NAM

Global Occurrence and Impact of Small-to-Medium Magnitude Earthquakes: A Statistical Analysis (Part 1)

Cecilia I. Nievas, Julian J. Bommer & Helen Crowley

Datum March 2017

Editors Jan van Elk & Dirk Doornhof

General Introduction

Earthquakes are complex phenomena, which can have a large impact on the people living in the vicinity of the epicentre. This can include damage to buildings ranging from cracks to collapse, damage to infrastructure and psychological effects on the community. Case studies of historical earthquakes can therefore contribute to the understanding of the diversity of the effects earthquakes can have on the built environment, the natural environment, the local economy, the community and individual people. Case studies of earthquakes are therefore an element of the assurance of the risk assessment (Ref. 1).

Many case histories of earthquakes are available, but these focus primarily on larger earthquakes, like the 1906 earthquake in San Francisco and the 1960 earthquake in Chile. These tectonic earthquakes are considerably larger than the earthquakes expected to contribute to the hazard of induced earthquakes in Groningen.

Several studies trying to learn from smaller earthquake in the range from 4 to 5.5 have been initiated. Because case histories for earthquakes in the magnitude range relevant for Groningen are more difficult to find, a compendium of earthquakes was compiled (Ref. 2). Additionally, an overview of all (potentially) human-induced earthquakes (Ref. 3) was prepared.

This report presents a statistical evaluation of earthquakes, focusing on earthquakes that occur in the upper crust in proximity to population centres and with a magnitude between M4 and M5.5. These earthquakes are most interesting for the human-induced earthquakes in Groningen.

References

1. Groningen Meet- en Regelprotocol, NAM, May 2017
2. A Database of Damaging Earthquakes of Moment Magnitude from 4.0 to 5.5, Cecilia Inés Nievas, Helen Crowley, Michail Ntinalexis and Julian J Bommer, June 2016
3. Human-induced Earthquakes, Gillian R. Foulger, Miles Wilson, Jon Gluyas and Richard Davies, June 2016.

Title	**Global Occurrence and Impact of Small-to-Medium Magnitude Earthquakes: A Statistical Analysis (Part 1)**	**Date**	March 2017
		Initiator	NAM
Author(s)	Cecilia I. Nievas, Julian J. Bommer & Helen Crowley	**Editors**	Jan van Elk Dirk Doornhof
Organisation	Team of Academic Experts	**Organisation**	NAM
Place in the Study and Data Acquisition Plan	Study Theme: Hazard and Risk Assessment Comment: Earthquakes are complex phenomena, which can have a large impact on the people living in the vicinity of the epicentre. This can include damage to buildings ranging from cracks to collapse, damage to infra-structure and psychological effects on the community. Case studies of historical earthquakes can therefore contribute to the understanding of the diversity of the effects earthquakes can have on the built environment, the natural environment, the local economy, the community and individual people. Case studies of earthquakes are therefore an element of the assurance of the risk assessment (Ref. 1). Many case histories of earthquakes are available, but these focus primarily on larger earthquakes, like the 1906 earthquake in San Francisco and the 1960 earthquake in Chile. These tectonic earthquakes are considerably larger than the earthquakes expected to contribute to the hazard of induced earthquakes in Groningen. Several studies trying to learn from smaller earthquake in the range from 4 to 5.5 have been initiated. Because case histories for earthquakes in the magnitude range relevant for Groningen are more difficult to find, a compendium of earthquakes was compiled (Ref. 2). Additionally, an overview of all (potentially) human-induced earthquakes (Ref. 3) was prepared. This report presents a statistical evaluation of earthquakes, focusing on earthquakes that occur in the upper crust in proximity to population centres and with a magnitude between M4 and M5.5. These earthquakes are most interesting for the human-induced earthquakes in Groningen.		

Directly linked research	(1) Hazard and Risk Assessment (2) Meet – en Regelprotocol
Used data	Open Literature.
Associated organisation	Team of Academic Experts
Assurance	Report is based on compilation of academic papers and open literature.

Global Occurrence and Impact of Small-to-Medium Magnitude Earthquakes: A Statistical Analysis

Cecilia I. Nievas, Julian J. Bommer & Helen Crowley

Version 1

November 2017

Table of Contents

1. INTRODUCTION

Studies have shown that events with moment magnitude (**M**) in the range 4.0-5.5 dominate the seismic hazard and risk estimates due to induced earthquakes in the Groningen field and, potentially, in many other areas of the world in which anthropogenic earthquakes pose a larger threat than tectonic seismicity (Bourne *et al.*, 2015; van Elk *et al.*, 2017). While earthquakes smaller than magnitude 5.0 will often be discarded in the estimation of seismic design loads (Bommer & Crowley, 2017), when examining the risk posed by induced earthquakes to a building stock constructed without consideration of seismic effects, these smaller-magnitude events can be important.

As part of the effort to quantify and understand the risk posed by the Groningen earthquakes, this work aimed to identify how many upper crustal earthquakes in the same magnitude range occur in close proximity to urbanised areas, and what proportion of these earthquakes cause damage and/or casualties. In order to do this, the work was divided in three fundamental parts, each of them explained in detail in each of the three chapters that follow. Firstly, a world database of crustal earthquakes in the range **M**4.0-5.5 that occurred sufficiently close to population or the built environment was generated. Secondly, a world database of earthquakes in the range **M**4.0-5.5 for which reports of damage and/or casualties exist was compiled. Finally, the two were confronted and a statistical analysis was carried out.

The challenges associated with all these three activities were many, and are described thoroughly all throughout the report. These range from dealing with multiple estimations of location and magnitude of earthquakes by different agencies, often involving large discrepancies, the definition of what “in close proximity to urbanised areas” means, the selection of appropriate magnitude scales, all the way through the scarcity of information regarding the damage caused by small-to-medium magnitude earthquakes, among many others.

2. WORLD DATABASE OF CRUSTAL SMALL-TO-MEDIUM MAGNITUDE EVENTS NEAR URBANISED AREAS

2.1. General

As has been explained in detail by Weatherill *et al.* (2016), generating a magnitude-homogeneous global earthquake catalogue is not trivial. Among the many challenges that need to be faced are the comparison of reports of events from different sources, the selection of a final source location and start time for each event, and the homogenisation of magnitude scales. These usual challenges become exacerbated in the magnitude range of interest of this work, as the uncertainty in earthquake location tends to be higher for weaker events that are recorded by fewer networks. In many cases, small events are only reported by local agencies that use extremely heterogeneous magnitude scales.

In this work, a two-fold strategy was implemented to face these challenges. On the one hand, advantage was taken of the magnitude-homogeneous catalogue compiled by Weatherill *et al.* (2016), which covers events that have been reported by the main international agencies and a series of relevant studies, and provides them with an estimate of moment magnitude **M** when the available magnitude estimates allow for robust conversions. This allowed to start from a solid base of events that have been gathered by means of a well-documented procedure, all of which have values of **M**. On the other hand, it is known that the strategy followed for its compilation translates into an unknown number of events not having been included because of them not complying with the quality criteria set up by the authors. To countervail this, the catalogue of Weatherill *et al.* (2016) was confronted against events from the ISC Bulletin that complied with a significantly loser set of criteria, and events that were not found in the former were added to make up the final so-called merged catalogue. Once the merged catalogue was compiled, events were selected in terms of their magnitude, depth and vicinity to urbanised areas.

All procedures generated for the compilation of this database were designed to be automatic, as the immense volume of data processed herein would not allow for a manual selection and adjustment of events. This generated an additional challenge, as algorithms needed to be designed to work for the whole set of events and, at the same time, take into consideration the extensive list of peculiarities that were found along the way. Due to the nature of automatic processes, it is possible that certain solutions not be perfect, though the stability observed within intermediate stages of the compilation when iterating on the improvement of specific algorithms suggests that they appear to be fit for our purposes.

The sections that follow explain in detail the process followed to merge the catalogue of Weatherill *et al.* (2016) and the events selected to be added from the ISC Bulletin, and the criteria used to filter events outside the magnitude-depth range of interest and/or not close enough to population or the built environment to pose a threat. The resolution of specific challenges that were relevant to the work are also discussed in detail. The resulting database and its characteristics are finally presented at the end.

2.2. Outline of the Methodology

The database of earthquakes in the range **M**4.0-5.5 was built using an updated version of the magnitude-homogeneous catalogue of Weatherill *et al.* (2016), referred to as WPG16 or WPG16v3b hereafter (*v3b* makes reference to the version). As the WPG16v3b catalogue does not include events for which the reported magnitudes do not allow what Weatherill *et al.* (2016) believe would be a sound conversion to moment magnitude, events present in the ISC Bulletin (ISC, see Web References) that are not part of WPG16v3b were added to the database if either a moment magnitude **M**, a surface-wave magnitude M_S or a local magnitude M_L were reported. As explained in Section 2.5, an assumption of equivalence between M_S, M_L and **M** was made in the relevant magnitude range. Events flagged as induced in the sources were flagged in our database as well, so as to allow for easy consideration or rejection of them in the statistical analysis.

The database was built for a 15-year time window starting on 1st July 1999 and finishing on 30th June 2014. This period was selected for a series of reasons:

- The ISC Reviewed Bulletin goes until 30th June 2014 at the time of starting this analysis (August 2017). This means that the WPG16v3b catalogue contains events from the ISC Reviewed Bulletin up to said date.
- The magnitude of the completeness of WPG16v3b decreases significantly from around 1998 onward, as will be shown in Section 2.3.
- The increasing popularity and penetration of the Internet during these years facilitates the search for information on damage for events in the magnitude range of interest. Focusing on this period made it relatively easier to retrieve information regarding damaging earthquakes.
- It is long enough to be of statistical significance and, at the same time, short enough to not pose an excessive computational demand.

While the final time period starts on 1st July 1999 and finishes on 30th June 2014, events that have occurred between 1st July 1996 and 30th June 2017 were considered for the identification of foreshocks and aftershocks, which was carried out using the algorithm of Gardner & Knopoff (1974), as implemented in the OpenQuake Hazard Modeller's Toolkit (Weatherill, 2014), modified to take into consideration hypocentral depth. As it is extremely difficult to distinguish the damage caused by each of the events in the sequence, this flagging of foreshocks and aftershocks was used to be able to generate separate statistics considering only main shocks or considering all events.

The decision to consider an additional three years of events before and after the period of interest was made after analysing the OpenQuake (Pagani *et al.*, 2014) implementation of the time windows proposed for declustering by Gardner & Knopoff (1974), Grünthal (as reported in van Stiphout *et al.*, 2012) and Uhrhammer (1986). Three years is slightly larger than the windows of the first two for **M** equal to or larger than 6.5, while they are only exceeded for **M** above 8.0 by the latter.

Due to the characteristics of induced seismicity, only upper crustal events were considered. While the definition of a threshold for a hypocentral depth to be considered an upper crustal event or not is not trivial, the magnitude-dependent criterion adopted herein is shown in Table 2.1.

Table 2.1. Adopted depth criterion.

Magnitude Range	Maximum Depth
$4.0 \leq \mathbf{M} < 4.5$	15 km
$4.5 \leq \mathbf{M} < 5.0$	20 km
$5.0 \leq \mathbf{M} \leq 5.5$	25 km

To eliminate earthquakes happening in extremely underpopulated areas, oceans or deserts that clearly pose no threat or minimal threat to human settlements, the number of people exposed to expected Modified Mercalli Intensity (MMI) values equal to or larger than IV was determined for each event. Expected MM intensities were calculated using the intensity prediction equation (IPE) of Allen *et al.* (2012), and the population exposed to each intensity level was estimated using the 2015 population counts from Gridded Population of the World GPW v4.0 (CIESIN, 2016). For each earthquake, the procedure was as follows:

1. Using the IPE of Allen *et al.* (2012), determine the epicentral distance at which the predicted MMI is 3.0. Select the part of the complete GPW v4.0 grid that falls within a square with sides equal to double that distance, centred in the epicentre of the earthquake.
2. Compute the estimated MMI for the centroid of each cell of the GPW v4.0 grid within the selected area. A constrained area was selected instead of working directly with the complete grid due to limits imposed by computational capacity.
3. Identify the cells whose MMI values are equal to or larger than 4.0.
4. Add the population counts of these cells to obtain the number of people exposed to MMI ≥ IV.
5. Identify the maximum value of population density within those cells.
6. Keep the event if any of the following two conditions are met:
    - maximum density in area where MMI ≥ IV: ≥ 300 people/km^2 (from 5)
      OR
    - cumulative population count for MMI ≥ IV: ≥ 2,500 people (from 4).

The IPE of Allen *et al*. (2012) was originally developed for earthquakes with moment magnitudes in the range 5.0-7.9. While here it was applied outside of this range, it was selected due to it being a well-established model that has been derived using a relatively large dataset of events from a variety of geographical locations. While perhaps lacking a guarantee of accuracy, its behaviour in the 4.0-5.0 range does not raise concerns with respect to stability or consistency, as shown in Figure 2.1. The three continuous lines correspond to a null hypocentral depth and, consequently, the highest values of MMI that can be obtained for the earthquakes of the database, given the constraints imposed by Table 2.1. For epicentral distances equal to or larger than, approximately, 0.5 km, these three lines behave as expected: the largest magnitude earthquake produces the largest MMI. For smaller distances, the lines cross. This is not due to being outside the range of applicability in terms of magnitude, but to the epicentral distances instead. As Allen *et al*. (2012) express, their model should not be used for hypocentral distances smaller than 6 km. Though here it is being applied at smaller distances, this does not pose a problem, as the results are not being used to compare one earthquake against the other but to estimate population exposure, and the MMI values keep on increasing with decreasing epicentral distance for a particular magnitude, which is the expected behaviour. Moreover, this only occurs for very shallow depths, as the 6 km limit applies to hypocentral (not epicentral) distances.

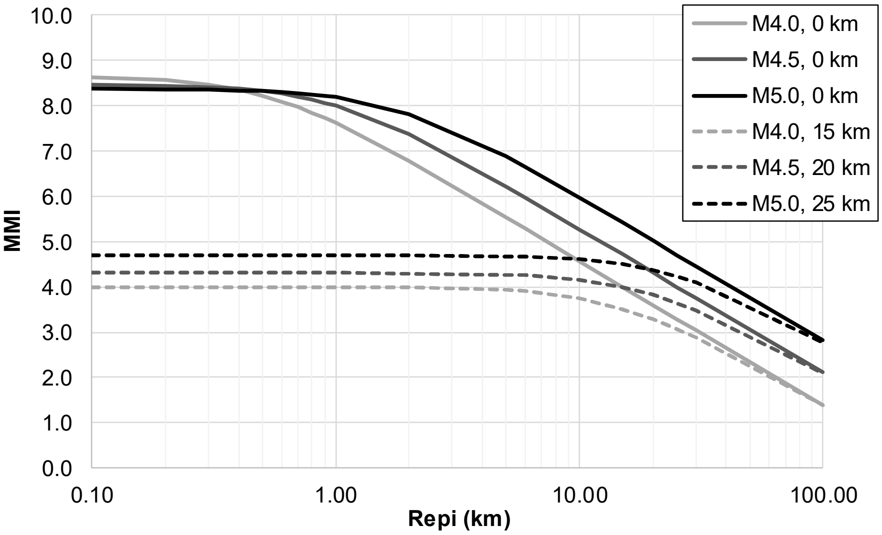


Figure 2.1. Modified Mercalli Intensity (MMI) predicted by the model of Allen *et al.* (2012) for three different magnitudes (**M**4.0, light grey, **M**4.5, middle grey, **M**5.0 black) and hypocentral depths (indicated in the legend), against epicentral distance (R_{epi}).

The population thresholds of step 6 were selected based on definitions of urbanisation by different sources. According to UNICEF (2012), the minimum population to define an urban settlement is around 2,000 people, though this number varies greatly around the world and can range between 200 and 50,000. For the 2010 census, the United States' Census Bureau defined an urbanized area as that having 50,000 people or more and a density of at least 1,000 people per square mile (386 people/km^2), and an urban cluster as that having between 2,500 and 50,000 people. According to Eurostat (2017), the European Union defines urban areas by first identifying grid cells of 1km^2 in which the population density is equal to or larger than 300 people/km^2, and then grouping adjoining cells that satisfy this criterion: if the resulting group of cells adds up to, at least, 5,000 people, it is considered an urban area. Most consulted sources highlight the fact that making the distinction between urban and rural populations is neither trivial nor objective, and that density-based criteria can be strongly dependent on the size of the grid or the areas used to calculate the density. As Eurostat specifies the grid cell size and it coincides with that of GPW v4.0, this number was adopted directly.

While a MMI of V or larger would have been a more logical threshold to assess population exposure, as it is described as the onset of damage, MMI IV was used herein because the minimum epicentral MMI predicted by the IPE of Allen *et al*. (2012) for the magnitude and depth ranges considered is IV, as was shown in Figure 2.1. If a higher threshold was selected, a series of magnitude-depth combinations would be automatically excluded. A MMI of IV is described (Wood & Neumann, 1931) as being felt indoors by many, though outdoors only by few, and causing fear only in exceptional cases. It is characterised by the rattling of dishes, windows and doors (but without any of these breaking or cracking), the creaking of walls and frames, and the swinging of hanging objects. A MMI of V would, in turn, involve some instances of damage such as broken dishes and/or cracked windows, as well as the overturning of unstable objects.

No uncertainty in moment magnitude, depth or the IPEs was initially considered, though such uncertainty may be incorporated in the future.

2.3. The WPG16 Magnitude-Homogeneous World Catalogue

The 31st July 2017 version of the magnitude-homogeneous world catalogue of Weatherill *et al.* (2016), referred to as WPG16v3b hereafter, was used as the starting point because it explicitly deals with the issue of magnitude conversion, which is quite relevant for the range of earthquakes being considered herein. While moment magnitude **M** is currently the preferred scale for seismic hazard analysis, it is often not calculated for earthquakes smaller than **M**5.0, which are most commonly reported in terms of the surface-wave (M_s), body-wave (m_b) and Richter/local (M_L) magnitude scales. Weatherill *et al.* (2016) addressed this issue by creating a series of tools that facilitates the simultaneous analysis of events from different catalogues and the homogenization of their magnitude estimates in terms of **M**.

The original version of the catalogue, WPG16v1, gathers events from the global ISC-GEM v3.0 catalogue (Storchak *et al.*, 2015), the ISC Reviewed Bulletin (ISC, 2014), the NEIC bulletin (United States Geological Survey, USGS, 2015), the ISC-EHB bulletin (Engdahl *et al.*, 1998), the Global Centroid Moment Tensor (GCMT) catalogue (Ekström *et al.*, 2012), the Pacheco & Sykes (1992) catalogue, and the bulletin of the National Research Institute for Earth Science and Disaster Prevention of Japan (NIED, 2015), and uses a well-defined set of hierarchy rules as well as a series of magnitude conversion models to assign one value of moment magnitude and one location per event. As this catalogue does not include anthropogenic earthquakes, Weatherill (2017, *pers. comm.*) compiled a new version of it that includes events flagged as geothermal, mining, reservoir, induced and any other anthropogenic origins, except for those from explosions, or with nuclear or chemical origins. This new version also gathers updated versions of some of the catalogues considered, such as the global ISC-GEM v4.0 catalogue (released in January 2017, Storchak *et al.*, 2015), the complete GCMT catalogue and NEIC bulletin until the end of 2016, and the ISC Reviewed Bulletin up to and including events from June 2014, and lowers the threshold magnitude from 3.0 to 2.5, of any kind of magnitude scale.

Not all the events from these catalogues are included in WPG16v3b. Only those for which there exists magnitude information in certain scales and coming from agencies for which enough information exists to develop an empirical conversion equation to moment magnitude **M** were included. Moment magnitude values from ISC-GEM, GCMT and Pacheco & Sykes (1992) were taken directly (without conversion), while moment magnitude from NEIC and NIED were adjusted to account for systematic differences between the different agencies. Surface-wave (M_s) and body-wave (m_b) magnitude estimates by the ISC and NEIC were converted to moment magnitude as well. WPG16v3b contains 630,960 events with dates as early as 1900.

Figure 2.2 shows the distribution of events in the WPG16v3b catalogue in time. The algorithm of Stepp (1971), as implemented in the OpenQuake Hazard Modeller's Toolkit (Weatherill, 2014), estimates the catalogue to be complete above **M**3.0 from 1998 onward. However, a close observation of Figure 2.2 suggests that the completeness magnitude is possible not as low as 3.0, though a significant improvement in the number of smaller magnitude events captured can be observed around the year 1998.

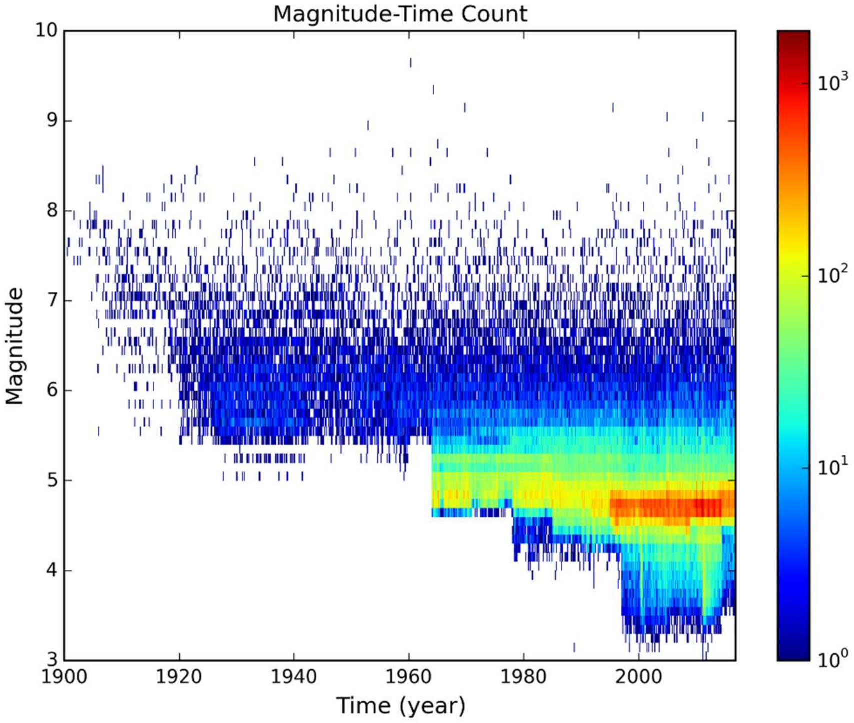
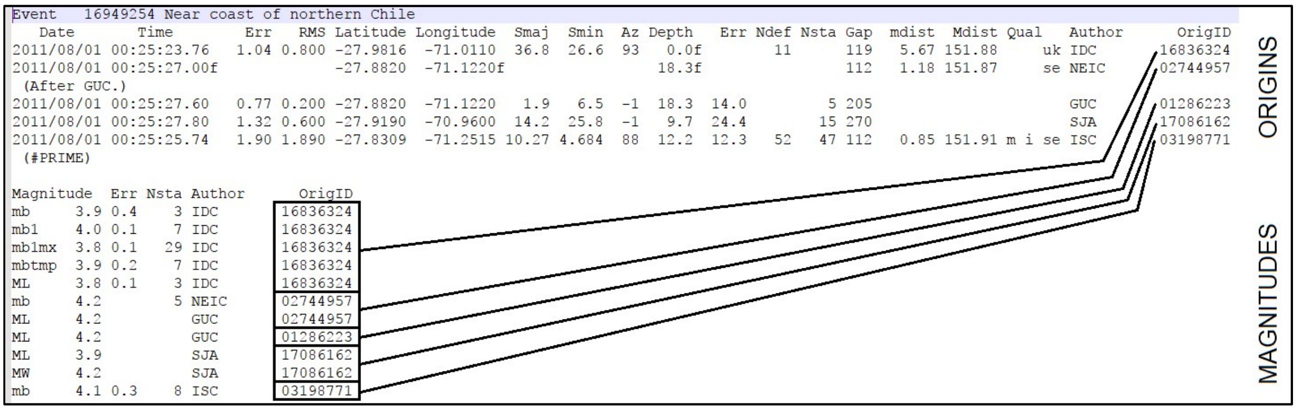


Figure 2.2. Distribution of events in the WPG16v3b catalogue in time and by magnitude.

2.4. The ISC Bulletin

The ISC Bulletin gathers reports of seismic events from an extensive list of agencies from around the world that contribute to it. The data is automatically processed and grouped into events to which an event ID is assigned. Each event may contain one or several estimates of origin and magnitude, each of which have their own origin ID and magnitude ID. Within the ISC Bulletin, the term "origin" refers to hypocentral location, date and time, that is, origin in a four-dimensional space, though it is possible for the hypocentral depth to be missing in some cases. A certain origin (and origin ID) may be associated with more than one magnitude estimate, either because the agency that calculated that origin produced estimates of magnitudes in different scales or because other agencies may have not calculated the origin by themselves but may have used an origin from a different agency to calculate magnitude. Figure 2.3 shows an example of an event in the ISC Bulletin. As can be observed, many origins are associated with more than one magnitude estimate and, in particular, origin ID 02744957 by NEIC is associated with a body-wave magnitude estimate of 4.2 by NEIC itself and a local magnitude of 4.2 by the National Seismological Centre of Universidad de Chile (acronym GUC in Figure 2.3).



```
Event    16949254 Near coast of northern Chile
   Date       Time        Err   RMS Latitude Longitude  Smaj   Smin  Az Depth   Err Ndef Nsta Gap  mdist  Mdist Qual   Author      OrigID
2011/08/01 00:25:23.76   1.04 0.800 -27.9816  -71.0110  36.8   26.6  93   0.0f        11       119   5.67 151.88     uk IDC      16836324
2011/08/01 00:25:27.00f             -27.8820  -71.1220f                  18.3f                 112   1.18 151.87     se NEIC     02744957
 (After GUC.)
2011/08/01 00:25:27.60   0.77 0.200 -27.8820  -71.1220   1.9    6.5  -1  18.3  14.0         5 205                       GUC      01286223
2011/08/01 00:25:27.80   1.32 0.600 -27.9190  -70.9600  14.2   25.8  -1   9.7  24.4        15 270                       SJA      17086162
2011/08/01 00:25:25.74   1.90 1.890 -27.8309  -71.2515 10.27  4.684  88  12.2  12.3   52   47 112   0.85 151.91 m i se ISC      03198771
 (#PRIME)

Magnitude  Err Nsta Author      OrigID
mb     3.9 0.4    3 IDC       16836324
mb1    4.0 0.1    7 IDC       16836324
mb1mx  3.8 0.1   29 IDC       16836324
mbtmp  3.9 0.2    7 IDC       16836324
ML     3.8 0.1    3 IDC       16836324
mb     4.2        5 NEIC      02744957
ML     4.2          GUC       02744957
ML     4.2          GUC       01286223
ML     3.9          SJA       17086162
MW     4.2          SJA       17086162
mb     4.1 0.3    8 ISC       03198771
```

Figure 2.3. Example of an event from the ISC Bulletin.

The ISC only generates its own origin and magnitude estimates when reviewing the Bulletin, a process that is usually two years behind real time, though it is around three years at the time of writing (November 2017). According to the website of the ISC, all events with at least one magnitude estimate (in any scale) equal to or above 3.5 are reviewed. The example of Figure 2.3 includes an estimate by the ISC, which is marked as #PRIME, meaning that it is the ISC's preferred solution. #PRIME tags are also automatically assigned by an algorithm before the ISC reviews the events, so they can correspond to agencies other than the ISC itself for the period not covered by the Reviewed Bulletin.

2.5. Considerations Regarding Magnitude Scales

Moment magnitude **M** (Hanks & Kanamori, 1979) is, nowadays, the preferred magnitude scale for most seismic hazard applications (*e.g.* Di Giacomo *et al.*, 2015). However, moment magnitudes tend to be calculated only for earthquakes above a certain threshold, which leads to a large proportion of the earthquakes that occur worldwide still being reported in other scales, most commonly surface-wave magnitude M_s, body-wave magnitude m_b, duration magnitude M_d, and Richter local magnitude M_L. (*e.g.*, Gasperini *et al.*, 2013; Weatherill *et al.*, 2016). In view of this, a rational decision was needed with respect to the magnitude scales to consider for the incorporation of events from the ISC Bulletin not in WPG16v3b to the merged world catalogue.

The four most commonly used magnitude scales other than moment magnitude **M**, can be grouped in two pairs: M_s and m_b, which are calculated from teleseismic data, and M_L and M_d, which are local by nature in their need to have a region-specific correction term (Scordilis, 2006; Gasperini *et al.*, 2013, Di Giacomo *et al.*, 2015). Studies aiming at developing relationships between these scales and moment magnitude for use in global catalogues (and global applications in general) focus on the first two, as any relation between the latter and **M** is necessarily regional.

Among these studies, those of Scordilis (2006) and Di Giacomo *et al.* (2015) stand out for their general robustness and impact on the community. They both focus on M_s and m_b, and arrive at similar conclusions, which are supported as well by the more recent work of Weatherill *et al.* (2016):

- M_s appears to hold almost a 1:1 relation with **M** for magnitudes greater than, approximately, 6.0;
- dispersion is larger for the relation between m_b and **M** than for the relation between M_s and **M**.

Figures 2.4 and 2.5 show the results obtained by the three studies. Due to this behaviour of M_s and m_b, Di Giacomo *et al.* (2015) prefer M_s over m_b to obtain an estimation of **M**. While the 1:1 relationship between M_s and **M** does not hold in the magnitude range of interest for the present work, M_s is also deemed herein as having a more satisfactory behaviour than m_b, in view of its smaller dispersion. Scordilis (2006) obtained standard deviations of 0.17 and 0.29 for their models for M_s and m_b, respectively. Similarly, Weatherill *et al.* (2016) obtained standard deviations of 0.147 and 0.317.

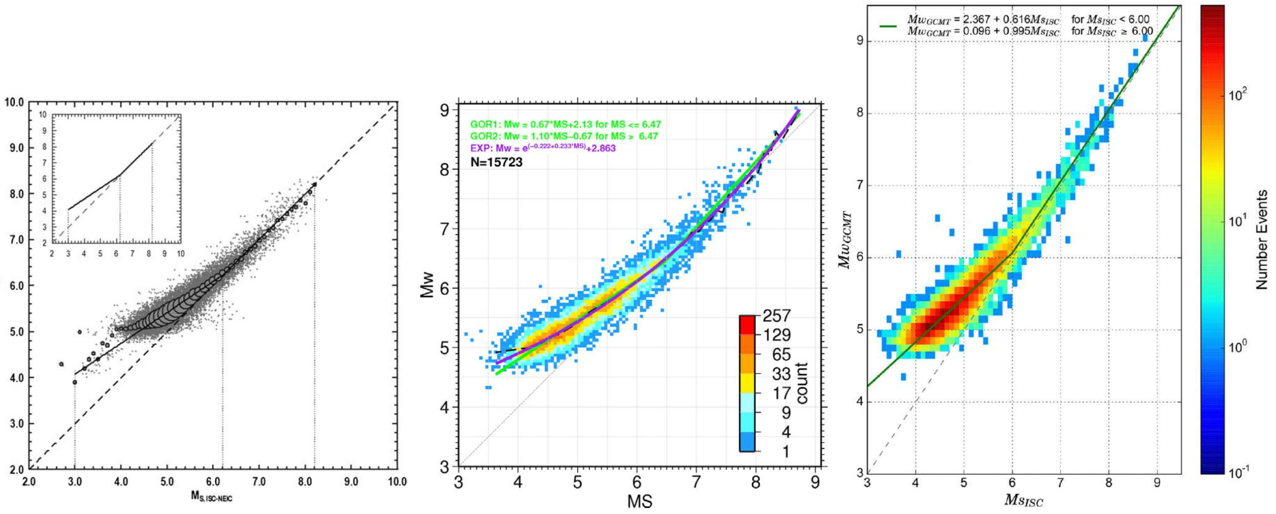


Figure 2.4. Relation between moment magnitude **M** (M_w) and surface-wave magnitude M_s according to Scordilis (2006, left), Di Giacomo *et al.* (2015, centre), and Weatherill *et al.* (2016, right). Each plot was taken from the corresponding publication.

While it would be possible to apply these conversion equations to obtain values of moment magnitude for those events of the ISC Bulletin that are not in the WPG16v3b catalogue and are to be added, it was herein preferred to assume a 1:1 relation, even in the range 4.0≤**M**≤5.5 (or $4.0 \leq M_s \leq 5.5$). The reason for this is that no model guarantees an exact conversion, and the estimates of M_s would come from agencies other than the ISC or the USGS (events that have M_s from either of the two are part of WPG16v3b), for which the relationship with **M** might be slightly different, as it is influenced by the specific methodologies used to calculate them. To illustrate this, Figure 2.6 (left) shows the relation between M_s values calculated by the ISC and M_s values calculated by the USGS, as per Weatherill *et al.* (2016). While the overall tendency is that of a 1:1 relation, the existing dispersion means, for example, that an estimate of M_s=4.0 by the USGS can easily correspond to values in the range $3.5 \leq M_s \leq 5.0$ by the ISC, as shown in the plot. This suggests that there is not guarantee that applying a conversion equation to M_s values calculated by a diverse set of agencies would yield more accurate values than the **M**=M_s assumption. Figure 2.6 (right) shows that the situation is even worse for m_b, supporting the idea that m_b might not be a sufficiently reliable scale for the purpose of this work.

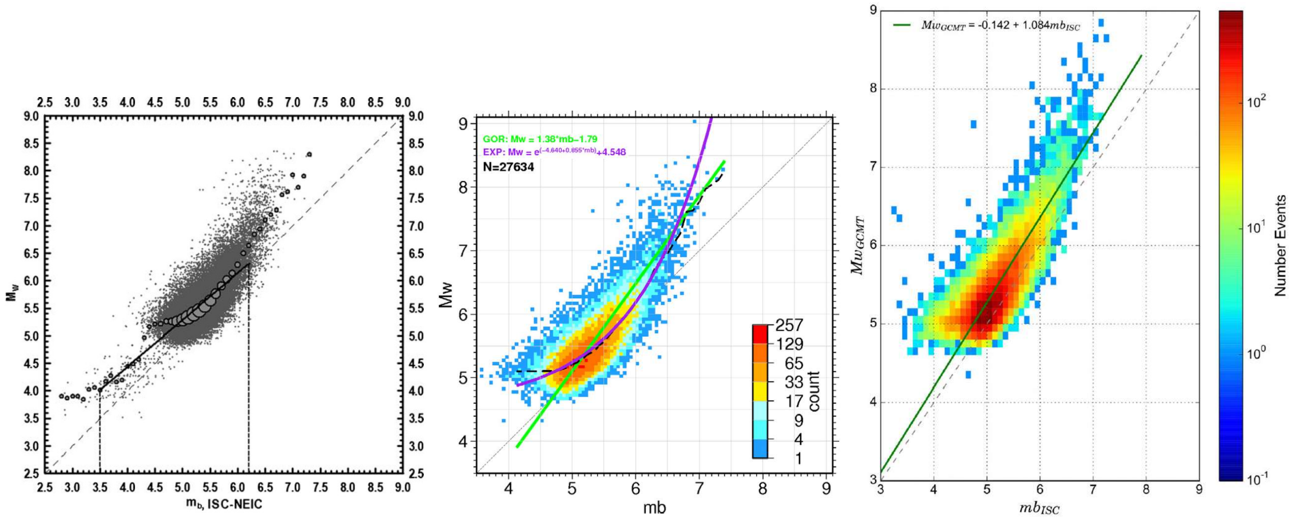


Figure 2.5. Relation between moment magnitude **M** (M_w) and body-wave magnitude m_b according to Scordilis (2006, left), Di Giacomo *et al.* (2015, centre), and Weatherill *et al.* (2016, right). Each plot was taken from the corresponding publication.

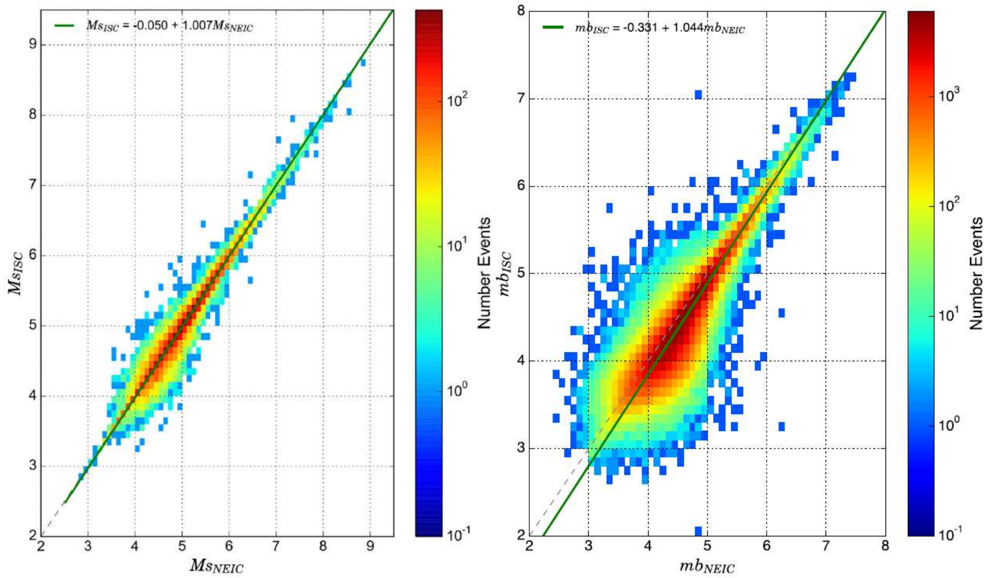


Figure 2.6. Relation between M_s (left) and m_b (right) estimates of the ISC (vertical axes) and the USGS (horizontal axes) for the events in the WPG16 catalogue. From Weatherill *et al.* (2016).

Figure 2.7 illustrates the implications of the **M**=M_s assumption in terms of the acceptance or rejection of events. If the relation between **M** and M_s were exactly as shown in Figure 2.7, irrespective of where the M_s estimation comes from, the **M**=M_s assumption would lead us to reject the events within the rectangles labelled A and C, and to keep the events within the rectangle labelled B in the database. According to the moment magnitude scale (vertical axis), events within rectangles A and C should be included in the database, while events within rectangle B should be rejected. If the relation between **M** and M_s were to be true, the number of events within rectangle C should be small, and the analysis can focus on rectangles A and B. According to the Gutenberg-Richter relation (Gutenberg & Richter, 1956), the number of events in A should be much larger than the number of events in B, so it is likely that the number of events that should be included and are rejected would be larger than the number of events that are included and should be rejected. Moreover, those that are rejected and should be included are less likely to cause damage than those that are included and should be rejected. As a consequence, the statistics regarding the proportion of earthquakes of the database that cause damage would be conservative, because more damaging earthquakes would be included than there should, and less non-damaging earthquakes would not be included, even though they should. For this and the reasons above, the **M**=M_s assumption was adopted in this work.

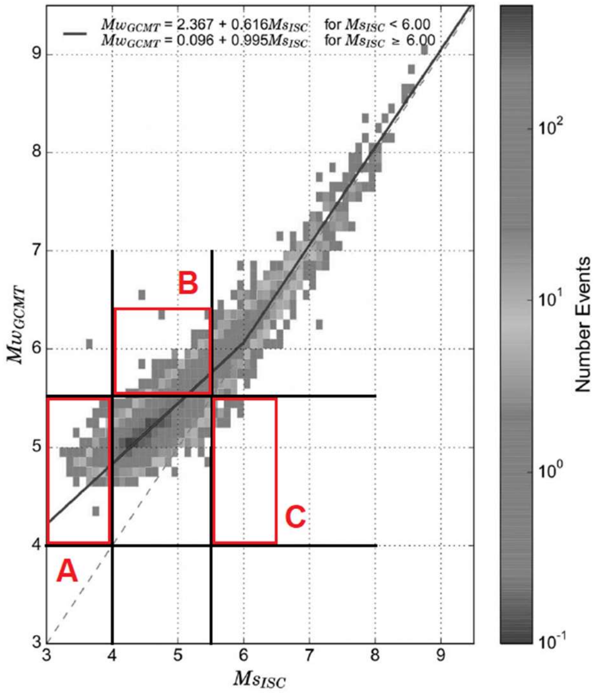


Figure 2.7. Relation between moment magnitude **M** (M_w) and surface-wave magnitude M_s according to Weatherill *et al.* (2016), modified so as to show the impact of the **M**=M_s assumption.

Regarding local magnitudes, Deichmann (2006) has analytically demonstrated that if the source characteristics of all earthquakes of a certain magnitude were constant, and those of the path and site were perfectly accounted for, then Richter local magnitude M_L and moment magnitude **M** would be the same in all magnitude ranges. Deichmann (2017) then demonstrated that this 1:1 scaling is lost for **M**<3.0, and a relation of the kind $M_L \alpha 1.5\mathbf{M}$ is observed and theoretically justified. This idea of a change of slope in the relation between the two scales is supported by the compilations carried out by Dost *et al.* (2016, Figure 2.8) and Strasser & Mangongolo (2012, Figure 2.9) of different models available in the literature. Both plots show, as well, a tendency for M_L to be larger than M, which was also reported by Braunmiller *et al.* (2005). In view of all this, the **M**=M_L assumption for the range 4.0≤**M**≤5.5 appears as reasonable and opens up access to a wider amount of data, because local networks tend to report magnitudes in terms of M_L.

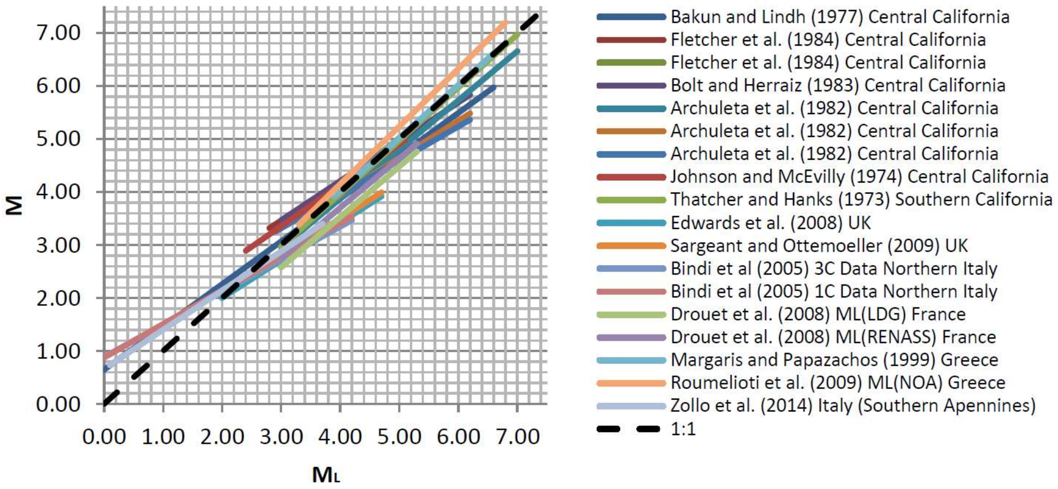


Figure 2.8. Relation between moment magnitude **M** and Richter local magnitude M_L according to studies available in the literature. From Dost *et al.* (2016).

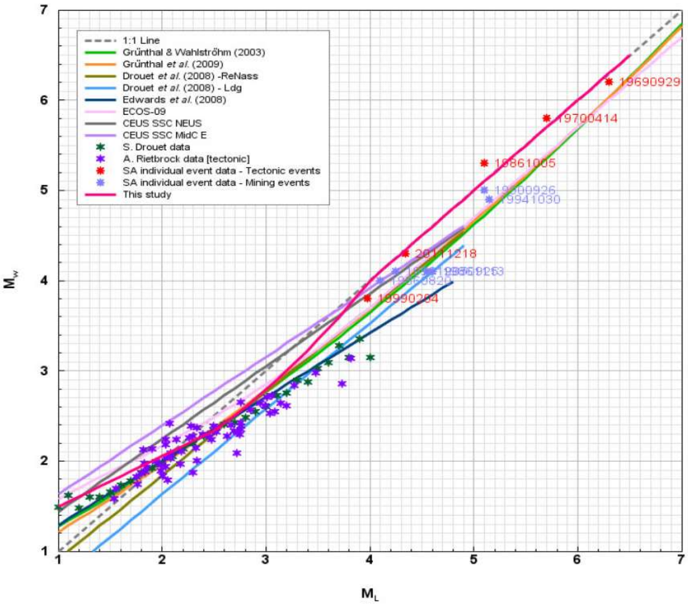


Figure 2.9. Relation between moment magnitude **M** and Richter local magnitude M_L according to studies available in the literature. From Strasser & Mangongolo (2012).

It is relatively common practice for local agencies to estimate a local magnitude based on the duration of the coda of the seismogram, the result of which is indicated as M_d. Gasperini *et al*. (2013) found that, at least for Italy, M_d tends to underestimate M_L at large magnitudes and overestimate it at low magnitudes, as shown in Figure 2.10, which is based on the ISIDE database of revised locations for Italy (Amato *et al.*, 2006). A similar tendency has been observed by Weatherill (2017, *pers. comm.*) for the solutions reported to the ISC by the Istituto Nazionale di Geofisica e Vulanologia (INGV, Italy), and for those of the National Observatory of Athens (NOA, Greece), as shown in Figures 2.11 and 2.12, though not so pronounced for those of the Kandili Observatory and Earthquake Research Institute (KOERI, Turkey) or the Disaster and Emergency Management of the Presidency (AFAD, Turkey), as shown in Figures 2.13 and 2.14. The comparisons of moment magnitude **M** against M_L and M_d shown in Figures 2.11 through 2.14 suggest that the former relation is closer to 1:1 and presents less scatter than the latter. These observations further support the **M**=M_L assumption and suggest that M_d might not be sufficiently reliable.

In light of this brief analysis, only moment magnitude **M**, surface-wave magnitude M_s and local magnitude M_L were considered when retrieving information from the ISC Bulletin, and a 1:1 relation was assumed among the three.

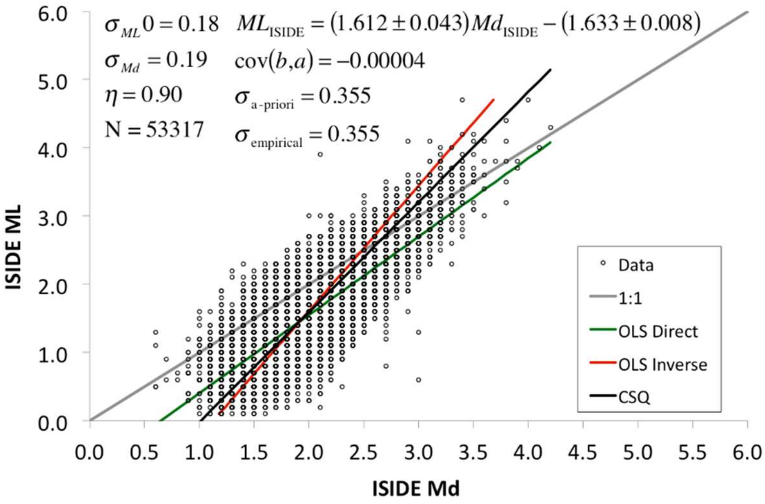


Figure 2.10. M_L vs. M_d for events from the Italian Seismic Instrumental and parametric DatabasE (ISIDE) (Amato *et al*., 2006). From Gasperini *et al.* (2013).

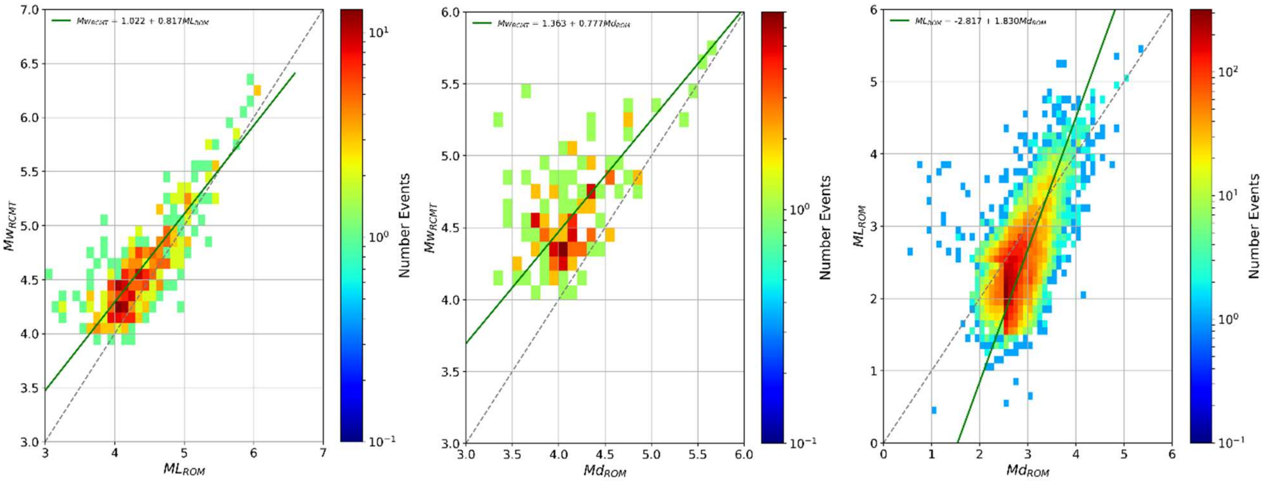


Figure 2.11. **M** vs. M_L (left), **M** vs. M_d (centre) and M_L vs M_d (right) for events reported by the INGV (Italy) to the ISC, retrieved from the ISC Bulletin. Courtesy of Weatherill (2017, *pers. comm.*).

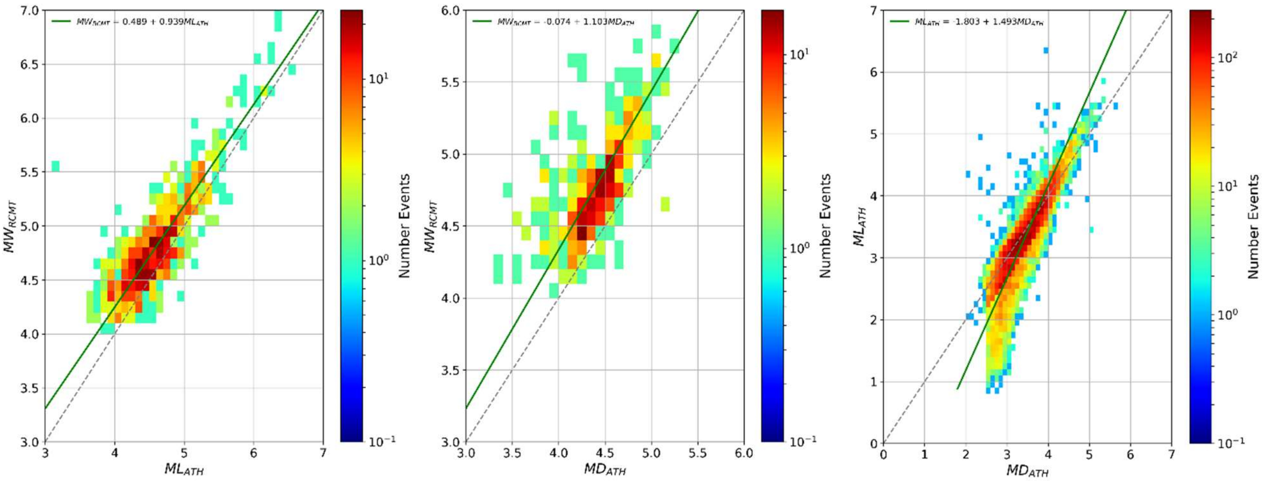


Figure 2.12. **M** vs. M_L (left), **M** vs. M_d (centre) and M_L vs M_d (right) for events reported by the NOA (Greece) to the ISC, retrieved from the ISC Bulletin. Courtesy of Weatherill (2017, *pers. comm.*).

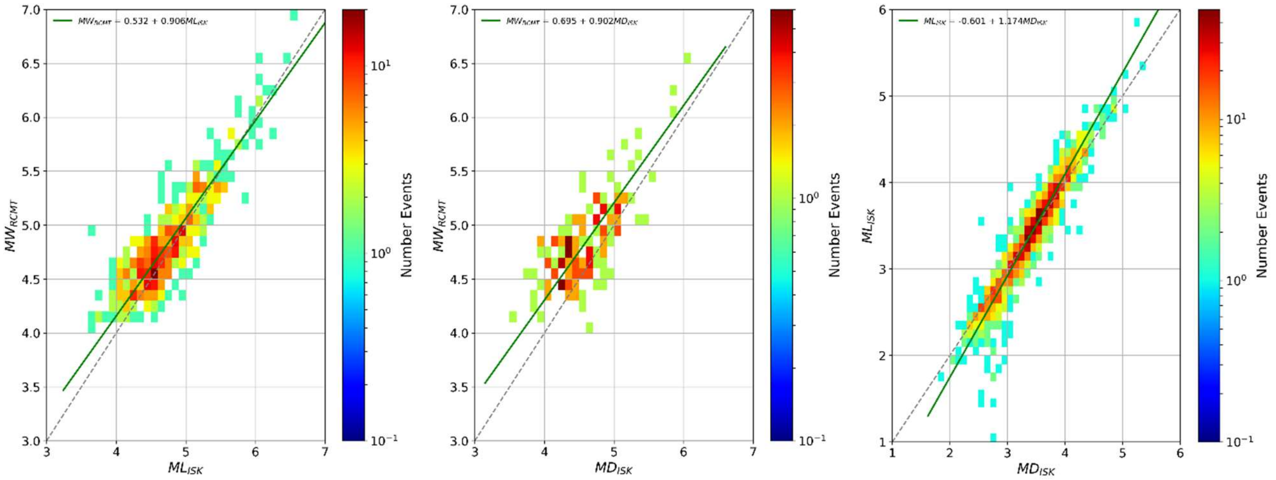


Figure 2.13. **M** vs. M_L (left), **M** vs. M_d (centre) and M_L vs M_d (right) for events reported by the KOERI (Turkey) to the ISC, retrieved from the ISC Bulletin. Courtesy of Weatherill (2017, *pers. comm.*).

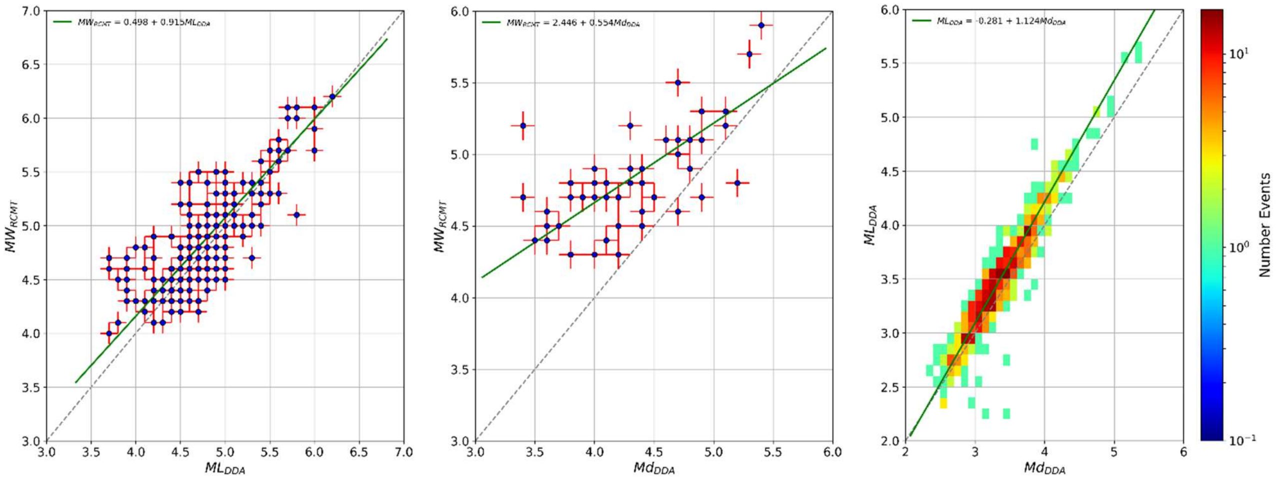


Figure 2.14. **M** vs. M_L (left), **M** vs. M_d (centre) and M_L vs M_d (right) for events reported by the AFAD (Turkey) to the ISC, retrieved from the ISC Bulletin. Courtesy of Weatherill (2017, *pers. comm.*).

As will be explained in Section 2.8, 717,285 events from the ISC Bulletin that are not found in the WPG16v3b catalogue were not considered within the final merged catalogue due to them not complying with the requisites established regarding information on origin and magnitude, and the agencies deemed relevant for each region of the world. Of these, 278,375 events have at least one estimate in terms of M_d, but no m_b, and 159,336 events have at least one estimate in terms of m_b, but no M_d. 438,986 have either an M_d or m_b estimate, while 717,285 – 438,986 = 278,299 events have neither an M_d nor an m_b value. If M_d or m_b were to be considered as acceptable magnitude scales, not all the 438,986 events could be added, because some of them would not comply with criteria related to the availability of information on depth and/or relevance of the agency reporting the estimation. An analysis carried out considering 4 years (48 months) suggests that around 98.7% of the 438,986 events would be finally included in the database, after considering all other criteria. This means that if M_d and m_b were considered herein, around 433,279 events could be further added to the merged catalogue, resulting in 1,549,552 events instead of the current 1,116,273 (note that this number of events includes all magnitudes and depths, and not just those of interest to the present work, as will be explained).

2.6. Incorporation of Events from the ISC Bulletin not in WPG16

The process started by querying the ISC Bulletin with the following criteria:

- magnitudes and locations from any agency;
- any magnitude estimates in the range $M_{any} \geq 2.5$;
- dated between 1st July 1996 and 30th June 2017
- not flagged as “explosion”, “chemical” or “nuclear”.

The toolkit published alongside the paper of Weatherill *et al.* (2016) was used to carry out the query over the ISF format files provided by the ISC in their FTP site, for the period before 30th June 2014, and for the ISF format files manually downloaded from their website, for the period starting on 1st July 2014.

It is noted that the filtering of events according to rejection keywords such as “explosion”, “chemical” or “nuclear” is likely to not be perfect, as the number of specific cases that can be found when parsing the ISF files is quite large. Moreover, and as Weatherill *et al.* (2016) point out, this filtering relies on the flagging carried out by contributing agencies.

The initial search cannot be restricted to the magnitude range or the time window of interest because declustering algorithms need to be run over the whole catalogue and a period of time that allows to identify foreshocks and aftershocks within the events closer to the time edges. The resulting raw catalogue was then compared against WPG16v3b, so as to determine if the events were already there or not. The search was carried out by means of a combination of strategies, first in terms of event IDs and origin IDs, and then using a time window of 60 seconds and a distance window of 100 km, as explained in Section 2.7.4. The outcome of this step was a list of events to be retrieved from the ISC Bulletin and a list of events to be taken directly from WPG16v3b.

The events to be retrieved from the ISC Bulletin may have more than one origin and magnitude estimations, authored by different agencies and using different magnitude scales. In order to select one location and one magnitude per event, a hierarchy of reporting agencies and magnitude scales was needed. The adopted hierarchy was the following:

1. Main agency, **M**.
2. Local agency, **M**.
3. Regional agency, **M**.
4. Main agency, M_s.
5. Local agency, M_s.
6. Regional agency, M_s.
7. Main agency, M_L.
8. Local agency, M_L.
9. Regional agency, M_L.

As can be observed, only moment magnitude **M**, local magnitude M_L, and surface-wave magnitude M_s were accepted, while all other magnitude scales were rejected. Magnitude scales were filtered in a case-insensitive fashion, which means that ML=Ml=ml=mL, for example. This is not necessarily true, as different agencies sometimes use different conventions to specify slightly different ways of calculating a particular scale. However, taking this into consideration in the present analysis is a challenge in itself, and so the issue was subsequently ignored. Moreover, an equivalency of $M=M_s=M_L$ is assumed for the range $4.0 \leq \mathbf{M} \leq 5.5$. The reasons for these choices are explained in detail in Section 2.5.

The criterion was evaluated in a sequential manner, stopping whenever a location-magnitude pair that satisfied the rule was found. It is possible to find cases in which the author of the magnitude estimate is different from the author of its associated location estimate. The overall author to be compared with the selection criterion was that of the magnitude estimate. As there are cases in which the location estimation does not include information on depth, an additional condition of depth being available was also included.

The application of this criterion required the classification of all possible contributing agencies as “main”, “regional” or “local”, and a definition of which local and regional agencies to consider for each event, based on their location. The list of all possible agencies was retrieved from the website of the ISC. Table 2.2 shows the agencies classified as “main” and the ranking assigned to them. The first 16 agencies follow the criteria used by Weatherill *et al.* (2016), but include aliases (*i.e.*, alternative acronyms used to refer to the same agency, sometimes because of changes in denomination with time) not considered by them. The ISC and its associated special collaborative projects (ISC-GEM, ISC-EHB) are regarded as primary sources due to the fact that the ISC collects data from an extensive list of agencies and uses it to carry out their own estimations. The United States Geological Survey (USGS) and the National Earthquake Information Center (NEIC) are also fundamental, as they record seismic events with their own network with extensive global coverage, and have a long legacy of processing and analysing earthquake data by means of well-documented procedures. The Global Centroid Moment-Tensor Project (GCMT) is the most complete database from which moment magnitude is derived. Like the ISC but at a continental level, the European-Mediterranean Seismological Center (EMSC/CSEM) gathers and re-processes data from multiple sources within Europe and the Mediterranean area. The International Data Centre (IDC) of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) is the oldest global network directly recording their own data, and uses state-of-the-art well-documented processing techniques. Their estimates can be of particular relevance for our magnitude range of interest, due to their origins and main objective of detecting worldwide nuclear testing. The Geophysical Survey of the Russian Academy of Sciences and the China Earthquake Networks Center are of relevance due to their extensive spatial coverage within their own countries and their high quality instrumentation and processing. The German Research Centre for Geosciences (GFZ) expanded its network to gain global coverage at the beginning of the 21st century, achieving this objective around 2008. While they provide rapid estimates, these are not revised after the events when more data becomes available.

Table 2.2. List of main agencies contributing to the ISC Bulletin and the ranking assigned to them herein.

Acronym	Name	Country	Ranking	Comments
GEM	ISC-GEM Global Instrumental Earthquake Catalogue	United Kingdom	1	-
ISC-GEM	ISC-GEM Global Instrumental Earthquake Catalogue (alias)	United Kingdom	2	Alias GEM
ISC-EHB	ISC-EHB	United Kingdom / United States	3	-
EHB	Engdahl, van der Hilst and Buland	United States	4	-
ISC	International Seismological Centre	United Kingdom	5	-
ISC1	International Seismological Centre (alias)	United Kingdom	6	Alias ISC
ISCJB	International Seismological Centre	United Kingdom	7	-
NEIC	National Earthquake Information Center	United States	8	-
NEIS	National Earthquake Information Service	United States	9	Alias NEIC
PDE	Preliminary Determination of Epicentres	United States	10	Alias NEIC
USCGS	United States Coast and Geodetic Survey	United States	11	Alias NEIC
CGS	Coast and Geodetic Survey of the United States	United States	12	Alias NEIS
USGS	United States Geological Survey	United States	13	-
GS	U.S. Geological Survey	United States	14	Alias USGS
GM	U.S. Geological Survey	United States	15	Alias USGS
GCMT	The Global CMT Project	United States	16	-
HRVD	Harvard University	United States Mainland	17	Alias GCMT
HRVD_LR	Department of Geological Sciences, Harvard University	United States Mainland	18	Alias HRVD
CSEM	Centre Sismologique Euro-Méditerranéen (CSEM/EMSC)	France	19	-
IDC	International Data Centre, CTBTO	Austria	20	-
MOS	Geophysical Survey of Russian Academy of Sciences	Russian Fed.	21	-
BJI	China Earthquake Networks Center	China	22	-
GFZ	Helmholtz Centre Potsdam GFZ German Research Centre For Geosciences	Germany	23	-
IRIS	IRIS Data Management Center	United States	24	-
EIDC	Experimental (GSETT3) International Data Center	United States	25	-
IASPEI	IASPEI Working Group on Reference Events	United States	26	-

Agencies or sources were classified as “regional” when their coverage was related to a region of the world other than a country. Finally, all other agencies providing estimates at the country-level were classified as “local”. For each country, they were ranked according to their relevance. Whenever the agencies were not particularly known at the international level and it was, thus, not possible to determine their relevance, the information provided within the ISC website regarding their activity and level of contribution was used as a supplementary criterion. Whenever there was an obvious national organization, this was selected as the most relevant for the country, unless it was already classified as a main agency, as main agencies were given priority over local ones. Well-established and well-instrumented local networks were ranked next, followed by national and seismic laboratories, as well as state or provincial level agencies. Universities and temporary experiments were considered last. The list of all contributing agencies and their ranking within each country or region can be found in Appendix II.

In order to determine the hierarchy of agencies to adopt for each event, average epicentral coordinates were calculated from all location estimates. These average coordinates were compared against bounding boxes for countries (or separate offshore regions), obtained from Nearby UK (see Web References) and slightly modified for this work. Given that bounding boxes are rectangles that contain the whole area of each country, it is perfectly common for them to overlap and for an epicentre to fall within more than one country. Neighbouring countries were considered as well, neighbours being defined as those countries whose bounding boxes intersect in any way the bounding boxes of the countries in which the epicentre is directly contained. A first round of listing countries was carried out dilating the bounding boxes by 70 km, acknowledging that an earthquake occurring in the border between two countries might be at risk of not being considered within all relevant countries if the bounding box was kept at the exact most extreme coordinate of the country profile. A second round of selection was carried out dilating the bounding boxes by 500 km, with the purpose of further adding countries to the list, in case no estimation from closer agencies was found first. This was prompted by the observation of cases for which no location or magnitude had been selected due to the epicentre falling far enough from a relevant agency. The ranking of countries was nevertheless carried out so that countries in which the epicentre is contained appear first (primary countries, hereafter), followed by neighbours identified with the 70-km dilation (70km-neighbours, hereafter), and finally followed by neighbours identified with the 500 km dilation (500km-neighbours, hereafter). The 70 km were selected as the epicentral distance for which the IPE of Allen *et al.* (2012) estimates a Modified Mercalli Intensity of IV for a hypothetical zero-depth **M**5.5 earthquake (*i.e.* worst possible conditions in our range).

Local agencies corresponding to each country were ranked with this criterion in mind. The agencies from primary countries and 70km-neighbours were ranked going first by ranking and then by country. As an example, if country A had agencies A1, A2 and A3, country B had agencies B1 and B2, and country C had agencies C1, C2 and C3, the final hierarchy was A1, B1, C1, A2, B2, C2, A3, C3. Then, the same logic was applied to the agencies from the 500km-neighbours, which were ranked after the former. Within the primary countries, 70km-neighbours and 500km-neighbours, countries were ranked in no particular order.

Figure 2.15 shows, as an example, the primary countries and 70km-neighbours for a hypothetical epicentre located in Groningen. The red rectangles are the bounding boxes of the Netherlands and Germany, the two primary countries, the larger ones corresponding to the 70-km dilation, and the smaller ones being their un-dilated counterparts. The yellow rectangles are the 70-km dilated bounding boxes of the 70km-neighbours. As can be observed, they intersect either the 70-km bounding box of the Netherlands or that of Germany, condition for which they are classified as neighbours. The 500km-neighbours are defined in a similar fashion. The final list of relevant countries (and offshore regions separated from the mainland) for this hypothetical earthquake would be (in order of consideration):

- Primary countries: Germany, the Netherlands.
- 70km-neighbours: Austria, Belgium, Croatia, Czech Republic, Denmark, France, Hungary, Italy, Liechtenstein, Luxembourg, Poland, Slovakia, Slovenia, Sweden, Switzerland, United Kingdom.
- 500km-neighbours: Canada, Albania, Andorra, Belarus, Bosnia-Herzegovina, Bulgaria, Estonia, Greece, Isle of Man, Kosovo, Latvia, Lithuania, Macedonia, Moldova, Montenegro, Norway, Romania, Russia, San Marino, Serbia, Spain, Turkey, Ukraine, Finland, Greenland, Ireland, Portugal, Algeria, Faroe Islands, Iceland, Libya, Malta, Morocco, Tunisia, United States Mainland, United States Alaska.

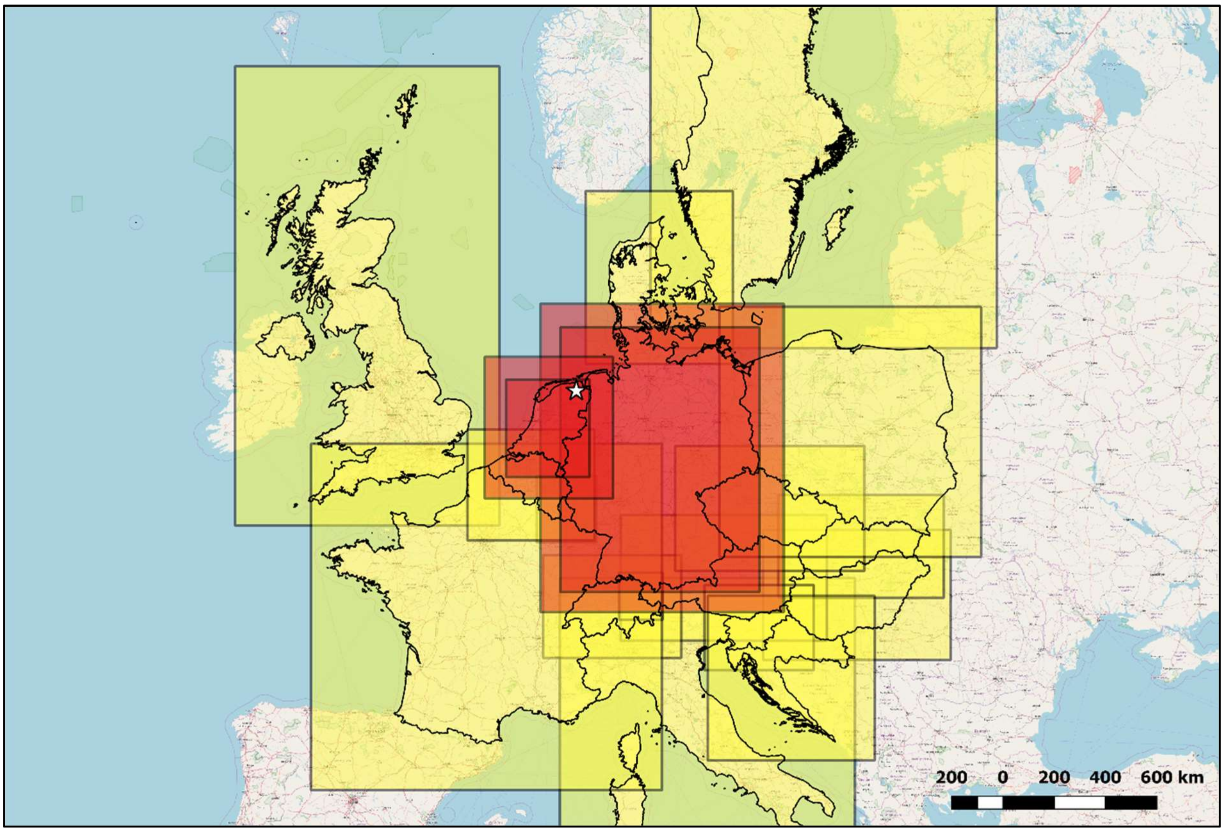


Figure 2.15. Example of determination of relevant countries for the hierarchization of local agencies for a hypothetical epicentre located in Groningen.

While it is acknowledged that the list of 500km-neighbours might seem an exaggeration in terms of how distant to the epicentre some of these countries are, it is noted that it is not very likely that an event does not have any origin or magnitude estimate from any of the primary countries or the 70km-neighbours. The 500km-neighbours were incorporated because it was observed that in some cases of events that occurred in islands, the estimate of the primary country may not satisfy other criteria (magnitude scale, availability of depth information), and the only other estimate was from a neighbouring country that was relatively far, but was still the closest to the event. Considering the list of countries in sequence allowed to make sure that the most relevant countries were taken into consideration first. The list of local agencies under consideration for this example would be (in order of hierarchy, and only showing the first ten):

- BGR: Bundesanstalt für Geowissenschaften und Rohstoffe (Germany)
- DBN: Koninklijk Nederlands Meteorologisch Instituut (Netherlands)
- VIE: Zentralanstalt für Meteorologie und Geodynamik (Austria)
- UCC: Royal Observatory of Belgium (Belgium)
- ZAG: Seismological Survey of the Republic of Croatia (Croatia)
- PRU: Geophysical Institute, Academy of Sciences of the Czech Republic (Czech Republic)
- DNK: Geological Survey of Denmark and Greenland (Denmark)
- LDG: Laboratoire de Détection et de Géophysique/CEA (France)
- KRSZO: Geodetic and Geophysical Reasearch Institute, Hungarian Academy of Sciences (Hungary)
- ROM: Istituto Nazionale di Geofisica e Vulcanologia (Italy)
- …

It is acknowledged that, within the 50km-neighbours in the example above, the hierarchy could be improved. However, any kind of automatic refinement is likely to improve the situation for some cases and make it worse for some others. It is clear that the determination of how many countries and which countries are considered for each event by means of this method is not exact, as it strongly depends on the size and shape of the countries surrounding the epicentre. The method is, nevertheless, deemed sufficient for the purpose of this work.

The next step consisted of merging the selected events with the WPG16v3b catalogue. First, events in the latter for which depth values are not available were purged (see Appendix I), and events within the time window of interest were selected. After merging, declustering was carried out using the algorithm of Gardner & Knopoff (1974), as implemented in the OpenQuake Hazard Modeller’s Toolkit (Weatherill, 2014), with a Gardner & Knopoff (1974) window and the same time span considered for both foreshocks and aftershocks. As the most commonly used declustering methods, and this one in particular, do not include depth in their algorithms, a small modification was introduced for this to be the case. Consequently, the distance window was not applied to the horizontal distance between epicentral coordinates but to the distance in three-dimensional space between the hypocentres.

As a result of declustering, each event was assigned two new parameters: a flag that indicates if it is a foreshock (-1), a main shock (0) or an aftershock (1), and an integer that indicates the cluster to which it belongs, which is zero if the event does not belong to any cluster.

Finally, events were filtered according to the depth criterion defined in Table 2.1. As this criterion is magnitude-dependent, the filtering was carried out considering each magnitude-depth pair, taking the opportunity to narrow down the magnitude range to that of interest, *i.e.*$4.0 \leq \mathbf{M} \leq 5.5$, and the overall database to the final 15 years between 1st July 1999 and 30th June 2014.

To sum up, an event that was originally in the ISC Bulletin and not in the WPG16v3b catalogue may not be part of the final set of events to add to WPG16v3b because of any of the following reasons:

- The event had no magnitude estimates that used any of the selected scales (**M**, M_L, M_s) and whose value was in the range of interest.
- The location associated with the accepted magnitudes did not have information on depth.
- The depth did not comply with the maximum depth criterion defined in Table 2.1.
- No main agency or relevant local agency had reported estimates for the event.

2.7. Resolution of Specific Issues

Alongside the general procedure described above, a series of smaller challenges needed to be addressed along the way.

2.7.1. Magnitude Estimates with Two Authors

Conventions to specify authors of magnitude estimations within the ISC Bulletin have evolved with time. There are several earthquakes from the years 1996, 1997 and 1998 for which certain magnitude estimates are assigned two authors. In most cases, the first author is a local agency, while the second one is the United States National Earthquake Information Center (NEIC). While no explanation has been found in the documentation regarding the meaning of this double-authorship, the website of the Advanced National Seismic System (ANSS) Composite Earthquake Catalogue indicates that NEIC sometimes incorporates data from different sources, and enumerates a series of agencies. Within these it is possible to find several of the agencies mentioned in the years 1996-1998 in the ISC Bulletin for these double-authorship cases, which are not listed within the contributing agencies of the ISC. This suggests that magnitudes with double-authorship have been estimated by the first author, and endorsed by the second one. This interpretation was adopted herein, and the first author was consequently adopted as the one and only author of each magnitude estimation. It is worth noting that, in many cases, these magnitude estimations were associated with origin estimations of the second author, which were kept this way (no double-authorship was observed for origins).

2.7.2. Repetition of Magnitude Scale–Author Combinations

There are events for which there exist magnitude estimates with the exact same scale and exact same author associated with the exact same origin. More of these cases are artificially generated due to the use of upper/lower case letters indistinctively, as explained above (*e.g.*, $M_L=M_l=m_l$). These repetitions of magnitude scale-author combinations were addressed by means of the following criteria:

- If the magnitude estimates include the number of stations used for their determination, the estimate with the largest number of stations was selected.
- If there is more than one magnitude estimate with the same (maximum) number of stations, one of them was randomly selected.
- If some estimates had numbers of stations and some did not, the latter were treated as having lower numbers of stations than the former.
- If the numbers of stations were not available, one estimate was randomly selected.

2.7.3. Several Origins with Same Magnitude Scale–Author Combinations

As explained above, the hierarchy of agencies was first tested within the magnitude estimates. Whenever a certain combination of magnitude scale and author existed for more than one origin estimate, the hierarchy was then tested within the origins as well.

2.7.4. Identification of Events Already in WPG16

As the comparison of different catalogues to identify events present in both is not a trivial task, this step was tackled with a combination of strategies, with the aim of minimizing the number of misclassified events.

For the period between 1st July 1996 and 30th June 2017, WPG16v3b contains events from five different sources: ISC, NEIC, EHB, ISC-GEM and GCMT. The first three preserve the event IDs from the ISC Bulletin, while this is not guaranteed *a-priori* for ISC-GEM and certainly not always the case for GCMT. Events from WPG16v3b whose original main source was ISC, NEIC or EHB were first compared against all events retrieved from the ISC Bulletin in terms of event IDs and origin IDs. At the time at which the WPG16v3b catalogue was compiled, the ISC Bulletin had only revised events until 31st May 2014. At the time of carrying out the merging of WPG16v3b and the ISC Bulletin, June 2014 and July 2014 have been revised as well. This means that WPG16v3b only contains events whose main agency is ISC until 31st May 2014, while later events come from either NEIC (albeit retrieved from the ISC Bulletin) or GCMT. It was thus observed that several events that were originally enumerated by the ISC Bulletin for June and July 2014, and were included in WPG16v3b, had been modified, eliminated or merged at the time of the analysis. It was also noted that, even if not fully reviewed, events from August 2014 whose main origins were NEIC or GCMT had also been modified, even if a direct calculation by the ISC was not available yet. As the merging or elimination of events implies the disappearance of some event IDs, the comparison was carried out also in terms of origin IDs, which are preserved even when events originally identified as separate are merged as being one unique event.

Whenever it was found that one event ID from WPG16v3b could be linked to more than one event from the most updated query of the ISC Bulletin, or that one event from the latter could be linked to more than one event from WPG16v3b, the event/s from WPG16v3b were eliminated, and the corresponding ones from the ISC Bulletin were retrieved instead, under the philosophy that these events appear to require an update. When, on the contrary, a unique relation between an event from WPG16v3b and an event from the ISC Bulletin could be established, the event from WPG16v3b was kept.

Events from WPG16v3b and the ISC Bulletin that remained unmatched after this first analysis were compared in terms of time and space, using windows of 60 seconds and 100 km.

As it was noted that some events from WPG16v3b whose original source were the ISC-GEM or GCMT catalogues did preserve event IDs from the ISC Bulletin, the comparison in this case was carried out in two stages. Firstly, event IDs from one and other were matched. Whenever the event ID was found in both, an additional check was executed to verify that the two events were sufficiently close in time and space, using the same 60-second and 100-km windows as before. This was done to prevent an unintended matching of event IDs to occur by accident for events that were not actually the same. Events that remained unmatched after this first round were then compared just in terms of the time and space windows, irrespective of their event IDs.

Regarding the uniqueness of event IDs in the ISC Bulletin it was noted that, for the events retrieved within this work, around 900 that have occurred about one decade apart had repeated event IDs. In particular, this is observed for events happening in 1997 through 2001, whose event IDs can be found again in 2010, the reason being unknown. This was, however, no problem for the comparison of the WPG16v3b catalogue and the ISC Bulletin, as the comparison was carried out on a monthly basis.

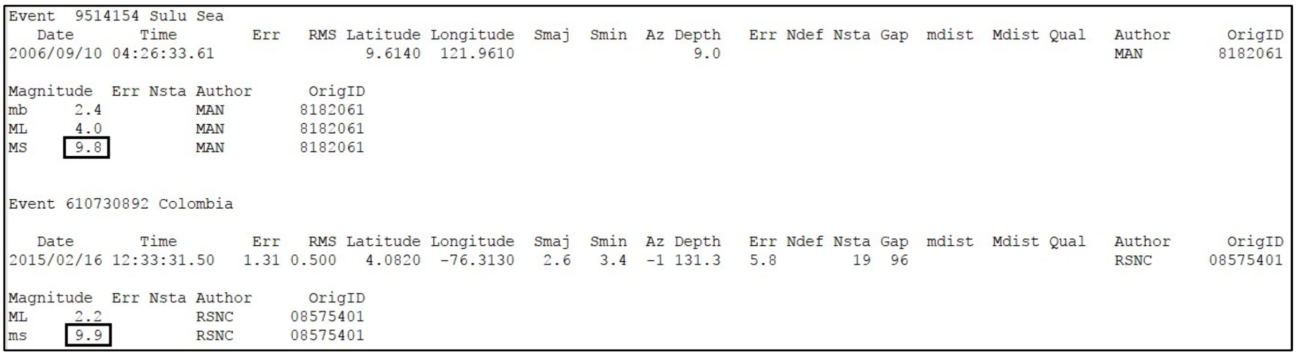
2.7.5. Flagging of (Potentially) Induced Earthquakes

The toolkit published alongside the paper of Weatherill *et al.* (2016) contains a feature to flag potentially induced earthquakes if their comments include a series of keywords related to anthropogenic activities. The keywords used herein were “geothermal", "reservoir", "mining", and “anthropogenic". Just like for the case of filtering with rejection keywords, this classification may not be perfect.

All events added from the ISC Bulletin were assessed and flagged accordingly using this tool. Events already present in WPG16v3b were assessed in a similar fashion. Each of them was looked up within the ISC Bulletin and the toolkit was used to carry out the classification. Events whose main sources were ISC, NEIC or EHB were identified directly by means of their event ID, while those from the ISC-GEM catalogue and GCMT were identified following the double-step check used in Section 2.7.4 based on event ID and proximity in time and space.

2.7.6. *Manual Modification of Outliers*

As explained before, the volume of data involved in the compilation of this database does not allow for manual processing of individual events in a large scale. However, it was not always possible to find straightforward algorithmic solutions whenever a particular case was observed. In the various visual inspections of the results obtained, two events were identified as problematic, as they appeared as having magnitudes 9.8 and 9.9. The two original reports from the ISC Bulletin are shown in Figure 2.16. As can be observed, it is very likely that these large magnitude estimations be some kind of error from the contributing agencies. Due to the adopted hierarchy of magnitude scales, it was these two large values (9.8 and 9.9) that were being selected to represent each event. The two were manually modified to be 4.0 and 2.2, respectively, moving on in the hierarchy to adopt M_L instead of M_s. In the future, the processing of data from the ISC Bulletin could be modified to first eliminate any obvious outlier magnitude values like the ones shown herein by comparing all magnitude estimates for each event. Such a solution would need to account for the dispersion that can be observed between different magnitude scales (see Section 2.5).



```
Event  9514154 Sulu Sea
   Date       Time        Err   RMS Latitude Longitude  Smaj  Smin  Az Depth   Err Ndef Nsta Gap  mdist  Mdist Qual   Author      OrigID
2006/09/10 04:26:33.61                9.6140  121.9610                   9.0                                          MAN        8182061

Magnitude  Err Nsta Author      OrigID
mb       2.4          MAN       8182061
ML       4.0          MAN       8182061
MS       9.8          MAN       8182061


Event 610730892 Colombia

   Date       Time        Err   RMS Latitude Longitude  Smaj  Smin  Az Depth   Err Ndef Nsta Gap  mdist  Mdist Qual   Author      OrigID
2015/02/16 12:33:31.50   1.31 0.500   4.0820  -76.3130   2.6   3.4  -1 131.3   5.8        19  96                      RSNC      08575401

Magnitude  Err Nsta Author      OrigID
ML       2.2          RSNC     08575401
ms       9.9          RSNC     08575401
```

Figure 2.16. Two events from the ISC Bulletin with unusual magnitude values.

2.7.7. *Potentially Duplicated Earthquakes*

Location of earthquake sources in time and space is not a trivial task. A quick look through the ISC Bulletin reveals how variable the estimates from different agencies can be. Differences of a few tens of seconds and several tens of kilometres for different estimates of the same event are not uncommon. As explained in the website of the ISC, before the Bulletin is reviewed (something that happens around two years after the time at which the earthquakes occurred) the process of grouping information received from all the contributing agencies is automatic. Depending on scores assigned to the different hypocentral locations as a function of the phase data that gave rise to them, as well as other parameters, groups of origins are created, merged or split. As a result, it is possible that one event be reported as two separate events.

The extent to which this can happen becomes clear when given the chance to compare older and newer versions of the ISC Bulletin, as occurred along the duration of this work, or when looking at events that have been studied in detail. For example, at the time of writing (November 2017), the **M**7.9 Gorkha (Nepal) earthquake of 25th April 2015 appears reported as two different events with IDs 607208674 and 610587872, each of which contains 17 and 3 origins. Moreover, 16 of the 17 origins of event 607208674 indicate that the earthquake started around 06:11:20 UTC, while one (OrigID 08495668) says 06:45:23 instead. This is clearly an error, but not all cases are as extreme and easy to identify as this one.

The **M**7.9 Gorkha earthquake, and all earthquakes after 31st July 2014 in general, have not been reviewed to elaborate the Reviewed ISC Bulletin yet (at the time of the analysis). When comparing the ISC Bulletin against the WPG16v3b catalogue, note was taken of events that were part of the latter but could not be found in the former. In some cases, this is due to some events being repeated in the WPG16v3b catalogue itself. In others, the events simply cannot be found anymore, because of the version of the ISC Bulletin used to compile WPG16v3b being older than the one used herein (downloaded on 25th August 2017). Having observed this reinforces the decision to consider only events up to 30th June 2014 for the final database, and using up to 30th June 2017 only for declustering purposes.

Errors in earthquake location can be originated in a variety of reasons, the most relevant being the difficulties associated with the accurate picking of arrival times in the waveforms and the limitations of the travel-time models of the Earth and, in particular, the upper mantle, used for standard location procedures (Engdahl *et al.*, 1998; Richards *et al.*, 2006). This difficulty in identifying reports that correspond to the same event that the ISC faces is similar to that of comparing two different earthquake catalogues and trying to determine which events are present in both.

Visual inspection of the merged catalogue (*i.e.*, the catalogue that results from the combination of WPG16v3b and the additional events from the ISC Bulletin selected as described in Section 2.6) suggested the possible presence of duplicate events. For this reason, a thorough study was carried out to try to identify these cases and make decisions with respect to them. A 100% conclusive determination of which events are duplicates of others and which are independent would only be possible by means of a complete reprocessing and analysis of the waveforms that were used to determine the origins of the seismic events. Besides requiring access to this information, this would be an extremely time-demanding task that is clearly outside the scope of this work. Moreover, the usual challenges associated with the location of earthquake sources would persist. In other words, this would be a complete research topic on its own. With this in mind, the methodology described in what follows aimed at trying to identify reasonable parameters for the automatic identification of duplicate events. The process needed to be automatic, as the amount of data involved makes it impossible for a manual one-by-one analysis to be carried out. Nevertheless, randomly selected events were subject to a visual inspection in order to assess the congruity of the results. It is clear that there can be false positives (*i.e.*, events identified as duplicates that were in reality two different events) and there can also be duplicates that are not caught by the algorithms. As a consequence, results should not be judged on a case-by-case basis but on their overall improvement of the merged catalogue.

First, a set of potential duplicate pairs of events was identified using pre-defined time and distance thresholds, which were selected based on predictions of significant duration of seismic events and distance windows commonly used for declustering. As only pairs of events pre-selected in this way were analysed further, the pre-selection criteria was set as loose as possible, but avoiding at the same time an unnecessary computational burden. If computational capacity was infinite, this step would be skipped and all possible pairs of events in the merged catalogue could be considered as potential duplicates. This logic is clearly extreme, as it is impossible to believe that events identified as happening years and thousands of kilometres apart are the same event, but it illustrates the need for defining a threshold.

The maximum magnitude that can be found in the merged catalogue corresponds to the **M**9.1 Tohoku (Japan) earthquake of 11th March 2011. According to the implementation of the models of Gardner & Knopoff (1974) and Grünthal (van Stiphout *et al.*, 2012) in OpenQuake (Pagani *et al.*, 2014), around 130 km would be a relevant distance within which to search for events associated with a **M**9.1 main shock. The model of Uhrhammer (1986) gives a much larger value of 540 km. As the present analysis aims at the identification of potentially duplicated entries in the database, this last value was discarded for being too large. While variations in the location of the epicentre of events can be in the order of tens of kilometres, it is extremely unlikely that they can reach the order of magnitude suggested by Uhrhammer (1986). The behaviour of the three models against magnitude is depicted in Figure 2.17.

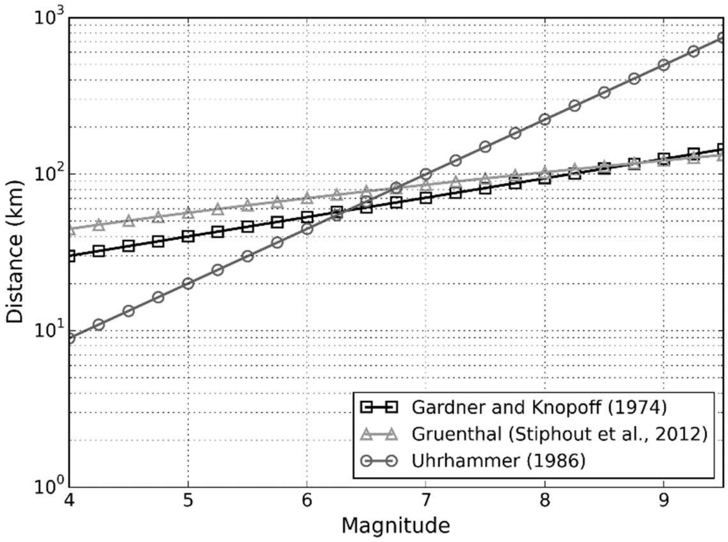


Figure 2.17. Declustering distance windows according to three different models.

Two models for the prediction of the significant duration of earthquakes were used to set the time threshold: that of Bommer *et al.* (2009) and that of Afshari & Stewart (2016). For the former, a 0 km depth to the top of rupture was used, while for the model of Afshari & Stewart (2016) an unknown focal mechanism and location other than California or Japan were indicated. A V_{s30} value of 100 m/s was used in both cases. All these parameters were selected so as to obtain duration values that would cover a relevant proportion of events of the merged catalogue. As both predictive models were derived using events with magnitudes up to **M**7.9, caution should be taken when analysing their output for **M**9.1. As shown in Table 2.3, the model of Bommer *et al.* (2009) predicts a longer duration right above the seismic source than 100 km away from it, which is physically impossible, while the model of Afshari & Stewart (2016) yields unrealistically long values. In view of the inapplicability of the models for this magnitude, the calculations were repeated for **M**7.9 and the values reported in Table 2.4 were obtained. A threshold of 120 seconds was finally adopted.

Table 2.3. Significant duration (5-95% of Arias intensity definition) predicted by different models for **M**9.1, V_{s30}=100 m/s, and other parameters specific of each model.

Distance	Model	Duration (s)	Duration (min)
0 km	Bommer, Stafford & Alarcón (2009)	89.4	1.49
	Afshari & Stewart (2016)	1353.3	22.55
100 km	Bommer, Stafford & Alarcón (2009)	41.4	0.69
	Afshari & Stewart (2016)	1380.5	23.01

Table 2.4. Significant duration (5-95% of Arias intensity definition) predicted by different models for **M**7.9, V_{s30}=100 m/s, and other parameters specific of each model.

Distance	Model	Duration (s)	Duration (min)
0 km	Bommer, Stafford & Alarcón (2009)	36.0	0.60
	Afshari & Stewart (2016)	71.1	1.19
100 km	Bommer, Stafford & Alarcón (2009)	39.6	0.66
	Afshari & Stewart (2016)	98.4	1.64

While having tried to follow a rational approach for their definition, the values selected herein are still arbitrary. The ideas behind the process followed to define them were:

- If two location estimates of the same event were further apart than 130 km, it would not even be possible to consider them part of the same cluster of events. If a distance larger than 130 km makes it unlikely for them to be part of the same cluster, it should make it even less likely for them to be the same event.
- Whether two estimates of the starting time of an event are too close or too distant is highly influenced by what the duration of the event is. If the event lasted 30 seconds, then two estimates that are 10 seconds apart might still correspond to the same event, while if the event lasted 3 seconds, a 10-second difference might be too large. With this in mind, the threshold of 120 seconds was chosen so that it would be very unlikely that one large event followed by another one could be mistaken by two estimations of the same event.

The 100 km used in Tables 2.3 and 2.4 are also arbitrary. The same 130 km defined above could have been used, but 100 km is the upper bound of applicability of the model of Bommer *et al.* (2009) and, ultimately, the difference between the results from the two is minimal. Bearing in mind that it is unlikely that large events not be well constrained and that they present an issue of potential duplicate events, the idea behind this value was to consider the duration at a relatively maximum distance at which a local network operated by a local agency could have recorded the event under analysis.

As a first measure, potential duplicate pairs whose event ID was identical were assumed to be the same event. Only two cases like this were identified in the merged catalogue. The first, event ID 7432797 of 8th November 2004, was already present as two events in WPG16v3b. As the algorithms used to compare the latter with the ISC Bulletin and merge them does not explicitly check for duplicates within WPG16v3b, it was only at this stage that it was caught. The second event, event ID 13876558, was present as one event in WPG16v3b and was then added again from the ISC Bulletin. This was due to the code comparing WPG16v3b against the ISB Bulletin checking not only event IDs but also differences in distance and time when the main agency indicated in WPG16v3b is GCMT, for which the use of the same ID of the ISC Bulletin is not guaranteed, as is the case with this event. The time check was correct (12 seconds between the UTC of both instances of the event), but the distance between the two hypocentres (around 110 km) was slightly larger than the 100 km used for the verification. Both events, ID 7432797 and ID 13876558, were thus purged at this stage.

Each remaining potential duplicate pair was then assessed in detail, considering a series of possibilities. As shown in Figure 2.18, a first classification of cases was carried out on the basis of whether the two events can be found within the ISC Bulletin or not, as this determines whether or not the retrieval of origin times estimated by different agencies is possible. Whenever this information could be redeemed, the time ranges (understood as the period in time during which the event has been estimated to have started) for the two events were determined and compared against each other. The two overlapping was taken as an indication of potential duplication, as was the case when the time ranges expanded assuming that the largest variability in time estimations applied for both events overlapped as well. When none of these cases of overlapping occurred, the pair was then treated as if no information from the ISC Bulletin could be retrieved, and predictions of ground motion duration were used instead of the time ranges. Each of these steps are explained in detail in what follows.

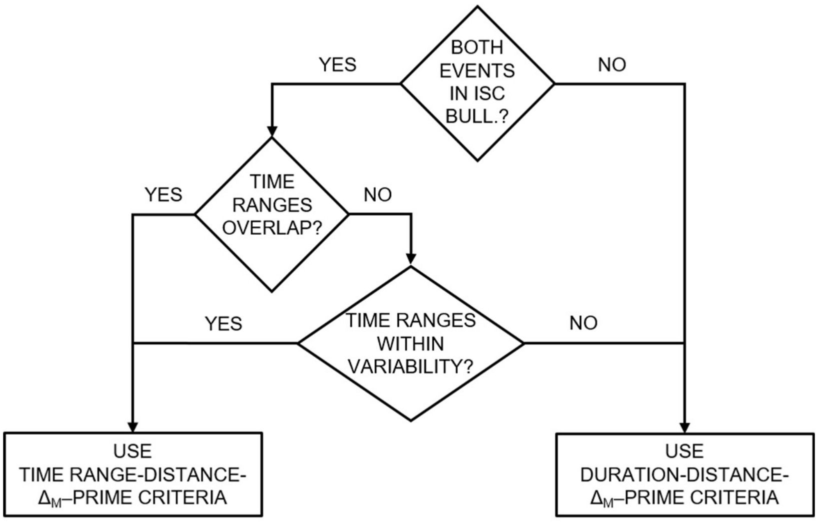


Figure 2.18. Flowchart for identifying duplicate events.

The final two possible cases depicted in Figure 2.18, namely “time range-distance-Δ_M-prime criteria” and “duration-distance-Δ_M-prime criteria”, refer to two sets of rules that differ mainly in the way that the time of occurrence of the earthquakes was analysed. As explained above, the expression “time range” makes reference to the minimum time period that contains all the estimates of starting times of an event. Representing it as a box, Figure 2.19 shows all the possible cases that can arise when comparing the time ranges for the two events. Assuming that the starting time selected to characterise each event (*i.e.*, the starting time within the merged catalogue) was older for event 1 than for event 2 (*i.e.*, the start of event 1 precedes the start of event 2), case A was impossible. While case B implies no overlap, a further possibility was analysed, as illustrated in Figure 2.20. The variability defined by the maximum time range of the two events was assumed to be applicable to both (*i.e.* it was assumed that there could be other time estimates that would cause the same variability in both). The median time of occurrence and a new extreme value resulting from the latter and half of the maximum time range were calculated for each event. If the resulting time ranges overlapped, they were treated as if their original time ranges had overlapped. Cases C and D in Figure 2.19 make reference to partial overlapping of the time ranges, while in E and F the time range of one event is completely contained within the other. Cases D and F appear to violate the condition that the start of event 1 precedes the start of event 2, but they do not, as the condition was applied to the one time estimate that was used to characterise each event in the merged catalogue, and not to the complete ranges of time estimates.

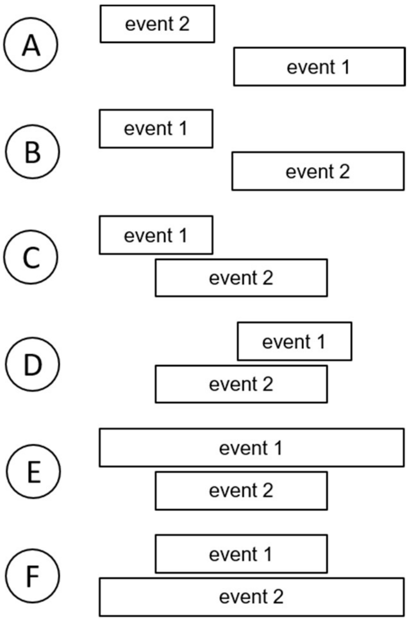


Figure 2.19. Possible cases of time ranges of the two events.

Whenever the time ranges were not available or did not overlap, the model of Bommer *et al.* (2009) was used to predict the 95%-of-Arias-intensity significant duration of the ground motion at 0 and 100 km from the fault rupture, using the largest of the two magnitude values, V_{s30} of 100 m/s (duration increases for decreasing values of V_{s30}), and 0 km depth to the top of the rupture (duration increases for decreasing values of depth). The choice of V_{s30} and depth to the top of rupture was made so as to obtain the largest possible values of duration, while the two distances of 0 and 100 km were selected as representing the duration right above the epicentre and at a large distance from it. Figure 2.21 illustrates the order of magnitude of significant durations that were obtained. The symbols Δt_0 and Δt_{100} are used in what follows to make reference to the significant duration values at 0 and 100 km, respectively. Both values were compared against the difference between origin time estimates of the two events (Δt) and used to define the criteria to identify duplicate events, as will be explained below.

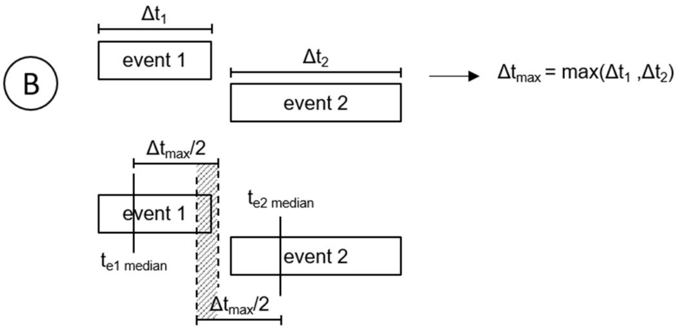


Figure 2.20. Case of overlap of time ranges of the two events under the assumption that the maximum variability of the two applies to both.

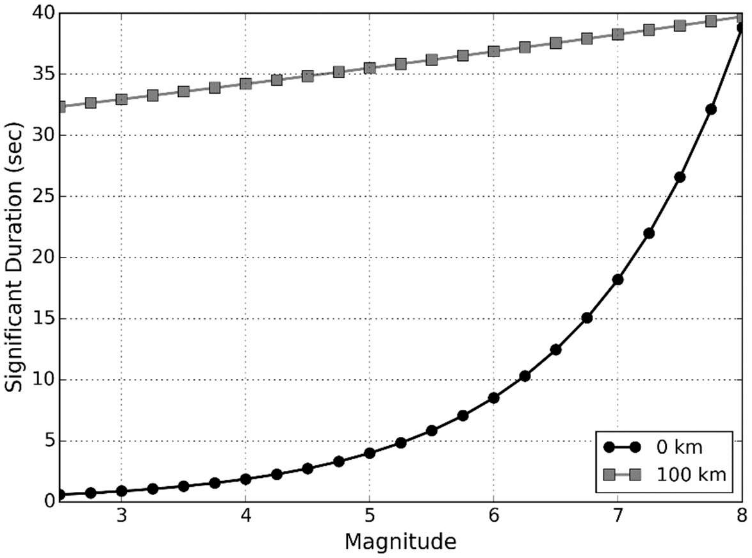


Figure 2.21. 95%-of-Arias significant duration predicted by the model of Bommer *et al.* (2009): Δt_0 (black line with circles) and Δt_{100} (grey line with squares) against magnitude, for V_{s30} of 100 m/s and 0 km depth to the top of the rupture.

When the time ranges of the two events overlapped in any of the ways described earlier, or the difference between the origin time estimates fell within the limits defined by Δt_0 and Δt_{100}, the final decision of whether the two events were the same or not was left in the hands of a series of three additional variables: the difference in magnitude, the distance between hypocentral coordinates, whether the two events had origin estimates by the same agencies or different ones, and whether one or both events had an estimate indicated as being the preferred solution for the ISC.

For events that have already been reviewed by the ISC (*i.e.* events older than 1st August 2014 at the time of elaborating this database), both events having a preferred solution (tagged as #PRIME in the ISC Bulletin) suggests that they both had a certain level of credibility as separate events, and was thus used as a hint against the possibility of the two being duplicates of each other. If, on the other hand, one of the events has a preferred solution and the other one does not, it is more likely that they are indeed the same event, and that the estimates from the event without a #PRIME solution are less reliable than those of the other one. This criterion could not be applied to events that do not belong to the reviewed period, as the #PRIME tagging is clearly done automatically. Moreover, it was observed that, within the 252 months being studied herein to make up the merged catalogue, 33 do not have any #PRIME indication (all 24 months of 2004 and 2005, and some months of 2001, 2002 and 2003). As the ISC expresses that, if an ISC solution is reported for an event, it is the prime solution, events with ISC solutions were considered as having prime solutions, irrespective of whether this was explicitly indicated or not. Events without ISC solutions and without #PRIME tagging were assumed to not have a prime solution, even though this might not be necessarily true for the 33 months identified above. No explanation could be found within the ISC website regarding a possible change in tagging criteria during these months.

The criterion regarding whether the two events had origin estimates by the same agencies or different ones was set after observing that pairs of events that were obviously the same earthquake usually contained estimates authored by different agencies. This is logical, as each agency would have detected the earthquake once, but then the grouping of data from different agencies to make up the ISC Bulletin would have ended up splitting the whole set in two. In view of this, the two events having estimates from different agencies was taken as a sign of them being a duplicate (when all other criteria was met as well).

The difference in magnitude was calculated as the absolute difference between the magnitude values used to characterise each event in the merged catalogue, that is, not considering all magnitude estimates, as this would be complex in terms of volumes of data and variety of magnitude scales used. It is noted that, while events taken directly from WPG16v3b have a moment magnitude estimate, events taken directly from the ISC Bulletin can have either $\mathbf{M}$, M_s or M_L, and the comparison carried out herein was carried out laying firmly on the assumption that $\mathbf{M}=M_s=M_L$ in the range of interest. The difference in magnitude $\Delta_{\mathbf{M}}$ so obtained was compared against a predefined threshold of 0.35 units. This threshold was selected by observing the standard deviations associated with the events in WPG16v3b for the period taken herein to compile the merged catalogue. As depicted in Figure 2.22 (note the logarithmic scale used for the vertical axis), an upper limit of 0.35 covers most of the events. While this is not conclusive in any way, it suggests that 0.35 might be a reasonable limit that allows for a plus/minus standard deviation in the magnitude estimates. Selection of larger values would increase the chances of concluding that two events are the same even when they are not.

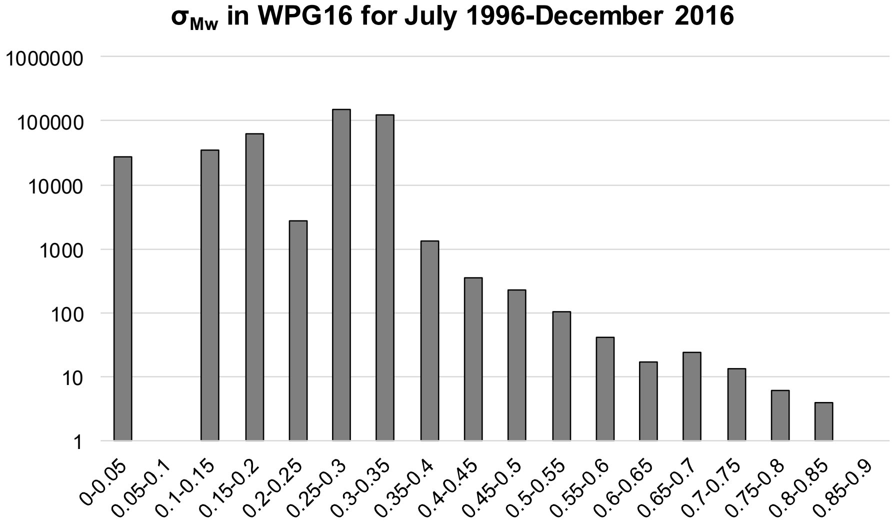


Figure 2.22. Standard deviation of moment magnitude estimates of events in the WPG16v3b world catalogue for the period comprising (and including) July 1996 through December 2016.

The proximity of the hypocentres in space was evaluated in relation with the declustering windows defined by Gardner & Knopoff (1974), Grünthal (van Stiphout *et al.*, 2012) and Uhrhammer (1986), as implemented in OpenQuake (Pagani *et al.*, 2014) (Figure 2.17). Using the maximum of the two magnitude values, the maximum and minimum distance windows were identified and labelled $D_{decl\ max}$ and $D_{decl\ min}$, respectively, and were used in combination with the other parameters to determine whether a pair of events was a case of duplication or not, as shown in Table 2.5. The three rows correspond to three possible cases related to time, while the three columns correspond to three possible cases in space. Within the former, Δt refers to the difference between the origin time estimates for the cases in which the events were not found in the ISC Bulletin, or those in which their time ranges did not overlap. If the time difference Δt was larger than Δt_{100} or if the distance between the two hypocentres **d** was larger than $D_{decl\ max}$, it was assumed that both events were independent, irrespective of the other parameters. If, on the other extreme, Δt was smaller than Δt_0 and the distance between the two hypocentres was smaller than $D_{decl\ min}$, the two events were assumed to be the same. In all other cases, namely, Δt falling between Δt_0 and Δt_{100} and **d** being smaller than $D_{decl\ max}$, or Δt being smaller than Δt_0 and **d** being larger than $D_{decl\ min}$ but smaller than $D_{decl\ max}$, a further check was carried out in terms of Δ_M and #PRIME tagging: if Δ_M was less than the 0.35 limit set earlier and at least one of the two events did not have a preferred (#PRIME) solution, then they were classified as being the same event, while if neither of these two criteria were fulfilled, they were kept as independent events.

Table 2.5. Criteria used to identify duplicate events.

<table>
<tr><th></th><th>$0 \leq d \leq D_{decl\ min}$</th><th>$D_{decl\ min} < d \leq D_{decl\ max}$</th><th>$d > D_{decl\ max}$</th></tr>
<tr><td>$0 \leq \Delta t \leq \Delta t_0$</td><td>duplicated</td><td>decide based on Δ_M and #PRIME</td><td rowspan="3">keep both</td></tr>
<tr><td>$\Delta t_0 < \Delta t \leq \Delta t_{100}$ or overlapping</td><td colspan="2">decide based on Δ_M and #PRIME</td></tr>
<tr><td>$\Delta t > \Delta t_{100}$</td><td colspan="2"></td></tr>
</table>

Once the decision regarding whether to keep both events or treat them as one has been made, the need to define which of the two to keep arises. The answer to this was tackled differently depending on the case. If the time range of event 2 was contained within that of event 1, event 1 was kept, while event 2 was kept when its time range contained that of event 1. If the two time ranges overlapped partially, or overlapped only once the maximum observed variability was applied to the two events (Figure 2.20), or the comparison was made in terms of predicted durations of ground motion, the following criteria were applied:

- If both events were in the WPG16v3b catalogue, the one whose agency had priority over the agency of the other according to the criteria established by Weatherill *et al.* (2016) was selected.
- If one event was in the WPG16v3b catalogue but the other one was not, the one from WPG16v3b was kept.
- If neither of the two were in the WPG16v3b catalogue, but both could be found in the ISC Bulletin, the following criteria were applied in sequential order:
    - If event 1 had a preferred (#PRIME) solution and event 2 did not, event 1 was kept.
    - If event 2 had a preferred (#PRIME) solution and event 1 did not, event 2 was kept.
    - If neither of the two conditions above were satisfied, the one with the largest number of estimates was kept.
    - If none of the above were satisfied, one of the two events was randomly selected.
- If neither of the two were in the WPG16v3b catalogue or the ISC Bulletin, one of the two events was randomly selected.

2.8. Resulting Database

The world catalogue of WPG16v3 contains 404,971 events in the period 1st July 1996 - 31st December 2016 (the last day included). Of these, 215 lack information on depth and were consequently discarded, though without major consequences to the database, given that all of them can be found in the ISC Bulletin and were treated in the same way as all other events that are not part of WPG16v3b (for more details, refer to Appendix I). Of the remaining 404,756, 67 were identified as either not existing anymore (3) or needing an update (64) from the ISC Bulletin, as per the procedure described in Section 2.7.4. These left 404,689 earthquakes to be taken directly from WPG16v3.

At the time of retrieving the information (25th August 2017), the ISC Bulletin contains 1,833,908 events satisfying the search criteria described in Section 2.6 for the period 1st July 1996 – 30th June 2017, 1,429,356 of which got classified as either not being in WPG16v3, or as required to update it. Of these, 712,071 ended up being added to those in WPG16v3, while the other 717,285 got discarded for lacking any origin and/or magnitude estimates that satisfy the criteria regarding magnitude scales, availability of depth information, and/or author being either a main global agency or a relevant local one.

The 404,689 events from WPG16v3b plus the 712,071 events added from the ISC Bulletin make up the merged catalogue of 1,116,760 events whose magnitude and depth distribution is shown in Figure 2.23. In order to understand the composition of the merged catalogue it is interesting to take a look at the same plot but with the events from WPG16v3b separated from those added from the ISC Bulletin. This is shown in Figure 2.24. From the plot on the left, it can be observed that WPG16v3b has its largest bulk of events in the range **M**4.5-5.0, while the number of events added from the ISC Bulletin decreases progressively as magnitude increases. Several points should be made in this respect. First, that the magnitude distribution of events of the merged catalogue is being influenced by the completeness of WPG16v3b. Second, that adding the events from the ISC Bulletin is not being able to sufficiently compensate this (reflected in the darker stripe of the range **M**4.5-5.0 being present in Figure 2.23), possibly due to the combined effect of the conversion of M_s and m_b into **M** to generate the WPG16v3b catalogue, and the addition of events with **M**, M_s and M_L from the ISC Bulletin without conversion. The plots on the right of Figures 2.4 and 2.5, which depict the conversion models used by Weatherill *et al.* (2016) to generate their catalogue, show that smaller numerical values of M_s and m_b become larger numerical values of **M**. If similar conversion equations were used on the events added from the ISC Bulletin, the distribution of magnitudes shown in Figure 2.24 (right) would likely shift slightly to higher values, its extent depending on the proportion of events with either of the three scales (**M**, M_s or M_L). This confirms what was stated in Section 2.5 (and explained by means of Figure 2.7) regarding the decision of not converting M_s into **M** being conservative, as a smaller number of events in the range **M**4.0-5.5 is finally selected thanks to this decision. Figures 2.23 and 2.24 illustrate as well the effects of considering local agencies and M_L in the elaboration of a world catalogue on its completeness.

While the discussion above is relevant to understand the origin of the data that will finally give rise to the final database, a series of modifications and filtering steps still followed. The two instances of earthquakes with magnitudes in the range 9.5-10.0 that can be observed in Figure 2.23 correspond to the two cases identified in Section 2.7.6, which were manually modified at this stage. The total number of events was reduced from 1,116,760 to 1,116,273 after identifying 487 duplicate events as per the procedure described in Section 2.7.7. Of these 487 cases, whose complete enumeration can be found in Appendix III, 44 correspond to the time period already covered by the Reviewed ISC Bulletin (pre-August 2014 in this work), while 443 correspond to events that have not been reviewed by the ISC yet. This significant larger number of unreviewed events was expected, as the grouping of data is carried out automatically before revision. 147 of the 443 pairs were identified using the duration-distance-Δ_M-prime criteria, and 340 were identified by means of the time range-distance-Δ_M-prime criteria (Figure 2.18).

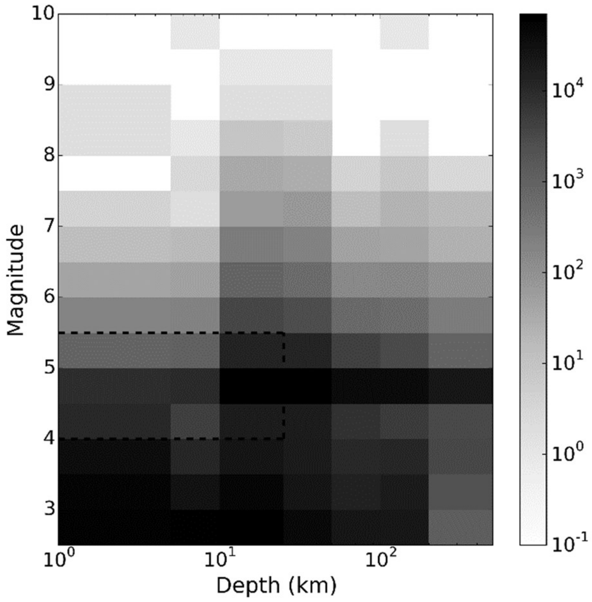


Figure 2.23. Magnitude-depth distribution of the 1,116,760 events in the merged catalogue, spanning from 1st July 1996 through 30th June 2017. Dashed lines enclose magnitude and depth range of interest. Grey scale indicates number of events.

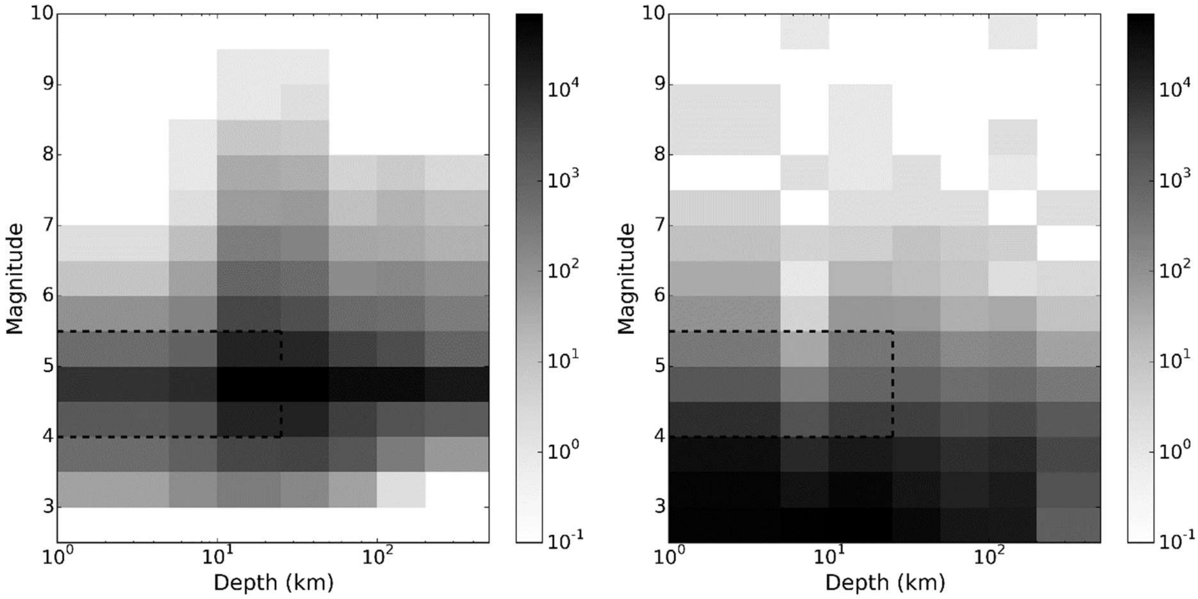


Figure 2.24. Magnitude-depth distribution of the 404,689 events from WPG16v3 (left) and the 712,071 events added from the ISC Bulletin (right), for the period spanning from 1st July 1996 through 30th June 2017. Dashed lines enclose magnitude and depth range of interest. Grey scale indicates number of events.

The 1,116,273 events of the merged catalogue were then declustered and filtered according to the magnitude-depth criteria defined in Table 2.1 and the final time interval of interest (1st July 1999 – 30th June 2014). Out of the 1,116,273 events, 871,169 corresponded to the time interval of interest. Of these, 62.7% lay outside the magnitude range of interest. Of the 324,578 events within the range **M**4.0-5.5, 68.8% were filtered out for not complying with the depth criteria defined in Table 2.1, representing a 25.6% of the total in the time interval of interest. After all this filtering, 101,248 events remained, 32,842 of which were classified as main shocks. Figure 2.25 shows this decomposition. Of all the events that occurred between 1st July 1999 and 30th June 2014, only 11.6% were kept. The percentage of events kept and discarded changes slightly by month, as shown in Figure 2.26. It is interesting to note that the percentage of events discarded for not complying with the depth criteria seems to decrease in time. It is possible that this be related to the USGS having changed their criteria to fix depths at 10.0 km instead of 33.0 km when the depth cannot be reliably computed, as explained in their website.

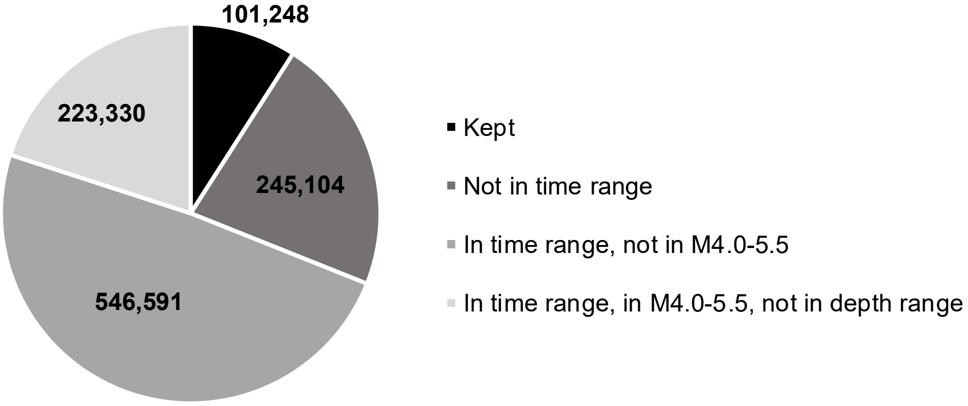


Figure 2.25. Filtering of the merged catalogue according to time interval of interest, magnitude and depth, but before applying exposure criteria. Foreshocks and aftershocks included.

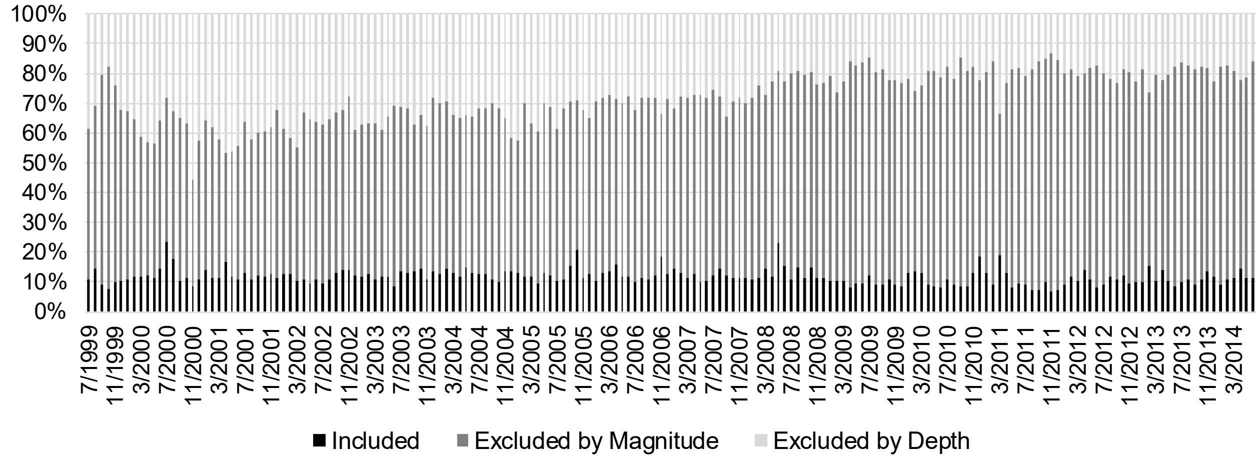


Figure 2.26. Proportion of events included (black), excluded by magnitude (dark grey) and excluded by depth (light grey) for each month in the final database (before applying exposure criteria).

88.1% of the 101,248 events from the filtered merged-catalogue were taken directly from WPG16v3b, while the remaining 11.9% were added from the ISC Bulletin. It is interesting to notice how the proportion changes after the filtering. When merging the catalogues, 36.2% corresponded to WPG16v3b events, while the remaining 63.8% were added from the ISC Bulletin. This change is due to the largest amount of added data corresponding to magnitudes below 4.0 that are not considered to build the final database. Figure 2.27 shows that the proportion of events taken from each source stays, in general, relatively stable in time. A more detailed decomposition of the sources of the events in the filtered merged catalogue at this stage is shown in Table 2.6, and their location is depicted in Figure 2.28. Flagging of induced events was carried out as described in Section 2.7.5.

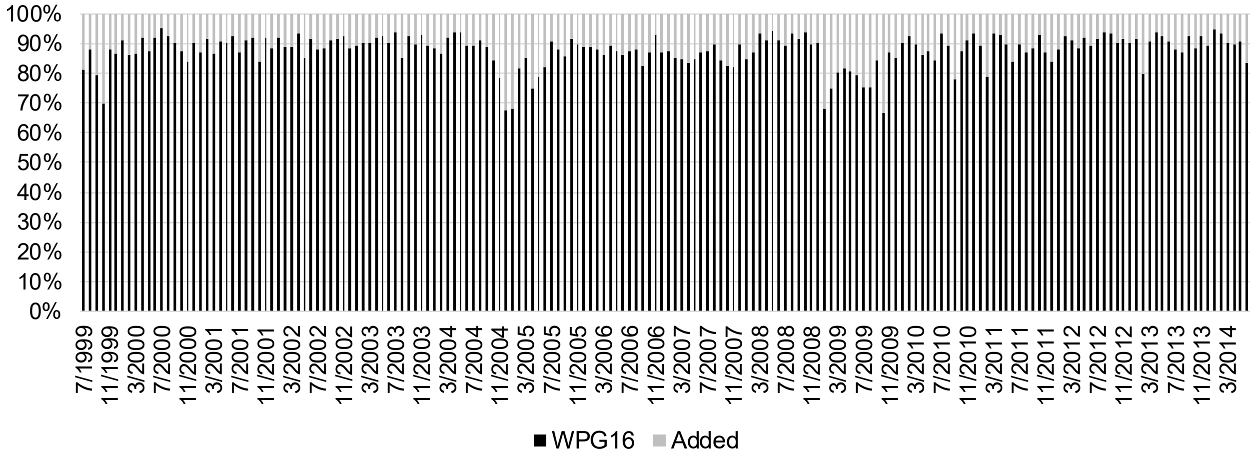


Figure 2.27. Proportion of events taken from WPG16v3b (black) and the ISC Bulletin (light grey) for each month in the final database (before applying exposure criteria).

Table 2.6. Number of events in the database for the period 01/07/1999-30/06/2014, with 4.0≤**M**≤5.5, and depths constrained by Table 2.1. Percentages make reference to the total 101,248 (All Events) and 32,842 (Only Mainshocks) events.

Source	**Induced**	**All Events**		**Only Mainshocks**	
		Number	**%**	**Number**	**%**
WPG16v3b	Induced	359	0.35%	81	0.25%
	Not Induced	88,806	87.71%	27,977	85.19%
	Not Classified	53	0.05%	32	0.10%
ISC Bulletin	Induced	15	0.01%	7	0.02%
	Not Induced	12,015	11.87%	4,745	14.45%
Total		101,248	-	32,842	-

Having defined the database of upper crustal events of magnitude **M**4.0-5.5 for the time period of interest, the final step for the building of the database was to establish which of these events occurred sufficiently close to the population and the built environment to pose a threat, which was done according to the procedure described in Section 2.2. As shown in Table 2.7, the total number of events reduced from 101,248 to 35,654, that is, to around one third. Similarly, the subset of main shocks reduced from 32,842 to 11,968. Figure 2.29 shows that a large number of the events that were rejected according to the exposure criterion occurred within seas and oceans, as would be expected. Figures 2.30 and 2.31 show the events that make up the final database, separated into main shocks, in the former, and fore- and aftershocks, in the latter.

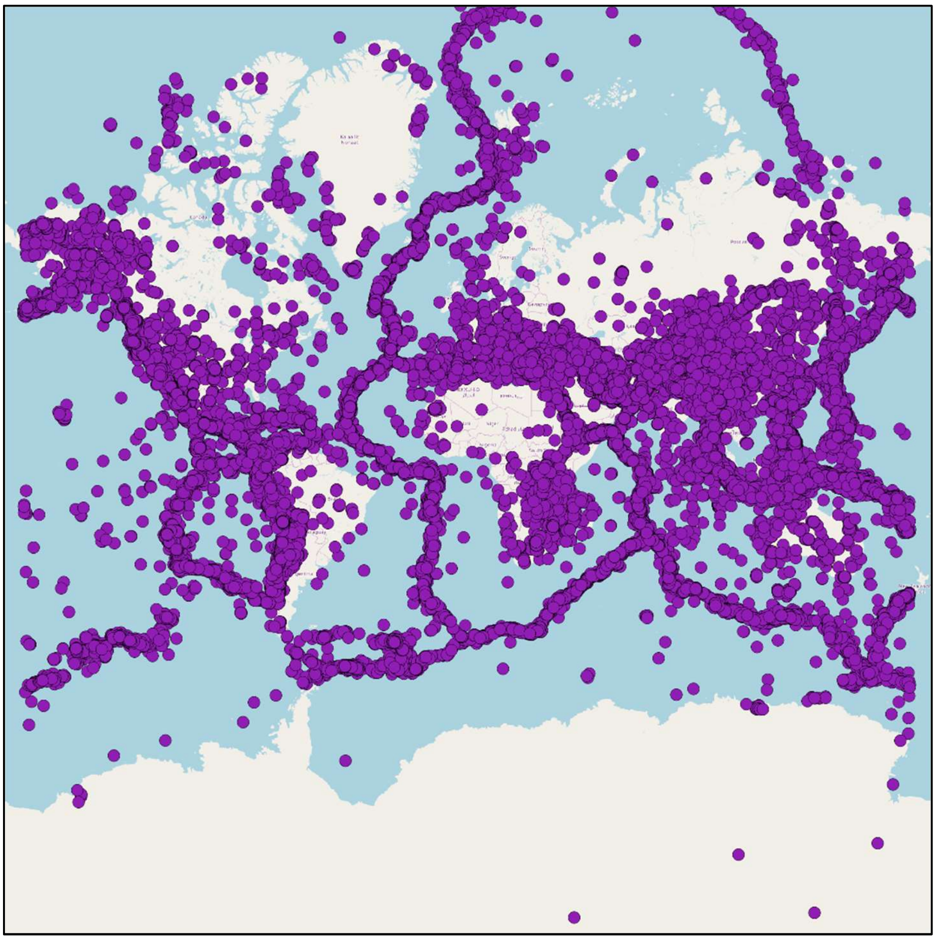


Figure 2.28. Database of 101,248 events obtained for the period 01/07/1999-30/06/2014, with 4.0≤**M**≤5.5, and depths constrained by Table 2.1.

Table 2.7. Number of events in the database for the period 01/07/1999-30/06/2014, with 4.0≤**M**≤5.5, depths constrained by Table 2.1, and either maximum population density greater than 300 people/km^2 or cumulative population count larger than 2,500 people in areas with MMI≥IV. Percentages make reference to the total 35,654 and 11,968 events.

Source	**Induced**	**All Events**		**Only Mainshocks**	
		Number	**%**	**Number**	**%**
WPG16v3b	Induced	355	1.00%	78	0.65%
	Not Induced	31,676	88.84%	10,460	87.40%
	Not Classified	4	0.01%	4	0.03%
ISC Bulletin	Induced	14	0.04%	7	0.06%
	Not Induced	3,605	10.11%	1,419	11.86%
Total		35,654	-	11,968	-

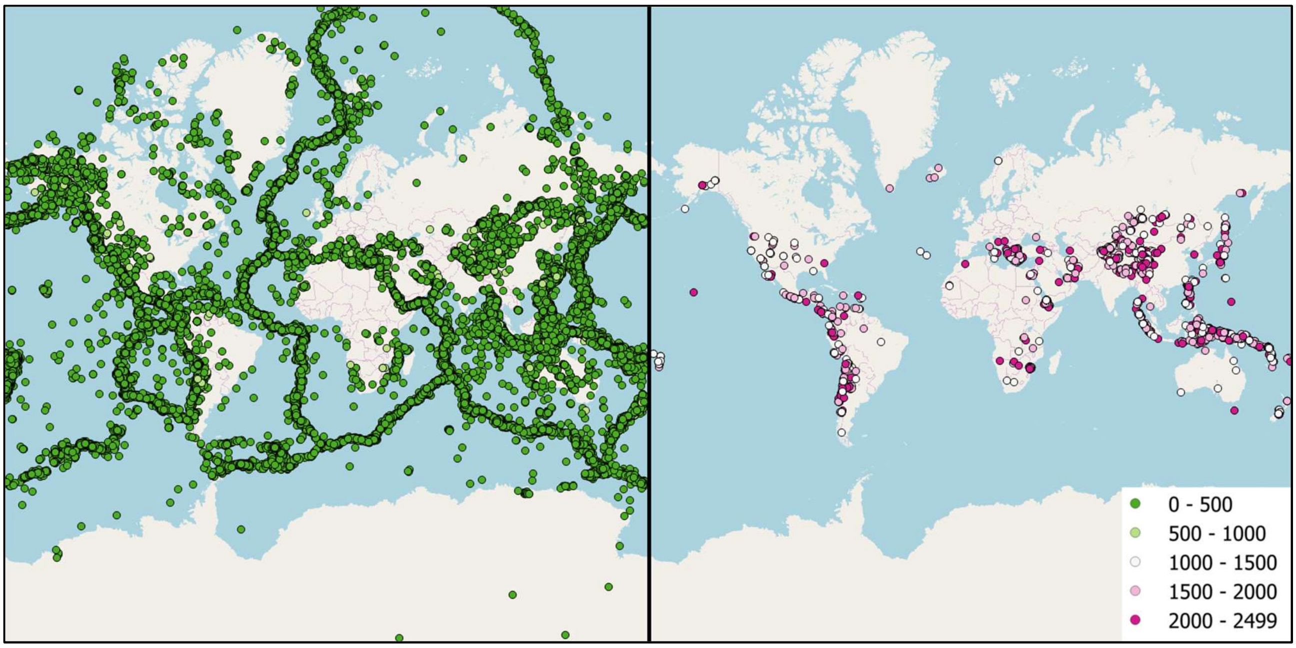


Figure 2.29. Events of the world catalogue of Figure 2.28 that do not satisfy the population exposure criteria. Colour scale depicts total number of people exposed to MMI≥IV. Left: less than 1,000 people. Right: more than 1,000 people but less than 2,500 people.

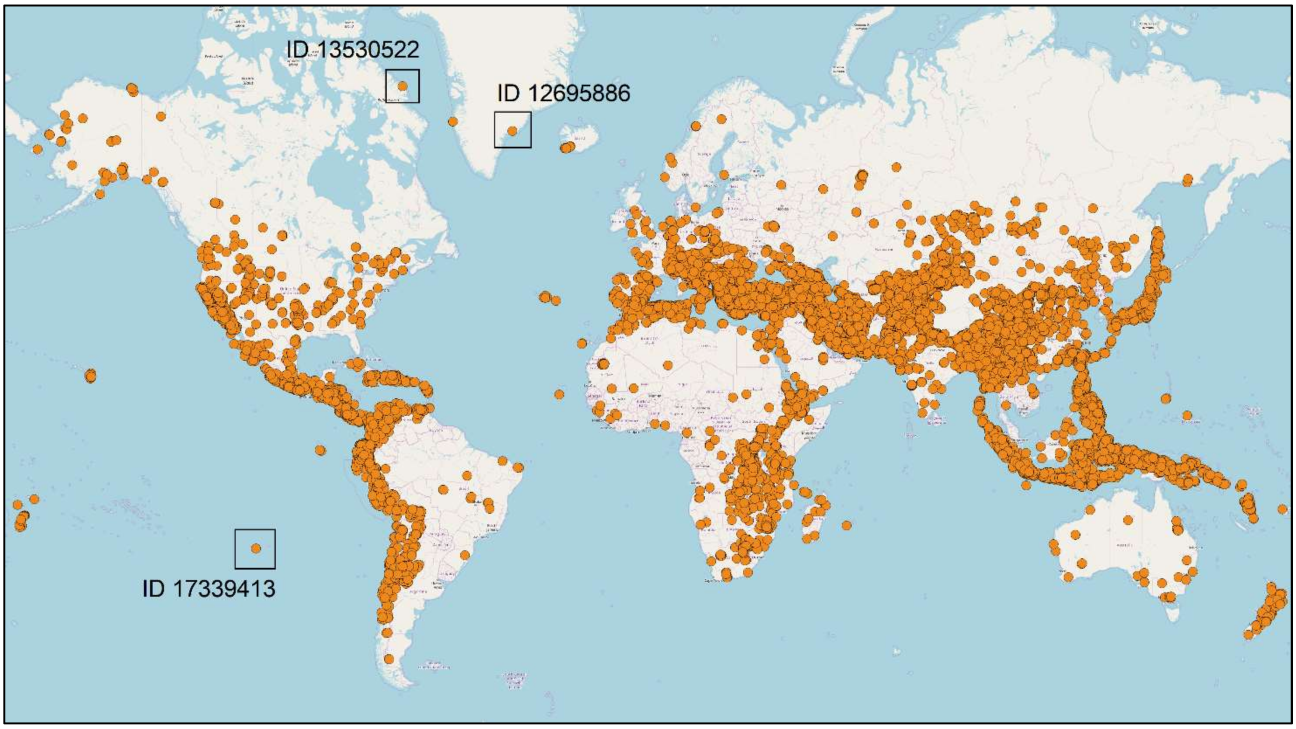


Figure 2.30. The 11,968 mainshocks of the database for the period 01/07/1999-30/06/2014, with 4.0≤**M**≤5.5, depths constrained by Table 2.1, and either maximum population density greater than 300 people/km^2 or cumulative population count larger than 2,500 people in areas with MMI≥IV. The three events marked are used as examples in Figure 2.32.

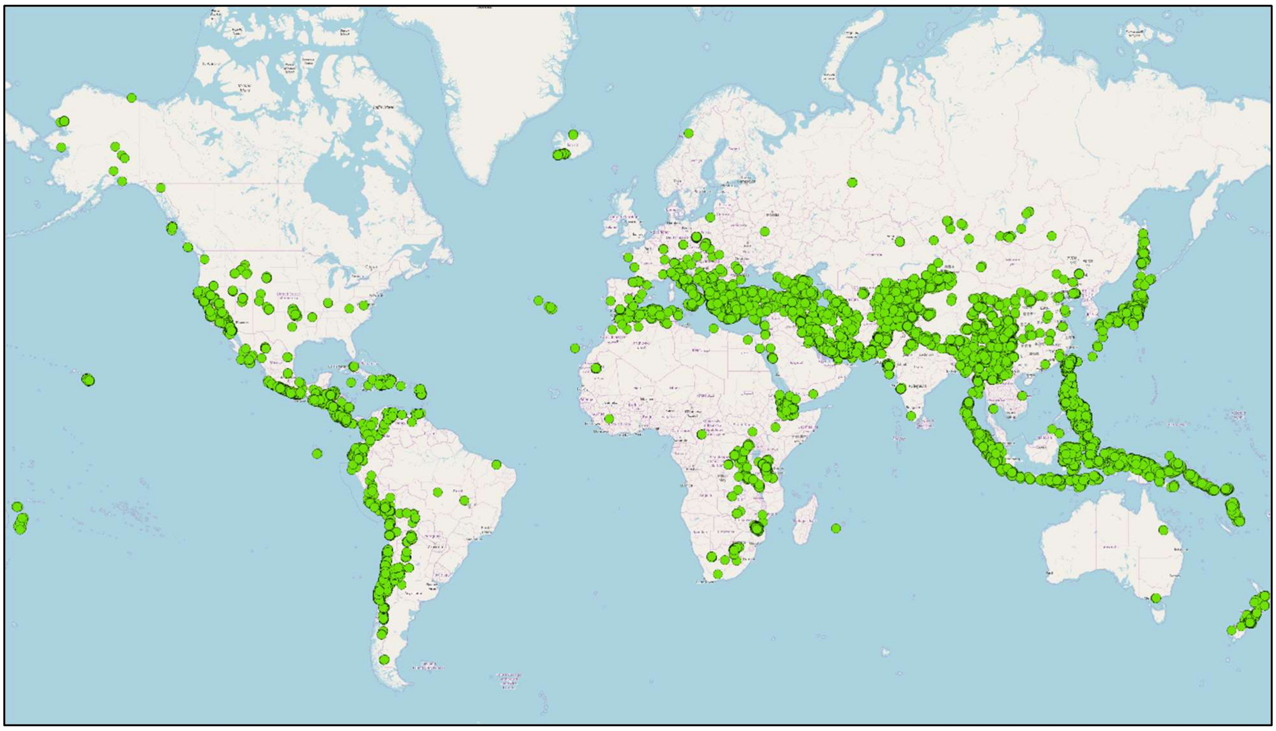


Figure 2.31. The 23,687 foreshocks and aftershocks of the database for the period 01/07/1999-30/06/2014, with 4.0≤**M**≤5.5, depths constrained by Table 2.1, and either maximum population density greater than 300 people/km^2 or cumulative population count larger than 2,500 people in areas with MMI≥IV.

While earthquakes coinciding with seas and oceans were expected to be filtered out of the catalogue, the presence of some of the events of the final database can be surprising. Three examples of such events are marked in Figure 2.30. They can call the reader's attention for being located in remote areas but still complying with the exposure criterion. Figure 2.32 demonstrates that their inclusion in the database is no error, but simply a consequence of them being borderline cases. In the case of ID 13530522, in northern Canada, the total population count is 858 people, clearly below the 2,500 people threshold, but the maximum density is 1,146 people/km^2, significantly above the 300 people/km^2 threshold, albeit being extremely localised, as shown in Figure 2.32 (left). The situation is very similar to that of ID 12695886, in Greenland (Figure 2.32, centre). For ID 17339413, near Easter Island, the situation is the opposite, as the maximum density is 33 people/km^2 and does not overcome the threshold, while the total count of population exposed is 5,514.

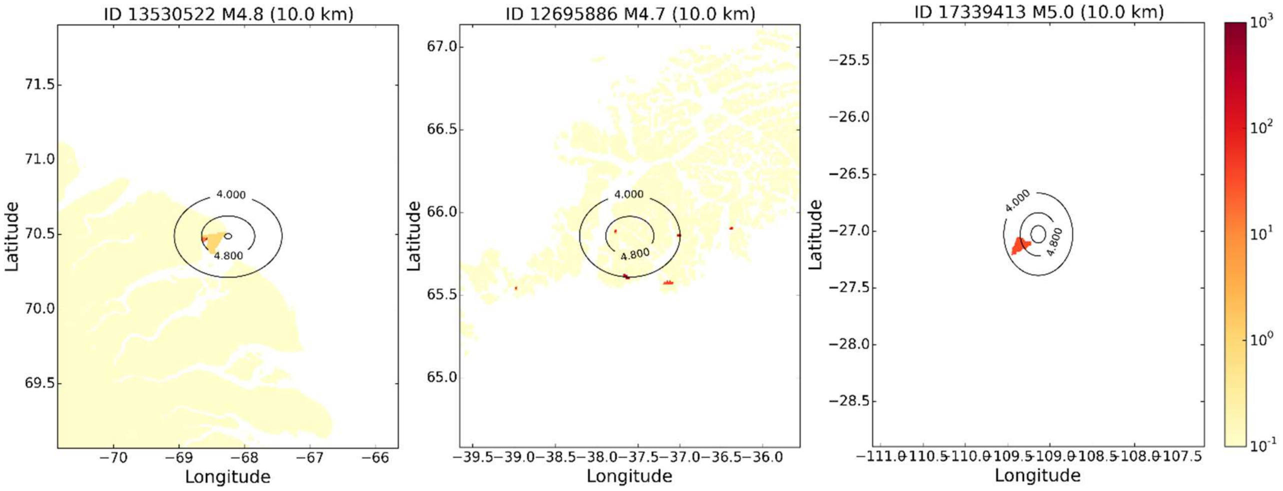


Figure 2.32. Contour lines of MMI values predicted with the model of Allen *et al.* (2012) for three earthquakes taken as examples. Background colour scale indicates population density in people per square kilometre (data from GPW v4.0, CIESIN, 2016).

3. WORLD DATABASE OF SMALL-TO-MEDIUM MAGNITUDE EVENTS WITH CONSEQUENCES FOR THE POPULATION

3.1. Description and Methodology

The compilation of a database of crustal small-to-medium magnitude earthquakes carried out in the previous chapter would be meaningless if it was not possible to know which of those events caused casualties and/or damage to the built environment. For this reason, a fundamental part of this work consisted on the generation of a database of small-to-medium magnitude events that have been reported to have consequences for the population.

It could be thought that the natural procedure for the generation of this second database would be to go one by one the events identified in Chapter 2 and assess whether reports for damage or casualties exist for each of them. However, there are two main reasons for which this may not be the most efficient strategy. Firstly, because the number of events identified in the previous chapter for the time interval of interest is very large. Secondly, because the 11,968 main shocks or the 35,654 total events have undergone two filtering processes, one based on depth and magnitude, and the other based on an estimation of the population exposed. Several points should be made with respect to the latter. While the criteria used to define which events are kept and which events are discarded have been defined rationally, they are still, to a certain extent, arbitrary. The hypothetical example of keeping a **M**5.1 at 24 km depth but discarding a **M**5.1 at 26 km depth exemplifies the issue. Moreover, depth is the most difficult parameter to constrain of an earthquake, and is thus linked to a large uncertainty. It is possible that the **M**5.1 at 26 km depth event may have been located at 18 km, and the **M**5.1 at 24 km occurred, in fact, at 32 km instead. With this in mind, the most logical thing would be not to focus on the final 11,968 or 35,654 events, but to consider all 871,169 events in the time interval of interest. Going back to the first point, going one by one 871,169 events is, undoubtedly, a colossal task.

For these reasons, the database of earthquakes with consequences for the population was compiled from various sources that report on earthquake damage and casualties, and the events were later reconciled with their corresponding entries in the database of Chapter 2. The main sources of information for this endeavour were the following:

- The International Events Database (referred to as well as the Emergency Events Database) of the Université Catholique de Louvain, Belgium (EM-DAT in what follows).
- The Signigicant Earthquake Database of the National Centers for Environmental Information of the National Oceanic and Atmospheric Administration (NOAA) of the United States (NOAA in what follows).
- The EXPO-CAT catalogue of human population exposure and the PAGER-CAT losses database of Allen *et al.* (2009).
- The earthquake catalogue of the United States Geological Survey (USGS).
- The ISC Bulletin.
- Earthquake-Report.com and its associated Damaging Earthquakes Reports.

- Scientific journal papers and reports.
- ReliefWeb, the digital service of the United Nations Office for the Coordination of Humanitarian Affairs (OCHA).
- Online newspapers and news agencies.
- Online blogs, personal websites, etc.

The range of magnitudes of interest was, of course, the same as in Chapter 2, that is, **M**4.0-5.5. However, given that in many of the sources it is not clear what kind of magnitude is being reported, and there is variability in the magnitude estimates made by different authors/agencies even when using the same scale, the limits were made flexible during the compilation phase. Then, if more reliable information was found and the magnitude was clearly outside of the **M**4.0-5.5 range for some events, they were eliminated. Magnitudes close to the lower and upper bounds (*e.g.*, **M**3.8, **M**5.6) were kept, as the final magnitude-range filtering was carried out in terms of the magnitude and depth values contained in the world database of crustal earthquakes of Chapter 2. Following a similar logic, location and magnitude values were usually retrieved from the USGS catalogue, the ISC Bulletin or relevant local agencies if readily available, as the final values would still correspond to those defined in Chapter 2.

In order to include an event in the database, at least one of the following criteria had to be met:

- At least one death or serious injury.
- At least five slightly injured.
- At least one building with major damage.
- Damaged infrastructure.
- At least five buildings with minor damage.
- Reports exist of damage claims in terms of money (of at least a few thousand USD).
- Reports exist of economic losses (measured or estimated).

As in many cases it is difficult to find exact numbers, expressions such as “some” and “a few” in reference to damaged/destroyed buildings or casualties were considered enough to include the event as well. The event could be later excluded if:

- It was part of an earthquake series with any shocks above **M**5.5 and it is not unambiguously clear which shocks caused the reported damage.
- The damage and/or casualties were not a direct or indirect result of the earthquake. For example, explosions and mine collapses get often reported as earthquakes, and the casualties and losses related to them are usually a consequence of the explosion or the collapse itself and not of the earthquake that followed. These cases were excluded. However, if the earthquake was the cause of the damage, even if one of the consequences was the collapse of a mine, then it was included. Cases in which the damage or casualties were due to phenomena triggered by the earthquakes (*e.g.*, landslides) were included.

Regarding the first exclusion criterion, it is noted that it can also happen that an earthquake is part of a series for which all the shocks are smaller than **M**5.5 and it might still not be clear how the damage evolved with the different shocks. Whenever situations like this have been identified, note has been taken that the consequences might refer to more than one event.

The kind of information that was sought for the compilation of the database was the following:

- City/province/state/small administrative subdivision, Country and Region in which the event occurred and/or where the consequences were observed.
- Date and time (UTC) of occurrence.
- Hypocentral coordinates (latitude, longitude, depth).
- Magnitude: **M**, M_L, m_b and/or M_s.
- Whether the event was part of a seismic series/swarm.
- Maximum intensity (MMI).
- Focal mechanism.
- Nature of the event (induced or tectonic).
- Population exposed to the ground shaking.
- Total number of people affected.
- Total number of deaths.
- Number of deaths due to shaking.
- Number of injured people.
- Number of homeless, evacuated, trapped and/or missing.
- Causes of death and/or injury.
- Number of damaged buildings.
- Number of destroyed buildings.
- Whether the infrastructure was affected or not.
- Maximum peak ground acceleration.
- Occurrence of landslides and/or liquefaction.
- Monetary losses.

Information regarding the consequences of small-to-medium magnitude earthquakes is often scarce and even contradictory. It is common to find events listed in databases like NOAA for which only a general estimation of monetary losses exist, and to not be able to find any specific information regarding the damage or the casualties. It has been observed as well that, sometimes, this information only exists in the local language (this has been observed for events occurring in countries whose language is known to the authors of this work, and is thus inferred that it also happens in languages outside our area of expertise). In view of this, the list above reflects what was aimed at, but does not mean that all that information is readily available for all, or even for most, events.

Estimations of monetary losses are often the hardest to find. Real reported values are rare, and availability of this information often reduces to either estimations reported by government officials to the media or estimations found in databases like EM-DAT or NOAA.

The latter are usually available in terms of broad ranges that are assigned based on a system to translate a description of damage into monetary terms. NOAA, for example, defines five different levels for economic losses: none, limited (less than 1 million USD), moderate (between 1 and 5 million USD), severe (between 5 and 24 million USD) and extreme (25 million USD or more). Whenever a better estimate was not found and the event had an estimate range in NOAA, the whole range was noted. If an independent, seemingly more precise estimate that lay within the range, the independent estimate was noted.

While it is usually more common to find reports of number of buildings damaged or destroyed than it is to find the equivalent monetary loss, there are many cases in which losses databases provide numbers of buildings in terms of ranges as well. For example, NOAA defines the following: none, 1-50, 50-100, 100-1,000, and more than 1,000. There are also many cases in which this information is not available and all there is are verbal descriptions from the USGS catalogue or online media reporting “a few buildings”, “some buildings”, “several buildings” damaged. In many cases, the phrase “damaged or destroyed” is used, so it is not clear what proportion of the total number or description corresponds to one or the other. Moreover, many cases have been observed in the NOAA database in which a non-generic (*e.g.*, something like 123, and not 100) number of damaged and destroyed buildings is provided, and it is exactly the same for both. This suggests that it is possible that the original source used by NOAA reported a number of “damaged or destroyed” buildings, without further specifications. In many other cases, descriptions are only limited to phrases like “slight” damage, without any hint of the number of buildings involved. Conversion of terms into numbers has not been attempted at this stage, so whenever information like this was found it was reported in the same way in the database.

Similar inaccuracies can be found in the reporting of deaths and injuries. The distinction between deaths and injuries due to ground shaking and those due to causes like heart attacks or panic reactions to the earthquake cannot always be found. Whenever a cause was identified, it was reported in the database.

It was noted that, many times, the number of homeless or evacuated coincides with the number of damaged or destroyed buildings, as if the assumption of one person per building had been made. If the information was reported under the titles “homeless” or “evacuated”, it was kept, but no inference was made when only information regarding the number of damaged or destroyed buildings was available. The purpose of this was to be as clear as possible regarding the kind of information that is available in the sources. If there was a certain number of destroyed buildings, then it is quite reasonable to think that there was also a certain number of people left homeless, but the readers can easily make these inferences on their own. Moreover, carrying out an estimation of number of homeless or evacuated based on the number of buildings reported to be damaged or destroyed entails making a series of assumptions regarding the building typologies, the number of dwellings per building, and the number of people per welling. In many sources, a damaged building can be a one-family house, a 3-storey building, or a 20-storey building, the occupancy of which are very different from one another. Most of the times, this information is not readily available, and its estimation from global sources like the PAGER Inventory Database (Jaiswal & Wald, 2008) would be an immense task of its own.

The compilation of information regarding the total number of affected people was carried out along these same lines. It could be thought that a number could be estimated from the number of deaths, injuries, homeless, etc. However, the number of evacuated, homeless, trapped, missing and injured can overlap, and an estimation of this kind can prove meaningless. It has been observed, however, that the total number of affected people reported in EM-DAT does correspond to the sum of number of injured, number of homeless and number of affected. The criterion followed herein was that if a source explicitly reported a "number of affected people", it was then noted as such in the database, but no calculations were made when this was not the case. The reason for doing this is that, in many cases, the source for the total number of affected people is newspapers and online reports that do not specify what this number specifically refers to, as they may just say "this earthquake affected over 1,000 people". In order to be as flexible as possible with the sources, numbers were thus included as found reported, the only exception to these being the events that have been studied in detail as part of the separate report by Nievas *et al*. (2018), as the amount of information collected allowed for some well-informed estimations to be made.

The number of people exposed to the shaking followed a similar logic. Whenever a number reported directly as "exposed population" was found, it was directly included. However, most of the times this data was obtained from EXPO-CAT (Allen *et al*., 2009) as the sum of the estimation of number of people exposed to MMI values of IV and above, which is what said source reports. These values are estimations obtained by combining the information regarding macroseismic intensities from USGS ShakeMaps of the events with Landscan 2006 (Dobson *et al*., 2000; Bhaduri *et al*., 2002), a global population database. As such, they are conceptually similar to what has been done herein in Chapter 2, though ShakeMaps are expected to be better estimations of macroseismic intensity than the use of one intensity prediction equation.

The maximum MMI and peak ground acceleration values gathered in the database correspond to values reported as part of detailed studies or observations, when available, ShakeMaps, or Did You Feel It data (when applicable). The soundness of these sources is clearly different, and detailed studies or observations were preferred over the rest. However, just like with all other data related to small-to-medium magnitude events, the latter are rare.

While a conscious effort was made to discard unreliable sources and make rational decisions in the face of contradictions, it is, in general, very difficult to judge which source is more or less trustworthy than the others for each particular earthquake. It is noted that the main sources of information have been EM-DAT, NOAA, EXPO-CAT, PAGER-CAT, the USGS catalogue, and the ISC Bulletin, and other online sources have been used in a smaller number of cases.

3.2. Resulting Database

The database of shallow crustal small-to-medium magnitude events that have caused damage and/or casualties in the period 1st July 1999 – 30th June 2014 is made up of 412 events, whose location is depicted in the map of Figure 3.1. The complete list, subdivided into three categories that result from the analysis presented in Chapter 4, can be found in Appendix IV. As the compilation of this database is still work in progress, consequences are expressed in Appendix IV in qualitative rather than quantitative terms.

Figure 3.1. World database of small-to-medium magnitude earthquakes with consequences for the population or the built environment, for the period 1st July 1999 – 30th June 2014.

Within these 412 events, there are 17 for which analysis of the sources suggests that reports on damage and/or casualties may refer to more than one event. Of these, four correspond to either foreshocks or aftershocks whose consequences may include those of the main shock, though the sources suggest as well that these events caused damage of their own. The remaining 13 correspond to cases of series of earthquakes or mainshocks whose consequences include those of fore- or aftershocks. Additionally, there are four events for which the description of their consequences includes the phrase “Additional damage to…”, making reference to the damaged caused previously by an earthquake earlier in the sequence. These numbers are the ones that have been noted down, but it does not imply that it is clear that the consequences listed for all the other earthquakes belong only to themselves.

Having identified some of these events, there is the temptation of adding a certain number to the number of events with consequences. However, one should also wonder up to what extent the damage kept on building up over structures weakened by the previous shocks. It may not be fair to conclude that each shock individually could have caused a similar amount of damage on its own. If each shock could be applied to a hypothetical set of buildings that reset themselves to undamaged state each time, it is quite likely that the consequences would be less than those of the complete real series. For this reason, no direct attempt of adding a number of damaging events was done at this stage, though this analysis will be considered later in Section 4.2.

It is noted, once more, that the numerous challenges associated with compiling a database of this kind, imply that it is unlikely that the list contains all events that have caused damage or casualties in the time interval of interest. Whether events end up being included in the database or not depends not only on their actual consequences but also on what has been reported, the language in which it has been reported, and how accessible these reports are to the general public. As will be discussed in Chapter 4, this is strongly dependent as well on the seismicity of the area and the perception of seismic hazard by the population, as areas that are used to constant ground shaking are less likely to report on the small non-structural damage caused by a weak event.

4. STATISTICAL ANALYSIS AND DISCUSSION

4.1. Identification of the Earthquakes with Consequences within the General Database

As explained in the previous chapters, the generation of the world database of crustal small-to-medium magnitude earthquakes and the world database of crustal small-to-medium magnitude earthquakes with consequences for the population was carried out in parallel. This implied that, at a certain point in the process, the two needed to be confronted in order to identify the latter within the former. When doing so, the following outcome emerged:

- 282 out of the 412 damaging events were directly identified in the final filtered database of crustal small-to-medium magnitude earthquakes (*i.e.* within the 35,654 events of Table 2.7);
- 122 out of the 412 damaging events were not part of the final filtered database composed of 35,654 events because their magnitude-depth combinations did not comply with the criteria set in Table 2.1;
- 5 out of the 412 damaging events were not part of the final filtered database composed of 35,654 events because they did not pass the exposure criterion described in Section 2.2, though their magnitude-depth combinations did comply with the criteria set in Table 2.1;
- 3 out of the 412 damaging events could not be found in the broader unfiltered merged catalogue at all.

The complete listings of each of these groups can be found in Appendix IV, while their characteristics are discussed herein.

4.1.1. Events Not Complying with the Magnitude-Depth Criterion

The criterion set up by Table 2.1 entails the possibility that earthquakes that caused damage or casualties get excluded of the database for two reasons. Firstly, because of the inherent arbitrariness of keeping a **M**4.3 earthquake with a 15 km depth and discarding a **M**4.3 one with a 15.1 km depth. Secondly, because depth is one of the most difficult parameters to constrain, and the uncertainty associated with either 15 or 15.1 km in the previous example is usually large.

Due to this, there are 122 events that make up the database of earthquakes with consequences to the population that are not part of the general database of crustal earthquakes once it is filtered according to the criterion of Table 2.1. Their magnitudes and depth, as they appear in the world database defined in Chapter 2, are depicted in Figure 4.1 (left), together with the limits set by Table 2.1. There can be several reasons for these 122 earthquakes to have been identified as damaging but getting discarded due to their magnitude-depth ranges:

- The final magnitude value is out of the **M**4.0-5.5 range.

- The magnitude-depth criterion is being applied to the magnitude and depth selected for each earthquake in the compilation of the world database of crustal small-to-medium magnitude events. There could be other depth estimations for the same earthquake that satisfy the criterion.
- No agency has been able to produce an accurate depth estimation due to the poor quality of the available waveforms or their scarcity and, thus, the depth is probably wrong.
- The earthquake may have not been actually damaging and its presence in the sources used to compile the database in Chapter 3 was an error.
- The use of a rigid boundary to define the depth limits in Table 2.1 makes depth estimations that can be 0.1 km apart fall on different sides of the selection (the 15 versus 15.1 km example above).

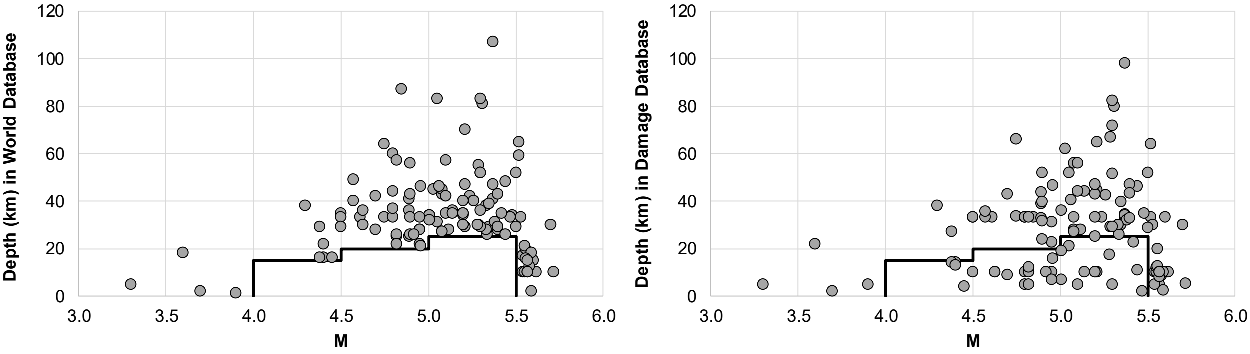
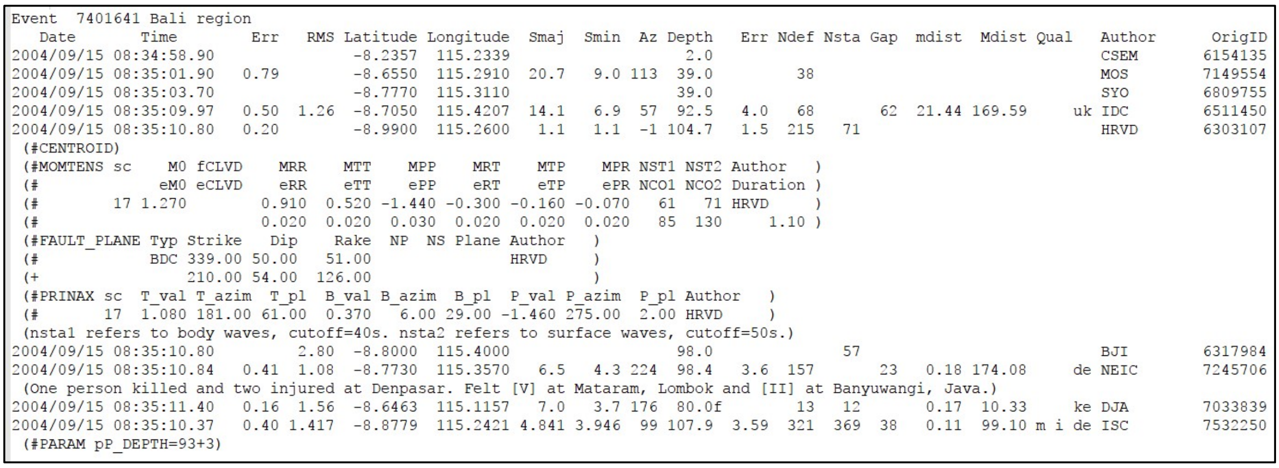


Figure 4.1. Magnitude and depth of the damaging events that do not pass the magnitude-depth criterion of Table 2.1 (continuous black line): depth as in the world database of crustal **M**4.0-5.5 events (left) and depth as collected for the world database of damaging events (right).

Regarding the first point, within these 122 earthquakes there are 4 cases with magnitude smaller than **M**4.0, and 20 cases with magnitude larger than **M**5.5. As explained in Section 3.1, events with smaller and larger magnitudes were included in the database of earthquakes with consequences for the population, so as to make sure that the filtering was carried out in terms of the magnitude values selected in Chapter 2. This means that only the remaining 98 cases correspond to earthquakes whose magnitude belongs to the **M**4.0-5.5 range, but whose depth does not comply with the criterion defined in Table 2.1.

An example of an event for which a different depth could have been selected is the **M**5.4 Denpasar (Indonesia) earthquake of 15th September 2004, which is event 7401641 in the ISC Bulletin and has entered the world catalogue with a depth of 107 km. As shown in Figure 4.2, the difference between depth estimations from different agencies is colossal, and the range goes from 2 km all the way through 107.9. As has been explained before, determining which of the estimations is the best is not trivial, and even less so is determining if any of the estimations is good at all. It is noted that, of all the depth estimations shown in Figure 4.2, only the 2-km one would have avoided this earthquake to be discarded. However, taking a look at the range of depth estimations, the 2-km one seems unlikely.



```
Event  7401641 Bali region
   Date       Time        Err   RMS Latitude Longitude  Smaj  Smin  Az Depth   Err Ndef Nsta Gap  mdist  Mdist Qual   Author      OrigID
2004/09/15 08:34:58.90               -8.2357  115.2339                   2.0                                          CSEM       6154135
2004/09/15 08:35:01.90   0.79        -8.6550  115.2910  20.7   9.0 113  39.0         38                               MOS        7149554
2004/09/15 08:35:03.70               -8.7770  115.3110                  39.0                                          SYO        6809755
2004/09/15 08:35:09.97   0.50  1.26  -8.7050  115.4207  14.1   6.9  57  92.5   4.0   68       62  21.44 169.59     uk IDC        6511450
2004/09/15 08:35:10.80   0.20        -8.9900  115.2600   1.1   1.1  -1 104.7   1.5  215   71                          HRVD       6303107
 (#CENTROID)
 (#MOMTENS sc    M0 fCLVD    MRR    MTT    MPP    MRT    MTP    MPR NST1 NST2 Author   )
 (#             eM0 eCLVD    eRR    eTT    ePP    eRT    eTP    ePR NCO1 NCO2 Duration )
 (#       17 1.270         0.910  0.520 -1.440 -0.300 -0.160 -0.070   61   71 HRVD     )
 (#                        0.020  0.020  0.030  0.020  0.020  0.020   85  130     1.10 )
 (#FAULT_PLANE Typ Strike   Dip    Rake  NP  NS Plane Author   )
 (#            BDC 339.00 50.00   51.00                HRVD     )
 (+                210.00 54.00  126.00                         )
 (#PRINAX sc  T_val T_azim  T_pl  B_val B_azim  B_pl  P_val P_azim  P_pl Author   )
 (#       17  1.080 181.00 61.00  0.370   6.00 29.00 -1.460 275.00  2.00 HRVD     )
 (nsta1 refers to body waves, cutoff=40s. nsta2 refers to surface waves, cutoff=50s.)
2004/09/15 08:35:10.80         2.80  -8.8000  115.4000                  98.0              57                          BJI        6317984
2004/09/15 08:35:10.84   0.41  1.08  -8.7730  115.3570   6.5   4.3 224  98.4   3.6  157       23   0.18 174.08     de NEIC       7245706
 (One person killed and two injured at Denpasar. Felt [V] at Mataram, Lombok and [II] at Banyuwangi, Java.)
2004/09/15 08:35:11.40   0.16  1.56  -8.6463  115.1157   7.0   3.7 176  80.0f        13   12        0.17  10.33     ke DJA        7033839
2004/09/15 08:35:10.37   0.40 1.417  -8.8779  115.2421 4.841 3.946  99 107.9  3.59  321  369   38   0.11  99.10 m i de ISC        7532250
 (#PARAM pP_DEPTH=93+3)
```

Figure 4.2. The **M**5.4 Denpasar (Indonesia) earthquake of 15th September 2004 in the ISC Bulletin.

Figure 4.3. Earthquakes for which damage or casualties are recorded, but that do not pass the depth-magnitude criterion of Table 2.1. Events marked in yellow would pass the criterion if the depth used to characterise them had been that adopted in the database of earthquakes with consequences instead of the database of crustal earthquakes.

Figure 4.1 (right) shows the depths with which the 122 out-of-range events are characterised in the database of earthquakes with consequences. The 30 events shown in yellow on the map of Figure 4.3 would not be discarded according to the magnitude-depth criterion if these depths had been used instead, though this does not mean that they would have passed the exposure criterion. Why were these depths not used herein? Because of the difficulties associated with defining the best origin and magnitude estimates for each event discussed in Chapter 2. The depths noted in the compilation of the world database of events with consequences (Chapter 3) were those that were readily available when searching for the damaging events, usually coming from either the USGS catalogue, the ISC Bulletin, or a relevant local agency, when easy to determine. The criteria set up in Chapter 2 to compile the database of crustal earthquakes of small-to-medium magnitude, as well as that used by Weatherill *et al.* (2016), were intended for the process to be as automatic and objective as possible. While 122 is a small enough number of events that would allow for a manual assessment of the depth estimations adopted to be feasible, doing so without revising all the other earthquakes in the database of crustal earthquakes would be strongly inconsistent.

4.1.2. Events Not Complying with the Exposure Criterion

There are 5 events with consequences for the population that could be part of the world catalogue but are not because they get filtered out by the exposure criterion defined in Section 2.2 (see Figure 4.4). These are:

- 5th August 2005 18:07:12 UTC, **M**5.0, Ho Chi Minh, Vietnam (C97): There is not much information about the consequences of this earthquake, except for the ISC Bulletin reporting a statement by the USGS saying that minor damage occurred at Ho Chi Minh city, and NOAA assigning an economic loss of less than 1 million USD. The epicentre was located over 90 km away from the cost, and the hypocentral depth is reported as 10 km. With these parameters, the IPE of Allen *et al.* (2009) yields an epicentral intensity of VI, and a distance to the MMI III isoseismal of 88 km. As a consequence, the estimation of population exposure is zero.

- 8th November 2005 07:54:37 UTC, **M**5.3, Ho Chi Minh, Vietnam (M169): There is not much information about the consequences of this earthquake either, except for the ISC Bulletin, the USGS catalogue and Ngo *et al.* (2008) reporting one death with no specified cause. Phuong & Truyen (2014) describe this earthquake as the main shock of a series of which the event of 5th August 2005 was a foreshock, but do not make any reference to damage or casualties caused by the series. With epicentral coordinates very close to the previous event, and slightly larger magnitude and shallower depth, the IPE of Allen *et al.* (2009) yields an epicentral intensity of VII, and 125 km to the MMI III isoseismal, which does not seem to be enough for any population to fall within predicted MMI values of IV and larger.

- 20th April 2010 00:17:10 UTC, **M**4.5, Kalgoorlie-Boulder, Australia (M55): Information about the damage caused by this earthquake is more detailed than for the previous two cases. Edwards *et al.* (2010) describe damage observed in around 60 buildings and a few minor injuries. The earthquake is believed to be connected to mining activities in the area. It is clear that this earthquake is of relevance to the database, but it gets filtered out based on low population exposure. The epicentral MMI predicted by the model of Allen *et al.* (2009) is slightly above V, and the MMI IV isoseismal passes aright by the side of the towns of Kalgoorlie and Boulder (Figure 4.5, left), where the damage was observed.

- 6th September 2010 22:48:34 UTC, **M**5.0, Porangahau, New Zealand (C51): Information regarding the damage caused by this earthquake appears to be contradictory. It has an estimate of economic losses in NOAA, and the USGS catalogue indicates the occurrence of slight damage. However, online newspapers suggest that there were no reports of damage (Otago Daily Times, 2010; Radio New Zealand, 2010). It is noted, though, that it is possible that damage reports may not have made the news, but may have been collected by the scientific community. Unlike the previous cases, the MMI IV isoseismal predicted by Allen *et al.* (2009) encloses population, as shown in Figure 4.5 (righ), but not enough to satisfy the exposure criterion.

- 26th November 2012 05:33:49 UTC, **M**5.1, Ruoqiang, China (C68): According to NOAA, this earthquake caused damage to around 50 to 100 buildings, amounting to monetary losses of less than 1 million USD. Information in online news sites does not seem to be abundant (at least in English), but the George Herald (2012) mentions homes having been damaged. The plot of isoseismals against population density is similar to that of Figure 4.5 (left), the area being severely underpopulated, as confirmed by the George Herald (2012) as well.

It is possible that some events of those discarded due to their magnitude-depth ranges may not satisfy the exposure criterion either. This possibility was not checked at this stage.

The fact that these events get filtered out of the world database for not satisfying the population exposure criterion reflects its imperfect nature. Alternatives to tackle this are discussed in Section 5.4.

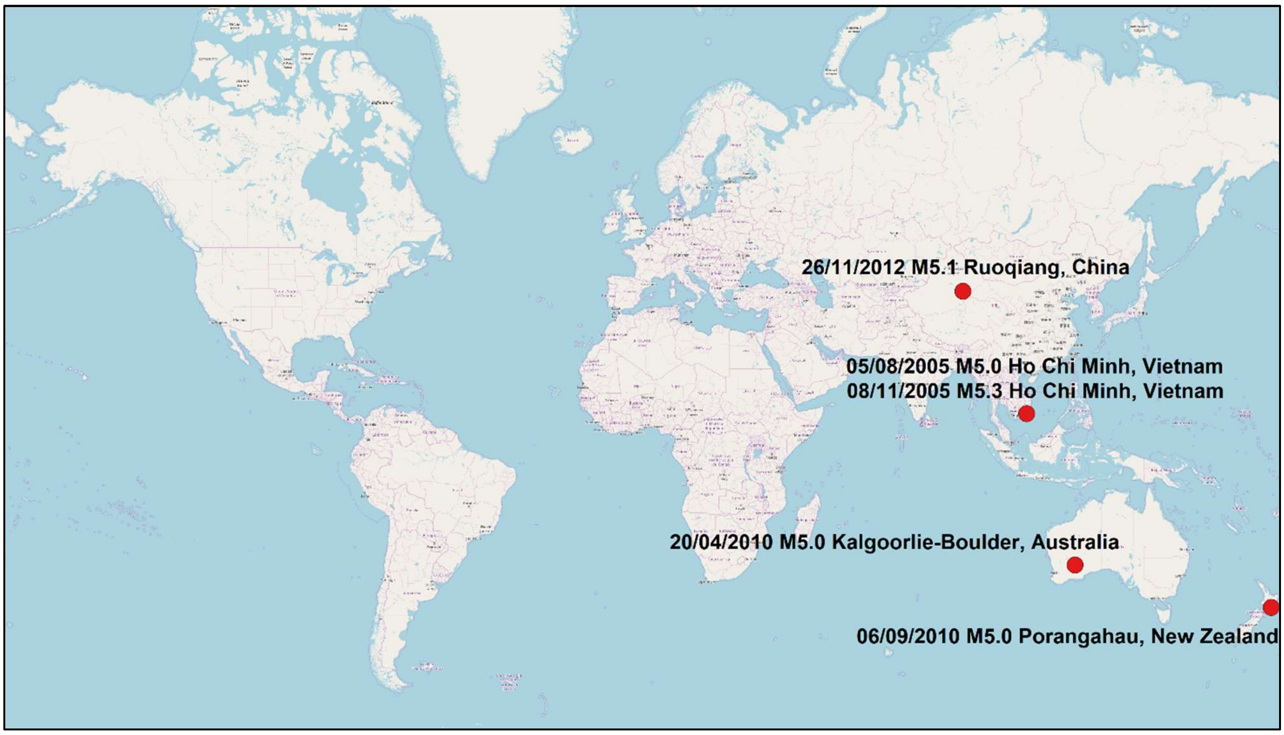


Figure 4.4. Earthquakes from the 1st July 1999 – 30th June 2014 world database of small-to-medium magnitude earthquakes with consequences for the population or the built environment, within the magnitude and depth of interest, that do not pass the population exposure criterion.

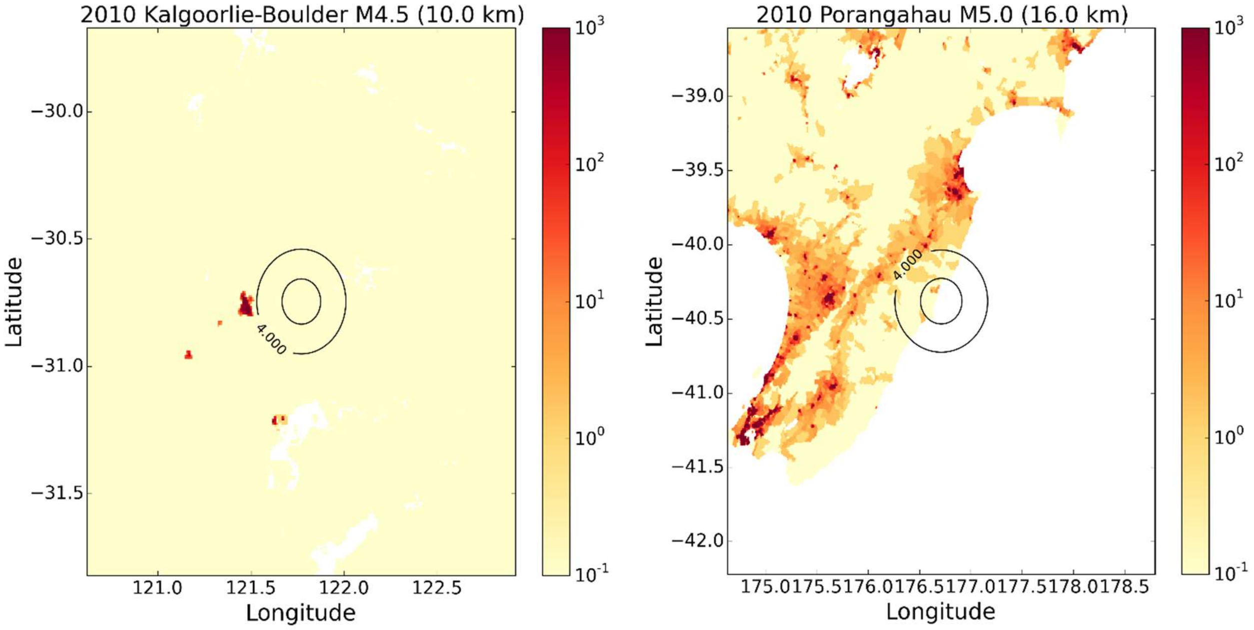


Figure 4.5. Contour lines of MMI values predicted with the model of Allen *et al.* (2012) for the 2010 Kalgoorlie-Boulder (left) and the 2010 Porangahau (right) earthquakes. Background colour scale indicates population density in people per square kilometre (data from GPW v4.0, CIESIN, 2016).

4.1.3. Events Not Found

The following 3 of the 412 earthquakes contained in the world database of small-to-medium magnitude events with consequences for the population could not be found in the merged catalogue:

- 1st March 2004 23:55:19 UTC, Celikhan, Turkey (M231): The USGS catalogue and the ISC Bulletin contain this earthquake, but its consequences cannot be found in neither EM-DAT nor NOAA. It is not part of the merged catalogue because it only has one magnitude estimate in terms of M_d. Both sources report 6 deaths and 2 injuries in Celikhan, Turkey. A Turkish news site (Hürriyet, 2004) specifies that the 6 deaths were due to the collapse of a house made of stone and mud. No estimate of monetary losses was found.

- 1st May 2005 12:23:00 UTC, Chuschi, Peru (M188): For unknown reasons, this earthquake and its consequences are only mentioned by governmental reports and offices from Peru, and is, therefore, not part of the merged catalogue. While information on damage and casualties is not fully consistent and is, in many ways, subject to the interpretation of the choice of words, analysis of the available sources suggests that at least around 2,000 people were affected by this earthquake, more than 300 buildings were damaged, and over 200 were destroyed (INDECI, 2005a, 2005b; Tavera *et al.*, 2016).

- 13th March 2007 08:04:00 UTC, Manica, Mozambique (M129): This earthquake could not be found in neither the USGS catalogue nor the ISC Bulletin, and it is not mentioned neither in EM-DAT nor in NOAA. As a consequence, it is not part of the merged catalogue. It was, however, reported in the news that six school children were injured when rushing into their school building due to the fear to the tremors (Earthweek, 2007; IOL, 2007). There does not seem to have been any damage or any other casualties.

These three cases exemplify that the problem of identifying damaging small-to-medium magnitude earthquakes is not only related to the difficulties of finding reports of damage for events that get reported by seismological agencies. For some reason, the last two events are not reported in the main international sources considered herein. In terms of consequences, the Peruvian case seems more relevant, but the information was only available in Spanish, which means that it is not easily accessible to researchers worldwide. While one of the authors of this work speak Spanish, none speak Turkish, and this presented a challenge for finding information regarding the 13th March 2007 event. While online translators can help, they render the task extremely difficult. Searches that involve translation from languages in which the authors do not have expertise can be done for particular cases, but not in a systematic way.

The first case enumerated above is different from the other two because it not being included in the merged catalogue is only a matter of having only one magnitude estimation available, in terms of a scale not considered herein.

4.1.4. Flagging of (Potentially) Induced Events

As explained in Section 2.7.5, the flagging of induced events within WPG16v3b and the ISC Bulletin was carried out in an automatic fashion, searching for the “geothermal", "reservoir", "mining", and “anthropogenic" keywords. As the compilation of the world database of earthquakes with consequences allowed for a more detailed search of the anthropogenic or tectonic origin of events, the identification of events from the later in the former presented an opportunity to assess the possible misclassification of events.

Out of the 412 events with consequences, three cases were identified in which the algorithm had indicated an anthropogenic origin but this had not been noted in the details of the damaging events. These three cases were verified manually, and it was found that, in all of them, the word “reservoir” appears but to make reference to the earthquake having caused damage to reservoirs, and not to the filling or emptying of the reservoir causing a change in stresses that could have triggered the earthquakes. At the same time, 16 cases that had not been classified as induced by the flagging algorithm are noted as having an anthropogenic origin in the database of earthquakes with consequences.

If we assumed that this proportion of misclassifications applies to the whole database, that is, that 3 in 412 earthquakes (0.73%) are identified as induced when they are not, and that 16 in 412 (3.88%) are not identified as induced even if they are, the numbers in Table 2.7 would change into those in Table 4.1 (considering those non-classified as not induced). It is noted that this is not necessarily true, and represents only an estimation.

Table 4.1. Number of events in the database for the period 01/07/1999-30/06/2014, with 4.0≤**M**≤5.5, depths constrained by Table 2.1, and either maximum population density greater than 300 people/km^2 or cumulative population count larger than 2,500 people in areas with MMI≥IV, with proportion of induced events adjusted assuming observed discrepancies over 412 events extrapolate to the whole database.

Source	Induced	All Events		Only Mainshocks	
		Number	%	Number	%
WPG16v3b	Induced	1,583	4.44%	484	4.04%
	Not Induced	30,452	85.41%	10,058	84.04%
ISC Bulletin	Induced	154	0.43%	62	0.52%
	Not Induced	3,465	9.72%	1,364	11.40%
Total		35,654	-	11,968	-

As has been mentioned earlier, the automatization required to process large volumes of data entails the natural risk of misclassifications. Alternatives to tackle this are discussed in Section 5.8.

4.2. Statistical Analysis

4.2.1. Kinds of Consequences Observed

Table 4.2 summarises the kinds of consequences observed for the earthquakes identified as having had consequences for the population. Of the whole list, the most relevant numbers are those corresponding to the 282 earthquakes that are part of the final world database of crustal small-to-medium magnitude events near urbanised areas.

Table 4.2. Number of events identified as having had consequences for the population per type of consequence and sub-group.

Sub-group	Total	With Deaths	With Injured	With Damaged Buildings	With Destroyed Buildings
In final database	282	79	170	201	76
Not complying with exposure criterion	5	1	1	3	0
Not complying with magnitude-depth criterion	122	38	80	91	42
Not found	3	1	2	1	2
All	412	119	253	296	120

The interpretation of these numbers needs to be made taking into consideration that deaths may not only include those directly caused by the failing of structures but also those caused by secondary effects (like landslides), heart attacks and panic reactions, such as jumping off windows. Similarly, injuries can range from serious to very light, such as cuts due to broken glasses, hitting walls in the rush to run out of buildings, etc. In this sense, it is relevant to highlight that, based on the data collected, training the population to react appropriately in case of an earthquake would appear to be able to prevent a lot of these casualties.

The range of types of damage included within the category “with damaged buildings” can be as broad as those of casualties. Damage to buildings can be anything from structural damage to fine cracks in walls and damage to chimneys or parapets. For example, it is possible to talk about hundreds of buildings having been damaged by the 2006 **M**3.2 Basel (Switzerland) earthquake, though the damage only consisted of very thin hairline cracks in plaster and damage to the paint work at building junctions, to the extent that it would have been extremely hard to determine whether it had been caused by the earthquake or not. Even more caution should be taken regarding reports of destroyed buildings, as the interpretation of what destruction means can be very different from one person to another. For example, several reports regarding the 2011 **M**5.7 Prague (Oklahoma, USA) talk about houses having been destroyed, but photographic documentation of the damage suggests that said “destruction” might have been localised to a particular feature of the building, and not have affected the building as a whole. The number of cases for which sufficient information to distinguish between different levels of damage is available is small.

4.2.2. Earthquakes with Consequences within the Complete World Database

Figure 4.6 shows again the 11,968 mainshocks and 23,687 fore- and aftershocks of the world database of crustal small-to-medium magnitude earthquakes near urbanised areas (*i.e.*, those shown in Figures 2.30 and 2.31), highlighting the 282 events with consequences for the population. The same events but classified in terms of main shocks and fore-/aftershocks are shown in Figures 4.7 and 4.8.

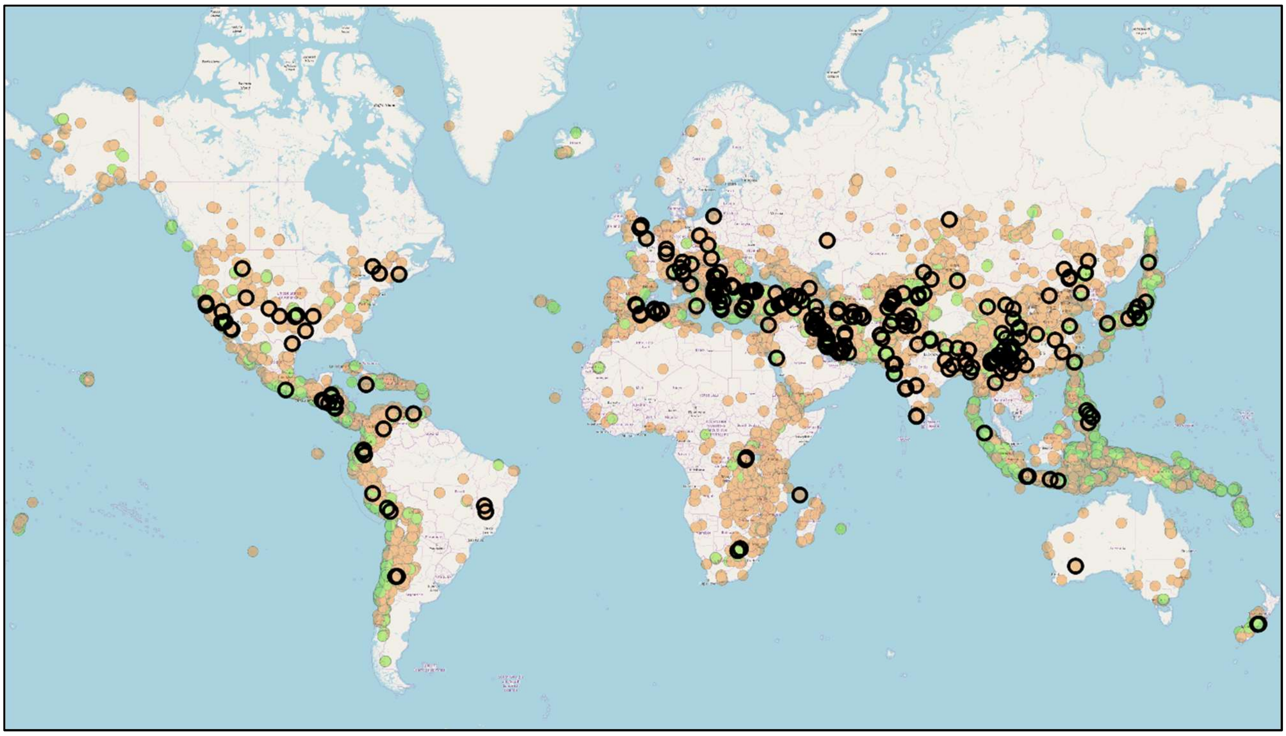


Figure 4.6. Confrontation of the two databases: database of crustal small-to-medium magnitude earthquakes near populated areas (main shocks in orange, fore- and aftershocks in green) and database of crustal small-to-medium magnitude earthquakes near populated areas that are known to have caused damage or casualties (black empty circles).

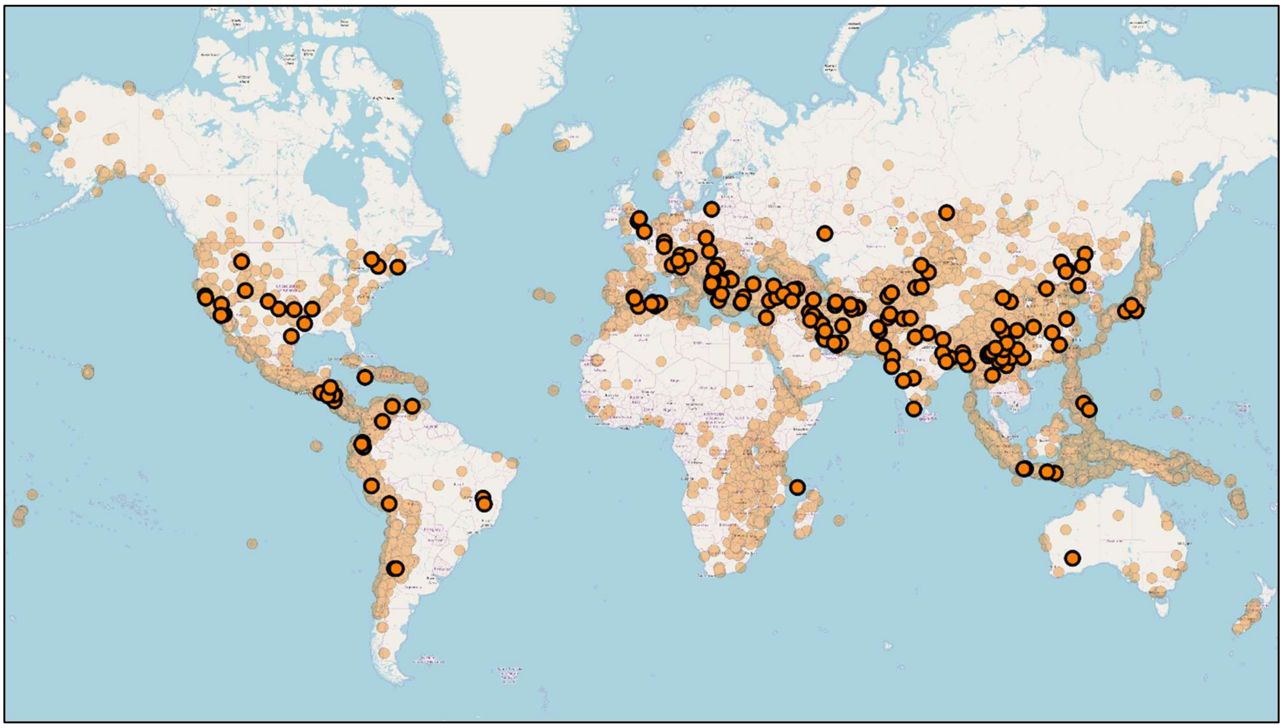


Figure 4.7. Confrontation of the two databases only in terms of main shocks: database of crustal small-to-medium magnitude earthquakes near populated areas (light orange) and database of crustal small-to-medium magnitude earthquakes near populated areas that are known to have caused damage or casualties (dark orange with thick black borders).

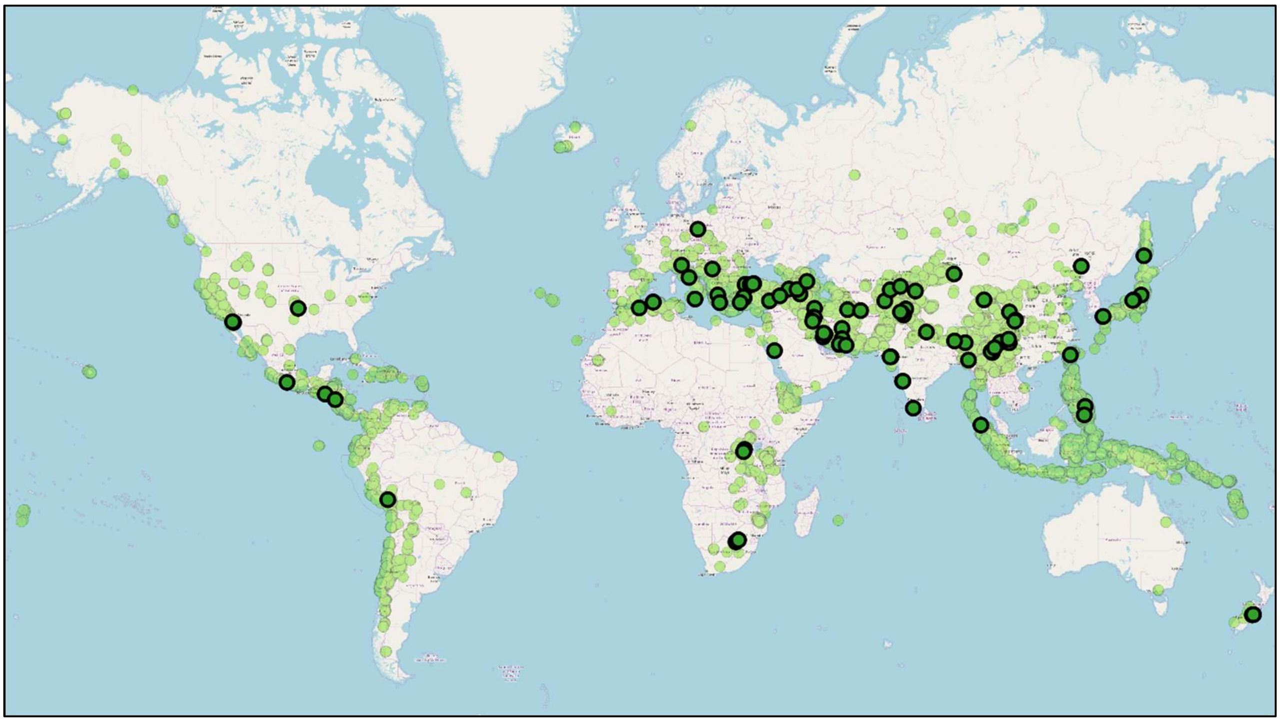


Figure 4.8. Confrontation of the two databases only in terms of fore- and aftershocks: database of crustal small-to-medium magnitude earthquakes near populated areas (light green) and database of crustal small-to-medium magnitude earthquakes near populated areas that are known to have caused damage or casualties (dark green with thick black borders).

These 282 events represent 0.79% of the total of 35,654 events of the database. In terms of mainshocks, those causing damage or casualties represent 1.55% (185 earthquakes out of 11,968). Table 4.3 shows how these sets of 282 and 185 events are composed in terms of source and nature, for the classification carried out with the automatic algorithm described in Section 2.7.5. As was noted in Section 4.1.4, a series of events had been identified as induced when compiling the database of earthquakes with consequences. The numbers in Table 4.4 reflect this manual identification of anthropogenic events.

Table 4.3. Number of events in the database causing damage and/or casualties for the period 01/07/1999-30/06/2014, with 4.0≤**M**≤5.5, depths constrained by Table 2.1, and either maximum population density greater than 300 people/km^2 or cumulative population count larger than 2,500 people in areas with MMI≥IV. Percentages make reference to the total 282 and 185 events. Flagging of induced events carried out automatically.

Source	**Induced**	**All Events**		**Only Mainshocks**	
		Number	**%**	**Number**	**%**
WPG16v3b	Induced	5	1.77%	3	1.62%
	Not Induced	271	96.10%	176	95.14%
	Not Classified	3	1.06%	3	1.62%
ISC Bulletin	Induced	0	0.00%	0	0.00%
	Not Induced	3	1.06%	3	1.62%
Total		282	-	185	-

Table 4.4. The same as Table 4.3, but with the number of induced events adjusted manually based on information collected in Chapter 3.

Source	**Induced**	**All Events**		**Only Mainshocks**	
		Number	**%**	**Number**	**%**
WPG16v3b	Induced	15	5.32%	11	5.95%
	Not Induced	262	92.91%	169	91.35%
	Not Classified	2	0.71%	2	1.08%
ISC Bulletin	Induced	0	0.00%	0	0.00%
	Not Induced	3	1.06%	3	1.62%
Total		282	-	185	-

Tables 4.5 through 4.7 summarise the final proportions of earthquakes that have caused damage and/or casualties, considering all events, only non-induced and non-classified events, and only induced events, respectively. The number of induced events takes into consideration the manual modification of a series of cases as per Table 4.4. As can be observed, the percentages are relatively well-preserved when filtering out the induced events of Table 4.5 to generate Table 4.6, but change significantly when only the induced events are considered in Table 4.7. While it is noted that the total number of events considered changes drastically, and this could imply a loss of statistical relevance of the sample, it is possible that this apparent larger number of earthquakes that cause damage

or casualties when only induced events are considered be due, at least partly, to damage from such events being more likely to be reported and feature in the media. Being associated with anthropogenic activities carried out by companies or governments instead of natural processes, damage or casualties caused by these earthquakes are perceived as unnecessary and, thus, are usually the subject of more attention than small tectonic counterparts.

Table 4.5. Final statistics showing proportion of earthquakes that have caused damage and/or casualties. All induced, non-induced and non-classified events considered.

Case	**All Events**		**Only Mainshocks**	
	Number	**%**	**Number**	**%**
Total	35,654	100%	11,968	100%
Damaging and/or causing casualties	282	0.79%	185	1.55%

Table 4.6. Final statistics showing proportion of earthquakes that have caused damage and/or casualties. Only non-induced and non-classified events considered.

Case	**All Events**		**Only Mainshocks**	
	Number	**%**	**Number**	**%**
Total	35,275	100%	11,875	100%
Damaging and/or causing casualties	267	0.76%	174	1.47%

Table 4.7. Final statistics showing proportion of earthquakes that have caused damage and/or casualties. Only induced events considered.

Case	**All Events**		**Only Mainshocks**	
	Number	**%**	**Number**	**%**
Total	379	100%	93	100%
Damaging and/or causing casualties	15	3.96%	11	11.83%

Tables 4.5 through 4.7 show as well that the proportion of damaging earthquakes increases significantly when only main shocks are considered. This can be due to a series of factors. Firstly, damage caused by a series of earthquakes that affect once and again the same population is often reported associated only to the main event, and not to each individual one. Even if there is not one main event, because the series is more like a swarm of events of similar magnitude, or even just a series of two or three events happening very close in time, this can be the case, as has been observed when gathering information about earthquakes with consequences. If that is the case, then it is possible that the number of damaging foreshocks, aftershocks or swarm-like events is not being fully registered in the databases and earthquake catalogues. Secondly, it is also likely that aftershocks within the magnitude range of interest whose main shocks are larger than **M**5.5 do not get reported even if they cause damage to different sites than the main shock, as all the attention is focused on the one with the worst consequences. It is possible, then, that the proportion of

damaging earthquakes might be underestimated when all events are considered with respect to when only main shocks are.

An important point needs to be made regarding the proportion of damaging induced main shocks (Table 4.7). Declustering algorithms work under the assumption that there exists a main shock and that there might be other events occurring sufficiently close in time and space that are associated with the main shock, but whose magnitude is smaller. As a consequence, they might not be the best tool to identify swarms or sequences, understood as series of events whose magnitudes are close to one another and for which the concept of main shock loses relevance. Due to their nature, it is common for induced events to occur in sequences of many thousands of events. Imagining a sequence that lasts several years and includes three events that cause damage in three neighbouring towns, each one at a time. A declustering algorithm might identify a main shock, which is likely to be one of the three damaging events. 1 out of 1 main shocks would be damaging, which yields a 100% rate of damaging induced main shocks. However, the whole sequence might include thousands of events, of which 3 were damaging, and this yields a damaging rate much smaller than 100%.

How much would these numbers change if some of the earthquakes discarded according to the magnitude-depth and exposure criteria had been included? This is not a simple question. In previous sections it has been said that there were 5 earthquakes that caused damage and/or casualties but were filtered out due to not complying with the exposure criterion. If these 5 events were to be included, but the total number of events were to stay the same (*i.e.*, 35,654), the final percentage would change from 0.79% to 0.80%, which is not a lot. However, including these 5 events would imply loosening the exposure criterion by an unknown amount, and the corresponding increase in the total number of events would remain unknown (*i.e.*, due to this loosening of the criterion, how many non-damaging events should be added as well?).

Something similar happens with the magnitude-depth criterion. It was said before that, had a depth value from a different author/agency been used, around 30 events of those that got discarded as a consequence of this criterion could have been added. But how many non-damaging earthquakes that got discarded for the same reason would have made it to the final database if a different depth estimate had been considered as well? This question cannot be answered without further analysis, as is discussed in Section 5.2.

A final issue to take into consideration is that of the completeness of the damage reports. In other words, how many damaging earthquakes are reported overall. Besides the already mentioned issue of small earthquakes with small consequences only being reported in local media using the local language, there is the more relevant matter of how many do not get reported at all. This can be due to many reasons. To begin with, the perception of the severity of damage changes drastically from highly seismic areas to lower seismicity ones. In highly seismic areas it is unlikely that a small magnitude event that caused cracks in some tens of houses gets reported, or even noticed, as the population is used to constant shaking. Similarly, the perception of the severity of damage also changes significantly as a function of the general quality of construction and level of maintenance. Less developed areas of the world in which a large proportion of the buildings might suffer from structural problems derived from poor construction practices are less likely to notice if a series of cracks in the walls are caused by a small magnitude earthquake, as the walls are probably full of cracks due to other issues, like settlements caused by inadequate foundations. The same happens if the overall state of maintenance of the building stock is such that the structures are so deteriorated that small new damage is difficult to identify. Along different lines, more severe natural, political or social events that may be contemporaneous to small-to-medium magnitude earthquakes causing slight damage, such as wars, coup d'etats, hurricanes, or any other threatening hazard or general unrest, may cause the earthquake damage to pass unreported. Making an estimation of how many crustal small-to-medium size events cause damage or casualties that are not reported is extremely difficult. Whatever assumption is made would imply that the proportions of damaging events shown in Table 4.5 increase.

5. FUTURE DIRECTIONS

5.1. General

Along the extent of this work, it has been possible to identify a series of decisions that may (or may not) have an influence on the final outcome of the analysis. Given the complexity that compiling a consistent global database of earthquakes entails, a conscious decision was made to make choices that would lead to the most transparent and simple outcome, and then work on assessing the influence of the choices made. What follows is a discussion of the points identified as relevant for further study or deemed plausible of improvement.

5.2. Maximum Depth Criterion

In Section 4.1.1 it was noted that a series of earthquakes identified as having caused damage or casualties were filtered out of the database due to not complying with the maximum depth criterion. Whether changing the depth criterion would lead to a larger or smaller proportion of events causing damage cannot be known *a priori*. The simplest way to assess the influence of this criterion in the filtering of the database would be to define a number of alternative criteria and evaluate the stability (or lack of) of the results. A more complex strategy would be to consider all available estimates of depth when carrying out the filtering, though it is recognised that the computational demand would increase significantly without an obvious gain. In that respect, an initial sensitivity analysis of the kind described before could be an indicator of whether a more sophisticated strategy is likely to yield any benefits or not.

5.3. Declustering

Declustering algorithms imply adopting assumptions regarding what main-, fore- and aftershocks are, and work purely in terms of proximity of events in time and space, without taking into account the structural geology close to the site. As such, a series of parameters can be tuned and defined within each algorithm, the final clusters depending on them. For example, for the algorithm of Gardner & Knopoff (1974) it is necessary to indicate if the time window for foreshocks will be the same than that of aftershocks, smaller, or if foreshocks should not be sought, besides the kind of time and space window to use (*e.g.*, Gardner & Knopoff, 1974; Grünthal (van Stiphout *et al.*, 2012); Uhrhammer, 1986; see Figure 2.17). As it would be impossible to unambiguously classify all events as main-, fore- or aftershocks, a sensitivity analysis using different parameters and/or declustering methods would allow to illustrate the extent to which these declustering decisions affect the results.

5.4. Intensity Prediction Models

In Section 4.1.2 it was discussed that five earthquakes identified as having caused damage and/or casualties did not comply with the exposure criterion. While the difficulty of setting an exposed population threshold to define how relevant each earthquake is as a potential threat is evident, the case of the **M**4.5 2010 Kalgoorlie-Boulder (Australia) earthquake suggests that a simple improvement to the methodology would be to consider a different intensity prediction model for parts of the world with a clear cratonic setting, such as western Australia. It has been observed (*e.g.*, Kaka & Atkinson, 2004) that environments such as this display a slower attenuation and potentially higher stress drop than tectonic margins or other regions of extended crust where the model of Allen *et al.* (2009) might be appropriate. The use of alternative intensity prediction equations could, thus, be explored.

5.5. Magnitude Scales

While the extensive discussion on magnitude scales presented in Section 2.5 led to a well-informed decision regarding which scales to consider when retrieving events from the ISC Bulletin, the possibility of adding events for which only m_b or M_d estimates are available, as well as the use of existing models to convert from M_s, m_b, and M_d into **M** can be explored.

5.6. Uncertainty in Depth, Magnitude and Intensity

The extent to which depth and magnitude estimates are uncertain has become very clear all along the extent of this work. Moreover, the IPE of Allen *et al.* (2009) used to estimate the population exposed to the shaking caused by each event has a certain degree of uncertainty associated with it, as any prediction model. The above discussion about the possibility of considering all depth estimates could be a way of incorporating the uncertainty associated with this particular parameter, and a similar strategy could be followed for the magnitude.

Inclusion of the uncertainty of the IPE could be done in terms of defining the probability associated with observing an MMI value equal to or larger than IV in each population cell, and multiplying that probability by the corresponding population count. Cells for which the expected median MMI turns out to be significantly larger than IV would be weighted almost by unity, while cells with very small expected median values would be almost ignored, and all cases in between would be weighted by some value in between 0 and 1. Given that the estimation of population exposure is only used to filter out events that are too far away from populated areas to be a threat, the influence of the uncertainty associated with the IPE is expected to be less significant than that associated with the depth and magnitude.

5.7. Improvement of the Identification of Duplicate Events

The procedure developed in Section 2.7.7 to identify potentially duplicate events makes use of all the information that is readily available regarding each event in the ISC Bulletin, and makes assumptions regarding the parameters that may indicate whether two events are different estimates of the same earthquake or not. As noted, even if it was possible to access all the waveforms from which the location and magnitude estimates were carried out, their processing would be a colossal task, not free from the usual challenges associated with the location of earthquake sources. In view of this, this possibility can be nothing but discarded. However, it would be possible to further analyse cases that may have been misclassified by the algorithm of Section 2.7.7 and try to identify possible trends that may help improve the procedure.

5.8. Improvement of Flagging of Induced Events

As it was noted, the automatic flagging of induced events based on the search for keywords related to anthropogenic events is imperfect by nature. This first identification of induced events could be complemented with a more thorough comparison against the Human-Induced Earthquake Database (Foulger *et al.*, 2016; Wilson *et al.*, 2017; Induced Earthquakes, 2017). The challenges are many, as the latter is not a list of individual earthquakes identified as being induced, but a list of projects that have generated series of earthquakes each, but defining spatial and time limits of influence of the projects would allow to define regions of the world and times in history during which earthquakes at a particular place and time are likely to have had an anthropogenic origin.

6. CONCLUSIONS

As part of the effort to quantify and understand the risk posed by earthquakes with moment magnitude in the range 4.0-5.5 to the Groningen field, this study has aimed to identify how many upper crustal earthquakes in this magnitude range occur in close proximity to urbanised areas, and what proportion of these earthquakes cause damage and/or casualties. A world database of crustal earthquakes in the range **M**4.0-5.5 that occurred sufficiently close to population or the built environment, as well as a world database of earthquakes in the range **M**4.0-5.5 for which reports of damage and/or casualties exist, were compiled for this purpose. The process and the challenges associated with compiling both databases have been thoroughly discussed in the preceding pages, together with the statistical analysis that has made use of the two.

The world database of crustal earthquakes in the range **M**4.0-5.5 that occurred sufficiently close to population or the built environment compiled herein is composed of 35,654 events, out of which 11,968 were identified as main shocks by means of the declustering algorithm of Gardner & Knopoff (1974). It was generated taking the world catalogue of Weatherill *et al.* (2016) as the starting point, and subsequently adding events from the ISC Bulletin that had information on depth and a value for magnitude either in terms of moment magnitude, surface-wave magnitude or local magnitude, under the assumption $\mathbf{M}=M_s=M_L$. Whether each earthquake was sufficiently close to populations or the built environment was determined as a function of the number and density of people expected to have been exposed to Modified Mercalli Intensities of IV or larger, calculated by means of the intensity prediction equation of Allen *et al.* (2012) and Gridded Population of the World v4.0 (CIESIN, 2016). Some 282 earthquakes out of the total (0.79%) and 185 out of the main shocks (1.55%) have been identified as having caused damage and/or casualties. The proportions of damaging events rise significantly when considering only those that have been marked as being of anthropogenic origin, becoming 3.96% and 11.83% for all events and for main shocks, respectively.

While all numerical results presented herein need to be interpreted within a full understanding of the inherent challenges of this work, the last two require particular caution for two main reasons. Firstly, since the number of earthquakes flagged as induced is relatively small, the relevance of the sample could be questioned. Secondly, it is likely that in areas of the world where a connection between seismicity and anthropogenic activities is strongly suspected, there will be a greater propensity to report earthquake damage, even if minor, than would be the case in areas dominated by frequent tectonic shaking. While damage due to tectonic earthquakes is accepted as natural (at least in terms of the origin of the shaking), that due to human-induced events will be viewed as an imposed—and therefore avoidable—risk. In the case in which only main shocks are considered, an additional factor may come into play, which is that it is common for induced events to occur in sequences or swarms, a fact that may explain, at least in part, the proportion of main shocks to total number of events being smaller for induced than for non-induced earthquakes (24.5% against 33.6%). As the proportion of damaging earthquakes that are classified as main shocks is approximately the same whether all events or only main shocks are considered (roughly 2/3), the fact that a smaller proportion of the total of induced events are main shocks (in comparison with all shocks) causes the final percentage of damaging induced main shocks to be significantly larger than in all other cases.

The influence of the discrimination of events into main shocks and non-main shocks is not exclusive to induced events. While it is hard to establish whether the increase from 0.79% to 1.55% in the proportion of damaging earthquakes is real or is an artefact of the definition of what a main shock is, it is likely that the effects of many aftershocks are not reported separately from the main shock, or that the effects of a swarm with several events of similar magnitude be associated to just one of the events and not to all. Naturally, it is not common to have knowledge of the precise damage caused by each of the earthquakes in a series, and the natural association of damage to the strongest event could be responsible for this apparent increase.

Another important caveat is that the database of earthquakes in the range **M**4.0-5.5 for which reports of damage and/or casualties exist may not be complete; in fact, it may be considered a lower bound estimate of the number of damaging events. The inclusion of events in the database depends strongly on the availability of damage reports both in terms of their accessibility and the language in which they are written. In this sense, translating from a report that has been identified is not a major problem (at least for languages using Latin script), but finding the report to begin with can be serious challenge. The propensity of societies to report the damage caused by small-to-medium magnitude earthquakes is directly influenced by the seismicity of the area, the general quality of construction and the level of building maintenance. Damage occurring in low-seismicity areas, where buildings are generally of good quality and well maintained, is much more likely to be reported than that occurring in places where people are used to constant weak shaking, and light cracks in walls are a common sight due to the persistence of seismic motion or other problems, such as subsidence. The response to an episode of induced shaking will also depend on the general levels of safety and well-being in a society—in regions of conflict, poverty or hunger, for example, there may be less tendency to report the comparatively minor disruption of induced ground motions. Other influencing factors will include how remote are the affected settlements and the levels of media and Internet coverage in the country or region. As a final remark on this subject, the simultaneous occurrence of small seismic events that cause slight damage and more severe natural, political or social events can significantly influence how much attention the former receive.

Apart from the challenges associated with identifying damaging small-to-medium magnitude damaging seismic events, those inherent to the compilation of a world catalogue of earthquakes of any kind are of no less importance. Making decisions regarding the lack of homogeneity in the magnitude scales and the selection of a set of hypocentral coordinates and a magnitude estimate to represent each event is not trivial, as different agencies report different estimates, and the accuracy associated to weaker events is generally lower than that of those of larger magnitude earthquakes. As estimates of the origin time can also vary significantly, the identification of different entries of the same event that may have been misclassified as separate events poses an additional challenge.

While a large effort has been invested in addressing all these issues in the best possible way, it should be noted that, for most of them, there is no unambiguously correct answer, only reasonable assumptions, the influence of which can be tested through sensitivity studies. As such, the next stage of this work will consist in continuing to expand and improve the quality of the database of earthquakes with consequences, refine the processes involved in the identification of duplicate events and flagging of induced events, and assessing the impact of some of the decisions made, including (but not limited to) those related to the maximum depth ranges considered and the population exposure criterion applied. While small adjustments of the latter are not expected to have a major influence on the number of events considered, it is noticeable that the 2010 **M**4.5 Kalgoorlie-Boulder earthquake, an event known to have caused damage to at least 60 buildings, is filtered out of the database for not complying with the depth criterion. On the contrary, further consideration of the maximum depth limits or the way in which the different estimates of hypocentral depth are treated, might lead to a change in the volume of events, though it cannot be known *a priori* whether this would reflect in a larger proportion of damaging events or the opposite.

The picture that emerges at this preliminary stage of the research is that on a global scale, 1 in every ~100 earthquakes in the magnitude range 4.0-5.5 that occur close (in plan and in depth) to population centres is reported to cause damage. For anthropogenically-induced earthquakes, the proportion of damaging events in the same magnitude range may be closer to 1-in-10. As has been pointed out above, however, there are several issues still to be investigated before these numbers can be taken as robustly reliable indicators. Even when the most probable proportions of damaging events are established, additional work will be needed—and has indeed been started in the compilation of detailed case histories—to determine the specific factors leading to the damage in each case, whether related to the intensity of the ground shaking or the susceptibility of the exposed building stock. Another point that needs to be addressed is that while 4.0-5.5 may seem a small interval of earthquake magnitudes, there is a ratio of almost 200 between the seismic energy release between the largest and smallest events. Therefore, an obvious refinement is to explore the statistical patterns within smaller intervals of magnitude: induced earthquakes with magnitudes 4.0-4.5 may be expected to occur frequently, but induced events larger than 5.0 would still be somewhat exceptional.

7. ACKNOWLEDGEMENTS

This work was funded by Nederlandse Aardolie Maatschappij B.V. (NAM) as part of the Study and Data Acquisition Program for induced seismicity in Groningen.

8. REFERENCES

8.1. Bibliography

Afshari, K. & J.P. Stewart (2016). Physically parametrised prediction equations for significant duration in active crustal regions. *Earthquake Spectra* **32**(4), 2057-2081.

Allen, T.I, D.J. Wald, P.S. Earle, K.D. Marano, A.J. Hotovec, K. Lin & M.G. Hearne (2009). An Atlas of ShakeMaps and population exposure catalog for earthquake loss modeling. *Bulletin of Earthquake Engineering* **7**, 701-718. EXPO-CAT and PAGER-CAT available from (last accessed 15th November 2017): https://earthquake.usgs.gov/data/pager/references.php.

Allen, T.I., D.J. Wald & C.B. Worden (2012). Intensity attenuation for active crustal regions. *Journal of Seismology* **16**, 409-433.

Amato, A., L. Badiali, M. Cattaneo, A. Delladio, F. Doumaz & F. Mele (2006). The real-time earthquake monitoring system in Italy. *Geosciences (BGRM)* **4**, 70–75.

Bhaduri B., E. Bright, P. Coleman & J. Dobson (2002). LandScan – locating people is what matters. *Geoinformatics* **5**(2),34–37.

Bommer, J.J. & H. Crowley (2017). The purpose and definition of the minimum magnitude limit in PSHA calculations. *Seismological Research Letters*, IN PRESS.

Bommer, J.J., P.J. Stafford & J.E. Alarcón (2009). Empirical equations for the prediction of the significant, bracketed, and uniform duration of earthquake ground motion. *Bulletin of the Seismological Society of America* **99**(6), 3217-3233.

Bourne, S.J., S.J. Oates, J.J. Bommer, B. Dost, J. van Elk & D. Doornhof (2015). A Monte Carlo method for probabilistic seismic hazard assessment of induced seismicity due to conventional gas production. *Bulletin of the Seismological Society of America* **105**(3), 1721-1738.

Center for International Earth Science Information Network - CIESIN - Columbia University (2016). *Gridded Population of the World, Version 4 (GPWv4)*. Palisades, NY: NASA Socioeconomic Data and Applications Center. http://dx.doi.org/10.7927/H4NP22DQ.

Di Giacomo, D., I. Bondár, D. A. Storchak, E. R. Engdahl, P. Bormann & J. Harris (2015). ISC-GEM: Global Instrumental Earthquake Catalogue (1900‐2009), III. Re-computed M_S and m_b, proxy M_W, final magnitude composition and completeness assessment. *Physics of the Earth and Planetary Interiors* **239**, 33-47.

Dobson J.E., E.A. Bright, P.R. Coleman, R.C. Durfee & B.A. Worley (2000). LandScan: a global population database for estimating populations at risk. *Photogrammetric Engineering and Remote Sensing* **66**(7),849–857.

Dost, B., B. Edwards & J. J. Bommer (2016). *Local and moment magnitudes in the Groningen field*. Report for Nederlandse Aardolie Maatschappij (NAM), Netherlands.

Edwards, M., M. Griffith, M. Wehner, N. Lam, N. Corby, M. Jakab & N. Habili (2010). The Kalgoorlie earthquake of the 20th April 2010: preliminary damage survey outcomes. *Australian Earthquake Engineering Society 2010 Conference*, Perth, Australia.

Ekström, G., M. Nettles & A. Dziewonski (2012). The Global CMT project 2004–2010: centroid-moment tensors for 13,017 earthquakes. *Physics of the Earth and Planetary Interiors* **200**, 1–9.

Engdahl, E.R., R. van der Hilst & R. Buland (1998). Global teleseismic earthquake relocation with improved travel times and procedures for depth determination. *Bulletin of the Seismological Society of America* **88**, 722–743.

Foulger, G.R., M. Wilson, J. Gluyas & R. Davies (2016). *Human-induced earthquakes*. Report for the Nederlandse Aardolie Maatschappij BV (NAM), The Netherlands. Report available online at: https://www.nam.nl/feiten-en-cijfers/onderzoeksrapporten.html#iframe=L2VtYmVkL2NvbXBvbmVudC8/aWQ9b25kZXJ6b2Vrc3JhcHBvcnRlbg. Last accessed 28th November 2017.

Gardner, J. K. & L. Knopoff (1974). Is the sequence of earthquakes in Southern California, with aftershocks removed, Poissonian? Bulletin of the Seismological Society of America **64**(5), 1363 – 1367.

Gasperini, P., B. Lolli & G. Vannucci (2013). Empirical calibration of local magnitude data sets versus moment magnitude in Italy. *Bulletin of the Seismological Society of America* **103**(4), 2227–2246.

Gutenberg, B. & C.F. Richter (1956). Magnitude and Energy of Earthquakes. *Annali di Geofisica* **9**, 1–15.

Hanks, T. & H. Kanamori (1979). A moment magnitude scale. *Journal of Geophysical Research* **82**(20), 2981–2987.

Jaiswal, K. & D.J. Wald (2008). *Creating a Global Building Inventory for Earthquake Loss Assessment and Risk Management*. USGS Open File Report 2008-1160. Available electronically at http://pubs.usgs.gov/of/2008/1160/. Last accessed: 9th February 2017.

Kaka, S.I. & G.M. Atkinson (2004). Relationships between instrumental ground-motion parameters and Modified Mercalli Intensity in Eastern North America. *Bulletin of the Seismological Society of America* **94**(5), 1728-1736.

Nievas, C.I., M. Ntinalexis, D. Kazantzidou-Firtinidou, J. Borozan, M. Sangirardi, H. Crowley & J.J. Bommer (2018). *A database of damaging earthquakes of moment magnitude from 4.0 to 5.5 – Version 2*. Report for the Nederlandse Aardolie Maatschappij BV (NAM), The Netherlands. Under preparation.

Ngo, T.D., M.D. Nguyen & D.B. Nguyen (2008). A review of the current Vietnamese earthquake design code. Special issue of the *Electronic Journal of Structural Engineering (EJSE): Earthquake Engineering in the low and moderate seismic regions of Southeast Asia and Australia*, 32-41.

Pacheco, J. & L.R. Sykes (1992). Seismic moment catalogue of large shallow earthquakes 1900–1989. *Bulletin of the Seismological Society of America* **82**, 1306–1349.

Pagani M., D. Monelli, G. Weatherill, L. Danciu, H. Crowley, V. Silva, P. Henshaw, L. Butler, M. Nastasi, L. Panzeri, M. Simionato, D. Vigano (2014). OpenQuake engine: an open hazard (and risk) software for the Global Earthquake Model. *Seismological Research Letters* **85**, 692–702.

Phuong, N.H. & P.T. Truyen (2014). Probabilistic seismic hazard assessment for the South Central Vietnam. *Vietnam Journal of Earth Sciences* **36**, 451-461.

Richards, P.G., F. Waldhauser, D. Schaff & W.-Y. Kim (2006). The applicability of modern methods of earthquake location. *Pure and Applied Geophysics* **163**, 351-372.

Scordilis, E. M. (2006). Empirical global relations converting M_S and m_b to moment magnitude. *Journal of Seismology* **10**, 225–236.

INDECI – Instituto Nacional de Defensa Civil de Perú (2005a). *Compendio estadístico de prevención y atención de desastres 2005. Series Cronológicas*. Lima, Perú. Available online at: https://www.indeci.gob.pe/compend_estad/2005/pdfs/doc322_5.pdf. Last accessed: 17th November 2017.

INDECI – Instituto Nacional de Defensa Civil de Perú (2005b). *Informes detallados de emergencias 2005*. Lima, Perú. Available online at (last accessed 17th November 2017): https://www.indeci.gob.pe/compend_estad/2005/pdfs/doc322_4e.pdf.

Stepp, J.C. (1971). *An investigation of earthquake risk in the Puget Sound area by the use of the type I distribution of largest extreme*. PhD thesis. Pennsylvania State University.

Storchak, D., D. Di Giacomo, E. Engdahl, J. Harris, I. Bondár, W. Lee, P. Bormann & A. Villaseñor (2015). The ISC-GEM Global Instrumental Earthquake Catalogue (1900–2009): Introduction. *Physics of the Earth and Planetary Interiors* **239**, 48–63.

Strasser, F.O. & A. Mangongolo (2012). *TNSP earthquake catalogue*. Council of Geoscience, Report number 2012-0166 Rev. 0. South Africa. Available online at (last accessed on 23rd October 2017): http://www.eskom.co.za/Whatweredoing/SSHAC_ProjectResults/Pages/DataPublications.aspx.

Tavera, H., C. Agüero & E. Fernández (2016). *Catálogo general de isosistas para sismos peruanos*. Instituto Geofísico del Perú, Dirección de Ciencias de la Tierra Sólida, Unidad de Sismología. Lima, Perú. Available online at (last accessed 17th November 2017): http://portal.igp.gob.pe/sites/default/files/images/documents/comunicaciones/Notasprensa/2016/catalogo_isosistas_peru_2016.pdf.

Uhrhammer, R. (1986). Characteristics of Northern and Central California Seismicity. *Earthquake Notes* **57**(1), 21.

Van Elk, J., S.J. Bourne, S.J. Oates, J.J. Bommer, R. Pinho & H. Crowley (2017). A probabilistic seismic risk model to inform decision-making in response to induced earthquakes in the Groningen gas field. *Submitted to Earthquake Spectra*.

Van Stiphout, T. van, J. Zhuang, & D. Marsan (2012). *Theme V -Models and Techniques for Analysing Seismicity*. Technical report. Community Online Resource for Statistical Seismicity Analysis. Available online at (last accessed 28th November 2017): http://www.corssa.org/export/sites/corssa/.galleries/articles-pdf/vanStiphout_et_al.pdf.

Weatherill, G. A. (2014). *OpenQuake Hazard Modeller's Toolkit - User Guide*. Global Earthquake Model (GEM), Technical Report.

Weatherill, G.A., M. Pagani & J. García (2016). Exploring earthquake databases for the creation of magnitude-homogeneous catalogues: tools for application on a regional and global scale. *Geophysical Journal International* **206**, 1652-1676. WPG16v1 World Catalogue (original) version of 2016. WPG16v2 World Catalogue version of 5th July 2017. WPG16v3b World Catalogue version of 21st July 2017.

Wilson, M.P., G.R. Foulger, J.G. Gluyas, R.J. Davies & B.R. Julian (2017). HiQuake: The human-induced earthquake database. *Seismological Research Letters*. DOI: 10.1785/0220170112.

Wood, H.O. & F. Neumann (1931). Modified Mercalli Intensity of 1931. *Seismological Society of America Bulletin* **21**(4), 277-283.

8.2. Web References

ANSS Composite Catalogue: http://quake.geo.berkeley.edu/anss/anss-catalog-source-codes.html. Last accessed: 30th August 2017.
Earthquake-Report.com: https://earthquake-report.com. Last accessed: 15th November 2017.

Earthweek (2007): http://www.earthweek.com/online/ew070316/ew070316k.html. Last accessed: 17th November 2017.

EM-DAT – The Emergency Events Database (Université Catholique de Louvain, Brussels, Belgium; Cred. Prof. Dr. D. Guha-Sapir): http://www.emdat.be/. Last accessed: 15th November 2017.

Eurostat – Urban-rural typology (last accessed 13th September 2017): http://ec.europa.eu/eurostat/statistics-explained/index.php/Urban-rural_typology.

George Herald (2012): https://www.georgeherald.com/news/News/International/40572/strong-earthquake-strikes-western-china-20170711. Last accessed: 17th November 2017.

Hürriyet, (2004): http://www.hurriyet.com.tr/adiyamanda-deprem-6-olu-206514. Last accessed: 17th November 2017.

Induced Earthquakes (2017): http://inducedearthquakes.org/. Last accessed: 28th November 2017.

International Seismological Centre (ISC), Online Bulletin: http://www.isc.ac.uk/iscbulletin/search/. *Internatl. Seismol. Cent.*, Thatcham, United Kingdom, 2014.
List of agencies contributing with the ISC Bulletin (last accessed 17th August 2017): http://www.isc.ac.uk/iscbulletin/agencies/.
Review procedure (last accessed 8th November 2017): http://www.isc.ac.uk/iscbulletin/review/.

IOL (2007): https://www.iol.co.za/news/africa/schoolchildren-hurt-in-mozambique-quake-319051. Last accessed: 17th November 2017.

National Geophysical Data Center / World Data Service (NGDC/WDS): Significant Earthquake Database. National Geophysical Data Center, National Oceanic and Atmospheric Admnistration

(NOAA). DOI:10.7289/V5TD9V7K. https://www.ngdc.noaa.gov/hazard/earthqk.shtml. Last accessed: 15th November 2017.

National Research Institute for Earth Science and Disaster Prevention (NIED, Japan): http://www.bosai.go.jp/e/.

Nearby UK – Country bounding boxes: http://www.nearby.org.uk/downloads.html.
Last accessed 17th August 2017.

Otago Daily Times (2010): https://www.odt.co.nz/news/national/53-earthquake-shakes-hawkes-bay. Last accessed: 17th November 2017.

Radio New Zealand (2010): http://www.radionz.co.nz/news/national/56218/porangahau-jolted-by-5-point-2-quake. Last accessed: 17th November 2017.

ReliefWeb: https://reliefweb.int. Last accessed: 15th November 2017.

UNICEF – The State of the World's Children 2012 – Definitions (last accessed 13th September 2017): https://www.unicef.org/sowc2012/pdfs/SOWC-2012-DEFINITIONS.pdf.

Unites States' Census Bureau - 2010 Census Urban and Rural Classification and Urban Area Criteria: https://www.census.gov/geo/reference/ua/urban-rural-2010.html. Last accessed: 13th September 2017.

United States Geological Survey (USGS, 2015):
Earthquake catalogue search engine: https://earthquake.usgs.gov/earthquakes/search/.
Why do so many earthquakes occur at a depth of 10km?: https://www.usgs.gov/faqs/why-do-so-many-earthquakes-occur-a-depth-10km?qt-news_science_products=7#qt-news_science_products.
Last accessed: 10th November 2017.

8.3. Other Resources

Earthquake catalogues processed with the aid of:

- Tools available in OpenQuake (Pagani *et al.*, 2014).
- The OpenQuake Hazard Modeller's Toolkit (Weatherill, 2014).
- The toolkit published alongside the paper of Weatherill *et al.* (2016).

QGIS free and open source Geographic Information System: http://qgis.org/.

Shapefiles of countries' administrative boundaries from DIVA-GIS: http://www.diva-gis.org/gdata.

World maps data copyrighted by OpenStreetMap contributors. Available from https://www.openstreetmap.org.

APPENDIX I: WPG16 EVENTS WITHOUT DEPTH INFORMATION

I.1. Objectives

There are 215 events of the WPG16v3b world catalogue that do not have information on depth, all of them within the time range of interest. The objectives of the work presented in this appendix were:

- to verify if/which of these events end up being considered within the merged catalogue because they are read again from the ISC Bulletin;
- to understand why those events that are not part of the merged catalogue are not considered;
- to assess the impact of the latter not being considered on the final number of events in the merged world catalogue.

I.2. Methodology

The 215 events were compared against the merged catalogue that contains events from all magnitudes and depths, and has not been filtered yet according to all the criteria used in this work. In other words, this merged catalogue is the result of considering all events from the WPGv3b world catalogue and the events from the ISC Bulletin that satisfy the criteria regarding agencies, magnitude scales and completeness of information.

The comparison was carried out using a distance window of 100 km and a time window of 60 seconds, as well as by doing a direct search of the event ID. All results were visually inspected.

I.3. Characterisation of the Events Under Analysis

All 215 events occurred within the years 2001 and 2005, which means that they belong to the period of interest covered by the merged catalogue. 207 of the 215 events lie as well within the final moment magnitude range of interest (4.0≤**M**≤5.5), while the remaining two and six events have magnitudes smaller and larger than this range, respectively. Figure I.1 shows the location of the 215 events in the world.

Eliminating these 215 events from the WPG16v3b world catalogue before comparing the latter with the events listed in the ISC Bulletin means that, if found in the Bulletin, the events are eligible again for their incorporation in the merged catalogue. Whether they are finally incorporated or not depends on the availability of estimations of origin and magnitude that satisfy the criteria set for events from the ISC Bulletin (see Section 2.6).

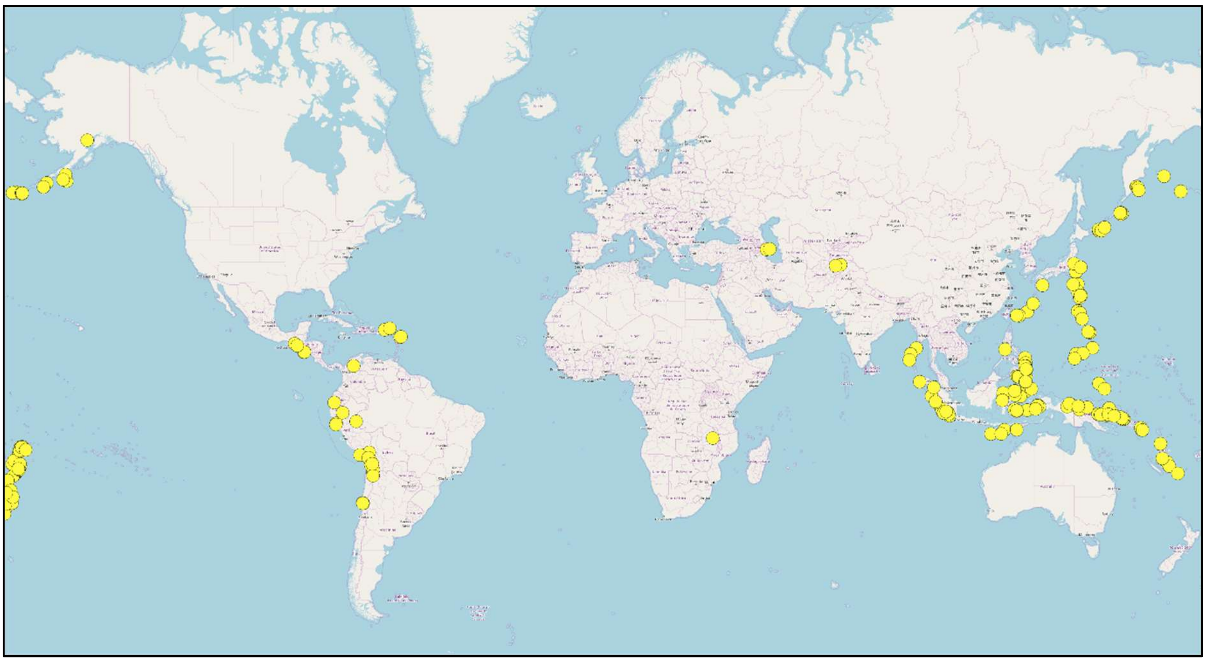


Figure I.1. Events from WPG16 without information on depth (215 events).

I.4. Events that Become Part of the Merged Catalogue

Of the 215 events of the WPG16v3b world catalogue that do not have information on depth, the 177 shown in Figure I.2 end up forming part of the merged catalogue.

Figure I.2. Events from WPG16 without information on depth that are included in the merged catalogue (177 events).

Figure I.3 shows a comparison between the moment magnitude of these 177 events in the WPG16v3b catalogue, which can result from either a direct estimation of moment magnitude or from the conversion of M_s or m_b, and the magnitude with which they are represented in the merged catalogue, which can be either **M**, M_s or M_L. As can be observed, except for the events that fall along the 1:1 relationship line, there is a tendency for magnitudes in the merged catalogue to be smaller than in their converted moment magnitudes in the WPG16v3b catalogue. This means that, when filtering events for the range of interest (4.0≤**M**≤5.5), 102 of the 177 events are kept when using the magnitude values from the merged catalogue, while 169 would be kept if the moment magnitude values from WPG16v3b were used instead. When applying the depth criterion over the 102 events that fall within the magnitude range according to the merged catalogue, only 40 events are left.

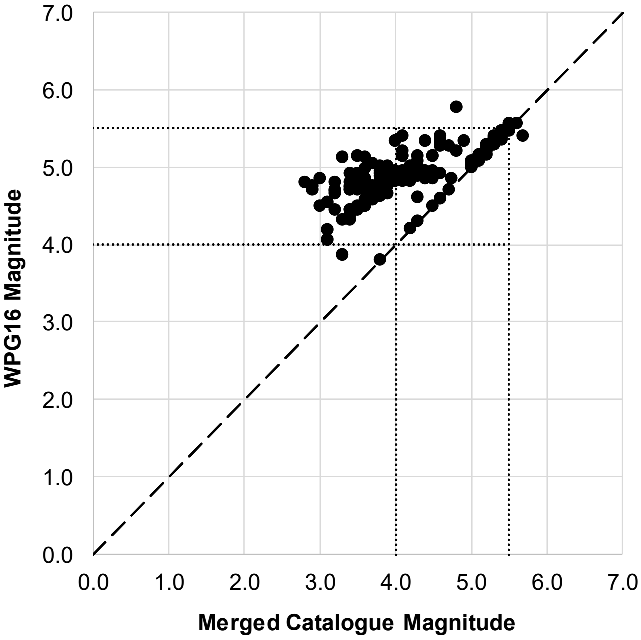


Figure I.3. Moment magnitude from WPG16v3b against magnitude (**M**, M_s or M_L) in the merged catalogue for the 177 events that have no depth information in WPG16v3b but belong to the merged catalogue.

I.5. Events that do not become part of the merged catalogue

The remaining 38 events shown in Figure I.4 do not become part of the merged catalogue. Their entries in the ISC Bulletin were analysed in detail in terms of the following:

- information from main agencies;
- information from local agencies;
- reported minimum, maximum, mean and median depths.

In most cases, magnitude estimates from main agencies were found to be only in terms of body-wave magnitude m_b, which is not being considered herein. Estimates in terms of other magnitude scales were available for some events, but they were related to origin estimates that lacked information on depth.

Most of these 38 events did not have estimates from local agencies. For those that did, either the local agencies that provided estimates were not relevant to the location of the epicentre, according to the criteria explained in Section 2.6, or they provided only body-wave magnitudes.

The minimum, maximum, mean and median depths of all those reported for each event were retrieved and compared against the depth limit corresponding to the moment magnitude reported in the WPG16v3b catalogue. When considering minimum values, only 4 out of these 38 events passed the criterion, while none passed when considering maximum values instead. Only one event passed the criterion when considering mean or median depths.

Figure I.4. Events from WPG16 without information on depth that are not included in the merged catalogue (38 events).

I.6. Conclusions

This analysis reveals that excluding the 215 events of the WPG16v3b world catalogue that do not have information on depth does not have any major consequences for the database, as all these events can be found within the ISC Bulletin and are treated in the same way as all other events that are not part of WPG16v3b. The only issue that can be pointed out is that moment magnitude estimates from WPG16v3b are lost for the events that are finally included in the database, and these would be preferable over values in terms of M_s or M_L that might replace them when taken directly from the ISC Bulletin. It could be possible to modify the algorithms so as to consider the values of moment magnitude from WPG16v3b for these events. However, given the very small number of events that would be affected by this procedure, the additional complexity is not warranted.

APPENDIX II: HIERARCHY OF AGENCIES CONTRIBUTING TO THE ISC

The agencies contributing to the ISC with data were ranked per country and region according to the criteria described in Section 2.6. The main list of agencies was retrieved from the website of the ISC, though some unlisted agencies were added as these were identified among the studied events. A similar table that exists for the ANSS Composite Catalogue of the United States was of use for cases in which information was missing.

Table II.1 shows the list of local and regional agencies used for the selection of one origin and magnitude estimate per event retrieved from the ISC Bulletin. The ranking restarts from 1 for each country/region. The list of main agencies can be found in Table 2.2 (Section 2.6).

As has been noted by Weatherill *et al.* (2016), ranking the different sources of data into a hierarchy is necessarily based on assumptions. The complexity of determining which agency to prioritise over which other is as large as the area of the globe covered by the analysis. Involving this work the whole world, it was impossible to study in detail the extent of the networks and quality of the equipment of each and every single agency listed below in order to make a decision. Fortunately, many countries have a very reduced number of agencies, and countries with a significant number of agencies tend to have at least a handful that are clearly more extensive than the rest. In the latter case, it is noted that it cannot be inferred that a position number 50 in the ranking is worse than a position 40, as it is likely that all positions after, let us say, 10, are more of an instrument to apply the algorithm than an actual statement of preference. This decision is not expected to have a great influence in the results, as it is expected that the natural tendency of very local agencies to report only about very local events take care of an event in California not being characterised by an agency in South Carolina, as there will be no estimate from the latter for that event.

Table II.1. List of local and regional agencies contributing to the ISC Bulletin and the ranking assigned to them herein. Ranking was assigned per country or region.

Acronym	Name	Country	Case	Ranking	Comments
KBL	Afghanistan Seismological Observatory	Afghanistan	Country	1	-
TIR	The Institute of Seismology, Academy of Sciences of Albania	Albania	Country	1	-
CRAAG	Centre de Recherche en Astronomie, Astrophysique et Géophysique	Algeria	Country	1	-
ALG	Algiers University	Algeria	Country	2	-
ABA	Alger-bouzareah	Algeria	Country	3	Alias ALG
SET	Setif Observatory	Algeria	Country	4	-
SJA	Instituto Nacional de Prevención Sísmica	Argentina	Country	1	-
ZON	Universidad Nacional de San Juan	Argentina	Country	2	-
BAA	Servicio Meteorologico Nacional	Argentina	Country	3	-
LPA	Universidad Nacional de La Plata	Argentina	Country	4	-
NSSP	National Survey of Seismic Protection	Armenia	Country	1	-
SPITAK	SPITAK	Armenia	Country	2	-
AUST	Geoscience Australia	Australia	Country	1	-
CAN	Australian National University	Australia	Country	2	-
MUN	Mundaring Observatory	Australia	Country	3	-
QDM	Queensland Department of Mines	Australia	Country	4	-
CUPWA	Curtin University	Australia	Country	5	-
BRS	Brisbane Seismograph Station	Australia	Country	6	-
RIV	Riverview Observatory	Australia	Country	7	-
RMIT	Royal Melbourne Institute of Technology	Australia	Country	8	-

Table II.1. Continued.

Acronym	Name	Country	Case	Ranking	Comments
TAU	University of Tasmania	Australia	Country	9	-
ADE	Primary Industries and Resources SA	Australia	Country	10	-
VIE	Zentralanstalt für Meteorologie und Geodynamik (ZAMG)	Austria	Country	1	-
VKA	Vienna-Zobenzl, Austria	Austria	Country	2	ANSS / Berkeley
AZER	Republic Center of Seismic Survey	Azerbaijan	Country	1	-
BELR	Centre of Geophysical Monitoring of the National Academy of Sciences of Belarus	Belarus	Country	1	-
UCC	Royal Observatory of Belgium	Belgium	Country	1	-
LPZ	Observatorio San Calixto	Bolivia	Country	1	-
SCB	Observatorio San Calixto (alias)	Bolivia	Country	2	Alias LPZ
BANJO	Broadband ANdean JOint Experiment	Bolivia	Country	3	United States
SEDA	Seismic Exploration of the Deep Altiplano	Bolivia	Country	4	United States
RHSSO	Republic Hydrometeorological Service, Seismological Observatory, Banja Luka	Bosnia - Herzegovina	Country	1	-
SAR	Sarajevo Seismological Station	Bosnia - Herzegovina	Country	2	-
BDF	Observatório Sismológico da Universidade de Brasília	Brazil	Country	1	-
VAO	Instituto Astronomico e Geofísico	Brazil	Country	2	-
MASS	Marcelo Assumpcao	Brazil	Country	3	-
SOF	Geophysical Institute, Bulgarian Academy of Sciences	Bulgaria	Country	1	-
KBC	Institut de Recherches Géologiques et Minières	Cameroon United Republic	Country	1	-
OTT	Canadian Hazards Information Service, Natural Resources Canada	Canada	Country	1	-
PGC	Pacific Geoscience Centre	Canada	Country	2	-
LDN	University of Western Ontario	Canada	Country	3	-
BNG	Observatoire ORSTOM de Bangui	Central African Republic	Country	1	-
GUC	Centro Sismológico Nacional, Universidad de Chile	Chile	Country	1	-
ANT	Antofagasta	Chile	Country	2	Alias GUC
SAN	Santiago	Chile	Country	3	Alias GUC
STL	Santa Lucia Seismological Station	Chile	Country	4	Alias GUC
PUNA	Puna Plateau, Argentina and Northern Chile Experiment	Chile	Country	5	Germany
ANCORP	Andean Continental Research Project	Chile	Country	6	Germany
FUBES	Earth Science Dept., Geophysics Section	Chile	Country	7	Germany
GEOMR	GEOMAR	Chile	Country	8	Germany
CNH	Changchun	China	Country	1	Alias BJI
NAN	Nanking Station	China	Country	2	Alias BJI
PEK	Peking	China	Country	3	Alias BJI
ZSC	Zose Seismological Station	China	Country	4	Alias BJI
BJT	Baijiatuan	China	Country	5	-
TIENSHAN	Tien Shan Continental Dynamics	China	Country	6	United States
INDEPTH3	International Deep Profiling of Tibet and the Himalayas	China	Country	7	United States
RSNC	Red Sismológica Nacional de Colombia	Colombia	Country	1	-
UVC	Universidad del Valle	Colombia	Country	2	-
BOG	Universidad Javeriana	Colombia	Country	3	-
GOM	Observatoire Volcanologique de Goma	Congo Democratic Republic	Country	1	-
LWI	Centre de Geophysique du Zaire	Congo Democratic Republic	Country	2	-
CASC	Central American Seismic Center	Costa Rica	Country	1	-
CADCG	Central America Data Centre	Costa Rica	Country	2	Alias CASC
HDC	Observatorio Vulcanológico y Sismológico de Costa Rica	Costa Rica	Country	3	-
UCR	Sección de Sismología, Vulcanología y Exploración Geofísica	Costa Rica	Country	4	-
ICE	Instituto Costarricense de Electricidad	Costa Rica	Country	5	-
SJS	Instituto Costarricense de Electricidad (alias)	Costa Rica	Country	6	Alias ICE
OSA	Osa Peninsula Project, Costa Rica	Costa Rica	Country	7	United States
SJR	Seccion de Sismologia, Univ. de Costa Rica, San Jose	Costa Rica	Country	8	ANSS / Berkeley
ZAG	Seismological Survey of the Republic of Croatia	Croatia	Country	1	-
SSNC	Servicio Sismológico Nacional Cubano	Cuba	Country	1	-
NIC	Cyprus Geological Survey Department	Cyprus	Country	1	-
CSS	Geological Survey Department	Cyprus	Country	2	ANSS / Berkeley
PRU	Geophysical Institute, Academy of Sciences of the Czech Republic	Czech Republic	Country	1	-
IRSM	Institute of Rock Structure and Mechanics	Czech Republic	Country	2	-
IPEC	The Institute of Physics of the Earth (IPEC)	Czech Republic	Country	3	-
PRA	Academy of Sciences of the Czech Republic	Czech Republic	Country	4	-
KHC	Geofysikalni Ustav, Ceske Akademie Ved	Czech Republic	Country	5	-
UGN	Institute of Geonics AS CR	Czech Republic	Country	6	-
VRAC	Vranov Seismological Station	Czech Republic	Country	7	-

Table II.1. Continued.

Acronym	Name	Country	Case	Ranking	Comments
WBNET	West Bohemia Seismic Network	Czech Republic	Country	8	-
DNK	Geological Survey of Denmark and Greenland	Denmark	Country	1	-
ARO	Observatoire Géophysique d'Arta	Djibouti	Country	1	-
INDR	Inst. Nacional de Recursos Hidraulicos	Dominican Republic	Country	1	-
OSPL	Observatorio Sismologico Politecnico Loyola	Dominican Republic	Country	2	-
SDD	Universidad Autonoma de Santo Domingo	Dominican Republic	Country	3	-
IGQ	Servicio Nacional de Sismología y Vulcanología	Ecuador	Country	1	-
QUI	Escuela Politécnica Nacional	Ecuador	Country	2	-
HLW	National Research Institute of Astronomy and Geophysics	Egypt	Country	1	-
CIG	Servicio Geologico Nacional de El Salvador	El Salvador	Country	1	-
SNET	Servicio Nacional de Estudios Territoriales	El Salvador	Country	2	-
SSS	Centro de Estudios y Investigaciones Geotecnicas del San Salvador	El Salvador	Country	3	-
ASM	University of Asmara	Eritrea	Country	1	-
EST	Geological Survey of Estonia	Estonia	Country	1	-
AAE	University of Addis Ababa	Ethiopia	Country	1	-
EAGLE	Ethiopia-Afar Geoscientific Lithospheric Experiment	Ethiopia	Country	2	-
EBSE	Ethiopian Broadband Seismic Experiment	Ethiopia	Country	3	-
SVA	Department of Mineral Resources	Fiji	Country	1	-
HEL	Institute of Seismology, University of Helsinki	Finland	Country	1	-
KAF	Kangasniemi Station	Finland	Country	2	-
SOD	Sodankyla Seismological Station	Finland	Country	3	Alias HEL
NUR	Nurmijarvi Station	Finland	Country	4	Alias HEL
FIA0	Finessa Array	Finland	Country	5	-
LDG	Laboratoire de Détection et de Géophysique/CEA	France	Country	1	-
IPGP	Institut de Physique du Globe de Paris	France	Country	2	-
BCIS	Bureau Central International de Sismologie	France	Country	3	-
STR	Institut de Physique du Globe	France	Country	4	-
PIST	P. Stahl	France	Country	5	-
PPT	Laboratoire de Géophysique/CEA	French Polynesia	Country	1	-
TIF	Institute of Earth Sciences/ National Seismic Monitoring Center	Georgia	Country	1	-
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe	Germany	Country	1	-
AWI	Alfred Wegener Institute for Polar and Marine Research	Germany	Country	2	-
LED	Landeserdbebendienst Baden-Württemberg	Germany	Country	3	-
STU	Stuttgart Seismological Station	Germany	Country	4	-
LEDBW	LED / STU (alias)	Germany	Country	5	Alias LED/STU
BRG	Seismological Observatory Berggießhübel, TU Bergakademie Freiberg	Germany	Country	6	-
CLL	Geophysikalisches Observatorium Collm	Germany	Country	7	-
HLUG	Hessisches Landesamt für Umwelt und Geologie	Germany	Country	8	-
GDNRW	Geologischer Dienst Nordrhein-Westfalen	Germany	Country	9	-
BUG	Institute of Geology, Mineralogy & Geophysics	Germany	Country	10	-
BNS	Erdbebenstation, Geologisches Institut der Universität, Köl	Germany	Country	11	-
FUR	Geophysikalisches Observatorium der Universität München	Germany	Country	12	-
SZGRF	Seismologisches Zentralobservatorium Gräfenberg	Germany	Country	13	-
GRF	Zentralobservatorium Gräfenberg, Erlangen, Germany	Germany	Country	14	ANSS / Berkeley
HAN	Hannover	Germany	Country	15	Alias SZGRF
JEN	Geodynamisches Observatorium Moxa	Germany	Country	16	-
LER	Besucherbergwerk Binweide Station	Germany	Country	17	-
BGLD	Geophysikalisches Observatorium der Ludwig-Maximilians Universität	Germany	Country	18	-
GRA1	Grafenberg Array	Germany	Country	19	-
HROE	Geophysikalisches Observatorium - Hohe Rhvn-Fladungen	Germany	Country	20	-
MROB	Geophysikalisches Observatorium - Rosenbuhl	Germany	Country	21	-
MZEK	Geophysikalisches Observatorium - Zeckenberg	Germany	Country	22	-
NORI	Geophysikalisches Observatorium - Nordlinger Ries	Germany	Country	23	-
OBER	Geophysikalisches Observatorium - Oberstdorf	Germany	Country	24	-
OGA	Geophysikalisches Observatorium - Obergurgl/A	Germany	Country	25	-
RJOB	Geophysikalisches Observatorium - Jochberg	Germany	Country	26	-
RNON	Geophysikalisches Observatorium - Staufen-Nonn	Germany	Country	27	-
ROTZ	Geophysikalisches Observatorium - Rotzenmuhle	Germany	Country	28	-
SCE	Geophysikalisches Observatorium - Schlegeis/Austria	Germany	Country	29	-
WET	Geophysikalisches Observatorium - Wettzell	Germany	Country	30	-
GEC2	Geress Array	Germany	Country	31	-

Table II.1. Continued.

Acronym	Name	Country	Case	Ranking	Comments
MOX	Moxa, Thuringen, Germany	Germany	Country	32	ANSS / Berkeley
GDSN	Ghana Geological Survey Department	Ghana	Country	1	-
KUK	Geological Survey Department of Ghana	Ghana	Country	2	-
ATH	National Observatory of Athens	Greece	Country	1	-
THE	Department of Geophysics, Aristotle University of Thessaloniki	Greece	Country	2	-
UPSL	University of Patras, Department of Geology	Greece	Country	3	-
VSI	University of Athens	Greece	Country	4	-
PAG	Le Parnasse, Guadeloupe	Guadeloupe	Country	1	ANSS / Berkeley
GCG	INSIVUMEH	Guatemala	Country	1	-
UNAH	Universidad Nacional Autonoma de Honduras	Honduras	Country	1	-
HKC	Hong Kong Observatory	Hong Kong	Country	1	-
KRSZO	Geodetic and Geophysical Reasearch Institute, Hungarian Academy of Sciences	Hungary	Country	1	-
BUD	Geodetic and Geophysical Research Institute	Hungary	Country	2	-
REY	Icelandic Meteorological Office	Iceland	Country	1	-
NDI	National Centre for Seismology of the Ministry of Earth Sciences of India	India	Country	1	-
HYD	National Geophysical Research Institute	India	Country	2	Alias NDI
POO	Poona Observatory	India	Country	3	Alias NDI
HYB	National Geophysical Research Institute	India	Country	4	-
SHL	Central Seismological Observatory	India	Country	5	-
MERI	Maharashta Engineering Research Institute	India	Country	6	-
MUM	Manipur University	India	Country	7	-
RRLJ	Regional Research Laboratory Jorhat	India	Country	8	-
GBA	Bhaba Atomic Research Centre	India	Country	9	-
BHUJ2	Study of Aftershocks of the Bhuj Earthquake by Japanese Research Team	India	Country	10	Japan
BHUJ	Bhuj Aftershock Study	India	Country	11	United States
DJA	Badan Meteorologi, Klimatologi dan Geofisika	Indonesia	Country	1	-
LEM	Lembang Station	Indonesia	Country	2	-
DJA	Lembang Station (alias)	Indonesia	Country	3	Alias LEM
BIAK	Biak earthquake aftershocks (17-Feb-1996)	Indonesia	Country	4	United States
TEH	Tehran University	Iran	Country	1	-
TAB	Tabriz Seismological Observatory	Iran	Country	2	-
SHI	Shiraz Observatory	Iran	Country	3	-
THR	International Institute of Earthquake Engineering and Seismology (IIEES)	Iran	Country	4	-
IASBS	Institute for Advanced Studies in Basic Sciences	Iran	Country	5	-
UPIES	Institute of Earth- and Environmental Science	Iran	Country	6	-
ISN	Iraqi Meteorological and Seismology Organisation	Iraq	Country	1	-
DIAS	Dublin Institute for Advanced Studies	Ireland	Country	1	-
GII	The Geophysical Institute of Israel	Israel	Country	1	-
IPRG	Institute for Petroleum Research and Geophysics	Israel	Country	2	-
JER	Seismological Laboratory, Geological Survey of Israel	Israel	Country	3	-
AFAR	The Afar Depression: Interpretation of the 1960-2000 Earthquakes	Israel	Country	4	-
ROM	Istituto Nazionale di Geofisica e Vulcanologia	Italy	Country	1	-
PAV	Pavia	Italy	Country	2	Alias ROM
MED_RCMT	MedNet Regional Centroid - Moment Tensors	Italy	Country	3	-
TRI	Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS)	Italy	Country	4	-
MES	Messina Seismological Observatory	Italy	Country	5	-
MSI	Messina Seismological Observatory (alias)	Italy	Country	6	-
AQU	L,Aquila	Italy	Country	7	-
GEN	Dipartimento per lo Studio del Territorio e delle sue Risorse (RSNI)	Italy	Country	8	-
RISSC	Laboratory of Research on Experimental and Computational Seimology	Italy	Country	9	-
ACI	Universita di Calabria	Italy	Country	10	-
OSUB	Osservatorio Sismologico Universita di Bari	Italy	Country	11	-
PRT	Observatorio San Domenico	Italy	Country	12	-
LIC	Station Géophysique de Lamto	Ivory Coast	Country	1	-
JSN	Jamaica Seismic Network	Jamaica	Country	1	-
HOJ	University of the West Indies, Mona, Jamaica	Jamaica	Country	2	ANSS / Berkeley
JMA	Japan Meteorological Agency	Japan	Country	1	-
TOK	Tokyo Observatory	Japan	Country	2	Alias JMA
NIED	National Research Institute for Earth Science and Disaster Prevention	Japan	Country	3	-
ERI	Earthquake Research Institute, University of Tokyo	Japan	Country	4	-
SYO	National Institute of Polar Research	Japan	Country	5	-

Table II.1. Continued.

Acronym	Name	Country	Case	Ranking	Comments
MAT	The Matsushiro Seismological Observatory	Japan	Country	6	-
HOKK_DSZ	Hokkaido Double Seismic Zone	Japan	Country	7	-
IFREE	Institute For Research on Earth Evolution	Japan	Country	8	-
JSO	Jordan Seismological Observatory	Jordan	Country	1	-
NNC	National Nuclear Center	Kazakhstan	Country	1	-
SOME	Seismological Experimental Methodological Expedition	Kazakhstan	Country	2	-
AAA	Alma-ata	Kazakhstan	Country	3	-
AAB	Alma-ata 2	Kazakhstan	Country	4	-
NAI	University of Nairobi	Kenya	Country	1	-
KRISP	Kenya Rift International Seismic Project	Kenya	Country	2	-
SIK	Seismic Institute of Kosovo	Kosovo	Country	1	-
KISR	Kuwait Institute for Scientific Research	Kuwait	Country	1	-
KRNET	Institute of Seismology, Academy of Sciences of Kyrgyz Republic	Kyrgyzstan	Country	1	-
KNET	Kyrgyz Seismic Network	Kyrgyzstan	Country	2	-
LVSN	Latvian Seismic Network	Latvia	Country	1	-
GRAL	National Council for Scientific Research	Lebanon	Country	1	-
KSA	Observatoire de Ksara	Lebanon	Country	2	-
BHL	Bhannes, Lebanon	Lebanon	Country	3	ANSS / Berkeley
LIB	Tripoli	Libya	Country	1	-
LDSN	Libyan Center for Remote Sensing and Space Science, Tripoli	Libya	Country	2	-
LIT	Geological Survey of Lithuania	Lithuania	Country	1	-
MCO	Macao Meteorological and Geophysical Bureau	Macau	Country	1	-
SKO	Seismological Observatory Skopje	Macedonia	Country	1	-
TAN	Antananarivo	Madagascar	Country	1	-
GSDM	Geological Survey Department Malawi	Malawi	Country	1	-
KLM	Malaysian Meteorological Service	Malaysia	Country	1	-
FDF	Fort de France	Martinique	Country	1	-
MEX	Instituto de Geofísica de la UNAM	Mexico	Country	1	-
UNM	Instituto de Geofisica, UNAM, Mexico City	Mexico	Country	2	ANSS / Berkeley
TAC	Estación Central de Tacubaya	Mexico	Country	3	-
OAX	Oaxaca	Mexico	Country	4	Alias TAC
MER	Merida	Mexico	Country	5	Alias TAC
COM	Comitan	Mexico	Country	6	Alias TAC
RSMAC	Red Sísmica Mexicana de Apertura Continental	Mexico	Country	7	-
ECX	Centro de Investigación Científica y de Educación Superior de Ensenada	Mexico	Country	8	-
MOLD	Institute of Geophysics and Geology	Moldova	Country	1	-
OBM	Research Centre of Astronomy and Geophysics	Mongolia	Country	1	-
EBM	Esen Boulak	Mongolia	Country	2	-
PDG	Seismological Institute of Montenegro	Montenegro	Country	1	-
TTG	Titograd Seismological Station	Montenegro	Country	2	Alias PDG
MVOV	Montserrat Volcano Observatory	Montserrat	Country	1	-
CNRM	Centre National de Recherche	Morocco	Country	1	-
RBA	Université Mohammed V	Morocco	Country	2	-
SPGM	Service de Physique du Globe	Morocco	Country	3	Alias RBA
AVE	Averroes	Morocco	Country	4	-
MOZ	Direccao Nacional de Geologia	Mozambique	Country	1	-
CNG	Seismographic Station Changalane	Mozambique	Country	2	-
NAM	The Geological Survey of Namibia	Namibia	Country	1	-
DMN	National Seismological Centre, Nepal	Nepal	Country	1	-
HIMNT	Himalayan Nepal Tibet Experiment	Nepal	Country	2	United States
DBN	Koninklijk Nederlands Meteorologisch Instituut	Netherlands	Country	1	-
ORF	Orfeus Data Center	Netherlands	Country	2	-
NOU	IRD Centre de Nouméa	New Caledonia	Country	1	-
WEL	Institute of Geological and Nuclear Sciences	New Zealand	Country	1	-
VUW	Victoria University of Wellington	New Zealand	Country	2	-
SAPSE	Southern Alps Passive Seismic Experiment	New Zealand	Country	3	-
INET	Instituto Nicaragüense de Estudios Territoriales	Nicaragua	Country	1	-
KEA	Korea Earthquake Administration	North Korea	Country	1	-
NAO	Stiftelsen NORSAR	Norway	Country	1	-
BER	University of Bergen	Norway	Country	2	-
ARA0	Arcess Array	Norway	Country	3	-

Table II.1. Continued.

Acronym	Name	Country	Case	Ranking	Comments
NRA0	Noress Array	Norway	Country	4	-
OMAN	Sultan Qaboos University	Oman	Country	1	-
QUE	Pakistan Meteorological Department	Pakistan	Country	1	-
MSSP	Micro Seismic Studies Programme, PINSTECH	Pakistan	Country	2	-
UPA	Universidad de Panama	Panama	Country	1	-
PANAMA97	Panama Canal Seismicity Study	Panama	Country	2	United States
PMG	Port Moresby Geophysical Observatory	Papua New Guinea	Country	1	-
RAB	Rabaul Volcanological Observatory	Papua New Guinea	Country	2	-
WOODLARK	Woodlark-D,Entrecasteaux Rift, Papua New Guinea	Papua New Guinea	Country	3	United States
ARE	Instituto Geofisico del Peru	Peru	Country	1	-
LIM	Lima	Peru	Country	2	Alias ARE
PISCO	Proyecto de Investigacion Sismologica de la Cordillera Occidental	Peru	Country	3	Germany
CINCA	Crustal Investigations Off- and On-shore Nazca - Central Andes	Peru	Country	4	Germany
MAN	Philippine Institute of Volcanology and Seismology	Philippines	Country	1	-
QCP	Manila Observatory	Philippines	Country	2	-
WAR	Institute of Geophysics, Polish Academy of Sciences	Poland	Country	1	-
LIS	Instituto de Meteorologia	Portugal	Country	1	-
PTO	Instituto Geofísico da Universidade do Porto	Portugal	Country	2	-
AZO	Centro de Informação e Vigilância Sismovulcânica dos Azores	Portugal	Country	3	-
SVSA	Sistema de Vigilância Sismológica dos Açores	Portugal	Country	4	-
OGAUC	Centro de Investigação da Terra e do Espaço da Universidade de Coimbra	Portugal	Country	5	-
IGIL	Instituto Geofisico do Infante Dom Luiz	Portugal	Country	6	-
INMG	Instituto Português do Mar e da Atmosfera, I.P.	Portugal	Country	7	-
ADH	Observatorio Afonso Chaves	Portugal	Country	8	-
PDA	Universidade dos Açores	Portugal	Country	9	-
RSPR	Red Sísmica de Puerto Rico	Puerto Rico	Country	1	-
MPR	University of Puerto Rico, Mayaguez, Puerto Rico	Puerto Rico	Country	2	ANSS / Berkeley
BUC	National Institute for Earth Physics	Romania	Country	1	-
MLR	Muntele Rosu Station	Romania	Country	2	-
VLA	Vladivostok Seismological Station	Russian Fed.	Country	1	Alias MOS
IDG	Institute of Dynamics of Geosphere, Russian Academy of Sciences	Russian Fed.	Country	2	-
BYKL	Baykal Regional Seismological Centre, GS SB RAS	Russian Fed.	Country	3	-
KRSC	Kamchatkan Experimental and Methodical Seismological Department, GS RAS	Russian Fed.	Country	4	-
CFUSG	Inst. of Seismology and Geodynamics, V.I. Vernadsky Crimean Federal University	Russian Fed.	Country	5	-
YARS	Yakutiya Regional Seismological Center, GS SB RAS	Russian Fed.	Country	6	-
ASRS	Altai-Sayan Seismological Centre, GS SB RAS	Russian Fed.	Country	7	-
DRS	Dagestan Branch, Geophysical Survey, Russian Academy of Sciences	Russian Fed.	Country	8	-
IEPN	Institute of Environmental Problems of the North, Russian Academy of Sciences	Russian Fed.	Country	9	-
MIRAS	Mining Institute of the Ural Branch of the Russian Academy of Sciences	Russian Fed.	Country	10	-
NERS	North Eastern Regional Seismological Centre, GS RAS	Russian Fed.	Country	11	-
NORS	North Ossetia (Alania) Branch, Geophysical Survey, Russian Academy of Sciences	Russian Fed.	Country	12	-
SKHL	Sakhalin Experimental and Methodological Seismological Expedition, GS RAS	Russian Fed.	Country	13	-
CMWS	Laboratory of Seismic Monitoring of Caucasus Mineral Water Region, GSRAS	Russian Fed.	Country	14	-
KOLA	Kola Regional Seismic Centre, GS RAS	Russian Fed.	Country	15	-
KRAR	Krasnoyarsk Scientific Research Inst. of Geology and Mineral Resources, Russia	Russian Fed.	Country	16	-
VKMS	Lab. of Seismic Monitoring, Voronezh region, GSRAS & Voronezh State University	Russian Fed.	Country	17	-
IEC	Institute of the Earth Crust, SB RAS	Russian Fed.	Country	18	-
RIPT	Research Inst. of Pulse Technique	Russian Fed.	Country	19	-
OBN	Geophysical Survey of the Russian Academy of Sciences, Obninsk, Russia	Russian Fed.	Country	20	EMSC
AFI	Apia Observatory	Samoa	Country	1	-
API	Apia Observatory (alias)	Samoa	Country	2	Alias API
RYD	King Saud University	Saudi Arabia	Country	1	-
SGS	Saudi Geological Survey	Saudi Arabia	Country	2	-
SNSN	Saudi National Seismic Network	Saudi Arabia	Country	3	-
BEO	Seismological Survey of Serbia	Serbia	Country	1	-
BRA	Geophysical Institute, Slovak Academy of Sciences	Slovakia	Country	1	-
SPC	Skalnate-Pleso Seismological Station	Slovakia	Country	2	Alias BRA
LJU	Slovenian Environment Agency	Slovenia	Country	3	-
HNR	Ministry of Mines, Energy and Rural Electrification	Solomon Islands	Country	1	-
PRE	Council for Geoscience	South Africa	Country	1	-
JOH	Bernard Price Institute of Geophysics	South Africa	Country	2	-

Table II.1. Continued.

Acronym	Name	Country	Case	Ranking	Comments
KMA	Korea Meteorological Administration	South Korea	Country	1	-
MDD	Instituto Geográfico Nacional	Spain	Country	1	-
MAL	Malaga	Spain	Country	2	Alias MDD
TOL	Toledo Observatory	Spain	Country	3	Alias MDD
CRT	Cartuja Seismological Station	Spain	Country	4	Alias MDD
SFS	Real Instituto y Observatorio de la Armada	Spain	Country	5	-
MRB	Institut Cartogràfic i Geològic de Catalunya	Spain	Country	6	-
IAG	Instituto Andaluz de Geofisica	Spain	Country	7	-
EBR	Observatori de l'Ebre	Spain	Country	8	-
FBR	Fabra Observatory	Spain	Country	9	-
ESLA	Centro Sismologico de Sonseca	Spain	Country	10	-
IBER	Institute of Earth Sciences Jaume Almera - CSIC	Spain	Country	11	-
SSN	Sudan Seismic Network	Sudan	Country	1	-
UPP	University of Uppsala	Sweden	Country	1	-
KIR	Kiruna	Sweden	Country	2	Alias UPP
HFS	Hagfors Observatory	Sweden	Country	3	-
HFS1	Hagfors Observatory	Sweden	Country	4	-
HFS2	Hagfors Observatory (alias)	Sweden	Country	5	-
CANSK	Canadian and Scandinavian Networks	Sweden	Country	6	Alias HFS
STK	Stockholm Seismological Station	Sweden	Country	7	Alias HFS
ZUR	Swiss Seismological Service (SED)	Switzerland	Country	1	-
ZUR_RMT	Zurich Moment Tensors	Switzerland	Country	2	-
NEU	Neuchatel Station	Switzerland	Country	3	Alias ZUR
OSS	Ova Spin	Switzerland	Country	4	-
NSSC	National Syrian Seismological Center	Syria	Country	1	-
DUSS	Damascus University, Syria	Syria	Country	2	-
TAP	CWB	Taiwan	Country	1	-
ASIES	Institute of Earth Sciences, Academia Sinica	Taiwan	Country	2	-
GSAST	Geophysial Survey of the Academy of Sciences of the Republic of Tajikistan	Tajikistan	Country	1	-
KHO	Khorog	Tajikistan	Country	2	-
TZN	University of Dar Es Salaam	Tanzania	Country	1	-
TANZANIA	Tanzania Broadband Seismic Experiment	Tanzania	Country	2	United States
BKK	Thai Meteorological Department	Thailand	Country	1	-
TRN	The Seismic Research Centre	Trinidad and Tobago	Country	1	-
TUN	Institut National de la Météorologie	Tunisia	Country	1	-
ISK	Kandilli Observatory and Research Institute	Turkey	Country	1	-
DDA	Disaster and Emergency Management Presidency	Turkey	Country	2	-
ATA	The Earthquake Research Center Ataturk University	Turkey	Country	3	-
IST	Institute of Physics of the Earth, Technical University of Istanbul	Turkey	Country	4	-
ITU	Faculty of Mines, Department of Geophysical Engineering	Turkey	Country	5	-
GBZT	Marmara Research Center	Turkey	Country	6	-
ENT	Geological Survey and Mines Department	Uganda	Country	1	-
SIGU	Subbotin Institute of Geophysics, National Academy of Sciences	Ukraine	Country	1	-
LVV	Department of Seismic Activity of Carpathian area (Lviv)	Ukraine	Country	2	-
DSN	Dubai Seismic Network	United Arab Emirates	Country	1	-
BGS	British Geological Survey	United Kingdom	Country	1	-
ISS	International Seismological Summary	United Kingdom	Country	2	-
EKA	Eskdalemuir Array Station	United Kingdom	Country	3	-
EPSI	Reference events computed by the ISC for EPSI project	United Kingdom	Country	4	-
KEW	Kew Observatory	United Kingdom	Country	5	-
ULE	University of Leeds	United Kingdom	Country	6	-
USOES	University of Southampton Ocean and Earth Science	United Kingdom	Country	7	-
UCDES	Department of Earth Sciences	United Kingdom	Country	8	-
AEIC	Alaska Earthquake Information Center	United States Alaska	Country	1	-
PMR	Alaska Tsunami Warning Center,	United States Alaska	Country	2	-
AGS	Alaska Seismic Project	United States Alaska	Country	3	-
UAF	Department of Geosciences	United States Alaska	Country	4	-
HVO	Hawaiian Volcano Observatory	United States Hawaii	Country	1	-
PTWC	Pacific Tsunami Warning Center	United States Mainland	Country	1	-
HON	Pacific Tsunami Warning Center - NOAA	United States Mainland	Country	2	-
SCEDC	Southern California Earthquake Data Center	United States Mainland	Country	3	-

Table II.1. Continued.

Acronym	Name	Country	Case	Ranking	Comments
NCEDC	Northern California Earthquake Data Center	United States Mainland	Country	4	-
PNNL	Pacific Northwest National Laboratory	United States Mainland	Country	5	-
BRK	Berkeley Seismological Laboratory	United States Mainland	Country	6	-
PAS	California Institute of Technology	United States Mainland	Country	7	-
BOU	University of Colorado at Boulder	United States Mainland	Country	8	-
LDO	Lamont-Doherty Earth Observatory	United States Mainland	Country	9	-
CENT	Centennial Earthquake Catalog	United States Mainland	Country	10	-
LAO	Large Aperture Seismic Array	United States Mainland	Country	11	-
COSMOS	Consortium of Organizations for Strong Motion Observations	United States Mainland	Country	12	-
ASL	Albuquerque Seismological Laboratory	United States Mainland	Country	13	-
CERI	Center for Earthquake Research and Information	United States Mainland	Country	14	-
ANF	USArray Array Network Facility	United States Mainland	Country	15	-
WMO	Wichita Mountains Observatory	United States Mainland	Country	16	Alias NEIS
JSA	Jesuit Society of America	United States Mainland	Country	17	-
TUL	Oklahoma Geological Survey	United States Mainland	Country	18	-
BUT	Montana Bureau of Mines and Geology	United States Mainland	Country	19	-
OGSO	Ohio Geological Survey	United States Mainland	Country	20	-
WES	Weston Observatory	United States Mainland	Country	21	-
PNSN	Pacific Northwest Seismic Network	United States Mainland	Country	22	-
SNM	New Mexico Institute of Mining and Technology	United States Mainland	Country	23	-
SLC	Salt Lake City	United States Mainland	Country	24	-
PAL	Palisades	United States Mainland	Country	25	-
SIO	Scripps Institution of Oceanography	United States Mainland	Country	26	-
TVA	Tennessee Valley Authority	United States Mainland	Country	27	-
PMEL	Pacific seismicity from hydrophones	United States Mainland	Country	28	-
GLD	Golden	United States Mainland	Country	29	-
PFO	Pinyon Flat Observatory	United States Mainland	Country	30	-
PIN	Pinedale Seismic Array	United States Mainland	Country	31	-
CDWR	California Department of Water Resources	United States Mainland	Country	32	-
COR	COAS Physical Oceanography	United States Mainland	Country	33	-
DOE	Department of Energy	United States Mainland	Country	34	-
DASA	Defense Atomic Support Agency	United States Mainland	Country	35	-
ERDA	Energy Research and Development Administration	United States Mainland	Country	36	-
USAEC	United States Atomic Energy Commission	United States Mainland	Country	37	-
LTX	Lajitas Seismic Array	United States Mainland	Country	38	-
USAF	US Air Force Technical Applications Center	United States Mainland	Country	39	-
USBR	US Bureau of Reclamation	United States Mainland	Country	40	-
BLA	Virginia Tech	United States Mainland	Country	41	-
SLM	Saint Louis University	United States Mainland	Country	42	-
REN	MacKay School of Mines	United States Mainland	Country	43	-
SEA	Geophysics Program AK-50	United States Mainland	Country	44	-
UUSS	The University of Utah Seismograph Stations	United States Mainland	Country	45	-
AFUA	University of Alabama	United States Mainland	Country	46	-
BUEE	Earth & Environment	United States Mainland	Country	47	-
CSC	University of South Carolina	United States Mainland	Country	48	-
UTEP	Department of Geological Sciences	United States Mainland	Country	49	-
AAM	University of Michigan	United States Mainland	Country	50	-
INY	Cornell university (INSTOC)	United States Mainland	Country	51	-
MSUGS	Michigan State University, Department of Geological Sciences	United States Mainland	Country	52	-
UCSC	Earth & Planetary Sciences	United States Mainland	Country	53	-
UREES	Department of Earth and Environmental Science	United States Mainland	Country	54	-
APT	University of Connecticut	United States Mainland	Country	55	-
BSE	Boise State University	United States Mainland	Country	56	-
EUO	Department of Geological Sciences, University of Oregon	United States Mainland	Country	57	-
KAAPVAAL	Kaapvaal Craton Seismic Experiment	United States Mainland	Country	58	-
ISU	Institute of Seismology, Academy of Sciences, Republic of Uzbekistan	Uzbekistan	Country	1	-
FUNV	Fundación Venezolana de Investigaciones Sismológicas	Venezuela	Country	1	-
CAR	Instituto Sismologico de Caracas	Venezuela	Country	2	-
UAV	Red Sismológica de Los Andes Venezolanos	Venezuela	Country	3	-
GUV	CVG Electrificacion del Caroni	Venezuela	Country	4	-
INTV	Instituto de Tecnología Venezolana para el Petróleo	Venezuela	Country	5	-

Table II.1. Continued.

Acronym	Name	Country	Case	Ranking	Comments
PLV	National Center for Scientific Research	Viet Nam	Country	1	-
DHMR	Yemen National Seismological Center	Yemen	Country	1	-
LSZ	Geological Survey Department of Zambia	Zambia	Country	1	-
BUL	Goetz Observatory	Zimbabwe	Country	1	-
BASV	British Antarctic Survey	Antarctica	Region	1	-
SPA	USGS - South Pole	Antarctica	Region	2	-
SEPA	Seismic Experiment in Patagonia and Antarctica	Antarctica	Region	3	United States
ANUBIS	Antarctic Network of Broadband Seismometers	Antarctica	Region	4	United States
EAF	East African Network	East Africa	Region	1	-
ECGS	European Center for Geodynamics and Seismology	KivuSNet Africa	Region	1	Luxembourg
NPO	North Pole Environmental Observatory	North Pole	Region	1	United States
SPASE	Southwest Pacific Seismic Experiment	Southwest Pacific	Region	1	United States

NOTE: Agencies labelled by the ISC as “unidentified historical agencies”, those for which there was no sufficient information to be identified unequivocally, and those whose time span was too old to be of relevance for the present study have not been included in Table II.1.

APPENDIX III: LIST OF EVENTS IDENTIFIED AS DUPLICATES

Table III.1 lists the events identified as duplicates when subjecting the database to the procedure described in Section 2.7.7. The differences in time and in hypocentral coordinates are labelled Δt and **d**, respectively. The “Outcome” column indicates which of the two events was kept in the catalogue: “Keep 1” implies that the first of the two events listed was kept, while “Keep 2” indicates the opposite.

Table III.1. Events identified as duplicates as per the procedure described in Section 2.7.7.

Case	Δt (s)	d (km)	Event ID	Source	Year	Month	Day	Hour	Minute	Second	Longitude	Latitude	Depth	M	Outcome
692	2	36.6	1436828	WPG16	1999	1	5	18	27	40	37.560	6.051	10.0	4.63	Keep1
			1915935	Added	1999	1	5	18	27	42	37.861	5.918	6.0	4.90	
744	0	35.5	1538041	WPG16	1999	3	4	8	52	1	121.835	5.281	15.0	7.07	Keep1
			1916101	Added	1999	3	4	8	52	1	122.078	5.413	33.0	7.10	
748	1	19.8	1916120	Added	1999	3	5	13	1	9	121.968	5.107	2.0	6.20	Keep2
			1538536	WPG16	1999	3	5	13	1	10	122.055	5.209	15.0	5.90	
766	3	29.4	1916237	Added	1999	3	13	16	27	31	96.043	3.116	88.1	4.70	Keep2
			1541916	WPG16	1999	3	13	16	27	34	95.905	2.892	85.0	4.69	
801	2	37.4	2159425	Added	1999	4	13	23	5	40	71.145	36.322	123.5	4.70	Keep2
			1623423	WPG16	1999	4	13	23	5	42	71.360	36.147	98.0	4.75	
802	5	28	2159437	Added	1999	4	14	17	24	29	79.377	30.339	9.4	5.10	Keep2
			1623710	WPG16	1999	4	14	17	24	34	79.350	30.304	37.0	4.76	
807	2	15.2	2159501	Added	1999	4	18	17	16	38	79.475	30.390	15.0	4.50	Keep2
			1625314	WPG16	1999	4	18	17	16	40	79.317	30.381	15.0	4.57	
811	3	27.6	2159519	Added	1999	4	20	11	43	22	70.659	36.576	185.7	4.50	Keep2
			1625947	WPG16	1999	4	20	11	43	25	70.863	36.405	194.0	4.57	
849	5	44.1	2160425	Added	1999	5	20	15	15	1	70.230	36.646	179.8	4.90	Keep2
			1680795	WPG16	1999	5	20	15	15	6	70.581	36.374	173.0	4.57	
911	2	39.4	2160970	Added	1999	7	17	23	7	34	69.587	29.688	0.0	4.40	Keep2
			1654610	WPG16	1999	7	17	23	7	36	69.575	29.851	35.0	4.44	
926	2	45.3	2161398	Added	1999	8	1	8	24	51	86.789	28.369	40.0	5.00	Keep2
			1702942	WPG16	1999	8	1	8	24	53	86.734	28.453	84.0	5.30	
955	3	32.7	2161634	Added	1999	8	26	9	7	22	71.119	36.396	93.3	4.60	Keep2
			1846094	WPG16	1999	8	26	9	7	25	71.284	36.160	106.0	4.85	
964	5	47.5	1655684	WPG16	1999	9	5	2	28	18	87.537	28.462	15.0	4.80	Keep1
			2162120	Added	1999	9	5	2	28	23	87.527	28.067	33.0	4.50	
971	0	25.8	2162216	Added	1999	9	12	9	0	11	77.578	30.974	33.0	4.00	Keep2
			1655912	WPG16	1999	9	12	9	0	11	77.759	31.146	35.0	4.12	
2128	4	36.3	2164590	Added	1999	10	6	4	55	46	93.973	14.148	20.0	4.60	Keep2
			1642936	WPG16	1999	10	6	4	55	50	93.876	14.356	46.0	4.70	
2269	2	22.2	1643672	WPG16	1999	10	15	8	29	48	71.178	36.246	132.0	4.75	Keep1
			2164676	Added	1999	10	15	8	29	50	71.201	36.445	132.0	4.60	
2360	1	19.1	1645276	WPG16	1999	10	25	7	29	55	142.297	32.014	15.0	5.74	Keep1
			2164796	Added	1999	10	25	7	29	56	142.251	31.971	33.0	5.60	
2519	77	7.8	4806594	Added	1999	11	16	22	53	0	142.400	42.100	62.0	4.80	Keep2
			1650744	WPG16	1999	11	16	22	54	17	142.382	42.152	67.0	5.13	
3514	1	9.3	2336523	Added	2000	10	11	10	7	54	7.805	43.576	2.0	2.50	Keep1
			2336525	Added	2000	10	11	10	7	55	7.860	43.640	6.0	2.50	
4294	4	14.6	3337590	WPG16	2001	11	26	13	7	14	-99.979	2.122	15.0	4.91	Keep1
			2936285	WPG16	2001	11	26	13	7	18	-100.101	2.102	10.0	5.14	
7097	4	37.5	7223266	WPG16	2004	1	1	5	58	57	154.183	46.778	33.0	5.20	Keep1
			GCMT_020859	WPG16	2004	1	1	5	59	1	154.440	47.010	14.0	5.22	
7341	4	18.6	7343727	WPG16	2004	5	16	7	21	0	141.487	34.180	31.0	5.00	Keep1
			GCMT_021423	WPG16	2004	5	16	7	21	4	141.530	34.160	13.0	5.06	

Table III.1. Continued.

Case	Δt (s)	d (km)	Event ID	Source	Year	Month	Day	Hour	Minute	Second	Longitude	Latitude	Depth	M	Outcome
7580	3	10.5	8280453	WPG16	2004	10	25	11	45	10	178.241	-35.539	33.0	5.01	Keep1
			8065234	Added	2004	10	25	11	45	13	178.176	-35.617	33.0	4.30	
7598	0	13.3	7432797	WPG16	2004	11	8	15	55	1	122.524	24.023	40.0	6.30	Keep1
			7432797	WPG16	2004	11	8	15	55	1	122.585	24.060	29.0	6.28	
7691	1	24.1	7448988	WPG16	2004	12	16	0	10	3	122.357	24.013	45.0	5.10	Keep1
			GCMT_022312	WPG16	2004	12	16	0	10	4	122.210	23.870	34.8	5.10	
7708	9	22	7453587	WPG16	2004	12	26	5	1	9	92.212	9.288	30.0	6.22	Keep1
			7453588	WPG16	2004	12	26	5	1	18	92.225	9.469	21.0	5.50	
8626	1	21.4	7381099	WPG16	2005	5	16	11	50	1	152.270	46.113	47.0	4.90	Keep1
			GCMT_023449	WPG16	2005	5	16	11	50	2	152.490	46.100	34.0	4.97	
8707	1	0.6	9899741	Added	2005	6	22	7	43	14	-21.992	63.927	4.9	3.60	Keep2
			9899742	Added	2005	6	22	7	43	15	-21.993	63.924	4.4	3.70	
8752	3	25.7	7365515	WPG16	2005	7	29	3	25	0	142.342	33.243	18.0	4.80	Keep1
			GCMT_023806	WPG16	2005	7	29	3	26	3	142.610	33.220	12.0	4.86	
8754	1	39.7	7365599	WPG16	2005	7	29	20	25	3	142.297	33.311	38.0	5.40	Keep1
			GCMT_023811	WPG16	2005	7	29	20	25	4	142.610	33.380	12.0	5.42	
8786	3	22.5	7748205	WPG16	2005	8	25	22	29	1	143.023	37.777	28.0	5.10	Keep1
			GCMT_023943	WPG16	2005	8	25	22	29	4	143.230	37.800	15.0	5.17	
8807	2	33.9	7519651	WPG16	2005	9	3	7	6	0	151.735	45.543	49.0	5.20	Keep1
			GCMT_023991	WPG16	2005	9	3	7	7	2	151.950	45.590	20.0	5.28	
10213	8	26.4	12799858	WPG16	2007	8	8	17	4	59	107.634	-6.038	299.9	7.54	Keep1
			13665141	WPG16	2007	8	8	17	5	7	107.451	-5.891	295.0	7.40	
10318	6	20.2	12975151	WPG16	2007	9	30	9	47	45	164.018	-49.453	9.0	5.02	Keep2
			13204359	WPG16	2007	9	30	9	47	51	164.108	-49.282	10.0	6.61	
10997	3	2.9	14519225	Added	2008	5	29	15	55	2	-21.159	63.905	5.0	3.70	Keep1
			14529025	Added	2008	5	29	15	55	5	-21.177	63.928	4.0	4.80	
12990	12	109.9	13876558	Added	2009	10	12	17	38	48	-104.885	14.616	0.0	4.20	Keep2
			13876558	WPG16	2009	10	12	17	39	0	-105.190	15.550	14.4	4.92	
14257	12	34.3	1265859	Added	2010	7	19	13	35	28	-169.462	52.704	1.5	3.30	Keep1
			15639213	Added	2010	7	19	13	35	40	-169.381	52.400	0.0	3.40	
15736	1	7.4	604057217	Added	2011	2	16	10	13	31	99.926	52.023	2.0	3.90	Keep2
			16166854	Added	2011	2	16	10	13	32	99.979	51.966	2.0	4.00	
16287	10	12.8	16476247	WPG16	2011	3	11	8	19	17	141.678	36.118	22.0	5.50	Keep2
			602707274	WPG16	2011	3	11	8	19	27	141.590	36.205	25.0	7.10	
19687	3	3.1	601475129	WPG16	2012	6	14	16	19	12	121.490	23.724	1.0	4.70	Keep1
			602023826	Added	2012	6	14	16	19	15	121.506	23.717	3.5	4.30	
23023	3	15.1	605099589	WPG16	2014	7	27	1	28	38	-45.585	23.725	11.0	6.10	Keep1
			610783321	WPG16	2014	7	27	1	28	41	-45.590	23.860	13.0	6.10	
23024	3	39.1	605099803	WPG16	2014	7	28	8	3	11	66.796	-17.325	11.0	5.49	Keep1
			610783325	WPG16	2014	7	28	8	3	14	66.600	-17.030	16.0	5.50	
23027	9	36.5	605136217	WPG16	2014	7	30	16	0	57	154.825	-7.136	11.0	5.94	Keep1
			610783333	WPG16	2014	7	30	16	1	6	154.990	-7.420	12.0	5.90	
23029	8	42.7	605136218	WPG16	2014	7	31	0	17	51	-176.352	-23.538	51.0	5.39	Keep1
			610783335	WPG16	2014	7	31	0	17	59	-176.090	-23.790	69.0	5.40	
23041	3	19.6	605130566	WPG16	2014	8	2	10	33	27	67.243	-9.195	12.0	5.59	Keep1
			610783339	WPG16	2014	8	2	10	33	30	67.100	-9.100	17.0	5.60	
23045	5	32.3	610783341	WPG16	2014	8	2	14	2	19	-28.358	-55.363	4.0	5.47	Keep1
			605246043	WPG16	2014	8	2	14	2	24	-28.080	-55.390	31.0	5.40	
23051	6	25.2	610639906	WPG16	2014	8	6	11	45	23	128.062	-7.297	12.0	6.22	Keep1
			610642412	WPG16	2014	8	6	11	45	29	127.920	-7.130	19.0	6.20	
23060	1	4.5	605143484	WPG16	2014	8	11	10	7	37	-175.840	-29.810	12.5	5.51	Keep2
			610571800	WPG16	2014	8	11	10	7	38	-175.840	-29.770	12.0	5.50	
23068	3	22.7	605145543	WPG16	2014	8	13	0	30	48	144.965	13.904	95.0	5.65	Keep1
			610571819	WPG16	2014	8	13	0	30	51	145.160	13.850	101.0	5.60	
23069	0	22.7	610571823	WPG16	2014	8	13	5	54	38	145.500	-3.340	12.0	5.60	Keep2
			605145548	WPG16	2014	8	13	5	54	38	145.434	-3.446	30.0	5.40	

Table III.1. Continued.

Case	Δt (s)	d (km)	Event ID	Source	Year	Month	Day	Hour	Minute	Second	Longitude	Latitude	Depth	M	Outcome
23074	0	1.1	605146557	WPG16	2014	8	14	17	9	50	128.070	28.050	12.0	5.43	Keep2
			610571867	WPG16	2014	8	14	17	9	50	128.070	28.040	12.0	5.40	
23123	6	23	605153268	WPG16	2014	8	20	23	18	20	-17.103	-59.100	6.0	5.64	Keep1
			610571998	WPG16	2014	8	20	23	18	26	-16.970	-59.250	20.0	5.60	
23143	4	19.1	605170353	WPG16	2014	8	26	1	26	8	-17.518	64.638	10.0	5.41	Keep1
			610572111	WPG16	2014	8	26	1	26	12	-17.120	64.630	12.0	5.40	
23145	3	29.8	605173206	WPG16	2014	8	27	0	16	29	-17.728	64.534	3.0	5.22	Keep1
			610572124	WPG16	2014	8	27	0	16	32	-17.160	64.610	12.0	5.20	
23146	6	19.6	605173218	WPG16	2014	8	27	6	10	18	-145.563	59.307	4.0	5.15	Keep1
			610572132	WPG16	2014	8	27	6	10	24	-145.360	59.430	12.0	5.10	
23147	6	15.4	605173305	WPG16	2014	8	27	16	31	14	-177.834	-15.582	8.0	5.74	Keep1
			610572141	WPG16	2014	8	27	16	31	20	-177.840	-15.550	23.0	5.70	
23149	6	17.8	605173937	WPG16	2014	8	28	8	13	42	-17.388	64.693	4.0	5.48	Keep1
			610572150	WPG16	2014	8	28	8	13	48	-17.100	64.620	12.0	5.40	
23153	5	19	605184068	WPG16	2014	8	29	21	16	45	84.867	-41.834	10.0	5.53	Keep1
			610572179	WPG16	2014	8	29	21	16	50	84.890	-41.670	15.0	5.50	
23154	4	19.8	605183450	WPG16	2014	8	30	7	3	4	-17.553	64.597	6.0	5.48	Keep1
			610572190	WPG16	2014	8	30	7	3	8	-17.160	64.620	12.0	5.40	
23156	3	13.1	610572205	WPG16	2014	8	31	3	6	57	-148.983	65.155	15.0	5.24	Keep1
			605184101	WPG16	2014	8	31	3	7	0	-148.980	65.270	18.0	5.20	
23159	4	20.4	605185591	WPG16	2014	9	1	11	41	10	-17.495	64.681	0.0	5.54	Keep1
			610572247	WPG16	2014	9	1	11	41	14	-17.190	64.610	12.0	5.50	
23160	5	18	610182937	WPG16	2014	9	3	3	9	56	-17.465	64.706	5.0	5.47	Keep1
			610572280	WPG16	2014	9	3	3	10	1	-17.180	64.620	12.0	5.40	
23161	7	44.4	610182922	WPG16	2014	9	3	8	13	28	-173.521	-15.025	10.0	5.55	Keep1
			610572284	WPG16	2014	9	3	8	13	35	-173.150	-14.850	12.0	5.50	
23162	7	9.3	605190964	WPG16	2014	9	3	11	34	41	-173.028	-14.890	10.0	5.69	Keep1
			610572288	WPG16	2014	9	3	11	34	48	-173.110	-14.890	13.0	5.70	
23163	4	33.8	605192663	WPG16	2014	9	3	20	34	0	-114.684	-26.528	9.0	6.00	Keep1
			605615856	WPG16	2014	9	3	20	34	4	-114.670	-26.830	12.0	6.00	
23167	4	18.1	605596678	WPG16	2014	9	4	17	23	15	-114.486	-26.633	10.0	5.37	Keep1
			610572309	WPG16	2014	9	4	17	23	19	-114.410	-26.780	12.0	5.30	
23169	6	28	605246940	WPG16	2014	9	6	6	53	12	-114.500	-26.648	7.0	6.14	Keep1
			610572344	WPG16	2014	9	6	6	53	18	-114.560	-26.890	12.0	6.10	
23170	8	40.6	605273887	WPG16	2014	9	6	19	22	59	-107.049	18.753	17.0	6.16	Keep1
			610572351	WPG16	2014	9	6	19	23	7	-107.380	18.930	24.0	6.10	
23181	1	11.1	610572412	WPG16	2014	9	10	16	36	43	-130.280	50.450	9.0	5.00	Keep1
			605282792	WPG16	2014	9	10	16	36	44	-130.270	50.450	20.1	5.03	
23184	3	25.8	605286933	WPG16	2014	9	12	7	47	25	143.774	22.149	117.0	5.25	Keep1
			610572442	WPG16	2014	9	12	7	47	28	143.930	22.280	131.0	5.20	
23189	3	13.7	605290123	WPG16	2014	9	15	8	5	2	-17.397	64.573	8.0	5.48	Keep1
			610572486	WPG16	2014	9	15	8	5	5	-17.130	64.600	12.0	5.40	
23203	3	29.2	605353638	WPG16	2014	9	22	16	1	43	-27.820	-56.009	106.0	5.79	Keep1
			610572620	WPG16	2014	9	22	16	1	46	-27.400	-56.020	119.0	5.80	
23205	1	40.9	605354947	WPG16	2014	9	23	15	24	1	151.737	-5.395	57.0	5.56	Keep1
			610572633	WPG16	2014	9	23	15	24	2	151.860	-5.680	35.0	5.50	
23206	4	4.1	610572655	WPG16	2014	9	24	12	45	46	141.456	37.552	52.0	5.30	Keep1
			605366000	WPG16	2014	9	24	12	45	50	141.480	37.570	54.9	5.32	
23208	1	18.8	605380384	WPG16	2014	9	25	5	0	7	-17.507	64.506	8.0	5.20	Keep1
			610572668	WPG16	2014	9	25	5	0	8	-17.190	64.600	12.0	5.20	
23214	0	10.3	605412692	WPG16	2014	9	27	3	53	11	-149.740	62.050	63.0	4.90	Keep2
			610572727	WPG16	2014	9	27	3	53	11	-149.847	62.004	56.0	4.94	
23216	3	22.2	605416959	WPG16	2014	9	28	6	23	36	-176.343	-19.132	10.0	5.71	Keep1
			610572745	WPG16	2014	9	28	6	23	39	-176.260	-19.310	15.0	5.70	
23223	5	16.3	605468274	WPG16	2014	9	30	16	45	56	67.712	1.614	4.0	5.56	Keep1
			610572784	WPG16	2014	9	30	16	46	1	67.660	1.510	14.0	5.50	

Table III.1. Continued.

Case	Δt (s)	d (km)	Event ID	Source	Year	Month	Day	Hour	Minute	Second	Longitude	Latitude	Depth	M	Outcome
23230	4	12	605481442	WPG16	2014	10	3	5	37	18	-82.610	4.743	10.0	5.33	Keep1
			610572847	WPG16	2014	10	3	5	37	22	-82.670	4.690	18.0	5.30	
23235	3	10.9	605501162	WPG16	2014	10	5	14	52	32	132.402	-1.312	3.0	5.30	Keep1
			610572900	WPG16	2014	10	5	14	52	35	132.350	-1.330	12.0	5.30	
23238	4	21.2	605502345	WPG16	2014	10	6	12	3	42	-68.431	-31.240	111.0	4.90	Keep2
			610572918	WPG16	2014	10	6	12	3	46	-68.470	-31.320	129.9	4.90	
23239	5	44	605502348	WPG16	2014	10	6	14	4	6	147.264	15.462	6.0	5.63	Keep1
			610572922	WPG16	2014	10	6	14	4	11	147.660	15.380	13.0	5.60	
23242	3	13.2	605504654	WPG16	2014	10	7	10	22	31	-17.199	64.530	4.0	5.56	Keep1
			610572936	WPG16	2014	10	7	10	22	34	-17.260	64.620	12.0	5.50	
23243	6	21.7	605725277	WPG16	2014	10	7	12	33	23	-71.004	-20.032	16.0	5.28	Keep1
			610572940	WPG16	2014	10	7	12	33	29	-71.200	-19.980	20.0	5.20	
23244	6	36.1	605504657	WPG16	2014	10	7	13	5	52	-70.938	-20.066	15.0	4.98	Keep1
			610572942	WPG16	2014	10	7	13	5	58	-71.210	-19.870	20.0	4.90	
23247	4	20.2	605505326	WPG16	2014	10	8	3	4	8	-41.886	30.314	10.0	5.58	Keep1
			610572959	WPG16	2014	10	8	3	4	12	-41.990	30.470	12.0	5.50	
23251	9	37.7	605524711	WPG16	2014	10	9	2	32	5	-110.865	-32.095	10.0	6.59	Keep1
			610572980	WPG16	2014	10	9	2	32	14	-111.070	-32.380	17.0	6.60	
23252	6	13	605524718	WPG16	2014	10	9	8	14	24	-111.656	-32.614	10.0	5.70	Keep1
			610572984	WPG16	2014	10	9	8	14	30	-111.580	-32.680	18.0	5.70	
23253	4	9.7	605525172	WPG16	2014	10	9	20	59	0	-111.212	-32.015	19.0	5.67	Keep1
			610572996	WPG16	2014	10	9	21	0	4	-111.190	-32.080	13.0	5.60	
23256	7	19.5	605642916	WPG16	2014	10	10	4	7	51	-110.836	-32.165	10.0	5.59	Keep1
			610572999	WPG16	2014	10	10	4	7	58	-110.720	-32.300	16.0	5.60	
23259	1	7.2	605532107	WPG16	2014	10	12	5	17	37	-33.267	57.299	10.0	5.36	Keep1
			610573029	WPG16	2014	10	12	5	17	38	-33.180	57.340	12.0	5.30	
23266	5	21.9	605534076	WPG16	2014	10	13	5	13	45	165.992	-46.141	14.0	5.78	Keep1
			610573050	WPG16	2014	10	13	5	13	50	165.740	-46.100	23.0	5.80	
23274	4	27.6	605546633	WPG16	2014	10	15	11	16	38	-17.810	64.550	11.0	5.58	Keep1
			610573094	WPG16	2014	10	15	11	16	42	-17.250	64.610	12.0	5.50	
23275	4	12.4	610573090	WPG16	2014	10	15	13	35	54	47.808	32.545	9.0	5.83	Keep1
			605551112	WPG16	2014	10	15	13	35	58	47.870	32.450	12.0	5.80	
23281	2	23.6	605566217	Added	2014	10	18	9	40	14	-17.350	64.790	4.0	5.30	Keep2
			610573158	WPG16	2014	10	18	9	40	16	-17.550	64.610	12.0	5.30	
23287	4	24.9	610573172	WPG16	2014	10	19	19	51	10	-39.406	8.701	10.0	5.31	Keep1
			605566383	WPG16	2014	10	19	19	51	14	-39.450	8.920	12.0	5.30	
23288	4	22.6	610573170	WPG16	2014	10	19	20	6	13	-39.334	8.680	10.0	5.39	Keep1
			605566384	WPG16	2014	10	19	20	6	17	-39.370	8.880	12.0	5.30	
23291	5	24	605566407	WPG16	2014	10	20	7	58	52	161.139	-62.002	4.0	5.75	Keep1
			610573204	WPG16	2014	10	20	7	58	57	161.280	-61.810	12.0	5.70	
23295	2	18.9	610573194	WPG16	2014	10	20	19	33	21	-77.846	0.588	4.0	5.64	Keep1
			605568087	WPG16	2014	10	20	19	33	23	-77.940	0.710	12.0	5.60	
23303	1	30.4	605570894	WPG16	2014	10	21	23	1	18	169.665	-63.468	8.0	5.64	Keep1
			610573214	WPG16	2014	10	21	23	1	19	170.040	-63.260	14.0	5.60	
23310	3	12.2	605600622	WPG16	2014	10	23	16	30	24	-148.979	65.151	14.0	5.02	Keep1
			610573294	WPG16	2014	10	23	16	30	27	-149.110	65.200	23.0	5.00	
23312	2	21.1	605604339	WPG16	2014	10	24	7	16	41	-72.352	-33.996	22.0	4.94	Keep1
			610573306	WPG16	2014	10	24	7	16	43	-72.500	-34.140	23.0	4.90	
23317	1	14.8	605617621	WPG16	2014	10	26	5	54	48	-17.324	64.531	8.0	5.39	Keep1
			610573349	WPG16	2014	10	26	5	54	49	-17.110	64.620	12.0	5.40	
23320	2	13.9	605617628	WPG16	2014	10	26	10	45	32	-74.084	-10.557	125.0	5.77	Keep1
			610573354	WPG16	2014	10	26	10	45	34	-74.080	-10.470	135.0	5.70	
23326	4	9	610573387	WPG16	2014	10	28	13	13	9	53.460	-36.039	7.0	5.40	Keep2
			605626982	WPG16	2014	10	28	13	13	13	53.430	-36.030	15.5	5.47	
23333	2	20.9	605635781	WPG16	2014	10	31	6	33	33	142.405	40.165	43.0	4.92	Keep1
			610573439	WPG16	2014	10	31	6	33	35	142.590	40.240	54.0	4.90	

Table III.1. Continued.

Case	Δt (s)	d (km)	Event ID	Source	Year	Month	Day	Hour	Minute	Second	Longitude	Latitude	Depth	M	Outcome
23336	4	15.8	605640144	WPG16	2014	11	1	10	5	44	-111.107	-31.920	10.0	5.72	Keep1
			610573456	WPG16	2014	11	1	10	5	48	-111.200	-32.030	15.0	5.70	
23337	5	15.4	610573459	WPG16	2014	11	1	10	59	55	-111.180	-31.822	5.0	6.06	Keep2
			606335020	WPG16	2014	11	1	10	59	0	-111.220	-31.940	12.0	6.00	
23341	8	36.3	605640197	WPG16	2014	11	2	17	17	4	154.278	-61.220	10.0	6.04	Keep1
			610573483	WPG16	2014	11	2	17	17	12	153.770	-61.020	19.0	6.00	
23343	2	39.3	605644780	WPG16	2014	11	4	11	44	52	-73.671	-41.144	33.0	4.90	Keep1
			610573529	WPG16	2014	11	4	11	44	54	-74.110	-41.250	40.4	4.96	
23346	4	8.9	610573557	WPG16	2014	11	5	7	23	4	-119.618	41.906	9.0	4.75	Keep1
			605645330	WPG16	2014	11	5	7	23	8	-119.650	41.950	16.0	4.70	
23366	0	14.8	607244113	WPG16	2014	11	8	23	15	44	20.369	38.126	21.0	5.16	Keep1
			610573684	WPG16	2014	11	8	23	15	44	20.310	38.010	16.0	5.10	
23369	6	10.9	605652319	WPG16	2014	11	9	21	19	41	-17.465	64.556	7.0	5.35	Keep1
			610573699	WPG16	2014	11	9	21	19	47	-17.410	64.640	12.0	5.30	
23374	7	30.9	610573724	WPG16	2014	11	10	11	38	59	-68.506	-21.613	113.0	5.50	Keep2
			605654185	WPG16	2014	11	10	11	39	6	-68.800	-21.630	118.1	5.58	
23378	4	13.2	608396528	WPG16	2014	11	11	7	50	8	94.304	7.461	8.0	5.48	Keep1
			610573743	WPG16	2014	11	11	7	50	12	94.340	7.540	17.0	5.40	
23383	0	4.5	605656379	WPG16	2014	11	12	11	16	51	-85.360	1.130	17.5	5.50	Keep1
			610573759	WPG16	2014	11	12	11	16	51	-85.360	1.130	22.0	5.50	
23384	4	15.6	610573780	WPG16	2014	11	13	6	36	8	-119.681	41.909	6.0	4.75	Keep1
			605657582	WPG16	2014	11	13	6	36	12	-119.560	41.910	18.0	4.70	
23386	6	14.3	605658096	WPG16	2014	11	13	10	24	18	173.061	-15.184	6.0	6.01	Keep1
			610573784	WPG16	2014	11	13	10	24	24	173.130	-15.280	12.0	6.00	
23392	1	30.8	605659521	WPG16	2014	11	15	0	18	40	-76.735	-12.690	44.0	5.41	Keep1
			610573827	WPG16	2014	11	15	0	18	41	-76.750	-12.630	74.0	5.40	
23396	1	15.5	605660412	WPG16	2014	11	15	3	8	5	123.889	-0.145	90.0	5.96	Keep1
			610573835	WPG16	2014	11	15	3	8	6	123.990	-0.230	85.0	5.90	
23411	3	31.8	605660418	WPG16	2014	11	15	9	47	58	126.533	1.754	47.0	5.49	Keep1
			610573842	WPG16	2014	11	15	9	48	1	126.380	1.960	33.0	5.50	
23424	2	24.1	605660617	WPG16	2014	11	17	4	34	12	94.421	20.780	66.0	5.34	Keep1
			610573891	WPG16	2014	11	17	4	34	14	94.440	20.780	90.0	5.30	
23425	1	5.1	605662413	WPG16	2014	11	17	11	27	7	-102.197	-36.001	19.0	5.47	Keep1
			610573896	WPG16	2014	11	17	11	27	8	-102.230	-36.010	15.0	5.40	
23426	1	10.2	605662645	WPG16	2014	11	17	13	27	17	155.142	-9.775	20.0	5.35	Keep1
			610573898	WPG16	2014	11	17	13	27	18	155.200	-9.770	12.0	5.30	
23434	0	16.9	610573912	WPG16	2014	11	17	23	5	58	23.460	38.540	18.2	5.36	Keep2
			605662926	WPG16	2014	11	17	23	5	58	23.378	38.671	23.0	5.30	
23439	2	21.6	605662945	WPG16	2014	11	18	7	59	14	-40.709	31.676	10.0	5.39	Keep1
			610573926	WPG16	2014	11	18	7	59	16	-40.710	31.870	12.0	5.40	
23454	6	23.4	610574036	WPG16	2014	11	22	6	50	54	-71.109	-20.079	16.0	5.10	Keep2
			605672703	WPG16	2014	11	22	6	50	0	-71.300	-19.980	21.1	5.11	
23459	1	10.1	610574052	WPG16	2014	11	22	19	14	17	27.158	45.865	32.0	5.70	Keep1
			605673666	WPG16	2014	11	22	19	14	18	27.170	45.800	25.0	5.71	
23467	3	11.9	605716569	WPG16	2014	11	24	21	2	19	154.962	-5.963	170.0	5.71	Keep1
			610574087	WPG16	2014	11	24	21	2	22	154.980	-6.040	178.0	5.70	
23483	5	33.4	605741110	WPG16	2014	11	26	22	26	1	-104.113	8.239	10.0	5.53	Keep1
			610574140	WPG16	2014	11	26	22	26	6	-104.040	8.530	12.0	5.50	
23484	2	14.8	605742589	Added	2014	11	28	2	30	7	29.006	39.332	10.8	4.30	Keep1
			610574169	Added	2014	11	28	2	30	9	28.895	39.240	5.9	4.30	
23488	1	9.1	605743502	WPG16	2014	11	28	13	23	16	61.326	5.753	10.0	5.47	Keep2
			610574178	WPG16	2014	11	28	13	23	17	61.250	5.730	12.0	5.40	
23490	3	31	605745251	WPG16	2014	11	29	4	14	16	-150.490	62.749	104.0	5.10	Keep1
			610574184	WPG16	2014	11	29	4	14	19	-150.750	62.980	115.2	5.13	
23491	3	11.9	606005198	WPG16	2014	11	29	13	5	9	61.356	5.715	4.0	5.58	Keep1
			610574191	WPG16	2014	11	29	13	5	12	61.280	5.690	12.0	5.50	

Table III.1. Continued.

Case	Δt (s)	d (km)	Event ID	Source	Year	Month	Day	Hour	Minute	Second	Longitude	Latitude	Depth	M	Outcome
23494	7	24.3	606005203	WPG16	2014	11	29	14	18	8	-71.069	-19.997	6.0	5.42	Keep1
			610574193	WPG16	2014	11	29	14	18	15	-71.260	-19.890	13.0	5.40	
23497	1	3.2	607685029	Added	2014	11	30	8	6	48	13.370	43.580	33.0	2.90	Keep1
			610049501	Added	2014	11	30	8	6	49	13.370	43.568	30.1	2.80	
23510	4	33.6	610574280	WPG16	2014	12	3	2	29	0	-71.082	-19.987	16.0	4.90	Keep1
			606176797	WPG16	2014	12	3	2	29	4	-71.360	-19.850	23.1	4.93	
23514	3	26.1	610574319	WPG16	2014	12	4	10	43	44	178.000	-38.230	90.0	4.88	Keep1
			606179914	WPG16	2014	12	4	10	43	47	177.800	-38.100	77.0	4.80	
23515	1	13.6	606179915	WPG16	2014	12	4	10	53	31	65.564	-12.076	4.0	5.43	Keep1
			610574322	WPG16	2014	12	4	10	53	32	65.540	-11.980	12.0	5.40	
23517	2	18.1	606335284	WPG16	2014	12	5	21	4	58	-17.311	64.555	0.0	5.43	Keep1
			610574363	WPG16	2014	12	5	21	5	0	-17.110	64.640	12.0	5.40	
23524	6	2.9	606335392	WPG16	2014	12	6	17	21	49	-82.697	8.014	17.0	6.02	Keep1
			610574386	WPG16	2014	12	6	17	21	55	-82.710	8.000	19.0	6.00	
23530	4	14.4	606928928	WPG16	2014	12	7	3	30	2	154.259	-6.461	10.0	5.59	Keep1
			610574398	WPG16	2014	12	7	3	30	6	154.310	-6.510	22.0	5.60	
23537	3	47.3	606335621	WPG16	2014	12	7	12	11	31	-91.382	13.747	28.0	5.87	Keep1
			610574404	WPG16	2014	12	7	12	11	34	-91.810	13.690	20.0	5.80	
23539	1	4.6	610574408	WPG16	2014	12	7	17	55	33	154.270	-6.720	12.0	5.40	Keep1
			606335631	WPG16	2014	12	7	17	55	34	154.230	-6.720	13.2	5.46	
23541	2	29	606338213	WPG16	2014	12	8	12	51	27	138.738	-1.820	40.0	5.46	Keep1
			610574424	WPG16	2014	12	8	12	51	29	138.680	-1.570	35.0	5.40	
23546	6	28.3	606347836	WPG16	2014	12	11	13	53	29	-25.425	-56.751	10.0	5.60	Keep1
			610574498	WPG16	2014	12	11	13	53	35	-25.100	-56.910	20.0	5.60	
23548	2	11.2	606348793	WPG16	2014	12	12	20	22	36	-176.450	-18.830	317.0	5.80	Keep1
			610574528	WPG16	2014	12	12	20	22	38	-176.430	-18.830	328.0	5.80	
23551	5	30.6	606349393	WPG16	2014	12	13	12	46	45	-112.196	-28.956	8.0	5.48	Keep1
			610574544	WPG16	2014	12	13	12	46	50	-112.480	-29.070	12.0	5.40	
23558	8	33.9	606366189	WPG16	2014	12	16	10	45	24	-150.499	-56.744	0.0	5.36	Keep1
			610574619	WPG16	2014	12	16	10	45	32	-150.800	-56.950	17.0	5.30	
23561	3	10.2	606367107	WPG16	2014	12	17	13	58	50	-17.763	64.591	8.0	5.38	Keep1
			610574640	WPG16	2014	12	17	13	58	53	-17.590	64.550	12.0	5.30	
23562	4	25	606367706	WPG16	2014	12	18	6	24	38	-68.888	-20.369	104.0	4.80	Keep2
			610574651	WPG16	2014	12	18	6	24	42	-68.990	-20.380	126.6	4.85	
23565	7	14.4	606389950	WPG16	2014	12	18	20	10	53	-25.370	-56.628	10.0	5.48	Keep1
			610574659	WPG16	2014	12	18	20	11	0	-25.140	-56.640	13.0	5.40	
23567	3	3.8	606393702	WPG16	2014	12	19	4	47	40	145.506	42.704	32.0	5.35	Keep1
			610574664	WPG16	2014	12	19	4	47	43	145.540	42.720	30.0	5.30	
23573	2	19.9	606396468	WPG16	2014	12	19	19	49	30	-61.796	16.208	107.0	5.65	Keep1
			610574688	WPG16	2014	12	19	19	49	32	-61.820	16.370	115.0	5.60	
23580	1	9.6	610574728	WPG16	2014	12	21	9	40	49	-130.540	50.710	6.0	5.10	Keep2
			606414201	WPG16	2014	12	21	9	40	50	-130.520	50.760	13.7	5.17	
23592	4	15.6	606415082	WPG16	2014	12	24	1	19	39	147.257	-56.300	10.0	5.49	Keep1
			610574793	WPG16	2014	12	24	1	19	43	147.050	-56.380	12.0	5.50	
23597	7	20.5	606417343	WPG16	2014	12	26	23	52	15	-82.346	6.519	10.0	6.02	Keep1
			610574832	WPG16	2014	12	26	23	52	22	-82.410	6.680	17.0	6.00	
23607	4	35.8	606436890	Added	2015	1	1	12	16	11	-125.400	40.400	8.0	5.20	Keep2
			610574944	WPG16	2015	1	1	12	16	15	-125.775	40.442	24.0	5.40	
23611	1	27.3	606436926	WPG16	2015	1	2	8	21	56	60.365	6.574	10.0	5.51	Keep1
			610574967	WPG16	2015	1	2	8	21	57	60.120	6.600	12.0	5.50	
23612	1	21.3	606436927	WPG16	2015	1	2	8	25	53	60.299	6.449	10.0	5.45	Keep1
			610574969	WPG16	2015	1	2	8	25	54	60.150	6.570	12.0	5.40	
23613	2	19.8	606436933	WPG16	2015	1	2	10	15	34	-130.365	50.863	10.0	5.34	Keep1
			610574974	WPG16	2015	1	2	10	15	36	-130.550	50.730	12.0	5.30	
23614	0	9.1	606436934	WPG16	2015	1	2	11	1	26	-104.170	-3.940	15.1	5.33	Keep2
			610574976	WPG16	2015	1	2	11	1	26	-104.220	-4.000	18.0	5.30	

Table III.1. Continued.

Case	Δt (s)	d (km)	Event ID	Source	Year	Month	Day	Hour	Minute	Second	Longitude	Latitude	Depth	M	Outcome
23622	3	12.9	610575018	WPG16	2015	1	4	1	49	56	-130.480	50.520	3.0	4.80	Keep1
			606490574	WPG16	2015	1	4	1	49	59	-130.540	50.500	15.0	4.79	
23630	3	11.3	606498988	WPG16	2015	1	5	17	48	43	171.230	-43.071	9.0	5.61	Keep1
			610575061	WPG16	2015	1	5	17	48	46	171.180	-42.980	12.0	5.60	
23634	4	45.6	606503505	WPG16	2015	1	6	22	9	13	163.251	55.212	10.0	5.49	Keep1
			610575101	WPG16	2015	1	6	22	9	17	163.960	55.150	12.0	5.50	
23639	3	11.7	606505114	WPG16	2015	1	8	2	2	54	-125.700	49.175	35.0	4.90	Keep1
			610575142	WPG16	2015	1	8	2	2	57	-125.700	49.080	29.9	4.95	
23643	4	14.1	606506317	WPG16	2015	1	8	14	56	31	161.331	-61.659	4.0	5.74	Keep1
			610575156	WPG16	2015	1	8	14	56	35	161.230	-61.650	17.0	5.70	
23647	3	20.3	606506726	Added	2015	1	8	23	51	46	-132.700	-54.400	30.0	5.50	Keep2
			610575172	WPG16	2015	1	8	23	51	49	-132.850	-54.330	14.0	5.40	
23651	3	8.8	606510066	WPG16	2015	1	10	2	5	46	68.340	-5.643	10.0	5.69	Keep1
			610575197	WPG16	2015	1	10	2	5	49	68.340	-5.720	12.0	5.70	
23659	4	21	606512011	WPG16	2015	1	12	20	25	14	133.962	-5.546	24.0	5.67	Keep1
			610575262	WPG16	2015	1	12	20	25	18	133.790	-5.470	21.0	5.60	
23666	2	25.9	606544074	WPG16	2015	1	13	19	50	44	141.509	37.276	11.0	4.10	Keep1
			610575297	Added	2015	1	13	19	50	46	141.470	37.330	36.0	4.10	
23677	2	25.1	606586143	WPG16	2015	1	17	23	39	52	131.863	-5.773	56.0	5.59	Keep1
			610575606	WPG16	2015	1	17	23	39	54	131.840	-5.710	80.0	5.60	
23678	2	12.7	606586148	WPG16	2015	1	18	4	47	38	179.579	51.923	100.0	5.57	Keep1
			610575613	WPG16	2015	1	18	4	47	40	179.760	51.940	98.0	5.50	
23680	4	30.6	606587450	WPG16	2015	1	18	23	13	37	-105.757	-35.456	8.0	5.68	Keep1
			610575629	WPG16	2015	1	18	23	13	41	-106.030	-35.310	16.0	5.70	
23684	4	23.2	606589242	WPG16	2015	1	19	17	19	45	119.758	4.641	7.0	5.67	Keep1
			610575650	WPG16	2015	1	19	17	19	49	119.830	4.810	18.0	5.60	
23688	9	24.2	606589318	WPG16	2015	1	20	17	34	41	-70.883	-23.354	20.0	5.17	Keep1
			610575851	WPG16	2015	1	20	17	34	50	-71.010	-23.220	34.0	5.10	
23691	4	12.4	606635972	WPG16	2015	1	21	20	8	34	146.320	-5.644	54.0	5.76	Keep1
			610575872	WPG16	2015	1	21	20	8	38	146.310	-5.710	64.0	5.70	
23693	6	19.8	606635976	WPG16	2015	1	23	3	47	27	168.527	-17.026	223.0	6.81	Keep1
			610578772	WPG16	2015	1	23	3	47	33	168.360	-17.060	231.0	6.80	
23707	0	33.3	606595992	WPG16	2015	1	25	9	20	56	126.430	1.141	35.0	5.62	Keep1
			610579059	WPG16	2015	1	25	9	20	56	126.270	1.370	23.0	5.30	
23710	5	2.7	610579170	WPG16	2015	1	26	17	44	53	-135.550	-54.700	16.0	5.60	Keep1
			610193417	WPG16	2015	1	26	17	44	58	-135.550	-54.720	17.5	5.59	
23711	4	43.5	606597530	WPG16	2015	1	27	0	53	19	97.240	1.337	12.0	5.72	Keep1
			610579257	WPG16	2015	1	27	0	53	23	96.950	1.090	22.0	5.70	
23722	6	43	606613653	WPG16	2015	1	29	3	49	35	-174.157	-19.287	43.0	5.49	Keep1
			610579392	WPG16	2015	1	29	3	49	41	-173.790	-19.180	58.0	5.50	
23730	3	16.3	606631737	WPG16	2015	1	31	17	39	11	-169.118	56.641	5.0	5.40	Keep1
			610585898	WPG16	2015	1	31	17	39	14	-169.070	56.770	12.0	5.40	
23731	2	5.9	606631740	WPG16	2015	1	31	18	55	44	-82.953	7.720	15.0	5.25	Keep1
			610585905	WPG16	2015	1	31	18	55	46	-82.930	7.680	12.0	5.20	
23734	3	19.4	606631781	WPG16	2015	2	1	17	40	32	-169.136	56.657	10.0	5.38	Keep1
			610585934	WPG16	2015	2	1	17	40	35	-169.140	56.830	12.0	5.30	
23735	5	33.9	606631998	WPG16	2015	2	1	20	2	21	-8.120	-49.318	10.0	5.65	Keep1
			610585940	WPG16	2015	2	1	20	2	26	-7.770	-49.520	12.0	5.60	
23739	4	10.9	606632862	WPG16	2015	2	2	8	25	48	145.220	-1.524	23.0	5.98	Keep1
			610585957	WPG16	2015	2	2	8	25	52	145.180	-1.470	15.0	6.00	
23741	2	16.3	610585965	Added	2015	2	2	15	22	9	-70.900	-22.300	10.0	5.60	Keep2
			606636041	WPG16	2015	2	2	15	22	11	-70.928	-22.311	26.0	5.30	
23747	4	25.9	606683154	WPG16	2015	2	4	8	20	44	-175.878	-25.738	19.0	5.66	Keep1
			610585996	WPG16	2015	2	4	8	20	48	-175.670	-25.600	19.0	5.60	
23755	7	12.6	606696905	WPG16	2015	2	5	4	40	51	-82.622	5.222	4.0	5.70	Keep1
			610586013	WPG16	2015	2	5	4	40	58	-82.650	5.240	16.0	5.70	

Table III.1. Continued.

Case	Δt (s)	d (km)	Event ID	Source	Year	Month	Day	Hour	Minute	Second	Longitude	Latitude	Depth	M	Outcome
23761	2	12.6	606707524	WPG16	2015	2	6	1	25	12	134.399	33.757	10.0	4.81	Keep1
			610586032	WPG16	2015	2	6	1	25	14	134.270	33.760	14.0	4.80	
23766	2	14.6	610586092	WPG16	2015	2	8	15	9	7	119.460	-2.360	17.0	5.50	Keep2
			606722341	WPG16	2015	2	8	15	9	9	119.375	-2.443	23.0	5.57	
23772	4	18.3	606723229	WPG16	2015	2	10	13	29	38	126.182	11.234	10.0	5.45	Keep1
			610586139	WPG16	2015	2	10	13	29	42	126.330	11.310	12.0	5.40	
23773	0	25.3	610586141	WPG16	2015	2	10	14	47	50	57.380	9.680	12.0	5.40	Keep2
			606723232	WPG16	2015	2	10	14	47	50	57.592	9.732	4.0	5.62	
23774	4	22	606724134	WPG16	2015	2	11	13	1	16	-66.720	-23.561	202.0	5.53	Keep1
			610586167	WPG16	2015	2	11	13	1	20	-66.840	-23.500	219.0	5.50	
23776	1	20.3	610586179	WPG16	2015	2	11	21	29	27	-179.661	-65.661	14.0	5.80	Keep2
			606724406	WPG16	2015	2	11	21	29	28	-179.650	-65.480	12.0	5.85	
23782	15	56.2	606733224	WPG16	2015	2	13	18	59	12	-31.910	52.664	22.0	7.11	Keep1
			610586216	WPG16	2015	2	13	18	59	27	-32.740	52.700	25.0	7.10	
23783	3	4.2	606725905	WPG16	2015	2	13	20	6	32	121.427	22.637	30.0	6.28	Keep1
			610586218	WPG16	2015	2	13	20	6	35	121.390	22.650	29.0	6.20	
23787	4	33	606726712	WPG16	2015	2	15	13	49	48	176.920	-18.305	16.0	5.51	Keep1
			610586242	WPG16	2015	2	15	13	49	52	176.620	-18.230	12.0	5.50	
23790	7	7.4	606760333	WPG16	2015	2	16	22	0	53	-28.224	-55.511	19.0	6.30	Keep1
			610586270	WPG16	2015	2	16	22	0	0	-28.140	-55.500	14.0	6.30	
23793	0	12.4	606730497	WPG16	2015	2	17	4	46	41	142.050	40.110	52.0	5.48	Keep2
			610586279	WPG16	2015	2	17	4	46	41	142.160	40.100	60.0	5.50	
23794	1	46.4	610586281	WPG16	2015	2	17	5	56	57	179.970	-37.360	16.0	5.10	Keep2
			606760340	WPG16	2015	2	17	5	56	58	179.647	-37.652	33.0	5.17	
23796	5	11.1	606732303	WPG16	2015	2	17	16	33	21	143.585	39.582	10.0	5.43	Keep1
			610586292	WPG16	2015	2	17	16	33	26	143.700	39.610	14.0	5.40	
23797	1	22.7	606732312	Added	2015	2	18	0	48	29	-103.323	8.446	10.0	5.30	Keep2
			610586302	WPG16	2015	2	18	0	48	30	-103.134	8.377	5.0	5.60	
23800	3	6.1	606745252	WPG16	2015	2	18	4	43	39	159.318	-8.894	135.0	5.48	Keep1
			610586307	WPG16	2015	2	18	4	43	42	159.360	-8.890	139.0	5.50	
23805	3	19.4	606733949	WPG16	2015	2	19	10	24	4	159.352	-53.442	10.0	5.50	Keep1
			610586328	WPG16	2015	2	19	10	24	7	159.080	-53.380	12.0	5.50	
23806	8	15.3	606760354	WPG16	2015	2	19	13	18	32	168.118	-16.441	21.0	6.43	Keep1
			610586334	WPG16	2015	2	19	13	18	40	168.230	-16.410	12.0	6.40	
23808	3	24.7	606734078	WPG16	2015	2	19	16	32	47	159.006	52.810	82.0	5.45	Keep1
			610586340	WPG16	2015	2	19	16	32	50	159.290	52.850	97.0	5.40	
23810	5	21.4	606734701	WPG16	2015	2	20	4	25	23	143.580	39.837	12.0	6.22	Keep1
			610586348	WPG16	2015	2	20	4	25	28	143.830	39.850	12.0	6.20	
23811	5	22.3	606745453	WPG16	2015	2	21	10	13	53	143.486	39.819	7.0	5.98	Keep1
			610586373	WPG16	2015	2	21	10	13	58	143.740	39.830	12.0	6.00	
23812	2	25.3	606745677	WPG16	2015	2	22	6	10	34	133.902	-4.969	10.0	5.23	Keep1
			610586394	WPG16	2015	2	22	6	10	36	133.990	-4.760	12.0	5.20	
23814	2	19.5	610586404	WPG16	2015	2	22	14	23	14	-106.840	18.681	3.0	6.20	Keep1
			606745691	WPG16	2015	2	22	14	23	16	-106.850	18.820	14.9	6.27	
23815	7	53.1	606745696	WPG16	2015	2	22	18	26	52	-67.051	-24.207	167.0	5.08	Keep1
			610586407	WPG16	2015	2	22	18	26	59	-67.100	-24.080	218.0	5.00	
23816	2	30.8	610586415	WPG16	2015	2	23	10	25	7	177.133	-36.602	5.0	5.13	Keep2
			606746784	WPG16	2015	2	23	10	25	9	177.410	-36.450	12.0	5.10	
23817	1	8.5	606746895	Added	2015	2	23	16	16	29	-2.680	38.970	14.1	4.70	Keep1
			610586418	Added	2015	2	23	16	16	30	-2.700	39.040	17.0	4.60	
23818	4	10.6	606747123	WPG16	2015	2	24	2	28	54	143.198	39.655	20.0	5.80	Keep1
			610586427	WPG16	2015	2	24	2	28	58	143.320	39.650	22.0	5.80	
23819	5	34	606747133	WPG16	2015	2	24	5	13	50	-66.663	-22.745	188.0	5.35	Keep1
			610586433	WPG16	2015	2	24	5	13	55	-66.860	-22.710	215.0	5.30	
23820	1	35.2	606747137	WPG16	2015	2	24	6	54	49	-26.102	0.998	10.0	5.38	Keep1
			610586435	WPG16	2015	2	24	6	54	50	-26.410	1.070	12.0	5.30	

Table III.1. Continued.

Case	Δt (s)	d (km)	Event ID	Source	Year	Month	Day	Hour	Minute	Second	Longitude	Latitude	Depth	M	Outcome
23822	2	12.2	606748687	WPG16	2015	2	25	1	31	42	119.840	6.082	9.0	5.70	Keep1
			610586446	WPG16	2015	2	25	1	31	44	119.870	6.150	18.0	5.70	
23824	4	14	606751103	WPG16	2015	2	25	7	1	1	141.820	31.066	9.0	5.89	Keep1
			610586455	WPG16	2015	2	25	7	1	5	141.930	30.990	13.0	5.90	
23830	2	12.3	606757558	WPG16	2015	2	28	8	40	40	140.732	35.654	48.0	5.04	Keep2
			610586508	WPG16	2015	2	28	8	40	42	140.800	35.560	46.0	5.00	
23834	5	40.7	610586529	WPG16	2015	3	1	15	48	19	-71.440	-27.200	25.0	5.04	Keep1
			606758219	WPG16	2015	3	1	15	48	24	-71.750	-27.420	36.0	5.00	
23837	3	25.8	606768011	WPG16	2015	3	2	2	50	48	-150.689	-59.581	13.0	5.51	Keep1
			610586536	WPG16	2015	3	2	2	50	51	-150.640	-59.810	16.0	5.50	
23839	3	32.4	606760430	WPG16	2015	3	2	16	53	46	-71.083	-27.869	32.0	5.32	Keep1
			610586548	WPG16	2015	3	2	16	53	49	-71.340	-28.050	34.0	5.30	
23843	3	6.3	606767624	Added	2015	3	3	10	37	28	98.761	-0.756	28.0	5.90	Keep2
			610586569	WPG16	2015	3	3	10	37	31	98.708	-0.767	26.0	6.20	
23844	3	28.1	606768026	WPG16	2015	3	3	12	45	19	-69.183	-20.360	108.0	5.20	Keep2
			610586572	WPG16	2015	3	3	12	45	22	-69.330	-20.160	115.7	5.20	
23850	1	36.4	606770912	WPG16	2015	3	4	8	35	7	-129.920	50.270	8.0	5.03	Keep1
			610586589	WPG16	2015	3	4	8	35	8	-130.150	49.980	12.0	5.00	
23853	3	9.7	606777693	WPG16	2015	3	5	0	7	12	96.959	0.206	8.0	5.28	Keep1
			610586602	WPG16	2015	3	5	0	7	15	96.890	0.200	14.0	5.20	
23857	3	22.7	606792825	WPG16	2015	3	5	21	30	33	-71.363	-29.225	46.0	5.26	Keep1
			610586633	WPG16	2015	3	5	21	30	36	-71.520	-29.310	60.0	5.20	
23859	5	14.6	606793791	WPG16	2015	3	6	8	22	19	80.560	-41.322	4.0	5.99	Keep1
			610586646	WPG16	2015	3	6	8	22	24	80.640	-41.230	12.0	6.00	
23865	2	41	610586706	WPG16	2015	3	8	20	42	14	-129.220	48.770	25.0	5.10	Keep2
			606816377	WPG16	2015	3	8	20	42	16	-128.859	49.051	28.0	5.09	
23866	1	4.2	606816378	WPG16	2015	3	8	20	47	27	19.936	44.126	9.0	4.54	Keep1
			610586708	Added	2015	3	8	20	47	28	19.900	44.100	10.0	4.40	
23867	3	4.6	606816386	WPG16	2015	3	9	2	48	46	-82.655	6.538	11.0	5.80	Keep1
			610586711	WPG16	2015	3	9	2	48	49	-82.680	6.510	13.0	5.80	
23869	1	32.5	606816393	WPG16	2015	3	9	7	53	37	-73.475	-34.347	15.0	4.91	Keep1
			610586718	WPG16	2015	3	9	7	53	38	-73.790	-34.480	14.0	4.90	
23873	4	27.1	610586754	WPG16	2015	3	11	16	23	39	-86.448	10.611	12.0	5.40	Keep2
			606823772	WPG16	2015	3	11	16	23	43	-86.660	10.500	18.8	5.39	
23881	3	40.1	606831134	WPG16	2015	3	15	2	17	8	-176.378	-22.279	112.0	5.58	Keep1
			610586837	WPG16	2015	3	15	2	17	11	-176.020	-22.390	122.0	5.50	
23882	4	29.2	606859007	WPG16	2015	3	15	4	47	19	146.423	18.722	50.0	5.83	Keep1
			610586840	WPG16	2015	3	15	4	47	23	146.680	18.710	61.0	5.80	
23884	11	7.8	606831410	WPG16	2015	3	15	23	17	17	122.307	-0.541	31.0	6.09	Keep1
			610586851	WPG16	2015	3	15	23	17	28	122.350	-0.530	25.0	6.10	
23887	1	4.1	606985107	WPG16	2015	3	16	3	0	6	152.020	-4.120	198.0	5.97	Keep1
			610586857	WPG16	2015	3	16	3	0	7	152.000	-4.090	197.0	5.90	
23890	3	5.4	606843601	WPG16	2015	3	17	20	16	19	-178.607	-17.811	557.0	5.61	Keep1
			610586904	WPG16	2015	3	17	20	16	22	-178.570	-17.790	560.0	5.60	
23894	5	38.2	606855453	WPG16	2015	3	18	19	7	49	-73.641	-36.051	10.0	5.43	Keep1
			610586925	WPG16	2015	3	18	19	7	54	-74.060	-36.090	14.0	5.40	
23896	5	23.7	606855735	WPG16	2015	3	19	8	34	17	-73.823	-36.022	11.0	5.05	Keep1
			610586942	WPG16	2015	3	19	8	34	22	-74.010	-36.170	14.0	5.00	
23901	2	39.3	610586966	Added	2015	3	20	15	42	50	154.980	-4.450	16.0	5.30	Keep2
			606985144	WPG16	2015	3	20	15	42	52	154.837	-4.774	16.0	5.60	
23910	4	24	606858338	WPG16	2015	3	22	5	56	22	145.719	13.225	10.0	5.51	Keep1
			610587009	WPG16	2015	3	22	5	56	26	145.870	13.080	17.0	5.50	
23920	2	17.3	610587061	WPG16	2015	3	24	11	9	20	161.719	53.668	21.0	5.20	Keep1
			606860972	WPG16	2015	3	24	11	9	22	161.970	53.630	23.6	5.19	
23922	5	19.6	610587075	WPG16	2015	3	24	22	46	52	-70.785	-20.680	21.0	5.10	Keep1
			606861261	WPG16	2015	3	24	22	46	57	-70.940	-20.580	21.2	5.17	

Table III.1. Continued.

Case	Δt (s)	d (km)	Event ID	Source	Year	Month	Day	Hour	Minute	Second	Longitude	Latitude	Depth	M	Outcome
23923	1	13.6	606861269	WPG16	2015	3	25	0	34	28	143.082	42.266	60.0	5.00	Keep1
			610587078	Added	2015	3	25	0	34	29	143.096	42.353	50.4	5.00	
23925	2	32.4	606920960	WPG16	2015	3	25	19	22	44	-128.152	49.422	13.0	5.19	Keep1
			610587097	WPG16	2015	3	25	19	22	46	-128.420	49.210	24.0	5.20	
23928	2	7.7	606939517	WPG16	2015	3	27	3	4	7	143.120	36.365	10.0	5.42	Keep1
			610587129	WPG16	2015	3	27	3	4	9	143.190	36.330	12.0	5.40	
23938	2	28	606949676	WPG16	2015	3	28	16	36	54	-68.543	-22.209	115.0	5.70	Keep1
			610587192	WPG16	2015	3	28	16	36	56	-68.760	-22.070	122.0	5.70	
23940	5	12.6	606949681	WPG16	2015	3	28	19	16	33	176.793	-18.282	8.0	5.54	Keep1
			610587194	WPG16	2015	3	28	19	16	38	176.680	-18.270	12.0	5.50	
23941	1	12.7	606950093	WPG16	2015	3	28	22	28	51	121.988	0.395	118.0	5.95	Keep1
			610587199	WPG16	2015	3	28	22	28	52	122.000	0.430	130.0	5.90	
23946	23	50.4	606951381	WPG16	2015	3	29	23	48	31	152.562	-4.729	41.0	7.48	Keep1
			610587229	WPG16	2015	3	29	23	48	54	152.590	-5.180	37.0	7.50	
23953	8	38.9	606950943	WPG16	2015	3	30	7	56	54	-173.095	-15.409	13.0	6.04	Keep1
			610587244	WPG16	2015	3	30	7	57	2	-172.770	-15.260	17.0	6.00	
23954	8	29.8	606950944	WPG16	2015	3	30	8	18	1	-172.941	-15.392	14.0	6.33	Keep1
			610587246	WPG16	2015	3	30	8	18	9	-172.680	-15.300	14.0	6.30	
23955	9	43.5	606985213	WPG16	2015	3	30	8	48	25	-173.029	-15.499	11.0	6.48	Keep2
			610587248	WPG16	2015	3	30	8	48	34	-172.650	-15.370	17.0	6.40	
23956	3	18.5	606951384	WPG16	2015	3	30	10	34	54	78.144	-39.330	20.0	5.91	Keep1
			610587251	WPG16	2015	3	30	10	34	57	77.980	-39.250	12.0	5.90	
23958	8	28.8	606951560	WPG16	2015	3	30	18	2	11	-172.864	-15.426	9.0	5.80	Keep1
			610587264	WPG16	2015	3	30	18	2	19	-172.640	-15.530	20.0	5.80	
23960	0	8.8	610587285	WPG16	2015	3	31	12	10	44	162.430	-10.960	38.0	5.70	Keep1
			606985217	WPG16	2015	3	31	12	10	44	162.360	-11.000	38.0	5.70	
23961	4	16.3	606985218	WPG16	2015	3	31	12	15	22	152.475	-4.915	35.0	5.68	Keep1
			610587287	WPG16	2015	3	31	12	15	26	152.460	-5.050	41.0	5.70	
23962	5	22.1	606962333	WPG16	2015	3	31	12	18	24	152.490	-4.895	39.0	6.02	Keep1
			610587291	WPG16	2015	3	31	12	18	29	152.430	-5.070	47.0	6.00	
23963	3	14	606962342	WPG16	2015	3	31	15	48	41	20.390	38.347	13.0	4.91	Keep1
			610587295	WPG16	2015	3	31	15	48	44	20.400	38.250	22.0	4.90	
23966	3	28.9	606962367	WPG16	2015	4	1	8	17	28	-71.718	-29.344	31.0	5.39	Keep1
			610587315	WPG16	2015	4	1	8	17	31	-71.970	-29.480	28.0	5.40	
23967	3	25.7	610587317	WPG16	2015	4	1	9	35	58	132.516	-6.943	9.0	5.50	Keep2
			606962585	WPG16	2015	4	1	9	36	1	132.440	-6.820	29.0	5.49	
23968	6	42.3	606962587	WPG16	2015	4	1	11	6	36	-172.835	-16.021	10.0	5.45	Keep1
			610587319	WPG16	2015	4	1	11	6	42	-172.450	-15.940	14.0	5.40	
23973	3	21.5	606963939	WPG16	2015	4	2	4	10	11	-178.668	-17.849	564.0	5.95	Keep1
			610587340	WPG16	2015	4	2	4	10	14	-178.570	-17.680	563.0	5.90	
23975	4	47.9	606981631	WPG16	2015	4	3	12	32	39	-176.346	-23.016	59.0	5.46	Keep1
			610587374	WPG16	2015	4	3	12	32	43	-175.990	-23.090	89.0	5.40	
23976	6	16.3	606982074	WPG16	2015	4	3	21	17	54	147.694	-6.313	33.0	5.94	Keep1
			610587383	WPG16	2015	4	3	21	17	0	147.730	-6.450	37.0	5.90	
23978	3	17.6	606982102	WPG16	2015	4	4	8	6	18	127.683	-2.773	24.0	5.32	Keep1
			610587401	WPG16	2015	4	4	8	6	21	127.710	-2.640	15.0	5.30	
23979	2	18.1	606982122	WPG16	2015	4	4	17	48	48	130.672	-6.074	111.0	5.16	Keep1
			610587412	WPG16	2015	4	4	17	48	50	130.690	-6.000	127.0	5.10	
23981	1	27.4	610587442	WPG16	2015	4	5	20	51	44	152.675	-5.581	8.0	5.50	Keep2
			606982799	WPG16	2015	4	5	20	51	45	152.800	-5.790	12.0	5.55	
23985	5	17	607270391	WPG16	2015	4	7	0	46	22	-173.225	-15.168	30.0	6.33	Keep1
			610587474	WPG16	2015	4	7	0	46	27	-173.170	-15.250	43.0	6.30	
23995	1	17.7	607008353	WPG16	2015	4	10	6	10	39	-88.752	-41.232	10.0	5.37	Keep2
			610587547	WPG16	2015	4	10	6	10	40	-88.730	-41.390	12.0	5.30	
23996	4	18.7	607008373	WPG16	2015	4	10	16	23	4	65.860	-13.766	6.0	5.74	Keep1
			610587560	WPG16	2015	4	10	16	23	8	65.740	-13.710	18.0	5.70	

Table III.1. Continued.

Case	Δt (s)	d (km)	Event ID	Source	Year	Month	Day	Hour	Minute	Second	Longitude	Latitude	Depth	M	Outcome
23997	1	14.6	607011044	WPG16	2015	4	10	18	59	39	-126.157	40.418	19.0	4.94	Keep1
			610587566	WPG16	2015	4	10	18	59	40	-126.290	40.500	21.0	4.90	
23998	2	26	607019134	WPG16	2015	4	11	5	0	42	126.695	2.117	50.0	5.65	Keep1
			610587576	WPG16	2015	4	11	5	0	44	126.520	2.210	36.0	5.60	
24004	0	27.7	610587638	WPG16	2015	4	13	13	37	37	152.968	-4.690	45.0	5.20	Keep1
			610424366	WPG16	2015	4	13	13	37	37	153.000	-4.930	51.3	5.25	
24005	8	39.3	607120309	WPG16	2015	4	14	8	13	55	-173.350	-15.197	8.0	5.72	Keep2
			610587651	WPG16	2015	4	14	8	14	3	-173.060	-14.990	15.0	5.70	
24007	3	12.3	607121199	WPG16	2015	4	15	8	25	12	32.331	34.808	10.0	5.34	Keep1
			610587672	WPG16	2015	4	15	8	25	15	32.360	34.720	17.0	5.30	
24008	5	18.8	607121234	WPG16	2015	4	15	10	22	8	151.672	-3.795	10.0	5.51	Keep1
			610587674	WPG16	2015	4	15	10	22	13	151.540	-3.690	12.0	5.50	
24018	8	12.4	607167804	WPG16	2015	4	17	15	52	52	-178.620	-15.875	12.0	6.51	Keep1
			610587708	WPG16	2015	4	17	15	52	0	-178.510	-15.900	15.0	6.50	
24036	6	28.2	610587758	WPG16	2015	4	20	9	5	32	102.484	-5.717	18.0	5.81	Keep1
			607175602	WPG16	2015	4	20	9	5	38	102.360	-5.910	30.0	5.80	
24037	2	24.2	607175608	WPG16	2015	4	20	11	45	13	122.453	24.085	29.0	5.92	Keep1
			610587760	WPG16	2015	4	20	11	45	15	122.400	23.880	35.0	5.90	
24046	1	17.3	610587790	WPG16	2015	4	21	13	1	24	-96.668	15.998	18.0	4.90	Keep2
			607182601	WPG16	2015	4	21	13	1	25	-96.550	16.070	26.8	4.93	
24048	3	6.1	607182614	WPG16	2015	4	21	19	0	21	-71.354	-14.764	153.0	5.32	Keep1
			610587799	WPG16	2015	4	21	19	0	24	-71.360	-14.710	154.0	5.30	
24049	1	27.2	610587802	WPG16	2015	4	21	19	10	18	154.758	-6.343	35.0	5.40	Keep1
			607200926	WPG16	2015	4	21	19	10	19	154.670	-6.540	47.9	5.45	
24056	5	21.8	610587823	WPG16	2015	4	22	22	57	16	166.424	-12.025	75.0	6.20	Keep1
			607188894	WPG16	2015	4	22	22	57	21	166.330	-12.070	93.6	6.29	
24062	3	11.7	607203497	WPG16	2015	4	24	1	34	56	-127.190	40.430	18.0	5.46	Keep1
			610587840	WPG16	2015	4	24	1	34	59	-127.280	40.510	17.0	5.40	
24063	4	6.9	607203502	WPG16	2015	4	24	3	36	42	173.007	-42.060	48.0	6.03	Keep1
			610587844	WPG16	2015	4	24	3	36	46	173.070	-42.020	48.0	6.00	
24067	1	14.3	607206280	WPG16	2015	4	24	13	56	15	-130.771	51.615	8.0	6.20	Keep1
			610587861	Added	2015	4	24	13	56	16	-130.752	51.738	12.0	6.30	
24072	9	11.4	607260021	WPG16	2015	4	25	6	22	3	85.114	27.801	10.0	5.21	Keep1
			607260024	Added	2015	4	25	6	22	12	85.079	27.763	0.0	7.10	
24086	8	43.3	607260065	WPG16	2015	4	25	6	45	21	84.822	28.224	10.0	6.70	Keep1
			610587874	WPG16	2015	4	25	6	45	29	84.930	27.860	21.0	6.70	
24142	9	24.5	607211055	WPG16	2015	4	26	7	9	11	86.017	27.771	22.0	6.73	Keep1
			610587895	WPG16	2015	4	26	7	9	20	85.950	27.560	20.0	6.70	
24154	2	36.4	607211832	WPG16	2015	4	26	23	35	30	-79.836	-8.311	19.0	5.76	Keep2
			610587910	WPG16	2015	4	26	23	35	32	-80.160	-8.330	26.0	5.70	
24158	2	36.4	607213198	WPG16	2015	4	28	11	19	50	-79.623	-2.086	89.0	5.41	Keep1
			610587936	WPG16	2015	4	28	11	19	52	-79.810	-2.300	107.0	5.40	
24169	6	46.2	610431679	WPG16	2015	4	30	10	19	9	-26.800	-60.377	4.0	5.70	Keep1
			610587975	WPG16	2015	4	30	10	19	15	-26.440	-60.740	15.0	5.70	
24170	4	21.1	610587977	WPG16	2015	4	30	10	45	5	151.831	-5.393	35.0	6.60	Keep1
			607216795	WPG16	2015	4	30	10	45	9	151.830	-5.580	38.3	6.64	
24176	6	26.8	607218360	WPG16	2015	5	2	16	50	43	140.213	31.529	10.0	5.75	Keep1
			610588021	WPG16	2015	5	2	16	50	49	139.940	31.470	12.0	5.70	
24178	8	26.8	607219277	WPG16	2015	5	3	22	32	39	151.676	-5.631	24.0	5.96	Keep1
			610588046	WPG16	2015	5	3	22	32	47	151.880	-5.760	23.0	5.90	
24179	3	17.4	610431718	WPG16	2015	5	3	23	40	57	151.927	-5.539	35.0	5.87	Keep1
			610588050	WPG16	2015	5	3	23	40	0	151.890	-5.690	33.0	5.80	
24180	3	17.2	607219231	WPG16	2015	5	4	2	29	11	168.883	-44.523	10.0	5.58	Keep1
			610588056	WPG16	2015	5	4	2	29	14	168.730	-44.420	14.0	5.50	
24183	4	11.1	610588076	WPG16	2015	5	4	12	24	10	154.154	-61.284	14.0	5.70	Keep1
			607219470	WPG16	2015	5	4	12	24	14	154.030	-61.360	16.8	5.75	

Table III.1. Continued.

Case	Δt (s)	d (km)	Event ID	Source	Year	Month	Day	Hour	Minute	Second	Longitude	Latitude	Depth	M	Outcome
24184	20	34.1	607744335	WPG16	2015	5	5	1	44	6	151.875	-5.462	55.0	7.49	Keep1
			610588097	WPG16	2015	5	5	1	44	26	152.100	-5.320	38.0	7.50	
24194	2	34.3	607281859	WPG16	2015	5	5	8	16	58	152.235	-5.529	45.0	5.87	Keep2
			610588103	WPG16	2015	5	5	8	17	0	152.180	-5.780	26.0	5.80	
24199	1	4.9	607220666	WPG16	2015	5	5	20	53	22	67.160	-15.340	12.0	5.47	Keep2
			610588116	WPG16	2015	5	5	20	53	23	67.140	-15.380	12.0	5.40	
24203	14	17.6	607281870	WPG16	2015	5	7	7	10	20	154.557	-7.218	10.0	7.01	Keep1
			610588152	WPG16	2015	5	7	7	10	34	154.490	-7.360	12.0	7.00	
24209	3	21.5	607222175	WPG16	2015	5	7	11	33	1	154.402	-7.086	10.0	5.50	Keep1
			610588156	WPG16	2015	5	7	11	33	4	154.450	-7.250	20.0	5.50	
24217	1	18.8	610588178	WPG16	2015	5	8	3	12	21	97.884	1.559	36.0	5.78	Keep1
			607222906	WPG16	2015	5	8	3	12	22	97.720	1.580	32.0	5.70	
24218	3	28.8	607281878	WPG16	2015	5	8	7	52	7	149.831	-6.159	35.0	5.95	Keep1
			610588184	WPG16	2015	5	8	7	52	10	149.940	-6.390	40.0	5.90	
24223	1	15.7	610588222	Added	2015	5	9	12	18	48	-155.593	19.143	8.8	4.50	Keep1
			607228529	Added	2015	5	9	12	18	49	-155.537	19.247	0.0	4.30	
24226	5	17.7	607229912	WPG16	2015	5	10	21	25	46	142.016	31.237	6.0	5.89	Keep1
			610588251	WPG16	2015	5	10	21	25	51	142.050	31.090	12.0	5.80	
24227	2	15.1	607281897	WPG16	2015	5	11	11	51	17	154.417	-7.206	10.0	5.26	Keep1
			610588267	WPG16	2015	5	11	11	51	19	154.420	-7.340	12.0	5.20	
24230	7	22.3	607234486	WPG16	2015	5	12	7	5	20	86.066	27.809	28.0	7.26	Keep1
			610588278	WPG16	2015	5	12	7	5	27	86.080	27.670	12.0	7.20	
24236	6	34.3	607234490	WPG16	2015	5	12	7	36	54	86.162	27.625	15.0	6.16	Keep1
			610588280	WPG16	2015	5	12	7	36	0	86.350	27.370	20.0	6.10	
24256	5	25.5	607244002	WPG16	2015	5	14	15	8	4	-71.474	-28.666	18.0	5.27	Keep1
			610588312	WPG16	2015	5	14	15	8	9	-71.690	-28.780	25.0	5.20	
24260	2	7.7	610588344	WPG16	2015	5	15	20	26	56	102.201	-2.620	155.0	6.00	Keep1
			607250635	WPG16	2015	5	15	20	26	58	102.140	-2.610	158.4	6.08	
24261	2	29.9	607250754	WPG16	2015	5	16	11	34	10	86.033	27.537	5.0	5.38	Keep1
			610588359	WPG16	2015	5	16	11	34	12	86.260	27.370	12.0	5.30	
24264	1	4.4	610588377	WPG16	2015	5	17	8	52	41	165.580	-12.120	25.0	5.60	Keep1
			607281927	WPG16	2015	5	17	8	52	42	165.550	-12.130	22.2	5.68	
24268	3	9.7	607252315	WPG16	2015	5	18	4	2	46	80.320	-41.550	12.0	5.76	Keep1
			610588403	WPG16	2015	5	18	4	2	49	80.250	-41.480	12.0	5.70	
24271	4	16.7	607281932	WPG16	2015	5	18	17	4	54	154.442	-7.148	10.0	5.71	Keep1
			610588417	WPG16	2015	5	18	17	4	58	154.400	-7.290	13.0	5.70	
24273	4	16.2	609901458	WPG16	2015	5	19	13	54	56	168.490	-18.609	45.0	5.88	Keep1
			610588435	WPG16	2015	5	19	13	55	0	168.390	-18.560	56.0	5.80	
24274	8	27.5	607254107	WPG16	2015	5	19	15	25	21	-132.162	-54.331	7.0	6.65	Keep1
			610588439	WPG16	2015	5	19	15	25	29	-132.390	-54.530	14.0	6.60	
24275	0	15.3	610588443	Added	2015	5	19	18	36	2	-120.884	36.667	0.0	3.80	Keep2
			607254111	Added	2015	5	19	18	36	2	-120.798	36.547	0.0	4.00	
24276	3	31.8	610588455	WPG16	2015	5	20	0	30	54	-175.438	-19.326	201.0	6.00	Keep1
			607254906	WPG16	2015	5	20	0	30	57	-175.140	-19.350	206.0	6.05	
24277	1	23.2	607254909	WPG16	2015	5	20	3	31	43	70.196	38.642	14.0	5.21	Keep1
			610588459	WPG16	2015	5	20	3	31	44	69.970	38.750	17.0	5.20	
24279	3	26.8	607255835	WPG16	2015	5	20	17	20	44	126.398	1.824	36.0	5.58	Keep1
			610588471	WPG16	2015	5	20	17	20	47	126.260	2.020	34.0	5.50	
24280	10	27.7	607270290	WPG16	2015	5	20	22	48	53	164.144	-10.873	16.0	6.83	Keep1
			610588475	WPG16	2015	5	20	22	49	3	163.910	-10.780	19.0	6.80	
24288	3	27	610612755	WPG16	2015	5	21	19	32	58	160.330	-9.776	6.0	5.70	Keep1
			610634724	WPG16	2015	5	21	19	33	1	160.400	-10.000	13.0	5.70	
24292	7	26.1	610634750	WPG16	2015	5	22	21	45	19	163.685	-11.086	13.0	6.98	Keep1
			607281992	WPG16	2015	5	22	21	45	26	163.540	-10.900	15.0	7.00	
24294	6	21.1	607261306	WPG16	2015	5	22	23	59	34	163.194	-11.157	13.0	6.89	Keep1
			610634754	WPG16	2015	5	22	23	59	40	163.220	-10.970	15.0	6.90	

Table III.1. Continued.

Case	Δt (s)	d (km)	Event ID	Source	Year	Month	Day	Hour	Minute	Second	Longitude	Latitude	Depth	M	Outcome
24299	4	29.9	607263622	WPG16	2015	5	23	19	28	17	152.591	-4.785	29.0	5.87	Keep2
			610634772	WPG16	2015	5	23	19	28	21	152.620	-5.020	43.0	5.80	
24303	5	11.4	607263633	WPG16	2015	5	24	4	53	24	-14.171	-16.855	10.0	6.34	Keep1
			610634778	WPG16	2015	5	24	4	53	29	-14.100	-16.780	12.0	6.30	
24306	6	11	607274096	WPG16	2015	5	24	14	38	0	-175.963	-19.393	10.0	6.29	Keep1
			610634789	WPG16	2015	5	24	14	39	6	-176.050	-19.400	16.0	6.30	
24307	6	51.2	607264419	WPG16	2015	5	24	21	6	41	-26.415	-59.644	35.0	5.78	Keep1
			610634794	WPG16	2015	5	24	21	6	47	-25.820	-59.980	46.0	5.80	
24308	0	8	607282006	WPG16	2015	5	25	4	48	24	154.920	-6.530	61.2	5.36	Keep2
			610634798	WPG16	2015	5	25	4	48	24	154.980	-6.490	62.0	5.30	
24313	3	25.5	607265447	WPG16	2015	5	26	10	32	3	-68.508	-22.057	124.0	5.64	Keep1
			610634832	WPG16	2015	5	26	10	32	6	-68.630	-21.940	142.0	5.60	
24314	3	58.8	607265562	WPG16	2015	5	26	16	42	33	135.734	-0.328	15.0	5.80	Keep1
			610634841	Added	2015	5	26	16	42	36	136.140	-0.260	52.0	5.70	
24317	4	48.4	607282017	WPG16	2015	5	26	23	41	41	-25.214	-58.736	35.0	5.68	Keep1
			610634851	WPG16	2015	5	26	23	41	45	-24.510	-58.970	30.0	5.70	
24324	5	47.9	607269403	Added	2015	5	29	4	28	16	-70.637	-28.221	42.7	5.40	Keep2
			610634880	WPG16	2015	5	29	4	28	21	-71.100	-28.230	58.0	5.20	
24332	5	20.6	607269414	WPG16	2015	5	29	8	40	13	99.924	-47.358	10.0	5.89	Keep1
			610634892	WPG16	2015	5	29	8	40	18	100.190	-47.340	14.0	5.90	
24339	7	24	607273371	WPG16	2015	5	30	11	23	3	140.492	27.838	660.0	7.89	Keep1
			610634918	WPG16	2015	5	30	11	23	10	140.560	27.940	680.0	7.90	
24340	11	63.5	607273382	WPG16	2015	5	30	17	18	35	-173.382	-15.722	10.0	6.01	Keep1
			610634924	WPG16	2015	5	30	17	18	46	-173.190	-15.690	70.0	6.00	
24341	1	7.8	610634927	Added	2015	5	30	18	49	6	143.040	30.770	2.0	6.20	Keep2
			607273388	WPG16	2015	5	30	18	49	7	142.972	30.786	6.0	6.20	
24342	7	31.1	607273416	WPG16	2015	5	31	16	8	28	-70.909	-19.942	20.0	5.06	Keep1
			610634941	WPG16	2015	5	31	16	8	35	-71.180	-19.850	28.0	5.00	
24345	1	32.6	607274454	WPG16	2015	6	1	6	52	42	-129.761	44.448	6.0	5.84	Keep2
			610634957	WPG16	2015	6	1	6	52	43	-130.130	44.350	15.0	5.80	
24350	1	37	610634963	WPG16	2015	6	1	10	46	27	-129.990	44.360	12.0	5.40	Keep2
			607274705	WPG16	2015	6	1	10	46	28	-129.588	44.519	18.0	5.44	
24358	3	9.3	607281187	WPG16	2015	6	3	19	34	16	144.104	43.468	10.0	4.75	Keep1
			610635021	WPG16	2015	6	3	19	34	19	144.060	43.540	13.0	4.70	
24364	3	27	607283827	WPG16	2015	6	5	14	54	1	78.127	-37.155	5.0	5.57	Keep1
			610635055	WPG16	2015	6	5	14	54	4	78.210	-36.930	12.0	5.50	
24365	2	39.1	607284876	WPG16	2015	6	5	20	2	55	-107.545	-34.863	7.0	5.46	Keep1
			610635058	WPG16	2015	6	5	20	2	57	-107.930	-34.990	17.0	5.40	
24371	6	22.6	607286708	WPG16	2015	6	8	6	1	8	142.031	41.562	42.0	6.09	Keep1
			610635101	WPG16	2015	6	8	6	1	14	142.240	41.490	54.0	6.10	
24373	3	17.7	607287572	WPG16	2015	6	9	1	9	3	23.383	38.663	9.0	5.32	Keep1
			610635122	WPG16	2015	6	9	1	9	6	23.430	38.510	12.0	5.30	
24374	4	2.8	607287580	WPG16	2015	6	9	6	41	39	-105.782	-35.356	14.0	5.46	Keep1
			610635125	WPG16	2015	6	9	6	41	43	-105.760	-35.340	15.0	5.40	
24382	10	29	607288481	WPG16	2015	6	10	8	33	4	143.319	39.680	31.0	5.73	Keep1
			610635146	WPG16	2015	6	10	8	33	14	143.640	39.660	22.0	5.70	
24383	3	24	607288602	WPG16	2015	6	10	13	52	10	-68.432	-22.400	124.0	6.10	Keep1
			610635148	WPG16	2015	6	10	13	52	13	-68.470	-22.480	146.0	6.10	
24389	3	19.8	607289498	WPG16	2015	6	11	4	45	30	143.331	39.672	10.0	5.70	Keep1
			610635158	WPG16	2015	6	11	4	45	33	143.540	39.650	18.0	5.70	
24390	4	23.3	607289499	WPG16	2015	6	11	4	51	24	143.312	39.615	10.0	5.68	Keep1
			610635160	WPG16	2015	6	11	4	51	28	143.520	39.610	25.0	5.70	
24391	4	41.7	607289500	WPG16	2015	6	11	4	56	32	143.241	39.610	10.0	5.37	Keep1
			610635163	WPG16	2015	6	11	4	56	36	143.640	39.610	34.0	5.30	
24394	5	37.6	610612921	WPG16	2015	6	12	11	7	8	-173.010	-15.676	48.0	6.04	Keep1
			610635195	WPG16	2015	6	12	11	7	13	-172.690	-15.540	51.0	6.00	

Table III.1. Continued.

Case	Δt (s)	d (km)	Event ID	Source	Year	Month	Day	Hour	Minute	Second	Longitude	Latitude	Depth	M	Outcome
24396	3	48.9	607292893	WPG16	2015	6	13	3	17	24	-176.211	-24.598	35.0	5.60	Keep1
			610635218	WPG16	2015	6	13	3	17	27	-175.730	-24.600	30.0	5.60	
24397	2	9.8	607292900	WPG16	2015	6	13	7	8	59	143.886	-3.233	8.0	5.42	Keep1
			610635223	WPG16	2015	6	13	7	9	1	143.850	-3.160	12.0	5.40	
24402	6	19.9	607295785	WPG16	2015	6	15	17	40	54	125.252	-9.742	20.0	5.84	Keep1
			610635264	WPG16	2015	6	15	17	40	0	125.120	-9.620	18.0	5.80	
24404	3	12.9	607296674	WPG16	2015	6	16	6	17	1	-178.991	-20.401	653.0	6.04	Keep2
			610635278	WPG16	2015	6	16	6	17	4	-178.930	-20.420	664.0	6.00	
24410	16	69.8	607297678	WPG16	2015	6	17	12	51	33	-17.161	-35.364	10.0	6.95	Keep1
			610635299	WPG16	2015	6	17	12	51	49	-16.400	-35.380	21.0	6.90	
24411	1	18.6	607298424	WPG16	2015	6	18	7	28	55	169.621	-19.136	24.0	5.39	Keep1
			610635312	WPG16	2015	6	18	7	28	56	169.710	-19.040	12.0	5.40	
24412	3	29	607299900	WPG16	2015	6	19	0	35	14	141.573	37.516	36.0	4.78	Keep1
			610635324	WPG16	2015	6	19	0	35	17	141.740	37.580	60.0	4.80	
24413	6	28.2	607304048	WPG16	2015	6	20	2	10	7	-73.789	-36.358	8.0	6.45	Keep1
			610635339	WPG16	2015	6	20	2	10	13	-74.100	-36.350	12.0	6.40	
24415	3	32.4	610635349	WPG16	2015	6	20	5	22	19	-73.764	-36.368	8.0	5.40	Keep2
			607304056	WPG16	2015	6	20	5	22	22	-74.100	-36.470	12.0	5.44	
24416	3	56.5	607304059	WPG16	2015	6	20	5	32	9	-26.503	-59.629	50.0	5.71	Keep1
			610635352	WPG16	2015	6	20	5	32	12	-25.820	-60.000	44.0	5.70	
24421	0	4.7	607307131	WPG16	2015	6	21	21	28	16	-178.328	-20.431	562.0	6.00	Keep1
			610635398	Added	2015	6	21	21	28	16	-178.340	-20.470	563.0	6.00	
24425	3	23.2	607308951	WPG16	2015	6	23	8	59	56	-175.040	-19.569	138.0	5.45	Keep1
			610635428	WPG16	2015	6	23	8	59	59	-174.940	-19.720	150.0	5.40	
24429	2	21.7	607309728	Added	2015	6	24	22	32	20	-152.260	61.730	114.0	5.80	Keep2
			610635456	WPG16	2015	6	24	22	32	22	-152.010	61.850	125.0	5.80	
24430	3	12.4	607310148	WPG16	2015	6	25	2	53	13	-82.866	8.303	7.0	4.87	Keep1
			610635459	WPG16	2015	6	25	2	53	16	-82.770	8.340	12.0	4.80	
24431	0	3.1	610635470	WPG16	2015	6	25	15	41	18	152.130	-10.280	12.0	5.40	Keep1
			607312880	WPG16	2015	6	25	15	41	18	152.110	-10.260	12.0	5.40	
24432	7	65.7	607312883	WPG16	2015	6	25	18	45	57	-178.324	-32.072	10.0	5.90	Keep1
			610635473	WPG16	2015	6	25	18	46	4	-177.650	-32.220	14.0	5.90	
24435	1	14.4	607313505	WPG16	2015	6	26	4	39	51	-154.193	57.791	21.0	4.91	Keep1
			610635483	WPG16	2015	6	26	4	39	52	-154.080	57.720	31.0	4.90	
24439	1	3.4	610635519	WPG16	2015	6	27	7	28	53	121.500	-48.990	12.0	5.40	Keep1
			607317004	WPG16	2015	6	27	7	28	54	121.490	-48.960	12.0	5.43	
24441	1	40.9	607317236	WPG16	2015	6	28	1	5	29	90.425	26.639	15.0	5.36	Keep2
			610635540	WPG16	2015	6	28	1	5	30	90.590	26.380	39.0	5.30	
24445	5	29.5	607318481	WPG16	2015	6	29	9	9	16	-74.256	-16.025	28.0	5.89	Keep1
			610635566	WPG16	2015	6	29	9	9	21	-74.510	-16.090	37.0	5.80	
24448	0	16.4	610635579	WPG16	2015	6	29	22	7	48	71.130	36.680	195.0	5.50	Keep2
			607318873	WPG16	2015	6	29	22	7	48	71.305	36.677	190.0	5.52	
24449	3	18.5	607318881	WPG16	2015	6	30	3	39	29	151.486	-5.495	43.0	6.01	Keep1
			610635583	WPG16	2015	6	30	3	39	32	151.610	-5.600	47.0	6.00	
24456	3	11.4	607321271	WPG16	2015	7	2	7	26	49	-16.184	-34.704	10.0	5.19	Keep1
			610635635	WPG16	2015	7	2	7	26	52	-16.100	-34.630	12.0	5.20	
24469	1	25.3	607675407	WPG16	2015	7	6	0	50	33	-150.705	62.141	65.0	5.00	Keep1
			610635697	WPG16	2015	7	6	0	50	34	-150.840	62.320	79.0	5.00	
24471	2	24.2	610432369	WPG16	2015	7	6	3	50	58	-142.110	-56.600	10.0	5.54	Keep1
			610635699	WPG16	2015	7	6	3	50	0	-142.430	-56.700	19.0	5.50	
24473	2	65	607328459	WPG16	2015	7	7	7	1	43	-111.632	-13.329	10.0	5.91	Keep2
			610635719	WPG16	2015	7	7	7	1	45	-112.230	-13.360	15.0	5.90	
24476	6	8.3	607334499	WPG16	2015	7	7	16	8	4	-111.302	-13.386	10.0	5.74	Keep1
			610635729	WPG16	2015	7	7	16	8	10	-111.260	-13.430	15.0	5.70	
24477	5	46.6	607339202	WPG16	2015	7	7	18	4	47	-111.639	-13.727	10.0	5.33	Keep1
			610635732	WPG16	2015	7	7	18	4	52	-111.340	-13.430	16.0	5.30	

Table III.1. Continued.

Case	Δt (s)	d (km)	Event ID	Source	Year	Month	Day	Hour	Minute	Second	Longitude	Latitude	Depth	M	Outcome
24483	12	53.1	607351517	WPG16	2015	7	9	13	25	54	-90.244	13.295	45.0	5.62	Keep2
			610635765	WPG16	2015	7	9	13	26	6	-90.660	13.100	27.0	5.60	
24506	6	18.4	607467356	WPG16	2015	7	16	10	48	4	-71.820	-29.481	16.0	5.23	Keep1
			610635901	WPG16	2015	7	16	10	48	10	-71.820	-29.400	32.0	5.20	
24507	3	15.6	607467358	WPG16	2015	7	16	11	1	46	-58.474	13.877	7.0	5.74	Keep1
			610635903	WPG16	2015	7	16	11	1	49	-58.360	13.910	16.0	5.70	
24508	3	19.1	607467802	WPG16	2015	7	16	15	16	34	-58.548	13.867	20.0	6.48	Keep1
			610635907	WPG16	2015	7	16	15	16	37	-58.380	13.920	19.0	6.50	
24509	4	20.3	607643784	WPG16	2015	7	17	11	11	22	-73.205	-35.524	18.0	5.35	Keep1
			610635928	WPG16	2015	7	17	11	11	26	-73.420	-35.570	21.0	5.30	
24511	4	33.7	610635940	Added	2015	7	17	19	36	49	69.318	36.761	0.0	3.50	Keep1
			607500565	Added	2015	7	17	19	36	53	69.450	37.000	17.0	3.80	
24520	1	37.8	610432501	Added	2015	7	20	9	23	57	-72.314	-33.782	0.0	3.90	Keep2
			610635985	Added	2015	7	20	9	23	58	-72.560	-33.786	30.2	4.10	
24521	5	24.6	607502551	WPG16	2015	7	20	11	8	19	-105.084	-35.525	14.0	5.83	Keep1
			610635989	WPG16	2015	7	20	11	8	24	-104.830	-35.450	17.0	5.80	
24527	3	24.5	607505156	WPG16	2015	7	23	3	56	53	-21.178	-0.694	8.0	5.66	Keep1
			610636043	WPG16	2015	7	23	3	56	56	-21.050	-0.600	25.0	5.60	
24533	5	39.2	607506869	WPG16	2015	7	24	23	14	39	-70.282	-20.291	40.0	5.30	Keep1
			610636079	WPG16	2015	7	24	23	14	44	-70.650	-20.280	48.0	5.30	
24534	4	32	610636096	Added	2015	7	25	19	57	41	-152.190	62.060	100.0	5.10	Keep2
			607507191	WPG16	2015	7	25	19	57	45	-152.230	62.130	131.0	5.20	
24606	5	27.7	607574964	WPG16	2015	7	30	18	51	6	-140.951	-56.972	9.0	5.67	Keep1
			610636402	WPG16	2015	7	30	18	51	11	-141.340	-57.030	22.0	5.60	
24617	3	23	607641552	WPG16	2015	8	3	14	1	53	-174.351	-16.473	179.0	5.78	Keep1
			610636474	WPG16	2015	8	3	14	1	56	-174.140	-16.450	183.0	5.80	
24623	2	9.9	607645495	WPG16	2015	8	6	9	22	30	140.595	36.452	52.0	5.18	Keep1
			610636539	WPG16	2015	8	6	9	22	32	140.690	36.460	57.0	5.20	
24626	3	30	607646409	WPG16	2015	8	7	1	28	37	28.952	-2.091	10.0	5.58	Keep1
			610636563	WPG16	2015	8	7	1	28	40	28.760	-2.110	31.0	5.50	
24631	2	25.9	607646421	Added	2015	8	7	5	53	57	-108.600	24.200	10.0	5.20	Keep2
			610636570	WPG16	2015	8	7	5	53	59	-108.850	24.180	15.0	5.30	
24633	2	21	607646520	WPG16	2015	8	7	12	18	49	-85.208	1.086	10.0	5.62	Keep1
			610636584	WPG16	2015	8	7	12	18	51	-85.370	1.000	15.0	5.60	
24636	5	20	607646899	WPG16	2015	8	9	8	36	13	-82.643	5.180	10.0	5.44	Keep1
			610636645	WPG16	2015	8	9	8	36	18	-82.650	5.020	19.0	5.40	
24640	3	9.5	607647629	WPG16	2015	8	10	4	24	31	157.954	-9.300	10.0	5.91	Keep1
			610636666	WPG16	2015	8	10	4	24	34	157.870	-9.310	12.0	5.90	
24644	5	48.6	607726098	WPG16	2015	8	10	19	19	32	-176.241	-27.081	6.0	5.58	Keep1
			610636680	WPG16	2015	8	10	19	19	37	-175.760	-27.080	16.0	5.50	
24652	5	42.2	607648573	WPG16	2015	8	11	13	35	49	-176.246	-27.060	4.0	5.52	Keep1
			610636692	WPG16	2015	8	11	13	35	54	-175.870	-26.900	13.0	5.50	
24654	4	4.7	607648574	WPG16	2015	8	11	13	49	4	-176.258	-19.172	10.0	5.45	Keep1
			610636695	WPG16	2015	8	11	13	49	8	-176.250	-19.140	13.0	5.40	
24656	4	23.1	607649017	WPG16	2015	8	12	0	14	40	-71.613	-31.698	39.0	5.54	Keep1
			610636707	WPG16	2015	8	12	0	14	44	-71.790	-31.840	38.0	5.50	
24657	6	18.4	607726112	WPG16	2015	8	12	18	49	24	157.868	-9.363	18.0	6.52	Keep1
			610636721	WPG16	2015	8	12	18	49	30	157.710	-9.320	14.0	6.50	
24662	5	53.4	607652999	WPG16	2015	8	13	10	39	54	78.010	-37.070	4.0	5.99	Keep1
			610636738	WPG16	2015	8	13	10	39	59	78.490	-36.790	12.0	6.00	
24663	5	2.4	607653000	WPG16	2015	8	13	11	28	15	78.352	-36.853	10.0	5.62	Keep1
			610636740	WPG16	2015	8	13	11	28	20	78.340	-36.860	12.0	5.60	
24670	6	43.2	607726126	WPG16	2015	8	14	13	28	1	-176.053	-27.315	11.0	5.59	Keep1
			610636767	WPG16	2015	8	14	13	28	7	-175.640	-27.190	14.0	5.60	
24671	1	14.7	607661762	WPG16	2015	8	14	18	3	3	-45.852	21.104	10.0	5.61	Keep1
			610636770	WPG16	2015	8	14	18	3	4	-45.730	21.170	12.0	5.60	

Table III.1. Continued.

Case	Δt (s)	d (km)	Event ID	Source	Year	Month	Day	Hour	Minute	Second	Longitude	Latitude	Depth	M	Outcome
24672	2	30.7	607665384	WPG16	2015	8	14	22	3	35	131.342	-6.873	35.0	5.14	Keep2
			610636777	WPG16	2015	8	14	22	3	37	131.300	-7.040	59.0	5.10	
24673	6	21.5	607665976	WPG16	2015	8	15	7	47	6	163.823	-10.897	8.0	6.46	Keep1
			610636783	WPG16	2015	8	15	7	47	12	163.710	-10.780	20.0	6.40	
24676	1	13.6	607666518	WPG16	2015	8	15	20	16	21	-175.158	51.674	32.0	5.68	Keep1
			610636790	WPG16	2015	8	15	20	16	22	-175.070	51.600	41.0	5.60	
24684	1	26	607674243	WPG16	2015	8	20	11	0	10	126.597	0.503	52.0	5.84	Keep1
			610636867	WPG16	2015	8	20	11	0	11	126.500	0.630	71.0	5.80	
24694	6	20.7	607677064	WPG16	2015	8	23	23	10	4	-71.351	-29.693	46.0	5.73	Keep1
			610636925	WPG16	2015	8	23	23	10	10	-71.530	-29.590	46.0	5.70	
24695	3	24.1	607677244	WPG16	2015	8	24	11	50	58	164.268	56.188	8.0	5.51	Keep1
			610636939	WPG16	2015	8	24	11	51	1	164.540	56.300	20.0	5.50	
24700	5	46.5	610636983	WPG16	2015	8	26	13	51	36	-25.894	-57.482	35.0	5.70	Keep2
			607682902	WPG16	2015	8	26	13	51	41	-25.170	-57.570	49.2	5.76	
24719	2	51.2	610637123	WPG16	2015	9	2	1	13	50	53.490	14.260	12.0	5.30	Keep2
			607725347	WPG16	2015	9	2	1	13	52	53.896	14.033	4.0	5.35	
24738	2	6.7	607726527	WPG16	2015	9	3	16	51	48	143.497	37.184	9.0	5.37	Keep1
			610637163	WPG16	2015	9	3	16	51	50	143.550	37.150	12.0	5.30	
24746	3	9	607728827	WPG16	2015	9	5	7	0	1	-174.368	51.440	15.0	5.58	Keep1
			610637215	WPG16	2015	9	5	7	0	4	-174.270	51.390	17.0	5.50	
24755	2	22.8	607729013	WPG16	2015	9	5	13	16	9	155.682	49.361	38.0	5.88	Keep1
			610637248	WPG16	2015	9	5	13	16	11	155.980	49.340	45.0	5.80	
24760	7	13.2	607861556	WPG16	2015	9	7	9	13	57	-177.860	-32.820	17.0	6.21	Keep1
			610637298	WPG16	2015	9	7	9	14	4	-177.730	-32.830	12.0	6.20	
24772	3	36.7	607732863	WPG16	2015	9	8	6	48	33	-178.534	-33.030	10.0	5.77	Keep1
			610637324	WPG16	2015	9	8	6	48	36	-178.150	-33.070	17.0	5.70	
24774	2	43	607732866	Added	2015	9	8	8	3	56	-93.810	14.740	15.0	5.70	Keep1
			610637326	WPG16	2015	9	8	8	3	58	-94.200	14.660	12.0	5.80	
24775	5	11.9	607732868	WPG16	2015	9	8	8	19	54	-178.205	-33.115	12.0	5.57	Keep1
			610637328	WPG16	2015	9	8	8	19	59	-178.110	-33.110	20.0	5.50	
24783	6	15.4	607734336	WPG16	2015	9	9	7	5	44	-116.303	-49.540	20.0	5.74	Keep1
			610637341	WPG16	2015	9	9	7	5	50	-116.470	-49.600	13.0	5.70	
24785	1	6.4	607734345	WPG16	2015	9	9	21	3	24	70.485	36.006	107.0	5.28	Keep1
			610637348	WPG16	2015	9	9	21	3	25	70.460	36.010	113.0	5.20	
24789	4	13.7	607735769	WPG16	2015	9	10	10	26	44	-169.537	52.085	18.0	6.02	Keep1
			610637364	WPG16	2015	9	10	10	26	48	-169.480	51.970	15.0	6.00	
24797	3	14.7	607737232	WPG16	2015	9	11	20	49	7	139.906	35.504	51.0	5.09	Keep1
			610637390	WPG16	2015	9	11	20	49	10	139.780	35.450	44.0	5.10	
24798	4	16.4	607737234	WPG16	2015	9	11	21	19	19	146.660	-5.972	23.0	5.54	Keep1
			610637392	WPG16	2015	9	11	21	19	23	146.720	-5.970	38.0	5.50	
24802	4	28.6	607738208	WPG16	2015	9	12	20	32	26	-178.097	-32.612	8.0	5.80	Keep1
			610637420	WPG16	2015	9	12	20	32	30	-177.800	-32.650	13.0	5.80	
24803	5	19.6	607860387	WPG16	2015	9	12	22	16	8	147.366	-6.124	27.0	5.55	Keep1
			610637423	WPG16	2015	9	12	22	16	13	147.380	-6.280	36.0	5.50	
24848	5	34.1	607742135	WPG16	2015	9	15	22	3	34	-70.894	-20.043	18.0	5.04	Keep2
			610637482	WPG16	2015	9	15	22	3	39	-71.170	-19.900	27.0	5.00	
24858	3	16.8	607742160	WPG16	2015	9	16	7	40	59	126.429	1.884	41.0	6.36	Keep1
			610637492	WPG16	2015	9	16	7	41	2	126.470	2.010	33.0	6.30	
24876	6	22.9	607742365	WPG16	2015	9	16	14	3	22	151.477	-6.011	6.0	6.05	Keep1
			610637504	WPG16	2015	9	16	14	3	28	151.530	-6.200	13.0	6.00	
24887	5	23.5	607742370	WPG16	2015	9	16	18	24	21	-70.943	-19.971	12.0	4.99	Keep1
			610637509	WPG16	2015	9	16	18	24	26	-71.140	-19.950	23.0	5.00	
24900	10	56.1	607860416	WPG16	2015	9	16	23	18	42	-71.426	-31.562	28.0	7.13	Keep1
			610637518	WPG16	2015	9	16	23	18	52	-71.950	-31.790	35.0	7.10	
24948	2	14.4	610637536	Added	2015	9	17	5	44	38	-72.024	-31.781	0.0	5.40	Keep2
			607743136	WPG16	2015	9	17	5	44	40	-72.131	-31.801	10.0	5.50	

Table III.1. Continued.

Case	Δt (s)	d (km)	Event ID	Source	Year	Month	Day	Hour	Minute	Second	Longitude	Latitude	Depth	M	Outcome
24972	8	15.1	607743707	WPG16	2015	9	17	13	32	26	-72.378	-32.143	10.0	5.96	Keep1
			610637544	WPG16	2015	9	17	13	32	34	-72.280	-32.230	17.0	5.90	
24997	3	17.9	610433425	WPG16	2015	9	18	3	15	41	-71.576	-31.455	36.0	5.05	Keep1
			610637580	WPG16	2015	9	18	3	15	44	-71.760	-31.440	40.0	5.00	
24999	3	21.9	610433427	WPG16	2015	9	18	4	24	3	-72.055	-31.361	9.0	5.50	Keep1
			610637582	Added	2015	9	18	4	24	6	-72.100	-31.400	30.0	5.30	
25005	4	24.8	610433436	WPG16	2015	9	18	8	18	18	-72.368	-32.229	6.0	5.49	Keep1
			610637591	WPG16	2015	9	18	8	18	22	-72.600	-32.320	12.0	5.50	
25007	7	10.5	607745130	WPG16	2015	9	18	9	10	45	-72.229	-32.368	8.0	6.13	Keep1
			610637593	WPG16	2015	9	18	9	10	52	-72.300	-32.310	13.0	6.10	
25012	5	8.6	610637607	WPG16	2015	9	18	13	51	18	-71.896	-31.408	27.0	4.96	Keep1
			607760496	WPG16	2015	9	18	13	51	23	-71.900	-31.480	30.0	4.90	
25023	0	30.7	610433470	WPG16	2015	9	18	22	35	21	-72.640	-30.264	10.0	4.97	Keep1
			610637635	WPG16	2015	9	18	22	35	21	-72.950	-30.330	12.0	4.90	
25028	4	23.9	607770395	WPG16	2015	9	19	5	6	48	-72.081	-29.642	7.0	5.98	Keep1
			610637647	WPG16	2015	9	19	5	6	52	-72.300	-29.730	12.0	6.00	
25029	5	19.6	607770404	WPG16	2015	9	19	8	31	25	-72.232	-30.100	8.0	5.42	Keep1
			610637654	WPG16	2015	9	19	8	31	30	-72.300	-30.260	13.0	5.40	
25030	4	29.3	610637657	WPG16	2015	9	19	9	7	9	-71.585	-31.106	28.0	5.82	Keep1
			610433486	WPG16	2015	9	19	9	7	13	-71.860	-31.200	36.0	5.80	
25033	6	4.3	607776564	WPG16	2015	9	19	12	52	20	-72.008	-32.330	18.0	6.25	Keep1
			610637668	WPG16	2015	9	19	12	52	26	-72.050	-32.340	19.0	6.20	
25034	3	13.2	610637670	WPG16	2015	9	19	13	9	2	-72.050	-30.670	23.0	5.60	Keep2
			610433496	WPG16	2015	9	19	13	9	5	-72.180	-30.710	23.0	5.63	
25040	2	27.2	610637680	WPG16	2015	9	19	18	13	17	-71.902	-31.279	34.0	5.00	Keep2
			607776566	WPG16	2015	9	19	18	13	19	-72.140	-31.410	38.2	5.01	
25042	1	33.1	607776782	WPG16	2015	9	19	21	50	31	-129.648	49.423	10.0	4.78	Keep2
			610637691	WPG16	2015	9	19	21	50	32	-129.910	49.200	21.0	4.80	
25052	4	13.3	610637713	WPG16	2015	9	20	9	2	34	-72.267	-30.251	13.0	5.10	Keep1
			607776798	WPG16	2015	9	20	9	2	38	-72.300	-30.360	17.4	5.12	
25062	4	15.3	607860432	WPG16	2015	9	21	5	39	35	-71.737	-31.574	30.0	6.13	Keep1
			610637737	WPG16	2015	9	21	5	39	39	-71.840	-31.660	37.0	6.10	
25065	2	22	607779224	WPG16	2015	9	21	12	49	26	-72.656	-31.065	10.0	4.80	Keep1
			610637743	WPG16	2015	9	21	12	49	28	-72.850	-31.170	12.0	4.86	
25068	4	16.6	610433564	WPG16	2015	9	21	15	37	8	-71.864	-31.042	33.0	5.50	Keep1
			610637748	WPG16	2015	9	21	15	37	12	-71.950	-31.170	31.0	5.50	
25070	6	41.2	607860433	WPG16	2015	9	21	17	40	0	-71.379	-31.728	35.0	6.62	Keep2
			610637750	WPG16	2015	9	21	17	40	6	-71.810	-31.770	39.0	6.60	
25071	5	30.8	610433566	WPG16	2015	9	21	18	36	53	-71.720	-31.053	32.0	5.82	Keep1
			610637752	WPG16	2015	9	21	18	36	58	-72.020	-31.140	38.0	5.80	
25073	5	31.2	607779466	WPG16	2015	9	21	19	56	9	-71.641	-31.782	28.0	5.76	Keep1
			610637756	WPG16	2015	9	21	19	56	14	-71.870	-31.940	42.0	5.70	
25083	3	20.1	610433581	WPG16	2015	9	22	7	13	1	-71.265	-31.444	58.0	6.09	Keep1
			610637770	WPG16	2015	9	22	7	13	4	-71.390	-31.580	64.0	6.00	
25087	1	11.2	607793641	WPG16	2015	9	22	13	24	51	-130.227	50.326	10.0	4.80	Keep1
			610637780	Added	2015	9	22	13	24	52	-130.253	50.227	10.0	4.70	
25096	2	29	607811389	WPG16	2015	9	24	13	48	58	-130.208	50.783	10.0	5.78	Keep1
			610637825	WPG16	2015	9	24	13	49	0	-130.420	50.560	12.0	5.80	
25108	4	23.9	607831512	WPG16	2015	9	26	2	51	18	-71.385	-30.820	46.0	6.30	Keep1
			610637872	WPG16	2015	9	26	2	51	22	-71.620	-30.880	51.0	6.30	
25116	5	45.5	607832217	WPG16	2015	9	26	21	40	35	-142.286	-57.063	13.0	6.03	Keep2
			610637893	WPG16	2015	9	26	21	40	40	-142.490	-56.680	23.0	6.00	
25117	1	11.4	607832234	WPG16	2015	9	27	2	56	15	129.640	-7.290	125.3	5.59	Keep2
			610637896	WPG16	2015	9	27	2	56	16	129.720	-7.240	130.0	5.60	
25120	1	12.4	610637933	WPG16	2015	9	28	0	32	34	-45.580	20.360	12.0	5.30	Keep2
			607833228	WPG16	2015	9	28	0	32	35	-45.658	20.278	10.0	5.13	

Table III.1. Continued.

Case	Δt (s)	d (km)	Event ID	Source	Year	Month	Day	Hour	Minute	Second	Longitude	Latitude	Depth	M	Outcome
25121	2	38.2	607833229	WPG16	2015	9	28	0	42	24	-45.460	20.093	10.0	5.43	Keep2
			610637935	WPG16	2015	9	28	0	42	26	-45.600	20.410	12.0	5.40	
25125	7	32.5	610637958	WPG16	2015	9	28	15	28	3	-66.579	-23.776	223.0	6.01	Keep1
			607833730	WPG16	2015	9	28	15	28	10	-66.890	-23.840	221.0	6.00	
25126	4	14	607834786	WPG16	2015	9	29	8	46	51	143.684	40.309	10.0	5.27	Keep1
			610637978	WPG16	2015	9	29	8	46	55	143.830	40.290	16.0	5.20	
25129	4	25.1	607835507	WPG16	2015	9	29	15	35	17	152.073	-5.439	21.0	5.35	Keep1
			610637989	WPG16	2015	9	29	15	35	21	152.130	-5.650	27.0	5.30	
25133	3	26.7	607846018	WPG16	2015	9	29	23	20	51	140.198	-2.559	19.0	5.45	Keep1
			610638003	WPG16	2015	9	29	23	20	54	140.290	-2.360	30.0	5.40	
25340	2	5.4	607997006	WPG16	2015	10	29	2	49	28	178.518	51.816	90.0	5.33	Keep1
			610459249	WPG16	2015	10	29	2	49	30	178.590	51.810	88.0	5.30	
25686	3	40	608297695	Added	2016	1	26	1	16	46	-4.080	35.521	0.0	3.60	Keep2
			610460288	Added	2016	1	26	1	16	49	-3.653	35.494	10.0	3.50	
25691	4	21.5	610460342	WPG16	2016	1	29	20	7	16	-71.539	-30.363	39.0	5.15	Keep1
			608301779	WPG16	2016	1	29	20	7	20	-71.740	-30.280	41.0	5.10	
25834	2	58.9	608556985	WPG16	2016	4	17	7	14	1	-80.201	-0.385	23.0	6.03	Keep2
			610468912	WPG16	2016	4	17	7	14	3	-80.700	-0.510	37.0	6.00	
25835	2	38.9	608556988	WPG16	2016	4	17	9	23	41	-80.694	-0.234	10.0	5.73	Keep1
			610468914	WPG16	2016	4	17	9	23	43	-81.030	-0.300	18.0	5.70	
25840	2	28.9	608588062	WPG16	2016	4	19	17	12	57	-81.080	-1.160	18.7	4.98	Keep2
			610468953	WPG16	2016	4	19	17	12	59	-80.865	-1.306	18.0	5.00	
25962	4	11.8	609087200	Added	2016	7	8	4	28	41	-80.832	-0.338	0.0	4.90	Keep2
			610502517	WPG16	2016	7	8	4	28	45	-80.814	-0.427	6.0	5.40	
26098	0	26	609586572	Added	2016	8	28	15	55	36	13.433	42.692	11.2	4.70	Keep2
			609386763	WPG16	2016	8	28	15	55	36	13.152	42.787	5.0	4.85	
26363	1	14.4	609625012	WPG16	2016	10	30	13	34	56	13.122	42.802	10.0	4.85	Keep1
			609916459	Added	2016	10	30	13	34	57	13.143	42.675	12.2	4.70	
26519	4	15.9	609767203	WPG16	2016	11	15	5	9	25	173.745	-42.354	10.0	5.16	Keep1
			610504817	WPG16	2016	11	15	5	9	29	173.620	-42.400	21.0	5.10	
26521	5	11.1	609774479	WPG16	2016	11	15	19	53	1	174.415	-41.723	13.0	4.94	Keep1
			610504842	WPG16	2016	11	15	19	53	6	174.470	-41.650	19.0	4.90	
26944	2	27.3	610660928	Added	2017	3	29	23	37	57	18.354	43.911	12.0	3.80	Keep2
			610452487	Added	2017	3	29	23	37	59	18.565	44.071	0.0	3.50	

APPENDIX IV: LIST OF SMALL-TO-MEDIUM MAGNITUDE EVENTS WITH CONSEQUENCES FOR THE POPULATION

The earthquakes that make up the world database of small-to-medium magnitude events with consequences for the population are listed herein. They are sub-grouped into the cases described in Section 4.1.

Table IV.1 explains a series of abbreviations used to present the database in the tables that follow.

Table IV.1. Abbreviations used in the tables that follow.

Abbreviation	Meaning	Content
Ind.	Induced	"I" if anthropogenic origin, nothing otherwise
Dam.	Damaged	"X" if damaged buildings observed, nothing otherwise
Destr.	Destroyed	"X" if destroyed buildings observed, nothing otherwise
Infrastr.	Infrastructure	"Y" if infrastructure affected, nothing otherwise
Landsl.	Landslides	"Y" if landslides observed, nothing otherwise
Liquef.	Liquefaction	"Y" if liquefaction observed, nothing otherwise

The column labelled "Consequences" contains comments regarding the damage or casualties described being related to more than one event (*e.g.* if the consequences correspond to the whole series, if they include the main shock, if it includes the aftershocks, etc).

Whenever an event is not marked as having had any casualties or damaged or destroyed buildings, it means that it was found within one of the loss databases only with a monetary estimate of losses, without any specifications of the damage observed.

IV.1. Damaging Events that Belong to the World Database of Crustal Small-to-Medium Magnitude Earthquakes Near Urbanised Areas

The 282 events presented in Table IV.2 are those earthquakes with consequences for the population that satisfy all the criteria described in Chapter 2 regarding magnitude, depth and closeness to populations, the latter measure in terms of the predicted exposure to MMI values equal to or larger than IV.

Table IV.2. Earthquakes with consequences to the population that belong to the world database of crustal small-to-medium magnitude events near urbanised areas.

Region	Country	Date and Time (UTC)						Coordinates			M	Ind.	Casualties		Buildings		Infrastr.	Landsl.	Liquef.	Consequences
		Y	M	D	H	M	S	Lon.	Lat.	Depth			Dead	Injured	Dam.	Destr.				
Mediterranean Europe	Serbia	1999	7	1	7	40	59	21.064	43.668	15	5.19					X				
North South America	Colombia	1999	7	17	12	21	56	-72.543	6.24	25	5.08				X					
Indian Subcontinent	Bangladesh	1999	7	22	10	42	16	91.924	21.625	25	5.08		X	X	X		Y			
Middle East	Iran	1999	8	10	19	34	0	54.635	36.153	20	5.08		X	X						
Asia Minor	Turkey	1999	8	31	8	10	51	29.911	40.767	8	5.18		X	X						
North America	Mexico	1999	9	10	13	40	3	-115.02	32.234	5	4.95									
Middle East	Iran	1999	9	13	23	32	7	50.601	31.907	15	5.01				X					
Middle East	Iran	1999	9	24	19	17	14	51.353	28.66	13	5.28			X			Y			

Table IV.2. Continued.

Region	Country	Date and Time (UTC)						Coordinates			M	Ind.	Casualties		Buildings		Infrastr.	Landsl.	Liquef.	Consequences
		Y	M	D	H	M	S	Lon.	Lat.	Depth			Dead	Injured	Dam.	Destr.				
Middle East	Iran	1999	9	27	2	31	23	51.326	28.692	9	4.85				X					
Asia Minor	Turkey	1999	9	29	0	13	7	29.354	40.734	7	5.19		X							
Asia Minor	Turkey	1999	10	5	0	53	30	28.226	36.739	19	5.19			X	X					
Middle East	Iran	1999	10	31	15	9	39	51.845	29.354	15	5.19			X	X		Y			
East Asia	China	1999	11	1	13	25	19	114.02	39.89	15	5.27			X	X	X	Y			
Asia Minor	Turkey	1999	11	7	16	54	45	30.728	40.701	16	4.97		X							
Middle East	Iran	1999	11	8	21	37	22	61.217	35.677	10	5.50					X				Possibly of many (5)
East Asia	China	1999	11	24	16	40	21	102.777	24.602	15	5.20		X	X		X				
Middle East	Iran	1999	11	26	4	27	23	54.886	36.918	10	5.33									
East Asia	China	1999	11	29	4	10	42	122.952	40.478	8	5.46				X					
South-East Asia	Philippines	1999	12	15	5	12	33	124.516	11.295	16	5.14		X		X					
East Asia	China	2000	1	26	20	55	18	103.621	24.137	15	5.20			X	X					
Middle East	Iran	2000	2	2	22	58	2	58.207	35.227	21	5.30		X	X	X	X				
Asia Minor	Turkey	2000	2	14	6	56	37	31.735	41.028	10	5.40			X	X					
Indian Subcontinent	India	2000	4	6	22	30	12	73.724	17.202	4	4.89			X	X					
Asia Minor	Turkey	2000	5	7	23	10	53	38.855	38.154	4	4.82		X	X	X					
East Asia	Taiwan	2000	5	17	3	25	51	121.078	24.167	15	5.44		X	X				Y		
Central America	Nicaragua	2000	7	6	19	30	18	-86.05	11.943	10	5.43		X	X	X	X				
Asia Minor	Turkey	2000	7	7	0	15	32	29.339	40.863	8	4.63		X	X						
North America	USA	2000	8	17	1	8	5	-101.7	35.361	5	4.65	I			X					
East Asia	China	2000	8	21	13	25	42	102.228	25.774	6	5.01		X	X	X		Y			
Asia Minor	Turkey	2000	8	23	13	41	29	30.781	40.787	15	5.30			X	X					
North America	USA	2000	9	3	8	36	30	-122.34	38.319	7	5.27			X	X		Y			
Asia Minor	Turkey	2000	10	4	2	34	1	29.029	37.87	19	4.95			X						
North South America	Ecuador	2000	10	8	20	12	31	-78.104	0.332	15	5.13		X		X		Y			
Indian Subcontinent	India	2000	12	12	1	23	58	76.763	9.824	10	4.44				X		Y			
Indian Subcontinent	India	2001	1	7	2	56	0	76.797	9.688	16	4.80		X	X	X					
Indian Subcontinent	India	2001	2	8	16	54	42	70.478	23.652	6	5.33			X						
Central America	El Salvador	2001	2	17	20	25	17	-89.201	13.716	11	4.61		X	X						
South-East Asia	Vietnam	2001	2	19	15	51	37	102.83	21.384	4	5.33			X	X	X				
Indian Subcontinent	India	2001	3	9	12	40	54	70.217	23.652	10	4.65			X						
Asia Minor	Turkey	2001	5	29	13	14	29	41.667	39.843	20	4.95			X	X	X				May include main shock
East Asia	China	2001	6	7	18	3	31	99.059	24.767	8	5.14			X	X					
Central America	Nicaragua	2001	6	13	12	25	59	-85.958	13.612	12	4.72				X					
Northern and Central Europe	France	2001	6	21	19	55	46	6.688	49.179	0	4.72	I	X	X	X					
Asia Minor	Turkey	2001	6	25	13	28	50	36.213	37.182	13	5.45			X	X					
South-East Asia	Indonesia	2001	6	28	3	46	27	108.167	-7.023	15	4.95			X	X					
East Asia	China	2001	7	14	18	36	7	102.564	24.423	10	5.01			X	X					
Indian Subcontinent	Nepal	2001	7	16	16	12	45	84.992	28.046	3	5.14			X		X				
Mediterranean Europe	Italy	2001	7	17	15	6	16	11.232	46.726	5	5.01		X	X	X	X		Y		
Asia Minor	Turkey	2001	8	26	0	41	16	31.522	40.936	17	5.08			X						
Mediterranean Europe	Greece	2001	9	16	2	0	47	21.925	37.256	10	5.47				X					
Northern and Central Europe	UK	2001	10	28	16	25	20	-0.739	52.861	11	4.65									
Asia Minor	Turkey	2001	10	31	12	33	53	36.187	37.235	12	5.27			X	X					
Central Asia	Tajikistan	2002	1	9	6	45	58	69.863	38.642	23	5.26		X	X	X					
Sub-Saharan Africa	Rwanda	2002	1	17	20	1	30	29.16	-1.785	13	5.01		X	X		X				May include volcano eruption
Middle East	Iran	2002	2	17	13	3	50	51.782	28.036	15	5.34		X	X	X					
Northern and Central Europe	Poland	2002	2	20	11	27	40	15.986	51.578	0	5.05	I		X	X					
Mediterranean Europe	Bulgaria	2002	4	5	13	14	0	24.863	42.069	5	4.70				X	X				Includes aftershocks
North America	USA	2002	4	20	10	50	47	-73.718	44.488	9	5.15				X		Y	Y	Y	
Middle East	Iran	2002	4	24	19	48	8	47.399	34.604	25	5.40		X	X	X		Y			
Mediterranean Europe	Romania	2002	5	24	20	42	26	21.649	44.729	7	4.70			X	X					
Middle East	Iran	2002	6	26	18	18	16	48.891	35.542	8	4.63			X						
Mediterranean Europe	Spain	2002	8	6	6	16	20	-1.911	37.959	10	5.14			X	X					
North America	Mexico	2002	9	25	18	14	49	-99.958	16.894	23	5.34			X	X					
Mediterranean Europe	Italy	2002	10	29	10	2	23	15.179	37.637	10	5.01			X	X		Y			
Indian Subcontinent	Pakistan	2002	11	1	22	9	30	74.63	35.392	24	5.35		X	X	X		Y	Y		
Middle East	Iran	2002	12	24	17	3	3	47.492	34.553	20	5.20			X	X	X				
Middle East	Iran	2003	1	11	17	45	29	51.491	29.629	10	5.20			X	X	X				
Northern and Central Europe	France	2003	2	22	20	41	5	6.625	48.32	7	4.99				X		Y			
East Asia	China	2003	2	25	3	52	44	77.358	39.405	17	5.35		X		X					Additional damage
Mediterranean Europe	Italy	2003	4	11	9	26	59	8.88	44.777	15	5.08			X	X					
Middle East	Iran	2003	6	24	13	1	33	49.449	33.038	15	4.82		X					Y		
Middle East	Iran	2003	7	3	14	59	27	60.85	35.575	2	5.18			X	X					Possibly of many (3)
Japan	Japan	2003	7	25	15	13	9	141.056	38.529	12	5.46			X	X		Y	Y		Includes main shock
Asia Minor	Turkey	2003	7	26	1	0	57	28.888	38.111	5	4.70			X	X					May include main shock
Asia Minor	Turkey	2003	7	26	8	36	51	28.913	38.057	21	5.44			X	X					
Indian Subcontinent	Bangladesh	2003	7	27	12	7	29	92.336	22.837	7	5.45		X	X	X		Y			Includes main shock
Middle East	Iran	2003	8	11	20	12	8	44.801	38.754	10	4.82				X		Y			
East Asia	China	2003	8	16	10	58	44	119.715	43.779	23	5.42		X	X	X	X	Y	Y		
East Asia	China	2003	8	21	2	17	54	101.289	27.358	16	5.01			X	X	X	Y			
Mediterranean Europe	Italy	2003	9	14	21	42	54	11.391	44.313	20	5.31			X	X	X				
East Asia	China	2003	11	13	2	35	10	103.885	34.713	4	5.13		X	X	X	X	Y			
Mediterranean Africa	Algeria	2004	1	10	18	38	13	3.372	36.99	10	4.89			X	X		Y			
Asia Minor	Turkey	2004	2	26	4	13	57	38.233	37.948	5	4.82				X					Joint with M232
East Asia	China	2004	3	24	1	53	48	118.209	45.349	18	5.37			X	X		Y			
Asia Minor	Turkey	2004	4	13	21	47	24	31.621	40.812	5	4.57			X						
East Asia	China	2004	5	4	5	4	56	96.704	37.452	13	5.38				X					Additional damage
Indian Subcontinent	Pakistan	2004	5	8	20	11	42	67.124	30.131	5	4.76		X	X	X					
Asia Minor	Turkey	2004	7	1	22	30	8	43.968	39.779	5	5.13		X	X						
Mediterranean Europe	Slovenia	2004	7	12	13	4	5	13.657	46.322	4	5.20		X	X	X	X		Y		
Central Asia	Afghanistan	2004	7	14	14	36	2	61.891	35.014	14	4.57				X					
Central Asia	Afghanistan	2004	7	18	8	31	44	69.521	33.286	15	5.19		X	X		X				
Asia Minor	Turkey	2004	7	30	7	14	8	43.974	39.761	10	4.95		X	X	X					

Table IV.2. Continued.

Region	Country	Date and Time (UTC)						Coordinates			M	Ind.	Casualties		Buildings		Infrastr.	Landsl.	Liquef.	Consequences
		Y	M	D	H	M	S	Lon.	Lat.	Depth			Dead	Injured	Dam.	Destr.				
East Asia	China	2004	8	10	10	26	14	103.821	27.226	10	5.35		X	X	X	X	Y			
Northern and Central Europe	Russia	2004	9	21	13	32	29	19.974	54.825	10	4.76			X	X		Y			
East Asia	China	2004	10	18	22	11	42	99.018	25.033	19	5.01			X	X					
Japan	Japan	2004	11	3	23	57	29	138.894	37.464	25	5.26			X						
Japan	Japan	2004	11	9	18	43	8	138.926	37.392	13	5.06			X				Y		
Mediterranean Europe	Albania	2004	11	23	2	26	13	20.62	40.327	6	5.48				X		Y			
Mediterranean Europe	Italy	2004	11	24	22	59	38	10.582	45.641	11	5.07			X	X	X	Y	Y	Y	
Mediterranean Africa	Algeria	2004	12	1	17	42	23	3.388	36.957	10	4.70			X						
Mediterranean Africa	Algeria	2004	12	5	8	30	58	3.387	36.922	15	4.82			X						
Mediterranean Europe	Albania	2004	12	9	18	35	19	20.379	42.04	12	4.80				X					
Asia Minor	Turkey	2004	12	20	23	2	15	28.363	36.937	25	5.34			X				Y		
Asia Minor	Turkey	2005	1	10	23	48	50	27.926	36.856	17	5.48		X	X						
East Asia	China	2005	1	25	16	30	36	100.73	22.451	10	5.33			X	X					
Mediterranean Europe	Spain	2005	1	29	7	41	30	-1.885	37.981	10	4.82			X	X					
South-East Asia	Indonesia	2005	2	2	5	55	16	107.683	-7.071	10	5.46		X	X	X		Y			
South-East Asia	Indonesia	2005	2	7	11	24	18	116.527	-8.275	6.5	4.90			X	X					Of many (2)
Sub-Saharan Africa	South Africa	2005	3	9	10	15	30	26.709	-26.871	2	5.01	I	X	X						
Japan	Japan	2005	4	19	21	11	27	130.272	33.635	18	5.48			X	X	X	Y	Y		
Japan	Japan	2005	5	1	16	23	58	130.322	33.664	19	4.60			X						
Middle East	Iran	2005	5	3	7	21	8	48.63	33.489	12	4.97		X	X	X					
Asia Minor	Turkey	2005	5	12	9	25	39	37.398	40.438	5	4.88				X					May include foreshock
Sub-Saharan Africa	South Africa	2005	5	23	6	9	10	27.39	-26.322	0	4.70	I		X						
Caribbean	Jamaica	2005	6	13	3	58	2	-77.444	18.31	17	5.21				X	X	Y	Y		
North America	USA	2005	6	16	20	53	23	-117.01	34.061	6	4.90		X							
East Asia	China	2005	7	25	15	43	36	124.944	46.91	16	5.01		X	X	X					
East Asia	China	2005	8	13	4	58	43	104.098	23.453	10	5.14			X	X		Y			
Japan	Japan	2005	8	21	2	29	29	138.677	37.332	14	4.85		X							
North South America	Peru	2005	10	1	22	19	47	-70.662	-16.627	10	5.33			X	X		Y	Y		
Indian Subcontinent	Pakistan	2005	10	15	4	24	5	74.017	33.969	13	5.08		X							
East Asia	China	2005	10	27	11	18	55	107.533	23.459	10	4.44		X	X	X	X		Y		
Indian Subcontinent	Pakistan	2005	11	6	2	11	52	73.404	34.544	13	5.16			X						
East Asia	China	2005	11	26	0	49	37	115.657	29.688	11	5.20		X	X	X	X				
East Asia	China	2006	1	12	1	5	29	101.698	23.198	10	5.08			X	X					
Central Asia	Tajikistan	2006	1	13	15	49	6	69.455	38.123	10	4.95				X	X	Y			Of many
Eastern Europe	Bulgaria	2006	2	20	17	20	10	25.501	41.679	7	4.82			X	X		Y			
Indian Subcontinent	India	2006	3	7	18	20	47	70.811	23.715	15	5.48		X							
Indian Subcontinent	Pakistan	2006	3	10	7	50	15	73.802	33.083	13	4.97		X	X	X					
Mediterranean Africa	Algeria	2006	3	20	19	44	25	5.351	36.657	13	5.21		X	X	X	X	Y	Y		
Mediterranean Europe	Serbia	2006	3	22	11	26	20	20.066	44.044	20	4.80				X					
East Asia	China	2006	3	31	12	23	18	124.149	44.592	12	4.77				X	X	Y			
Indian Subcontinent	Pakistan	2006	4	4	9	12	25	73.146	34.679	16	4.64			X	X	X				
Middle East	Iran	2006	5	7	6	20	55	56.65	30.794	10	4.99			X	X		Y			
Middle East	Iran	2006	6	3	7	15	36	55.884	26.784	13	5.18		X							
Mediterranean Europe	Albania	2006	6	13	14	15	40	19.935	40.26	1	4.95			X	X	X				
Central Asia	Afghanistan	2006	7	29	10	57	17	68.728	37.225	15	5.45		X	X	X	X	Y			
North America	USA	2006	10	3	0	7	37	-68.202	44.336	10	4.31						Y	Y		
Indian Subcontinent	Pakistan	2006	10	9	5	12	51	66.627	30.929	10	4.44			X						
East Asia	China	2006	11	3	6	21	39	119.523	43.44	10	4.50				X	X				
South-East Asia	Thailand	2006	12	12	17	2	30	98.859	18.858	11	4.95				X		Y			
Central America	El Salvador	2006	12	20	17	6	57	-89.798	14.134	10	5.00				X	X	Y			Of many
Eastern Europe	Hungary	2006	12	31	13	39	24	19.334	47.448	11	4.67				X					
East Asia	China	2007	1	9	14	49	47	103.935	36.971	10	4.70				X	X				
Asia Minor	Turkey	2007	1	21	7	38	59	42.895	39.6	8	5.20			X	X					
Asia Minor	Turkey	2007	1	26	8	20	38	40.13	38.678	9	4.90				X					
Central Asia	Kyrgyzstan	2007	1	31	10	52	35	70.249	39.675	17	5.20				X		Y	Y		
Asia Minor	Turkey	2007	2	9	2	22	58	39.119	38.343	0	5.50			X	X					
Middle East	Iran	2007	3	6	22	32	6	48.865	33.406	17	4.89			X	X					
East Asia	China	2007	3	13	2	23	0	117.713	26.759	13	4.54				X		Y			Of many (2)
Mediterranean Europe	Greece	2007	4	10	3	17	57	21.593	38.541	7	5.00				X					Possibly of many
Japan	Japan	2007	4	15	3	19	31	136.276	34.825	16	5.20			X	X					
Mediterranean Europe	Albania	2007	4	16	7	38	55	20.022	41.189	12	5.08									
Northern and Central Europe	United Kingdom	2007	4	28	7	18	10	1.072	51.058	1	4.95			X	X		Y			
North America	USA	2007	5	8	15	46	50	-112.15	45.464	12	4.82				X					
South-East Asia	Philippines	2007	7	19	15	10	18	125.245	10.312	10	5.30			X	X	X	Y			
North America	USA	2007	7	20	11	42	22	-122.19	37.804	5.3	4.20				X		Y			
Central Asia	Tajikistan	2007	7	21	22	44	15	70.53	38.954	16	5.20		X	X	X	X	Y			
Russia	Russia	2007	8	4	22	21	54	141.829	46.671	11	4.40		X							
North America	USA	2007	8	6	8	48	42	-111.07	39.445	0	4.65	I	X							
Middle East	Iran	2007	8	25	4	24	23	56.688	28.273	10	5.00			X						
Indian Subcontinent	India	2007	9	6	7	9	44	76.688	18.082	8	4.45			X			Y			
South-East Asia	Indonesia	2007	9	9	18	36	34	114.254	-7.88	2	4.90			X			Y			
Central America	Honduras	2007	9	15	17	59	52	-87.16	15.18	12	5.30									
Indian Subcontinent	India	2007	11	6	9	38	6	70.536	21.151	10	5.10		X	X	X					
Amazonia	Brazil	2007	12	9	2	3	30	-44.281	-15.118	10	4.95		X	X	X	X				
Central Asia	Kyrgyzstan	2007	12	26	4	45	27	73.1	40.408	3	5.10				X		Y			
Mediterranean Africa	Algeria	2008	1	9	22	24	4	-0.577	35.62	10	4.89		X		X					
Mediterranean Africa	Algeria	2008	2	1	7	33	41	3.393	36.86	10	4.89			X						
Indian Subcontinent	India	2008	2	6	6	9	41	87.083	23.408	10	4.57		X	X		X				
North America	Mexico	2008	2	9	7	12	8	-115.31	32.395	10	5.20						Y			
Middle East	Iran	2008	2	13	20	55	32	50.964	31.788	10	5.46			X	X					
Sub-Saharan Africa	Rwanda	2008	2	14	2	7	48	28.867	-2.41	14	5.30		X	X	X		Y			
Middle East	Lebanon	2008	2	15	10	36	19	35.331	33.322	10	5.20			X	X		Y			
East Asia	China	2008	2	26	17	50	1	101.862	30.085	10	5.10				X		Y			
Northern and Central Europe	United Kingdom	2008	2	27	0	56	45	-0.32	53.318	9	4.89			X						

Table IV.2. Continued.

Region	Country	Date and Time (UTC)						Coordinates			M	Ind.	Casualties		Buildings		Infrastr.	Landsl.	Liquef.	Consequences
		Y	M	D	H	M	S	Lon.	Lat.	Depth			Dead	Injured	Dam.	Destr.				
East Asia	China	2008	3	21	12	36	58	97.66	24.527	10	5.10				X	X	Y			
Middle East	Iran	2008	3	23	12	11	30	48.59	37.407	3	4.70				X	X				
East Asia	China	2008	3	30	8	32	26	101.835	37.881	4	5.10				X		Y			
Central Asia	Kazakhstan	2008	4	26	13	14	54	51.8	50.71	12	5.13				X	X				
Middle East	Iran	2008	5	1	0	15	25	48.514	33.921	10	4.70			X						
Mediterranean Africa	Algeria	2008	6	6	20	2	58	-0.606	35.924	10	5.50		X	X	X	X	Y			
Indian Subcontinent	India	2008	6	6	21	16	34	84.875	24.673	17	4.51			X			Y			
East Asia	China	2008	6	17	5	51	43	105.634	32.763	10	4.63		X							
East Asia	Bangladesh	2008	7	26	18	51	51	90.513	24.743	18	4.82			X						
North America	USA	2008	7	29	18	42	16	-117.87	33.827	16	5.50		X	X	X	X	Y			
North South America	Venezuela	2008	8	11	7	19	26	-64.183	10.466	10	5.20				X		Y			
Indian Subcontinent	India	2008	9	16	21	47	13	73.874	17.385	0	4.95		X	X	X	X	Y			
Middle East	Iran	2008	10	25	20	17	17	55.023	26.583	10	5.40			X	X	X	Y			
Northern and Central Europe	Czech Republic	2008	11	22	22	27	54	18.382	49.906	0	4.74	I	X	X			Y			
Middle East	Iran	2008	12	7	13	36	21	55.901	26.913	13	5.40			X	X	X	Y			
East Asia	China	2008	12	9	18	53	9	105.391	32.528	9	5.10		X	X						
South South America	Argentina	2008	12	10	10	53	51	-69.18	-33.109	7	4.63				X	X				
East Asia	China	2008	12	25	20	20	47	97.632	23.932	4	4.80			X	X	X	Y			
Mediterranean Europe	Greece	2009	1	4	5	10	35	22.127	36.815	14	4.70		X	X						
North South America	Peru	2009	1	21	18	17	3	-75.629	-11.779	10	4.85				X	X				
East Asia	China	2009	1	25	1	47	47	80.897	43.316	20	5.10				X	X				
Indian Subcontinent	India	2009	3	26	4	44	11	85.873	22.414	10	4.61			X						
Central America	Nicaragua	2009	3	31	17	50	32	-86.191	13.518	15	4.31				X	X				
Mediterranean Europe	Italy	2009	4	7	17	47	38	13.474	42.317	15	5.50		X		X					Additional damage
Central Asia	Afghanistan	2009	4	16	21	27	53	70.075	34.193	16	5.20		X	X	X					
Middle East	Saudi Arabia	2009	5	17	19	50	7	37.597	25.244	10	5.08					X				
Indian Subcontinent	India	2009	5	19	19	29	49	75.79	33.228	19	4.76				X					
Mediterranean Europe	Macedonia	2009	5	24	16	17	52	22.703	41.295	13	5.30				X					
Central Asia	Kazakhstan	2009	6	13	17	17	39	78.825	44.727	19	5.40		X		X					
Mediterranean Europe	Albania	2009	9	6	21	49	43	20.414	41.482	7	5.50				X					
North America	USA	2009	10	3	1	16	1	-117.82	36.417	10	5.20								Y	
North South America	Ecuador	2009	10	9	18	11	36	-77.896	-1	12	5.20				X					
East Asia	Bhutan	2009	10	29	17	0	38	91.395	27.265	24	5.10					X				
Middle East	Iran	2009	11	3	23	26	52	56.195	27.261	22	5.00			X						
North South America	Venezuela	2009	11	27	8	15	54	-69.768	10.435	13	5.40				X					
Sub-Saharan Africa	South Africa	2009	12	6	21	52	0	27.455	-26.378	11	4.76	I	X	X						
Indian Subcontinent	India	2009	12	12	11	51	27	73.82	17.214	16	4.80				X					
Japan	Japan	2009	12	17	23	45	39	139.235	34.953	18	5.00			X	X	X				
Middle East	Iran	2010	1	16	20	23	36	48.368	32.512	10	5.14				X					Possibly of many (2)
East Asia	China	2010	1	17	9	37	23	105.877	25.529	10	4.75		X	X				Y		
East Asia	China	2010	1	30	21	36	59	105.762	30.278	13	5.08		X	X	X	X				
East Asia	China	2010	2	25	4	56	53	101.99	25.478	18	5.20			X	X					
Mediterranean Africa	Algeria	2010	5	14	12	29	24	4.107	36.03	15	5.30		X	X						
Indian Subcontinent	India	2010	6	22	23	14	12	80.46	29.91	20	4.89					X				
North America	Canada	2010	6	23	17	41	41	-75.587	45.876	19	5.20				X		Y	Y		
Middle East	Iran	2010	7	30	13	50	13	59.383	35.268	19	5.50			X			Y			
East Asia	China	2010	8	29	0	53	28	103.014	27.137	15	4.95			X	X	X				
Oceania	New Zealand	2010	9	6	11	24	2	172.4	-43.576	5	4.80									
Oceania	New Zealand	2010	9	7	19	49	57	172.756	-43.523	3	4.70				X					
Indian Subcontinent	Bangladesh	2010	9	10	17	24	17	90.669	23.474	13	5.10				X					
North America	USA	2010	10	13	14	6	28	-97.326	35.22	4	4.30			X						
Mediterranean Europe	Serbia	2010	11	3	0	56	56	20.683	43.767	13	5.50		X	X	X	X	Y		Y	
Oceania	New Zealand	2010	12	25	21	30	16	172.681	-43.5	16	4.89				X					
Middle East	Iran	2011	1	5	5	55	48	51.815	30.159	9	5.40			X	X					Of many
North America	USA	2011	2	28	5	0	49	-92.3	35.326	10	4.80	I			X					
South-East Asia	Philippines	2011	3	3	15	11	59	126.05	9.524	25	5.47				X					
East Asia	China	2011	3	10	4	58	16	97.901	24.758	23	5.50		X	X	X	X				
Indian Subcontinent	Nepal-India	2011	4	4	11	31	41	80.729	29.627	17	5.40				X					
East Asia	China	2011	4	10	9	2	45	100.772	31.333	18	5.40				X					
Mediterranean Europe	Spain	2011	5	11	16	47	28	-1.65	37.7	12	5.12	I	X	X	X	X	Y	Y		
East Asia	China	2011	6	8	1	53	26	88.251	43.035	22	5.10			X	X					
East Asia	China	2011	6	20	10	16	53	98.724	25.046	19	5.00			X						
Japan	Japan	2011	6	29	23	16	40	137.981	36.207	14	5.00			X						
East Asia	China	2011	8	9	11	50	21	98.701	24.893	25	5.10			X	X					
North America	USA	2011	8	23	5	46	19	-104.65	37.068	10	5.30	I			X			Y		
Indian Subcontinent	India	2011	9	7	17	58	19	77.171	28.636	15	4.44			X	X					
North America	USA	2011	10	20	12	24	42	-98.148	28.848	14	4.80	I			X					
Indian Subcontinent	India	2011	10	20	17	18	34	70.622	21.176	10	5.10			X	X					
Indian Subcontinent	India	2011	10	29	0	43	55	88.399	27.698	4	4.72		X							
North South America	Ecuador	2011	10	29	13	50	49	-78.4	-0.135	12	4.57			X	X			Y		
South-East Asia	Philippines	2011	11	7	9	43	12	125.013	7.945	15	4.90			X	X					
North America	USA	2011	11	8	2	46	56	-96.792	35.528	2	5.00				X					
Central America	El Salvador	2011	11	24	21	13	10	-87.923	13.32	6	5.00				X					
Middle East	Iran	2012	1	19	12	35	52	58.961	36.359	15	5.30			X	X					
Middle East	Iran	2012	2	27	18	48	56	56.778	31.401	24	5.20			X	X					
Middle East	Iran	2012	5	3	10	9	36	47.735	32.789	14	5.40			X	X					
North America	USA	2012	5	17	8	12	1	-94.394	31.936	10	4.90	I			X					
Asia Minor	Azerbaijan	2012	5	18	14	47	23	46.75	41.477	19	5.21				X					Possibly of many
Amazonia	Brazil	2012	5	19	13	41	22	-43.91	-16.724	10	4.61				X					
Mediterranean Europe	Italy	2012	5	20	13	18	3	11.392	44.817	14	5.20									Additional damage
Asia Minor	Turkey	2012	6	14	5	52	54	42.483	37.216	11	5.20			X	X					
South South America	Argentina	2012	6	18	8	29	3	-68.65	-33.095	16	5.00			X	X	X				
East Asia	China	2012	7	20	12	11	53	119.7	33.022	18	5.00		X	X	X	X				
East Asia	China	2013	2	19	2	47	2	102.973	27.189	12	4.90			X	X	X				

Table IV.2. Continued.

Region	Country	Date and Time (UTC)						Coordinates			M	Ind.	Casualties		Buildings		Infrastr.	Landsl.	Liquef.	Consequences
		Y	M	D	H	M	S	Lon.	Lat.	Depth			Dead	Injured	Dam.	Destr.				
North South America	Peru	2013	2	22	21	1	48	-71.506	-15.757	10	5.30				X					
East Asia	China	2013	3	3	5	41	18	99.751	25.902	18	5.40			X	X	X	Y			
East Asia	China	2013	3	11	3	1	37	77.29	40.082	10	5.20					X				
Central America	Honduras	2013	4	10	19	14	2	-87.205	15.602	8	5.40				X	X				
East Asia	China	2013	4	17	1	45	56	99.706	25.963	10	5.30			X	X	X				
Mediterranean Africa	Algeria	2013	5	19	9	7	27	5.192	36.743	13	5.20			X	X					
Russia	Russia	2013	6	18	23	2	10	86	54.28	12	5.27				X					
Mediterranean Africa	Algeria	2013	7	17	3	0	57	3.086	36.534	16	5.20			X	X					
Mediterranean Europe	Greece	2013	8	7	9	6	53	22.68	38.698	15	5.40				X	X				
South-East Asia	Indonesia	2013	10	22	5	40	40	95.836	5.083	17.4	5.47		X	X	X					
East Asia	China	2013	11	22	22	4	25	124.15	44.611	10	5.20				X	X				Possibly of many
East Asia	China	2013	12	1	8	34	25	78.905	40.292	12	5.30				X	X				
East Asia	China	2013	12	16	5	4	53	110.438	31.08	10	4.90	I		X	X	X		Y		
Asia Minor	Iran	2014	1	2	3	13	56	54.407	27.177	9	5.30		X	X	X	X				
Middle East	Iran	2014	2	2	14	26	48	57.78	26.624	19	5.30				X					
Oceania	Australia	2014	2	26	0	0	6	121.386	-30.63	10	4.63	I			X					
Sub-Saharan Africa	Comoros	2014	3	12	20	43	32	44.096	-12.203	10	4.95							Y		
North America	USA	2014	3	29	4	9	44	-117.92	33.885	13	5.10				X		Y	Y	Y	
East Asia	China	2014	4	4	22	40	35	103.647	28.132	18	4.90			X		X	Y			
Central America	Nicaragua	2014	4	14	5	7	5	-86.339	12.185	16	5.20					X				
Indian Subcontinent	Pakistan	2014	5	8	22	51	15	68.325	26.23	10	5.00		X	X		X				
Mediterranean Europe	Albania	2014	5	19	0	59	21	19.937	40.938	19	5.10				X					

IV.2. Damaging Events that Get Filtered out of the World Database of Crustal Small-to-Medium Magnitude Earthquakes Near Urbanised Areas

Of the 412 events identified as having caused damage or casualties, the 127 shown in Tables IV.3 and IV.4 were not part of the world database of crustal small-to-medium magnitude earthquakes near urbanised areas. The five in Table IV.3 satisfied the magnitude-depth criterion defined in Table 2.1 but not the exposure criterion, while the 122 in Table IV.4 were discarded when filtering by depth.

Table IV.3. Earthquakes with consequences to the population that were filtered out of the world database of crustal small-to-medium magnitude events due to not complying with the exposure criterion.

Region	Country	Date and Time (UTC)						Coordinates			M	Ind.	Casualties		Buildings		Infrastr.	Landsl.	Liquef.	Consequences
		Y	M	D	H	M	S	Lon.	Lat.	Depth			Dead	Injured	Dam.	Destr.				
East Asia	Vietnam	2005	8	5	18	7	12	108.363	9.985	10	5.01				X					Possibly of many (2)
South-East Asia	Vietnam	2005	11	8	7	54	37	108.225	9.95	6	5.33		X							
Oceania	Australia	2010	4	20	0	17	10	121.77	-30.745	10	4.50	I		X						
Oceania	New Zealand	2010	9	6	22	48	34	176.711	-40.379	16	5.00				X					
East Asia	China	2012	11	26	5	33	49	90.371	40.408	11	5.10				X					

Table IV.4. Earthquakes with consequences to the population that were filtered out of the world database of crustal small-to-medium magnitude events due to not complying with the magnitude-depth criterion.

Region	Country	Date and Time (UTC)						Coordinates			M	Ind.	Casualties		Buildings		Infrastr.	Landsl.	Liquef.	Consequences
		Y	M	D	H	M	S	Lon.	Lat.	Depth			Dead	Injured	Dam.	Destr.				
Mediterranean Europe	Cyprus	1999	8	13	15	31	40	32.922	34.723	27	5.08				X					
North South America	Peru	1999	10	31	13	27	41	-74.255	-13.204	33	4.75		X	X	X	X				
East Asia	China	2000	1	11	23	44	3	123.031	40.577	35	5.10			X	X	X				
Sub-Saharan Africa	Swaziland	2000	2	7	19	35	2	30.876	-26.203	37	4.80	I		X	X			Y		
Asia Minor	Turkey	2000	5	12	3	1	50	36.055	36.992	36	4.63			X	X		Y			
Middle East	Iran	2000	7	10	22	51	9	52.830	33.120	38	4.30				X					
South-East Asia	Indonesia	2000	7	12	1	10	44	106.820	-6.851	29	5.37			X	X	X	Y			
Asia Minor	Turkey	2000	8	19	21	26	17	41.445	39.812	33	4.61			X						
North South America	Ecuador	2000	9	20	8	37	21	-80.454	-1.870	59	5.52		X		X	X	Y			
Japan	Japan	2000	10	30	16	42	53	136.274	34.280	34	5.48			X						
Central Asia	Tajikistan	2000	10	30	22	39	8	69.590	37.495	28	5.12				X	X	Y			
Japan	Japan	2001	4	3	14	57	12	138.088	34.936	29	5.35			X						
East Asia	China	2001	5	23	21	10	44	100.941	27.591	33	5.47		X	X	X		Y			

Table IV.4. Continued.

Region	Country	Date and Time (UTC)						Coordinates			M	Ind.	Casualties		Buildings		Infrastr.	Landsl.	Liquef.	Consequences
		Y	M	D	H	M	S	Lon.	Lat.	Depth			Dead	Injured	Dam.	Destr.				
Central Asia	Afghanistan	2001	6	1	14	0	44	69.349	35.113	45	5.03		X	X		X	Y	Y		
Asia Minor	Turkey	2001	7	10	21	42	11	41.629	39.818	35	5.42			X	X					
South South America	Chile	2001	7	24	17	42	44	-71.578	-32.968	42	5.24			X						
Asia Minor	Turkey	2001	8	20	18	50	45	42.049	40.144	30	4.63				X					
Middle East	Iran	2001	10	8	1	17	16	60.276	32.899	27	5.08			X	X	X				
Central Asia	Afghanistan	2001	11	15	15	35	48	69.411	36.905	33	4.80				X	X				
Indian Subcontinent	Bangladesh	2001	12	19	7	54	14	90.283	23.640	60	4.80		X	X	X	X				
South South America	Chile	2002	1	14	15	36	25	-69.174	-19.442	15	5.60				X			Y		
Asia Minor	Turkey	2002	1	21	14	34	27	27.881	38.626	26	4.82		X							
Central Asia	Tajikistan	2002	2	3	20	59	27	69.869	38.723	41	4.89			X	X					
Central Asia	Tajikistan	2002	2	4	13	46	1	69.990	39.119	44	4.80			X	X					
Central Asia	Tajikistan	2002	2	11	17	13	55	69.863	38.675	40	4.57			X	X	X				
Oceania	Papua New Guinea	2002	4	1	6	14	17	147.533	-6.231	81	5.31		X	X	X		Y	Y		
North South America	Peru	2002	4	22	4	57	4	-76.578	-12.427	64	4.75		X							
Asia Minor	Georgia	2002	4	25	17	41	28	44.856	41.767	34	5.01		X	X	X	X	Y	Y		
Sub-Saharan Africa	Tanzania	2002	5	18	15	15	8	33.673	-3.050	10	5.54		X		X					
Japan	Japan	2002	6	14	2	42	49	139.845	36.238	56	4.90		X							
Indian Subcontinent	Bangladesh	2002	6	20	5	40	45	88.904	25.987	25	4.89			X	X					
Mediterranean Africa	Tunisia	2002	6	24	1	20	43	9.876	35.936	47	5.21			X	X	X				
East Asia	China	2002	8	8	11	42	6	99.892	30.866	30	5.29				X	X	Y			
Northern and Central Europe	United Kingdom	2002	9	22	23	53	15	-2.156	52.497	28	4.70		X	X	X					
South-East Asia	Indonesia	2003	1	23	0	8	24	118.388	-8.872	33	5.53			X	X					
South-East Asia	Indonesia	2003	3	21	11	38	22	108.386	-7.033	35	4.50				X					
Central Asia	Afghanistan	2003	4	10	14	0	47	70.756	35.963	87	4.85		X	X	X					
Japan	Japan	2003	5	11	15	57	7	139.982	35.852	55	5.29			X						
South-East Asia	Indonesia	2003	7	11	0	19	29	108.007	-6.633	33	4.50				X					
Central America	Panama	2003	8	13	8	29	28	-79.892	9.361	47	5.37			X	X	X				
East Asia	China	2003	11	26	13	38	59	103.767	27.283	43	5.08			X	X	X	Y			
South-East Asia	Indonesia	2003	12	5	23	41	30	120.358	-8.199	38	5.33				X					
Middle East	Iran	2003	12	11	16	28	18	49.234	31.994	25	4.82		X		X	X				
Middle East	Jordan	2004	2	11	8	15	3	35.452	31.711	26	5.34			X	X			Y		
Indian Subcontinent	Pakistan	2004	2	14	10	30	23	73.161	34.746	26	5.44		X	X	X	X	Y	Y		Includes aftershock
South-East Asia	Indonesia	2004	2	16	14	44	37	100.592	-0.513	45	5.08		X	X	X	X				
Sub-Saharan Africa	Burundi	2004	2	24	2	14	35	29.429	-3.487	28	4.95		X	X		X				
Asia Minor	Turkey	2004	2	25	22	2	0	30.583	35.949	57	4.82				X					Joint with C31
Asia Minor	Turkey	2004	3	25	19	30	50	40.879	39.917	10	5.62		X	X	X					
Asia Minor	Turkey	2004	3	28	3	51	11	40.880	39.909	10	5.57			X	X					
East Asia	Taiwan	2004	5	1	7	56	11	121.648	24.059	29	5.21		X	X		X	Y	Y		
Asia Minor	Turkey	2004	8	4	3	1	6	27.768	36.837	10	5.55			X						
East Asia	China	2004	9	7	12	15	47	103.833	34.694	2	5.59			X	X	X				
South-East Asia	Indonesia	2004	9	15	8	35	10	115.242	-8.878	107	5.37		X	X						
Japan	Japan	2004	11	8	2	15	59	138.946	37.428	17	5.54			X				Y		
Middle East	Iran	2004	11	22	4	1	28	47.920	33.206	34	5.01			X	X		Y			
Indian Subcontinent	India	2004	12	9	8	48	59	92.536	24.715	41	5.37			X						
Middle East	Iran	2005	1	10	18	47	29	54.514	37.213	31	5.38			X						
Japan	Japan	2005	2	15	19	46	35	139.775	35.992	48	5.44			X			Y			
Indian Subcontinent	Pakistan	2005	3	2	11	12	14	68.343	30.095	83	5.05			X	X					
Indian Subcontinent	India	2005	3	14	9	43	50	73.873	17.288	26	4.92			X	X		Y			
Middle East	Iran	2005	4	2	22	24	51	56.711	31.239	16	4.40			X	X					
Sub-Saharan Africa	South Africa	2005	5	10	5	38	53	27.447	-26.365	2	3.70	I	X							
Japan	Japan	2005	6	20	4	3	13	138.518	37.263	21	4.96			X	X		Y			
East Asia	China	2005	8	5	14	14	46	103.010	26.568	40	5.26			X	X					
Japan	Japan	2005	10	16	7	5	41	139.893	35.989	46	5.06			X						
North South America	Peru	2005	10	31	2	10	27	-78.802	-5.879	39	5.35				X					
Northern and Central Europe	Switzerland	2005	11	12	19	31	16	8.155	47.524	18	3.60									
Indian Subcontinent	India	2005	12	14	7	9	52	79.250	30.515	36	5.14		X	X	X	X		Y		
Japan	Japan	2005	12	24	2	1	53	136.797	35.274	42	4.70		X							
Indian Subcontinent	India	2006	2	14	0	55	25	88.416	27.387	28	5.33		X	X	X		Y	Y		
South-East Asia	Indonesia	2006	5	24	10	11	8	139.152	-2.261	30	5.70		X							
East Asia	China	2006	6	20	16	52	58	104.952	33.077	22	4.95			X	X	X	Y	Y		
East Asia	China	2006	7	22	1	10	28	104.187	28.049	46	4.96		X	X	X	X	Y	Y		
South South America	Argentina	2006	8	5	14	3	43	-68.835	-33.116	20	5.56			X	X					
Indian Subcontinent	Pakistan	2006	8	17	12	24	13	67.901	29.372	36	4.89			X	X					
East Asia	China	2006	8	25	5	51	46	104.177	28.074	31	5.05		X	X	X		Y	Y		
Caribbean	Trinidad and Tobago	2006	9	29	18	23	6	-61.745	10.794	52	5.50		X							
Northern and Central Europe	Switzerland	2006	12	8	16	48	39	7.593	47.569	1	3.90	I			X					
South-East Asia	Indonesia	2007	3	3	4	4	26	134.257	-0.897	43	4.90				X		Y			
North South America	Colombia	2007	3	6	13	5	12	-76.453	2.090	40	5.20			X	X	X	Y			
Indian Subcontinent	India	2007	7	22	23	2	17	78.288	30.869	32	5.01			X	X		Y			
Indian Subcontinent	Pakistan	2007	10	26	6	50	10	76.705	35.252	30	5.20		X	X		X	Y			
Asia Minor	Turkey	2007	10	29	9	23	19	29.327	36.916	36	5.30				X					
South-East Asia	Philippines	2007	11	7	4	12	37	124.646	9.788	52	5.30		X							
Indian Subcontinent	Bangladesh	2007	11	7	7	10	22	92.402	22.163	29	5.50			X			Y			
Middle East	Iran	2007	11	20	5	20	5	49.948	31.623	33	4.95			X	X					
Asia Minor	Turkey	2007	12	26	23	47	11	33.114	39.414	12.5	5.58				X		Y			
North South America	Peru	2008	3	29	12	51	25	-77.136	-12.161	52	5.30			X		X	Y			
North South America	Peru	2008	7	1	0	17	33	-75.502	-10.357	28	5.40			X	X	X	Y	Y		
South-East Asia	Indonesia	2008	9	9	3	7	30	102.928	-3.899	35	5.20		X		X					
Indian Subcontinent	Pakistan	2009	2	20	3	48	50	73.824	34.236	21	5.55			X				Y		
East Asia	China	2009	2	20	10	2	31	78.707	40.613	30	5.28				X	X				May include aftershocks
Indian Subcontinent	India	2009	4	9	1	46	58	70.769	27.169	42	5.10			X						
North America	USA	2009	5	2	1	11	12	-118.91	34.003	16	4.38			X						
East Asia	China	2009	8	8	13	26	20	105.511	29.273	29	4.50		X	X	X	X				
East Asia	Myanmar	2009	8	30	19	27	49	95.072	25.238	83	5.30				X					

Table IV.4. Continued.

Region	Country	Date and Time (UTC)						Coordinates			M	Ind.	Casualties		Buildings		Infrastr.	Landsl.	Liquef.	Consequences
		Y	M	D	H	M	S	Lon.	Lat.	Depth			Dead	Injured	Dam.	Destr.				
East Asia	China	2009	11	1	21	7	21	100.767	25.895	26	4.90			X	X	X				
East Asia	Bhutan	2009	12	31	9	57	31	91.481	27.332	18	5.59			X	X	X				
Central Asia	Tajikistan	2010	1	2	2	15	10	71.452	38.294	29	5.40				X	X				
South-East Asia	Indonesia	2010	1	10	0	25	5	107.924	-7.906	70	5.21		X	X						
North South America	Venezuela	2010	1	15	18	0	47	-63.486	10.474	10	5.57			X	X	X				
Indian Subcontinent	India	2010	5	1	22	36	31	80.020	30.078	49	4.57				X					
Indian Subcontinent	Pakistan	2010	10	10	21	44	26	72.884	33.826	34	5.20		X	X	X	X				
Middle East	Iran	2010	11	6	3	52	22	48.927	33.413	22	4.82			X	X					
Indian Subcontinent	Pakistan	2010	11	12	9	37	20	67.141	30.081	29	4.38			X	X					
North America	USA	2010	12	19	5	5	30	-96.772	35.827	5	3.30				X					
East Asia	China	2011	2	1	7	11	26	97.888	24.669	28	4.95		X	X	X	X				
South South America	Argentina	2011	2	21	6	58	37	-64.718	-27.113	15.9	5.56				X	X				
East Asia	China	2011	6	26	7	48	17	95.963	32.412	29	5.30				X	X				
North America	USA	2011	11	6	3	53	11	-96.705	35.533	10	5.72	I		X	X					
East Asia	China	2011	12	1	12	48	18	76.833	38.248	33	4.90				X					
Oceania	New Zealand	2011	12	3	6	19	10	174.337	-41.403	57	5.10				X					
Indian Subcontinent	India	2012	5	11	12	41	35	92.857	26.219	43	5.40			X	X					
East Asia	China	2012	6	24	7	59	36	100.706	27.740	15	5.57		X	X	X		Y			
East Asia	China	2012	9	7	3	19	42	104.019	27.527	10	5.57		X	X	X	X	Y			
Indian Subcontinent	India	2012	10	18	2	33	32	81.258	23.801	35	5.14				X	X				
East Asia	China	2012	12	7	14	8	46	88.045	38.839	30	5.20				X	X				
Eastern Europe	Hungary	2013	4	22	22	28	49	20.272	47.676	22	4.40				X					
Central Asia	Afghanistan	2013	4	24	9	25	30	70.236	34.513	65	5.52		X	X	X					
South-East Asia	Indonesia	2013	6	22	5	42	39	116.046	-8.389	35	5.20			X	X	X				
Northern and Central Europe	Germany	2014	5	17	16	46	26	8.636	49.827	16	4.45				X					

IV.3. Damaging Events that Cannot be Found in the World Catalogue

The three events presented in Table IV.5 were identified as having caused damage or casualties during the compilation of the database of earthquakes with consequences for the population, but could not be found in the merged world catalogue, even before the application of magnitude-depth and exposure filters. The characteristics of these events are discussed in Section 4.1.3.

Table IV.5. Events identified as having caused damage or casualties not found in the unfiltered merged catalogue.

Region	Country	Date and Time (UTC)						Coordinates			M	Ind.	Casualties		Buildings		Infrastr.	Landsl.	Liquef.	Consequences
		Y	M	D	H	M	S	Lon.	Lat.	Depth			Dead	Injured	Dam.	Destr.				
Asia Minor	Turkey	2004	3	1	23	55	20	38.277	38.058	5	3.80		X	X		X				
North South America	Peru	2005	5	1	12	23	0	-13.583	-74.35	0	4.70				X	X				Possibly of many (4)
Sub-Saharan Africa	Mozambique	2007	3	13	8	4	0	-18.083	33.2	0	4.50	I		X						

IV.4. Final Remarks

As noted in Chapter 3, the database of damaging small-to-medium magnitude earthquakes is still work in progress. As such, and taking into account the numerous challenges associated with compiling a database of this kind, it is unlikely that this Appendix contain absolutely all events that have caused damage or casualties in the time interval of interest, in spite of all the efforts invested in tracking them.