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Seismic hazard assessment in terms of macroseismic intensity for the Italian area

a cura di

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Abstract

A seismic hazard map, in terms of macro seismic intensity with 10% probability of exceedance in 50 years, is proposed for the Italian territory. The input elements used to evaluate the seismic hazard are: the seismogenic zoning ZS9 (Meletti *et al.*, 2007), the earthquake catalogue CPTI04 (Gruppo di lavoro CPTI04, 2004) and intensity attenuation relationships. The first two elements and the historical and statistical completeness of the catalogue are those used in the national seismic hazard map for Italy MPS04 (Gruppo di Lavoro MPS, 2004). Two intensity attenuation models are used: 1) one national relationship obtained with a new approach by Pasolini *et al.* (2006) and a relationship for the Etna volcanic zone proposed by Azzaro *et al.* (2006) 2) a set of regional relationships derived from a previous cubic model (Berardi *et al.*, 1993) which is recalibrated in the present study using the macro seismic intensity database DBMI04 (Stucchi *et al.*, 2007), which was used for compiling CPTI04. The computer code adopted to evaluate the seismic hazard, with the elements cited above, is SeisRisk III (Bender and Perkins, 1987), which has been modified within this study to incorporate the aleatory variability of the ground motion (macroseismic intensity). A logic-tree framework allowed to explore some possible alternatives of epistemic character. The seismic hazard map obtained in terms of intensity was subsequently transformed into PGA by means of a linear relation between intensity and PGA, in order to compare it with the recently national seismic hazard map MPS04.

Key words: Probabilistic seismic hazard assessment (PSHA), macroseismic data, intensity attenuation, Italy

1. Introduction

Seismic hazard is generally assessed in terms of peak ground acceleration (PGA) for the purpose of deriving engineering design parameters for new buildings. However, the short time interval covered by the instrumental records can be a problem in regions where the earthquake cycle is rather slow and seismicity not very frequent. In terms of seismic hazard assessment this can affect the evaluation of seismicity rates in that the data sample may not be representative of seismogenic process. Furthermore, the low density of recording stations determines in some parts of the world a limited availability of the strong-motion data needed to study the attenuation. It is clear that in these cases the macroseismic data are very important as they may represent the only available data.

In Italy, as in other countries, most of the earthquake catalogue data are derived from macroseismic studies (Gruppo di Lavoro CPTI, 2004). The historical research has contributed to the knowledge of the historical seismicity dating back 2000 years (Stucchi *et al.*, 1991; Albini *et al.*, 2004); the earthquakes occurred before the early 20th century are only qualified with macroseismic intensity data. In the last years, a number of macroseismic databases have been proposed (Monachesi and Stucchi, 1997; Boschi *et al.*, 2000; Stucchi *et al.*, 2007). This wealth of data permitted to assess the seismic hazard in terms of macroseismic intensity (e.g.

Slejko *et al*., 1998; Albarello and Mucciarelli, 2002; Albarello *et al*., 2000; Mucciarelli *et al*., 2000).
The main aim of this work is to propose a complementary map, which evaluates the occurrence of large earthquakes and associated damaging ground motion using PSHA. The macroseismic intensity relates specifically to damage in a way that parameters like PGA do not. However our results should be useful for comparison with the National Seismic Hazard Map (MPS04) (Gruppo di Lavoro MPS, 2004).
We proposed a new seismic hazard map of Italy in terms of intensity derived by using updated date such as earthquake catalogue (CPTI04) and seismogenic zonation (ZS9), which were developed in the frame of compilation of MPS04, and two macroseismic intensity attenuation models. In this last item, we used that attenuation relationship proposed by Pasolini *et al*. (2006), which is a classical model derived on the basis of models of wave propagation. This attenuation model is made to national scale obtained with a new approach from DBMI04 (Stucchi *et al*., 2007).
As an aim of this study we developed and used an alternative attenuation model that is proposed as a set of intensity attenuation relationships derived from a previous empirical relationship proposed by Berardi *et al.* (1993). This empirical relation is a root cubic functional which is recalibrated in the present study from the most updated Italian macroseismic database DBMI04 (Stucchi *et al*., 2007). We have carefully analysed and used the macroseismic dataset to get more accurate results in the attenuation model that include different relationships for style-of-faulting and their standard deviation which is incorporated in the hazard calculations.
We describe also the modification introduced in SeisRisk III (Bender and Perkins, 1987) to compute hazard in terms of macroseismic intensity, i.e. allowing to consider the normal distribution of the residuals. A logic-tree framework is used to explore some possible alternatives of epistemic character regarding the catalogue completeness, seismicity rates and the attenuation models. The seismic hazard map obtained is compared with those previously derived by Slejko *et al*. (1998) and Albarello *et al.* (2000). The obtained probability intensity values have been preliminary transformed to PGA by using specific empirical relationships developed by Margottini *et al.* (1992) and a relationship developed in Gómez Capera (2006) from dataset published by Faccioli and Cauzzi (2006). The intensity map transformed in PGA is then compared with the recently derived hazard map in terms of PGA MPS04 (Gruppo di Lavoro MPS, 2004).

2. State-of-the art of seismic hazard assessment in terms of macroseismic intensity

The macroseismic intensity has been used as ground-motion parameter in seismic hazard assessment (SHA) in many studies in different countries in the last 40 years. McGuire (1993) is summarized more than 60% of the countries have expressed the hazard assessment in terms of maximum observed intensity or intensity at a given probability level (Slejko *et al*., 1998). Early studies were proposed in terms of maximum observed intensities using as input data isoseismal maps (Riznichenko, 1966; Buné, 1974; CERESIS, 1985) and more recently using intensity data points and attenuation relationships (Molin *et al*., 1996, Miyazawa and Mori, 2006).
In Garcia-Mayordomo *et al*. (2004) is given a state-of-the-art of SHA of 16 European countries. In this study is observed that in European countries, the most common method used for SHA in terms of intensity is the probabilistic approach (Cornell, 1968; Cornell, 1971; Merz and Cornell, 1973). Most of the official European SHA were made more than 10 years ago, in terms of macroseismic intensity, taking into account seismogenic zonation, estimating maximum earthquakes from historical data, using macroseismic intensity attenuation relationships and assuming that earthquake occurrences follow a Poisson process. Until

recently, the most common earthquake scale used in Europe in SHA was macroseismic intensity (MSK, MCS, MM).

Examples of studies of PSHA in terms of intensity in Europe are given by: Ahorner *et al*. (1976), Saegesser and Mayer-Rosa (1978), Schenk *et al*. (1984), Working Group on Seismic Risk (1992), Grünthal and Bose (1996), Grünthal *et al*. (1998), Schenk *et al*. (2000), Pelaez Montilla and López Casado (2002). Out of the European continent, PSHA have been proposed in terms of intensity as for example in Berberian (1976), Smith and Berryman (1986), Gaull *et al*. (1990), Garcia *et al.* (2003) and Chiu and Kim (2004) .

Most early studies cited by McGuire (1993) and Garcia Mayordomo (2004) the aleatory variability of the ground-motion parameter is not incorporated in the hazard calculationsin terms of intensity. In Bommer and Abrahamson (2006) is cited that in literature the early relationships of macroseismic intensity attenuation did no include the standard deviation; McGuire (1976) list many attenuation relationships in terms of PGA and macroseismic intensity, published between 1954 and 1974, which did not report the associated standard deviation. The absence of the aleatory variability in many early relationships had an important influence on the early development of PSHA.

The second most common approach used in Europe is the deterministic method and the third is Gumbel I extreme distribution which is much less represented (McGuire, 1993; Garcia-Mayordomo *et al*., 2004). Examples of studies about the SHA using the deterministic approach in terms of macroseismic intensity are given by Despreyroux and Godefroy (1986), and Drimmel (1993). Studies about SHA using Gumbel extreme distributions are developed by Petrini *et al*. (1981) and Stanishkova and Slejko (1994). In these two approach cannot be accommodated the influence of the scatter in the intensity attenuation relationships.

Other methodologies have been used for SHA in terms of macroseismic intensity as for example is that called the site approach, which is a method to estimate seismic hazard based on documentary data concerning local history of seismic effects (Albarello and Mucciarelli, 2002). This method has been used in Italy by Monachesi *et al*. (1994), Mucciarelli *et al*. (2000), S1 project, which is available in http://esse1.mi.ingv.it/d9.html, and in Japan by Bozkurt *et al*. (2007).

In particular in Italy, PSHA in terms of macroseismic intensity has been proposed by Slejko *et al*. (1998) and Albarello *et al*. (2000) using SeisRisk III (Bender and Perkins, 1987). The seismic hazard map by Slejko *et al*. (1998) was based on the earthquake catalogue NT4.1 (Camassi and Stucchi, 1996), the ZS4 seismogenic zonation by GNDT, which is available in http://emidius.mi.ingv.it/GNDT/ZONE/zone_sismo.html, then published in Meletti *et al.* (2000), and two intensity attenuation relationships (Grandori *et al*., 1987; Berardi *et al.,* 1993). The hazard map by Albarello *et al*. (2000) adopted the seismogenic zonation by Meletti *et al.* (2000), the same earthquake catalogue NT4.1 and intensity attenuation relationships used by Slejko *et al*., (1998) but a new procedure to estimate the completeness of the earthquake catalogue and related uncertainty. Both studies discard the standard deviation of the macroseismic intensity attenuation relationships in the hazard computing.

3. Methodology and input elements

The seismic hazard map in terms of macroseismic intensity is evaluated using probabilistic seismic hazard analysis (PSHA), which was presented by Esteva (1969, 1970) as an extension of Cornell (1968) that incorporated the aleatory variability in ground-motion relationships and reported logarithmic standard deviations for PGA and PGV. This variability in acceleration, for example, is commonly modelled by assuming that acceleration from earthquakes of a given magnitude and distance is lognormally distributed with standard deviation in logarithm of acceleration. A brief history of PSHA is given by Bommer and

Abrahamson (2006), which references the probabilistic method of seismic hazard analysis, as it is currently understood, was presented by Cornell (1971) and by Merz and Cornell (1973). Most seismic hazard software (McGuire, 1976; Bender and Perkins, 1987; Ordaz *et al*., 2003) is designed to work with PGA or spectral acceleration i.e. residuals that follow a lognormal distribution (Sabetta and Pugliese, 1987; Ambraseys *et al*., 1996; Boore *et al*., 1997).
When computing seismic hazard using macroseismic intensity, it is important to remember that the residuals of the intensity attenuation relationships follow a normal distribution (see section 4.2; Gasperini, 2001; Albarello and D'Amico, 2004; Musson, 2005).
In the frame of the present study the program SeisRisk III (Bender and Perkins, 1987) is modified in order to evaluate the seismic hazard by implementing a normal distribution scatter (Gómez Capera and Sudati, 2005). The normal distribution of ground-motion residuals is not truncated in SeisRisk III, which computed the integration of probability density function across the full distribution of ground-motion variability (Arnold, 1989; Bender and Perkins, 1987)
In table 1 are described the input elements used to evaluate the seismic hazard applying Benders and Perkins (1987). The first three elements are taken from the MPS04 national seismic hazard map released in 2004 (Gruppo di Lavoro MPS, 2004), in particular:

- the earthquake catalogue CPTI04 (Gruppo di Lavoro CPTI, 2004);
- the seismogenic zonation ZS9 (Meletti *et al*., 2007) (fig. 1);
- the historical and statistical completeness time intervals.

A valid alternative of earthquake catalogues and seismogenic zonation are not presented in literature. The other two elements, i.e. seismicity rates in terms of epicentral intensity have been computed by Gómez Capera (2006) and Gómez Capera *et al*. (2007); the intensity attenuation models are those proposed in Pasolini *et al*. (2006) and Azzaro *et al.* (2006) and in the present study which is developed on the following paragraph.

Input element	Used in this study
Earthquake Catalogue	CPTI04 *
Seismogenic Zonation	ZS9 *
Completeness of the earthquake catalogue	Historical completeness time intervals (CO-04.2) * Statistical completeness time intervals (CO-04.4) *
Seismicity rates	Activity rates (AR) in epicentral intensity classes (I_o)** Gutenberg-Richter rates (GR) in epicentral intensity (I_o)**
Ground-motion attenuation relationship	Intensity attenuation relationship as a function of epicentral distance **

Tab. 1. Input elements used to evaluate seismic hazard in terms of macroseismic intensity. The elements with * are proposed in Gruppo di Lavoro MPS (2004), while those with ** are proposed in Gómez Capera (2006), Gómez Capera *et al*. (2007) and in the present study.

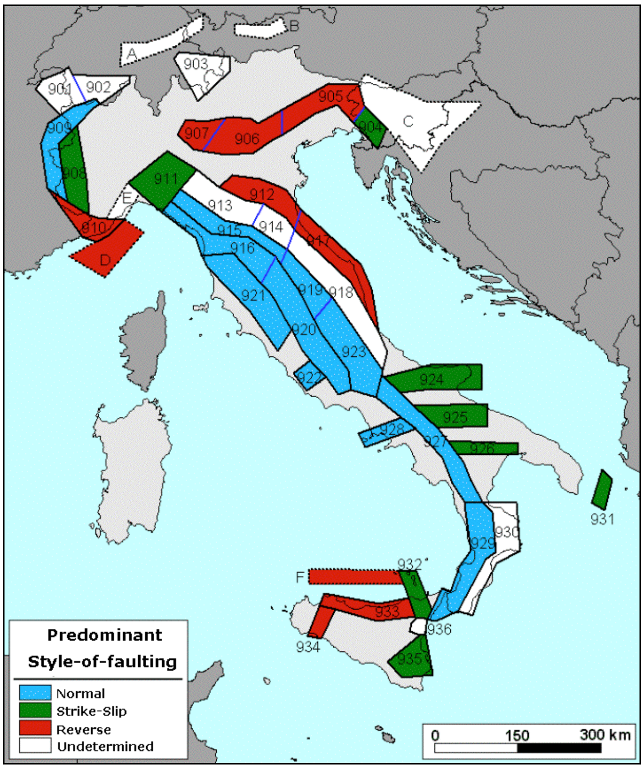


Fig.1.Seismogenic zonation ZS9 proposed by Meletti *et al* (2007) (http://zonesismiche.mi.ingv.it/documenti/App2.pdf).

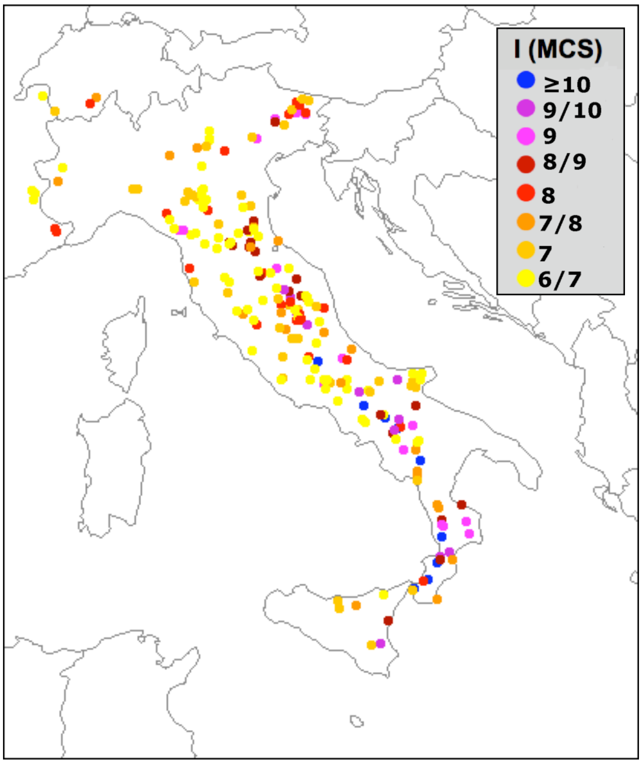


Fig. 2. Epicentral distribution of the earthquakes selected for deriving macroseismic intensity attenuation.

4. Macroseismic intensity attenuation relationships

4.1 State-of-the-art

Macroseismic intensity attenuation is described by IASPEI (2002) as the rate of decay of shaking, expressed in terms of intensity, with distance from the epicentre. The literature provides a number of empirical relationships that model the intensity decay in varied regions of the world as a function of epicentral or hypocentral distance. Many intensity attenuation relationships have been developed for applying in seismic hazard assessment (e.g. Gasperini, 2001; Albarello *et al*., 2004), which are studied in the present work. Other studies of intensity attenuation are developed for estimating the epicentral location and magnitude of historical earthquakes as for example Bakun and Wentworth (1997) which has been applied in USA (Bakun *et al*., 2003; Bakun, 2006), France (Bakun and Scotti, 2006) and Japan (Bakun, 2005); this type of relationships are not examined in this work.

One of the first intensity attenuation relation was proposed by Kövesligethy (1906) at the beginning of the last century and assumes that the energy of seismic waves declines owing to the geometrical spreading and to the absorption of the geophysical media. Mathematically, the attenuation of intensity is written as the difference between epicentral and site intensity ($\Delta I = Io - I$), where ΔI is a function of hypocentral distance (R), focal depth (*h*) and one free parameter α (see Tab. 2).

In Blake (1941), the Kövesligethy relationship is simplified eliminating the linear term (absorption coefficient) but letting the coefficient of the logarithm (geometrical coefficient) as a free parameter *b* (see Tab. 2). Following Blake (1941), other authors (Karnik, 1969; Howell and Schultz, 1975; Kaila and Sarkar, 1982; Ambraseys, 1985; Dowrick, 1992; López Casado *et al*., 2000) proposed attenuation intensity models as special cases of the Kövesligethy relationship introducing additional simplifications. However, what is often overlooked is that many early attenuation relationships did not include the standard deviation. In McGuire (1976) relations are listed many relations for prediction macroseismic intensity, published between 1954 and 1974, which did not report the associated standard deviation. According to this list, the first intensity attenuation relationship to report an associated standard deviation was that for Eastern Canada by Milne and Davenport (1969) (Tab. 2).

Table 2 illustrates some of the studies proposed in literature; for further references see: Neumann (1954), Brazee (1972), Anderson (1978), Grandori *et al*. (1991), Feldman and Shapira (1994), Chandler and Lam (2002), ECOS (2002), Gómez Capera and Salcedo Hurtado (2002), Carletti and Gasperini (2003), Albarello and D’Amico (2005) and many others. We can see in Table 2 none of these relations includes style-of-faulting and that the macroseismic intensity attenuation models proposed in the literature are either logarithmic or non-logarithmic (linear, polynomial).

The logarithmic models are derived empirically assuming that the macroseismic intensity is proportional to the logarithm or to a power of the seismic energy density (Howell and Schultz, 1975; Ambraseys, 1985; Dugue, 1989). These models can present some limitations about the correlation with macroseismic data. For example, the Kövesligethy relationship cannot be used to estimate the coefficients of geometric spreading and absorption and at the same time the focal depth (*h*) (Ambraseys, 1985; Zsìros, 1996).

As shown in Table 2, in Italy this type of model has been proposed, among others, by Albarello and D’Amico (2004) and Pasolini *et al*. (2006). In particular, Albarello and D’Amico (2004) describe the intensity decay as a function of epicentral intensity and hypocentral distance using four free parameters; Pasolini *et al*. (2006) propose an intensity attenuation model as a function of hypocentral distance and assuming the focal depth as a free parameter (h=3.9km).

For what concerns non-logarithmic models which have been proposed on the basis of empirical considerations, in Italy two studies are to be mentioned: the one by Berardi *et al.* (1993) who proposed a simple attenuation model called the Cubic Root Attenuation Model (CRAM) with only two free parameters, and the one by Gasperini (2001) who proposed a bilinear attenuation model with three free parameters (see Tab. 2).
The CRAM model has been applied in different Italian studies as for example in PSHA by Slejko *et al* . (1998) and Albarello *et al*. (2000). The CRAM assumes that the intensity decay, ΔI expressed by the difference between intensity of the epicentre and site intensity, is proportional to the cubic root of the epicentral distance, without dependence on the earthquakes focal depth; the functional form is described as:

$$\Delta I=\alpha+\beta D^{1/3} \quad (1)$$

where α=-0.729 and β=1.122, D is the epicentral distance. The CRAM is as fairly simple model as it uses only two free parameters. However, it provides a better fit of the macroseismic data compared to other models such as the logarithmic and square root (Berardi *et al.*, 1993). This functional model has been chosen in the present study to model the attenuation of intensity by using the Italian macroseismic data from DBMI04.

Author	**Attenuation relationships**	**Intensity Scale**	**σ**	**Region**
Kövesligethy (1906)	I_0-I_i=3 Log(R_k/h)+3 α Log(e) (R_k-h)	-	-	Hungary
Blake (1941)	I_{max}-I_k = b Log (R_k/h)	MM	-	USA
Milne and Davenport (1969)	I=I_7-9.66-0.0037 D+1.38 M+0.00528 *DM*	MM	0.53	Canada
Cornell and Merz (1975)	I=2.6 I_0-1.3 Ln(D); D≥10 mi	MM	0.20	Northeastern-USA
Howell and Schultz (1975)	Ln (I/I_0) = 0.364-0.130 Ln(R)-0.0019 R	MM	0.43	San Andreas-USA
Gupta and Nuttli (1976	I=I_0+3.7-2.7 Log(D)-0.0011 D; D≥20 km	MM	-	Central USA
Chandra *et al*. (1979)	I= I_0+6.453-4.960 Log(D+20)-0.00121 D	MM	0.23	Iran
Sbar and DuBois (1984)	I =12+3.24-1.54 Ln(D)–0.0015 D	MM	1.52	Northern Sonora-Mexico
Ambraseys (1985)	I_0-I=-0.22+0.0024 (R-h)+2.85 Log(R/h)	MSK	0.92	Northwest Europe
Greenhalgh *et al*. (1989)	$I = I_0\, e^{-0.032R/2} / R$	MM	0.0022 (Std.error)	Australia
Dugue (1989)	I_0-I=0.2 Ln(D-d)+0.04 (D-d), d>10 km	MSK	-	France
Dowrick (1992)	I=2.18+1.411 M-2.709 Log(R)-0.0044 R	MM	-	New Zealand
Berardi *et al.* (1993)	$I_0-I=-0.729+1.122\sqrt[3]{D}$	MCS	1.085	Italy
Zsiros (1996)	$I_0-I=3\,\mathrm{Log}(\frac{D}{h})+3(0.0161)\,\mathrm{Log}(e)(D-h)$	MSK	-	Hungary
Gasperini (2001) (update in Carletti and Gasperini, 2003)	$Io-I=\begin{cases}0.445+0.059R & (R\le 45km)\\ 0.445+0.059*45+0.0207(R-45) & (R>45km)\end{cases}$	MCS	1.04	Italy
Albarello and D'Amico (2004)	I=3.6-0.003 R-0.98 Ln(R)+0.705 I_0	MCS	1.25	Italy
Musson (2005)	I=3.31+1.28 Ml-1.22 LnR	EMS98	0.46	UK
Pasolini *et al.* (2006)	I=I_E-0.0086 (R-h)-1.039 (Ln (R)-Ln (h))	MCS	0.75	Italy
Azzaro *et al*. (2006)	I_0-I=0.98 Ln (R)+1.01	MCS	0.82	Etna-Italy

Tab. 2. Examples of intensity attenuation relationships referenced in literature. All relationships are logarithmic, except Berardi *et. al.* (1993) and Gasperini (2001). I_0=epicentral intensity, I_7=intensity of a magnitude 7 earthquake in the same location; I_E=Macroseismic magnitude, R=hypocentral distance(km), R_k is the hypocentral distance where $R_k^2= D_k^2+h^2$, *h* is the focal depth and D_k is the radius (km) of the area enclosed within the i-th isoseismal *k* (km); D=epicentral distance (km); h=depth of focus (km); Ml=local magnitude, M=magnitude; b, d, α, are constants; mi=mile.

4.2 Deriving a new intensity attenuation relationship

The dataset

The Italian macroseismic database DBMI04 (Stucchi *et al.*, 2007) has been considered in the present study. DBMI04 contains about 60,000 intensity data points (IDP), in MCS scale, related to 1,042 earthquakes occurred from 217B.C. to 2002.

In order to derive an intensity attenuation relationship for whole Italian territory to be used in PSHA a careful selection of the macroseismic data was carried out considering several criteria. Table 3 describes 13 criteria followed to filter the intensity records. As an example, macroseismic observations of the Etna volcanic region (seismogenic zone ZS936 of ZS9) are eliminated because the propagation of the seismic energy in this zone is different than in the other tectonic zones (Del Pezzo *et al.*, 1987; Ciccotti *et al.*, 2000). The IDP of the Etna zone will be used later for deriving an attenuation relationship of this volcanic region. Other filters are used to remove earthquakes characterised by epicentral intensity $I_0<7$, site intensities $I_s<3$, because the present study is focused on strong earthquakes and intensities. Earthquakes with number of macroseismic observations $N_{IDP}<13$ are filtered because this events with few IDP could bias the regression analysis. Earthquakes with epicentres outside the seismic zones of ZS9 are rejected because this study is focused on events inside seismogenetic zones.

The IDP of deep earthquakes are also disregarded. For example the 1914 earthquake is described by Meloni *et al*. (1988) as deep event, which are not easy to use in a statistical study of the macroseismic intensity attenuation because they are distributed over a very large area.

Another criterion is based on the distance: for every I_0, the distance where $I_s=4$, called $Dist\_I_{s4}$, is determined using the relationship of Albarello and D'Amico (2004); for every I_0, IDP with $D \geq Dist\_I_{s4}$ are rejected.

After applying the 13 criteria of table 3, the intensity database is reduced to 20,873 IDP related to 212 earthquakes that occurred from 1279 to 2002. Figure 2 shows the epicentre distribution of the 212 selected earthquakes.

The distribution of the selected IDP for each epicentral intensity class and for each site intensity class is shown in figure 3a and 3b respectively. The largest number of IDP belongs to the $I_0=7$ and 8/9 and the $I_s= 5$ classes.

The frequency distribution of IDP for intensity decay observed sii differences between intensity of epicentre and site intensity (I_0-Is=ΔI) is shown in figure 3c that indicates that the majority of data are located between the ΔI-class 1 and 5. The class $\Delta I>5$ are included less than 7% of records from all dataset; in these class are found IDP located far away of the epicentre of strong earthquakes.

Figure 3d shows the frequency distribution of IDP as a function of epicentral distance, which indicates that the majority of data are located within 100 km from the epicentre

The IDP of the volcanic areas are divided into two datasets:

- The first corresponds to the seismogenic zones ZS921 (Etruria), ZS922 (Colli Albani) and ZS928 (Ischia-Vesuvio);
- The second corresponds to the seismogenic zone ZS936 (Etna).

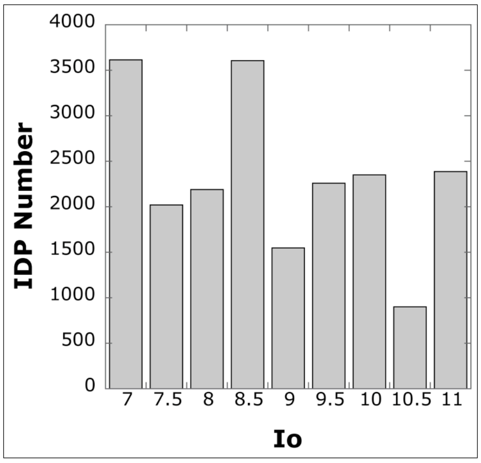
From these two datasets, a selection of macroseismic data was carried out considering the criteria described in table 4, resulting in a subset of 716 IDP for Ertruria, Colli Albani and Ischia-Vesuvio and 1,328 IDP related to 54 earthquakes for the Etna zone (ZS936).

#	Eliminated data	Reason
1	Earthquakes of the Etna volcanic zone (ZS936).	The volcanic zone is excluded because the energy propagation is different from the other zones.
2	Earthquakes with epicentral intensity $I_0<7$	The present study is focused on strong earthquakes.
3	Earthquakes with number of IDP (N_{IDP})≤12.	Earthquakes with few IDP could bias the regression analysis.
4	Particular earthquakes, for example the 1117, 1456, 1753 and 1914 events.	The literature describes these earthquakes as deep events.
5	Offshore earthquakes.	These events could bias the regression analysis because the distribution of IDP is inhomogeneous.
6	Earthquakes in border regions (as a consequence, the seismogenic zones ZS903 and ZS904 are rejected).	These earthquakes are not well known.
7	Earthquakes that do not match the catalogue completeness criteria.	To be coherent with the earthquakes used to assess the seismicity rates in PSHA
8	Earthquakes with epicentres outside the seismogenic zones of ZS9.	This study is focused on events inside seismogenic zones of ZS9.
9	Special cases (SC) IDP (DBMI04) with code: TE (Territory), SS (small settlement), SB (solitary building).	The statistical nature of intensity is not met.
10	IDP for which intensity has not been assessed.	These data are not easy to use in statistical studies.
11	IDP with $I_s<3$ (I_s=site intensity)	The present study is focused on strong intensities.
12	IDP with epicentral distance less than 1 km.	Earthquakes with few IDP could bias the regression analysis.
13	IDP rejected according to the following distance criterion: For every I_0 it is determined the distance where I_s=4, called $Dist\_I_{s4}$, using the relationship of Albarello and D'Amico (2004); for every I_0, IDP with $D \geq Dist\_I_{s4}$ are rejected.	**I_0 class** / **$Dist\_I_{s4}$** 11.0 / 453.5 10.5 / 387.4 10.0 / 326.1 9.5 / 270.2 9.0 / 220.0 8.5 / 176.0 8.0 / 138.0 7.5 / 106.0 7.0 / 80.0

Tab. 3. Criteria for selecting the intensity data points (IDP) to be used in the statistical analysis of the intensity attenuation in the Italian territory.

#	Data eliminated	Reason
1	Special cases (SC) (DBMI04, 2005) with code: TE (Territory), SS (small settlement), SB (solitary building).	The statistical nature of intensity is not met.
2	Data for which intensity has not been assessed.	These data are not easy to use in statistical study in attenuation.
3	IDP with $I_s<3$ (I_s=site intensities).	The present study is focused on high intensities.
4	IDP with D>40km for ZS936 (Etna).	Records outside seismogenic zones
5	IDP with D>90km for ZS921, ZS922 e ZS928.	Records outside seismogenic zones

Tab. 4. Data for the volcanic areas from DBMI04 (Stucchi *et al.*, 2007) not used to fit the intensity attenuation relationship for the volcanic areas. The total number of selected IDP is 716 for Etruria (ZS921), Colli Albani (ZS922) and Ischia-Vesuvio (ZS928), and 1,328 IDP for the Etna zone (ZS936).



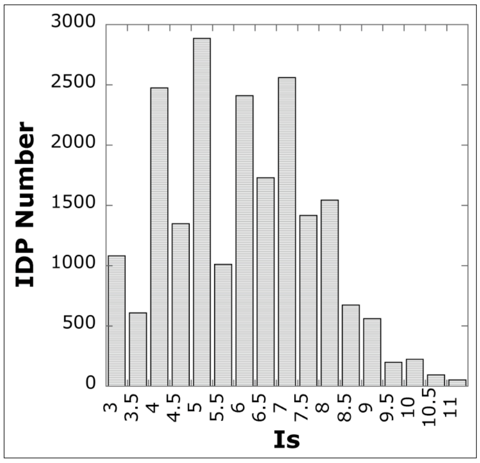
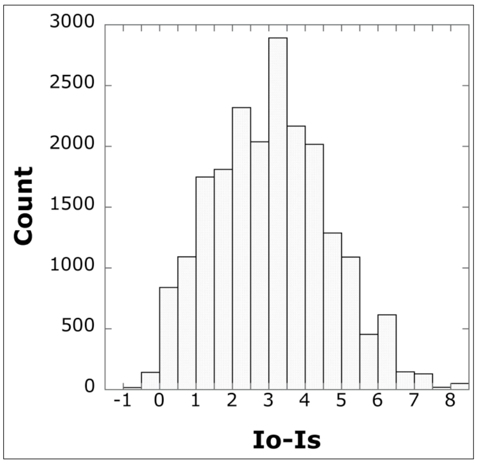


Fig. 3a **Fig. 3b**



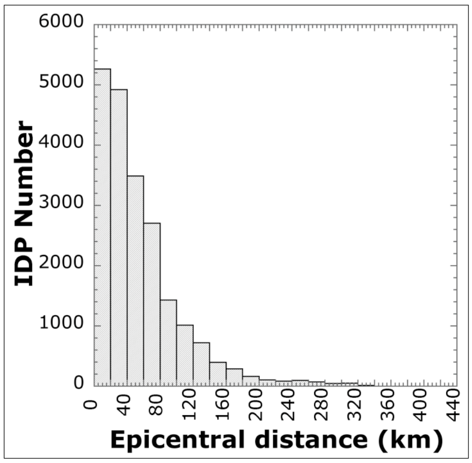


Fig. 3c **Fig. 3d**

Fig. 3. Frequency distribution of IDP *vs.* : a) I_o (epicentral intensity) class; b) I_s (site intensity) class; c) $I_o - I_s$; d)epicentral distance.

Regression analysis and results

According to Bommer *et al*. (2003), the combination of seismic source characterisation including rupture mechanism and ground-motion prediction equations that explicitly account for style-of-faulting should produce refined estimates of the seismic hazard. The most recent seismic source zone model of Italy, called ZS9 (Gruppo di Lavoro MPS, 2004), includes for each zone an average depth of the seismogenic layer and an indication of the predominant faulting style (Fig. 1). This information was used to assess the seismic hazard of Italy (Gruppo di Lavoro MPS, 2004) by using regional attenuation relationships with the Bommer *et al.* (2003) style-of-faulting scaling factors.

In analogy with the PGA attenuation relationships and using the information provided by ZS9, the present study derived a set of macroseismic intensity attenuation relationships from the 20,873 selected IDP described in the previous section. The set includes:

1. a relationship valid for whole Italian territory (Whole Italy);

2. a relationship for areas with predominant normal style-of-faulting (Normal);
3. a relationship for areas with predominant strike-slip and reverse style-of-faulting (Strike-Slip+Reverse).
4. a relationship for the Etna volcanic zone (Etna) that is derived from 1,328 IDP describe in the previous section.

Table 5 summarizes the values of the parameters of equation 1 ($\Delta I=\alpha+\beta D^{1/3}$) and relevant standard deviation obtained for each attenuation relation. The macroseismic data have been fitted by nonlinear regression using Levenberg-Marquardt algorithm.
In Gómez Capera (2006) independent attenuation relationships for areas with reverse and strike-slip style-of-faulting, respectively, were also derived, but they have been disregarded because the data sample is not statistically significant and the fit curves are similar. Also, attenuation relations for the volcanic areas ZS921, ZS922 and ZS928 have been rejected because they are not significantly different from "Whole Italy" model. The IDP of these 3 seismogenic zones (Etruria, Colli Albani and Ischia-Vesuvio) are included in the dataset used for deriving the "Whole Italy" relationship.

Figure 4a shows a plot of the intensity decay ($\Delta I=Io-I$) predicted by the "Whole Italy" relationship as a function of epicentral distance and standard deviation ±0.94 along with the 20,873 IDP considered. Figure 4c shows the ΔI residuals (observed-computed) as a function of the epicentral distance grouped in 5 km classes.
The intensity attenuation model for predominant normal faulting (Normal) obtained from 13,393 IDP is shown in figure 4b, while the distribution of the ΔI residuals as a function of epicentral distance is in fig. 4d.

The distributions of ΔI residuals as a function of epicentral distance for Whole Italy and Normal models are very similar (fig. 4c and fig. 4d) and show moderate oscillations from 5 to 150km, meaning that the computed intensities can be considered a good estimate of the observed ones. For epicentral distances greater than 150km the attenuation models do not provide a good estimate of the intensity observations. In both attenuation models, the distribution of the residuals in fig. 4c and 4d, the 95% (2σ) confidence intervals are shown as error bars, which strongly increase for distances greater than 330km.
Figure 4e shows the attenuation relation for both reverse and strike-slip faulting (5,020 IDP) and relevant ΔI residuals in fig. 4g. In the distance range 5-80km the calculated intensity decay overestimates the observed and beyond 80km the model tends to underestimate the intensity decay.

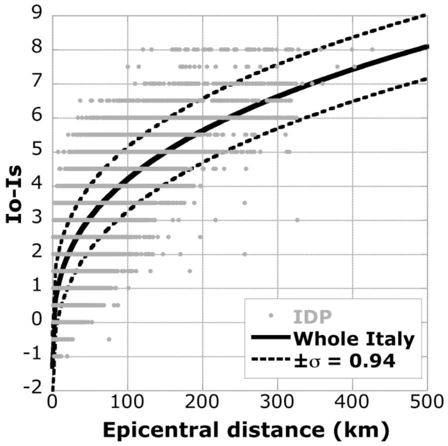


Fig. 4a

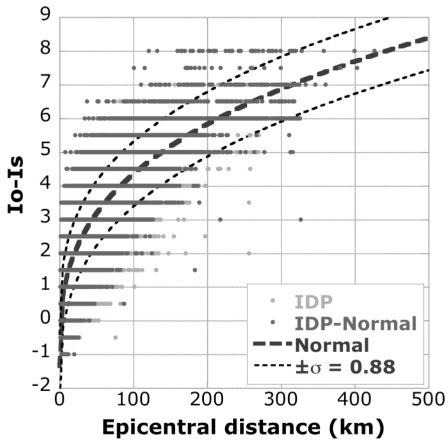


Fig. 4b

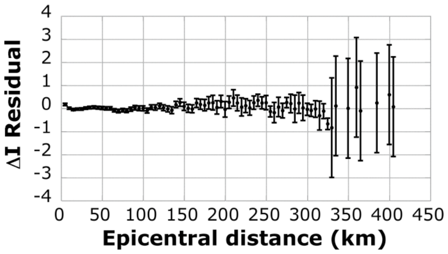


Fig. 4c

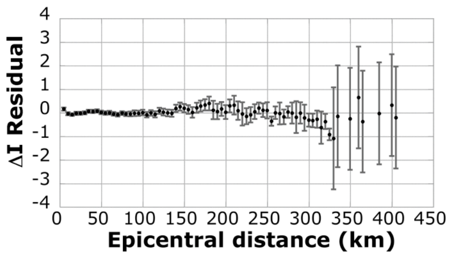


Fig. 4d

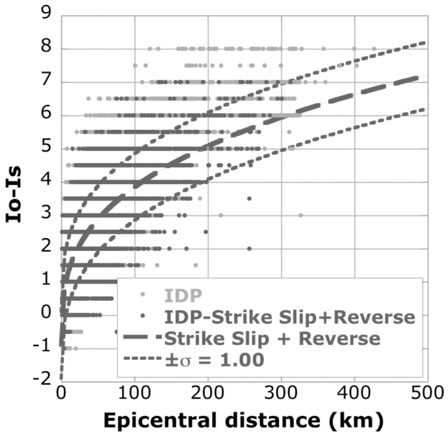


Fig. 4e

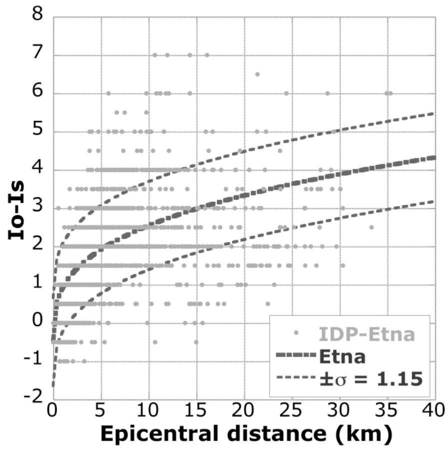


Fig. 4f

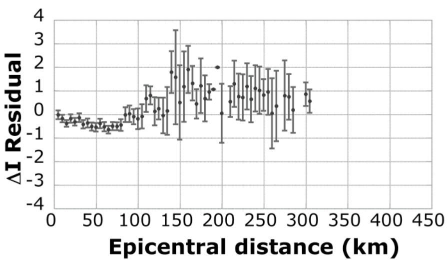


Fig. 4g

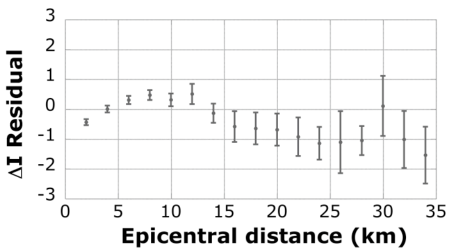


Fig. 4h

Fig. 4. a) Intensity attenuation model for "Whole Italy" obtained from 20,873 selected IDP (grey points); **b)** Intensity attenuation model obtained from 13,393 selected IDP for areas with predominant "Normal" style of

faulting (dark grey points); **c)** Distribution of the residuals relative to "Whole Italy"; **d)** Distribution of the residuals relative to "Normal"; **e)** Intensity attenuation model obtained from 5,020 selected IDP for areas with predominant "Strike-Slip and Reverse" style of faulting (dark grey points); **f)** Intensity attenuation model obtained from 1,328 selected IDP for the Etna volcanic area; **g)** Distribution of the residuals relative to "Strike-Slip and Reverse"; **h)** Distribution of the residuals relative to Etna volcanic area.

The distribution of the residuals are shown as a function of the epicentral distance grouped 5km intervals for 4c), 4d) and 4g) and 2km for 4h). In the distribution of the residuals, the 95% confidence intervals are shown as error bars.

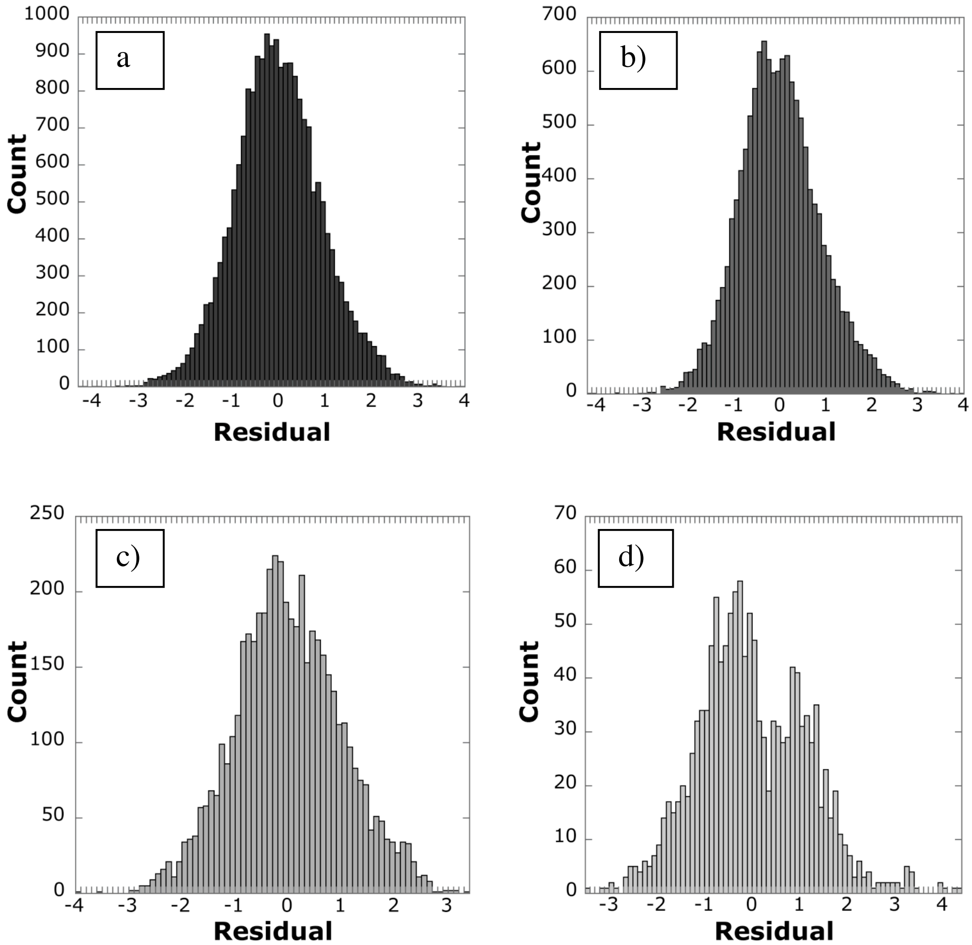


Fig. 5. Frequency distribution of the residuals (ΔI: observed - computed) obtained from the 4 intensity attenuation models: a) All territory; b) Normal; c) Strike-Slip+Reverse; d) Etna

The attenuation relationship for the Etna seismogenic zone is presented in figure 4f and the distribution of Δ*I* residuals in figure 4h shows a slight increase of the standard error beyond 10 km of epicentral distance.

Figure 5 shows that the frequency distributions of the Δ*I* residuals obtained from the four relationships (Whole Italy, Normal, Reverse and Strike-Slip, Etna) are Gaussian curves (normal distribution). This follows from the fact that intensity relationships are written as *f(I)=I* and not *f(I)=Ln I* (Musson, 2005). Each Gaussian curve in figure 5 has a standard deviation (Tab. 5) that can be used to model the aleatory uncertainty of the ground shaking in hazard studies.

Figure 6 compares the four attenuation models in Table 5. From it the following observations stem out:

1. the Etna relationship shows the highest intensity attenuation, consistently with its peculiar geological setting (i.e. volcanic area);
2. within the first 30km of distance Whole Italy and Normal models are similar; beyond 30km the Normal model predicts a slightly greater attenuation than the Whole Italy model;
3. the Reverse and Strike-Slip model is very similar to Whole Italy model within the first 20km, but beyond this distance the attenuation is significantly lower.

In other words, at a given epicentral distance, the Normal model predicts lower *Is* compared to the Whole Italy while the Strike-Slip and Reverse model predicts higher values. This is similar to what empirically observed from strong ground motion. It should be noted, however, that the classification adopted based on style-of-faulting implicitly carries a regionalization: the normal faulting style is found, in fact, along the Apennines, while the strike slip and reverse one in the NE Italy and in the Apulian area in Southern Italy (see Fig. 1).
Recent studies by Malagnini *et al.* (2000; 2002) show that these areas are characterized by different geometric and anelastic attenuation that leads to a faster decay of the ground motion in central and southern Apennines compared to North-Eastern Italy. Thus, the results shown in Fig. 6 can be attributed both to the effect of the regionalization and to the style-of-faulting, but at this stage it is impossible to discriminate between them.
Compared to the attenuation models proposed by Carletti and Gasperini (2003), Albarello and D'Amico (2004) and Pasolini *et al.* (2006), in the Whole Italy model intensity decays less rapidly within the first 90km of epicentral distance (Fig. 7). For distances greater than 90km, the attenuation predicted by the Whole Italy model is greater than the Albarello and D'Amico (2004) model, but lower than the Carletti and Gasperini (2003) and Pasolini *et al*. (2006) models. At the epicentre the value of ΔI predicted by the Whole Italy model asymptotically tends to zero.

The fit curve of the Etna volcanic proposed in the present study is very similar to that one proposed by Azzaro *et al*. (2006).
In fig. 8, we compare the attenuation relationships obtained in this study (Etna relationship is excluded) with intensity decays observed for some earthquakes which were not used in the regression analysis, i.e. macrosismic data of new earthquakes compiled in the updated Italian macroseismic database which are online at: http://emidius.mi.ingv.it/DBMI07/.

In particular the figure 8a compares the Normal attenuation relationships obtained in this study with the intensity decay observed in the Irpinia earthquake of 1466-01-15 (I_{Max}=8/9; N_{IDP}=31); the epicentre of this earthquake is located in Sannio-Irpinia-Basilicata seismogenic zone (ZS927) which is characterized by predominant normal style-of-faulting.
In fig. 8b and 8c, the attenuation relationships for Strike Slip+Reverse is confronted with the intensity decay observed of Vizzini earthquake of 1895-04-13 (I_{Max}=6/7; N_{IDP}=32) and Valle del Chiampo earthquake of 1908-03-15 (I_{Max}=6; N_{IDP}=28). The first event is located in the Iblei seismogenic zone (ZS935) which has a predominant strike-slip style-of-faulting and the second event is located in a seismogenic zone with predominant reverse style-of-faulting (Garda-Veronese; ZS906). The intensity decay observed of Biellese earthquake of 1936-10-17 (I_{Max}=6/7; N_{IDP}=15), which is outside the seismogenic zones of ZS9, is confronted with the relationship Whole Italy. The three relationships can be considered as a good estimation of the intensity decay observed of these four earthquakes.

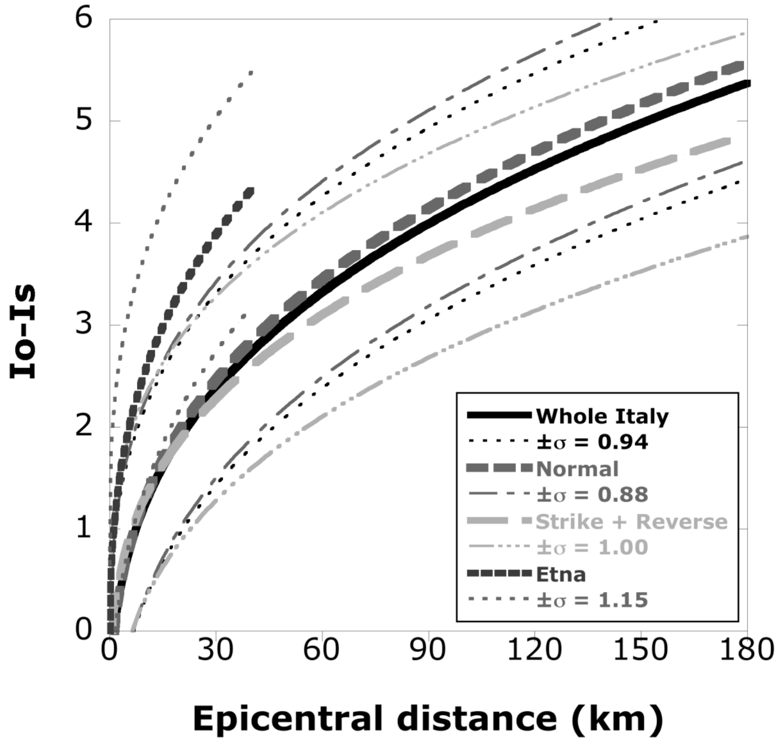


Fig. 6. Intensity attenuation models obtained in this study.

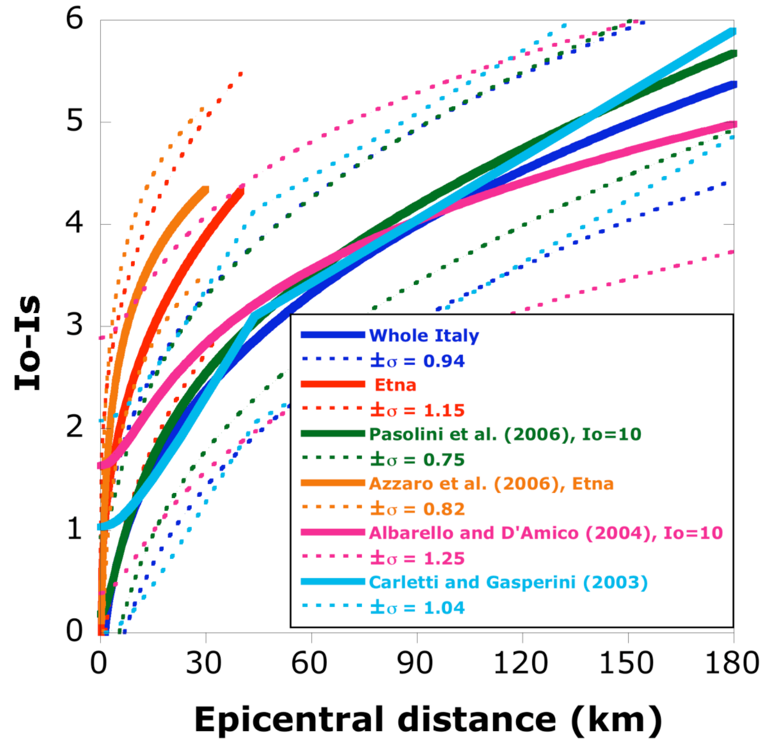


Fig. 7. Comparison between the intensity attenuation models "Whole Italy" and "Etna" with those obtained by recent studies in Italy.

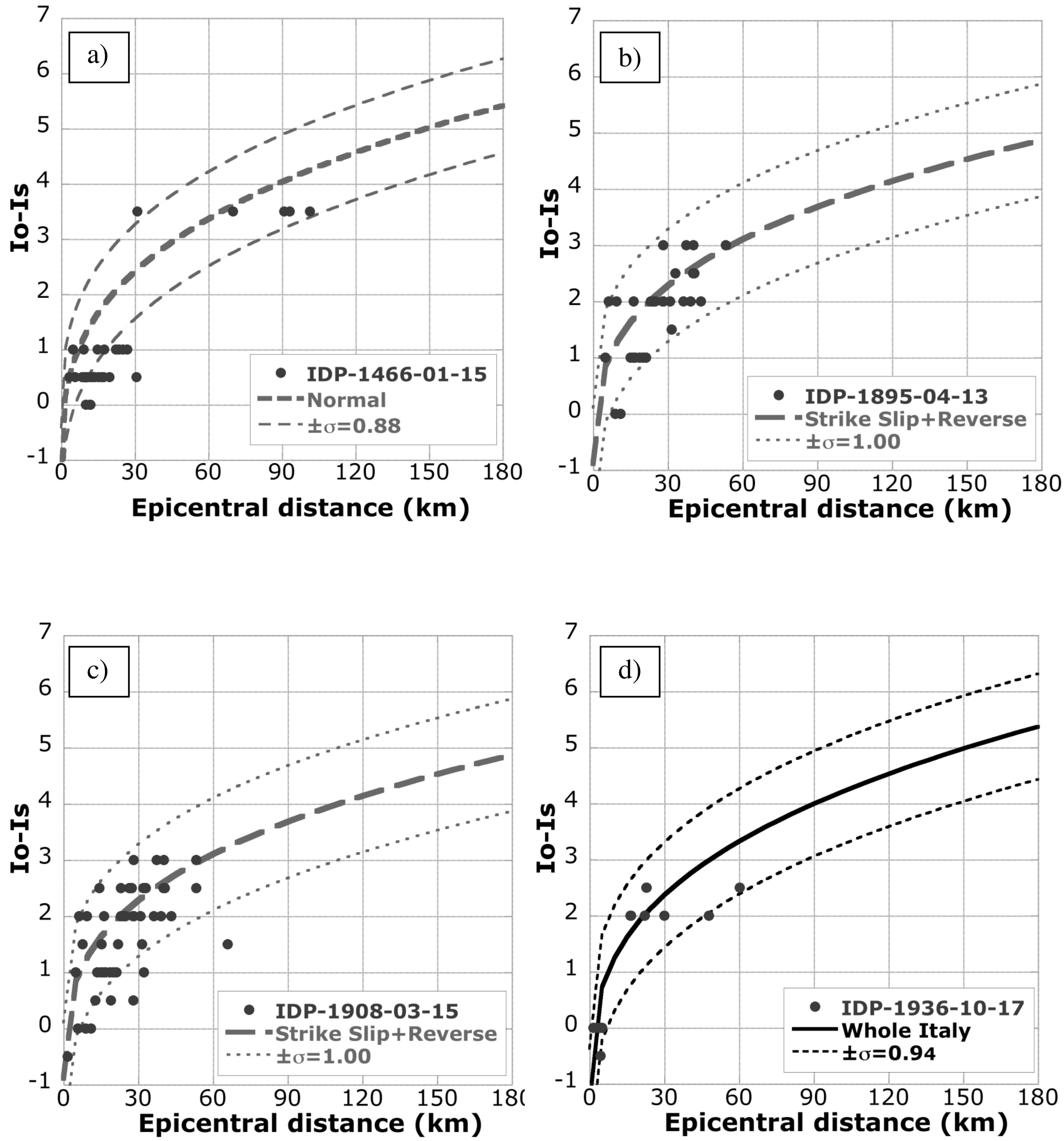


Fig. 8. Comparison between attenuation relationships obtained in this study with the IDP of four earthquakes which were not used in the regression analysis. a)Irpinia earthquake; b)Vizzini earthquake; c)Valle del Chiampo earthquake; d)Biellese earthquake.

5. Results

Logic tree

Logic trees are used in PSHA as a tool to capture the epistemic uncertainty associated with the seismogenic sources and the ground-motion relationships used to evaluate the seismic hazard (Bommer *et al*., 2005). In Italy, there isn't in scientific literature a valid alternative seismogenic zonation of ZS9. Ground-motion relationships in terms of intensity by Pasolini *et al*. (2006), Azzaro *et al*. (2006) and those developed in the present work are considered as alternatives in the present study.

Following the above assumptions and the state-of-the-art and the methodology used in Gruppo di lavoro MPS (2004), some alternatives of epistemic character have been explored using a logic tree in the present study:

a) Earthquake catalogue completeness time-intervals determined using either the historical or statistical approach (Gruppo di lavoro MPS, 2004);
b) Criteria to assess I_0max i.e., the maximum epicentral intensity for each seismogenic zone of ZS9; I_0max1 is derived from seismological and geological data and I_0max2 is based from criterion to carry the value I_0max =9 all the seismogenic zone with I_0max of catalogue CPT04 less than this value.
c) Criteria to compute the seismic rates: activity rates (AR) and Gutenberg-Richter rates (GR);
d) Two groups of intensity attenuation relationships. The first group uses the relationships obtained in the present study (Tab. 5; Fig. 6); the second group uses the relationship proposed by Pasolini *et al.* (2006; Tab. 2) for all seismogenic zones of ZS9, except the Etna volcanic zone (ZS936), which has been applied the relationship proposed by Azzaro *et al*. (2006).

Figure 9 shows the logic tree and the weighting scheme:

1) To the historical completeness and the statistical completeness weights of 60% and 40% respectively are assigned. Historical completeness was given a larger weight because they included an analysis of a larger amount of data;
2) The set of individual seismicity rates (activity rates, AR) and of Iomax1 (60%) are weighted more than the Gutenberg-Richter rates (GR-rates) and the set of Iomax2 (40%) because AR are considered cautionary values.
3) The weight of the relationships developed in this study is equal (50%) to Pasolini *et al.* (2006) and Azzaro *et al.* (2006) relationships (50%) because both studies are based from the same intensity database (DBMI04) but the physical assumptions are different. Style-of-faulting are included in the present study of intensity attenuation using CRAM model while Pasolini *et al*. (2006) proposed a new approach on the analysis data and physical assumptions such as to consider the anelastic dissipation and geometrical spreading. The two alternative levels of intensity attenuation models used in the logic tree have the same distance metrics which have been calibrated using epicentral distance observed in the intensity data points for each earthquake of DBMI04. On the other hand, for each relationship are associated with different standard deviations as follows (Tab. 5): in the present study, 0.94 in "Whole Italy" model, 0.88 in "Normal " model, 1.00 in "Reverse + Strike-Slip" model and 1.15 in "Etna" model. In Pasolini *et al*. (2006) the standard deviation is 0.75 and in Azzaro *et al*. (2006) is 0.82 for the Etna zone (Tab. 2).

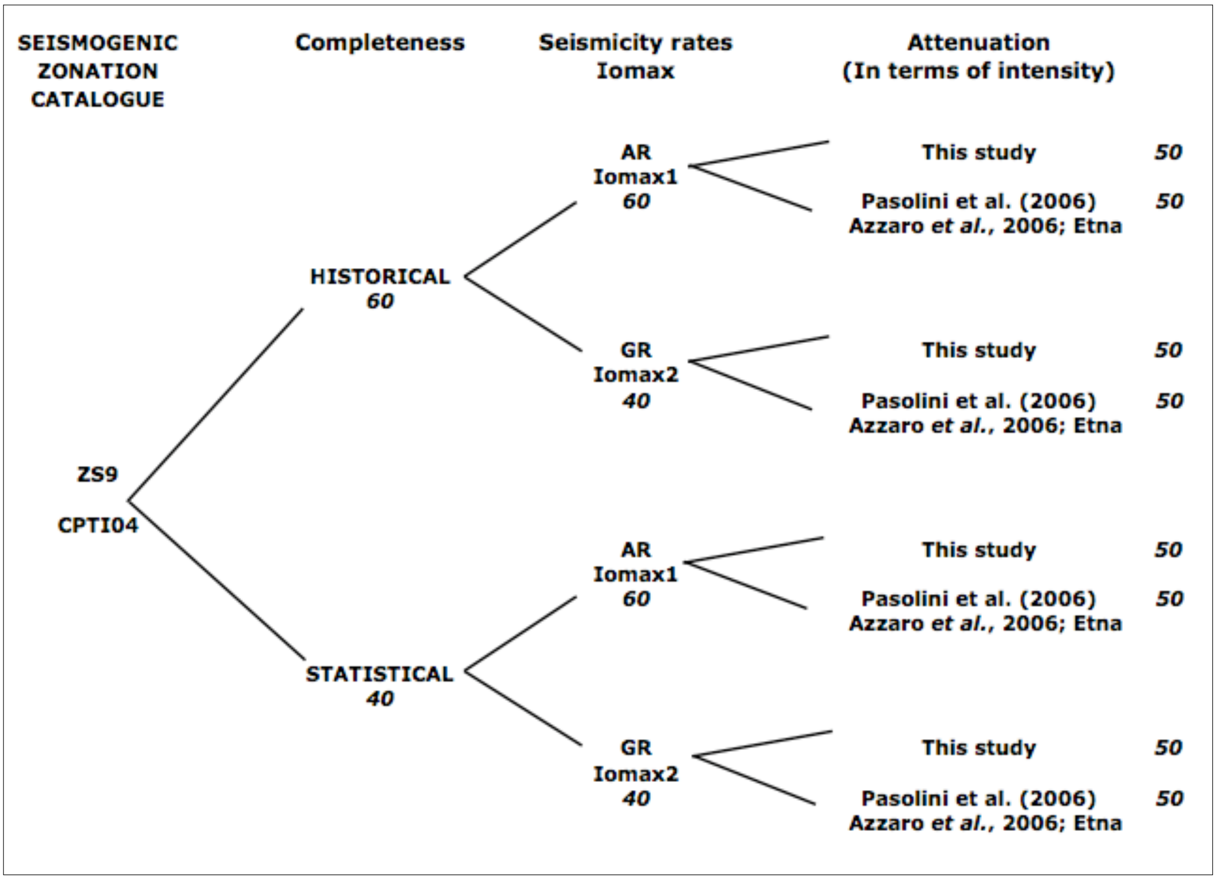


Fig. 9. Logic tree and weight values for seismic hazard calculation in terms of macroseismic intensity.

5.1 Seismic hazard in terms of macroseismic intensity

The values of *Imax* with a 10% probability of exceedance within a 50-year exposure time (475-year return period) were obtained applying the logic-tree framework (fig. 9). Results are given as:

- Distribution of median (50th percentile; fig. 10a) of the 8 branches of the logic tree;
- Distribution of 16th percentile (fig. 10b);
- Distribution of 84th percentile (fig. 10c).

In figure 10a, the higher Imax value is 9 MCS, observed in Central and Southern Italian continental territory and Eastern Sicily.

The minimum value in the Italian peninsula is equal to 5/6 MCS. The values of the distribution of 16th and 84th percentile are not very different (fig. 10b and fig. 10c), as they range between 5/6 MCS and 9 MCS in the first case and between 6 MCS and 9 MCS in the second one.

The difference between the value of the 84th percentile and the median (i.e. the maximum uncertainty on the seismic hazard assessment) can be as high as 0.5. Such moderate difference between the percentiles can be due to the small number of branches (only 8) used in the logic tree, but it also related to the discrete nature of the intensity data. Thus adding more branches to the logic tree may not introduce enough variability to determine an increase (or decrease) of the intensity level at a given site.

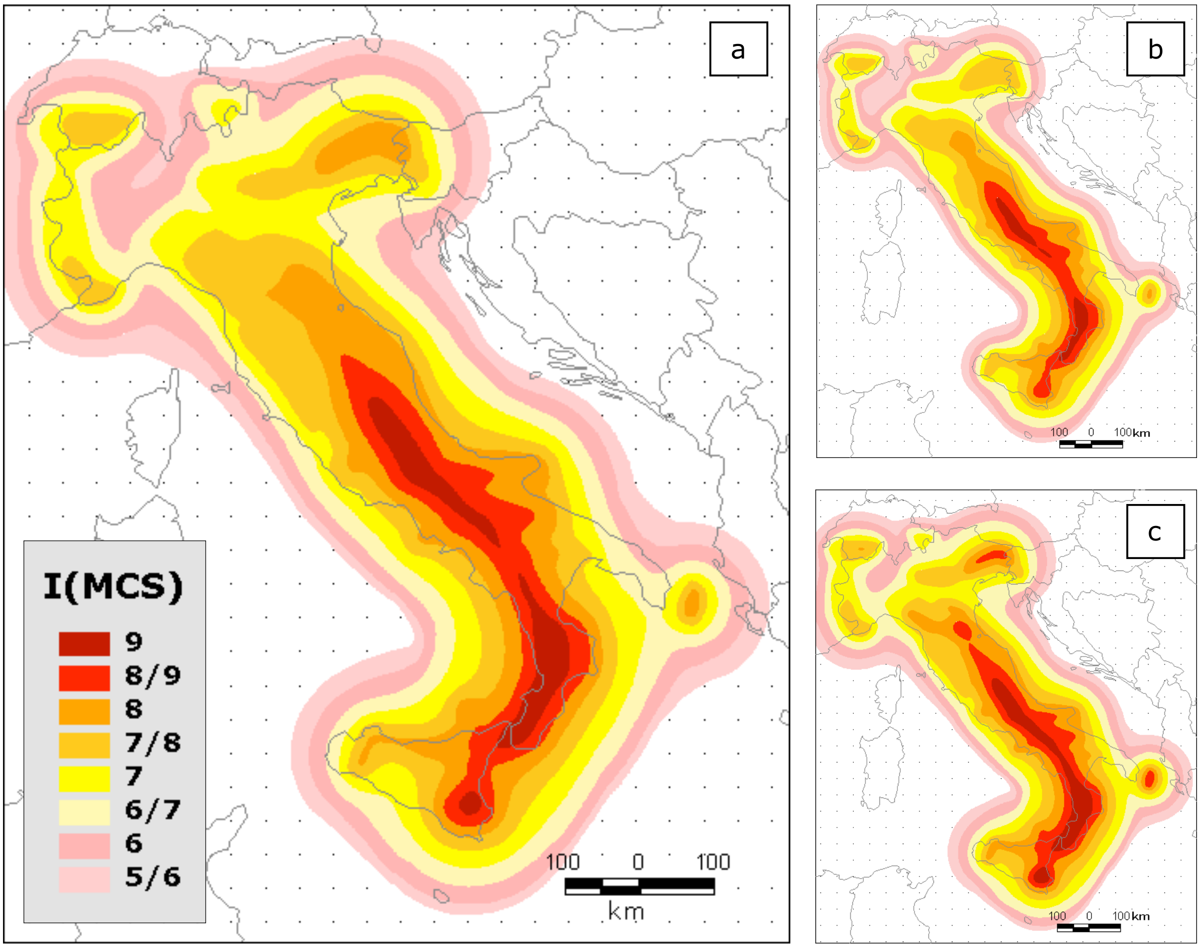


Fig. 10. Seismic hazard map in terms of macroseismic intensity (*Imax* with a probability of exceedance 10% within a 50-year exposure time) for Italy. The standard deviation in the intensity attenuation model has been accounted for.

a) Map of distribution of the 50th percentile;
b) Map of distribution of the 16th:
c) Map of distribution of the 84th.

5.2 Comparison between this study and previous PSHA in terms of intensity

Fig. 11 shows the Italian seismic hazard maps (10%/50 years) proposed by Slejko *et al.* (1998), Albarello *et al*. (2000) and this study, which are represented in integer degrees values. In Slejko *et al*. (1998), the most hazardous areas are in the North-eastern Alps, Central and Southern Apennines and Calabria. The highest values of Imax are greater than 10 MCS in Calabria.

In Albarello *et al*. (2000) the most hazardous areas (Imax=9) are in the Central and Southern Apennines, Calabria and Northeastern and Southern Sicily.
The comparison between the maps in figure 11 shows that:

- the Imax values in the present study are generally higher than those obtained from Slejko *et al* (1998) and Albarello *et al*. (2000);
- in our results, areas with Imax lower than 5 MCS disappear;
- as concerns values equal to 6 MCS, in our study the areas are significantly reduced respect to Slejko *et al*. (1998) and Albarello *et al*. (2000);
- in the present study, areas with 7 or 8 MCS expand nearly all over Italy and Sicily; in particular the areas with Imax equal to 7 MCS expand in Po Plain, Tuscany, South-western of Sicily and Apulia region and the areas with Imax equal to 8 MCS expands nearly all Italian peninsula, Sicily and eastern Alps;
- in the three studies, the areas with Imax equal to 9 MCS are very similar in Central and Southern Apennines and Calabria while disappear in North-eastern of Italy (eastern Alps) in our results respect to Slejko *et al*. (1998);
- in Southern of Sicily, areas with Imax equal to 9 are similar between our results and Albarello *et al*. (2000);
- the highest values of Imax (8, 9 MCS) in Slejko *et al*. (1998) and Albarello *et al*. (2000) are more spatially heterogeneous than those obtained in the present study.

With the exception of Calabria and eastern Alps, it should be noted that the hazard values in this study are generally increased respect to Slejko *et al.* (1998) and Albarello *et a*l. (2000) where aleatory uncertainty associated to intensity attenuation model had been disregarded.
Discrepancies observed between the three maps could be mostly attributed to input data since the 3 studies are based on the some methodology i.e. PSHA. The input elements used in PSHA by Slejko *et al*. (1998) and Albarello *et al*. (2000) are different from those used in the present study.

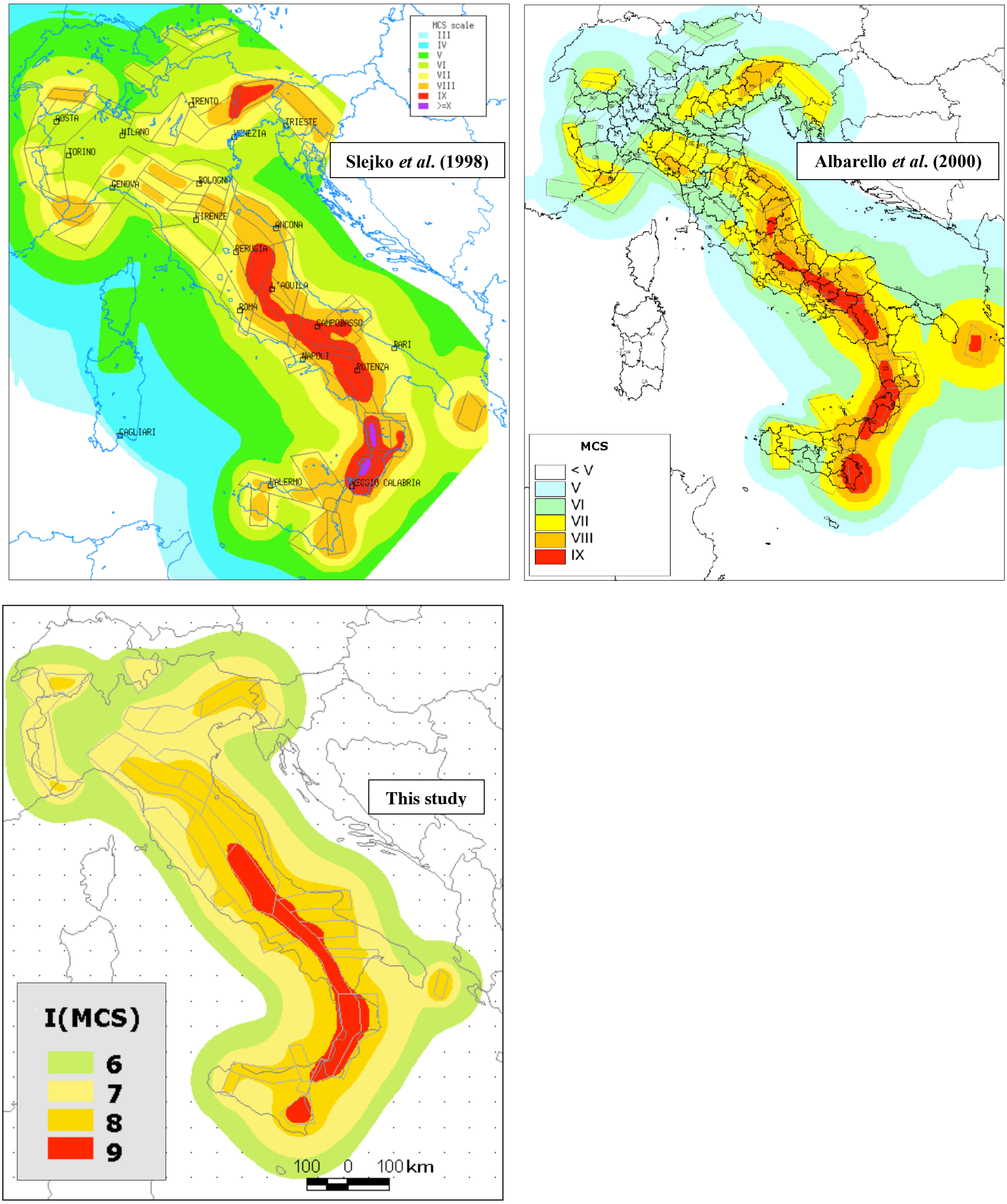


Fig. 11. Comparison between Slejko *et al.* (1998), Albarello *et al.* (2000) and results of this study, which are represented in integer intensity degrees.

5.3 Comparison between this study and MPS04

Empirical relations between macroseismic intensity and PGA are mathematical tools useful to transform the probability of macroseismic intensity level into the probability of PGA. These empirical relations dependent on large and damaging well-recorded calibration earthquakes with both instrumental records and macroseismic intensities observed. Not many studies deal with the relationship between intensity and PGA and the majority have been published for the western USA and Japan (Boatwright *et al*., 2001; JMA, 1996; Midorikawa *et a*l., 1999; Karim and Yamazaki, 2002; Atkinson and Kaka, 2007; more examples in Tab. 6). Particularly is observed that PGA often not to correlate well with damage as consequence the standard deviation is large; various examples of standard deviation in logarithm scale are shown in Tab. 6.

Earthquake Research Committee (2005) has used this method to transform the probability national seismic hazard map in terms of PGV into probability macroseismic intensity map in JMA scale. To small geographic scale, Bozurt *et al.* (2007) have been used intensity-PGA relationships (Fujimoto and Midorikawa, 2005) to transform seismic hazard in terms of intensity to seismic hazard in terms of PGA, in the Kanto plain (Japan) on which Tokyo sits, without incorporated the standard deviation of the intensity-PGA relation. In the present study we compared preliminary the seismic hazard map in terms of intensity (figure 10a) with the national seismic hazard maps MPS04 using Intensity-PGA empirical relations.

In Italy, relationships between the intensity data and PGA records have been proposed among others by Margottini *et al*. (1992) and by Faccioli and Cauzzi (2006) which used earthquakes of the Mediterranean area (Italy, Turkey, Algeria, France and Slovenia; Tab. 6). The relationship of Margottini *et al.* estimates PGA from intensity. Margottini *et al.* (1992) define the local intensity as those intensity data determined using a localized approach, based on a description of effects in the immediate vicinity and in the same lithological, morphological and hydrogeological conditions as the recording instrument itself. On the contrary, the relationship of Faccioli and Cauzzi estimates intensity from PGA. In Gómez Capera (2006) is obtained a relationship that estimate PGA from intensity using the dataset published by Faccioli and Cauzzi (2006) (Tab. 6). Some relationships published in literature are shown in figure 12.

The seismic hazard map in terms of Imax values shown in figure 13a has been converted in PGA values using the relationship of Margottini *et al*. (1992) (local intensity) and a relationship obtained in Gómez Capera (2006) from data published by Faccioli and Cauzzi (2006). Following as example to Earthquake Research Committee (2005) and Bozurt *et al.* (2007), we simplify the use of the intensity-PGA relationships such that the standard deviation of these relations have not been treated in this study. The propagation of the uncertainty of the intensity-PGA relation inside of probabilistic frame is a technical, which are even working.

Figure 14 shows the converted seismic hazard map obtained through the weighted mean of the two empirical relationships used, according to the scheme shown in figure 13. The relationship obtained in Gómez Capera (2006) from data of Faccioli and Cauzzi (2006) receives a higher weight (67%) compared with 33% of Margottini *et al*. (1992) because the dataset used in that study is more recent.

The maximum PGA value is equal to 0.32g for a site located in Calabria (Southern Italy). Figure 15 shows the MPS04 seismic hazard map in PGA proposed by Gruppo di Lavoro MPS (2004), where the maximum value is equal to 0.28g.

Figure 16 shows the difference between the maps in figures 14 and 15: the positive values (shades of red) indicate areas where the values of the converted map are greater than those of the MPS04 map; on the contrary, the negative values (shade of blue) indicate areas where MPS04 values are greater than seismic hazard map converted in PGA from Imax.

The smaller differences between the two maps are in the interval -0.010*g* to 0.010*g* (in white). In general, the areas outside the seismogenic zones of ZS9 (fig. 16) show greater PGA values in the converted map (up to 0.075g) than those in MPS04. It can be observed that for an epicentral distance greater than 100km, the macroseismic intensity decays less rapidly than PGA, thus providing higher ground-motion values.
In Central and Southern Italy the PGA values obtained from Imax are on average 0.025g greater than the values of MPS04. It should be noted however that the intensity is a measure of ground shaking while the seismic hazard map MPS04 has been derived specifically for hard ground. This can in part explain such difference.
Negative difference values (up to 0.075g) in North-Eastern Italy, Northern Apennines and North-Western Sicily can be related to the use of regional empirical ground-motion attenuation relations in MPS04.

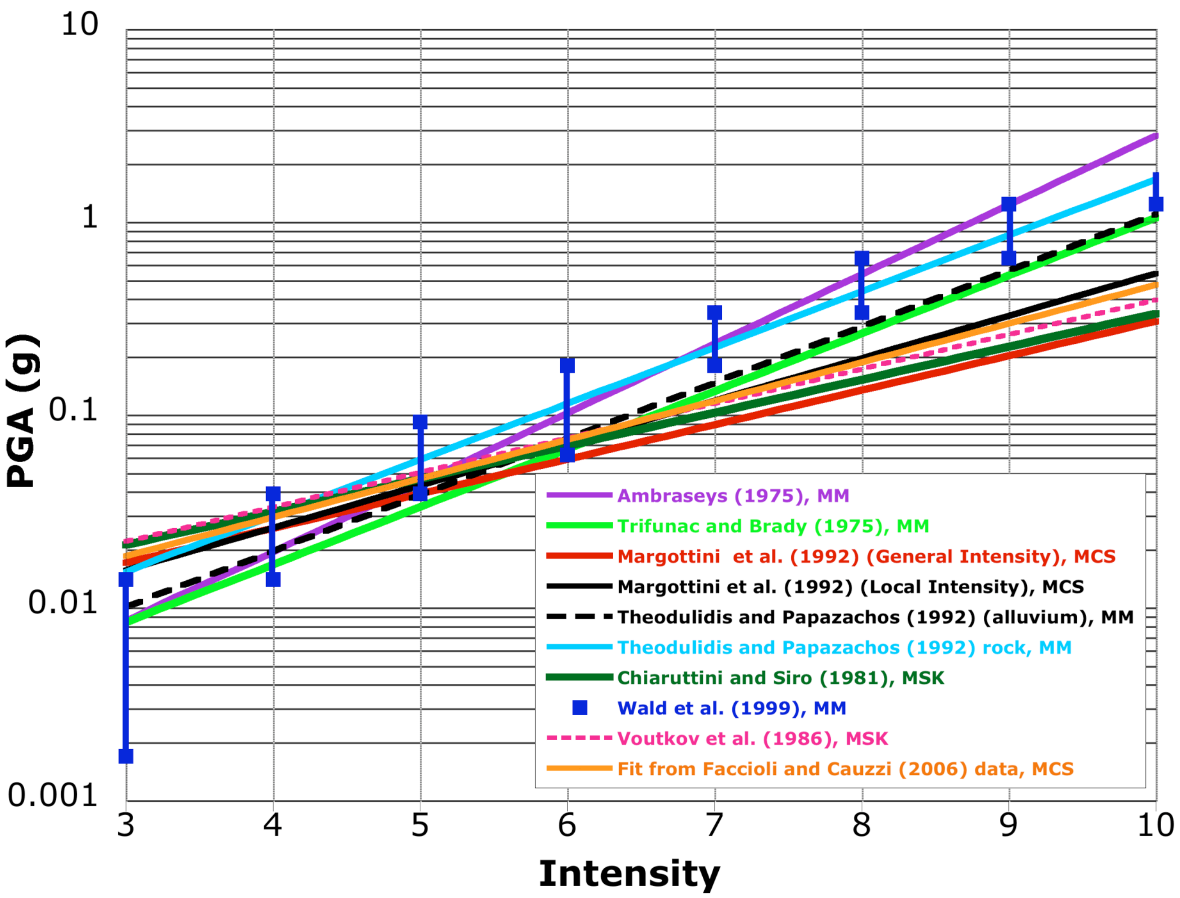


Fig. 12. Comparison of some macroseismic intensity/PGA relationships published in literature.

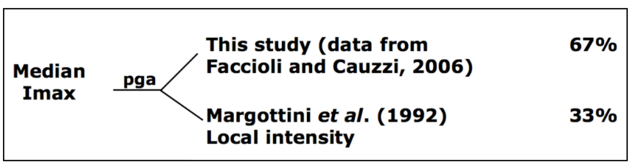


Fig. 13. Weigh values used to convert the *Imax* in PGA

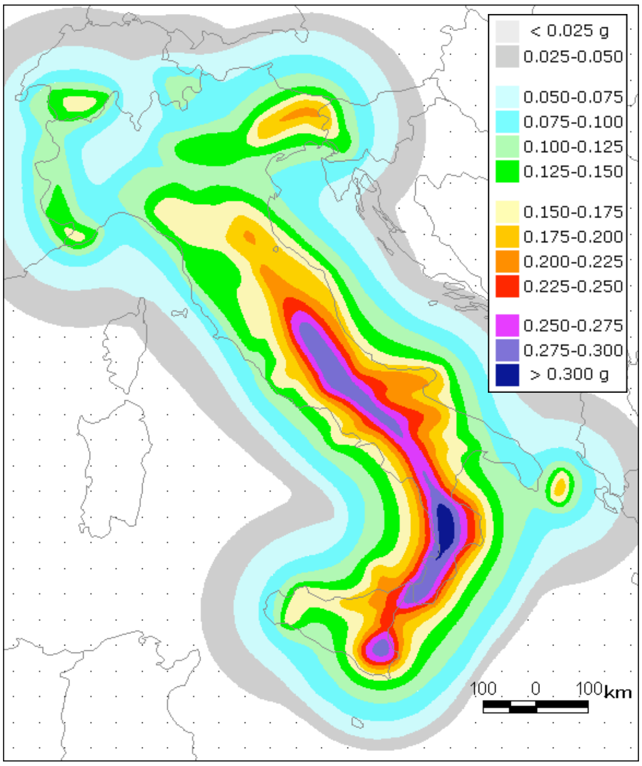


Fig. 14. According to the weighting scheme in figure 16, seismic hazard map in terms of intensity converted in PGA values using the relationships of Margottini *et al*. (1992) and that one obtained by Gómez Capera (2005) from dataset of Faccioli and Cauzzi (2006).

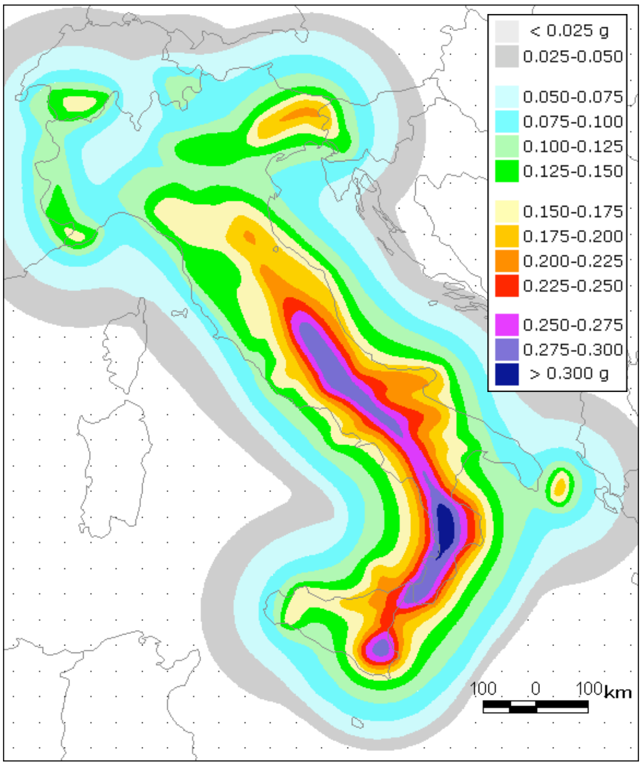


Fig. 15. Seismic hazard map in PGA proposed by Gruppo di Lavoro MPS (2004; http://zonesismiche.mi.ingv.it).

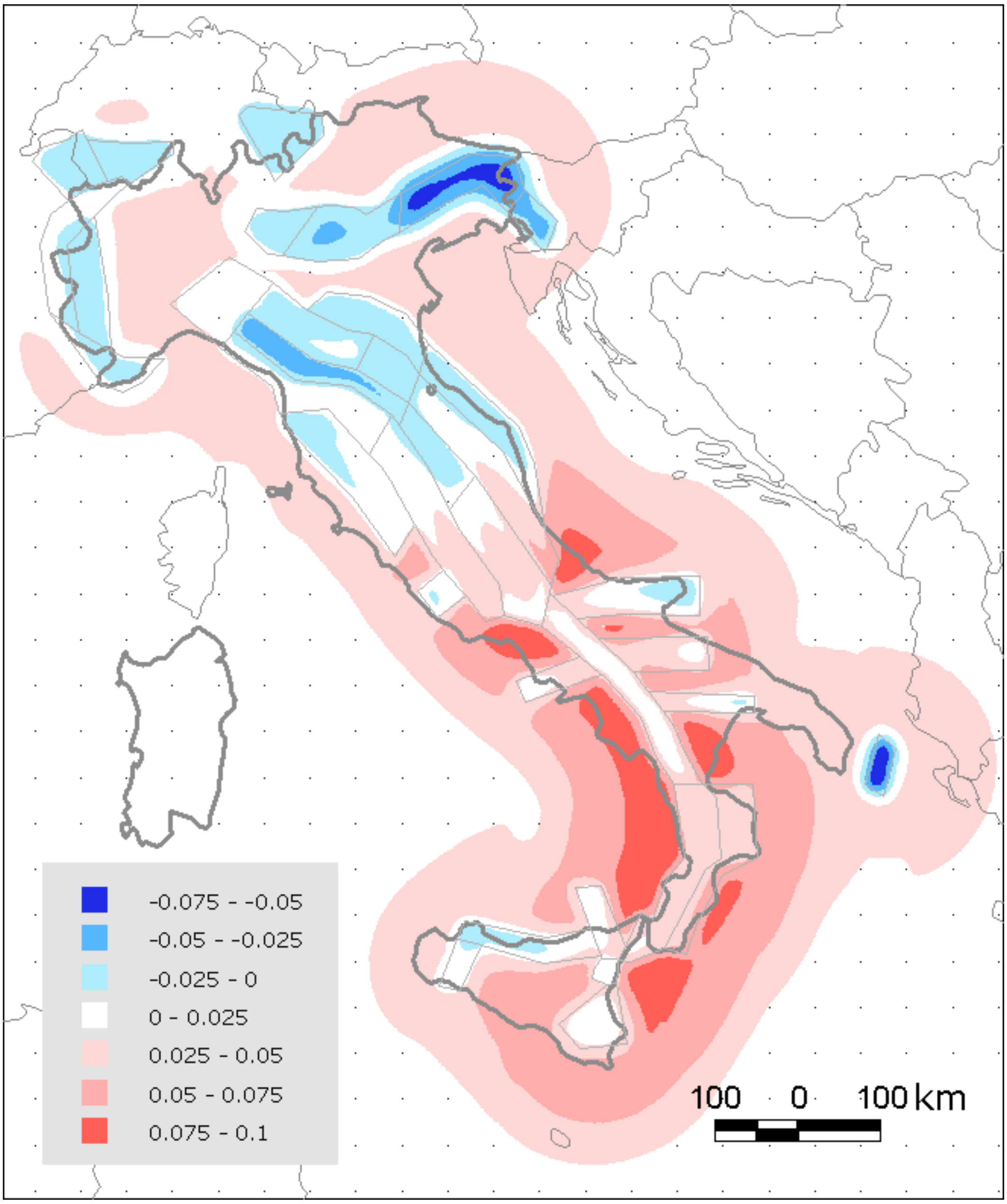


Fig. 16. Difference between the maps shown in figures 17 and 18.

6. Summary and Conclusions

The present study has used the informative content of the macroseismic data to gain a better knowledge of the intensity attenuation and of the seismic hazard in Italy.
New intensity attenuation relationships for Italian territory are proposed using the most recent Italian macroseismic database DBMI04. These relationships include one valid for the whole Italian territory, a set of relations that account the predominant style-of-faulting (normal, reverse and strike-slip) and one relationship for the Etna volcanic zone (these relationships are shown in Tab. 5).
After Slejko *et al*., (1998) and Albarello *et al*. (2000), a new seismic hazard map in terms of macroseismic intensity with 10% probability of exceedance in 50 years is proposed for Italy. The hazard map has been deduced by applying the PSHA and updated input elements, such as:

- Earthquake catalogue CPTI04 (Gruppo di Lavoro CPTI, 2004);
- Seismogenic zonation ZS9 (Gruppo di Lavoro MPS, 2004);
- Historical and statistical completeness time intervals (Gruppo di Lavoro MPS, 2004);
- Two macroseismic intensity attenuation models: one set proposed in this study and one proposed by Pasolini *et al.* (2006); Azzaro *et al.* (2006) was used for the seismogenic zone ZS936 (Etna zone).

The calculation of the seismic hazard has taken into account the epistemic and aleatory uncertainties; this is a regular practice in PSHA in terms of peak ground acceleration. Through the computer code SeisRisk III (Bender and Perkins, 1987) which has been modified to be used with intensity data, i.e. allowing a normal instead of a lognormal distribution of the residuals.
The seismic hazard map in terms of macroseismic intensity obtained has been preliminary converted in PGA. The standard deviation of the intensity-PGA relationships have not been treated in this study. However the converted seismic hazard map in PGA proposed is in agreement with the results obtained by Gruppo di Lavoro MPS (2004).
The work demonstrates, that in case of reasonable filtering of input macroseismic dataset (Tab. 3) plus some modifications of the computer code it is possible to get more accurate probabilistic hazard assessment in terms of macroseismic intensity. Here the work starts from the beginning to examine of the macroseismic database to define the dataset with the intensity observation with better quality. In the intensity decays observed, it is very clearly shown that better to stop at 100 km from epicenter for earthquakes with assessed epicentral intensity Io=7 to 450 km for strong events with epicentral intensity Io=11. Beyond that limit the result can become meaningless. What is very important that this approach reduces systematic error which is seen in Fig. 19 shows very regular pattern.
From the other hand is demonstrated that the refinement of macroseismic intensity attenuation model is within the range of the uncertainties associated to the hazard evaluation. In fact, the converted seismic hazard map in PGA proposed is in agreement with the results obtained by Gruppo di Lavoro MPS (2004).
Therefore, the work shows what for is the battle: to get a better result and to understand what are the limits of this “better”. Also it is very important to understand up to what limits can be extended extrapolations.
The probabilistic seismic hazard map in terms of intensity is a tool to understand the seismic hazard associated directly with damage, which can be applied to calculate the seismic risk on a national scale.

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