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INGe: Intensity-ground motion dataset for Italy

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Abstract

In this paper we present an updated and homogeneous earthquake dataset for Italy compiled by joining the intensities available in the Italian Macroseismic Database DBMI15 and the peak ground motion (PGM) parameters present in the Engineering Strong-Motion (ESM) accelerometric data bank. The database has been compiled through an extensive procedure of evaluation and revision based on two main steps: 1) the selection of the earthquakes in DBMI15 with homogeneous macroseismic intensities in terms of data sources and 2) the extraction of all the localities reporting intensity data which are located within 3 km from the accelerograph stations that recorded the data. The final dataset includes 519 intensity-PGM data pairs from 65 earthquakes and 227 stations in the time span 1972–2016. The reported intensities are expressed either in the Mercalli-Cancani-Sieberg (MCS) or the European macroseismic (EMS-98) scales.

The events are characterized by magnitudes in the range 4.1–6.8 and depths in the range 0–55 km. Here, we illustrate the data collection and the properties of the database in terms of recording, event and station distributions as well as macroseismic intensity points. Furthermore, we discuss the most relevant features of engineering interest showing several statistics with reference to the most significant metadata (such as moment magnitude, several distance metrics, style of faulting etc). The dataset is expected to be useful for benchmarking existing and for developing new ground motion intensity conversion equations offering a common basis, and sparing the time and effort required for assembling to the interested researchers.

The dataset is available at https://zenodo.org/record/4623732#.YNX-AZMzbdc.

Keywords: Ground motion; Macroseismic intensity; Earthquakes; Italy; Dataset.

1. Introduction

Availability of public, high-quality and verified datasets is important in order to develop new techniques and for bench-marking and comparing the performance of existing ones. These datasets provide (i.) a common ground upon which it is possible to make fair comparisons between different techniques and (ii.) their availability can save much time to the developers of new methodologies.

In recent years in seismology, much attention has been put to the development of techniques that adopt macroseismic data from databases (e.g., DBMI15: https://emidius.mi.ingv.it/CPTI15-DBMI15; SISFRANCE: BRGMEDF-IRSN: https://sisfrance.net/; MECOS: http://seismo.ethz.ch; The Catalan Macroseismic database:

https://www.icgc.cat/en/Public-Administration-and-Enterprises/Tools/Databases-and-catalogues/; Macroseismic Data of Southern Balkan area: http://www.itsak.gr/en/db/data/macroseismic_data/) or gathered rapidly after an earthquake (e.g., internet-based questionnaires, such as the U.S. Geological Survey (USGS) "Did You Feel It?" (DYFI) system [Quitoriano and Wald, 2020] and the Italian "Hai Sentito Il Terremoto?" HSIT database [Tosi et al., 2007]; the LastQuake smartphone app developed by the European Mediterranean Seismological Centre (EMSC) for global earthquake eyewitnesses [Bossu et al., 2017] to quantify the strong ground motion and the associated impact. To this end, there have been developed several ground motion intensity conversion equations (GMICE) that allow to convert from a given intensity scale (e.g., the modified Mercalli intensity scale MM or MMI [Wood and Neumann, 1931; Richter, 1958], the Mercalli-Cancani-Sieberg scale MCS [Sieberg, 1930] and the European macroseismic scale EMS-98 [Grünthal, 1998]) to ground motion units and vice-versa. Although since its publication EMS-98 has been widely adopted inside and also outside Europe, MCS scale is still in use especially in Italy due to the desire to maintain compatibility with past datasets. Furthermore, as the MCS scale does not fully take into account the vulnerability of each single building, it allows a widespread and expeditious survey, rapidly providing the key information that is directly correlated to the damage level, that is, necessary to the organization of resources for dealing with all humanitarian aspects of the disaster. In turn, as the EMS-98 requires the reconnaissance of the vulnerability class of each building, it is less extensively applicable in the first survey of large earthquakes [Galli et al., 2017]. It follows that intensity data, despite their sometime inevitable subjectivity [Musson et al., 2010], can play an important role when compiling maps of seismic hazard that avail of historical earthquakes that have no or very few recorded data, or to increase the density of the observations when producing shakemaps right after an earthquake through the compilation of internet questionnaires. To this purpose, the ShakeMap software [Wald et al., 1999b], developed by the USGS, was adopted by several operational centres worldwide (e.g., in Europe at National Institute for Earth Physics, Romania, [Sokolov et al., 2009]; Institute of Engineering Seismology and Earthquake Engineering (ITSAK), Greece, [Theodoulidis et al., 2019]; Bureau Central Sismologique Français – Réseau National de Surveillance Sismique, France, [Schlupp and Grunberg, 2018]). In summary, in the seismological-engineering community there has been much effort to assemble two types of databases — peak ground motion (PGM) parameters extracted from instrumental recordings and macroseismic data obtained through bibliographic research of historical sources and their interpretation or, for the recent events, from questionnaire based methodologies [Lesueur et al., 2013]. In the first case, comprehensive sets of event, source and station metadata, in addition to the PGM data and other parameters of interest, are usually summarized in a flatfile and used for calibrating Ground Motion Models (GMMs), Probabilistic Seismic Hazard Assessment (PSHA), calibrating ShakeMap local or regional configurations, and for other engineering applications. Several researchers have presented such databases for different parts of the world (e.g., Chiou et al. [2008] for shallow crustal earthquakes as part of the NGA-West 1 project; Akkar et al. [2010] for Turkey; Arango et al. [2011b] for the Central American subduction zone; Arango et al. [2011a] for the Peru-Chile subduction zone; Pacor et al. [2011] for the ITACA database in Italy). Recently, the flatfile extracted from the Engineering Strong-Motion (ESM) [Lanzano et al., 2018, 2019] provides a handy and single source of PGM data for the earthquakes that have occurred in Europe and neighbouring regions since 1969.

With regard to macroseismic databases, a trans-national European portal called AHEAD (Archive of Historical EArthquake Data, [Locati et al., 2014]) has been created supporting the growth of other European intensity databases (Catalonia, Spain, Portugal, Greece and UK) while, at worldwide scale, the Global Historical Earthquake Archive, GHEA [Albini et al., 2014] has been compiled. This latter archive collects and critically organizes the best and most recent information available for earthquakes falling within the time-window 1000–1903 and with magnitudes equal to or higher than 7. In Italy, the latest version of the Italian Macroseismic Database, DBMI15 [Locati et al., 2021], has been released in January 2021, replacing the previous version, [Locati et al., 2019]. DBMI15 makes available a set of macroseismic intensity data related to Italian earthquakes that cover the time window 1000–2016. The data originate from studies carried out by researchers from institutions, both in Italy and bordering countries (France, Austria, Slovenia, and Croatia).

Several studies proposed datasets of different macroseismic intensity scales and ground motion parameters. In Italy, the first correlations between instrumental parameters and macroseismic intensity scales were proposed by Margottini et al. [1992] who used a database of 56 records related to 9 Italian earthquakes that occurred between 1980 and 1990. This study was followed by Decanini et al. [1995] who used 24 data points in the MCS range [5,8]. Wald et al. [1999a] compared horizontal peak ground motions (Peak Ground Acceleration (PGA) and Velocity (PGV)) to observed intensities (MMI) for 8 Californian earthquakes. A large dataset of MMI and ground-motion parameters, such as PGA, PGV and pseudo-spectral acceleration (PSA) deriving from California earthquakes was utilized by Worden et al. [2012]. Faenza and Michelini [2010, 2011] assembled, respectively, a Peak Ground Acceleration (PGA) and Velocity (PGV) versus intensity dataset and a Spectral Acceleration (SA) versus intensity dataset. They adopted the DBMI04 intensity database [Stucchi et al., 2007], a previous version of the Italian macroseismic database, and the above mentioned ITACA accelerometric data bank [Pacor et al., 2011]. Recently, other authors based their studies on cross-matching of the DataBase of Macroseismic observations of Italy (DBMI) and the ITalian ACceleration Archive (ITACA). Specifically, Zanini et al. [2019] assembled a PGM versus EMS-98 intensity dataset, collecting 220 data pairs of observations with site-station distances lower than 3 km, from 22 different Italian seismic events. Masi et al. [2020] considered macroseismic data (EMS-98 and MCS scales) and PGMs such as PGA, PGV and Housner Intensity by selecting 179 ground-motion records belonging to 32 earthquake events occurred in Italy in the last 40 years. Gomez-Capera et al. [2020] obtained a dataset that corresponds to 240 intensity-PGM pairs from 67 Italian earthquakes in the time window 1972–2016 with moment magnitude ranging from 4.2 to 6.8 and macroseismic intensity in the range [2, 10–11].

Here, we merge the DBMI15 reported intensities and the ESM flatfile values of PGA, PGV and SA (at 0.3, 1.0, and 3.0 s) to build a dataset of intensity-PGM pairs. This dataset includes the most recent events and we pay particular attention to select only those earthquakes with homogeneous data source, as explained in detail in section 2. The objective of this work is to develop a benchmark dataset upon which existing and novel techniques can be validated and compared. To this purpose, the dataset described here includes additional and useful information when compared to other existing datasets. In particular, it includes uncertainty estimates associated with the hypocentral coordinates and the magnitude values, accompanied by reference to their source, distance measurements (station-to-macroseismic data point distance and epicenter-to-macroseismic data point distance). We have also included a detailed legend in the section dedicated to the description of the dataset on Zenodo to facilitate its adoption by the interested users. One main reason for our effort is to make available in a useful, understandable and transparent way an updated, homogeneous and verified dataset which leaves the users the freedom to select the data according to their choice, and it is thought that this dataset will allow the benchmarking of existing and proposed regression relations between macroseismic and instrumental data in Italy.

The article is organized as follows. In section 2, we describe the data collection and selection procedure adopted for the compilation of the dataset in terms of the primary sources of information. In section 3, we discuss the main database fields including their geographical, temporal, and magnitude distribution. This section presents also some general statistics of the dataset, with reference to the most significant metadata for GMMs calibrations, such as moment magnitude, focal depth, several distance metrics, uncertainties in earthquake epicentral location, focal depth and magnitude, style of faulting and parameters for site characterization, as well as the distribution of intensity measures. The paper ends with a brief discussion of the database and its potential applications, but also looking at how this resource may be updated and improved in the future.

2. Compilation of the dataset

The ESM flatfile [Lanzano et al., 2018] is a parametric table which contains strong motion data and associated reliable metadata of manually processed waveforms related to the ESM database. This flatfile was built within the Thematic Core Service Seismology of the project EPOS (European Plate Observing System, http://epos-eu.org). Most of ESM data consist of accelerograms, available through the European Integrated Data Archive (EIDA, http://www.orfeus-eu.org/data/eida/), key infrastructure aimed at archiving digital waveforms, and, for Italy, the national accelerometric network (rete accelerometrica nazionale, RAN, http://ran.protezionecivile.it/IT/index.php). In addition, the ESM database also includes data recorded by analogue instruments. To this regard, digital accelerographs started to become available only since the late 90s, and generally operate in continuous mode and the precision of the recorded ground motion depends on the instrument settings, such as digitizer dynamic range, sampling rate and sensor full scale. When compared to analog accelerographs data, those recorded by digital accelerographs feature smaller noise to signal ratios and include the whole earthquake signal. This owes to (a) analog accelerographs are optical mechanical instruments having moving parts, (b) these devices generally record ground motion in standby mode and are triggered by a specified acceleration threshold, so they do not preserve the pre- and, sometimes, the post-event time history, (c) the natural frequency of transducers and their dynamic range are generally limited and (d) it is necessary to digitize the traces in order to use the recording for additional analysis. Due to these reasons, a different treatment of data recorded by analog or digital instruments is automatically implemented when waveforms are uploaded in ESM in order to allow the full compatibility among these recordings [Puglia et al., 2018]. The dataset for the flatfile compilation includes 2179 earthquakes recorded by 2080 stations from Europe and Middle-East during 1969–2016 and originated in different tectonic environments, whose magnitude ranges from 4.0 to 8.0. Strong motion intensity measures consist of peak and integral parameters and duration of each waveform. The periods at which the spectral amplitudes (5% damping) of the acceleration and displacement response are computed fall in the range 0.01–10 s, whereas the frequency range of the amplitudes of the Fourier spectrum is 0.02–25 s. The site classification is based on the average shear wave velocity in the uppermost 30 meters (v_{S30}), according to the Eurocode 8 (EC8, CEN [2004]) categorization scheme. v_{S30} values are obtained from in situ geophysical measurements, where available, or derived from geology maps. In addition, an estimation of v_{S30} is provided using the empirical correlation with the topographic slope by Wald and Allen [2007]. Furthermore, the flatfile includes the epicentral distance for all the records and, when the fault geometry is available, the Joyner-Boore distance. Additional details on the structure and organization of the flatfile are discussed by Lanzano et al. [2019].

To compile our dataset, we have extracted from the ESM flatfile the station information, distance measurements, style of faulting, maximum among the two horizontal components of Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), and peak response spectral acceleration amplitudes (at 0.3, 1.0, and 3.0 s). The choice of the periods is based on those used in ShakeMap [Wald et al., 1999b; Worden et al., 2020]. In our dataset, the event location is instead assigned according to a specific hierarchy that firstly prefers catalogues and earthquake-specific studies which give reliable uncertainty estimates, secondly the Italian earthquake catalogue CPTI15 [Rovida et al., 2021]. The magnitude is provided by the HORUS catalog, a homogeneous catalog of Italian earthquakes with magnitudes calibrated to be consistent with Mw standard estimates made by the Global Centroid Moment Tensor project [Lolli et al., 2020].

The latest version of the Italian Macroseismic Database, DBMI15 [Locati et al., 2021], includes 123,956 Macroseismic Data Points (MDPs) related to 3,228 earthquakes. The intensity is usually provided in the MCS scale, but, especially for recent earthquakes, the EMS-98 has been used. DBMI adopts a specific and continually updated gazetteer related to the whole Italian territory. In the gazetteer each record is associated to a locality, with place name, an identifier, and other useful information. As explained in Locati et al. [2021] (https://emidius.mi.ingv.it/CPTI15-DBMI15/description_DBMI15_en.htm), "… the term "locality" equally refers to either region, province, or municipality capitals, and to variously sized hamlets, towns, or cities". The gazetteer ensures the correspondence between the place name of a locality and a pair of geographical coordinates matching the intensity value representative of the total macroseismic observations per locality with a point (MDP). For parametrization purposes, the MDPs expressed with non-numerical codes ("HF" for Highly Felt, "SD" for Slightly Damage, "D" for Damage, "HD" for Heavy Damage) were converted to numerical values as described in Locati et al. [2019, 2021] and reported in https://emidius.mi.ingv.it/CPTI15-DBMI15/description_CPTI15_en.htm. According to this approach, the converted numerical value was rounded to the closest half degree (F = 4.0, HF = 5.0, SD = 5.5, D = 6.5, HD = 8.5). For reasons of practicability, also when the available information is not detailed enough to assess an intensity degree in a straightforward way, and such an uncertainty is expressed with a range (e.g., 6–7, 7–8), we assign the MDP an intermediate value (e.g., 6.5, 7.5). We note also that the MDPs collected and organized in DBMI15 come from works of different authors and institutions, such as Macroseismic Bulletin, online databases [e.g., CFTI4Med; Guidoboni et al., 2007] and published studies based on historical research or field surveys, conducted by teams of experts.

To assemble our dataset, we have extracted all the MDPs from DBMI15 corresponding to earthquakes listed in the ESM flatfile with the attention of excluding preliminarily those earthquakes listed in the Macroseismic Bulletin [see, for example, Gasparini et al., 2011]. This latter data source has been considered to make the dataset inhomogeneous because the intensity assessments have been provided by non-practitioners in the evaluation of the macroseismic intensities (e.g., staff personnel of the public administration in Italy like carabinieri or employees of the local municipalities), whereas other studies propose macroseismic intensity estimates made by macroseismic experts. After this initial selection procedure, we have cross-matched the ESM and the DBMI15 datasets in order to pair intensity and PGM values. To this end, we have chosen a distance criterion, common to most of the studies in this field [e.g., Faenza and Michelini, 2010, 2011; Caprio et al., 2015; Locati et al., 2017; Zanini et al., 2019; Masi et al., 2020]. Notably, Gomez-Capera et al. [2020] adopted a slightly different criterion by pairing only those localities that feature similar topographic conditions with respect to the station and within 3 km. In our dataset and to the purpose of completeness and to give the user the maximum flexibility on what data to use, we have included all the localities reporting intensity data which are located within 3 km from the strong motion stations that recorded the data. This gives additional freedom to the researcher to select which MDP to extract from the dataset or to adopt other criteria to average the available MDPs associated to that particular recording strong motion station.

With respect to the adopted macroseismic scale, we have extracted all the localities reporting intensity data located within 3 km from recorded accelerograms regardless of whether the scale used in DBMI is MCS or EMS-98. According to Codermatz et al. [2003] a practical equality exists between MCS and EMS-98. Also, Musson et al. [2010] concluded that assigning EMS intensities to the MCS scale descriptions themselves generally leads to equality, making the two intensity assessments comparable. In contrast, other authors [e.g., Molin, 1995] stated how MCS and EMS-98 intensity assignments can differ for the same data. In order to allow the user to recognize the type of macroseismic scale reported in DBMI15, we have added this information for all MDPs selected following our distance criterion.

One main issue remains the intrinsic high spatial variability of the two different types of ground shaking values assembled together in datasets like this one. In fact, an instrumental recording is obtained at a well-defined geographical point whereas and in contrast, several observations contribute to assigning a unique intensity level to a locality that refers to an extended urbanized area featuring often different geological, geomorphological, and topographic characteristics. Margottini et al. [1992] define as standard approach the description of the effects for which the intensity data are estimated by the damage and/or by human perception in the town closest to the instrument. Thus, unlike ground-motion measurements, intensity observations do not exist at a point [Worden et al., 2010] because intensity is a classification of the severity of the effects caused by the ground shaking on a “statistically” consistent sample of buildings inside the locality that, by definition, has an areal extension. This aspect is implicitly contained in the EMS-98 definition [Grünthal, 1998] for which the macroseismic intensity is the classification of the severity of ground shaking on the basis of observed effects in an area. Ripperger et al. [2008] state that, although macroseismic and instrumental intensity have different reference areas, the matching is fairly good, mostly taking into account the error of the conversion relationship. We took into account this aspect by assigning an uncertainty of 0.5 to all the intensity values. Although this kind of intrinsic uncertainty can be considered as aleatory, some researchers have estimated different standard deviation values of the intensity range [e.g. Albarello and D’Amico, 2004; Pasolini et al., 2008]. Although alternative estimates are possible and other choices can be made [see, e.g., Magri et al., 1994; D’Amico and Albarello, 2008], we considered it reasonable to introduce an uncertainty of 0.5 to all the intensity values because in DBMI15 intensity data are listed as intermediate values (e.g., 6, 6.5, 7, 7.5, ...) in order to express uncertainty affecting the reported values. We are aware that this choice is somewhat subjective, but the users of the dataset nevertheless remain free to assign their own uncertainties for their research if they wish (e.g., based on the distance between the seismic stations and the closest MDP).

3. Data and metadata

The information that was included for the characterization of each data point in the dataset can be summarized as follows:

- **Earthquake source parameters**: primary ESM and INGV event ids, date and time of occurrence (origin time), hypocentral coordinates (geographical coordinates and depth) with uncertainty, style of faulting (SoF), magnitude (moment-Mw) with uncertainty.
- **Station information**: network and station code, and location of the receiver; EC8 class, measured v_{S30} from the ESM flatfile and extracted v_{S30} from the v_{S30} grid adopted by ShakeMap [Michelini et al., 2020];
- **Distance measurements**: epicentral distance, R_{EPI}, azimuth and finite-source distance measure related to fault geometry R_{JB}, distance between the selected macroseismic points and the strong motion stations, and distance between the selected macroseismic points and the events location. The Joyner-Boore distance is available for 28 percent of earthquakes. Epicentral distance is calculated when R_{JB} is not provided. In the following, we will refer to a generic “Station-to-event distance” matching either R_{JB} or R_{EPI} according to the above described procedure.
- **Peak ground motion values**: the maximum of the two horizontal components of the peak ground motion measures (PGA and PGV) and the 5% damping elastic response spectral ordinates in acceleration (SA) at 0.3, 1.0 and 3.0 s;
- **Macroseismic data**: macroseismic values located within 3 km from the stations (referred to a locality, with place identifier, name and geographical coordinates).

For explanatory and descriptive purposes, we considered it interesting to show also the selection of only the closest intensity points for each recording station in some of the following figures (Figs. 2b, 4b, 11). In this case, the resulting final dataset is a subset of the original dataset and it consists of a total of 323 associated PGM-intensity pairs.

Moving to the description of the data taken from DBMI15, first of all we note that our full dataset, which contains 519 macroseismic intensity-PGM pairs related to 65 earthquakes and 338 localities, shows that the larger intensity values correspond to the previously mentioned significant seismic sequences that occurred in Italy: the 1976 Friuli, the 1980 Irpinia, the 2009 Abruzzo and the 2016–2017 Central Italy (Figure 1). Noteworthy and in addition to the previous datasets compiled by Faenza and Michelini [2010, 2011], this new assembled dataset includes also intensity-PGM pairs for intensity levels larger than 8.0, thanks to the inclusion of recent earthquake data.

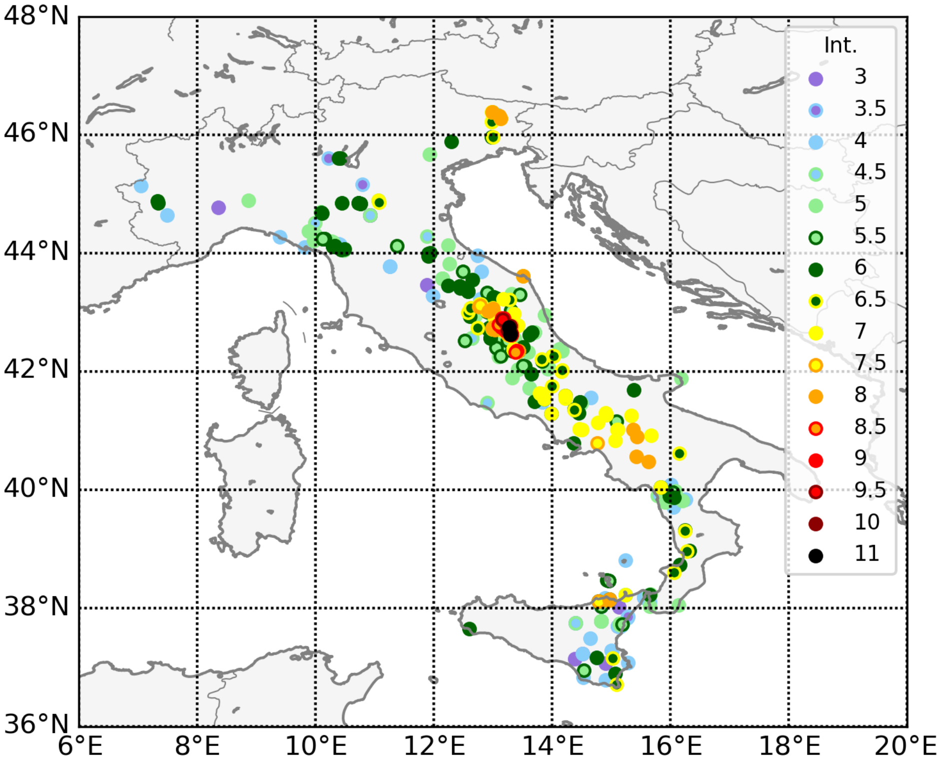

Figure 1. The selected observed macroseismic intensities for the earthquakes included in our dataset.

The number of available intensity-PGM pairs per earthquake is extremely variable; when selecting only the closest intensity points within 3 km for each recording station, it can be observed that 40% of earthquakes have only 1 pair; about 11% of earthquakes have 2 pairs; about 39% have between 3 and 10 pairs; about 9% have between 11 and 50 pairs; only one has more than 50 pairs (Figure 2b). Comparing Figures 2a and 2b, there is a great increase in the total number of intensity data per earthquakes when considering all the MDPs with distance less than 3 km from the accelerograph stations. In this latter case, about a quarter (24.6%) of the earthquakes has only 1 pair; a seventh (13.9%) has between 11 and 50 pairs; only one has more than 100 pairs and the remaining part has a set of pairs between 2 and 10 (see Figure 2b). The variable distribution of intensity-PGM pairs with time is due primarily to the great increase over time of earthquakes with many MDPs in DBMI15 and the availability of a larger number of high quality seismological stations for the more recent events. Furthermore, the number of pairs increases when we select all the localities reporting intensity data which are located within 3 km from the strong motion stations.

No spatial clustering of earthquakes by number of pairs is observed as they are equally distributed all along the Italian peninsula, while it is evident that earthquakes with a large number of pairs occurred in 2016 (Figures 1 and 2).

As reported in Table 1, our dataset includes 65 earthquakes (Figure 3) that occurred between June 1972 and October 2016 ($4.1 \leqslant M_w \leqslant 6.8$). The earthquakes in the dataset were recorded by 227 stations (Figure 4) located at distances within 300 km from the earthquakes. The number of available MDPs per station for the full dataset

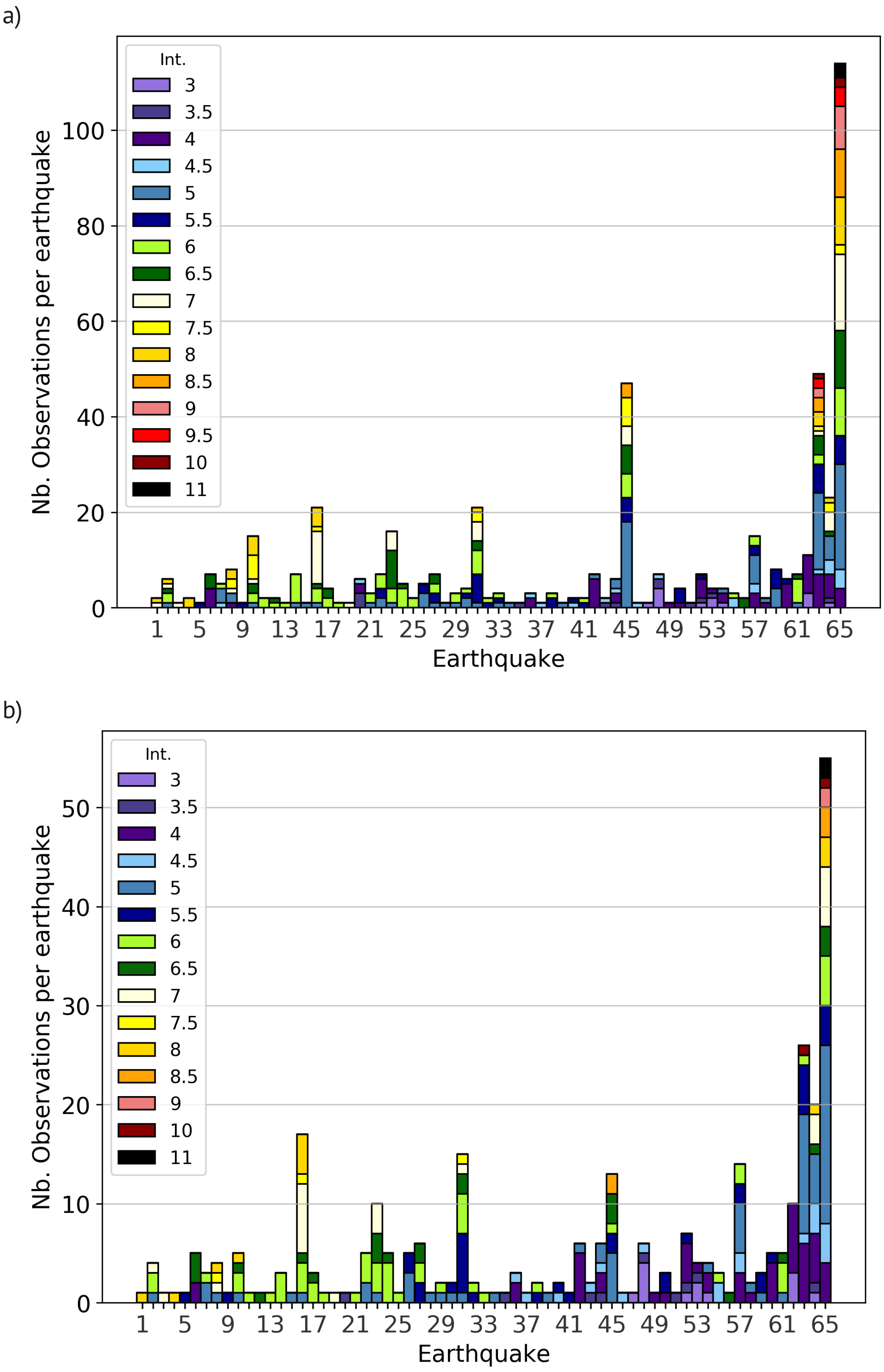

Figure 2. Number of intensity-PGMs per earthquake for different macroseismic intensities ranges. The full dataset of 519 intensity-PGM pairs (a), and the 323 pairs with the closest MDP to the station (b). The earthquakes are sorted in chronological order (from 1972 to 2016).

and selecting only the closest intensity points is shown, respectively, in Figure 4a and Figure 4b. Relative position between earthquakes and recording stations are expressed through the event-to-station azimuth (degrees) and the distance (km). The event distribution in km distance and azimuth is reported in Figure 5. The dataset does not contain earthquake signals arriving at receiver from all azimuths; there are gaps in the azimuthal coverage along the axis North-East South-West at larger distances. This is mainly due to the geographical setting of the Italian peninsula and the density of the instruments through time.

Time	Lat	Lon	Depth	ERH	ERZ	Mw	ERMw	Nb.MDPs	Nb.stations
1972-06-14 18:55:46	42.6880	13.4650	3.00			4.67	0.19	2	1
1976-05-06 20:00:12	46.2620	13.3000	5.71	1.4	1.6	6.45	0.10	6	4
1976-09-11 16:35:01	46.2560	13.2330	4.30	1.3	1.5	5.60	0.10	1	1
1976-09-15 09:21:18	46.3000	13.1740	11.26	0.8	0.8	5.95	0.10	2	1
1977-07-24 09:55:30	41.1600	14.9600	35.00			4.19	0.19	1	1
1977-09-16 23:48:07	46.2830	13.0190	10.78	1	0.9	5.26	0.10	7	5
1978-03-11 19:20:43	38.0500	16.0170	15.00	4	3.6	5.22	0.10	5	3
1978-04-15 23:33:47	38.4120	15.1290	17.70	3.8	3.6	6.03	0.10	8	4
1978-12-05 04:45:26	43.0930	12.8190	10.00			4.30	0.19	1	1
1979-09-19 21:35:37	42.7800	13.0000	10.00	2.8	4.8	5.83	0.10	15	5
1980-01-05 14:32:26	45.0510	7.3680	15.00	3.5	7.7	4.82	0.10	2	1
1980-02-20 02:34:01	39.2900	16.1500	3.70			4.42	0.10	2	1
1980-02-28 21:04:40	42.7530	12.9960	12.90	3.1	4.8	4.97	0.10	1	1
1980-06-07 18:35:01	44.0500	10.6000	30.00			4.64	0.10	7	3
1980-06-09 16:02:47	42.1860	13.7810	39.30			4.64	0.10	1	1
1980-11-23 18:34:53	40.8700	15.3780	10.00	3.7	3.3	6.81	0.10	21	17
1980-12-09 05:50:12	38.7600	16.1810	55.00	6.5	19.8	4.67	0.10	4	3
1981-06-07 13:01:00	37.6740	12.4770	21.40			4.93	0.10	1	1
1982-03-21 09:44:00	39.7043	15.6385	18.90	2.3	0.7	5.23	0.10	1	1
1983-07-20 22:03:30	37.5487	15.1680	24.70	2	1.6	4.10	0.50	6	1
1983-11-09 16:29:52	44.6487	10.3665	28.10	0.1	0.1	5.04	0.10	3	1
1984-04-29 05:03:00	43.2100	12.5700	5.97	0.1	0.8	5.62	0.10	7	5
1984-05-07 17:49:43	41.7000	13.8600	20.50	0.1	0.1	5.86	0.10	16	10
1984-05-11 10:41:48	41.7800	13.8900	12.10	0.1	0.2	5.47	0.10	5	5

Time	Lat	Lon	Depth	ERH	ERZ	Mw	ERMw	Nb.MDPs	Nb.stations
1987-05-02 20:43:54	44.7940	10.6780	23.67	0.1	0.1	4.71	0.10	2	1
1988-02-01 14:21:40	46.3590	13.0750	3.10	0.2	0.4	4.94	0.21	5	5
1990-12-13 00:24:26	37.3300	15.2410	0.31	0.7	9.1	5.61	0.10	7	6
1995-10-10 06:54:22	44.1330	10.0180	8.23	0.3	0.7	4.82	0.10	1	1
1996-10-15 09:56:00	44.7630	10.6050	25.54	0.3	0.3	5.38	0.10	3	2
1997-09-03 22:07:30	43.0260	12.8770	5.74	0.1	0.4	4.54	0.07	4	2
1997-09-26 09:40:24	43.0150	12.8540	9.87	0.1	0.3	5.97	0.07	21	15
1998-09-09 11:28:00	40.0600	15.9490	29.21	0.7	0.3	5.53	0.07	2	2
1999-02-14 11:45:53	38.2660	15.0220	20.67	0.2	0.2	4.66	0.07	3	1
2001-04-22 13:56:34	37.7230	14.9890	0.03	0.2	1.7	4.19	0.07	1	1
2002-04-05 04:52:21	39.1660	15.4800	0.00	0.4	2.1	4.49	0.07	1	1
2002-09-06 01:21:28	38.3810	13.6540	27.01	0.4	0.4	5.91	0.07	3	3
2002-10-27 02:50:26	37.7660	15.1060	0.04	0.3	7	4.84	0.07	1	1
2003-01-26 19:57:03	43.8830	11.9600	6.53	1.77	1.46	4.67	0.07	3	2
2003-04-11 09:26:57	44.7580	8.8680	8.15	1.49	5.08	4.81	0.07	1	1
2003-09-14 21:42:53	44.2550	11.3800	8.33	1.64	2.52	5.24	0.07	2	2
2004-11-24 22:59:38	45.6850	10.5210	5.44	1.1	0.77	4.99	0.07	2	1
2006-02-27 04:34:01	38.1550	15.2000	9.20	1.06	1.2	4.38	0.07	7	6
2006-12-19 14:58:06	37.7780	14.9130	23.80	1.14	1.2	4.20	0.07	2	2
2008-12-23 15:24:21	44.5440	10.3450	22.90	1.06	0.9	5.36	0.07	6	6
2009-04-06 01:32:40	42.3420	13.3800	8.30	0.71		6.29	0.07	47	13
2009-11-08 06:51:16	37.8470	14.5570	7.60	0.99	1.2	4.52	0.07	1	1
2009-12-15 13:11:58	43.0070	12.2710	8.80	0.71	1	4.22	0.07	1	1
2009-12-19 09:01:16	37.7820	14.9740	26.90	1.28	1.4	4.40	0.07	7	6
2010-04-02 20:04:45	37.7990	15.0790	0.31	0.2	0.2	4.20	0.07	1	1
2010-08-16 12:54:47	38.4100	14.9190	16.90	9.22	1	4.68	0.07	4	3
2011-05-06 15:12:35	37.8040	14.9430	20.35	0.3	0.5	4.30	0.07	1	1
2011-06-23 22:02:46	38.0640	14.7840	7.30	0.92	1.1	4.70	0.07	7	7
2011-07-17 18:30:27	45.0100	11.3670	2.40	0.94		4.68	0.07	4	4

Time	Lat	Lon	Depth	ERH	ERZ	Mw	ERMw	Nb.MDPs	Nb.stations
2011-07-25 12:31:20	45.0160	7.3650	11.00	1.39		4.55	0.07	4	4
2012-01-25 08:06:37	44.8710	10.5100	29.00	0.86	0.7	4.98	0.07	3	3
2012-05-20 02:03:50	44.8955	11.2635	9.50	0.72	1	6.09	0.07	2	1
2012-10-25 23:05:24	39.8747	16.0158	9.70	0.64	0.7	5.32	0.07	15	14
2013-01-04 07:50:06	37.8810	14.7190	9.57	0.3	0.3	4.37	0.07	2	2
2013-06-21 10:33:56	44.1308	10.1357	7.00	0.91		5.32	0.07	8	3
2013-08-15 23:06:51	38.1627	14.9138	24.80	0.75	0.9	4.27	0.19	6	5
2013-12-29 17:08:43	41.3952	14.4342	20.40	0.37	0.6	5.14	0.07	7	5
2016-02-08 15:35:43	36.9745	14.8678	7.40	0.83	0.8	4.43	0.07	11	10
2016-08-24 01:36:32	42.6983	13.2335	8.10	0.15	0.2	6.18	0.07	49	26
2016-10-26 19:18:06	42.9048	13.0902	9.60	0.2	0.2	6.08	0.07	23	20
2016-10-30 06:40:18	42.8303	13.1092	10.00	0.19	0.2	6.61	0.07	114	55

Table 1. List of the 65 selected seismic events: hypocenter with uncertainty, moment magnitude with uncertainty, number of macroseismic data and number of stations for each event are indicated.

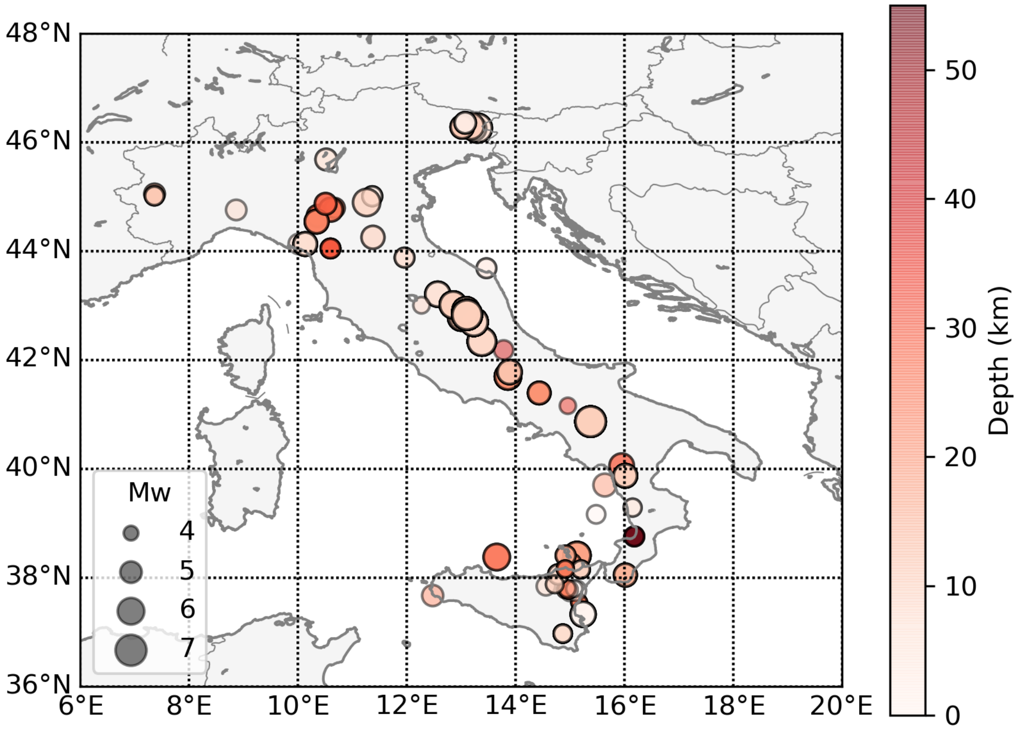

Figure 3. Epicentral map of the earthquakes in the dataset. Circles sizes were plotted relative to their magnitude value.

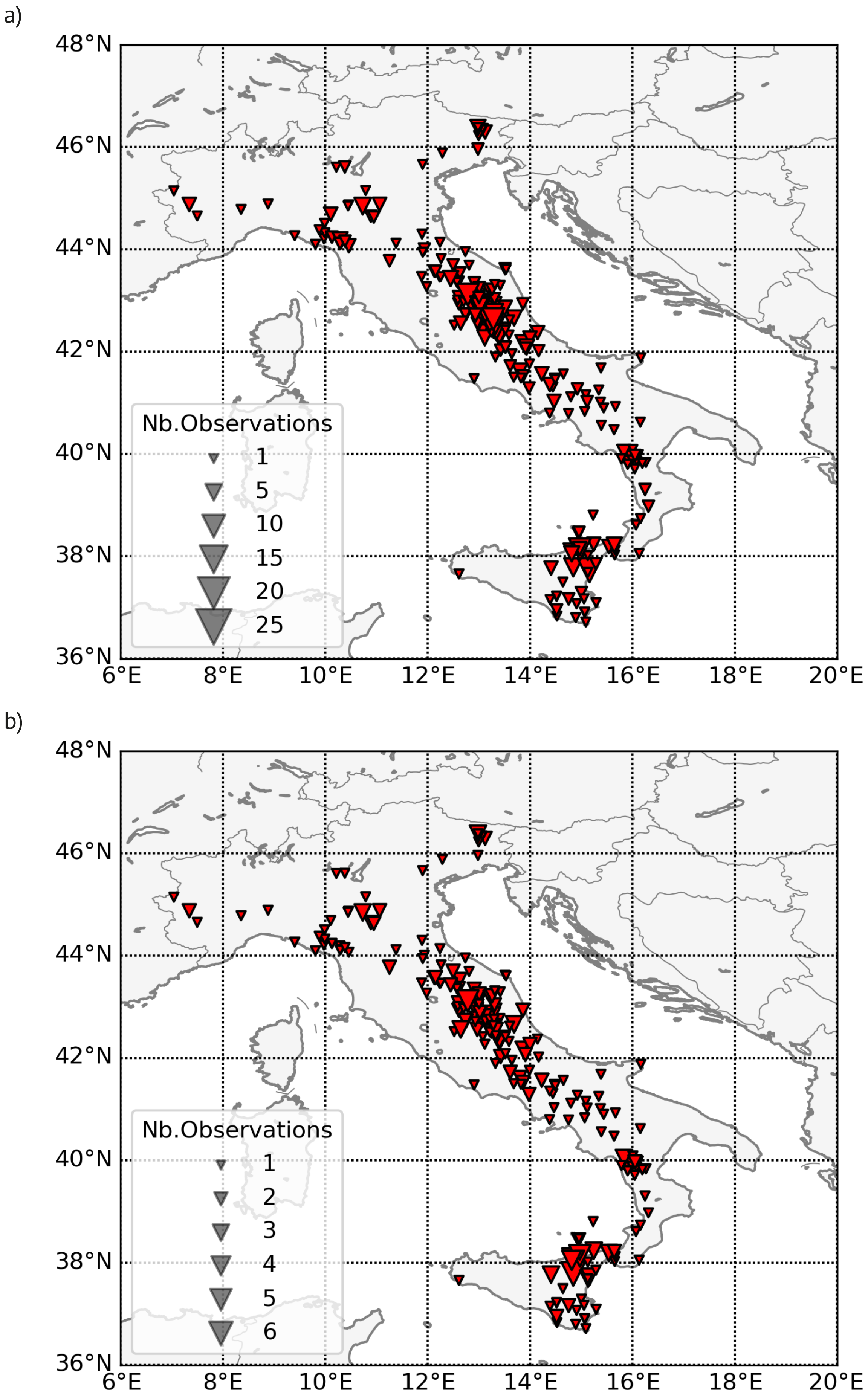

Figure 4. Location of the stations considering, the dataset of a) 519 and b) 323 data pairs, respectively. The two maps are identical with the exception that the size of the symbol is proportional to the number of MDPs per station.

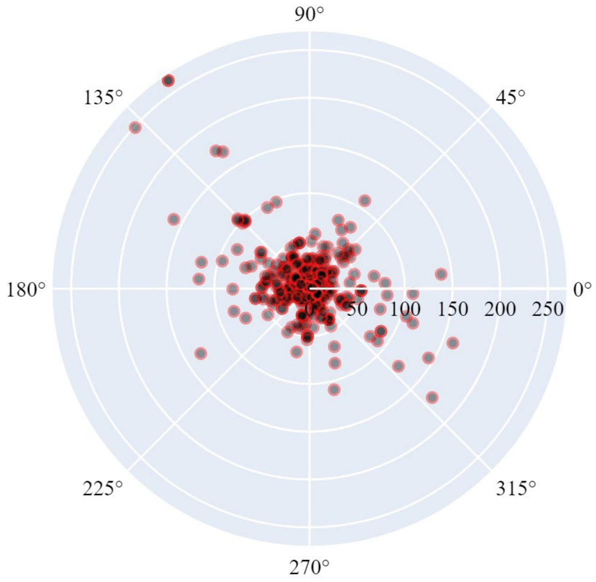

Figure 5. Azimuth-distance distribution of the selected stations with respect to the earthquake epicenter.

The distribution of the source to site distance in km is given in Figure 6. We observe that most of the recordings were acquired within 80 km from the epicenter. In Figure 6 R_{JB} if available otherwise R_{EPI}.

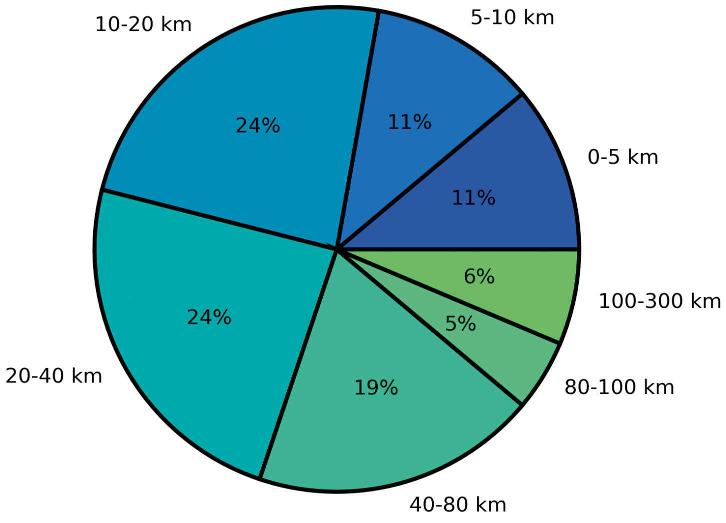

Figure 6. Distribution of the source to the recording station distances of the full dataset.

Figure 7 shows the number of events in the database as a function of time for different magnitude ranges. A larger number of earthquakes is observed in those years when important sequences occurred (i.e., Friuli 1976; Irpinia, 1980; L'Aquila, 2009; Emilia, 2012 and Central Italy, 2016).

Figure 8 illustrates the histograms of (a) magnitude, (b) focal depth and (c) SoF. Most of the data belong to earthquakes with magnitudes in the range 4.0 to 5.0, underlining the dominance of moderate events (Figure 8a). A relevant part of the dataset, however, belongs to earthquakes in the magnitude range 6.0–7.0, owing to the contribution of the events mentioned above. The following features of the events are also considered: focal depth and focal mechanisms. The distribution of earthquakes focal depths (Figure 8b) indicates that seismicity is concentrated in the upper 30 km of the crust, corresponding to about 94% of the total events. Comparison of the focal mechanisms in Figure 8c shows that the normal faulting (NF) earthquakes are prevalent (40%) when compared to the 20% and 17% of the total events that have Thrust (TF) and Strike-Slip (SS) style of faulting, respectively.

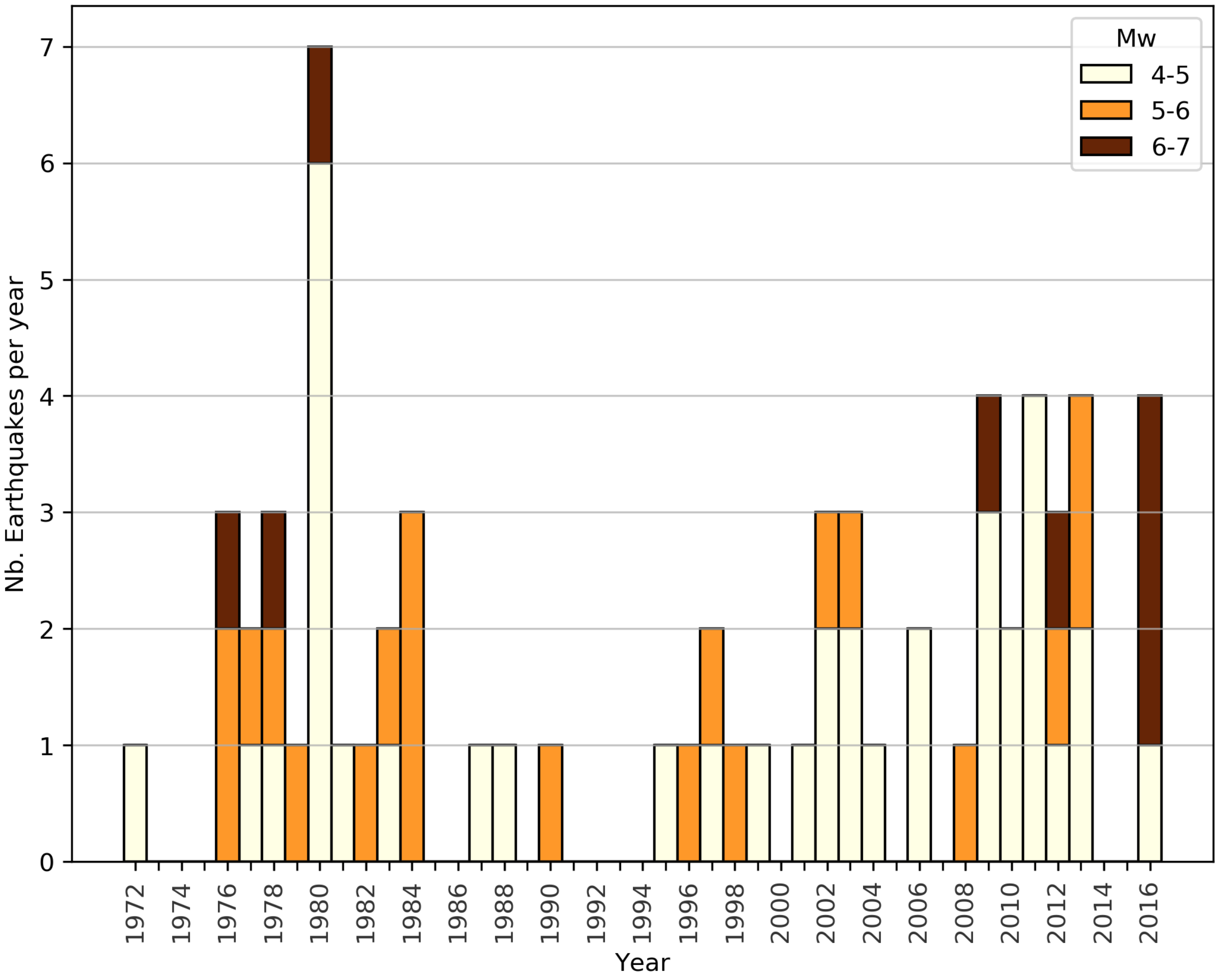

Figure 7. Number of earthquakes in the compiled dataset in the time interval 1972–2016 for different magnitude ranges.

The distribution of the station-to-macroseismic data point distance for the full dataset and selecting only the closest intensity points is illustrated in Figure 9. The station-to-MDP distances range between 0.01 km and nearly 3 km and the figure evidences that most intensity–PGM pairs, when selecting only the closest intensity points for each recording station (323 pairs), are not farther than 1.5 km. This implies that the greatest majority of the MDPs is within ~1.5 km leaving, however, the freedom to the users to select other criteria to assign the MDP value to the associated instrumental recording (e.g., mean value of all the MDPs within the 3 km or other choices).

The magnitude-distance distribution of our dataset is given in Figure 10, grouped by style of faulting. The Joyner-Boore distance (R_{JB}) is relevant only for events with $M_w > 5.5$ and is available for 340 records. Data are quite well sampled for distance between 10 and 100 km. Looking at the focal mechanisms distribution in Fig. 10, the normal faulting style is predominant for strong events with magnitude comprises between 6.0 and 6.8.

Figure 11 shows the distribution of the strong motion and macroseismic intensity data versus distance grouped by style of faulting. Overall, the database is quite well distributed although we note that only two data-points are related to stations with distances > 200 km and there are few intensity data at closer distances for small intensity values. This follows from the DBMI15 data being compiled for damaging events [i.e. medium-large magnitude earthquakes producing microseismic damage; e.g. Allen and Wald, 2009]. Also the removal of several earthquakes, whose source has proved to make the dataset inhomogeneous (i.e., those belonging to the Macroseismic Bulletin), affects the number of intensity data when the distance is very small. However, Fig. 11 also illustrates the relevant number of MDPs with moderate intensities, and, in particular, those between 4 and 5. The increase, in comparison to the previous DBMI releases, results from the inclusion of many moderate energy earthquakes [Locati et al., 2019]. Looking at the focal mechanisms distribution in Figure 11, the normal faulting style is predominant for high peak ground motion values.

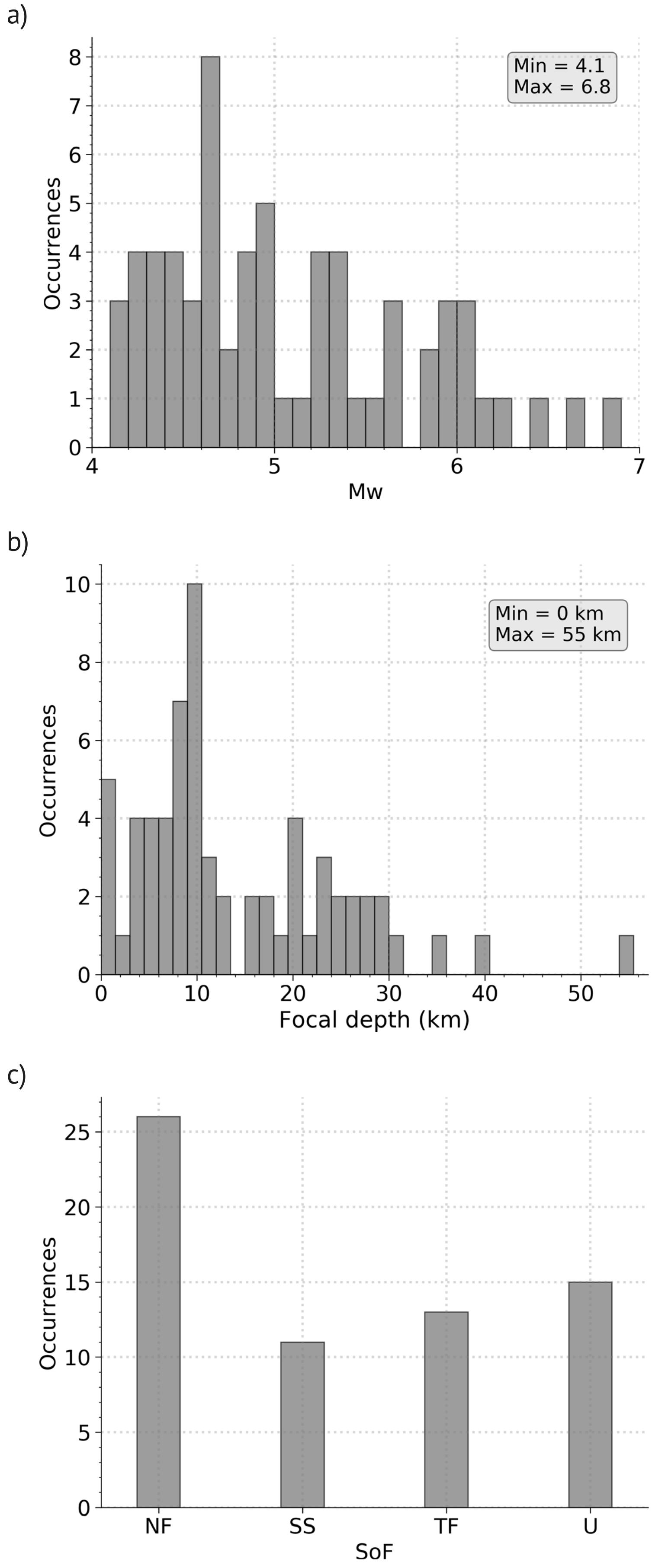

Figure 8. Distribution of earthquake (a) magnitudes, (b) depths and (c) styles of faulting. U: undefined; SS: strike-slip; TF: thrust; NF: normal faulting.

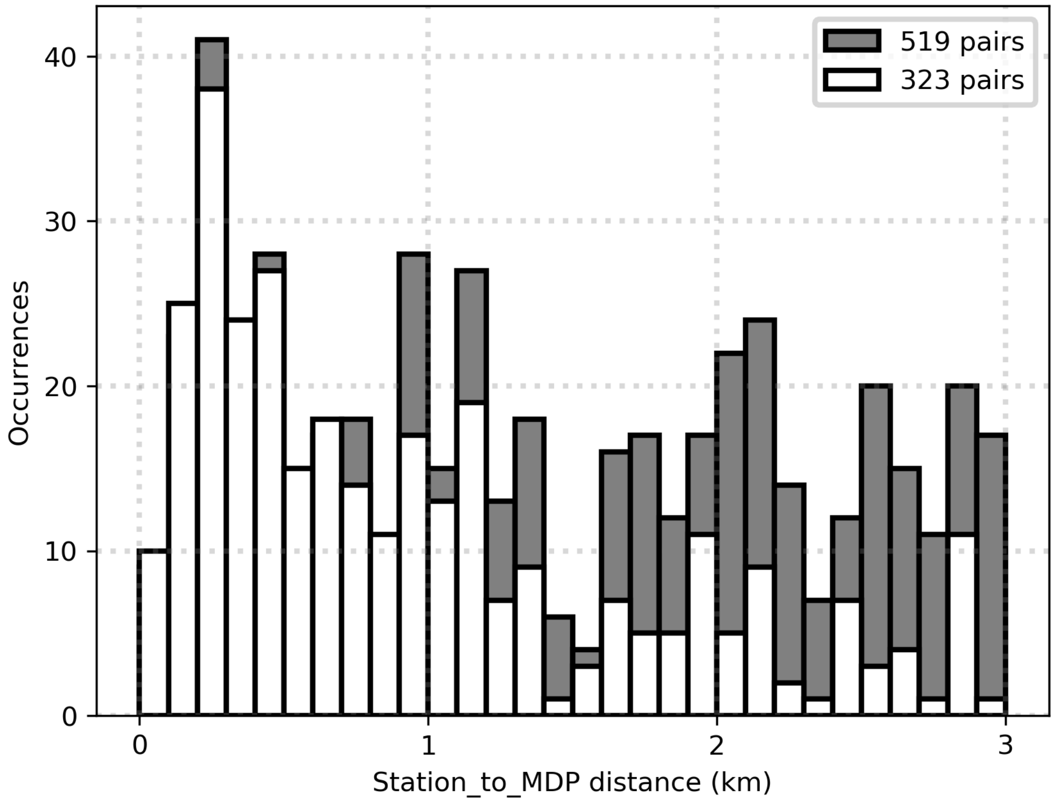

Figure 9. Histogram of the distribution of the station-to-MDP distance for the full dataset (gray bars) and selecting only the closest intensity points (white bars) .

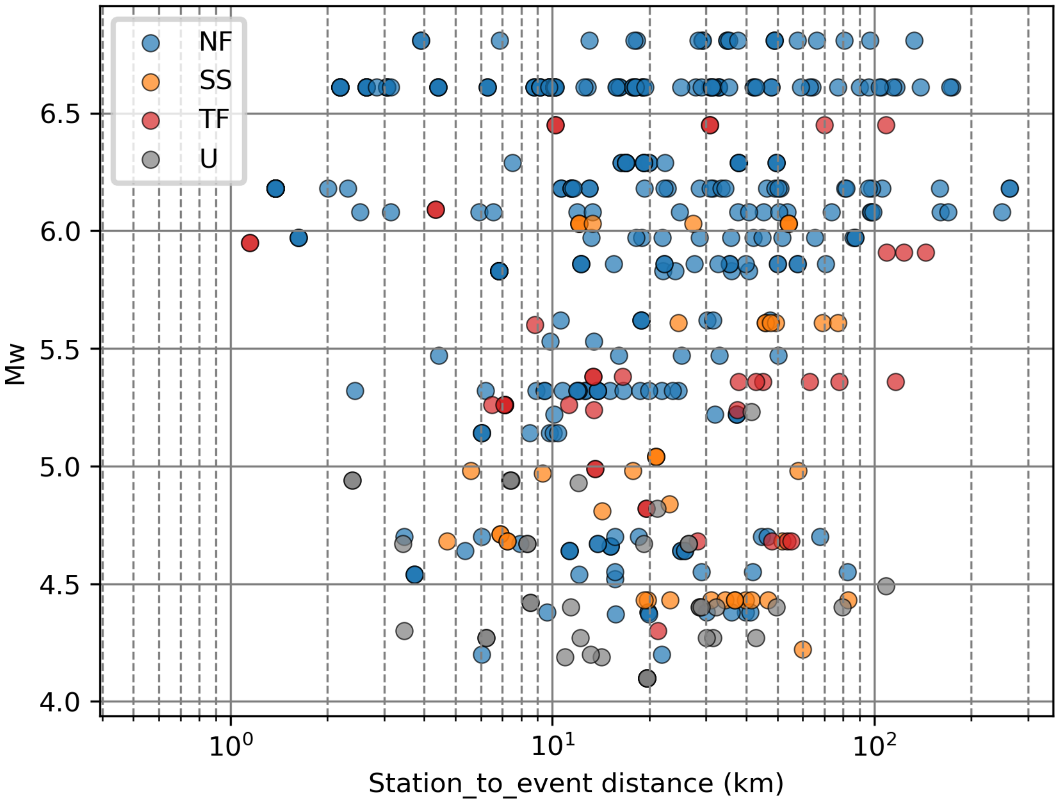

Figure 10. Magnitude versus station-to-event distance plot of recordings grouped by style of faulting. U: undefined; SS: strike-slip; TF: thrust; NF: normal faulting. In order to avoid the loss of distance values equal to zero, we assigned a slightly bigger value than zero (1 km).

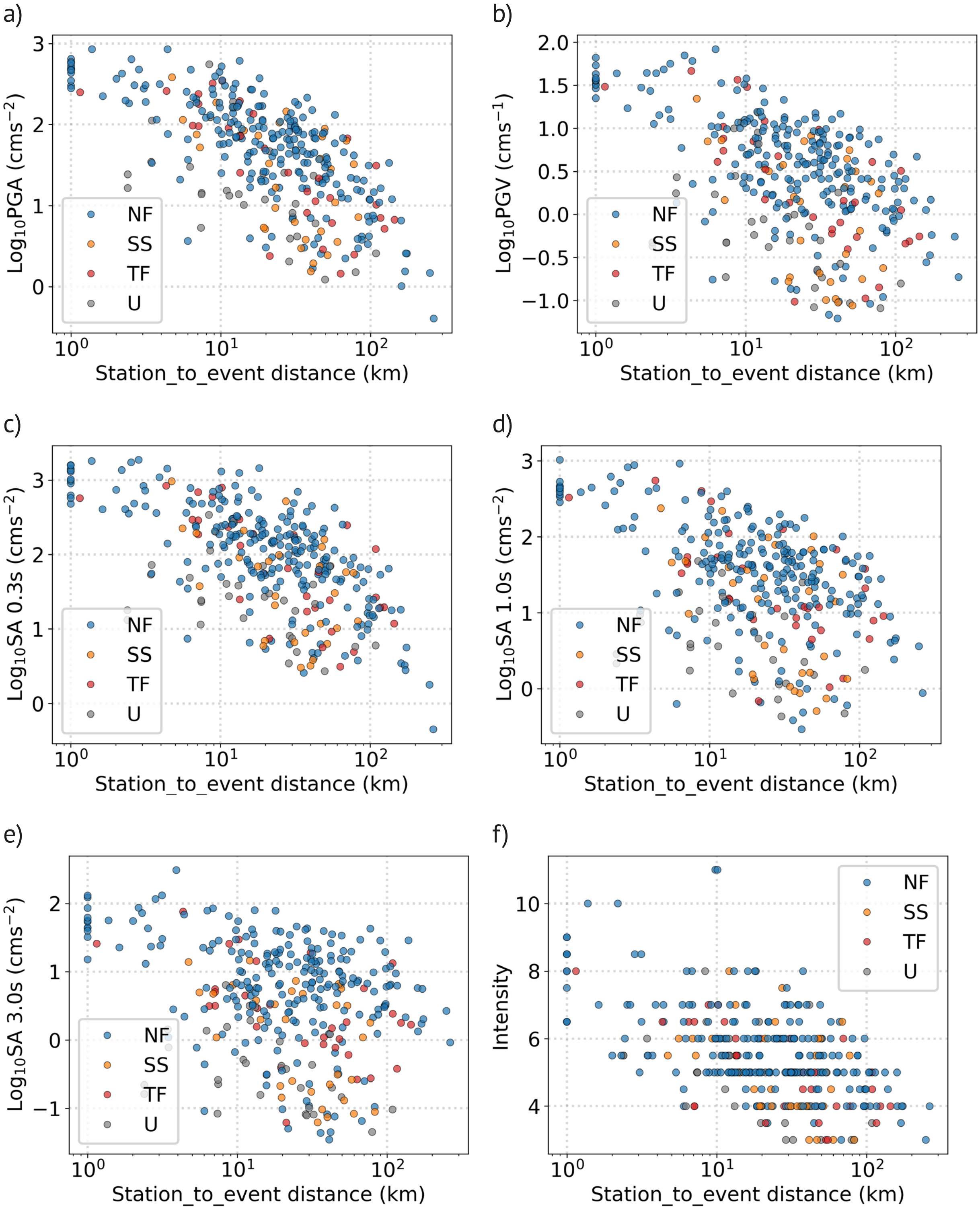

Figure 11. The attenuation characteristics of PGAs (top left, (a)), PGVs (top right, (b)), spectral accelerations at periods 0.3 s (middle left, (c)), 1.0 s (middle right, (d)) and 3.0 s (bottom left, (e)) and macroseismic intensity (bottom right, (f)) grouped by style of faulting. U: undefined; SS: strike-slip; TF: thrust; NF: normal faulting. Dots refer to the closest intensity points for each recording station (323 MDPs). In order to avoid the loss of distance values equal to zero, we assigned a slightly bigger value than zero (1 km).

4. Conclusions

A dataset consisting of macroseismic intensity-PGM pairs has been compiled for earthquakes in Italy. It comprises 65 events of magnitude 4.1–6.8 that occurred from 1972 through 2016 for a total of 519 pairs of macroseismic and ground motion parameters. The dataset has been built by intersecting the DBMI15 intensity database [Locati et al., 2021] and the ESM accelerometric data bank [Lanzano et al., 2018], and selecting all the localities reporting intensity data which are located within 3 km from the recording stations. Attention was paid to remove macroseismic data provided by non-practitioners in order to make the dataset homogeneous in terms of data sources.

To each data point pair, an extensive set of metadata is provided that includes earthquake information (e.g. origin time, depth, moment magnitude, focal mechanism, etc), and recording station information (e.g. station code and location of the receiver, EC8 site class attribution, v_{S30} values), and distance measurements. Also uncertainties in earthquake epicentral location, focal depth and magnitude and the type of macroseismic scale used to estimate intensity are given. The inclusion of this rather rich set of parameters makes the dataset the most complete for earthquakes in Italy to our knowledge and it will allow the users to make their data selection swiftly based on several parameters and, perhaps more importantly, saving a rather consistent amount of time to compile the dataset from several original catalogs and databases.

The data collected can be used for development and testing of Ground Motion Intensity Conversion Equations (GMICE) and Intensity Prediction Equations (IPE). These both are important for seismic hazard studies and for the calculation of ShakeMaps. Overall, the publication of this dataset is expected to promote the adoption of best practices and to accelerate research progress.

Data and sharing resources. The dataset compiled in this study is based on two primary databases: the ESM accelerometric data bank available at https://esm.mi.ingv.it/flatfile-2018/ and the DBMI15 intensity database available at https://emidius.mi.ingv.it/CPTI15-DBMI15/. v_{S30} values were derived from the v_{S30} grid adopted by ShakeMap [Michelini et al., 2020]. Assembled dataset table (csv format) may be found at https://doi.org/10.13127/inge.2 [Oliveti et al., 2021].

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