Large effects of Moho reflections (SmS) in the Po Plain and implications for ground-motion prediction in northern Italy

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Ground motions of the 23 December, 2008 Parma Apennines earthquake

The distribution of PGA data vs the epicentral distance for the Parma Apennines earthquake of 23 December 2008 (ML 5.1, Mw 5.4) has very large dispersion, especially at distances between 100 and 200 km (Fig. 1).

An automatic procedure for seismic zonation finds spatial correlation of the residuals and clearly distinguishes two trends of attenuation: along the Apennines (green points in Fig. 2) and in the northern sector of the Po Plain and along the Alps (red points in Fig. 2).

The latter behavior is significantly different from what predicted by the available ground-motion models, including those adopted for the ShakeMap implementation at INGV (Michelini et al., 2008)

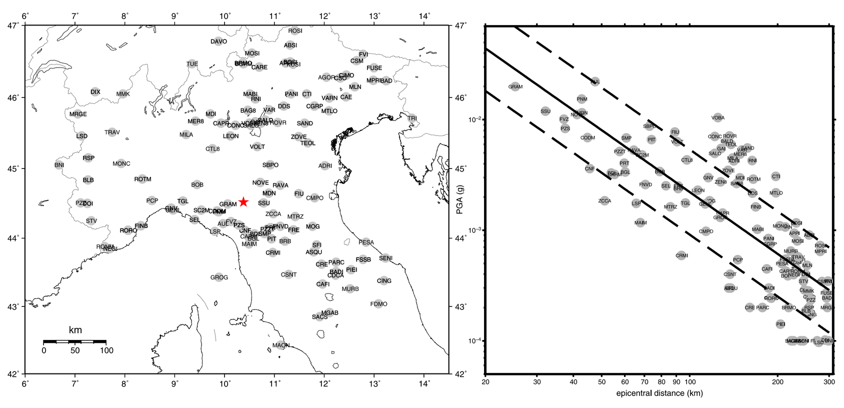

Figure 1 Station that recorded the Parma Apennines earthquake within 300 km from the epicenter (left) and (right) fit of PGA data according to the linear model *log*(PGA)=a+b*log*(d_{epi}) (continuos line) +/-σ (dashed lines). The fit has σ=0.38, which increase to 0.46 for distances between 100 and 200 km

Automatic Zonation

Find N zones and estimate N regression models *log*(PGA)=a+b*log*(d_{epi}) so that the overall σ of the residuals *log*(observed)-*log*(predicted) is minimized (Bragato, 2009).

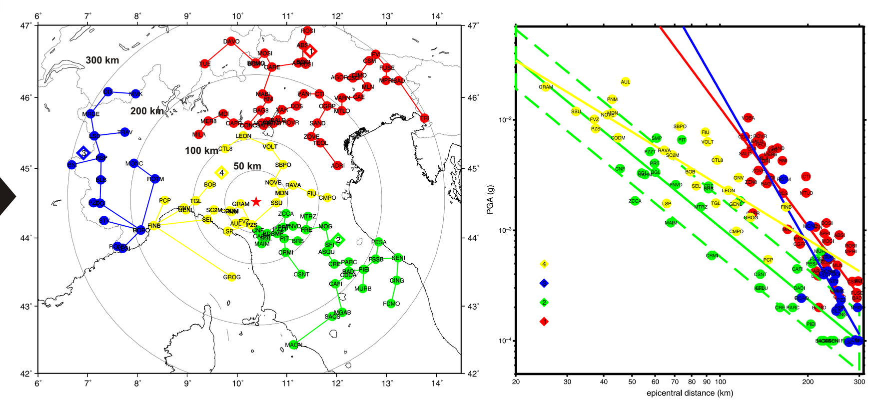

Figure 2 Result of the automatic zonation.

Objectives, data and preliminary results

We started an investigation in order to assess if the observed ground motions depend on specific characteristics of propagation across the Po Plain.

We have collected a large data set of PGA data recorded by seismometric and accelerometric stations existing in the area, managed either by INGV or OGS (Fig. 3). The data set includes 2235 observations of PGA at 87 stations and refers to 203 earthquakes of magnitude ML between 2.8 and 5.2 occurred in the time period January 2003-April 2009, and recorded up to 200 km of epicentral distance (Figs. 3 and 4).

We have performed a preliminary analysis using non-parametric regression of PGA as a function of magnitude and epicentral distance. The resulting ground-motion model evidences lack of attenuation for distances between 70 and 130 km (Fig 5). Such feature seems to be independent on the location of the earthquake (it applies to both apenninic and alpine/prealpine earthquakes) and the site conditions of the recording station. This lead to hypothesize a regional effect of propagation. The distances at which the feature appears and the matching of the seismograms to the theoretical arrival times suggest that it is caused by a strong reflection at the Moho of the S waves (SmS phase).

Further investigation is required for assessing if and how the effect is related to the morphology of the Moho, which is quite complex in the area (Fig 6). We are performing an analysis of the residuals by azimuth and distance. We are also using the algorithms developed by Herrmann (2009) for producing synthetic seismograms to compare with the available recordings.

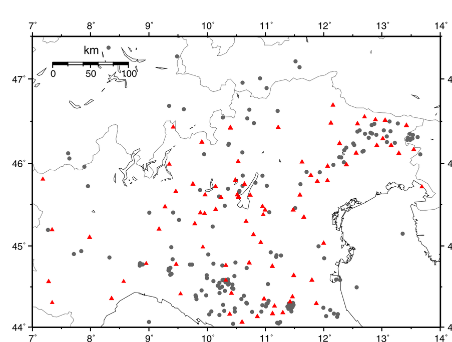

Figure 3. Epicenters of the earthquakes (circles) and seismometric stations (triangles) used for the analysis.

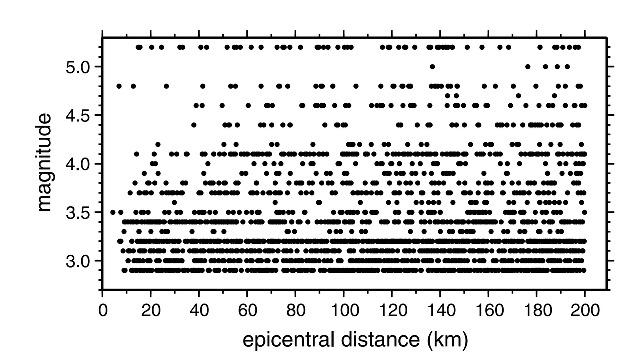

Figure 4. Magnitude/distance distribution of the data used for the analysis.

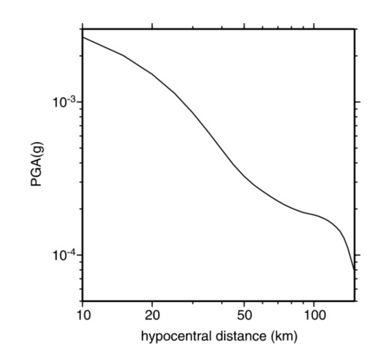

Figure 5. Distance decay of PGA for ML=3.5 estimated by non-parametric regression in northern Italy.

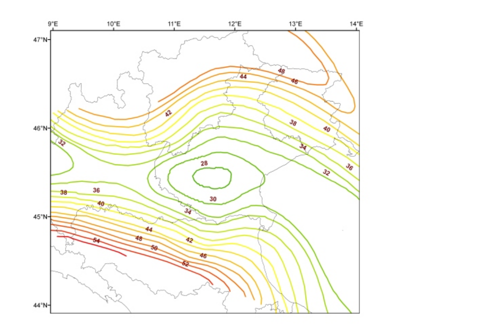

Figure 6. Depth of the Moho in northern Italy.

Extrapolation to strong earthquakes

A key question for the ShakeMap implementation and for hazard analysis is if the lack of attenuation can be applied also to strong earthquakes. We have no data for extending the empirical model by statistical analysis. Nonetheless, some elements seem to support the hypothesis.

In a previous work, restricted to the Garda region, Castro et al. (2008) estimated the distance decay of velocity Fourier amplitude spectra and found that the unattenuation feature is persistent over a broad range of frequencies (Fig. 7).

We have also reconsidered the PGA data of the 1976, Friuli earthquake (Mw 6.4), which is the strongest event in the area having instrumental recordings (Fig. 8) . Even in that case it is observable a set of relatively high PGA values at distances that are compatible with the Moho reflection.

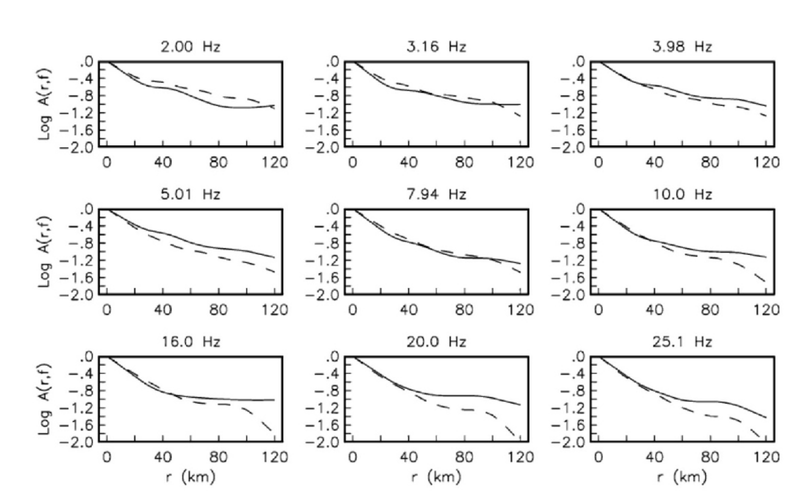

Figure 7. Velocity Fourier amplitudes at nine frequencies estimated by non-parametric regression analysis for the region of Garda: for P waves (continuous lines) and for S waves (dashed lines) (from Castro et al., 2008).

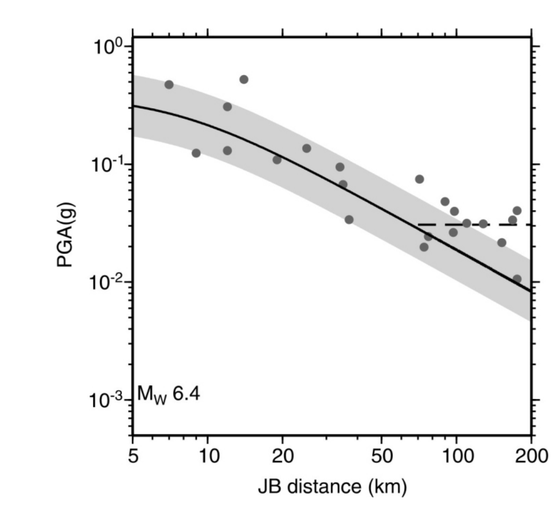

Figure 8. PGA of the 1976 Friuli earthquake (Mw 6.4) (dots) and predictive equation by Ambraseys et al. (2005) (continuos line) +/-σ (gray strip). The dashed line represents the trend with constant PGA for distances over 70 km extrapolated from weak-motion data.

Significance of the Moho effects

We have further analyzed the significance of the Moho reflections from the point of view of the applications of the empirical ground-motion models.

For ShakeMap implementation, the contribution is surely of interest, as it explains the asymmetry of the effects, which are much larger across the Po Plain than along the Apennines (see the macroseismic intensities for the Parma earthquake in Fig. 9). Furthermore, it accounts for the differences between the estimations of ML at OGS and INGV: using only stations in northeastern Italy, OGS furnishes magnitudes that are often 0.3-0.4 degrees larger than those estimated at INGV using stations in the Apennines as well.

Assessing the significance for probabilistic seismic hazard (PSH) requires accurate analysis and is out of the scope of this preliminary work. It expected that the relative contribution to PSH will be larger for those sites in northern Italy that are not too near to the main seismic sources.

This is the case, for example, of the city of Milan: a disaggregation study by Barani et al. (2009) evidences the strong contribution to the hazard of earthquakes located at about 100 km from the city (Fig. 10). Such contribution should be further enhanced if the Moho effect is taken into consideration.

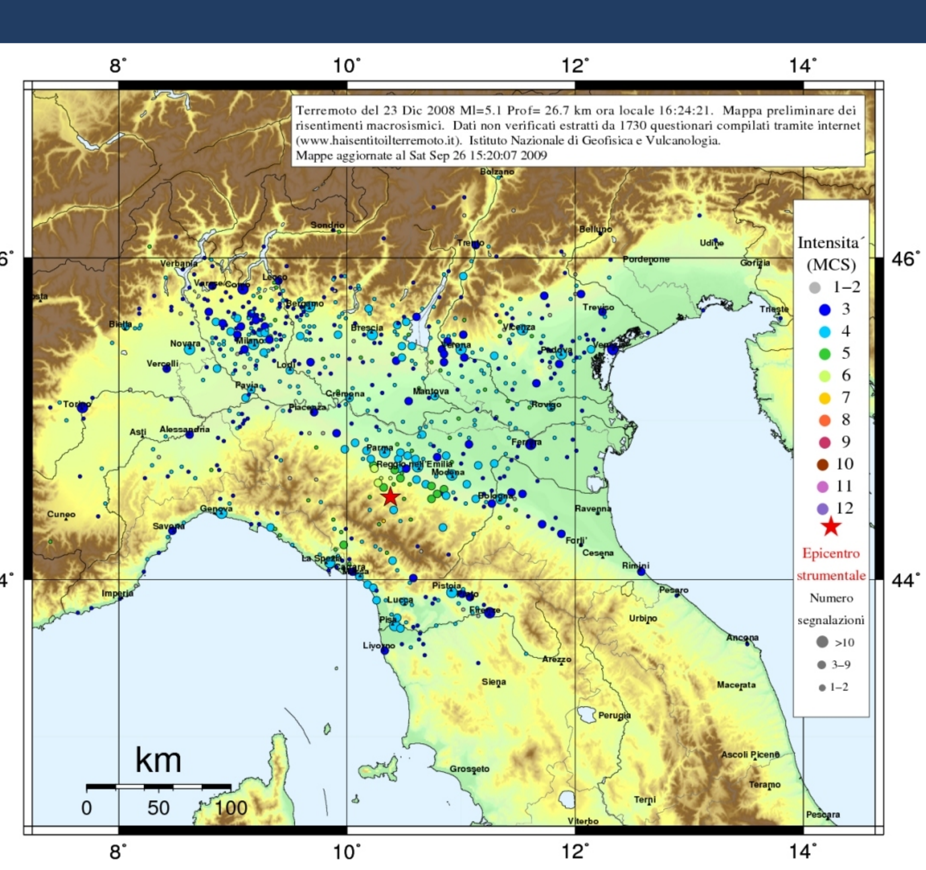

Figure 9. Preliminary MCS Intensity map for the 23 December, 2008 Parma Apennines earthquake estimated at INGV from on-line questionnaires (downloaded from the site http://www.haisentitoilterremoto.it)

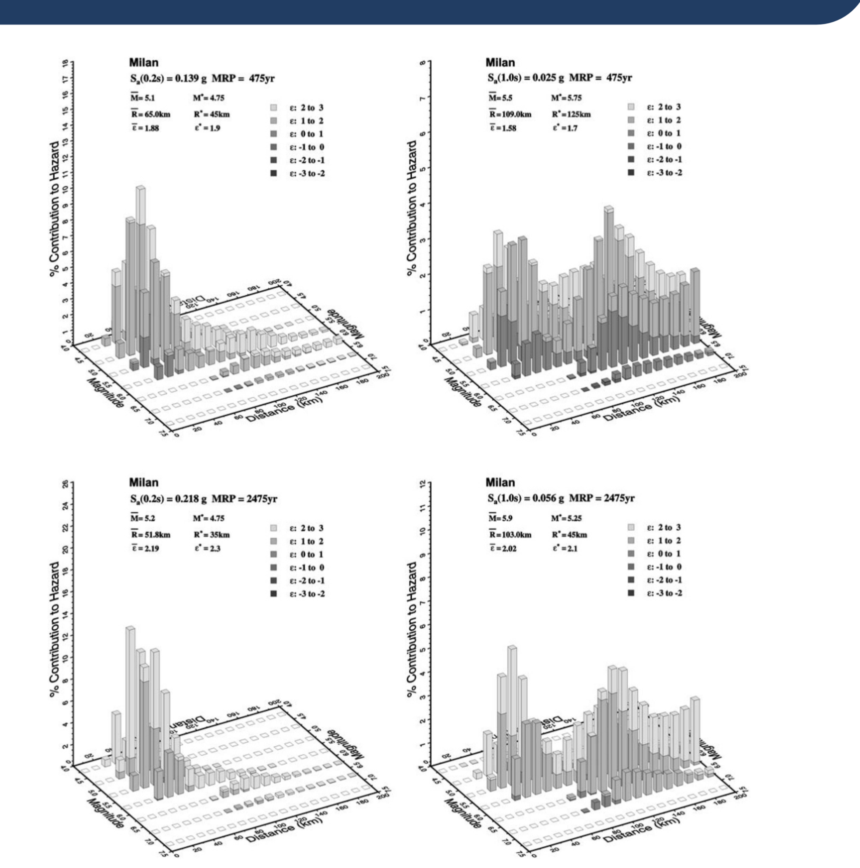

Figure 10. From Barani et al. (2009): joint M–R–ε probability mass functions (PMFs) for Milan as obtained from the disaggregation of the Sa(0.2 sec) and Sa(1.0 sec) values corresponding to mean return periods (MRPs) of 475 (top row) and 2475 yr (bottom row). M: magnitude; R: sourec-to-site distance; ε: ground-motion error term.

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