ISTITUTO NAZIONALE DI OCEANOGRAFIA E DI GEOFISICA SPERIMENTALE

Assessing regional and site-dependent variability of ground motions for ShakeMap implementation in Italy

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Objectives

The aim of the work (Bragato, 2009) is to use ground-motion parameters (PGA, PGV and SA at 0.3, 1 and 3 seconds) collected at the stations of the Italian seismometric network in the framework of the ING-DPC S3 project (ShakeMap implementation) for:

1. assessing the relative contribution of regional attenuation and local effects to the uncertainty of ground-motion predictive equations (GMPE) for the national territory;
2. estimating the optimal zonation of th Italian territory in order to reduce such uncertainty and highlight attenuation differences;
3. assessing if and how the available soil classification schema based on Vs30 could help to reduce the uncertainty related to site conditions.

Data

922 observations of PGA, PGV, and PSA values at 0.3, 1, and 3 sec collected in Italy between December 2005 and July 2008 from the INGV stations. The data were drawn from the INTERNET site of the ShakeMap project http://earthquake.rm.ingv.it/shakemap/shake/archive.

- 116 earthquakes;
- 137 stations (Fig 2);
- magnitude range (ML): 2.7-4.5;
- type of distance: epicentral distance (performs better than hypocentral distance, i.e., better fit)

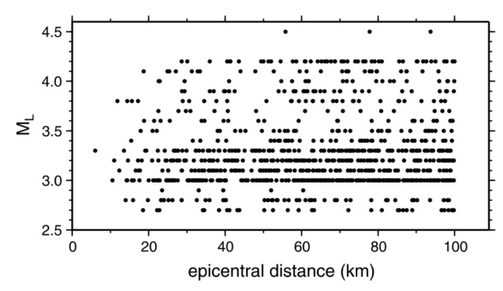

Figure 1. Magnitude/distance distribution of PGA data.

Method

In order to assess the impact of regional and local effects on ground-motion variability and find the optimal zonation of the Italian territory, the available stations are connected in a Delaunay triangulation (Fig. 2). By removing edges of the triangulation, the stations are partitioned into connected subsets or clusters. For each cluster it is estimated a simplified ground-motion model including station correction terms s_k:

$$\log(A_{ij}) = c_1 + c_2 M_{Li} + c_3 \log(d_{epi_{ij}}) + \sum_{k=1}^{N_S} s_k \delta_{kj}$$

For each zonation the overall standard deviation of the residuals *r=log(observed)-log(predicted)* is given by:

$$\sigma_{N_{cluster}} = \sqrt{\frac{\sum_{i=1}^{N_{data}} r_i^2}{N_{data} - 3N_{cluster} - N_{stat}}}$$

The optimal zonation is that making the best trade-off between low σ and low number of zones. It corresponds to the zone that minimizes the Bayesian Information Criterion (BIC, Schwarz, 1978):

$$BIC(N_{cluster}) = N_{data} \ln\left(\frac{\sum_{i=1}^{N_{data}} r_i^2}{N_{data}}\right) + (3N_{cluster} - 1)\ln(N_{data})$$

How to generate the alternative partitions ?

The search is restricted to the partitions of an Euclidean Minimum Spanning Tree (EMST) of the triangulation, that is, a sub-graph of the triangulation without cycles connecting all the points so that the total length of the edges is minimized (e.g., thick lines in Fig. 2). In general, a triangulation admits multiple EMSTs. One of them can be easily generated using the Kruskal's algorithm (Kruskal, 1956; Cormen et al., 2001). An EMST can be partitioned into *N* sub-graphs by simply removing *N-1* edges.

How to explore the alternative partitions ?

Alternative partitions are explored using a Genetic Algorithm (GA, Goldberg 2002): an element of the domain of the objective function (an *individual*, here a partition of the triangulation) is represented by a string of bits (a *chromosome*). The algorithm starts from a set of individuals (a *population*), generated randomly, and computes the corresponding values of the objective function. Such information is used to produce a new set of individuals (the population of the next *generation*) according to the mechanisms of selection, crossover, and mutation. The process is repeated for a fixed number of generations. In this schema the edges of the triangulation are enumerated from 0 and a partition into $N_{cluster}$ sub-graphs is represented by $N_{cluster}$-1 integers

$$(n_1, n_2, \ldots, n_{N_{cluster}-1})$$

where n_i is the number of the edges in the triangulation to remove for producing the partition. The GA is repeated for increasing number of zones until σ stabilizes.

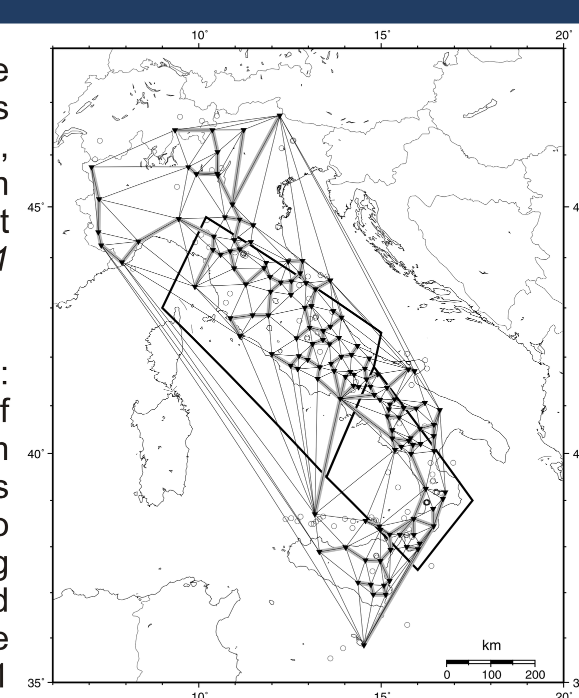

Figure 2. Earthquakes (circles) and stations (triangles) used for the analysis. The thin black lines indicates the Delaunay triangulation of the seismometric stations. The thick grey lines evidence one of the Euclidean Minimum Spanning Trees of the triangulation.

Results

Results are here discussed for PGA, although they are very similar for the other ground-motion parameters. Preliminarily, two ground-motion relationships for the entire Italian territory have been estimated, not including and including the station correction terms, respectively. The standard deviation decrease from 0.38 to 0.27, indicating that site effects contribute for about 30% of the overall σ. Such percentage is comparable to those estimated in northeastern Italy for a similar magnitude range by (Bragato and Slejko, 2005) (38%) and for strong earthquakes in the European area by (Bragato, 2008) (33%).

The optimal zonation has been searched exploring up to to 9 zones. The estimated σ (Fig. 3) decreases from 0.27 to around 0.25 (reduction by 7.4%) for more than 6 zones. The BIC-optimal zonation (Fig. 7, where it is compared to the six zones of the current ShakeMap implementation) gas 4 zones and σ=0.26.

The distance-decay curves of the optimal zones computed for M=3.5 (Fig. 5) evidence major differences for the zones 3 and 4. The regression line for zone 3 (north Italy) has slope similar to the others but predicts higher median accelerations, although the estimation suffers the relative scarcity of data (32 observations for estimating 13 parameters).

A strong distance decay characterizes the zone 4, roughly corresponding to the Calabrian Arc. Some tests have evidenced that the behavior is not related to source characteristics (e.g. by comparing the distance decay in the adjacent zone 1 for the same earthquakes).

It is in agreement with the estimation of Q by (Tuvè et al., 2006): for the Straits of Messina zone they find relatively high frequency-dependent total attenuation (1/Qt), with a large contribution from the scattering component (1/Qs). This suggests higher level of fracturation and lithological heterogeneity of the Calabrian Arc in respect to the nearby regions, in agreement with the structural complexity of the area.

Finally, the estimated station residuals have been compared with soil classes based on Vs30 values adopted in the current ShakeMap implementation (Vs30 are indirectly estimated based of surface geology, Michelini et al., 2008). As shown in Fig.6, there is only a weak correlation between them.

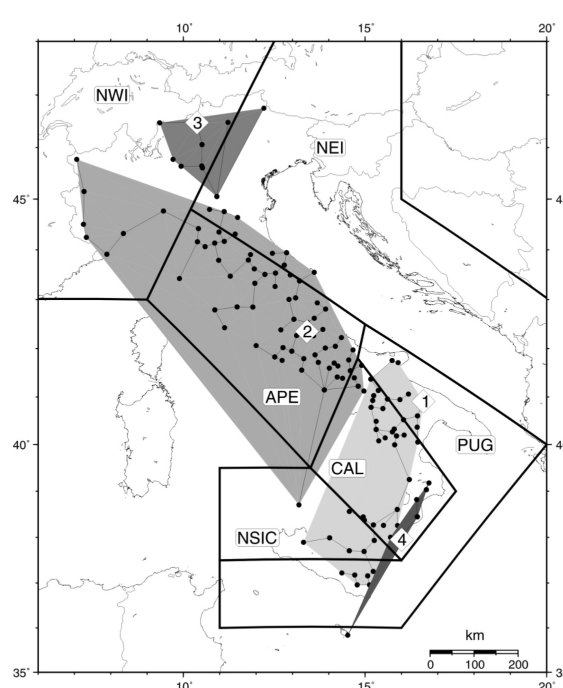

Figure 7. BIC-optimal zonation for PGA (dots=stations, thin lines=portion of the EMST used for partitioning, grey polygons=zones labelled from 1 to 4). The 6 attenuation zones used for the current ShakeMap implementation at INGV are also shown (polygons labeled NWI, NEI, APE, CAL, NSIC, and PUG, thick lines).

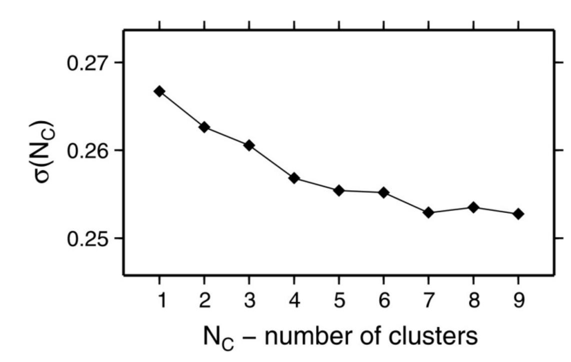

Figure 3. Standard deviation of the residuals vs. the number of clusters for PGA.

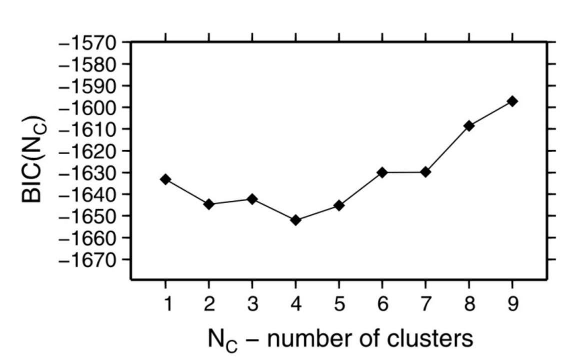

Figure 4. BIC parameter vs. the number of clusters for PGA.

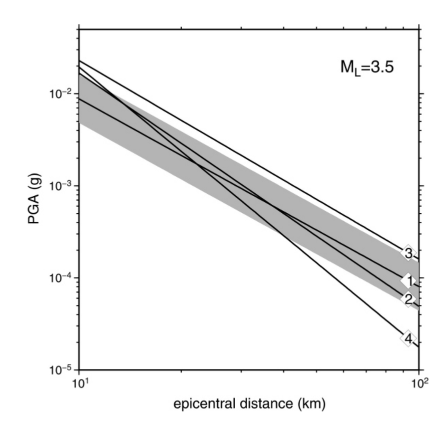

Figure 5. Distance decay of PGA for magnitude 3.5 estimated for the four zones in the optimal BIC zonation (Fig. 7). The grey strip indicates the median value ± σ for area 1.

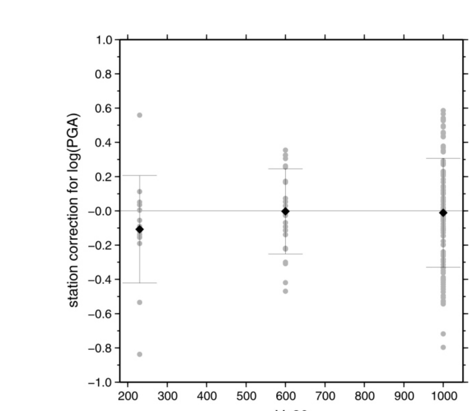

Figure 6. Distribution of the station correction terms of the BIC-optimal solution for different soil classes. The average station correction term +/- σ for each class is also shown (black diamonds with error bars).

Conclusions

Referring to the initial objectives, it is possible to conclude that:

1. the variability of ground-motions in Italy has a large component depending on local effects (about 30%), while regional differences of attenuation contribute to less than 4% of the overall σ;

2. the optimal zonation of the Italian territory has 4 areas. It matches the zonation of the current ShakeMap implementation for the Apennines, while it suggests an alternative partition for the northern and southern sectors. Two areas have peculiar behavior: the Calabrian Arc, featuring stronger attenuation, ad north-eastern Italy, characterized by larger acceleration for the same magnitude and distance. The latter result must be confirmed by further data and investigation;

3. The amplification factors estimated from the data as station correction terms are weakly correlated with the classification of the soils based on Vs30, suggesting that alternative criteria for site characterization should be devised.

References

Bragato, P.L. (2008). Limits for the improvement of ground-motion relations in Europe and the Middle East by accounting for site effects, Bull. Seism. Soc. Am. 98, 2061-2065.

Bragato, P.L. (2009). Assessing regional and site-dependent variability of ground motions for ShakeMap implementation in Italy, Bull. Seism. Soc. Am. 99, 2950-2960.

Bragato, P.L., and D. Slejko (2005). Empirical ground motion attenuation relations for the eastern Alps in the magnitude range 2.5-6.3. Bull. Seism. Soc. Am. 95, 252-276.

Cormen, T.H., C.E. Leiserson, R.L. Rivest, and C. Stein (2001). Introduction to algorithms, Second Ed., MIT Press, Cambridge, Massachusetts, and McGraw-Hill, New York.

Goldberg, D.E. (2002). Genetic Algorithms in Search, Optimization, and Machine Learning, Addison Wesley Longman, Inc., Reading, Massachusetts.

Kruskal, J.B. (1956). On the shortest spanning subtree of a graph and the traveling salesman problem, Proc. Am. Math. Soc. 7, 48-50.

Michelini, A., L. Faenza, V. Lauciani, and L. Malgnini (2008). ShakeMap Implementation in Italy, Seismological Research Letters 79, 688-697.

Schwarz, G. (1978). Estimating the dimension of a model, Annals of Statistics 6, 461-464.

Tuvè, T., F. Bianco, J. Ibáñez, D. Patanè, E. Del Pezzo, and A. Bottari (2006). Attenuation study in the Straits of Messina area (southern Italy). Tectonophysics 421, 173-185.

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