Nat. Hazards Earth Syst. Sci. Discuss., 2, 3561–3576, 2014
www.nat-hazards-earth-syst-sci-discuss.net/2/3561/2014/
doi:10.5194/nhessd-2-3561-2014

Natural Hazards and Earth System Sciences
Discussions
Open Access

A proposal for a new parametrization of historical intensity data providing a better handling of uncertainties

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Received: 5 April 2014 – Accepted: 5 May 2014 – Published: 20 May 2014

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Published by Copernicus Publications on behalf of the European Geosciences Union.

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◀| |▶
◀ ▶
Back | Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

Abstract

In recent times a great deal of research was aimed to the reduction of uncertainties on Probabilistic Seismic Hazard Analysis (PSHA). Most attention was paid to the role of Ground Motion Prediction Equations (GMPEs), while no studies were devoted to a possible larger source of uncertainties: the historical catalogues of earthquakes.

In areas where historical catalogues provide a many centuries long record and surface geology does not permit at the moment to have complete catalogues of seismogenic faults, their use is unavoidable for estimating seismicity rates required for PSHA. Their use is also gaining popularity as an independent tool for the estimation of PSHA (D'Amico and Albarello, 2008) or for their use for validation purposes (Stirling and Petersen, 2006; Mucciarelli et al., 2008).

This paper proposes an alternative way for the parametrization of historical macroseismic intensity and then discusses which is the real impact of starting uncertainties in intensities on the final uncertainties on PSHA.

1 Introduction

For each known historical earthquake, the first step of research is to assign macroseismic intensity at any point affected by what is recognized to be a single event. Then a parametrization is made to have epicentral data such as location and epicentral intensity.

In several instances, the historical seismologist is not able to assign unambiguously a single intensity value whose description matches exactly the observations. Is then common practice to assign values such as VI–VIII which are subsequently handled as 7.5 in further calculations. This is not a correct way to proceed, since half-degrees are not foreseen in intensity scales. This is an advice included also in the second version of the EMS scale (Grünthal et al., 1998):

“It will often be the case that no single intensity degree can be decided upon with any confidence. In such cases, it is necessary to decide whether some approximate assessment of intensity can be made, or whether the data are so contradictory that it is better to leave the matter unresolved... It is recommended that the user preserves the integer character of the scale, and not uses forms such as ‘6.5’ or ‘6 1/2’ or ‘6+’. . . In such cases the intensity should be written as 6–7, meaning either 6 or 7; it does not imply some intermediate value”.

2 Methodology

The use of forms like 6.5 is a remnant of the punched card era, when earthquake catalogues needed to have all the information compressed in the 80 characters available for each line/event. Nowadays uncertainty on intensity data could be handled using vectorial intensity, such as proposed for site hazard estimates by Magri et al. (1994) ad subsequently by Albarello and Mucciarelli (2002). This is commonly done when using probabilistic attenuation relationships, but could be a great opportunity for the revision of catalogues, leaving to the historical seismologist the possibility of expressing his feeling that an event is “almost certainly” an intensity VIII (e.g. 0.9 probability) while it cannot be completely ruled out that the effects reached IX (e.g. 0.1 probability). For 12° intensities scales (like MMI, MCS, MSK, EMS) this will result in a 12 term probability vector, with a value for each intensity class expressing the probability that the intensity is equal to or larger than that class:

[1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.9 0.1 0.0 0.0 0.0]

This formulation could be used both for single site intensity data and for the epicentral parametrization of the earthquake. Of course this could apply also to data that now are taken as integer intensity values but could raise some doubts in historical seismologists.

The use of probability to express the degree of belief should be subjected to simple “conversion rules” such those listed in the EMS-98 scale for the definition of quantity such as “many”, “few”, or “most”. A possible conversion rule is given in Table 1.

3 The effect of intensity uncertainty on PSHA

Mucciarelli and Albarello (2012) discussed a rough approximation of the effect of intensity uncertainty on PSHA: if one is not sure that a quake was an intensity, say, 5 event because some elements suggest that it could be an intensity 6, then from the point of view of relative error, this means that we are compiling our input catalog with data that are affected by a $(6-5)/5 = 20\,\%$ starting error. The theory of error propagation procedures states that relative errors cannot decrease throughout the procedure from input data to final outcomes, thus the minimum effect on PSHA will be at least an uncertainty of 20 %.

To explore the effect that uncertainty on intensity assignment has on Mean Recurrence Times, the simplest estimate of PSHA at a given site, I have chosen sites in the area affected by the recent 2012 Emilia, Italy, earthquake. The Po Plain is an ideal study area, because many cities have a complete seismic history dating back to middle ages. Considering the site earthquake catalogue for Ferrara and Modena, the two closest cities to the 2012 earthquake sequence, we note many damaging earthquake as well as an abundance of uncertain intensities (Table 2).

There are two possible ways to proceed then. They have in common the Monte-Carlo simulation of hundreds of run to estimate MRTs with fixed intensity values when possible, while at each simulation the “half-degrees” are treated in two alternative ways:

1. each half-degree between the nth and the $n+1$th degree is assigned with a random probability p between 0 and 1 to the nth degree and with a probability $1-p$ to the $n+1$th degree.

2. each half-degree is assigned with a random selection either to the *n*th degree or to the $n+1$th degree

For the site intensities I modified the catalogue following the first approach, while the second will be used for the sensitivity analysis on seismogenic zones.

The result of 5000 runs on modified site catalogues for Modena and Ferrara is shown in Fig. 1, with the MRT estimated separately for each intensity class as the time between the first and last shock divided by the sum of probabilities of events (see Magri et al., 1994).

It is possible to note that as expected the dispersion increases with the increase of intensity. On the other hand the MRTs are smaller for lower intensities, so the relative error on estimates remains similar.

This can be seen in a better way plotting histograms instead of ECDFs (see Fig. 2)

It is worth noting that the distributions are slightly asymmetrical for lower intensities as an effect of the Gutenberg–Richter-like distribution as a function of intensity, with less events coming from above than from below. The highest class is highly asymmetrical due to the fact that no contribution may come from above.

Stitching to the non-parametric style adopted for this exercise, the uncertainty can be estimated as the ratio between median and inter-quartile range, with results in the range 25–30 % for all intensity thresholds.

The last step of this study considers recurrence model using epicentral intensities data, as given from the CPTI catalogue of INGV (http://emidius.mi.ingv.it/CPTI11/). The area selected is reported in Fig. 3, and comprises the four seismogenic zone covering most of the Po Valley, according to the zoning available from INGV at the web page http://zonesismiche.mi.ingv.it/documenti/App2.pdf.

The parametric catalogue for this area (CPTI11) reports 184 events with intensity greater or equal to V degree MCS, and 76 are listed with half-integer intensity values (see Fig. 4).

To estimate the effect of this uncertainty on seismic rates the four zone were considered together. Hundreds of simulation were run to estimate seismic rates (again as described in Magri et al., 1994), and at every run each half-degree was assigned either to the lower or to the higher degree using a random selection with uniform probability.

Figure 5 reports the result of 2000 runs. As expected, the variability increases with increasing of intensity in a way similar to that observed for site intensities. In this case a further analysis was performed: at each random generation, it was possible to save the distribution of inter-event times of each modified catalogue, to study the distribution of ratio average vs. standard deviation (Fig. 6) compared with a Poisson distribution for which the ratio should be equal to 1.

The result is puzzling. Moving from the lowermost intensities to the highest, the behavior seems to change from clustered to slightly periodic. This may be explained in several ways:

1. no single relationships exist for the frequency distribution of events (Gutenberg–Richter-like);
2. notwithstanding the fact that CPTI11 is declared as a de-clustered catalogue, clustering is still present for lower intensities, maybe due to medium-range correlation of seismicity between the borders of the Po Plain as suggested by Bragato (2014);
3. the move toward periodic behavior ($\alpha < 1$) at higher intensities could be due to a problem of under-sampling, because not all the modified catalogues allow for enough events of intensity IX to be present. For a discussion of the role of under-sampling in assessing correctly the time distribution of large event, see Ellsworth et al. (1999) or Mucciarelli (2007).

4 Conclusions

The uncertainty in assignment of intensity both at each site or in parametric historical catalogues propagates to PSH estimates affecting final result with a relative error around 25–30 %. To avoid this uncertainty, existing catalogues should be revised avoiding fake half-degrees in favor of a probabilistic translation of expert judgment. The intensity could then be given for each event as a 12 values vector, that can provide alternative input to standard PSHA codes or be easily incorporated in existing PSHA softwares designed for exploitation of intensity data like SASHA (D'Amico and Albarello, 2008).

Acknowledgements. This research was funded by a grant under project SIGMA (http://projet-sigma.com).

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Table 1. Proposal of conversion rule of expert judgment into probability for the statement “the intetsity is equal to or greater than a given class”.

Absolutely true	1
Very likely	0.9
Uncertain	0.5
Unlikely	0.1
Absolutely false	0

Title Page
Abstract Introduction
Conclusions References
Tables Figures
◀| |▶
◀ ▶
Back Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

Table 2. Site seismic history for Modena and Ferrara, Italy, from the Italian Data-Base of Macroseismic Intensities, available on INGV website (http://emidius.mi.ingv.it/DBMI11/).

Modena		Ferrara	
Year	Intensity	Year	Intensity
1222	7	1117	5.5
1249	7.5	1222	6
1323	5	1234	7
1348	5	1285	7
1399	7	1304	5
1474	6	1339	6
1501	7.5	1346	7.5
1504	6	1348	5
1505	5	1365	5
1505	5	1409	6
1505	6	1410	6.5
1511	4.5	1411	7
1536	5	1483	5.5
1547	6	1483	5
1661	6.5	1504	5
1671	7	1505	6
1806	4.5	1505	5
1810	4.5	1511	5.5
1811	5	1511	6
1831	4.5	1536	6
1832	7	1561	6.5
1832	4.5	1570	8
1834	5	1591	5
1837	5	1624	6
1850	6	1661	5
1869	6	1672	5
1873	5	1688	5
1873	5	1693	4.5
1886	5	1695	6.5
1887	4.5	1695	5.5
1891	4.5	1743	6.5
1909	5	1781	4.5
1914	5	1781	5
1916	5	1787	6.5
1920	5.5	1787	6.5
1923	6	1796	7
1929	5	1812	4.5
1929	5	1832	5
1929	5	1870	5
1929	5	1875	5.5
1937	4.5	1895	5
1939	5	1909	6
1971	5	1914	5
1976	4.5	1915	5
1978	5	1920	5
1980	4.5	1922	4.5
1983	6	1926	4.5
1987	6	1929	4.5
1987	4.5	1967	4.5
1996	5.5	1971	5
2003	4.5	1983	5
		1989	4.5
		1996	4.5

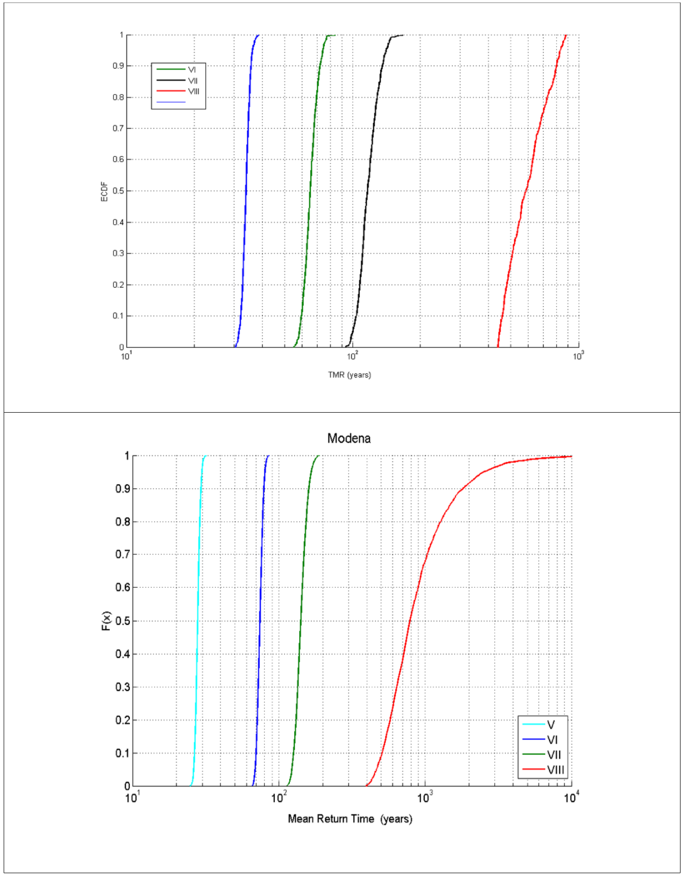

Figure 1. The Empirical Cumulative Distribution Frequency for 5.000 runs estimating the MRT in Ferrara (above) and Modena (below).

Title Page
Abstract Introduction
Conclusions References
Tables Figures
I◀ ▶I
◀ ▶
Back Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

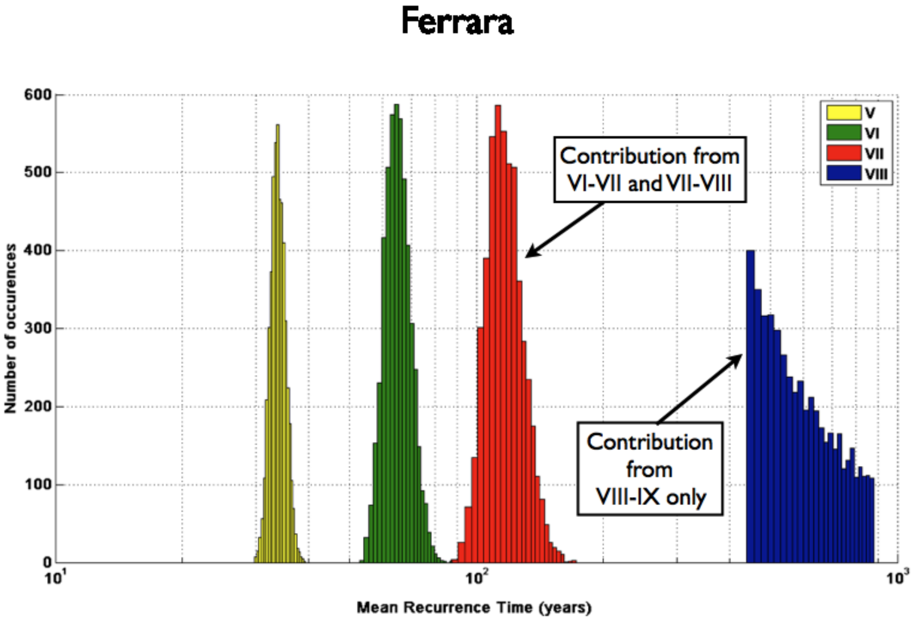

Figure 2. The frequency histograms for 5000 runs estimated the MRT in Ferrara.

Title Page
Abstract
Introduction
Conclusions
References
Tables
Figures
◀I
▶I
◀
▶
Back
Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

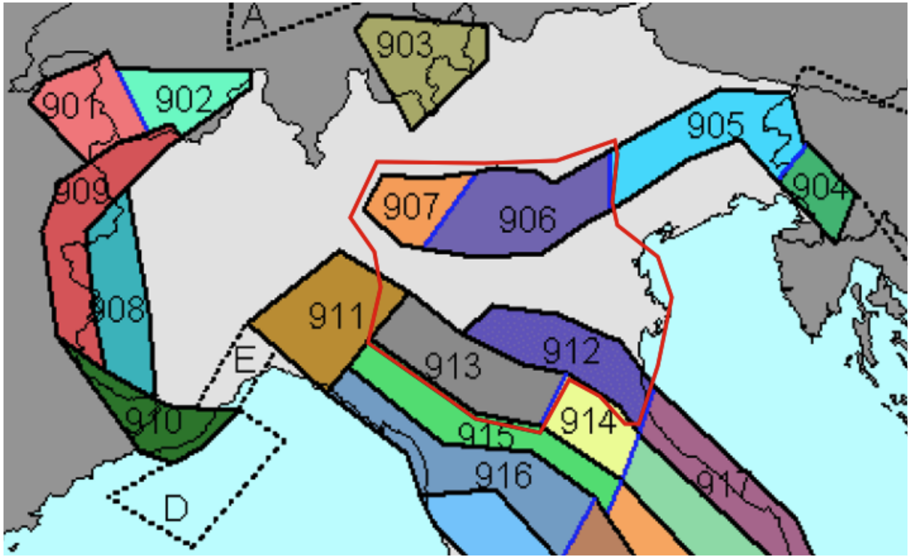

Figure 3. The seismogenic zones whose earthquakes were used for simulations.

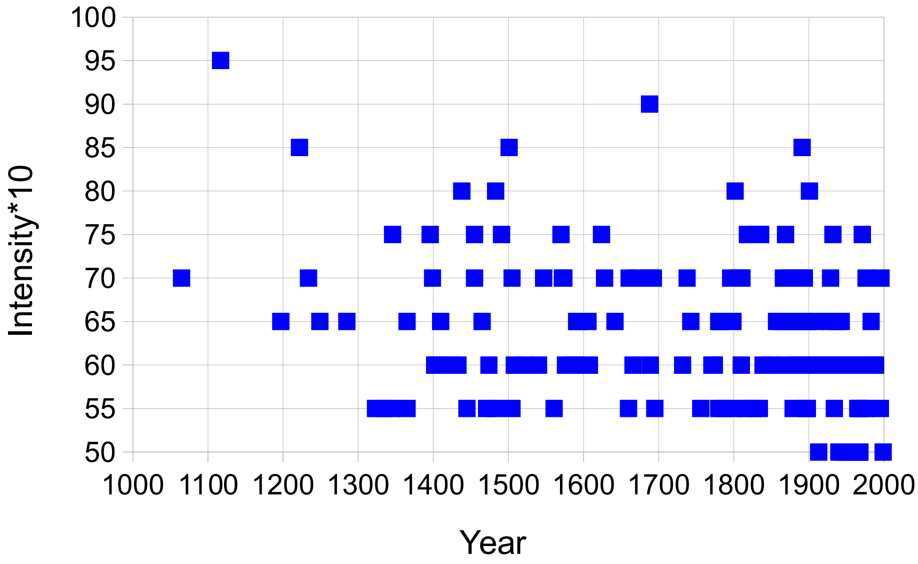

Figure 4. The earthquakes used for simulations, plotted by year and intensity. Note the large amount of half-degree intensities.

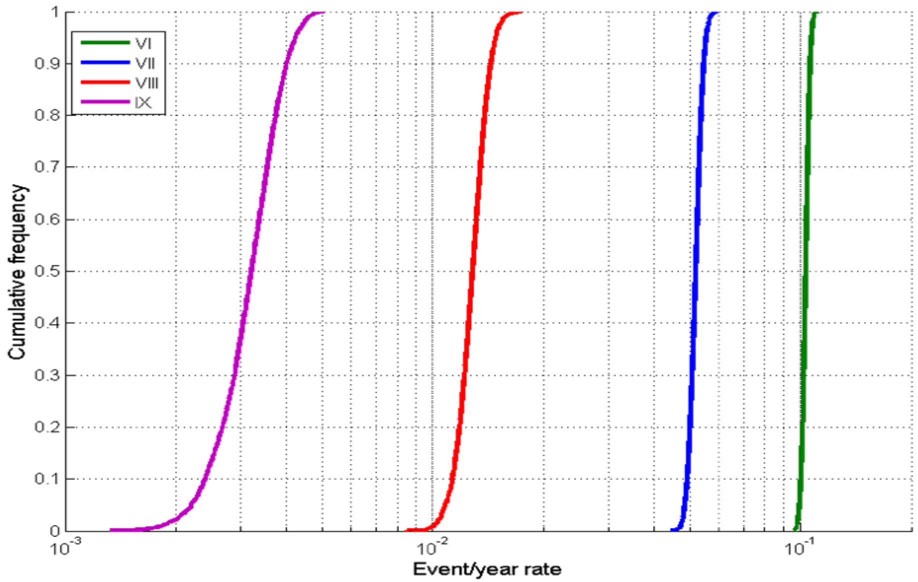

Figure 5. ECDF of the activity rates for 4 intensity classes.

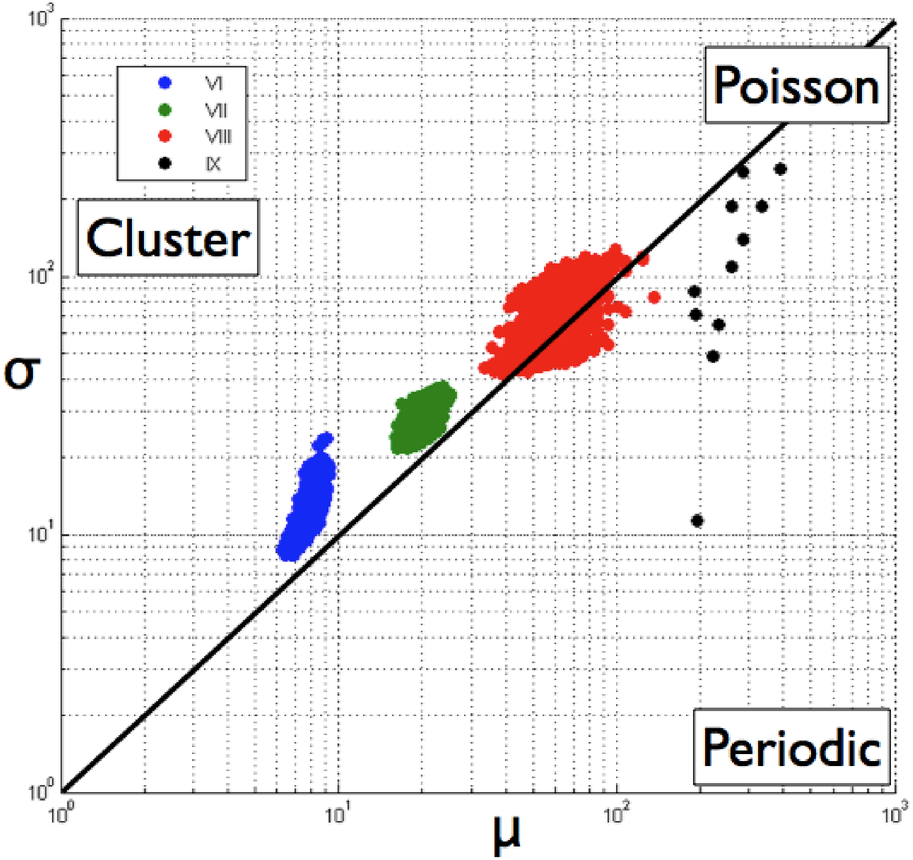

Figure 6. Aperiodicity and clustering for 2000 runs of a modified historical catalogues of the Po Plain.