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# Journal of Seismology

## Do French macroseismic intensity observations agree with expectations from the European Seismic Hazard Model 2013?

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<b>Abstract:</b>	<p>Probabilistic seismic hazard assessments are the basis of modern seismic design codes. To test fully a seismic hazard curve at the return periods of interest for engineering would require many thousands of years' worth of ground-motion recordings. Because strong-motion networks are often only a few decades old (e.g. in mainland France the first accelerometric network dates from the mid-1990s), data from such sensors can be used to test hazard estimates only at very short return periods. In this article several hundreds of years of macroseismic intensity observations for mainland France are interpolated using a robust kriging-with-a-trend technique to establish the earthquake history of every French mainland municipality. At twenty-four selected cities representative of the French seismic context, the number of exceedances of intensity IV, V and VI are determined over time windows considered complete. After converting these intensities to peak ground accelerations using the global conversion equation of Caprio et al. (2015), these exceedances are compared with those predicted by the European Seismic Hazard Model 2013 (ESHM13). In half of the cities, the number of observed exceedances for low intensities (IV and V) is within the range of predictions of ESHM13. In the other half of the cities, the number of observed exceedances is higher than the predictions of ESHM13. For intensity VI, the match is closer, but the comparison is less meaningful due to a scarcity of data. According to this study, the ESHM13 underestimates hazard in roughly half of France, even when taking into account the uncertainty on the conversion from intensity to acceleration. However, these results are valid only for the acceleration range tested in this study (0.01 to 0.09 g).</p>	
<b>Response to Reviewers:</b>	The reference of Cauzzi and Faccioli (2008) has been removed as requested.	

[Click here to view linked References](#)

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## Do French macroseismic intensity observations agree with expectations from the European Seismic Hazard Model 2013?

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## Abstract

Probabilistic seismic hazard assessments are the basis of modern seismic design codes. To test fully a seismic hazard curve at the return periods of interest for engineering would require many thousands of years' worth of ground-motion recordings. Because strong-motion networks are often only a few decades old (e.g. in mainland France the first accelerometric network dates from the mid-1990s), data from such sensors can be used to test hazard estimates only at very short return periods. In this article several hundreds of years of macroseismic intensity observations for mainland France are interpolated using a robust kriging-with-a-trend technique to establish the earthquake history of every French mainland municipality. At twenty-four selected cities representative of the French seismic context, the number of exceedances of intensity IV, V and VI are determined over time windows considered complete. After converting these intensities to peak ground accelerations using the global conversion equation of Caprio *et al.* (2015), these exceedances are compared with those predicted by the European Seismic Hazard Model 2013 (ESHM13). In half of the cities, the number of observed exceedances for low intensities (IV and V) is within the range of predictions of ESHM13. In the other half of the cities, the number of observed exceedances is higher than the predictions of ESHM13. For intensity VI, the match is closer, but the comparison is less meaningful due to a scarcity of data. According to this study, the ESHM13 underestimates hazard in roughly half of France, even when taking into account the uncertainty on the conversion from intensity to acceleration. However, these results are valid only for the acceleration range tested in this study (0.01 to 0.09 g).

## Keywords

Earthquake, macroseismic intensity, seismic hazard, probabilistic seismic hazard assessment, kriging, France

## Introduction

Databases of macroseismic intensities covering several centuries of earthquake history provide an attractive resource for various applications in engineering seismology and earthquake engineering, including the estimation of earthquake magnitude and the public understanding of seismic risk. Another application is to provide an independent check on the results of a probabilistic seismic hazard assessment (PSHA). Intensity databases have a considerable advantage over strong-motion databases for this purpose, as in Europe (and elsewhere, e.g. China and Japan) they generally cover periods of several centuries rather than only a few decades. They do, however, have disadvantages, such as the difficult-to-quantify but undoubtedly large uncertainties associated with intensities obtained from historical

1 documents. Also intensity databases only provide observations at specific locations because  
2 of the availability of historical texts for only those sites.  
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4 To overcome this limitation of the official French macroseismic intensity database (SisFrance,  
5 [www.sisfrance.net](http://www.sisfrance.net), BRGM/IRSN/EDF, 2017), in a recent project co-financed by the French  
6 Ministry of the Environment we have estimated the intensities in all municipalities for over  
7 1,600 earthquakes that occurred during the past millennium. This estimation was made using  
8 a kriging-with-a-trend technique (Olea, 1999; Ambraseys and Douglas, 2004), where the  
9 attenuation of intensity with distance is controlled by the data and in which the available  
10 intensities automatically shape the isoseismals. A database of isoseismal maps was  
11 constituted for all earthquakes with at least three Intensity Data Points (IDP) available. For any  
12 municipality of interest, the sequence of “observed” intensities can be obtained and the  
13 number of occurrences of an intensity level can be compared to the expected number, over  
14 time windows of interest. As PSHA is usually in terms of instrumental ground-motion  
15 measures (e.g. peak ground acceleration, PGA), a conversion from intensities to these  
16 measures is needed before any comparison. The conversion was achieved here using Ground  
17 Motion to Intensity Conversion Equations (GMICE). As these conversions carry large  
18 uncertainties, the uncertainty was propagated to evaluate its impact on the comparison. An  
19 alternative is to evaluate the hazard in terms of macroseismic intensities directly (Musson,  
20 2000). There is, however, no intensity-based PSHA study published for France [see Douglas,  
21 (2017) for a list of published intensity prediction equations], and such calculations would also  
22 be associated with their own uncertainties, such as the poorly-constrained sigma of the  
23 intensity prediction equation, which plays a major role in PSHA.  
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38 The current version of the French seismic zoning regulations, based on a PSHA study  
39 performed in 2002, is applicable since May 2011. Seismic loading conditions are defined for  
40 five zones of increasing hazard, the zone of highest hazard being in the Antilles. We select  
41 twenty-four cities in order to sample evenly the four seismic zones in mainland France (“very  
42 low” to “medium” hazard, Figure 1). At these 24 sites, observed numbers of occurrences for  
43 three intensity levels (IV, V, and VI) are counted and compared to the predicted numbers  
44 based on the mean hazard from the European Seismic Hazard Model 2013 (ESHM13,  
45 Woessner *et al.*, 2015). The aim of this study is to understand if the several centuries of  
46 intensity data are in agreement with the latest European probabilistic seismic hazard map in  
47 a region of low-to-moderate seismicity.  
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## Previous studies comparing estimated seismic hazard with observations

To test fully a seismic hazard curve at the probability levels of interest for engineering would require many thousands of years' worth of ground-motion recordings. Because in mainland France the first accelerometric stations were installed in the mid-1990s, accelerometric data can be used to test hazard estimates only at very short return periods [see Beauval *et al.* (2008) and Tasan *et al.* (2014) for applications in France].

Since the advent of PSHA methods, some authors have proposed comparing hazard curves to observed intensity rates, thus enlarging the observation time window. For example, Stirling and Petersen (2006) converted intensities to accelerations and made comparisons for selected sites in New Zealand and the United States. Another direction was explored by Mucciarelli *et al.* (2008) who reconstructed the intensity history at a site from observed intensities and calculated ones (based on epicentral information and neighbouring intensity observations). They chose not to make an intensity–acceleration conversion and hence they compared probabilistic seismic hazard and intensity-based recurrences through the ranking of hazard evaluated at many sites in Italy. The reader can refer to Beauval (2011) for more details on these studies testing PSHAs using intensities. More recently, Mak *et al.* (2016) used 'Did You Feel It' intensity records to compare PSHA with observations in the central and eastern USA.

Uncertainties are numerous in these comparisons: two major ones are the uncertainty in the intensity-acceleration relationship and the uncertainty in the determination of complete time windows for given intensity levels. They are discussed in the following sections.

## Construction of a database of interpolated intensities for France

### *Introduction to the SisFrance database*

In France, macroseismic characteristics of both contemporary and historical earthquakes are collected in the SisFrance database (Scotti *et al.*, 2004). SisFrance is the current name for the macroseismic database originally named Sirene, which was created in 1978 by BRGM, in partnership with Electricity of France (EDF) and the Radioprotection and Nuclear Safety Institute (IRSN). BRGM is responsible for the management, the updating and the interpretation of the macroseismic information contained in SisFrance. The principal purpose of this database is to provide the general public with information on earthquakes that were felt or caused damage in France. The database, however, is also used extensively for scientific research (e.g. Bakun and Scotti 2006; Manchuel *et al.*, 2017) as well as for engineering purposes (e.g. to provide input to site-specific seismic hazard assessments for the design of

1 critical infrastructure). There are about 200,000 unique visits each year to the SisFrance  
2 website.  
3

4 The database extends up to 2007. It is updated annually through the inclusion of information  
5 about earthquakes of local magnitudes above 3.5. Contemporary accounts are principally  
6 studies by the French Central Seismological Office (BCSF), the national academic bureau for  
7 seismology based at the University of Strasbourg since 1921. The BCSF is in charge of the  
8 macroseismic enquiries and intensity estimations for each new earthquake that affects the  
9 French territory. When new information appears about earthquakes already in the database,  
10 obtained by careful examination and analysis of newly-identified historical documents (e.g.  
11 municipal, departmental and national archives as well as newspapers and other historical  
12 publications), it is added. In this case, the new information is compared with existing previous  
13 documents to reevaluate the characteristics of the event, sometimes leading to the inclusion,  
14 modification or suppression of IDPs.  
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23 An IDP in the database usually corresponds to an average observation at the scale of a village,  
24 town or city. All intensities in the database have been evaluated with the Medvedev–  
25 Sponheuer–Karnik 1964 intensity scale (MSK64, Medvedev *et al.*, 1967). The more recent  
26 EMS98 scale (Council of Europe, 1998) was principally designed to take into account the  
27 behaviour of modern constructions. As shown by various authors (e.g. Musson *et al.*, 2009),  
28 there is equivalence or only minor differences between MSK and EMS98 intensity scales for  
29 intensities IV to VI, which are used in the present study. Both intensity scales relate the level  
30 VI to “little damage”, level V to “fairly strong, fright”, and level IV to “largely observed, awaking  
31 sleepers”.  
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39 Because of the nature of the historical sources used for the construction of the database, the  
40 intensity levels and their locations are associated with uncertainties that are difficult to quantify.  
41 In SisFrance the reliability of an IDP is described by: A (high), B (moderate) or C (low). In  
42 addition, some observations simply state that the event was felt at that site but there is  
43 insufficient information to assign an intensity. Over the past 40 years, the information  
44 contained in SisFrance has been greatly expanded and refined. Currently there are 5,739  
45 earthquakes listed in SisFrance but only 28% of these (1,623 events) have at least three IDPs  
46 and an estimate of the epicentral intensity. For these 1,623 best-known earthquakes more  
47 than 82,000 IDP are available (representing almost 80% of all IDPs in the database). While  
48 1,073 events are described by at least 7 observations, the number of events described by at  
49 least 200 observations drops to 73. Most of the events with fewer than three IDPs are tagged  
50 as foreshocks or aftershocks in SisFrance. The events identified as foreshock, aftershock or  
51 swarm events in SisFrance are not included in the present study.  
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## *Estimating automatic isoseismal maps using IDPs from SisFrance*

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2 For many earthquakes, particularly those that occurred over a century ago, only observations  
3 at a limited number of locations are available. The exact spatial extent of the felt area of these  
4 earthquakes will never be known. Nevertheless, using the available IDPs for an earthquake,  
5 isoseismal maps can be drawn. Once an isoseismal map is established for an earthquake, an  
6 intensity estimate can be retrieved for any location. The aim is thus to deduce seismic history  
7 for all French municipalities from isoseismal maps. Given the large number of events, an  
8 automatic procedure needs to be implemented. For the 1,623 earthquakes with three or more  
9 IDPs, 1,623 isoseismal maps were automatically derived from the existing IDPs using a  
10 “kriging with a trend” algorithm described below. Next, because of the large quantity of data,  
11 the complete calculation chain was programmed to allow batch processing to generate  
12 automatically the maps and intensity database for all the considered earthquakes (Rey *et al.*,  
13 2015a, 2015b).

22  
23 Ambraseys and Douglas (2004) generated isoseismal maps for dozens of earthquakes in the  
24 Himalayas. To establish these maps, they implemented a technique of interpolation known as  
25 “kriging with a trend” (Olea, 1999). The present study uses the same algorithm, slightly  
26 adapted to the French context (Rey *et al.*, 2013). This approach presents various advantages:  
27 it is reproducible, it makes only a few assumptions, it works even when only a handful of IDPs  
28 are available (Rey *et al.*, 2013), and it has a reasonable calculation time, which is essential  
29 when processing thousands of events and locations.

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35 In SisFrance, an IDP is attributed to a municipality. Following Ambraseys and Douglas (2004),  
36 the IDP is assumed to be the centroid of the corresponding geographical area, rather than the  
37 average value on the territory of the municipality (which is arguably more correct). The use of  
38 the centroid rather than the average value has a negligible effect on the results and makes  
39 the calculations easier to automate.

44  
45 The geostatistical method of kriging spatially interpolates a variable (in this case macroseismic  
46 intensity) by calculating the expected value by means of a semivariogram describing how  
47 related neighboring points are. Kriging provides the best non-biased linear estimate of the  
48 variable by taking into account not only the distance between the data points (here IDPs) and  
49 the point of estimation, as in a classical method of interpolation, but also the distances  
50 between all couples of data points (here IDPs). Because, on average, intensities decrease  
51 with the logarithm of the distance (e.g., Bakun and Scotti, 2006), an underlying trend is  
52 included within the kriging algorithm to force this decay. The rate of the decay is controlled by  
53 the data available for an individual earthquake. The interested reader is referred to Ambraseys  
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1 and Douglas (2004, Appendix A) for details of the kriging technique applied and to Rey *et al.*  
2 (2013) for its application in France.  
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4 The proposed approach was tested on eight representative earthquakes from the most  
5 seismic regions in France: Pyrenees, Vosges, Alps and Atlantic coast (Rey *et al.* 2013). In  
6 each region, one historical destructive event with a limited number of IDPs and one recent  
7 and, often, smaller event with many IDPs were selected. Figure 2 displays results for an  
8 earthquake in the Pyrenees. As a check, the isoseismal maps generated by the kriging  
9 approach were compared to maps manually drawn by the BRGM expert in charge of the  
10 SisFrance database (Lambert, 2004). A careful analysis of the test events' results shows that  
11 the automatically-drawn maps are close to the manually-drawn maps, e.g. in terms of the  
12 average radius of isoseismals for a given intensity, particularly in the far field (see Figure 2).  
13 The low-intensity (II-IV) isoseismals are generally smaller and more circular in the manual  
14 maps, whereas in the automatic maps they cover a larger area and have a less circular shape  
15 (Rey *et al.* 2013). Moreover, the shape of the automatic isoseismals are more complex than  
16 those drawn by hand, particularly for earthquakes with many IDPs. Overall, 70% to 80% of the  
17 points on the isoseismal maps estimated with the kriging approach belong to the same  
18 intensity degree as on the manually drawn maps, 20% to 30% present a difference of a single  
19 degree of intensity and fewer than 0.5% of points show differences of two degrees of intensity  
20 (more details in Rey *et al.* 2013). Based on these tests, we concluded that the kriging with a  
21 trend approach leads to reliable and rather objective estimated intensities (Rey *et al.*, 2013).  
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35 The processing chain was completely automated to treat the 1,623 earthquakes described in  
36 the SisFrance database by three or more IDPs and an epicentral intensity. Epicentral intensity  
37 is usually not an IDP and is thus not used for the calculations, but its absence indicates poorly  
38 known events, which must be discarded. Obviously, the larger the number of IDPs available,  
39 the more accurate should be the isoseismal map. At each grid point, the kriging algorithm  
40 delivers an intensity estimate as well as a standard deviation quantifying the precision in the  
41 interpolation (Rey *et al.* 2015b). An automatic check on the obtained intensity range per  
42 earthquake is used to identify earthquakes with potential anomalies and which deserve a  
43 visual check. Approximately half of the 1,623 isoseismal maps have thus been visually  
44 inspected. Based on this thorough analysis, interpolated values with standard deviations  
45 larger than 0.5 or 1.0, depending on the earthquake, were considered as unreliable and  
46 discarded (Rey *et al.* 2015b).  
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56 For every earthquake, the software automatically produces an isoseismal map over a  
57 geographical grid as well as estimated intensities at the administrative centroid of every  
58 municipality in mainland France (i.e. the location of the town hall). The resulting database  
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1 consists of roughly 60 million estimated IDPs, corresponding to the intensities at the 36,000  
2 French municipalities from 1,623 earthquakes. Excluding unreliable interpolated values and  
3 keeping only intensities larger than III, the final total number of estimated IDPs in the database  
4 drops to approximately 2 million. As future uses of the interpolated database might need  
5 uncertainty classes, the intensity estimates are classified into three groups roughly equivalent  
6 to the A, B and C grades of SisFrance, based on the standard deviation estimated in the  
7 kriging procedure (Rey *et al.*, 2015b).  
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#### 10 *More information on the semivariogram used in the kriging technique*

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12 A critical input to the kriging algorithm is the semivariogram, which defines how to relate  
13 neighbouring points. An exponential semi-variogram of the form:  $\gamma(h)=c_0+c_1 [1-\exp(-3 h/a)]$ ,  
14 where  $h$  is the lag and equals the distance between two intensity points, was adopted for this  
15 study in agreement with Ambraseys and Douglas (2004). Ambraseys and Douglas (2004)  
16 adopted values of  $c_0=1$ ,  $c_1=1$  and  $a=1000\text{km}$  for this function. The critical parameter is  $a$ , which  
17 roughly corresponds to the distance to which an IDP has an influence on the surrounding area.  
18 Small values of  $a$  (e.g. 100km) lead to intricate maps where the isoseismals can be jagged as  
19 the predicted intensity at a given location is only influenced by close-by observations. Large  
20 values of  $a$  (e.g. 1000km) lead to isoseismals with a smooth shape, which is closer to those  
21 obtained by manual drawing (e.g. Figure 2).  
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32 To determine which  $a$  is best adapted to France, experimental semivariograms were derived  
33 for the 109 earthquakes with 100 or more intensity points in the database. To construct these  
34 semivariograms a standard procedure was adopted (e.g. Jayaram and Baker, 2009) but with  
35 the modification that only intensities at roughly the same epicentral distances were compared  
36 (within intervals of 25km). This is to limit the impact of the expected decay in intensities.  
37 Distance intervals of 25km were used to construct the experimental semivariograms, although  
38 intervals of 10km and 50km were also tried with similar results. Exponential models were fitted  
39 by least-squares regression in order to find  $a$ . Most of the experimental semivariograms  
40 obtained did not show clear patterns, with  $\gamma(h)$  not showing much dependence on the lag  $h$   
41 (e.g. in the case of the Saint Dié 2003 event, Figure 3a). This implies that close-by intensities  
42 are not more inter-correlated than distant observations.  
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52 The difficulty of measuring the spatial correlation of IDPs might be due to the narrow range of  
53 available intensities (generally for SisFrance database from III to VII) and their discrete nature  
54 (i.e. integer values). Also, local effects could add additional variability to the intensity  
55 observations, thereby making the experimental semivariogram more variable. Nonetheless,  
56 for some earthquakes, the experimental semivariograms showed the expected behaviour with  
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1 correlation decreasing with lag (separation between two intensity observations). As an  
2 example, in Figure 3b the experimental semi-variogram obtained from the 431 intensity points  
3 of the 1972 Ile d'Oléron earthquake is shown (exponential model fitted with  $a=1,979\text{km}$ ).  
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6 Finally, the same  $a$  value as Ambraseys and Douglas (2004) was selected ( $a=1000\text{km}$ ) as it  
7 provided the best match to the manually drawn maps (Rey *et al.*, 2013). As intensity is a  
8 discrete quality, which does not generally show large differences between neighbouring  
9 locations,  $a=1000\text{km}$  appears to be an appropriate choice. This is in contrast to correlation  
10 models for instrumentally-measured ground-motion parameters (e.g. PGA), for which much  
11 smaller values of the parameter  $a$  are justified (e.g. Jayaram and Baker, 2009).  
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### 16 **Comparison between estimated intensities and PSHAs**

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19 Rather than testing the MEDD2002 PSHA study (Martin *et al.* 2002), used to establish the  
20 current French zoning but which relies on models that are now mostly out-dated, we decided  
21 to test the latest European seismic hazard results (ESHM13) produced by the SHARE  
22 European project (Woessner *et al.*, 2015). Mean hazard values for PGA and elastic response  
23 spectral accelerations for selected structural periods are available, based on a logic tree  
24 including three alternative source models and a set of ground-motion prediction equations.  
25 The mean hazard curves at the twenty-four selected cities in France have been downloaded  
26 from the epher.org website (Figure 4). Hazard estimates vary greatly between the cities, ranging  
27 from 0.013 (in Paris) to 0.3g (in Lourdes) for PGA and a return period of 475 years.  
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#### 35 *Preparing the data to enable the comparisons*

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38 Because ESHM13 hazard estimates are in terms of PGAs, intensities must be converted into  
39 PGAs to compare the model predictions with the intensity history. The best option would be to  
40 use a GMICE based on French data. This would require a large set of co-located PGA and  
41 intensity observations from France; a dataset which is not available at present given the low  
42 seismicity rates in France. The Caprio *et al.* (2015) global GMICE is used for this purpose  
43 here. This equation is used in the ShakeMaps produced by the BCSF because it proved to be  
44 rather well adapted for France (Schlupp, 2016).  
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51 Determining the time windows of completeness for each intensity level at the 24 sites is a  
52 difficult task. Ideally, completeness time periods should be determined using methods that are  
53 independent of the intensity datasets, e.g. on historical grounds like Stucchi *et al.* (2013). In  
54 France, such a historical analysis is not available, and complete time windows can only be  
55 determined from the intensity data itself. An analysis of the intensity dataset shows that  
56 intensity level III is not complete; therefore only intensities higher or equal to IV are considered  
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1 further. As done classically for determining completeness of earthquake catalogues (e.g.  
2 Burkhard and Grunthal 2009; Beauval *et al.* 2013), the complete time window is determined  
3 visually from the cumulative number of intensities versus time (Table 1). Stable rates of  
4 occurrence over time indicate complete periods. Time windows of completeness are estimated  
5 considering intensities higher or equal to IV. These time windows are also used for higher  
6 intensity levels, as the datasets for these intensity levels is too restricted to evaluate  
7 meaningful time windows. Graphs showing the cumulative number of intensities versus time,  
8 for the 24 selected sites, are displayed in the Electronic Supplement. As the identification of  
9 the complete time window is associated with large uncertainties, comparison tests are also  
10 made using slightly longer and slightly shorter time windows (extension and reduction,  
11 respectively, by 50 years), to evaluate the impact on the results.  
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#### 19 *Summary of the comparison procedure for a given intensity level (e.g. IV)*

- 21 1. The history in intensity has been produced at the 24 selected French communities  
22 relying on interpolations of the SisFrance database (see section “Construction of a  
23 database of interpolated intensities for France”), then for each city;
- 24 2. Estimate the complete time window for intensities higher or equal to IV (e.g. 1750-2007  
25 for Clermont-Ferrand, 258 years);
- 26 3. Count the number of exceedances of intensity level IV over the complete time window;
- 27 4. Convert the intensity IV into PGA using the Caprio *et al.* (2015) global relation. Extract  
28 from the ESHM2013 PGA hazard curve the annual exceedance rate corresponding to  
29 this PGA. Calculate the expected mean number of exceedances of this PGA over a  
30 window with same length as the complete time window (e.g. 258 years for Clermont-  
31 Ferrand). Calculate also the number of exceedances corresponding to the percentiles  
32 2.5 and 97.5% assuming a Poisson distribution [for details see, e.g., Tasan *et al.*  
33 (2014)];
- 34 5. Compare observed and expected numbers of exceedances, corresponding to the  
35 same time window (with the same length as the complete time window). Note that we  
36 could re-scale the observed number based any length of windows.  
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#### 49 *Comparisons in terms of number of exceedances*

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51 For a given intensity level, the predicted mean number of exceedances is compared to the  
52 observed number of exceedances. The time window considered has the same length as the  
53 time window of completeness for intensity IV, thus this time window varies from one city to the  
54 other. For example, for Clermont-Ferrand and an intensity of IV (corresponding to a PGA of  
55 0.011g), the ESHM13 mean annual rate of exceedance is 0.0294. As the time period of  
56 completeness is 258 years (1750-2007), the predicted mean number of exceedances of  
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1 intensity IV over 258 years is  $0.0294 \times 258 = 7.6$  (Figure 5, abbreviation “CFE”). In the  
2 probabilistic seismic hazard model, earthquake ground motions are assumed to occur  
3 according to a Poisson process, so this number is only a mean value. It is more appropriate  
4 to consider an interval and the percentiles 2.5 and 97.5% corresponding to 3 to 13 expected  
5 intensities higher or equal to IV (Figure 5). In the case of Clermont-Ferrand, the observed  
6 number is within the predicted distribution, with 12 intensities higher or equal to IV “observed”  
7 during the period 1750-2007.  
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12 Figure 5 displays the comparison between predicted and observed exceedance numbers for  
13 intensity IV at the 24 selected cities. The order of the cities, from left to right, corresponds to  
14 increasing hazard estimated by ESHM13 (increasing annual exceedance rate for intensity IV).  
15 For half of the cities (12 out of 24 cities), the observation is within the predicted range, i.e.  
16 within the percentiles 2.5 and 97.5% (e.g. Rennes, Lille, Aix-en-Provence and Avignon). For  
17 the other half, the observed numbers are larger than predicted. The sites where the observed  
18 number is much higher than predicted are distributed all over France, in the west (e.g. Le  
19 Havre and Bordeaux), in the south-west (Lourdes), and in the east (Grenoble, Chambéry,  
20 Annecy and Strasbourg). Lourdes is where the discrepancy between predicted and observed  
21 number is the largest, with 7 to 22 intensities expected over 1850-2007, compared to 53  
22 observed.  
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32 As the determination of completeness time windows is associated with large uncertainties, the  
33 comparison is repeated considering slightly longer or slightly shorter complete time windows.  
34 Extending the window back in time by 50 years, or shortening this window by 50 years, leads  
35 to results that are not that different: 14 out of 24 cities with observations within the predicted  
36 range when extending the window, 15 out of 24 cities when shortening the window (results  
37 not shown).  
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43 The analysis for intensity level V leads to comparable results (Figure 6), but with lower expected  
44 numbers of exceedance. 14 cities out of 24 have experienced a number of exceedances within  
45 the expected range. In Clermont-Ferrand, for example, up to 5 intensities higher or equal to V  
46 are expected over a time window of 258 years (97.5<sup>th</sup> percentile), whereas 3 have been  
47 observed (between 1750 and 2007). Ten out of 24 sites have experienced a number of  
48 exceedances larger than the predicted percentile 97.5%. This is the case, for example, for  
49 Bordeaux, Besançon, Grenoble, Chambéry and Annecy.  
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55 The results for intensity level VI are less clear (Figure 7), there are few available data and the  
56 observed numbers of exceedances are small over the considered periods. The time windows  
57 considered are too short with respect to the return periods of such levels. Nonetheless, for 7  
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1 out of 8 cities with observed numbers larger than zero (Bordeaux, Lille, Grenoble, Chambéry,  
2 Nice, Strasbourg, Lourdes), observations are within the range of predictions (the exception is  
3 Annecy).  
4

5 Throughout this article, mean hazard estimates are considered in the comparison with  
6 observations. However, as with any state-of-the-art PSHA study, ESHM13 results are  
7 expressed in terms of mean and percentile hazard curves, resulting from the exploration of a  
8 source model logic tree as well as a ground-motion model logic tree (Woessner *et al.* 2015;  
9 note that this percentile has no relation with the percentile associated with the Poisson  
10 distribution). As expected, comparisons are different if considering other hazard estimates  
11 than the mean. For example, if the 85<sup>th</sup> percentile (taken from the epher.org website) is  
12 considered, predicted exceedance numbers increase, and all but three cities show an  
13 agreement between observations and predictions (Figure 8).  
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### 21 *Taking into account the uncertainty associated to the GMICE in the comparison*

22 The uncertainty in the conversion from intensity to PGA using the GMICE is significant. For a  
23 given intensity, Caprio *et al.* (2015) associates a standard deviation of 0.4 to the predicted  
24 logarithm of the mean PGA. To check how much this uncertainty impacts the results, the  
25 normal distribution modelled by the Caprio *et al.* (2015) GMICE is sampled and 10,000  
26 synthetic PGA datasets are generated from the original intensity dataset, at a location. An  
27 example dataset is displayed in Figure 9 for Clermont-Ferrand. Including the uncertainty on the  
28 conversion from intensity to PGA, a distribution for the observed number of exceedances over  
29 the time period of completeness is obtained.  
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38 Figure 10 compares the number of exceedances predicted by ESHM13 in Lourdes over a time  
39 window of 158 years, for accelerations between 0.001g and 1g, with the observed distribution  
40 including the uncertainty on the intensity-PGA conversion (counted over the time window of  
41 completeness 1850-2007). Intensity levels IV, V and VI are considered. Again, observations  
42 are larger than predicted by the model for accelerations of 0.011g and 0.046g (intensities IV  
43 and V). At 0.084g (intensity VI), the predicted and the observed distributions are slightly  
44 overlapping. The results for intensity VI should be considered with care; there are few intensity  
45 observations greater than or equal to VI and the time windows considered are short with  
46 respect to the return periods of such intensities. Including the uncertainty in the intensity-PGA  
47 conversion does not change the overall results. For Clermont-Ferrand, for example,  
48 observations and predictions agree rather well, with means of observed distributions within  
49 the predicted range (percentiles 2.5 and 97.5%, Figure 11). For Nancy, observations are above  
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1 predictions for acceleration levels of 0.011g and 0.046g (Figure 12), which is in agreement with  
2 Figure 5.  
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## 4 **Conclusions**

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7 An inventory of macroseismic intensities at the municipal level was created in this study for  
8 the first time for mainland France. This database was produced via a robust interpolation  
9 technique from an existing well-established database of intensities of historical earthquakes  
10 (SisFrance). The intensity history is thus obtained for 24 French cities distributed over the  
11 whole country in various seismotectonic contexts. These interpolated intensities were  
12 compared with the history expected from the recent probabilistic seismic hazard assessment  
13 for Europe (ESHM13) produced by the SHARE project. The benefit of using macroseismic  
14 intensities for this comparison is that it extends the time period available for this comparison  
15 to centuries rather than decades, which is the case for instrumental records. This is particularly  
16 important for an area of low to moderate seismicity, such as mainland France. This advantage  
17 in the temporal domain (as well as increased spatial coverage with respect to instrumental  
18 networks), however, needs to be weighed against disadvantages concerning uncertainties  
19 from: the original estimation of macroseismic intensities from historical documents; problems  
20 in interpolation due to, e.g., lack of data and offshore epicentres; assessment of completeness  
21 time periods; and the conversion between intensity and peak ground acceleration.  
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33 We find that exceedance rates estimated in ESHM13 (mean model) are in agreement with the  
34 observations (intensity IV and V, corresponding to moderate shaking) for approximately half  
35 of the sites considered. For the other sites, the estimated exceedance rates are lower than  
36 the observations. The comparison is also made for intensity level VI, which shows a better  
37 match; however, great caution must be taken for this intensity as few data are available. A  
38 reason for predicting lower intensities than observed could be related to the minimum moment  
39 magnitude 4.5 used for ESHM13 (Woessner *et al.*, 2015). Magnitudes lower than 4.5 do not  
40 contribute to the hazard estimated although they can produce intensities higher or equal to IV  
41 close to the epicentre. Another reason for the discrepancy could be due to epistemic  
42 uncertainty in the choice of the equation to convert intensities to peak ground acceleration and  
43 also the uncertainty inherent in making such a conversion. Finally, the hazard calculations in  
44 ESHM13 are for average 'rock' conditions, whereas the interpolated intensities inevitably  
45 include local site effects that may amplify ground motions (Bossu *et al.*, 2000).  
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55 The database of the interpolated intensities also includes the municipalities of French  
56 overseas territories (Rey *et al.*, 2015b). The same type of comparison could also be  
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1 undertaken for these locations but it will be even more challenging as the historical catalogue  
2 is shorter (rough 200 years) and it includes many offshore epicenters.  
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4 The Matlab script used for kriging is freely available on request from the corresponding author.  
5 The database is available as a French web-service for geological risks:  
6 <http://www.georisques.gouv.fr/dossiers/seismes/donnees#/> (last accessed October 2017).  
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14 Environment. Early versions of this study were presented at the 35<sup>th</sup> General Assembly of the  
15 European Seismological Commission, the 9<sup>th</sup> National Colloquium of the French Association  
16 of Earthquake Engineering (AFPS2015) and the 4<sup>th</sup> International Colloquium on Historical  
17 Earthquakes and Macroseismology. We thank those people who commented on these  
18 presentations. Finally, we thank two anonymous reviewers for their comments on the first  
19 version of this article.  
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## 28 **References**

- 29 Ambraseys, N. N. and Douglas, J. (2004), Magnitude calibration of north Indian earthquakes,  
30 *Geophysical Journal International*, **159**, 165–206.  
31  
32  
33  
34  
35  
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62  
63  
64  
65
- Bakun, W.H. and O. Scotti (2006), Regional intensity attenuation models for France and the estimation of magnitude and location of historical earthquakes. *Geophysical Journal International*, **164**, 596-610.
- Beauval, C., Bard, P.-Y., Hainzl, S. and Guéguen, P. (2008), Can strong-motion observations be used to constrain probabilistic seismic hazard estimates?, *Bulletin of the Seismological Society of America*, **98**, 509-520.
- Beauval C. (2011), On the use of observations for constraining probabilistic seismic hazard estimates-brief review of existing methods, *Applications of Statistics and Probability in Civil Engineering*, Faber, Kohler and Nishijima editors, London, 763-767 (ISBN 978-0-415-66986-3).
- Beauval, C., H. Yepes, P. Palacios, M. Segovia, A. Alvarado, Y. Font, J. Aguilar, L. Troncoso, and S. Vaca (2013), An earthquake catalog for seismic hazard assessment in Ecuador, *Bulletin of the Seismological Society of America*, **103**, 773–786, doi: 10.1785/0120120270.

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62  
63  
64  
65

Bossu, R., Scotti, O., Cotton, F., Cushing, M. and Levret, A. (2000), Determination of geomechanical site effects in France from macroseismic intensities and reliability of macroseismic magnitude of historical events. *Tectonophysics*, **324**, (1–2), 81–110.

BRGM/EDF/IRSN (2017), Base de données SISFRANCE – [www.sisfrance.net](http://www.sisfrance.net), Last accessed April 2017.

Burkhard M. and G. Grünthal (2009), Seismic source zone characterization for the seismic hazard assessment project PEGASOS by the Expert Group 2 (EG1b), *Swiss Journal of Geosciences*, **102**, 149-188, DOI 10.1007/s00015-009-1307-3.

Caprio, M., Tarigan, B., Worden, C. B., Wiemer, S. and Wald, D. J. (2015), Ground motion to intensity conversion equations (GMICEs): A global relationship and evaluation of regional dependency, *Bulletin of the Seismological Society of America*, **105**(3), 1476-1490, doi: 10.1785/0120140286.

Council of Europe (1998), European macroseismic scale 1998 (EMS-98), Grünthal G (ed.), vol. 15, Centre Européen du Géodynamique et de Séismologie: Luxembourg.

Douglas, J. (2017), Ground motion prediction equations 1964–2017, <http://www.gmpe.org.uk>. Last accessed October 2017.

Jayaram, N. and Baker, J. W. (2009), Correlation model for spatially distributed ground-motion intensities, *Earthquake Engineering and Structural Dynamics*, **38**, 1687-1708, doi: 10.1002/eqe.922.

Lambert, J. (2004), Base de données SisFrance et SisFrance-Antilles, Sites internet, année 2004. Rapport final. Rapport BRGM/RP-53333-FR, 33 pp. In French.

Mak, S. and Schorlemmer, D. (2016), A Comparison between the Forecast by the United States National Seismic Hazard Maps with Recent Ground-Motion Records, *Bulletin of the Seismological Society of America*, **106**(4), 1817-1831.

Manchuel, K., Traversa, P., Baumont, D., Cara, M, Nayman, E., Durouchoux, C., (2017), The French seismic CATalogue (FCAT-17), *Bulletin of Earthquake Engineering*, doi: 10.1007/s10518-017-0236-1.

Martin, C., Combes, P., Secanell, R., Lignon, G., Carbon, D., Fioravanti, A. & Grellet, B., 2002. Révision du zonage sismique de la France: étude probabiliste, under the supervision of the Groupe d'Etude et de Proposition pour la Prévention du risque sismique en France and the

1 Association Française du Génie Parasismique (in French), Geoter Report, GTR/MATE/0701-  
2 150.

3  
4 Medvedev, S. P., Sponheuer, W. and Karnik, V. (1967), Seismic intensity scale version 1964.  
5 *Inst. Geody. Publ.*, Jena, 48 pp.

6  
7  
8 Mucciarelli, M., Albarello, D. and D'Amico, V., (2008), Comparison of probabilistic seismic  
9 hazard estimates in Italy, *Bulletin of the Seismological Society of America*, **98**, 2652–2664.

10  
11  
12 Musson, R. M. W. (2000), Intensity-based seismic risk assessment, *Soil Dynamics and*  
13 *Earthquake Engineering*, **20**(5-8), 353-360. doi: 10.1016/S0267-7261(00)00083-X.

14  
15  
16 Musson R.M.W., Grünthal G., Stucchi, M. (2010). The comparison of macroseismic intensity  
17 scales. *Journal of Seismology*, **14** (2), pp.413-428.

18  
19  
20  
21 Olea, R. A. (1999), *Geostatistics for engineers and earth scientists*, Kluwer Academic  
22 Publishers, Dordrecht.

23  
24  
25 Rey, J., Auclair, S., Douglas, J. and Lambert, J. (2013), Faisabilité et test d'une base de  
26 données des intensités macrosismiques historiques extrapolées pour les communes  
27 métropolitaines (phase 1), Final report. BRGM/RP-62941-FR, 75 p., 40 fig., 2 tabl., 1 ann. In  
28 French.

29  
30  
31  
32 Rey, J., Auclair, S. and Monfort Climent, D. (2015a), Etablissement d'une base de données  
33 des intensités historiques extrapolées pour toutes les communes françaises (phase 2), Final  
34 report, BRGM/RP-64384-FR, 52 p., 11 fig., 4 tabl., 2 ann. In French.

35  
36  
37  
38 Rey, J., Auclair, S., Daniels, P., Monfort Climent, D. and Raout, S. (2015b), Etablissement  
39 d'une base de données des intensités historiques extrapolées pour toutes les communes  
40 françaises (phase 3), Final report, BRGM/RP-65304-FR, 39 p., 2 ann. In French.

41  
42  
43  
44 Schlupp, A. (2016), ShakeMap fed by macroseismic data in France: feedbacks and  
45 contribution for improving SHA, AGU Fall Meeting, December 12-16, San Francisco.

46  
47  
48 Scotti, O., Baumont, D., Quenet, G. and Levret, A. (2004), The French macroseismic database  
49 SISFRANCE: objectives, results and perspectives, *Annals of Geophysics*, **47**(2/3).

50  
51  
52  
53 Stirling, M. and Petersen, M. (2006), Comparison of the Historical record of earthquake hazard  
54 with seismic-hazard models for New Zealand and the Continental United States, *Bulletin of*  
55 *the Seismological Society of America*, **96**, 1978–1994.

56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1 Stucchi, M., Rovida, A., Gomez Capera, A.A. *et al.* (2013), The SHARE European Earthquake  
2 Catalogue (SHEEC) 1000–1899, *Journal of Seismology*, **17**(2), 523–544.  
3 doi:10.1007/s10950-012-9335-2.  
4

5 Tasan, H., Beauval, C., Helmstetter, A. Sandikkaya, A. and Guéguen, P. (2014), Testing  
6 probabilistic seismic hazard estimates against accelerometric data in two countries: France  
7 and Turkey, *Geophysical Journal International*, **198**(3), 1554-1571.  
8  
9

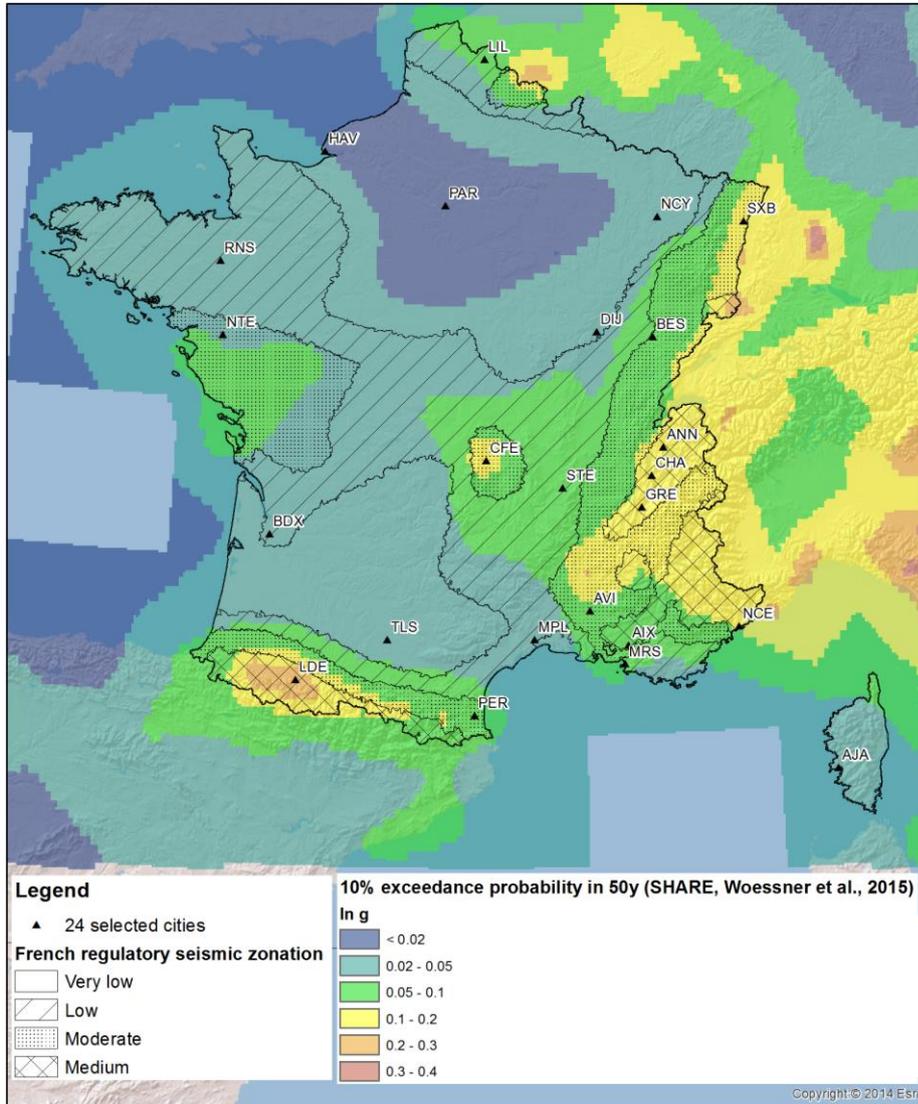
10  
11 Woessner, J., Laurentiu, D., Giardini, D. *et al.* (2015), The 2013 European Seismic Hazard  
12 Model: Key components and results, *Bulletin of Earthquake Engineering*, **13**(12), 3553-3596,  
13 doi: 10.1007/s10518-015-9795-1.  
14  
15  
16  
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Tables

Municipality	Abbreviation	Time window (level IV and V)	Number of IDPs >= level IV	Number of IDPs >= level V	Number of IDPs >= level VI
<b>Aix-en-Provence</b>	AIX	1800-2007	19	9	1
<b>Ajaccio</b>	AJA	1750-2007	3	0	1
<b>Annecy</b>	ANN	1750-2007	44	15	12
<b>Avignon</b>	AVI	1650-2007	23	9	1
<b>Besançon</b>	BES	1575-2007	37	13	1
<b>Bordeaux</b>	BDX	1620-2007	13	9	2
<b>Chambéry</b>	CHA	1750-2007	26	17	9
<b>Clermont- Ferrand</b>	CFE	1750-2007	19	6	3
<b>Dijon</b>	DIJ	1550-2007	28	7	0
<b>Grenoble</b>	GRE	1750-2007	27	22	4
<b>Le Havre</b>	HAV	1550-2007	17	4	1
<b>Lille</b>	LIL	1350-2007	11	4	4
<b>Lourdes</b>	LDE	1850-2007	54	27	12
<b>Marseille</b>	MRS	1850-2007	20	7	0
<b>Montpellier</b>	MPL	1750-2007	19	4	0
<b>Nancy</b>	NCY	1550-2007	24	6	2
<b>Nantes</b>	NTE	1750-2007	29	2	1
<b>Nice</b>	NCE	1800-2007	25	10	7
<b>Paris</b>	PAR	1350-2007	11	1	0
<b>Perpignan</b>	PER	1750-2007	23	12	3
<b>Rennes</b>	RNS	1750-2007	24	6	0
<b>Saint-Etienne</b>	STE	1750-2007	26	8	0
<b>Strasbourg</b>	SXB	1550-2007	42	23	5
<b>Toulouse</b>	TLS	1620-2007	18	6	3

**Table 1:** Time window of completeness for intensity levels IV, extended to levels V and VI, and number of IDPs within this time windows for the 24 municipalities of the study.

Figures



**Figure 1:** Peak Ground Accelerations with 10% exceedance probability in 50 years predicted by the mean ESHM13 ([www.efher.org](http://www.efher.org), Woessner *et al.*, 2015), and the twenty-four selected municipalities representative of the four zones of the French regulatory seismic zonation. AIX : Aix-en-Provence; AJA : Ajaccio ; ANN : Annecy ; AVI : Avignon ; BDX : Bordeaux ; BES : Besançon ; CHA : Chambéry ; CFE : Clermont-Ferrand ; DIJ : Dijon ; GRE : Grenoble ; HAV : Le Havre ; LDE : Lourdes ; LIL : Lille ; MPL : Montpellier ; MRS : Marseille ; NCE : Nice ; NCY : Nancy ; NTE : Nantes ; PAR : Paris ; PER : Perpignan ; RNS : Rennes ; STE : Saint-Etienne ; SXB : Strasbourg ; TLS : Toulouse.

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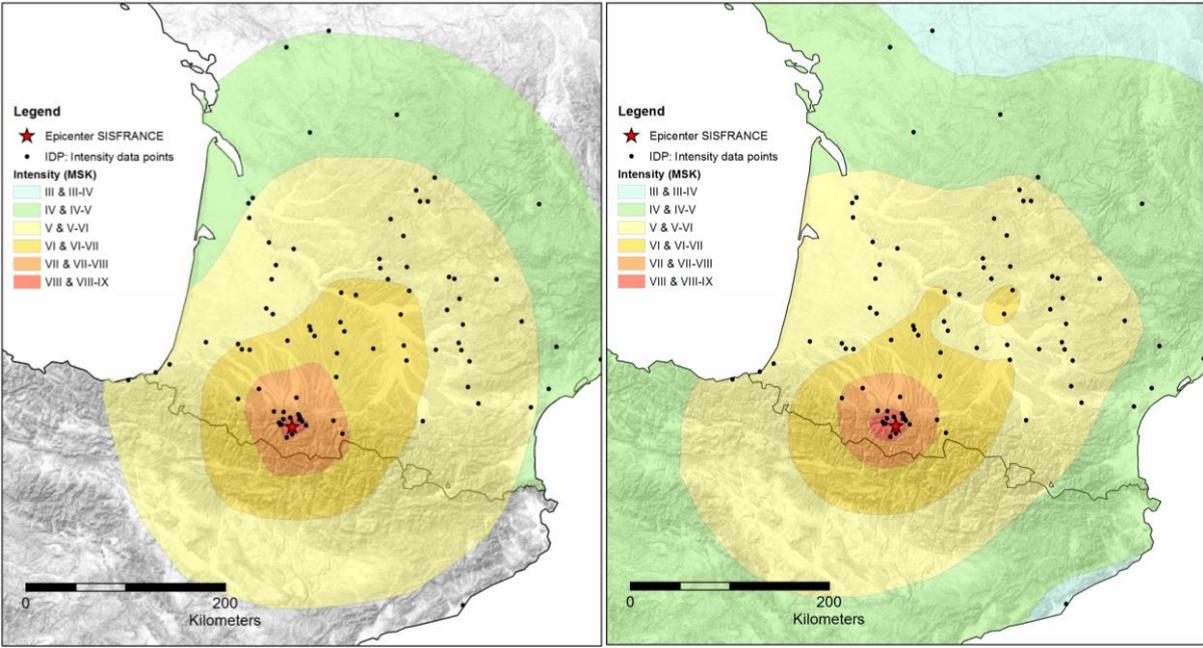
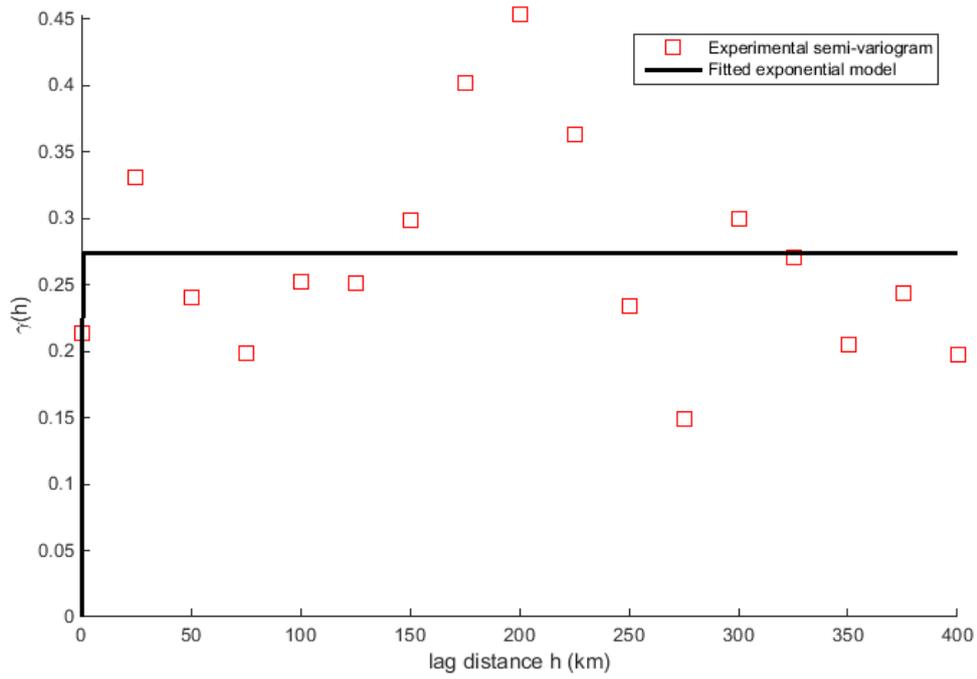


Figure 2: Isoseismal maps for the 21 June 1660 Bigorre earthquake drawn manually (left, from Lambert, 2004) and using the kriging approach (right, this study).

(a)



(b)

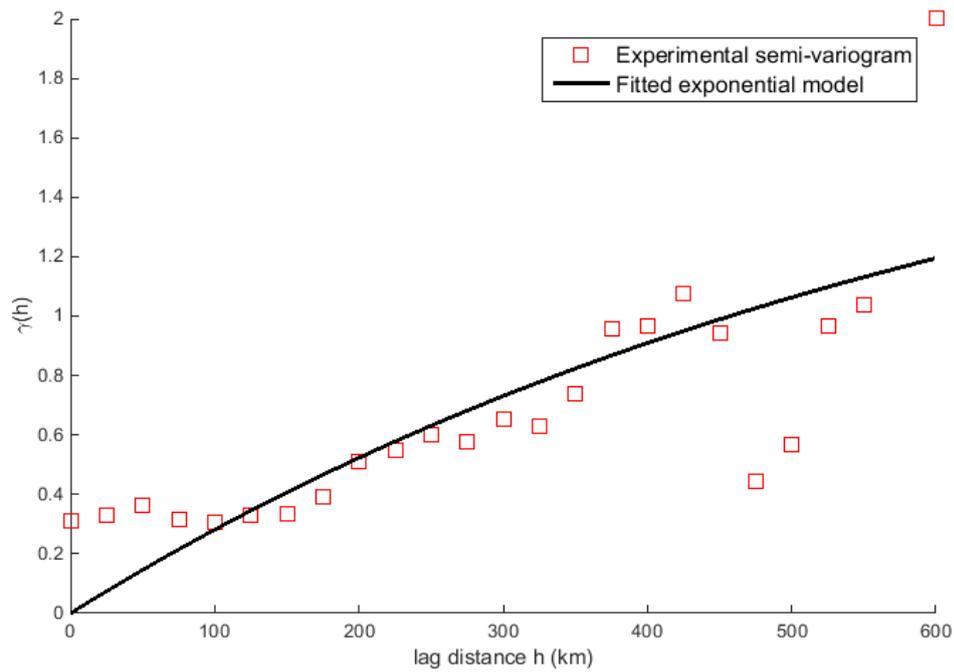
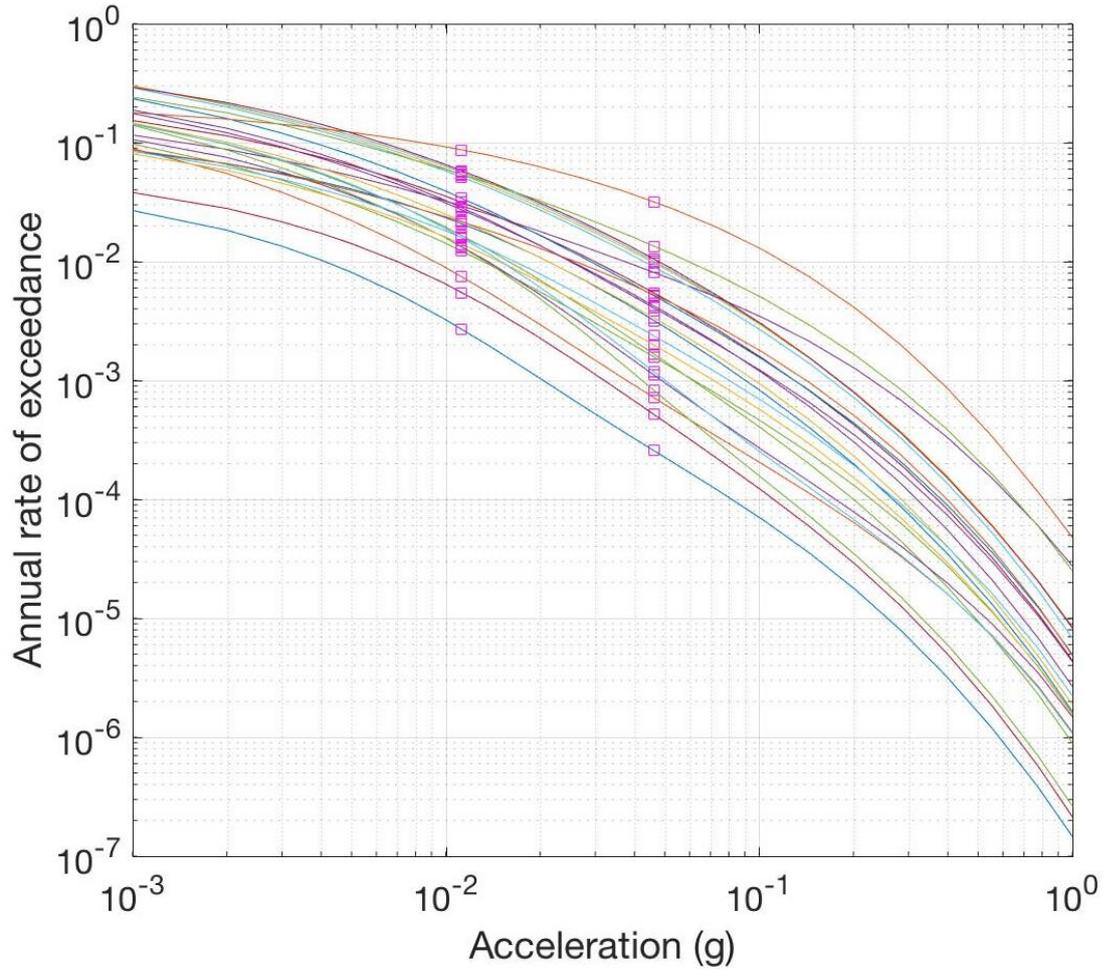


Figure 3: Experimental semi-variogram and the fitted exponential model for the (a) 22 February 2003 St Dié and (b) 7 September 1972 Ile d'Oléron earthquakes.



**Figure 4:** ESHM13 mean hazard curves (PGA, rock), obtained from epher.org. Pink squares indicate the rates interpolated for intensity IV (0.011g) and intensity V (0.046g, Caprio *et al.* 2015). Accelerations for 10% exceedance probability over 50 years (0.0021 annual rate) vary from 0.013g to 0.3g depending on the municipality.

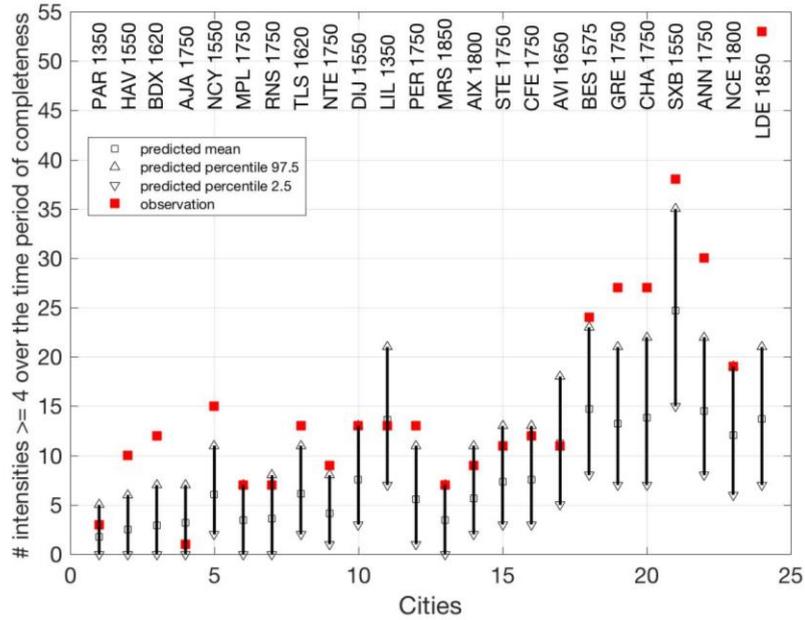


Figure 5: Comparison of predicted number of exceedances with “observed” number, for intensity level IV at 24 cities (equivalent to PGA 0.011g, Caprio *et al.* 2015). For each city, the time window considered has the same length as the time window of completeness for intensity IV. Mean exceedance number obtained from the mean SHARE annual exceedance rate; percentiles account for the variability of the number over the time window (Poisson distribution). Beginning date of complete time window indicated after the acronym of the city. See legend of Fig. 1 for acronyms. Cities are ordered, from left to right, according to increasing hazard as estimated by ESHM13 (increasing annual exceedance rate for PGA 0.011g).

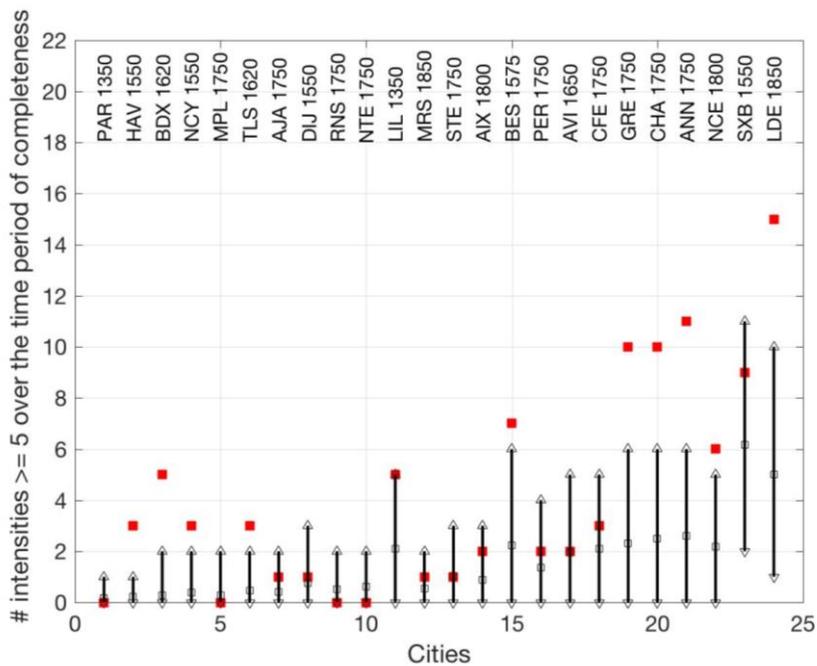
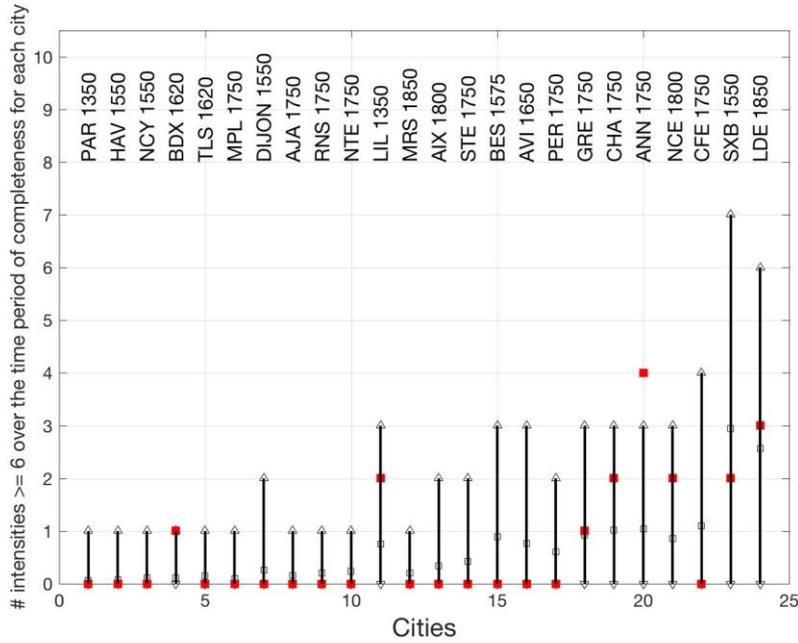
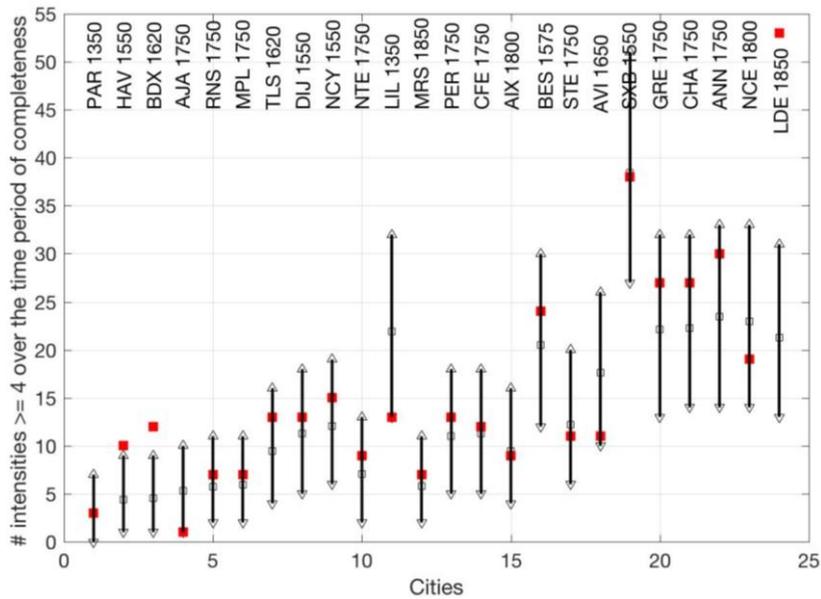


Figure 6: Comparison of predicted number of exceedances with “observed” number, for intensity level V at 24 cities (equivalent to PGA 0.046g, Caprio *et al.* 2015). Beginning date of complete time window indicated after the acronym of the city. Cities are ordered, from left to right, according to increasing hazard as estimated by ESHM13 (increasing annual exceedance rate for PGA 0.046g). See legend of Figure 6.



**Figure 7:** Comparison of predicted number of exceedances with “observed” number, for intensity level VI at 24 cities (equivalent to PGA 0.084g, Caprio *et al.* 2015). Beginning date of complete time window indicated after the acronym of the city. Cities are ordered, from left to right, according to increasing hazard as estimated by ESHM13 (increasing annual exceedance rate for PGA 0.084g). See legend of Figure 6.



**Figure 8:** Comparison of predicted number of exceedances with “observed” number, for intensity level IV at 24 cities (PGA 0.046g). The difference with Figure 5 is that instead of using the mean annual rate of exceedance provided by SHARE relying on the logic tree calculations (efher.org), the percentile 85% is used. See also legend of Figure 6.

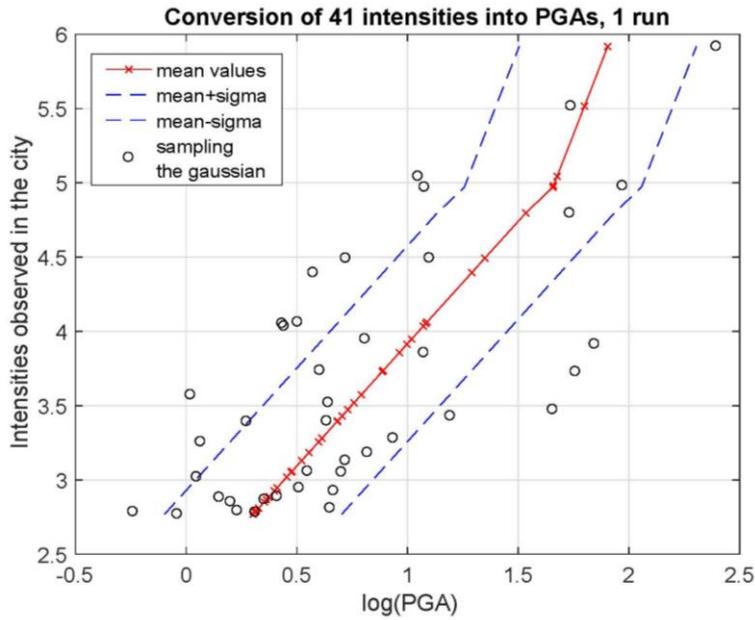


Figure 9: Example of one synthetic PGA dataset generated from the observed intensities within the time window of completeness, in Clermont-Ferrand. Sampling the Gaussian distributions predicted by Caprio *et al.* (2015), 10,000 synthetic datasets like this one are generated.

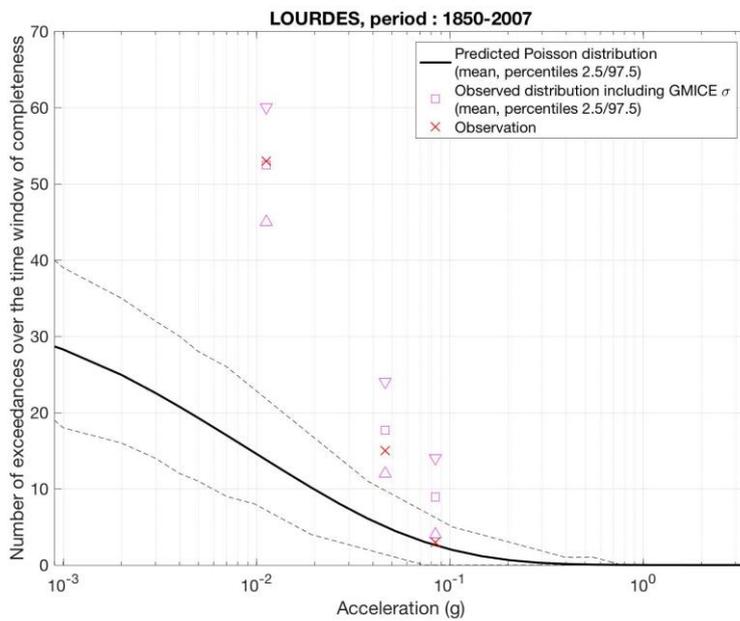


Figure 10 : Lourdes, comparison of predicted number of exceedances with observed number, for three intensity levels: IV (0.011g), V (0.046g), VI (0.084g, Caprio *et al.* 2015). The time window considered is the time window of completeness (1850-2007). Predicted Poisson distribution obtained from the mean annual rate estimated in SHARE. The uncertainty on the intensity-acceleration equation is taken into account by means of 10,000 synthetic PGA datasets, with intensities converted in PGAs by sampling the normal distribution predicted by Caprio *et al.* (2015, global equation).

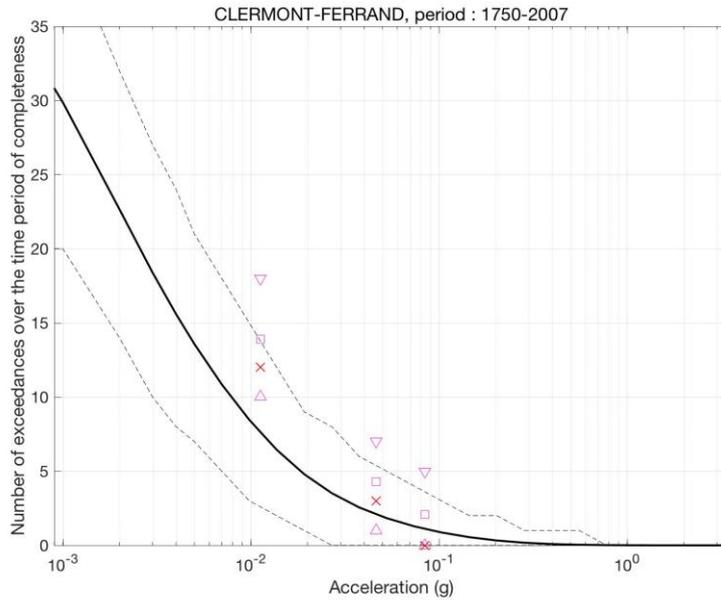


Figure 11 : Clermont-Ferrand, comparison of predicted number of exceedances with observed number, for three intensity levels: IV (0.011g), V (0.046g) and VI (0.084g). The time window considered is the time window of completeness (1750-2007). See legend of Figure 10.

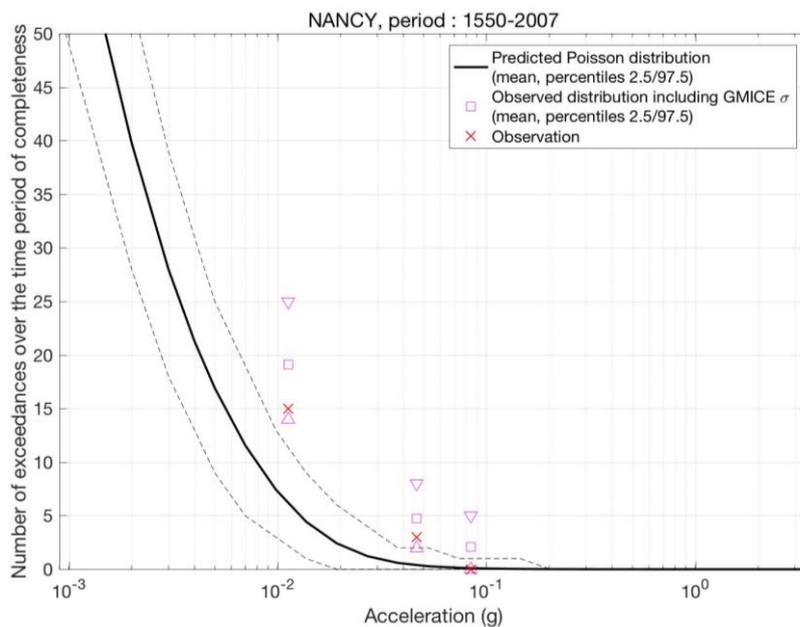
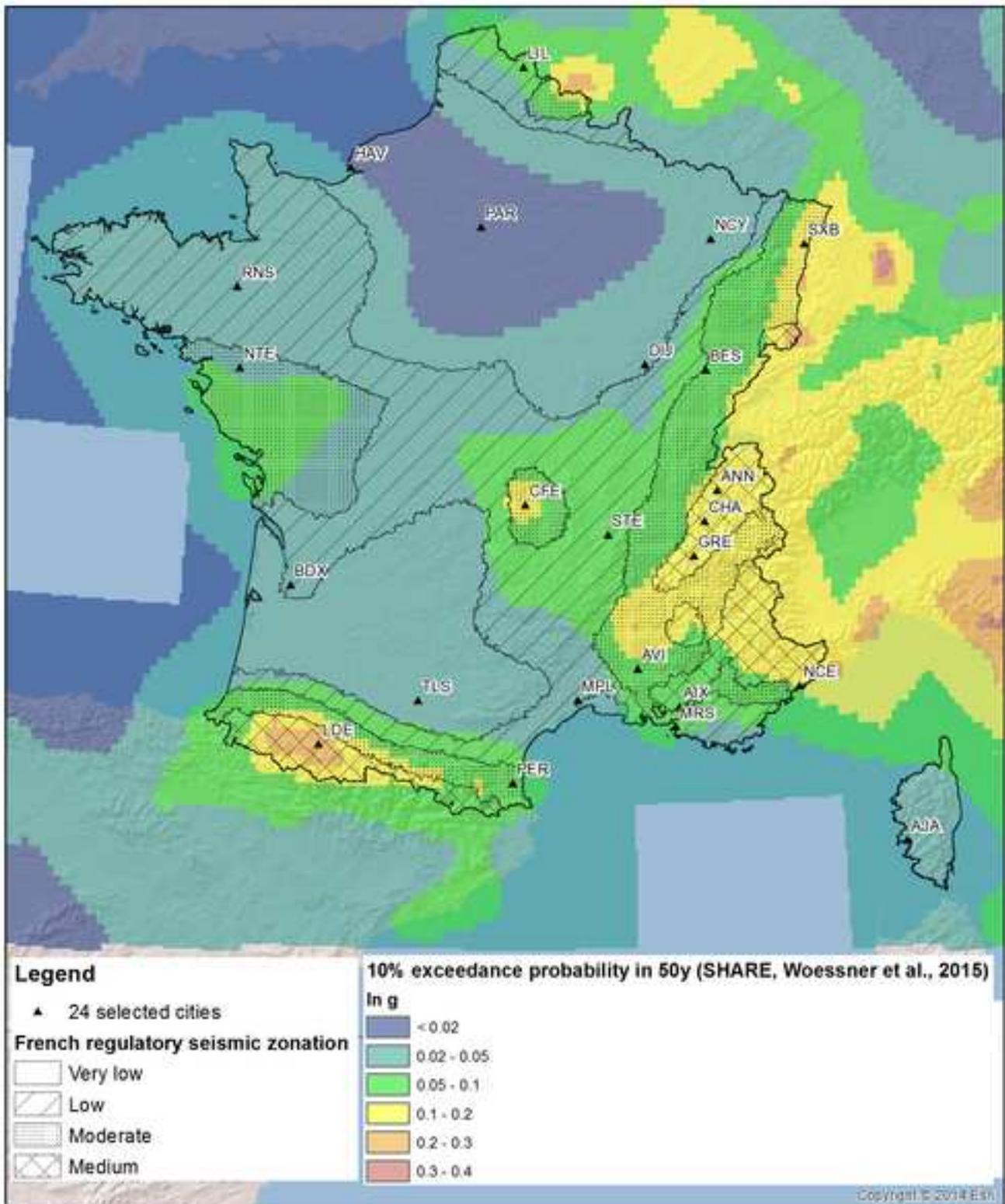
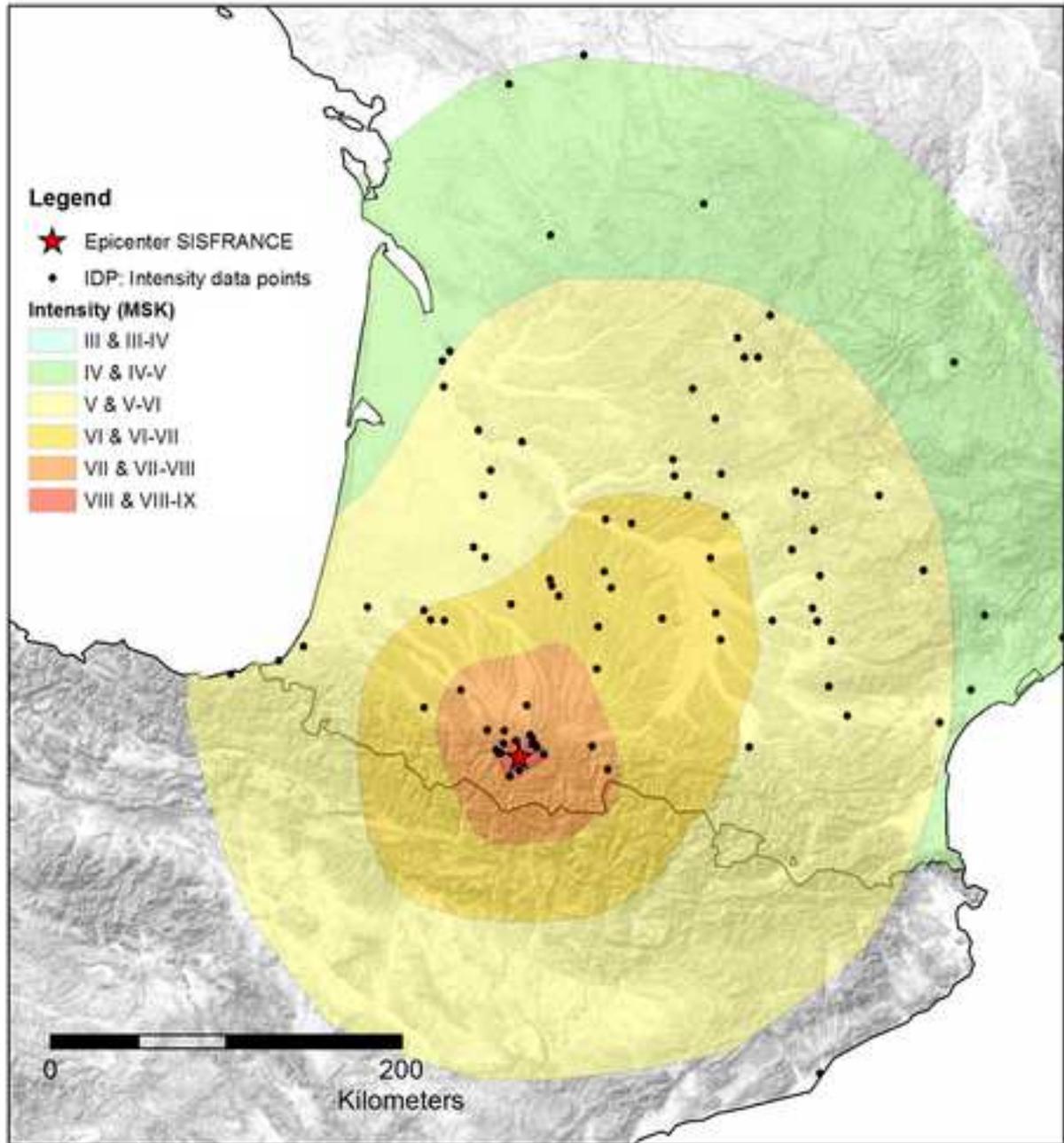
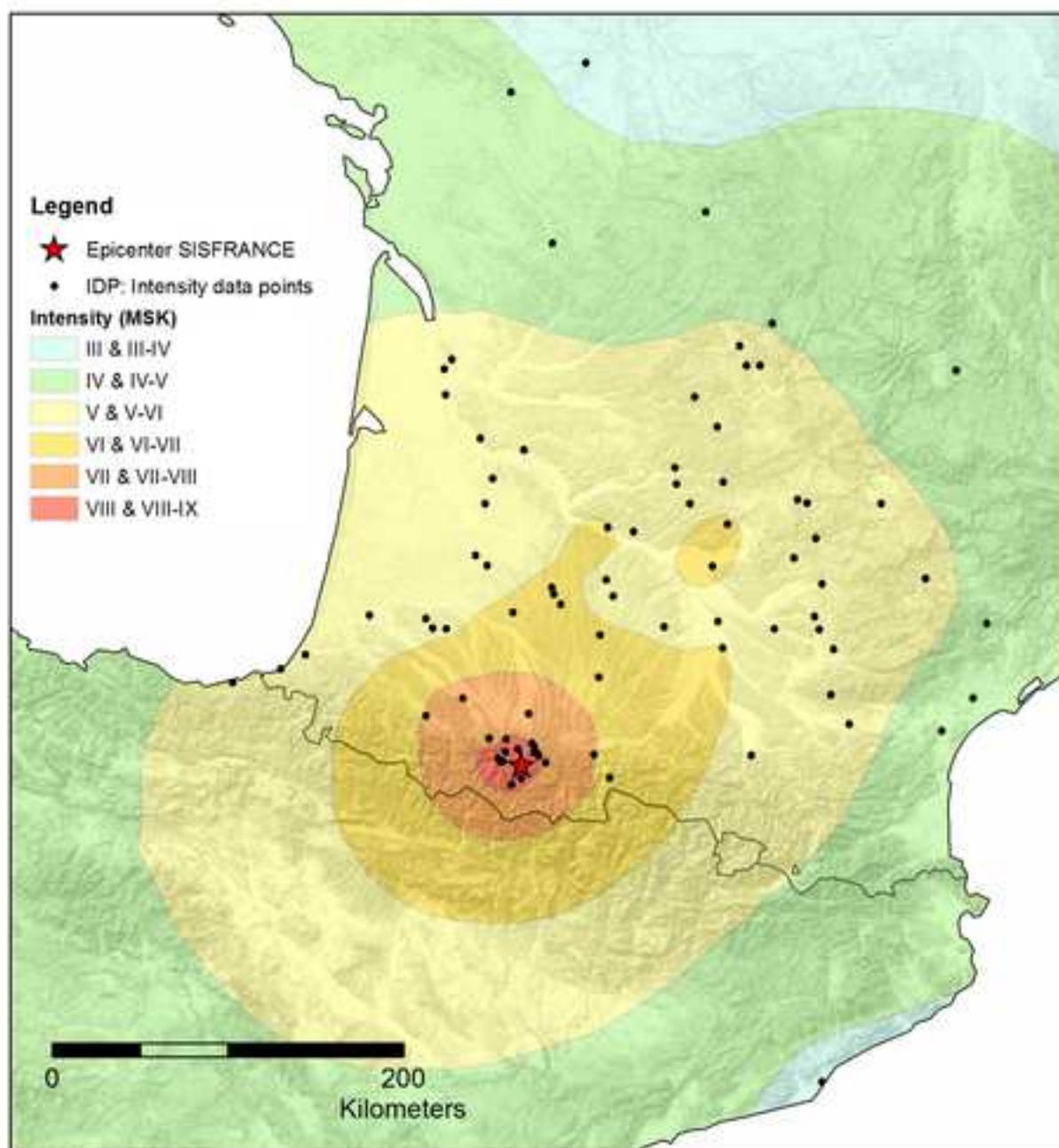


Figure 12 : Nancy, comparison of predicted number of exceedances with observed number, for three intensity levels: IV (0.011g), V (0.046g) and VI (0.084g). The time window considered is the time window of completeness (1550-2007). See legend of Figure 10.









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**Supplementary Material**

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