Orti Superiore to investigate the epistemic uncertainty caused only by different slip distributions (ME1 to 4). The simulation consider 16 rupture models (4 hypocenters and 4 slip models) resulting in 480 stochastic time series.

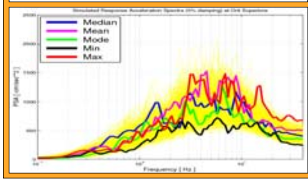
Frequency-PGA distributions are shown in the bottom left for the 480 time series (yellow), ME1 (blue), ME2 (red), ME3 (green) and ME4 (magenta).

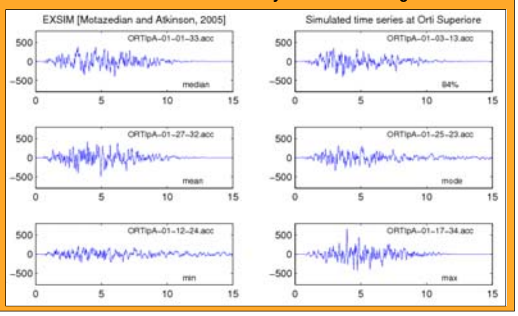


Example accelerograms for a few specific cases (table to the left) are plotted below. PGA ranges between 223 and 666 cm/s²

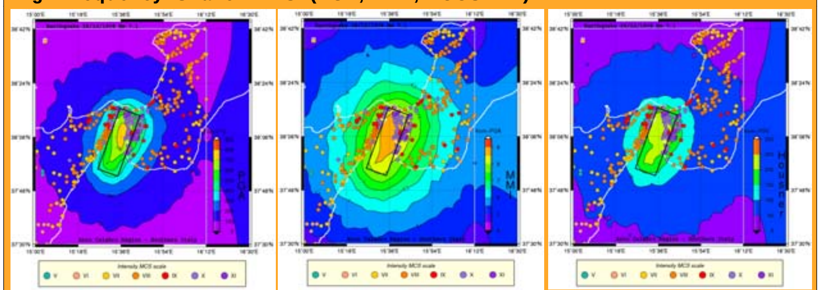
	value	File name
median	394.996	ORTIpA-01-01-33.acc
84%	404.416	ORTIpA-01-03-13.acc
mean	**495.931**	**ORTIpA-01-27-32.acc**
mode	337.572	ORTIpA-01-25-23.acc
min	223.824	ORTIpA-01-12-24.acc
max	666.500	ORTIpA-01-17-34.acc

We use the "mean" HF-time series (marked in bold font, PGA=496cm/s²) for our following broadband synthetic seismograms.



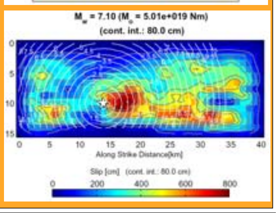


High Frequency Shake MAPS (PGA, MMI, HOUSNER)

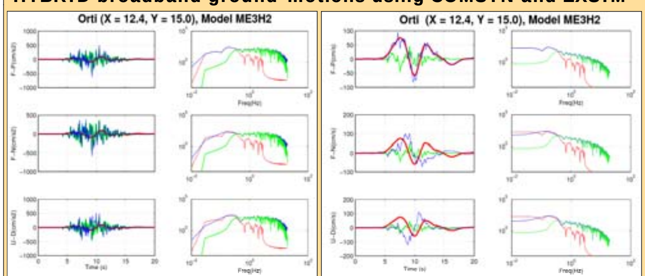


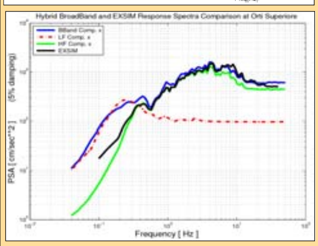
Here we display Shake maps for the rupture model shown to the left: ME3H2, Hypo: X=14.0, Z=10.0 km; contour lines show the rupture propagation, assuming constant rupture speed v_r = 2.7 km/s; the rise time is fixed to 1.5 s.

The Shake Maps (PGA, MMI and Housner) can be qualitatively compared with the overlapped observed intensities (MCS scale) of the Messina 1908 earthquake. For example, the derived MMI shake maps, as a function of PGA (Wald et al., 1999), can be compared with the observed intensities considering that there is a roughly equivalence between the MMI and MCS intensity scale: MCS=IMM +1.



HYBRID broadband ground-motions using COMSYN and EXSIM





Deterministic LF waveforms are combined with HF stochastic synthetic seismograms. Amplitude spectra are reconciled at intermediate frequencies, where their domain of validity overlaps (Mai and Beroza, 2003). We display a test case for a single site, using rupture model ME3. The matching frequency is chosen to be 0.4 Hz.
The top panels display acceleration (left) and velocity (right) waveforms. The left panel displays the corresponding spectral accelerations.

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Conclusions & Outloook

- **We compute HF time-series using EXSIM, at single site (Orti Superiore), to investigate the epistemic uncertainty caused only by different slip distributions (ME1 to 4);**
- **We successfully combine EXSIM HF-synthetics with deterministic LF-time series. Both HF and LF time series, and hence the entire BB-waveforms, represent earthquake rupture complexity;**
- **We apply our method to simulations of the 1908 M 7.1 Messina earthquake, and find good agreement with observed intensities;**
- **We will apply our methodology to additional scenarios for the 1908 Messina earthquake to further study ground-motion variability in the near-field of large earthquakes;**
- **In the future, we plan to run our method in a semi-automated fashion on additional source of the DISS database.**