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Reassessing the Italian seismic hazard using soil classification

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Reassessing the Italian seismic hazard using soil classification

Riccardo Cesari[(a)] and Leandro D'Aurizio[(b)*]

Abstract

Almost two decades have passed since the publication of Italy's official model of seismic risk (MPS04) by the National Institute of Geophysics and Volcanology (INGV). The model has undergone a thorough revision in the most recent years, leading to the new MPS19 model, still unavailable because the final evaluation steps required for its release are still in progress. The present paper aims to contribute to the awareness that physical risk measurements evolve over time with the accumulation of scientific progress, the processes' evolution and new data availability. With this purpose, the probabilistic hazard derived from the baseline view of seismic risk provided by the MPS04 model is compared with that obtained under an alternative approach recently proposed in the geo-physical literature to take into account the soil characteristics. The relevant differences of the two models are analysed and the new hazard probabilities, useful for insurance purposes, are calculated. The differences with the baseline results are highly significant and a riskier picture for the Italian seismic hazard emerges.

JEL codes: G22
Keywords: earthquake, seismic risk, hazard.

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1. Introduction

A commonly accepted approach to measure the consequences of natural risks (Poljanšek et al., 2017, cap. 2) combines the probability distribution of events (hazard), the exposure value, and a vulnerability measure.

This paper aims to evaluate the probabilistic hazard of seismic risk for Italy because it is the most relevant physical peril for the country (EIOPA, 2023).

We assess this hazard on an extensive grid currently used by the Italian National Institute of Geophysics and Vulcanology (INGV) to evaluate seismic risk. It is relevant to remark that only 54% of these points are on the ground, while almost all the other are in the sea and a very limited number on the ice of glaciers.

Our starting point is the measurement of Peak Ground Acceleration (PGA), a physical measure of ground shaking in different micro-areas expressed as a percent of g (the acceleration due to Earth's gravity, amounting to 9.81 meters per second squared, m/s^2).

We derive the PGA from a recently developed technique (REASSESS) that relies on the superficial soil's features and we then compare it with the traditional PGA publicly available on the INGV web site from 2004, obtained by the MPS04 model. We compare both the statistical distributions and the geographical diffusions of the two PGAs and for this latter our results are displayed both with the traditional representation and by an innovative one that will be used with the new MPS19 model of seismic risk as soon as it is officially released.

Our following step is to transform the REASSESS PGA into an exceedance probability (relative a measure of the damages caused by an earthquake) by a methodology developed and tested on the INGV PGA (Cesari and D'Aurizio, 2019, 2021). It emerges that the new exceedance probability is higher than the older one, indicating that Italy's actual seismic risk might be under-estimated.

The paper is organised as follows. The second paragraph briefly exposes the MPS04 and the REASSESS models which we use to derive the PGA. The third paragraph presents the method producing the exceedance probabilities from the PGA. The fourth paragraph displays and comments the results. The fifth paragraph concludes.

2. The models

2.1 The MPS04 model

The INGV divides Italy's surface into areas with uniform seismic hazard by using 16,852 points forming an evenly spaced grid, with each square having 0.02 degrees of longitude and latitude.

For every point of the grid the official INGV methodology called Modello di Pericolosità Sismica 2004 (NGV, 2004), known under the acronym MPS04, derives sixteen geographical distributions for the PGA, each obtained by combining all the levels of three factors: a) different degree of completeness of the historical catalogues of earthquakes used (2 levels), b) different methods of determining seismic intensity (2 levels), c) different measurements of earth-shaking attenuation (4 levels). Each geographical distribution is assigned a weight, representing the degree of trust in the specific method. From the sixteen possible values obtained for each point of the map, the weighted 16th, 50th and 84th percentiles are finally determined. The median is the central evaluation, with the 16th and 84th percentiles, respectively representing an optimistic and a pessimistic assessment of the local seismic risk. The measurement is replicated for the nine exceedance probabilities

{2%,5%,10%,22%,30%,39%,50%,63%,81%}, representing the probabilities of at least one event with PGA equal or higher than the assigned PGA over a 50-year observation period.

In all our future developments we will consider the median values of the PGA.

If we indicate the exceedance probability per the grid point z over 50 years with $\alpha_{z,50,PGA}$ and if the events are distributed according to a Poisson law, the average yearly number of events with PGA higher or equal than the assigned PGA $\lambda_{z,50,PGA}$ can be written as:

$$\lambda_{z,50,PGA} = -\frac{\ln(1-\alpha_{z,50,PGA})}{50} \qquad [eq. 1]$$

The return period $n_{z,50,PGA} = \frac{1}{\lambda_{z,50,PGA}}$ is the average number of years between two consecutive events with PGA higher or equal than the assigned PGA.[1]

For any given exceedance probability α_m in *m* years, the MCS04 model provides a PGA for the point *z,* corresponding to this probability, formally expressed as:

$$PGA_{z,\alpha_m} = max\left\{PGA_z\text{:}\quad Prob\left(\left[\sum_{t=1}^{m} I_{PGA_{z,t}>PGA_z}\right] \geq 1\right) = \alpha_m\right\}, \qquad where\; m = 50 \qquad [eq. 2]$$

In eq. 2, $I_{PGA_{z,t}>PGA_z}$ denotes a dummy variable equal to one in case of occurrence of the event $PGA_{z,t} > PGA_z$, zero otherwise (*z* and *t* indicate respectively a point of the grid and a year). PGA_{z,α_m} is hence the greatest value exceeded with probability α_m over *m* years by at least one ground shaking.

The Italian building code NTC18 (NTC, 2018), which civil engineers use to compute buildings' resilience to seismic events, is based on this model, with $m = 50$ and $\alpha_m = 10\%$.

A new model known with the acronym MPS19 is going to replace MPS04 as soon as all the complex evaluations required by all the stakeholders are completed (Meletti *et al.*, 2021). The new model should update the Italian building code, currently based on MPS04 model. For this reason, the model considers only declustered seismicity and covers the whole national territory using rock as the reference soil; the hazard is expressed in terms of PGA, peak ground velocity (PGV), peak ground displacement (PGD) and other physical parameters. The model is based on Probabilistic Seismic Hazard Analysis and describes in a probabilistic way the forecast of a variety of ground motion intensity measures on the Italian territory. It is based on open and transparent procedures that guarantee completely reproducible outcomes, but up to now it has not yet been released.

2.2 The new REASSESS model

The alternative model we consider in the paper takes into account that during an earthquake the seismic wave amplification related to local site conditions can have a significant impact on the ground motion (Forte *et al.*, 2019) and that the average shear-wave velocity of the upper 30m ($V_{S,30}$), or the equivalent shear-wave velocity from the ground to the depth of the seismic bedrock when this is less than 30m ($V_{S,eq}$) must be taken into account.[2] The paper's authors have made available to the practitioner a stand-alone software (SSC-Italy), which derives those parameters and is therefore a useful support for large-scale seismic risk studies such as this one.

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[1] By using the previous equation, the nine exceedance probabilities used by INGV become the following nine return periods: {2475, 975, 475, 201,140,101,72, 50, 30}.

[2] $V_{S,eq}$ overcomes some limitations of $V_{S,30}$ and for this reason it is referred by the recent Italian building code ItBC2018.

We have used the software to classify all the points of the INGV grid according to the characteristics of the shallow soil and hence derive the shear-wave velocity. This parameter is an input to get an estimate of the PGA according to the Reassess method (Chioccarelli *et al.*, 2019). The software also provides the standard deviation of the shear-wave velocity.

Like MPS19, this method uses the Probabilistic Seismic Hazard Analysis (PSHA) in order to evaluate the rate of earthquakes causing an exceedance of any arbitrary ground-motion intensity measure at an arbitrary site of interest. The measurement is carried out by focusing on the main shock of a seismic event, considering the exceedance beyond a given threshold due to the earthquake of prominent magnitude within a cluster of events. In such a way the homogeneous Poisson process can be used.[3]

According to the homogeneous Poisson process, earthquakes on a seismic source exceeding a given intensity *im* take place by the rate λ_{im} and the probability of observing $N_{im}(\Delta T)=n$ events of this kind in the time interval ΔT is given by:

$$Prob(N_{im}(\Delta T) = n) = e^{-\lambda_{im}\Delta T}\frac{(\lambda_{im}\Delta T)^n}{n!} \qquad n = 0,1,2,\ldots$$

The main feature of the Reassess method is the computation by numerical methods of the following hazard integral for the rate λ_{im}, when the given site is exposed to earthquake risk derived from n_s seismic sources.

$$\lambda_{im} = \sum_{i=}^{n_s} \nu_i \cdot \iiint\limits_{M\ X\ Y} P[IM > im|m,x,y]_i\, f_{M,x,y,i}(m,x,y)dm \cdot dx \cdot dy$$

In the equation the *i* subscript indicates the ith seismic source; ν_i is the rate of earthquakes within the range deemed possible for the source; $f_{M,x,y,i}(m,x,y)$ is the joint probability density function (PDF) of earthquake magnitude *M* and location {*X, Y*} ; $P[IM > im|m,x,y]_i$ is the exceedance probability conditional on the magnitude and location (via a source-to-site distance metric).

This integral relies on a joint probability distribution of the exceedance where earthquake magnitude and location are considered stochastically independent, with the first factor modelled according to an exponential distribution and the second by a suitable form of the uniform distribution.

The model uses soil condition as input and enables to derive for the single points the PGA, together with an array of other physical parameters under two hypotheses of soil conditions: 1) rock, which is the standard condition; 2) user-defined soil condition identified by the shear-wave velocity obtained by the SSC-Italy software. We apply the model to the 8,859 points of the INGV grid that are neither at sea nor on ice, covering the whole surface of Italy's landmass, and obtain the PGA for the 9 INGV return periods.

Differently from MPS04, the REASSESS model does not provide the time length (indicated with *m* and measured in years) of the observation period, from which the exceedance probabilities could be derived by using the Poisson law written as:

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[3] The method also enables to take into account of the aftershock effects by keeping the properties of the homogeneous Poisson process. This version of the method is called Sequence-based probabilistic seismic hazard analysis (SPSHA). We prefer not to use this version of the method in our paper in order to get PGA estimates more comparable with those obtained from the MPS04 method, which does not explicitly model aftershock effects. We have used the version of the method called *multi-site probabilistic seismic hazard analysis* (MSPSHA), to account for the stochastic dependence existing among the processes counting exceedances at each of the considered sites. This feature is suitable for the risk assessment of building portfolios or spatially-distributed infrastructure for which hazard must account for exceedances at multiple sites jointly.

$$\alpha_{z,m,PGA} = 1 - e^{-m\lambda_{z,m,PGA}}$$

As shown in Section 3, this is not an obstacle for the derivation of our exceedance probabilities.

3. From pga to exceedance probability

We have developed (Cesari and D'Aurizio, 2021) a method to derive from the PGA an expression for the exceedance probability:

$$\alpha_{z,m}(\overline{MCS}) = Prob\left(\left[\sum_{t=1}^{m} I_{MCS_{z,t} > \overline{MCS}}\right] \geq 1\right) \qquad [eq. 3]$$

where MCS is the macro-seismic intensity measure developed by Mercalli, Cancani and Sieberg, on an ordinal scale ranging from I to XII that assesses the total damages caused by an earthquake to population and buildings.[4]

The expression in eq. 3 is suitable for insurance pricing, for which the main interest is estimating the exceedance probability of a seismic event greater than a measure of earthquake damages over a time horizon usually shorter than 50 years (e.g. 5 or 10 years).

We recapitulate the method's main steps

- We derive the MCS from the PGA by using the equations developed by Michelini and Faenza (2010), which require the knowledge of Peak Ground Velocity (PGV), another physical measure normally associated to seismic events. These equations are routinely used by the INGV to produce a quick estimate of MCS within a few hours after a seismic event.[5]

  Therefore we first need to estimate PGV and we do this by fitting a log-linear model on an extensive collection of seismic events for which both PGA and PGV are available, before applying the Michelini and Faenza's model to derive MCS. The dataset on which the log-linear relation is estimated is very large and the model's fitting capacity is very high, enabling to generalize the utilization of these parameters.

- We obtain λ by estimating the relation between λ and MCS through the following log-linear relation:

  $$ln(\lambda_{z,j}) = \beta_0 + \beta_{1,z} + \beta_2 MCS_{z,j} + \varepsilon_{z,j} \qquad [eq. 4]$$

  where *j* indicates the generic exceedance probability among the nine available.

  The equation is estimated by a panel model with fixed effects, where the unit is the geographical point *z* and the repeated measurements are indexed with *j*.

  To obtain α from λ, we use the following relation (valid under the standard assumptions of the Poisson model) linking the exceedance probability (relative to a macro-intensity level equal to MCS) over m years with the average yearly number of events higher or equal to MCS indicated with λ:

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[4] MCS is a slight modification of the original scale proposed by Luigi Mercalli in 1908. When it is used (with small variations) in the English-speaking countries it is indicated as MMI (*Modified Mercalli Intensity*).

[5] The INGV produces a *ShakeMap* for any seismic event occurring in Italy or in the surrounding areas. These maps are downloadable from the webpage: http://shakemap.rm.ingv.it/shake/archive/. They collect the M_L, a map of the geographical diffusion of the MCS/MMI and a complete list of PGA and PGV for all the points of the INGV grid covering all the Italian territory, with an MCS/MMI estimate obtained with the orthogonal regression of Faenza and Michelini (2010). The *ShakeMap* is available within a few hours after the seismic event.

$$\alpha_{z,m}(MCS) = 1 - e^{-m\lambda_z(MCS)} \quad [eq. 5]$$

- From the coefficients estimated by eq. 4 we derive the exceedance probability over any number m of years and for any $MCS = \overline{MCS}$ level by simply plugging the estimate of $\lambda_z(MCS)$ into eq. 5:

$$\alpha_{z,m}(\overline{MCS}) = 1 - e^{-m\left(\hat{f}e^{(\hat{\beta}_0+\hat{\beta}_{1,z}+\hat{\beta}_2\overline{MCS})}\right)} \quad [eq. 6]$$

In eq. 6 we insert an adjustment factor $\hat{f}$, in order to constrain the predicted values obtained by a transformation of a log-linear model such as eq. 4 to have the same mean as the empirical values.

This method was originally applied to the INGV (MPS04) PGA, but it is applicable to other earthquake scenarios too. We therefore use it to derive an alternative exceedance probability (in terms of MCS) from the REASSESS PGA. Note that the various steps do not require the knowledge of the exceedance probabilities for the PGA, not provided by the REASSESS model.

We finally remark that the need of a measure for seismic risk also usable outside the building codes has recently been acknowledged also within the geo-physical community. In their presentation of the results of the MPS19 model, Meletti *et al.* (2021) represent the exceedance probability referred to PGA=0.15g over a 50-year time interval. This PGA value is chosen as a measure of significant shaking. The authors think that this representation is more interpretable to laymen and it should also dispel the misinterpretation that the PGA reported by standard maps is the maximum, not just a conditional maximum, which can occur in a given area.

4. Comparing and discussing the results derived from INGV and REASSESS pgas

4.1 The differences in the PGA

The comparison between the $PGAs$ from the two models is feasible for the 8,859 points of the INGV grid not on sea or ice, covering the whole Italian landmass, and for the nine return periods for which the INGV releases the PGA obtained by the MPS04 model (tab. 1).

The box-plots (fig. 1) display the higher dispersion of the REASSESS PGA, that emerges both in the higher gap between the third and the first quartiles and in the higher distance of the extreme values from the core of the distribution.

The REASSESS PGA tends to be greater than the INGV one and this gap increases as the return period becomes higher (fig. 2). Within the same return period the discrepancy tends to affect the right tail of the distribution more than the left part. The REASSESS PGA also shows a higher degree of dispersion (measured by the variation coefficient) than the INGV one, even if it tends to slightly decrease for higher return periods, whereas the dispersion of the INGV PGA increases. Finally, the correlation between the two $PGAs$ rises from 0.8367 (for the 30-year return period) to the maximum of 0.9403 when the return period attains 2475 years (fig. 3). For high-frequency events (30-year return period) the median REASSESS PGA decreases by -19%, but for low-frequency events (2475-year return period) It increases by +72%.

Table 1

Distributions of the *PGAs* from the INGV (MPS04) and the REASSESS models

return period (years)(a)	number of points(b)	1st decile	1st quartile	median	mean	3rd quartile	9th decile	variation coefficient	standard deviation
	INGV (MPS04)								
30	8,859	0.0195	0.0295	0.0418	0.0424	0.0549	0.0648	39.0080	0.0166
50	8,859	0.0253	0.0367	0.0542	0.0545	0.0704	0.0845	39.9250	0.0218
72	8,859	0.0295	0.0424	0.0640	0.0644	0.0829	0.1010	40.6320	0.0262
101	8,859	0.0333	0.0488	0.0750	0.0751	0.0969	0.1187	41.4630	0.0311
140	8,859	0.0370	0.0551	0.0868	0.0866	0.1124	0.1383	42.3480	0.0367
201	8,859	0.0414	0.0627	0.1016	0.1008	0.1312	0.1644	43.3550	0.0437
475	8,859	0.0545	0.0854	0.1408	0.1415	0.1860	0.2375	45.6800	0.0646
975	8,859	0.0661	0.1092	0.1798	0.1839	0.2437	0.3159	47.7460	0.0878
2475	8,859	0.0828	0.1455	0.2434	0.2517	0.3360	0.4447	50.6090	0.1274
	REASSESS								
30	8,859	0.0097	0.0181	0.0338	0.0410	0.0593	0.0814	68.5540	0.0281
50	8,859	0.0140	0.0239	0.0428	0.0545	0.0769	0.1120	70.2890	0.0383
72	8,859	0.0204	0.0355	0.0613	0.0752	0.1067	0.1526	66.5050	0.0500
101	8,859	0.0262	0.0456	0.0784	0.0940	0.1312	0.1905	65.8960	0.0620
140	8,859	0.0316	0.0535	0.0959	0.1145	0.1589	0.2313	65.8730	0.0754
201	8,859	0.0404	0.0695	0.1287	0.1489	0.2065	0.3027	64.6910	0.0964
475	8,859	0.0633	0.1127	0.2056	0.2334	0.3219	0.4691	63.0740	0.1472
975	8,859	0.0873	0.1579	0.2873	0.3233	0.4472	0.6436	61.8600	0.2000
2475	8,859	0.1245	0.2313	0.4195	0.4670	0.6547	0.9130	60.4670	0.2824

(a) The return period is the average number of years between two consecutive events with PGA higher or equal than the assigned PGA and is expressed as the reciprocal of the average yearly number of events with PGA higher or equal than the assigned PGA. From eq.1 it corresponds to an exceedance probability - (b) Number of points of the INGV grid for which the REASSESS PGA was computable, corresponding to all Italy's landmass (54% of the total grid points).

We finally compare the geographical distribution of the PGAs from the two models for the 475-year return period. We first use the standard classification used by the INGV for its maps (fig. 4.a-4.b), which uses a unique category for the $PGAs$ greater than 0.275g.[6] A riskier picture of seismic events by using the alternative model REASSESS clearly emerges, since the geographical areas with the uppermost PGA values are greater in fig. 4.b compared to fig. 4.a.

We also represent (fig. 5) the two sets of PGA by a new categorization that will be adopted in the risk maps produced with the new MPS19 model (Meloni *et al.*, 2019). Its main innovations are that:

1) whereas the previous categorization used a constant 0.025g width, this width is used only up to the category [0.175,2.000], whereas the upper categories are wider;

2) six additional categories are introduced to cover PGA values above the previous 0.300g maximum of the MPS04 model;

3) a new palette of colors is associated to this new categorization, based on well-established international practices, which avoids using the green color (normally associated with absence of danger) for areas where a certain degree of risk is however present.[7]

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[6] The map in fig. 4.a for the INGV PGA has a maximum of 0.30g and includes the points of the INGV grid located in the sea and on ice.

[7] The epicentre of the strong earthquake that struck Emilia-Romagna in 2012 was in an area colored with green in the traditional maps. For an interesting discussion about this new representation of seismic risk, see https://www.eucentre.it/a-breve-il-nuovo-modello-di-pericolosita-sismica-del-territorio-italiano-intervista-a-carlo-meletti/.

This new representation is particularly suitable for the REASSESS PGA because it makes possible to classify the areas with PGA above 0.300g (fig. 5.b) into more than one group to get a better graduation of high-risk levels.

Figure 1

Box – plots of the distributions of the INGV (MPS04) *PGA* and the REASSESS *PGA*

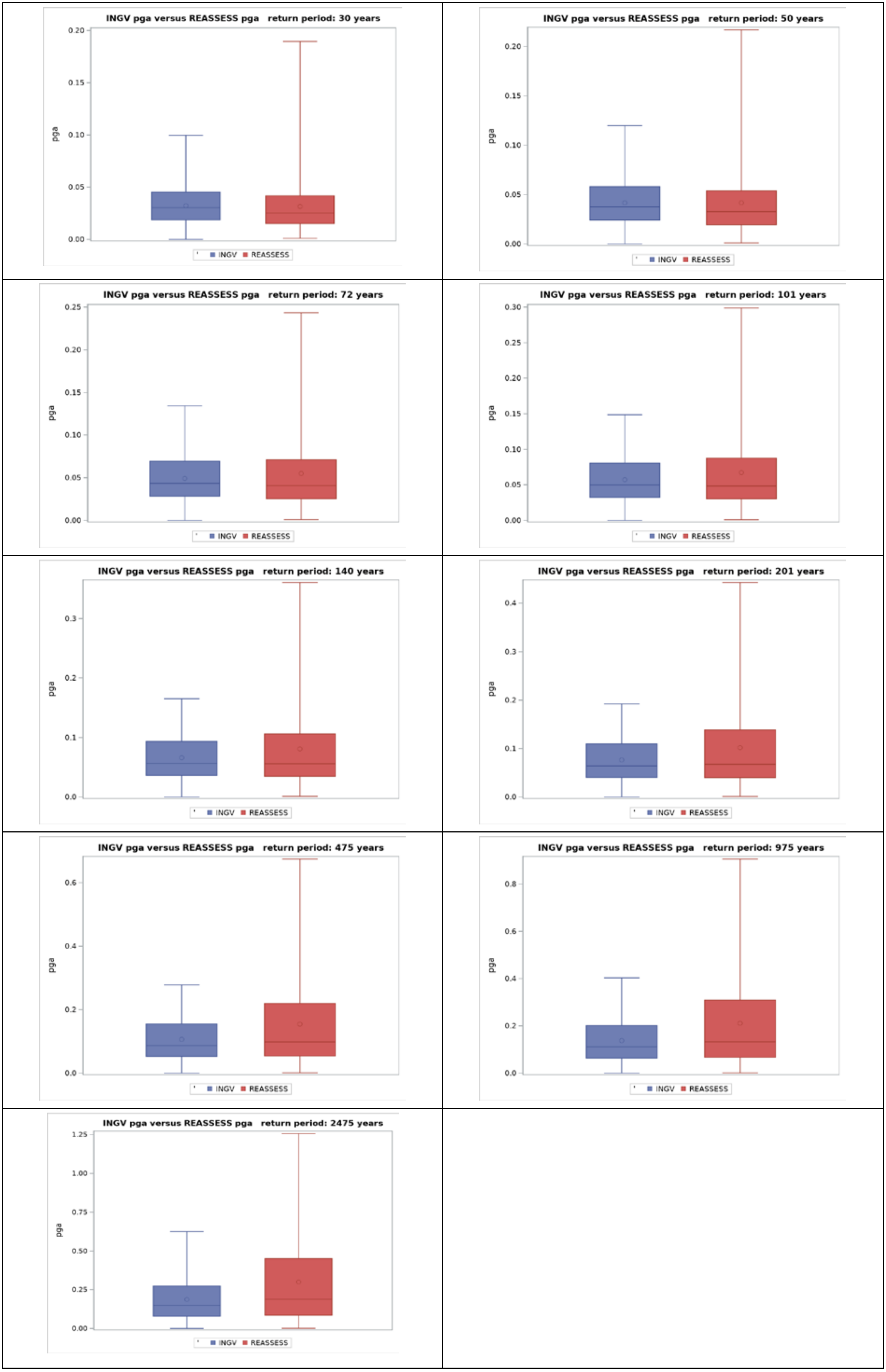


Figure 2

Distribution parameters of the REASSESS PGA

(percent ratio of REASSESS PGA over MPS04 PGA)

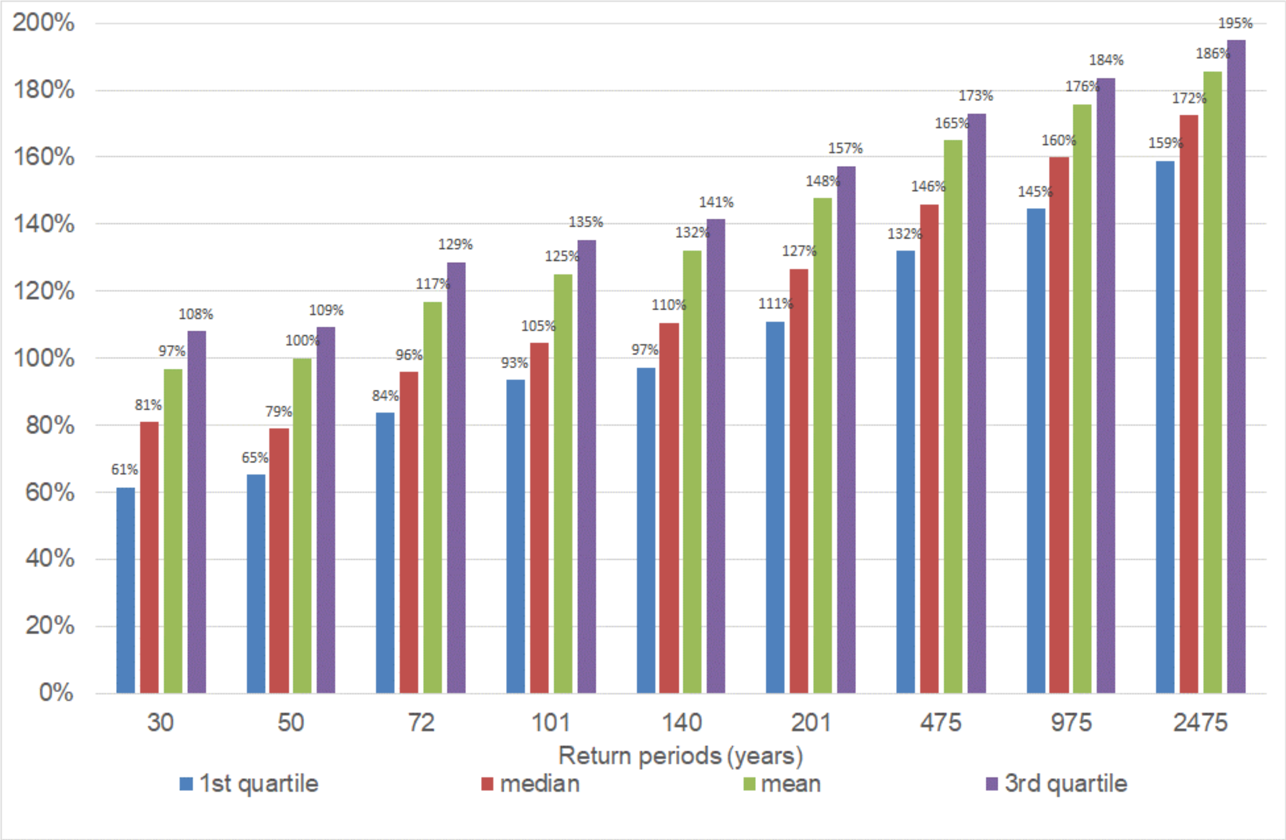


Figure 3

Correlation between the REASSESS *PGA* and the INGV (MPS04) PGA

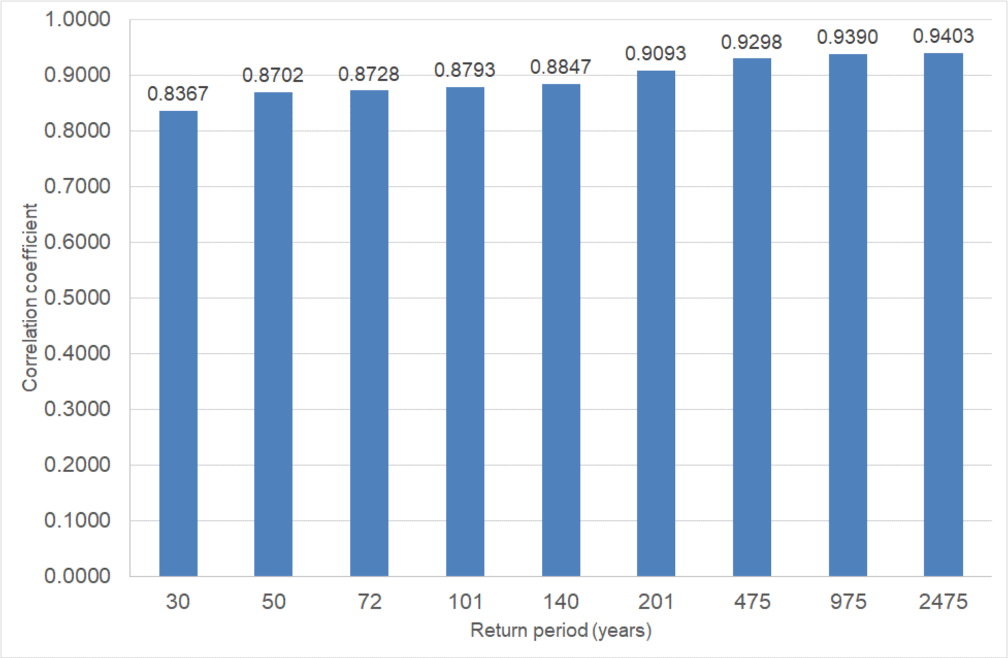
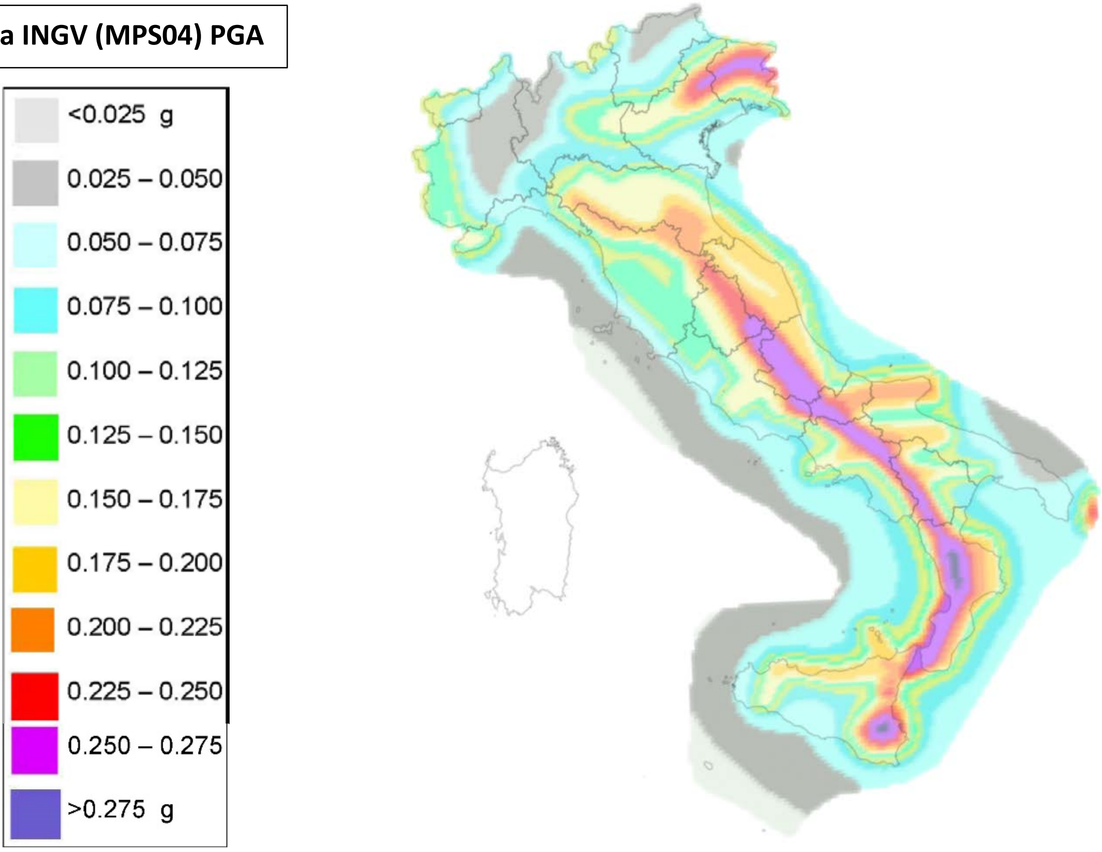


Figure 4

Risk map for the *PGA* (as a fraction of g) with a 475-year return period

4.a INGV (MPS04) PGA



4.b REASSESS PGA

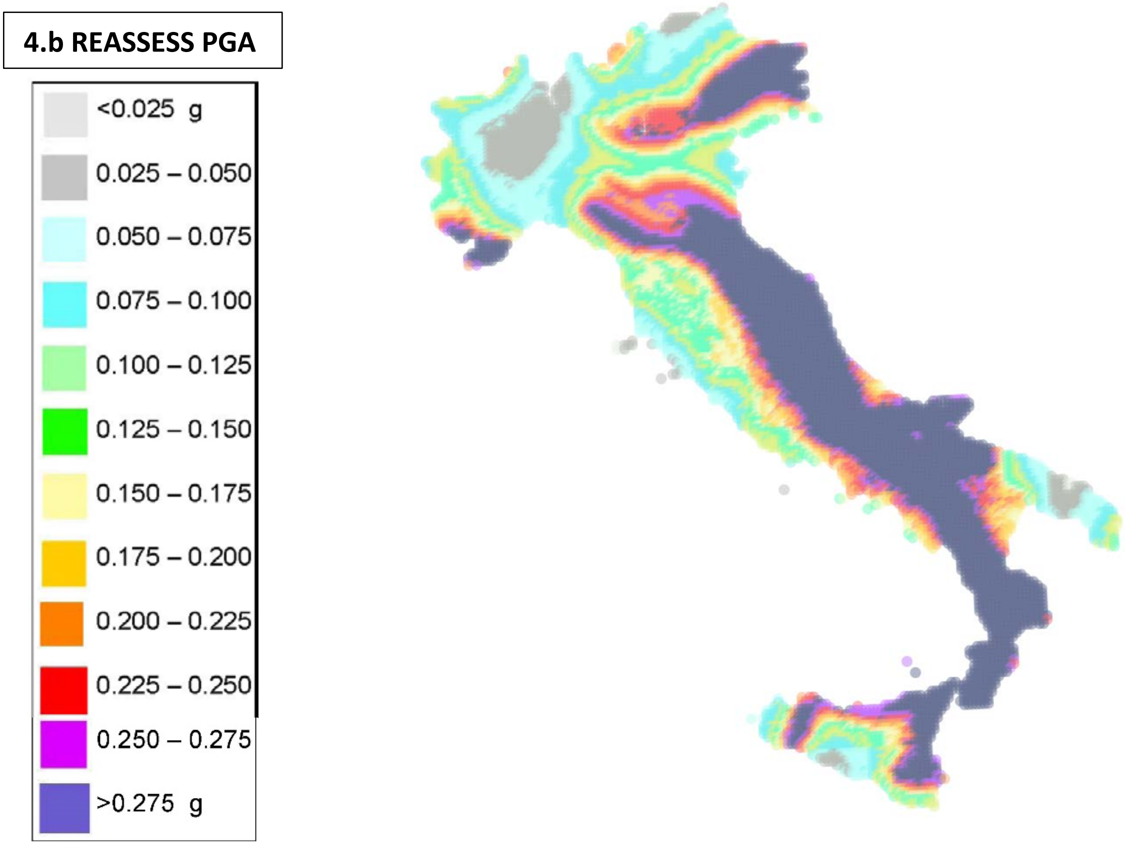
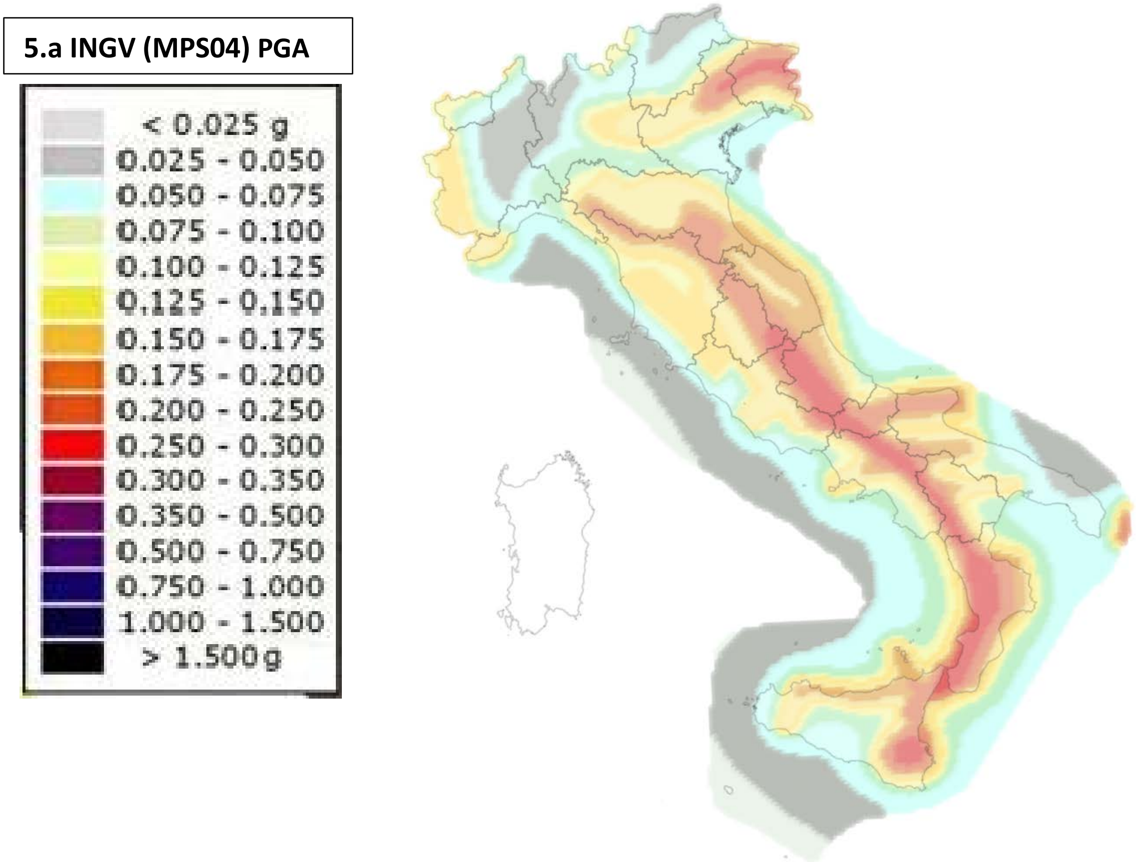


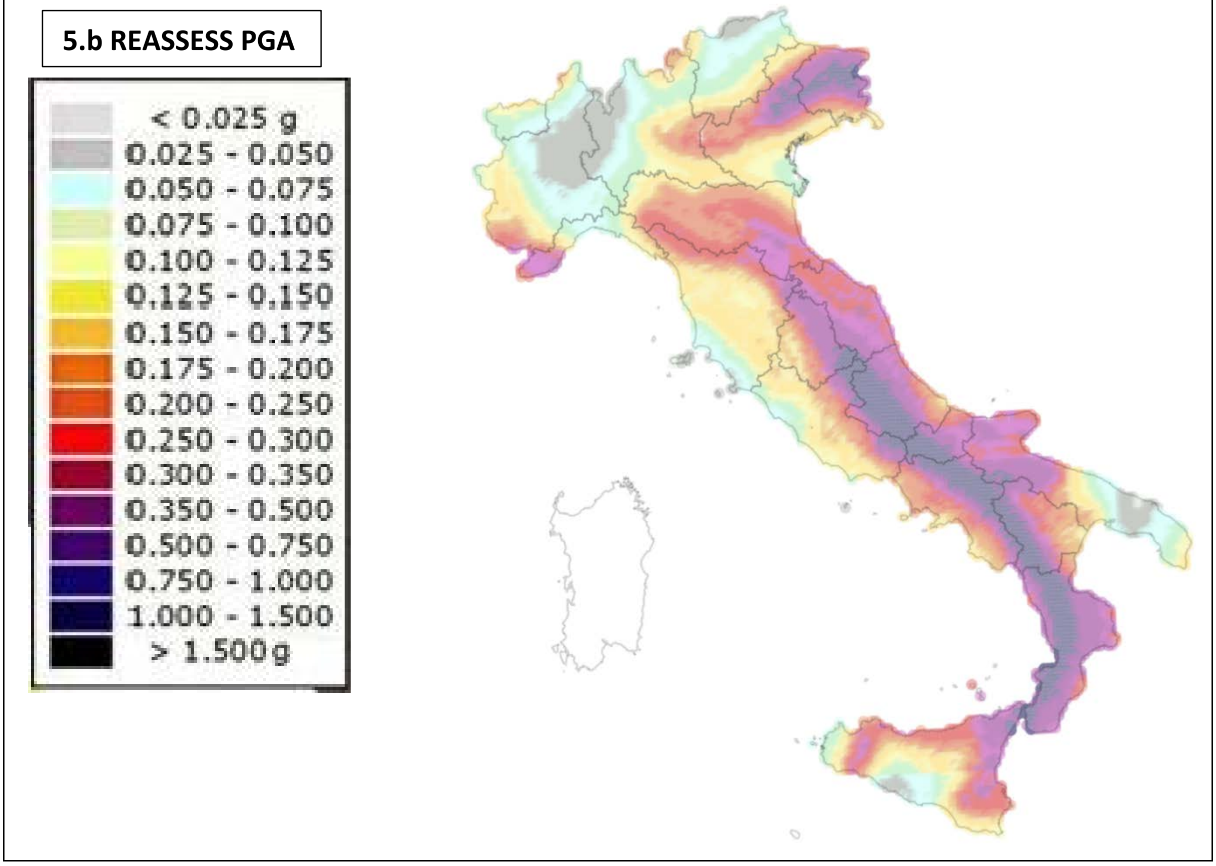
Figure 5

Risk map for the Peak Ground Acceleration (PGA) (as a fraction of g) with 475-year return period using the categorization and colors to be adopted in the MPS19 model

5.a INGV (MPS04) PGA



5.b REASSESS PGA



4.2 The exceedance probability

We now apply the method synthetically described in Section 3 to derive the exceedance probability relative to an indicator of macro-seismic intensity (MCS) from the PGA of the REASSESS model and we then compare the results with those obtained from the MPS04 PGA.

We compute the exceedance probabilities for four MCS levels VI, VII, VIII, IX, corresponding to the following levels of disruption and damage.[8]

$MCS = VI$. Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.

$MCS = VII$. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.

$MCS = VIII$. Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.

$MCS = IX$. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations. Liquefaction.

The exceedance probabilities derived from the REASSESS model are much higher than those obtained from the INGV (MPS04) model (tab. 2), with the gap (in relative terms) increasing as the level of macro-seismic risk grows (fig. 7). Within the same MCS risk category, the REASSESS exceedance probability is much more heterogeneous than the other (fig. 6), whereas the degree of correlation between the two probabilities remains stably high (fig. 8) without significant variations across the different MCS levels. For low-risk MCS (VI), the median exceedance probability decreases by -5%, but for higher-risk MCS (IX) it increases by +128%.

Table 2

Distributions of the exceedance probabilities (%) over 10 years from the *PGA*s of the INGV (MPS04) and of the REASSESS models

macro seismic intensity (*MCS*)	number of points(a)	1st decile	1st quartile	median	mean	3rd quartile	9th decile	variation coefficient	standard deviation
	INGV (MPS04)								
VI	8,859	3.7851	10.8480	24.8950	24.8470	36.2410	47.5110	62.7080	15.5810568
VII	8,859	0.7375	2.1788	5.3441	5.6696	8.2720	11.6320	69.4620	3.93821755
VIII	8,859	0.1419	0.4217	1.0481	1.1270	1.6428	2.3444	70.9210	0.79927967
IX	8,859	0.0272	0.0810	0.2019	0.2177	0.3173	0.4541	71.2070	0.15501764
	REASSESS								
VI	8,859	4.0490	9.9534	23.6530	28.5290	44.5280	62.0420	74.4790	21.2481139
VII	8,859	1.0586	2.6635	6.7133	9.2281	14.0780	22.0750	86.2340	7.95775975
VIII	8,859	0.2737	0.6927	1.7734	2.5380	3.8317	6.2206	89.9130	2.28199194
IX	8,859	0.0705	0.1788	0.4597	0.6650	1.0010	1.6401	90.9110	0.60455815

(a) Number of points of the INGV grid for which the REASSESS PGA was computable, corresponding to all Italy's landmass (54% of the total grid points).

The higher level of danger posed by seismic risk according to the REASSESS model is also graphically highlighted by the geographical representations of the exceedance probabilities for the four MCS levels considered (fig. 9-12). The maps represent the discretized exceedance probabilities by using a specific discretization for each MCS level considered.

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[8] See https://en.wikipedia.org/wiki/Modified_Mercalli_intensity_scale for further details.

Figure 6

Box – plots of the exceedance probabilities over 10 years derived from the PGAs of the INGV (MPS04) and of the REASSESS models

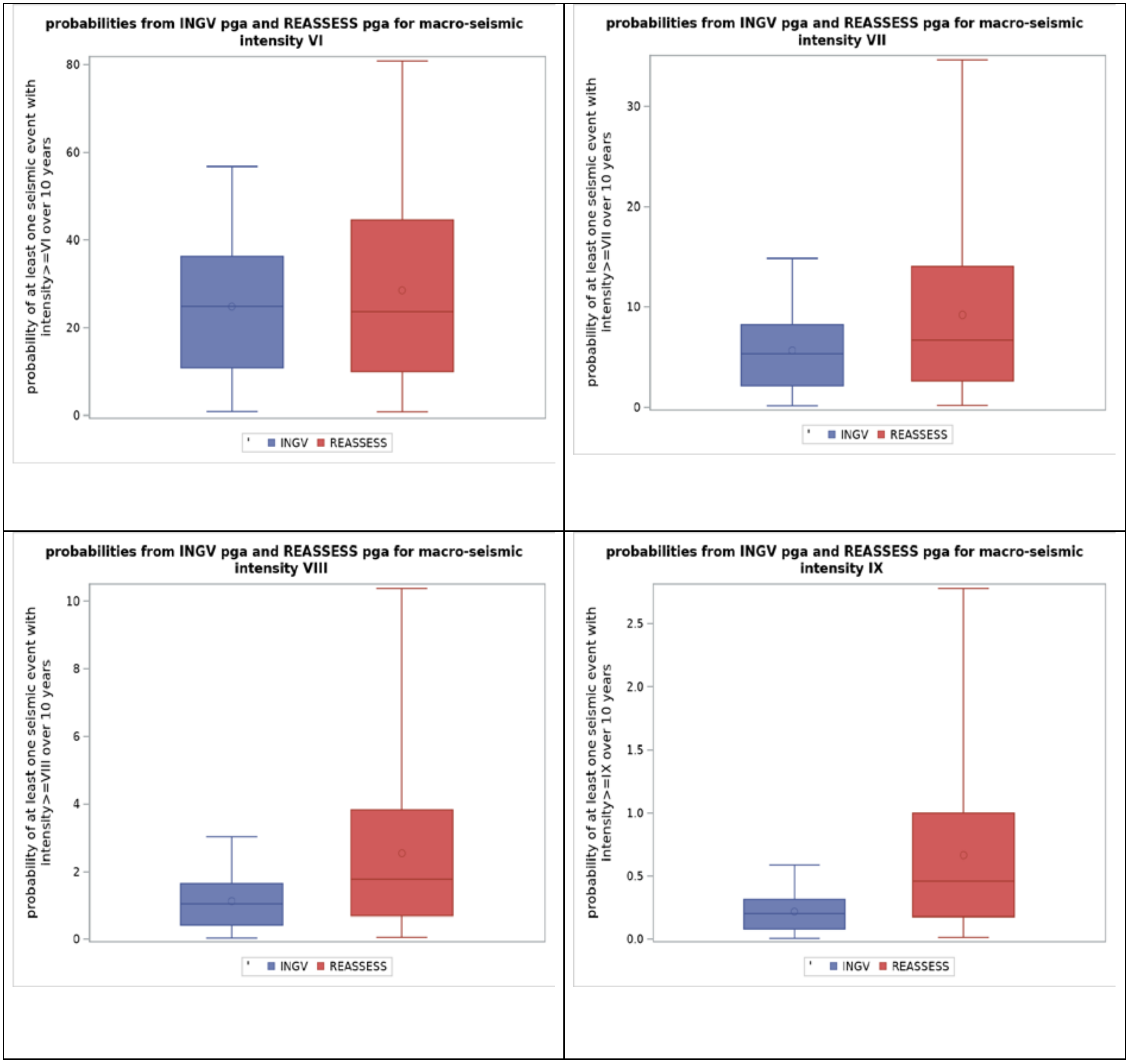


Figure 7

Distribution parameters of the exceedance probability over 10 years derived from the *PGA* of the REASSESS model

(percent ratio of REASSESS probability over MPS04 probability)

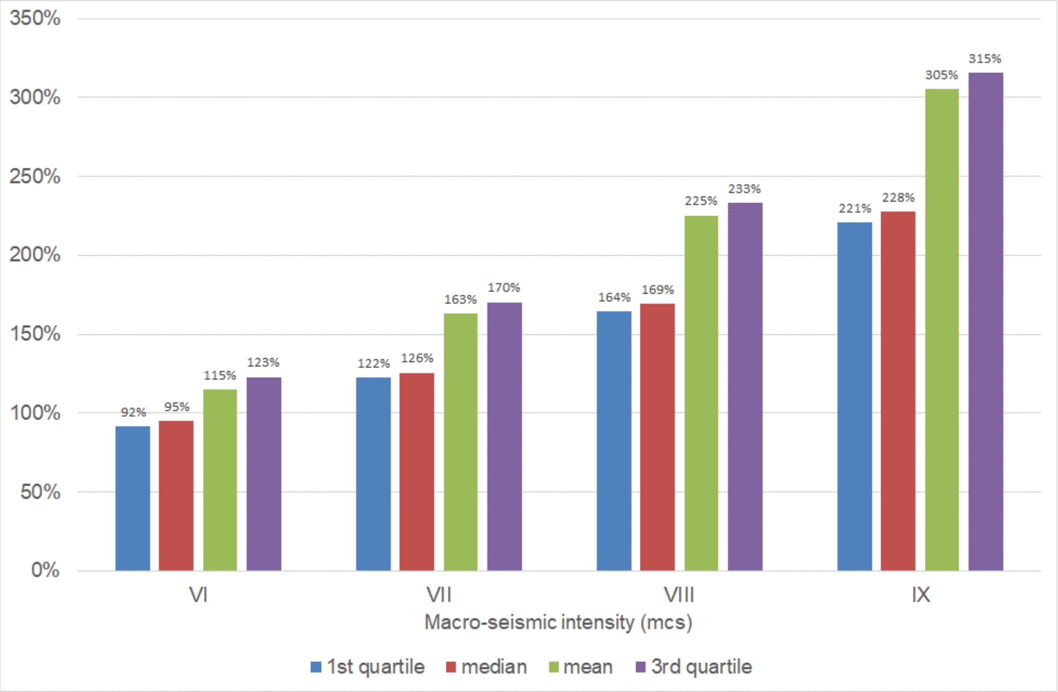


Figure 8

Correlation between the exceedance probabilities over 10 years derived from the $PGAs$ of the REASSESS and the INGV (MPS04) models

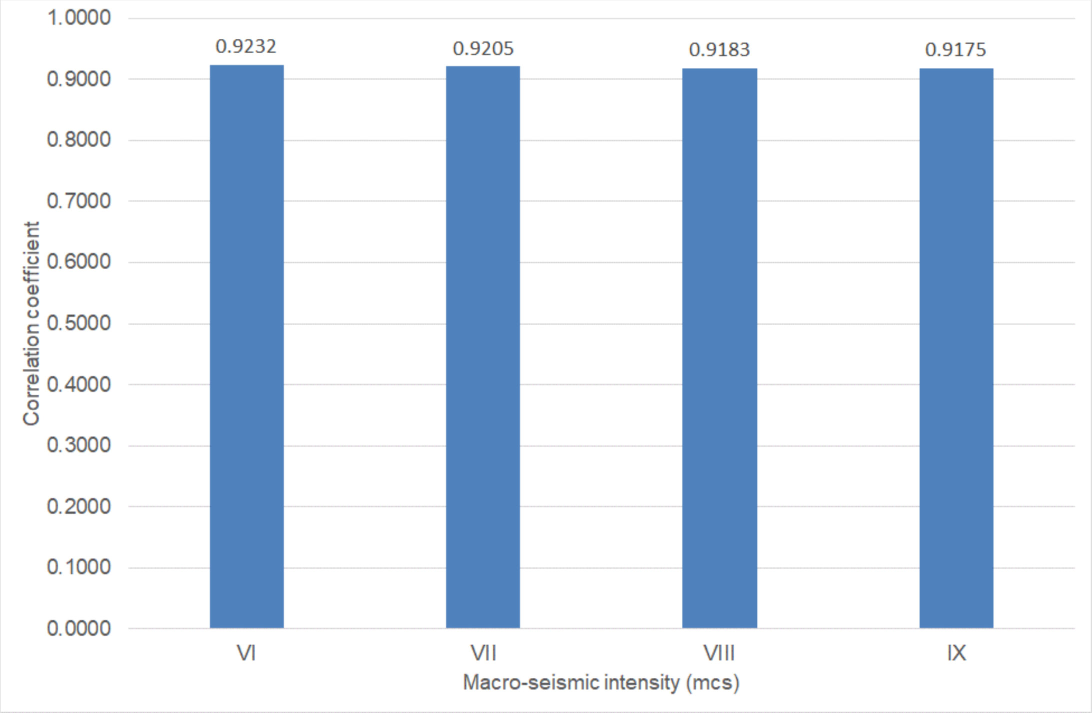
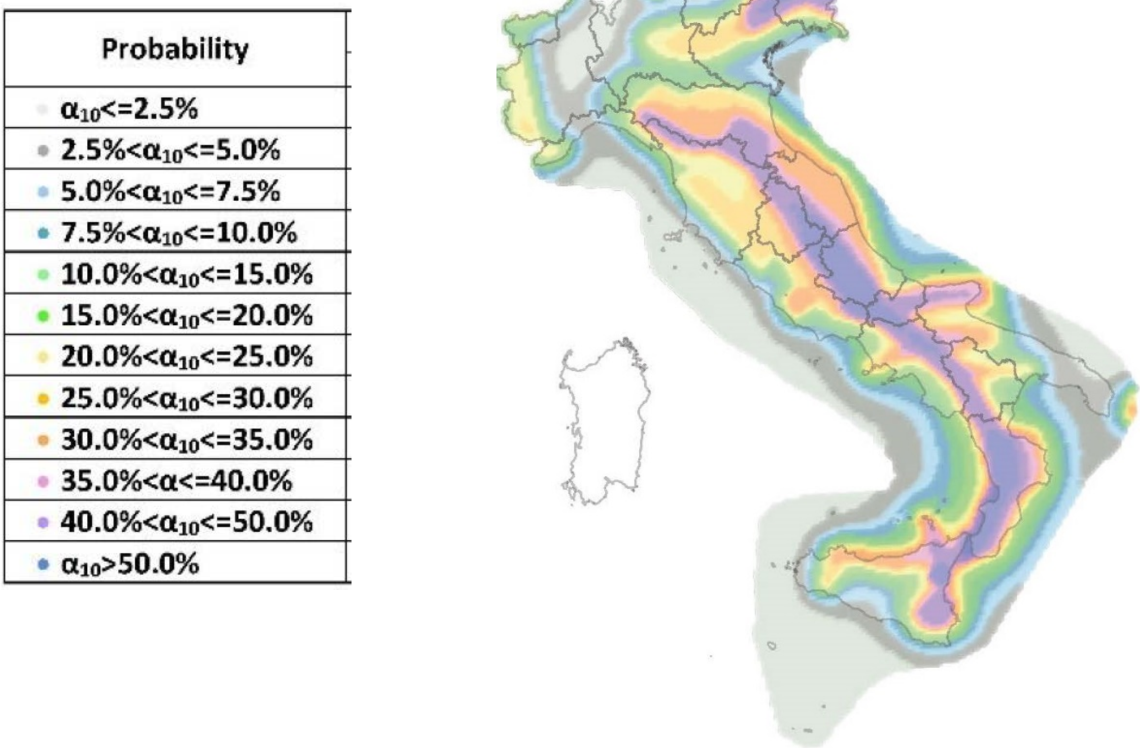


Figure 9

Risk map of the exceedance probability for the macro-seismic intensity $MCS = VI$ over 10 years

9.a INGV (MPS04) PGA



9.b REASSESS PGA

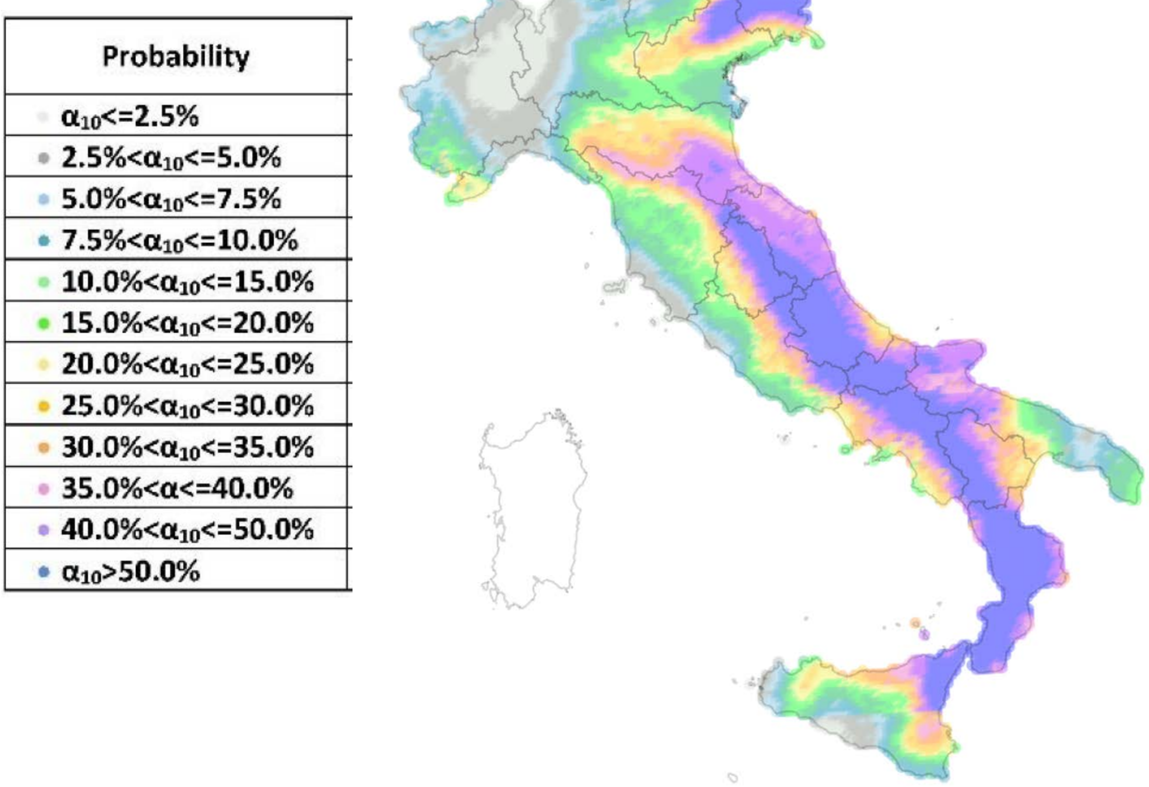
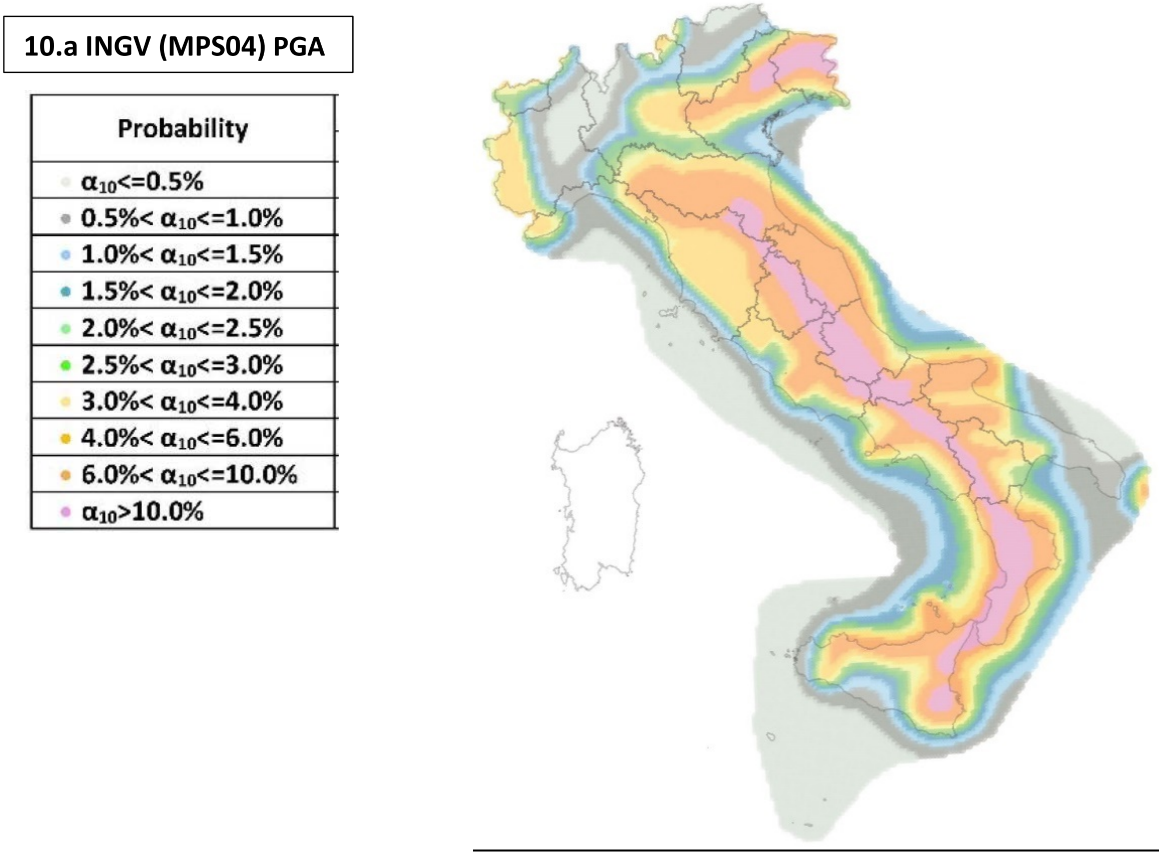


Figure 10
Risk map of the exceedance probability for the macro-seismic intensity $MCS = VII$ over 10 years

10.a INGV (MPS04) PGA



10.b REASSESS PGA

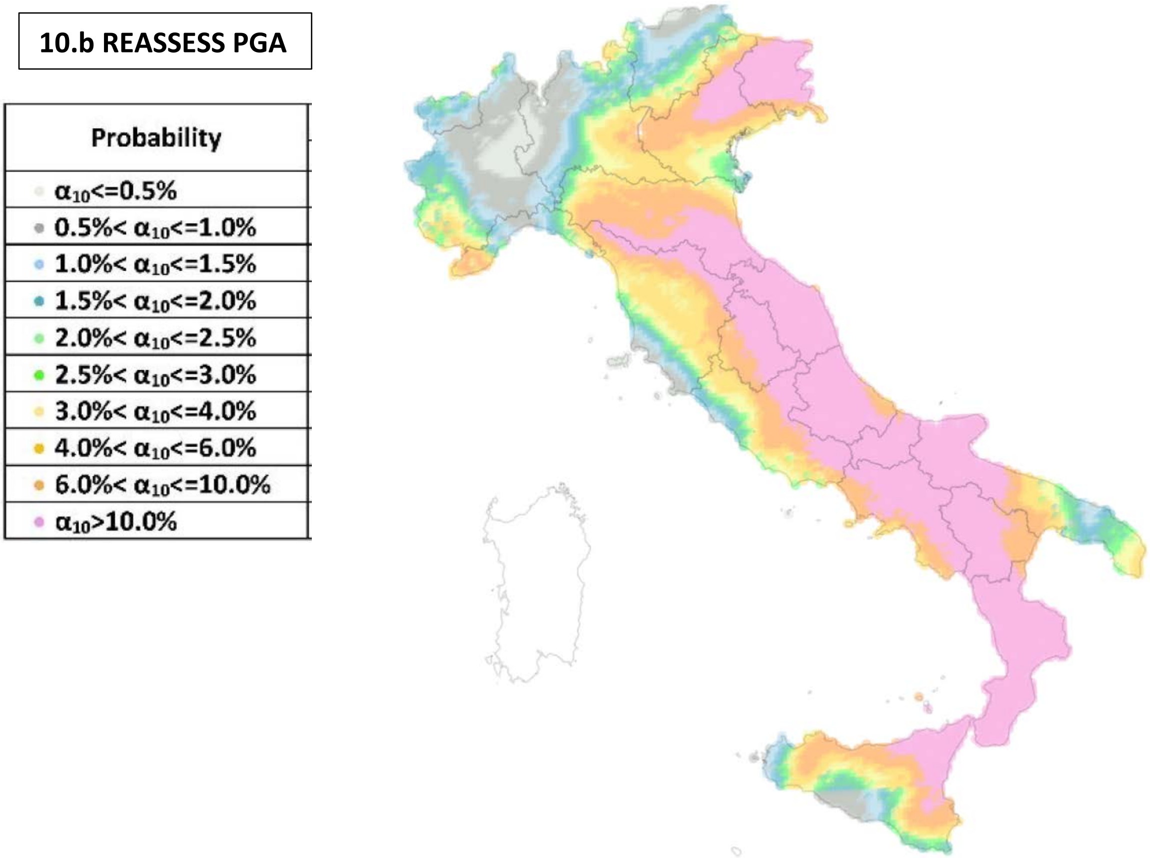
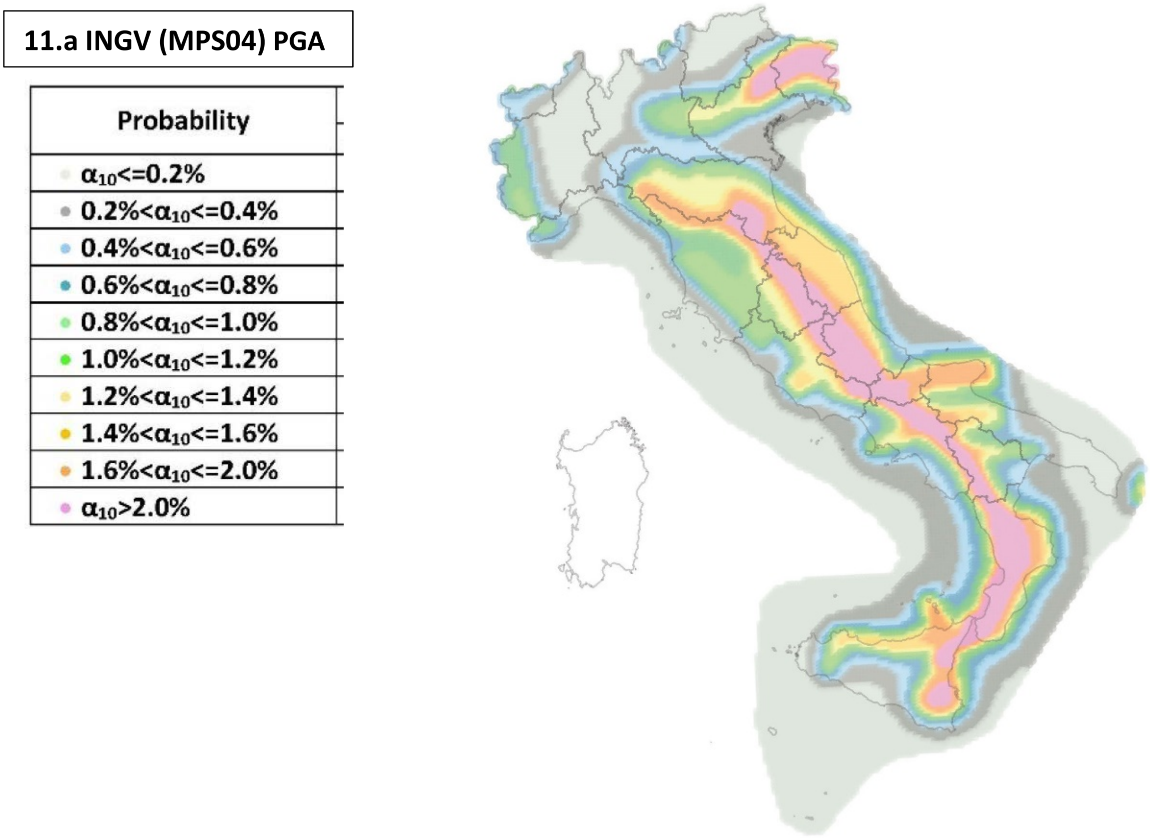


Figure 11

Risk map of the exceedance probability for the macro-seismic intensity $MCS = VIII$ over 10 years

11.a INGV (MPS04) PGA



11.b REASSESS

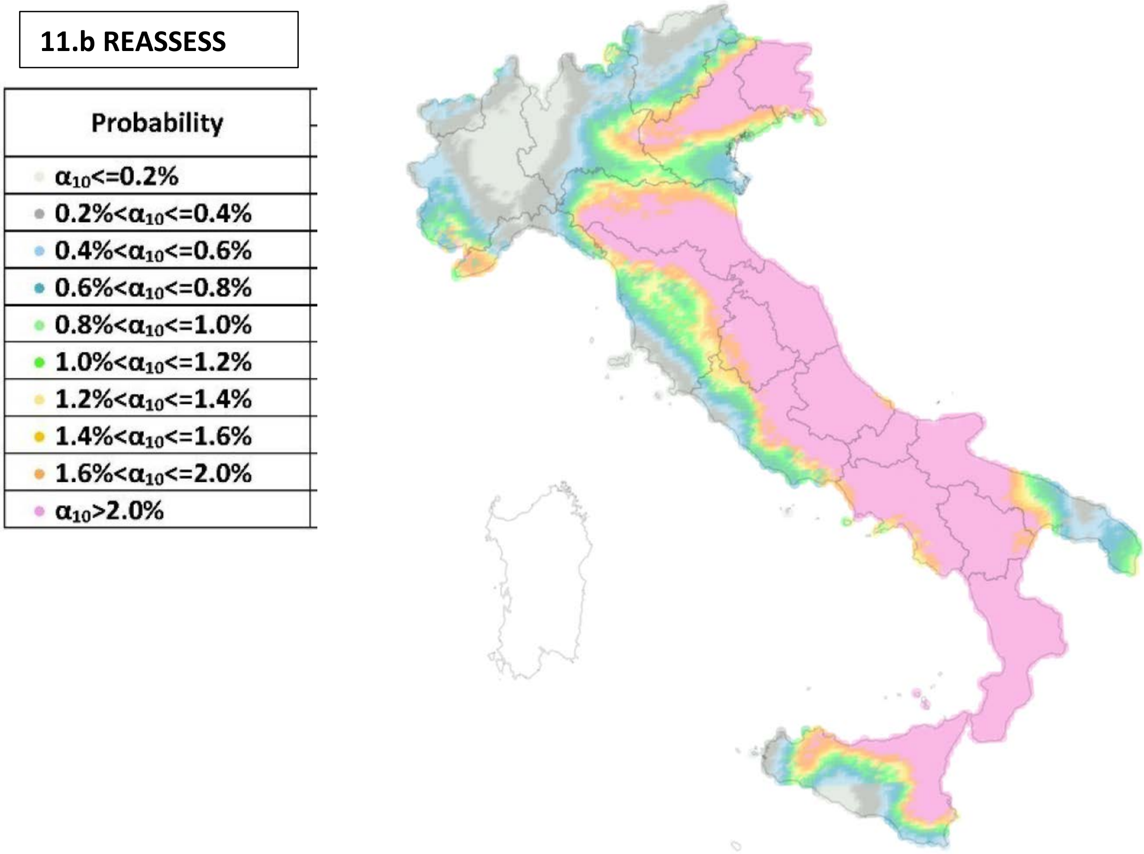
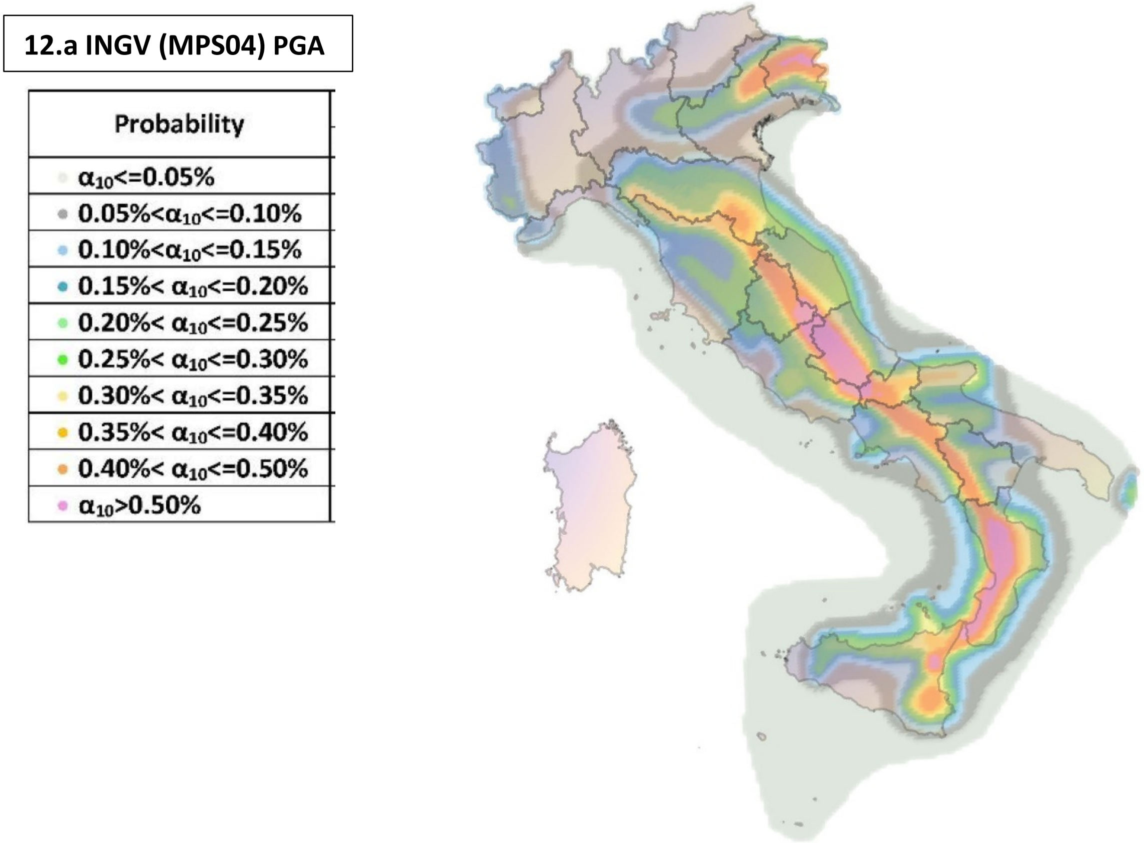


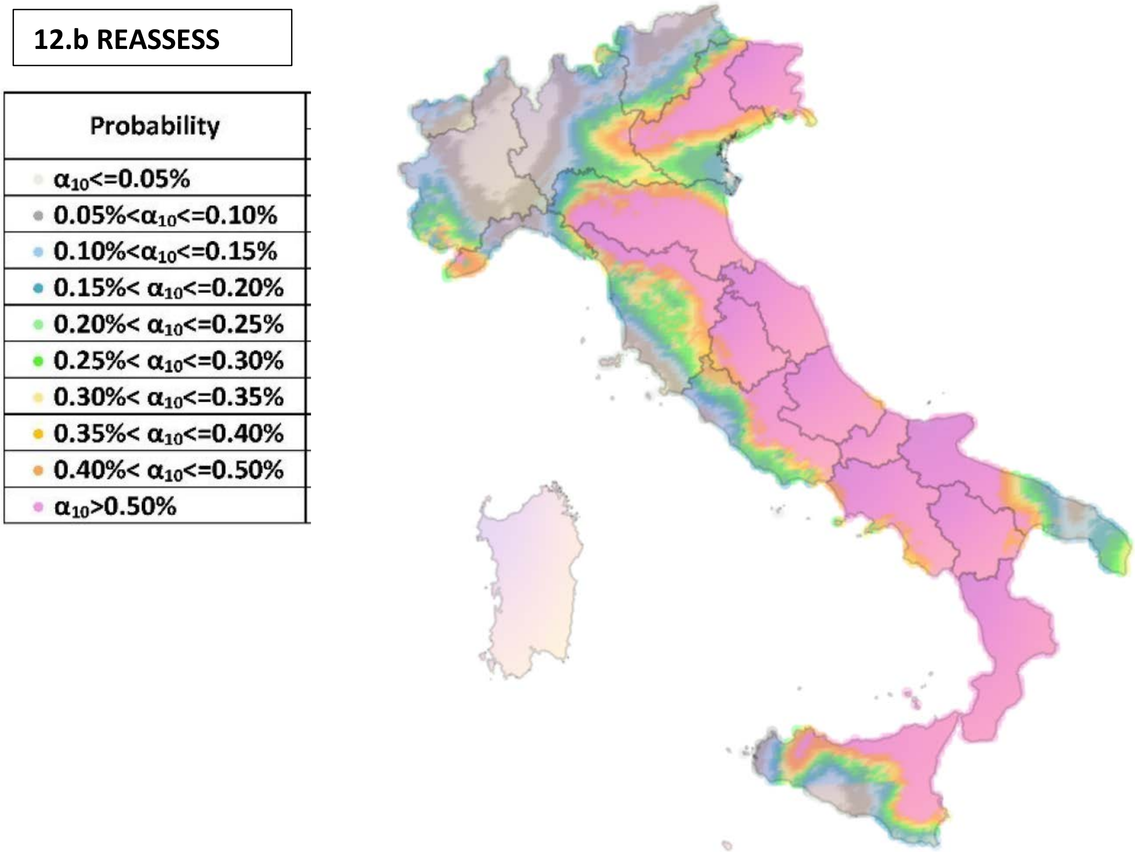
Figure 12

Risk map of the exceedance probability for the macro-seismic intensity $MCS = IX$ over 10 years

12.a INGV (MPS04) PGA



12.b REASSESS



5. Conclusions

Earthquake risk is the most dangerous natural peril in Italy. A reliable assessment of this risk is of the greatest importance from many points of view, like building safety and insurance.

In this paper we improve the traditional approach to earthquake risk with a more general approach (Probabilistic Seismic Hazard Analysis, PSHA) combined with the consideration of the soil characteristics (REASSESS modelling approach). The results of this model in terms of PGA are compared with the current INGV MPS04 model, showing a significant increase in both mean and variance. Moreover, as in Cesari and D'Aurizio (2021), we evaluate the exceedance probabilities with regards to MCS intensities and, by using the REASSESS approach, we find a relevant increase, ranging, on average, from 15% with $MCS = VI$ to 205% with $MCS = IX$. This should have an impact on many nat-cat insurance issues.

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