An outline of earthquake catalogues, databases and studies of historical seismicity in the Iberian Peninsula

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Abstract
The general purpose of the present paper is to summarize the state-of-the-art of historical earthquake knowledge and research in the Iberian Peninsula, giving an account of the main references, the historical developments and the present situation of earthquake catalogues. The most representative historical works for compiling earthquake data (catalogues) up to 1985 are referred together with those of more recent investigations carried out in Spain and Portugal for the period 1985-2003. Existing databases on historical seismicity are presented, mentioning the most important achievements in relation to quality of information.

Key words *historical seismicity – catalogues – macroseismic data – earthquake database – Iberian Peninsula*

1. Introduction

The knowledge of the historical evolution of catalogues is extremely important to understand the origin of modern catalogues. A detailed analysis of the ways the information contained in these catalogues is transmitted over time helps to better interpret modern catalogues and to be aware of the real problems they may hold. Muñoz and Udias (1982) gave a thorough outline of main Spain's works related to historical earthquake data compilation and listed the main catalogues produced until 1982. The most significant works reported in that study are mentioned here together with some of the new publications on particular events and some new earthquake catalogues which have appeared in Spain and Portugal since then. All these works lead to a quality improvement of the knowledge of the seismicity in our study area, the Iberian Peninsula, including Spanish, Portuguese and the Mediterranean and the Atlantic islands – Canaries, Balearic and the Azores – (fig. 1).

2. Overview of historical catalogues

The first works on seismicity of Iberia go back to mid 18th century as a consequence of the 1755 Lisbon earthquake. The great damage produced by this event in an important European town shocked the entire European society. A large amount of literature was written, including not only a number of seismic reports and studies concerning damage at different sites

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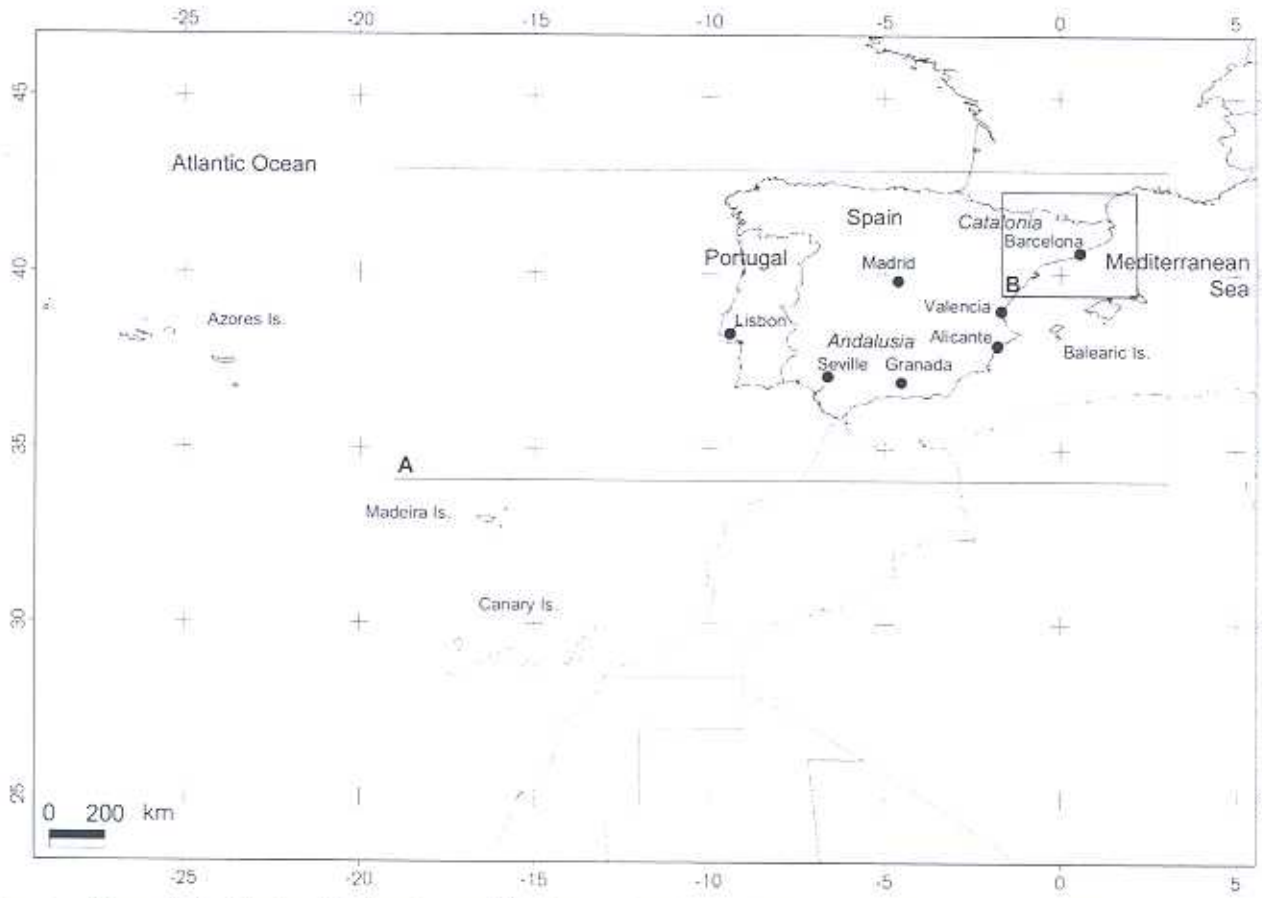

Fig. 1. Map of the Iberian Peninsula and insular territories of Spain and Portugal, with geographical names mentioned in the text. Rectangles A and B represent the areas covered by the catalogues of Martínez-Solares and Mezcua (2002) and Susagna and Goula (1999), respectively.

but also philosophical and scientific discussions, religious explanations and even poetry (Muñoz and Udias, 1982; Martínez-Solares, 2001). This earthquake can be considered the initiator of scientific interest in the compilation of seismic events in the Iberian Peninsula.

According to Muñoz and Udias (1982), the first lists of earthquakes in the Iberian Peninsula were compiled by Nipho (1755) and Roche (1756). Also, Moreira de Mendonça (1758), in his world catalogue from 1815 B.C. to 1755 A.D., containing about 400 well documented events with complete references, includes earthquakes in the Iberian Peninsula.

The work by Perrey (1847) is an important reference catalogue in Iberia, being the basis of many later studies. For earthquakes in Southern Spain, the catalogue by Taramelli and Mercalli (1886), as part of a field study on the 25 December 1884 earthquake, an outstanding example of early seismological work, completed the information contained in Perrey's catalogue adding other sources. For earthquakes in NE Spain, Teixidor Cros (1884) gives a summary of the earthquake history of Catalonia, which mainly relies on a booklet from Bolós (1841) about the Olot volcanic area. Mengel (1908; 1909; 1929) deals with seismic data for Catalonia (both Spain's and France's) and Pyrenees region. This is a reference work for Catalonia although the author is not very critical about historical sources.

Sánchez Navarro-Neumann (1917, 1920) published a catalogue for Spain including data from different sources, mainly from previous catalogues.

One of the most valuable references for seismicity of the Iberian Peninsula is the cata-

logue from Galbis (1932; 1940). It is a catalogue (1032 B.C.-1933 A.D.) which uses a large amount of historical sources, giving the corresponding references, including the works from contemporary Spanish seismologists such as Rey Pastor, Sánchez Navarro-Neumann, Faura i Sans and Fontseré, among others. Munuera (1963) in his catalogue, in table format, presents basically the information from Galbis with some modifications, removing some events considered not sufficiently supported by data.

Fontseré and Iglesias (1971) is the essential reference catalogue for Catalan speaking areas: both Spanish and French Catalonia, Valencia and the Balearic Islands. It contains historical data from 1100 to 1906 A.D. based on well-reported references.

In Portugal, besides the already mentioned pioneer work by Moreira de Mendonça (1758), the most important studies on earthquake compilations prior to 1980 were produced in the early 20th century, based on data gathered in various types of publications. For example, in relation to the Azores Archipelago, mention should be made of *Arquivo dos Açores* (re-edition 1981-1986) and to Frutuoso (re-edition 1998 of the 16th century work). The work of Pereira de Sousa (1919), dedicated essentially to the 1755 Lisbon earthquake, is a piece of documentation of major importance. It also refers to earthquakes in the past. Choffat and Bensaude (1912) made a notable description of the 23 April 1909 Benavente earthquake in the Lower Tagus Valley, Lisbon and of the large amount of aftershocks. Miranda (1930) made an account of all felt events in Portugal in the 1920's.

But the greatest contributions to the historical earthquake compilation in Portugal were made during the commemoration of the 2nd centennial of the 1755 earthquake in the «Simpósio sobre a Acção dos Sismos». Ferreira (1955) and Agostinho (1955) presented collections of important earthquakes in the Mainland and in the Azores, respectively.

In the early 1980's, some revisions of earthquake data in the Iberian Peninsula were carried out. Among others, mention should be made of the work by Rodríguez de la Torre (1980) on the seismicity of Alicante up to the 18th century, the parametric catalogue by Suriñach and Roca (1982) for Catalonia and Pyrenees which includes a collection of isoseismal maps published in different works, the parametric catalogue by Monge (1981) on earthquakes in the Canary Islands; an extensive study by Bisbal (1984) for the Valencia region, and the study by Gentil and Justo (1983) for the region of Seville with data related to the Arab period in South Spain together with other works on Andalusian earthquakes by these same authors.

Mezcua (1982) published a catalogue of isoseismal maps for earthquakes in the Iberian Peninsula and, one year later, a parametric catalogue from the Instituto Geográfico Nacional (IGN) for the Ibero-Magreb region (Mezcua and Martínez-Solares, 1983) was completed.

In Portugal, various studies on historical seismicity were carried out in the first half of the 1980 decade. A catalogue of earthquakes in Mainland Portugal was published by Moreira (1984) and reviewed later (Moreira, 1991).

In Iberia, macroseismic data are compiled by various institutions and published on a routine basis in monthly and annual bulletins. Since 1907 the Fabra Observatory in Barcelona has carried out macroseismic surveys for all events felt in Catalonia. From 1984 this task has been undertaken in collaboration with the *Servei Geològic de Catalunya* – at present as part of the *Institut Cartogràfic de Catalunya* (ICC). Starting in 1909, the IGN obtained macroseismic data for earthquakes in Spain. In Portugal, since 1947, the *Instituto Nacional de Meteorologia e Geofísica* (former *Serviço Meteorológico Nacional*) has been responsible for macroseismic surveys. For the Azores, in 1998, they started carrying out these tasks in collaboration with the University of Azores (consortium SIVISA).

3. Recent studies and modern catalogues (1985-2003)

In the late 1980's there was an important development on the studies of historical seismicity by the establishment of teams of historians and seismologists working together in a more systematic way. Some EC funded projects as for example RHISE (Review of Historical

Seismicity in Europe – 1988-1991) and BEECD (A Basic European Earthquake Catalogue and Database for the evaluation of long term seismicity and seismic hazard – 1995-1997) were of special interest for increasing international collaboration. Within the framework of these two projects efforts were devoted to comparing methodologies used by European investigators of historical seismology and establishing common principles and criteria for cataloguing seismic events, respectively (Stucchi, 1993; Albini and Moroni, 1994; Albini and Stucchi, 1997).

The major problems encountered when historical earthquakes are reviewed are related to: (i) the reliability and insufficiency of the documentary sources; (ii) errors in the transmission of the information through not-independent sources; (iii) difficulties in assessing the characteristics, typologies and, consequently, the vulnerability classes of damaged buildings; (iv) difficulties in assigning damage descriptions to individual events in earthquake sequences; (v) lack of information on damage to the complete building stock when sources report only on one or a few specific buildings like, for instance, churches or royal buildings; and (vi) problems related to the identification of toponyms and to misinterpretations of the calendar.

Examples of the concern for reliability and quality of macroseismic data in Iberia can be found in Olivera *et al.* (1994; 1999), Paula and Oliveira (1996), Susagna *et al.* (2001), among others. Several studies on particular events, earthquake series or specific time windows have been published in the last decade. Examples of these studies are as follows: Olivera *et al.* (1994; 1999) and Salicrú (1995) studied historical earthquakes in Catalonia; Espinar (1994) and Espinar *et al.* (1994) investigated historical sources for earthquakes in South Spain and also Muñoz and Udías (1991) studied a few large events in the same region; Cruz *et al.* (1996) initiated studies on historical seismicity in Mainland Portugal until the end of 17th century, criticising and analysing the sources of information. Most of these recent studies on historical seismicity use the technique of family trees to analyse the traceability of the sources, detecting repetition of sources not contemporary with the event.

Another topic related to the improvement of knowledge of historical earthquakes from the first half of the 20th century is the processing of early instrumental records using modern digitising techniques. This information can complement the available data obtained from the analysis of contemporary macroseismic surveys (Susagna *et al.*, 1993). Very good records on paper support have been carefully kept in the archives of early observatories and attempts are being made to digitise and to process available records (Batlló *et al.*, 1997; Badal *et al.*, 2000). This type of investigation has been important to calibrate, for instance, the magnitude of the Benavente earthquake of 23 April 1909 in the Lower Tagus Valley, Lisbon (Dineva *et al.*, 2002). A catalogue of digital historical seismograms recorded on the Wiechert seismograph of the Toledo Observatory between 1912 and 1962 was published by Samardjieva *et al.* (1997). An ongoing project of the IGN consists of digitising all the available records existing in its observatories for earthquakes of magnitude equal to or larger than 4.5 which occurred until 1962.

The following sections present, as a matter of illustration, a brief review of recent studies in Portugal, and of two Spanish catalogues, one for Catalonia and the other for the entire Iberian Peninsula. In addition to these studies, a few other works on revisions of earthquake data have been carried out. Among others, we should mention Rodríguez de la Torre (1990), who studied the seismicity of Iberia in the 19th century through an intensive work in newspaper archives and other sources, producing a revised catalogue from 1850 to 1900; Muñiz Gómez (2001) who, based on the works by Rodríguez de la Torre (1990), extended the historical research in Galicia (NW Spain) for the 19th and 20th centuries also through the analysis of newspapers; and various historical studies in Andalusia based on the analysis of Spanish-Arabic documentary sources, as the work by Bretón and Espinar (1996).

4. Recent revisions in Portugal

In early 1980, a Working Group to study historical earthquakes and produce a National Catalogue was launched by the *Gabinete de Pro*

tecção e Segurança Nuclear, Secretaria de Estado do Ambiente e dos Recursos Naturais, involving the participation of several institutions (*Faculdade de Ciências, Universidade de Lisboa, Universidade Nova de Lisboa, Laboratório Nacional de Engenharia Civil, Electricidade de Portugal, Instituto Geológico e Mineiro*) under the presidency of the *Instituto de Meteorologia*. Several studies were conducted by the Department of History of *Universidade Nova de Lisboa* which compiled an enormous amount of information on sources of earthquakes.

Among these works mention can be made of the monographs on revisions of historical seismicity in the 17th and 18th centuries (Wagner, 1993; Wagner *et al.*, 1993), and in the 16th century (Henriques *et al.*, 1988). At the *Instituto de Meteorología* efforts were made to compile and analyse the historical seismicity, such as the work by Moreira *et al.* (1993), reviewing the historical seismicity in the Gulf of Cadiz area before 1 November 1755 earthquake. As mentioned before, Moreira (1991) made an overview of seismicity in Portugal and Cruz *et al.* (1996) initiated studies on historical seismicity in Mainland Portugal until the end of 17th century.

Besides the «Anuário Sismológico» published since 1947, studies have been performed to compile information from different sources. Two examples from late 1980 - early 1990 are the catalogues by Martins and Mendes-Victor (1989) and Sousa *et al.* (1992). To quantify earthquake parameters from macroseismic information, Oliveira and Sousa (1991) made a first contribution to reduce subjectivity in treatment of historical data by introducing the concept of *quality factor* when analysing the large earthquake events in the Lower Tagus River. Paula and Oliveira (1996) revised all data from the «Anuário Sismológico», transformed the information in the earlier EMS-92 scale and applied a *quality factor* for a better definition of macroseismic intensity.

The *Instituto de Meteorologia* is preparing a catalogue, to be published possibly in 2004, of all earthquakes between 1980 and 2000, including macroseismic events.

For the Azores, several recent studies have been produced in relation to macroseismic catalogues. Among them, reference should be made to the work of Nunes Costa (1986) who recently compiled historical events for the Archipelago and to Silveira (2002) which made a contribution on historical seismicity for the evaluation of the hazard in San Miguel Island. Sousa and Martins (2000) made a comparison between the seismic parameters of important events from different catalogues for the Azores (Portuguese and international) and produced a first version catalogue used for hazard studies in the region. Nunes *et al.* (2003; 2004) have revised many documents and compiled a large amount of information; besides analysing the elements contained in the «Anuário Sismológico» and in the work of Nunes (1986), they mention a large amount of historical references transcribing the original texts. They gathered the documentary sources from the authors who dedicated most of their lives to the history of the Azores and also revised the information contained in newspapers.

5. A macroseismic catalogue for Catalonia (NE Spain)

An example of a catalogue compiled according to modern criteria, in particular those established within the above mentioned BEECD project (Albini and Stucchi, 1997; http://emidius.mi.ingv.it/BEECD) is the one by Susagna and Goula (1999) for Catalonia. The geographical area covered is a rectangle in NE Iberia between Longitude 0°20'W to 3°30'E and Latitude 40°N to 43°30'N (fig. 1). It covers Catalonia and surroundings, in particular the Central and Eastern Pyrenees region, both Spanish and French parts. This Catalogue is part of a project of the *Institut Cartogràfic de Catalunya* for assessing earthquake hazard, vulnerability and risk.

This Catalogue, which is based on macroseismic data, is the result of a long process (Susagna *et al.*, 2001) that includes: i) consideration of the existing earthquake compilations, representing the most significant information sources; ii) incorporation of the results from the studies carried out in recent years referring to the historical earthquakes; iii) re-assessment of the macroseismic questionnaires corresponding to the earthquakes during the 20th century, and

iv) construction of a database which facilitated the critical comparison between the different sources. One of the results is a homogeneous parametric catalogue, which comprehensively represents all the available seismic information for the region under study.

An *epicentre quality index* and an *intensity quality* are given for each event together with the common macroseismic parameters; the number of macroseismic observations used for the focal parameters assessment is also reported.

The Catalogue contains 918 individual records, one for each catalogued event. Out of them, 306 records correspond to events before 1900; 612 correspond to events after 1900; and 58 earthquakes, considered in former compilations as real events, have been qualified as false or doubtful. Out of the remaining 860 earthquakes, 258 events do not have assigned intensity due to the lack of sufficient information.

The most interesting part of the Catalogue is the individual information for each earthquake, which shows the value of the parameters chosen from the aforementioned analysis. A map with all intensity data point information is also included for a total of 109 earthquakes. As a synthesis, the Catalogue includes several maps of epicentres, in particular one with the known earthquakes that have caused damage throughout history (intensity equal to or above VII MSK) and another with all events of intensity equal to or above V which occurred in the 20th century.

6. A new earthquake catalogue for the Iberian Peninsula

The recently published new catalogue by Martínez-Solares and Mezcua (2002) constitutes a revision of the former catalogue from the *Instituto Geográfico Nacional* (IGN) by Mezcua and Martínez-Solares (1983) for the region inside the rectangle A in fig. 1.

According to the authors of this catalogue, in the time interval between the publication of these two catalogues – 20 years – problems in several records had been detected, mainly duplications, fake earthquakes, errors in epicentre locations and inaccurate intensity assessments together with lack of available references for some catalogued events. For the revision of the Catalogue, an evaluation of each one of the entries has been undertaken through an analysis of all the available documents in the IGN archive which contains published studies, internal reports, copies of contemporary sources, etc. Each document was referenced with a number, which was included in the earthquake database. All available data for each earthquake were then analysed and the corresponding parameters and quality factors for the epicentral intensity and location assigned.

A code explaining the modifications in the different parameters in this catalogue with respect to the former Mezcua and Martínez-Solares (1983) is given. For each catalogued event the number of data points with macroseismic information is indicated together with the bibliographic references.

The catalogue includes tables and maps showing intensity data points for the earthquakes with epicentral intensity equal to or greater than VIII (EMS 98) or for those with at least 15 data points available. The equivalent moment magnitude is computed following the Bakun and Wentworth (1997) methodology.

A comparison of the number of entries between this new catalogue and that of 1983 is shown in fig. 2. On the one hand, there is an increase in the number of events of low intensity, due to the inclusion in the catalogue of detailed studies such as those mentioned for the 19th and 20th century by Rodríguez de la Torre. On the other hand, some of the largest events decreased the value of I_o as a result of intensity re-evaluations.

7. Earthquake databases

Several attempts to provide the scientific community with data easily accessible through organised databases have been made by various institutions in Spain and Portugal, but up to now most of these projects have not been completed and databases are essentially working systems mostly for internal use in seismological centres.

The *Instituto Geográfico Nacional* (IGN) maintains various computer files organised with

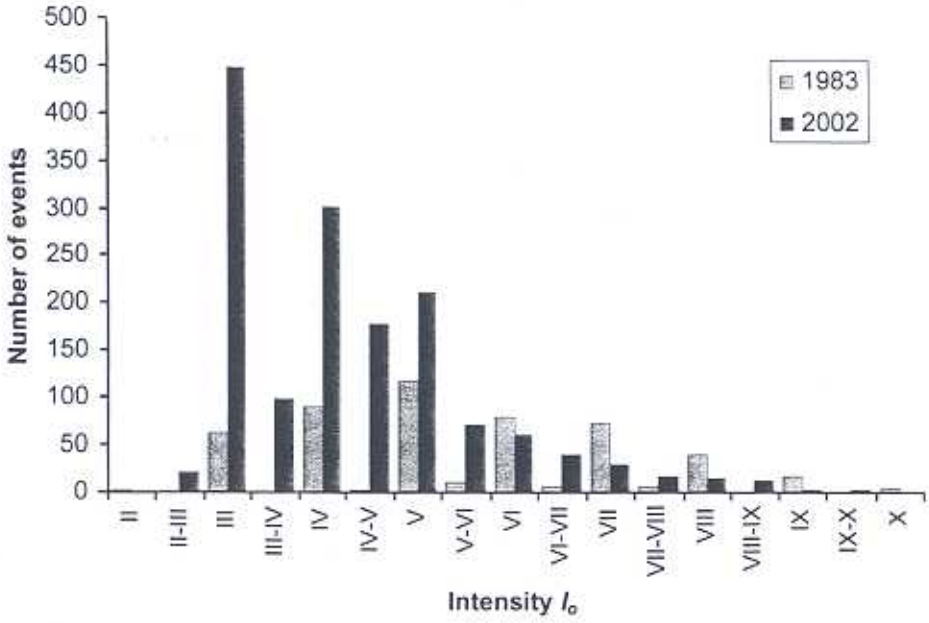

Fig. 2. Comparison of the number of events for each intensity class contained in the catalogues of Mezcua and Martínez-Solares (1983) and Martínez-Solares and Mezcua (2002) for the period 1000-1900.

database structures. The historical earthquake data available in digital form are:

- earthquakes parametric file;
- bibliography, references;
- tsunamis on the Spain's coast;
- tistorical instruments;
- some macroseismic questionnaires.

Some digital seismic cartography is also contained in the IGN digital archives: geo-referenced isoseismal maps from Mezcua (1982) and maps with geo-referenced macroseismic information as given in the recent catalogue from Martinez Solares and Mezcua (2002). Works to establish a more complete database with all the available macroseismic information are currently being carried out.

The *Instituto Andaluz de Geofísica y Prevención de Desastres Sísmicos* has in operation a database of historical earthquakes in Andalucia (South Spain) which includes parametric data, macroseismic information and isoseismal maps (Feriche and Botari, 2002).

The *Institut Cartogràfic de Catalunya* has a database with the intensity data points of all the earthquakes in the area of the catalogue from Susagna and Goula (1999). A computer file with the catalogue parametric data is available from the ICC web site (http://www.icc.es).

Nunes *et al.* (2004) prepared a database with the available information on Azores earthquakes for the period 1850-1998, and published it on a CD-ROM. Simões (2004) is now preparing the first Internet version of a catalogue of the Portuguese earthquakes.

8. Final remarks

It can be considered that the history of earthquake catalogues in the Iberian Peninsula starts with the occurrence of the 1755 Lisbon earthquake. Since then, many authors have been involved in the collection and analysis of past earthquakes. In this paper, the leading works have been presented and the main references given.

Efforts have been made in the recent decades to review the macroseismic information and to improve earthquake catalogues. However, there is still a need to carry out studies on specific historical earthquakes and to take some of the existing – published and un-

published – works, review them under modern acknowledged procedures, that is, through an objective classification and analysis of reliability of sources, and a well-stated and justified methodology for interpreting historical data.

There is also a need to establish current policies to incorporate the validated research works into the national catalogues and databases. Very often the period of time between the publication of new research works on historical earthquakes and the corresponding changes in the institutional databases – through a necessary validation process – is too long.

Given the unquestionable importance of observed intensities for attenuation studies which are crucial for earthquake hazard and risk assessment, databases with intensity data points should be constructed and made available to the technical and scientific communities.

Many earthquakes take place on border areas and thus, for these regions a transnational collaboration is clearly needed. It would be desirable to increase this collaboration at European level with Northern Africa countries in order to go towards a cooperative Euro-Mediterranean database.

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