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MACROSEISMIC ATTENUATION FROM PROBABILISTIC PERSPECTIVE IN EUROPEAN COUNTRIES

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This study was performed in the framework of the European project on Preparedness and Prevention *Urban disaster Prevention Strategies using MAcroseismic Fields and FAult Sources* (UPStrat-MAFA - Num.230301/2011/613486/SUB/A5, DG ECHO Unit A5) and it constituted its Task B.

The work consisted of the application of a probabilistic attenuation model to earthquakes that occurred in seismic regions of different European countries. The aim was the implementation of common strategies to forecast damage scenarios from macroseismic fields in order to assess the seismic hazard.

According to the ordinal nature of the intensity scale, the considered probabilistic attenuation model is defined as a binomial-beta model (Zonno et al. 2009) based on the hypothesis that, conditioned on the epicentral intensity I_0 and on a fixed epicentral distance, the intensity I_s at site has a binomial distribution with parameter p, i.e.

$$Pr(I_s = i \mid I_0 = i_0, p) = \binom{i_0}{i} p^i \left(1-p\right)^{(i_0-i)} \quad . \tag{1}$$

In order to consider the variability in ground shaking even among sites with the same epicentral distance, the parameter p is taken as a beta distributed random variable with parameters α and β.

The analysis was basically divided into two steps; the former dealt with the methodological aspects and the construction of potential learning sets derived on the basis of the most updated database of Italian macroseismic fields, the DBMI11 database (Rotondi et al. 2013a).

We considered the 298 macroseismic fields of the DBMI11 database corresponding to the earthquakes of MCS ≥ V that occurred in Italy from 1500 and had at least 40 data points; their spatial locations cover all the Italian territory. At first, these macroseismic fields were grouped through the Ward method, a well-known clustering method belonging to the class of the hierarchical agglomerative methods (Kaufman and Rousseeuw, 1990). The clustering algorithm selected four classes of macroseismic fields with similar attenuation trend within the Italian database and produced a classification tree able to assign any new macroseismic field to one of the four classes.

By following the Bayesian paradigm, the beta-binomial model was fitted to all sets of earthquakes with given epicentral intensity I_0 belonging to the same attenuation class. Under the assumption of isotropic intensity decay (i.e. the isoseismal lines bounding the locations of equal intensity are circular), J circular bins were drawn around the epicentre and the estimation procedure assumed that I_s has the same binomial distribution with parameter p_j in all the sites within each j-th bin, for each $j = 1, 2, \ldots, J$.

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Once estimated the parameters p_j through their posterior mean $\hat{p}_j$, in order to get an estimate of the parameter p at any distance d from the epicentre, we smoothed the values $\hat{p}_j$ by using an inverse power function $g(d) = \left[c_1 / \left(c_1 + d\right)\right]^{c_2}$. That enabled us to forecast, in terms of macroseismic intensity I_s, the damage scenario that a future earthquake of given epicentral intensity I_0 could cause at any site at distance d from the epicentre by the smoothed binomial probability function:

$$Pr(I_s = i \mid I_0 = i_0, g(d)) = \binom{i_0}{i} g(d)^i \left[1 - g(d)\right]^{(i_0 - i)} \quad . \tag{2}$$

The mode of this distribution provides the estimate of the intensity at distance d.
When additional information about the extremes of the fault rupture was available, the distribution of the intensity at site was evaluated under the assumption of anisotropic decay in the case of elliptic isoseismal lines. The key idea was to apply the model as in the isotropic case to the plane transformed so that ellipses with the major axis along the fault rupture became circles with centre in the middle point of the rupture (Azzaro et al. 2013).
In the second step of this study we examined solutions to specific issues arisen in applying the above-mentioned methods to the test areas considered in the project: Mt. Etna (Italy), Portugal and Azores Islands, Alicante-Murcia (Spain), Iceland (Rotondi et al. 2012, Rotondi et al. 2013b).
As for Iceland, the data set was enriched by the digitalization in a GIS of isoseismal images drawn from the literature and related to five historical earthquakes occurred in North Iceland
The attenuation trend of each test area was compared to that of the four Italian attenuation classes in order to select the most suitable learning set. Since the impact areas of the Italian and test area earthquakes may be different, we had to look for a scaling factor k which made comparable, in the two environments, the distances at which the same decays were observed. For example, in the Mt Etna case, we ended up to choose a factor k=10, which means that the decay recorded at some distance in the Mt Etna environment is equal to that observed at ten times the same distance in the Italian environment. In this case, when the scaling factor was applied, the intensity decay trend turned out more similar to that of the class selected as learning set for Mt Etna.
If there was uncertainty between two classes, the classification tree obtained from the construction of the learning sets was used as an additional tool to assign the macroseismic fields (scaled by factor k) of the test areas to one of those two Italian classes. To enable the use of this tool when some of the summaries that drive the rules of the classification were missing (as for the offshore earthquakes where there are no felt intensities at short distances from the epicentre), the missing summaries were roughly derived by fitting a regression model estimated by the least squares method.
Then the binomial-beta model was fitted to the macroseismic fields of each test area, for a given epicentral intensity, by setting the prior values of the parameters p_j equal to those previously obtained from the analysis of the learning set and suitably scaled according to the factor k. Figure 1 compares the estimated attenuation distributions obtained by applying the beta-binomial model to the macroseismic fields of epicentral intensity I_0 = IX in each test area; the color scale indicates the various probability values that are associated with the random variable I_s at a given distance.
To check the goodness of fit of the proposed model, observed and estimated intensities at site were compared by three validation criteria: the logarithmic scoring, the log odds ratio criterion and the absolute discrepancy between observed and estimated intensities at site (Rotondi et al. 2013c). The resulting values of the discrepancy are less than one degree of the intensity scale and almost all less than the values obtained by estimating the intensities at site by means of regional laws. In particular, the average values of the discrepancy are 0.4 for Offshore Portugal, 0.5 for Azores, 0.6 for Mt. Etna and Inland Portugal, 0.7 for Iceland and 0.9 for Alicante-Murcia.

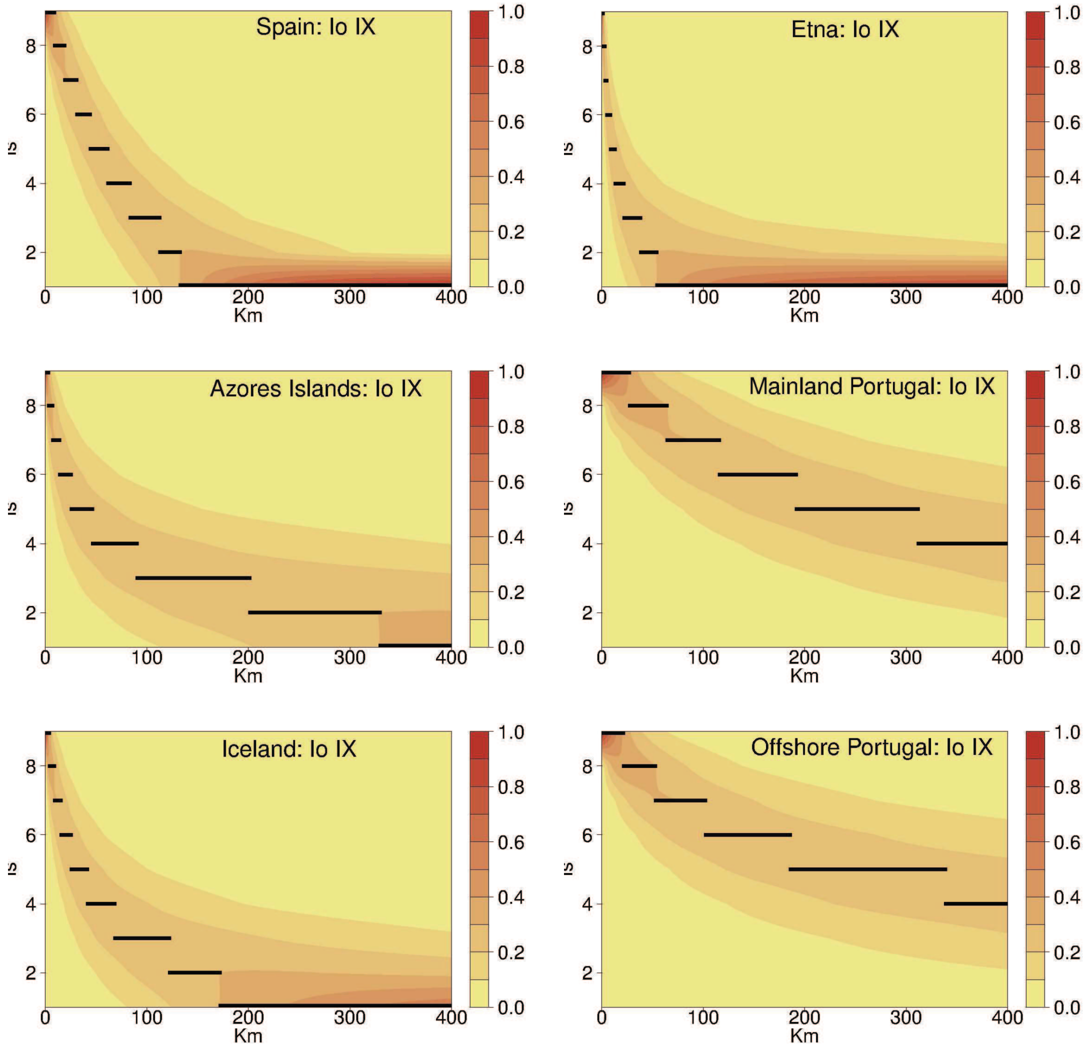

Figure 1. Probability distribution of the intensity I_s for earthquakes of epicentral intensity I_0 = IX in each test area.

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