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The pan-European Engineering Strong Motion (ESM) flatfile: compilation criteria and data statistics

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Abstract:	The ESM strong motion flatfile is a parametric table which contains verified and reliable metadata and intensity measures of manually processed waveforms included in the Engineering Strong Motion database (ESM). The flatfile has been developed within the Seismology Thematic Core Service of EPOS-IP (European Plate Observing System Implementation Phase) and it is disseminated throughout a web portal (http://esm.mi.ingv.it/flatfile-2018/flatfile.php) for research and technical purposes. The adopted criteria for flatfile compilation aim to collect strong motion data and related metadata in a uniform, updated, treaceble and quality-checked way to develop Ground Motion Models (GMMs) for Probabilistic Seismic Hazard Assessment (PSHA) and engineering applications. In this paper, we present the characteristics of ESM flatfile in terms of recording, event and station distributions, and we discuss the most relevant features of the Intensity Measures of engineering interest included in the table. The dataset for flatfile compilation includes 23,014 recordings from 2,179 earthquakes and 2,080 stations from Europe and Middle-East. The events are characterized by magnitudes in the range 3.5 - 8.0 and refer to different tectonics regimes, such as shallow active crustal and subduction zones. Intensity measures include peak and integral parameters and duration of each waveform. The spectral amplitudes of the (5% damping) acceleration and displacement response are provided for 36 periods, in the interval 0.01-10s, as well as the 103 amplitudes of the Fourier spectrum for the frequency range 0.04-50Hz. Several statistics are shown with reference to the most significant metadata for GMMs calibrations, such as moment magnitude, focal depth, several distance metrics, style of faulting and parameters for site characterization. Furthermore we also compare and explain the most relevant differences between the metadata of ESM flatfile with those provided by the previous flatfile derived in RESORCE (Reference Database for Seismic Ground Motion in Europe) project.

The pan-European Engineering Strong Motion (ESM) flatfile: compilation criteria and data statistics.

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ABSTRACT

Engineering Strong Motion database (ESM) ...

The ESM strong motion flatfile is a parametric table which contains verified and reliable metadata and intensity measures of manually processed waveforms included in the Engineering Strong Motion database (ESM). The flatfile has been developed within the Seismology Thematic Core Service of EPOS-IP (European Plate Observing System Implementation Phase) and it is disseminated throughout a web portal (http://esm.mi.ingv.it/flatfile-2018/flatfile.php) for research and technical purposes.
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Please either use "Ground Motion Prediction Models (GMPEs)" or "Ground Motion Models (GMMs)" throughout the text.

Keywords: strong motion records; flatfile; metadata; GMPEs; Engineering Strong Motion database.

1. INTRODUCTION

Within the Thematic Core Service for Seismology of EPOS project (European Plate Observing System, www.epos-eu.org), several hazard-oriented products are expected to be disseminated to scientists, public managers, and citizens, such as the Engineering Strong Motion (ESM) database (http://esm.mi.ingv.it; Luzi et al. 2016). ESM encompasses all the previous European databases and largely overtakes all of them, because it is also closely linked to the European Integrated Data Archive (EIDA; http://www.orfeus-eu.org/data/eida), a key infrastructure aimed at archiving and disseminating digital waveforms. The availability of continuous data streams from EIDA allows access to seismic signals in quasi-real time and to progressively populate the ESM database through semiautomatic procedures.

The records and the metadata included in ESM are the basis for compiling a comprehensive reference table (i.e. flatfile) for event/station metadata and strong motion intensity measures in Europe and Middle East. It is motivated by the need to uniformly collect strong motion data and related information in a quality-checked way to develop Ground Motion Models (GMMs) for Probabilistic Seismic Hazard Assessment (PSHA) and for the analysis of the seismic structural response.

The ESM strong motion flatfile is the result of a collaboration between EPOS Task 8.6.3 European Ground Motion Prediction Equations (GMPEs) Database (Lead GFZ) & Task 8.4.2 Strong Motion Data and Products Services (Lead INGV). It is disseminated throughout a web portal (http://esm.mi.ingv.it/flatfile-2018/flatfile.php) for research and technical purposes, to engineers and seismologists, scientists and practitioners, as well as to decision makers and public authorities, in line with the main goals of the EPOS project. Indeed, the flatfile will be the primary source of information to develop a regionalized GMPE logic-tree (Weatherill et al. 2018; Douglas, 2018) required by the next update of the probabilistic hazard map in Europe in the framework of the SERA EU project (Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe; http://www.sera-eu.org/en/home/). ESM flatfile will also be the base for calibration and validation of the European Ground Shaking Models in the framework of EFEHR (European Facilities for Earthquake Hazard and Risk; http://www.efehr.org/en/home/) service, under the coordination of EPOS project.

The first version of ESM flatfile has been released in May 2017 (Lanzano et al. 2018) and it is composed by 18,336 recordings from 2,121 earthquakes and 2,035 stations. Based on user's feedback, we implemented some modification/integration in the flatfile, such as the site characterization of several recording stations in France, Switzerland and Italy, and a flatfile for acceleration Fourier Amplitude Spectrum (FAS). We also extended the temporal duration of the flatfile up to 2016 and therefore key events of the recent Central Italy seismic sequence are included, such as the 24/8/2016 M_W 6.0 Amatrice and 30/10/2016 M_W 6.5 Norcia earthquakes. As a result, the second version of the flatfile has been released in March 2018 (see Data and Resources section) and is composed by 23,014 recordings from 2,179 earthquakes and 2,080 stations.

ESM flatfile updates the previous European datasets, prepared for GMPEs calibration, such as ISESD (Internet-Site for European strong motion Data, Ambraseys et al. 2002; Ambraseys et al. 2004) and RESORCE database (Reference Database for Seismic Ground Motion in Europe; Akkar et al. 2014). The latter is the most recent published flatfile (latest release in 2013) and includes 5,882 records from 1,540 strong motion stations and 1,814 events, in the moment magnitude range $2.8 \leq Mw \leq 7.8$. After the publication of RESORCE, several ground motion models to be applied in pan-European regions have been calibrated (Douglas et al. 2014).

In this paper, we show the adopted criteria for the ESM flatfile compilation in terms of available data and metadata. We also report the statistics of the most significant metadata for GMMs calibrations, such as moment magnitude, focal depth, several distance metrics, style of faulting and parameters for site characterization. In the end, we compare the metadata of ESM flatfile with those provided in RESORCE. In the companion paper by Bindi et al. (2018a), a sanity check of the data is performed via the residual analysis, in order to test the capability of the flatfile in producing the new generation of Ground Motion Models for Europe and Middle East.

2. COMPILATION OF THE FLATFILE

The flatfile is arranged as a table which contains verified and reliable metadata and intensity measures of manually processed waveforms included in the Engineering Strong Motion database (ESM) (http://esm.mi.ingv.it; Luzi et al. 2016). ESM provides more than 50,000 quality-checked acceleration, velocity and displacement time-series, and acceleration and displacement response spectra in the Pan-European area, to be conveniently used in engineering seismology and earthquake engineering fields (last access March 2018). ESM started in 2010 in the framework of the EU NERA project (Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation; www.nera-eu.org) and it is the result of the collaboration of ORFEUS WG5 (acceleration and strong motion data).

Could you please check the link, since I it is not working.

All data contained in ESM database are periodically updated and subjected to a review process of the event and station metadata. Information that are not well documented or that are not provided by reliable source are systematically excluded.
The dataset for the flatfile have been selected from ESM database according to the following criteria:

- Events in the latitude range 23.5°-72.0°; 23.5° to 72.0°
- Events in the longitude range -26.0°-68.5°; -26.0° to -68.5°
- At least one magnitude estimate (moment, local or surface) higher or equal than 4.0;
- Events in the time interval 1969-2016.

The metadata and data are arranged as a table in a '.csv' file, separated by ';' and are provided separately in three files:

- **ESM_flatfile_SA.csv** contains table data with 36 spectral acceleration ordinates (5% damping) in the period range 0.01-10s;
- **ESM_flatfile_SD.csv** contains table data with 36 spectral displacements ordinates (5% damping) in the period range 0.01-10s;
- **ESM_flatfile_FAS.csv** contains table data with 103 acceleration Fourier amplitudes smoothed calculated using the Konno & Ohmachi (1998) smoothing function (b=40) in the frequency range 0.04-50Hz.

The table fields related to event/station metadata, peak and integral intensity measures and duration parameters are repeated at the beginning of each file. The ESM flatfile can be downloaded by registered users at http://esm.mi.ingv.it/flatfile-2018/flatfile.php (Figure 1).

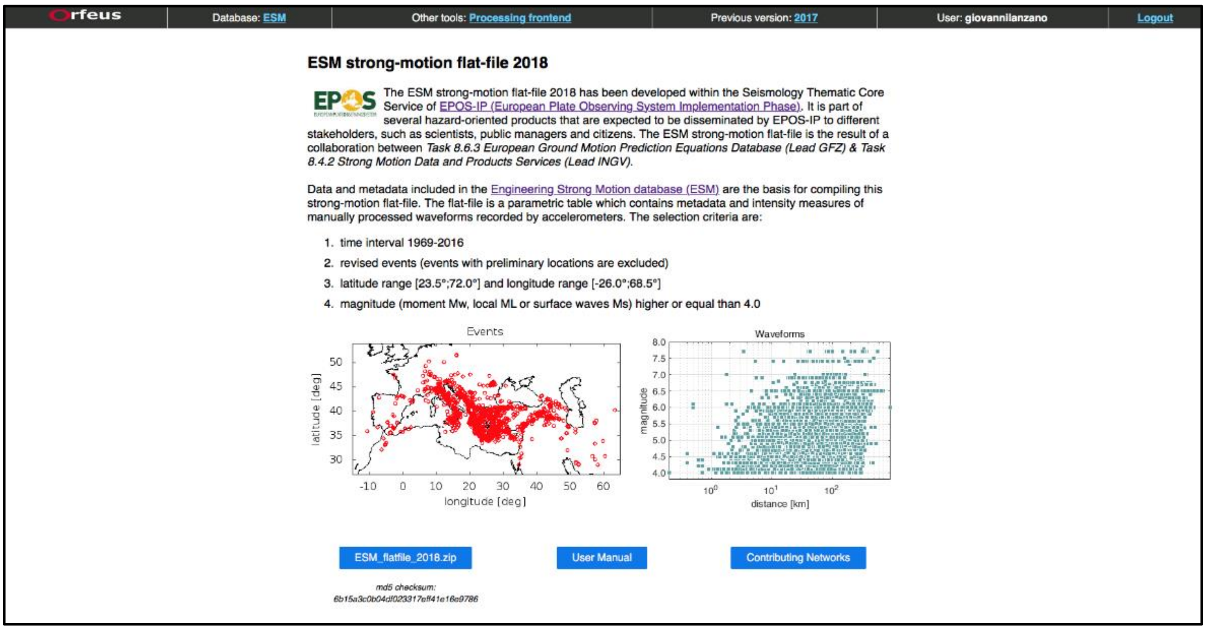


Figure 1. Webpage of ESM strong motion flatfile (http://esm.mi.ingv.it/flatfile-2018/flatfile.php)

2.1 Flatfile structure

The fields of flatfile can be grouped as 6 main blocks (Figure 2): (1) Event-related metadata; (2) Source-related metadata; (3) Station-related metadata; (4) Metrics of source-to-site distances; (5) Waveform-related metadata; (6) Intensity Measures (IMs).

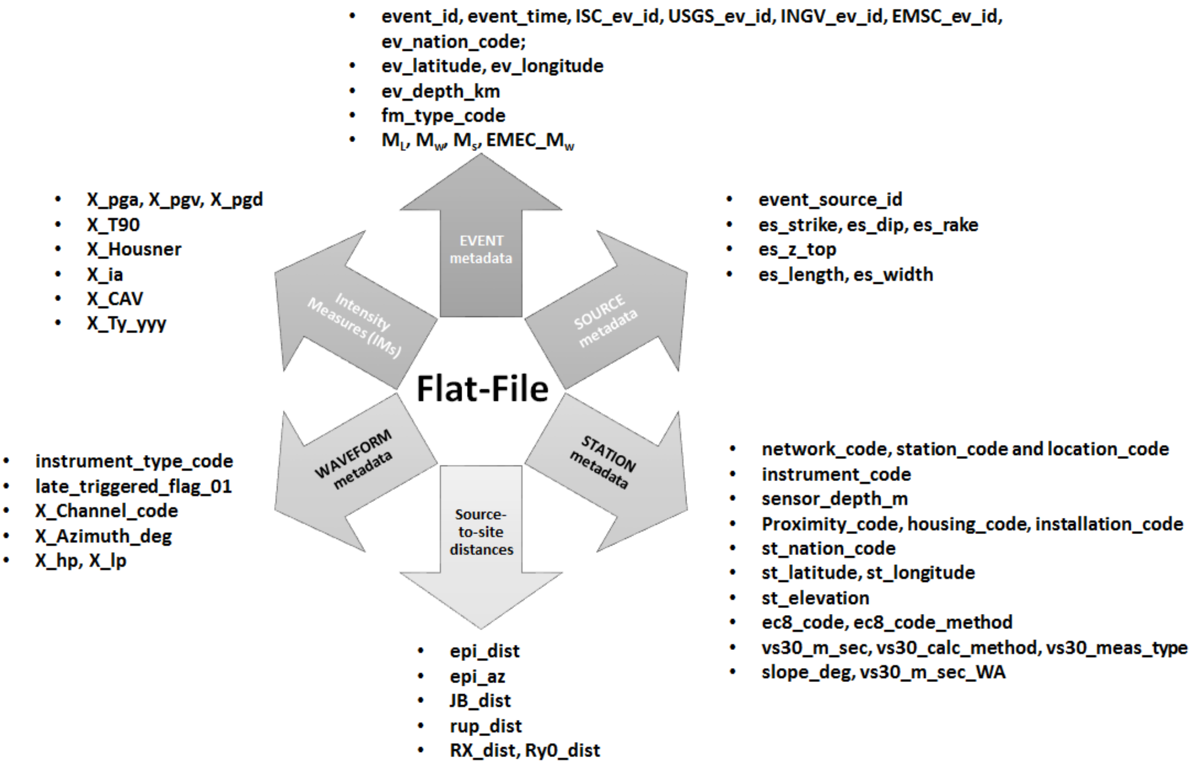


Figure 2. Schematic structure of the ESM flatfile contents. The meaning of each table field can be found in the flatfile "User Manual" (http://esm.mi.ingv.it/flatfile-2018/flatfile.php).

Event-related metadata: Several fields in the table are devoted to event parameters as: i) identification codes (according to different seismological agencies), including the event time; ii) event location (geographical coordinates and depth); iii) magnitude estimates (moment - Mw, local - M_L and surface M_S); iv) style of faulting. The attribution of events locations and magnitudes in ESM database is defined according to the following hierarchy: earthquake-specific literature studies as a primary reference; regional catalogs (e.g., the Istituto Nazionale di Geofisica e Vulcanologia Bulletin for Italy) as a secondary reference; finally, the Bulletin of the International Seismological Centre (ISC) is considered in case regional catalogs are unavailable (after 1 year). The events characterized by a preliminary location are not included in the flatfile. The focal mechanisms are obtained from the rake of the moment tensor solutions (Aki and Richards, 2009). Moment magnitudes of the EMEC catalog (Euro-Mediterranean Earthquake Catalogue), compiled by Grünthal and Wahlström (2012) are also included in the table. The EMEC magnitude analysis followed the lines of the Grünthal et al. (2009a, 2009b) studies, where existing magnitudes and intensities were converted to Mw, using regional relations or on those derived by Grünthal et al. (2009a) and by Grünthal and Wahlström (2012). Totally, the EMEC moment magnitude is available for 61% of the records. All the event metadata, like the magnitude or the event location, are fully referenced, introducing a specific field in the table for each estimate to allow the traceability of the information source.

Source-related metadata: Information on the geometries of the seismic sources in ESM are taken from specific source-model studies or, alternatively, from regional or international catalogs (e.g. Database of Individual Seismogenic Source – DISS, http://diss.rm.ingv.it/diss/). For the events with moment magnitude larger than 5.5, a fault geometry (represented by a rectangular planar surface) is provided. When the fault geometry is not available from literature studies or catalogs, a *virtual* fault geometry is generated (Pacor et al. 2018), using empirical relation (Kalakamos et al., 2011) among moment magnitude, strike and dip of the source. In the table field "event_source_id", the virtual faults are identified by initial "v" and they are relative to about 19% of the events with an associated source. The classification of the events according to the tectonic regimes (i.e., interface, inslab, shallow crustal, stable continental, volcanic) are not included in the flatfile. However, they can be deduced by combining information of the style of faulting and the hypocentral location of each event (Garcia et al. 2012; Zhao at al. 2015). Similarly, to event metadata, all the estimates of the source geometry parameters are traceable, since the references were included in the table.

Are the instruments and their response information provided?

Station-related metadata: There are several fields associated to the recording stations; some of them are related to the station identification (network code, station code, location code, nation code) and to the features of the recording instruments, such as the sensor depth and housing type. The site response is characterized in the flatfile by the average shear wave velocity in the uppermost 30 meters ($V_{S,30}$), according to the Eurocode 8 (EC8, CEN 2004) classification scheme. $V_{S,30}$ values are derived from *in-situ* geophysical measurements, obtained from regional databases (e.g. the ITalian ACcelerometric Archive, http://itaca.mi.ingv.it, or TR-NSMN, http://kyhdata.deprem.gov.tr, for the National strong motion Network of Turkey) or from specific literature studies. When a measured $V_{S,30}$ is available, the source of this information was reported in the specific reference field.
On the basis of $V_{S,30}$ measurements, the site category is assigned according to EC8 classification; when the measurement is not available, it is inferred by surface geology and is marked by an asterisk (e.g. A*). To date, the surface geology information is available for Italian strong motion stations, according to Di Capua et al. (2011) classification. In addition, an estimation of $V_{S,30}$ is provided using the empirical correlation with the topographic slope by Wald and Allen (2007) for 99% of the records. Specifically, the slope used in the flatfile was computed from the Digital Elevation Model (DEM) provided by Shuttle Radar Topography Mission (SRTM90). (SRTM 90m)

Source-to-site distances: The flatfile includes the epicentral distance (R_{EPI}) for all the records. When the fault geometry is available, it also provides the most used site-to-source distance metrics for GMPEs calibration, such as the closest distance to the surface projection of the fault rupture plane, named Joyner-Boore distance (R_{JB}), and the closest distance to the fault rupture plane (R_{RUP}). The hanging/footwall distances (R_X and R_{Y0}), introduced in the NGA-West project (Ancheta et al. 2014), are also provided (Kaklamanos et al. 2011): R_X is the horizontal distance measured perpendicular to the fault strike, from the top edge of rupture plane; R_{Y0} is the horizontal distance off the surface projection of rupture plane, measured parallel to the fault strike.

Waveform metadata: The waveforms in the flatfile are uniformly processed by using the processing service of the Engineering Strong Motion Database (ESM, http://esm.mi.ingv.it/processing/, Puglia et al., 2018), following the procedure described in Paolucci et al. (2011) and detailed in Pacor et al. (2011a), which prescribe the application of a second-order acausal time-domain Butterworth filter to the zero-padded acceleration time series and zero-pad removal to make acceleration and displacement consistent after double integration. Waveforms were manually revised so the bad-quality records, i.e. noisy records or time-histories containing spikes, can be identified and excluded. The band-pass corner frequencies associated to each record component are reported in the table.

Intensity Measures (IMs): The flatfile table contains the peak ground motion measures (PGA, PGV, and PGD), the most common integral parameters (Housner intensity, Cumulative Absolute Velocity, Arias Intensity) and the significant duration T90 (Trifunac and Brady, 1975). The 5% damping elastic response spectral ordinates in acceleration (SA) and displacement (SD) are also provided at 36 periods ranging from 0.01 to 10s. Fourier spectral amplitudes in acceleration are provided in the frequency-range 0.04-50 Hz, using a Konno and Ohmachi (1998) function with the coefficient of bandwidth smoothing b=40. IMs are provided for each record component (2 horizontal and 1 vertical) and in terms of orientation independent values, RotDnn (Boore, 2010). In detail, the flatfile collects the RotD50 (the median), the RotD100 (the maximum) and the RotD00 (the minimum) of IM distribution.

Would it be possible to provide the actual FAS data before smoothing?

3. DATA AND METADATA

Figure 3 shows the number of recordings and events in the flatfile as a function of time for different distance ranges (i.e. distances less than 50 and 10km).

what distance metric?

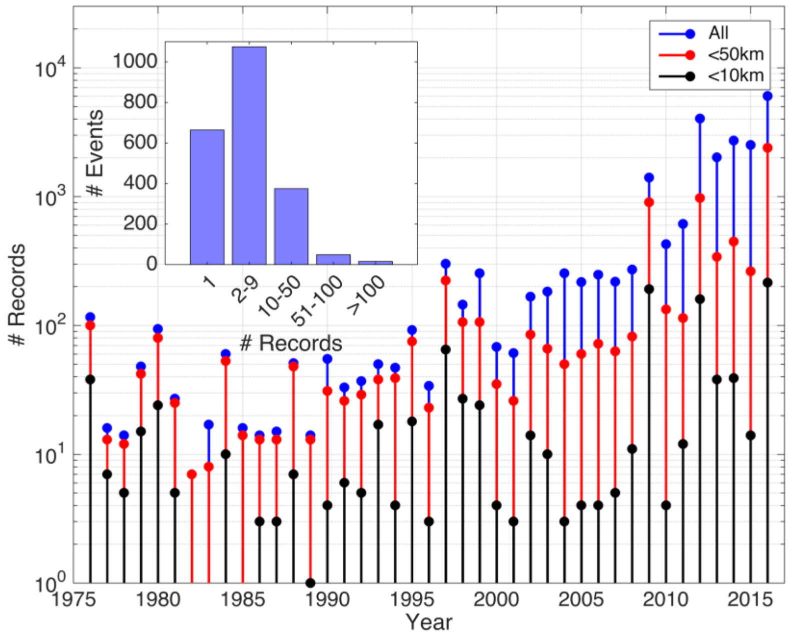


Figure 3. Number of recordings in the time interval 1975-2016 for different distance ranges. In the box, histogram of the number of records per event.

The amount of data is nearly constant until 1996 and then it significantly increases as a consequence of the rapid growth of the number of strong motion stations. Peaks of records number are observed when important seismic sequences occurred, as in 1997 (Umbria-Marche, Central Italy), 1999 (Izmit, Turkey), 2009 (L'Aquila, Italy), 2012 (Po Plain, Italy) and 2016 (Central Italy). The number of records in the proximity of the source also increases, thanks to the installation of temporary stations during the seismic sequences.

According to the box in Figure 3, most of the events have a number of records between 2 and 9 (about 50%); about 500 events are sampled by more than 10 records. However, a large number of recordings for each earthquake has become available for the most recent events, e.g. the M_w 6.5 2016 Norcia earthquake has more than 160 records within 200km.

As before stated, the flatfile also contains the filtering corner frequencies for each component of the recordings. Figure 4 shows the scatter plot of the high-pass and low-pass corner frequencies as a function of magnitude: the median value of low-pass frequency is about 30Hz and is found to be magnitude independent; the high-pass frequencies are instead dependent on magnitude, showing average values of 0.15Hz for M<4 and about 0.05Hz at M>6, respectively.

In the text it is mentioned that PSA values are calculated down to 0.01 s (up to 100 Hz).

The histogram plots do not add any further information. I think instead you could add horizontal lines to show the mmean values of corner frequencies to the plot on the left.

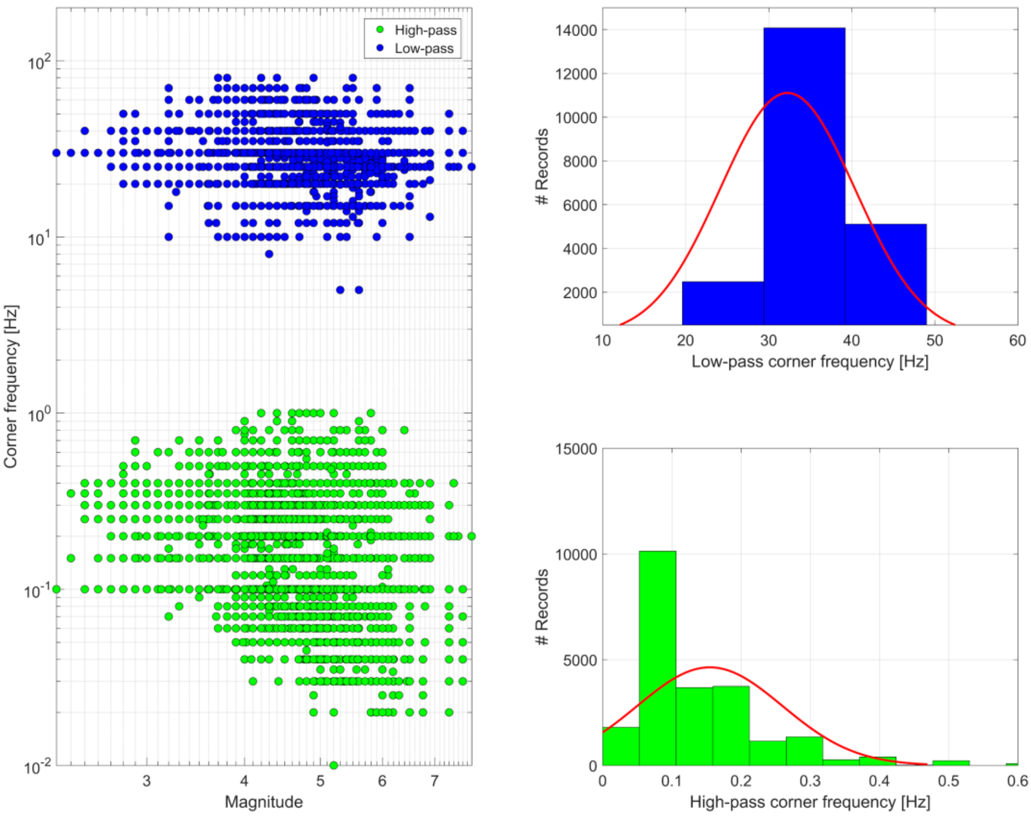


Figure 4. High-pass and low-pass corner frequencies as a function of magnitude (a, *left*) and their distributions for flatfile records (a, *right*).

The number of recordings within the usable frequency bandwidth of FAS table is plotted in Figure 5. In the interval 0.4 -15 Hz, the number of records corresponds to the total amount of FAS data.

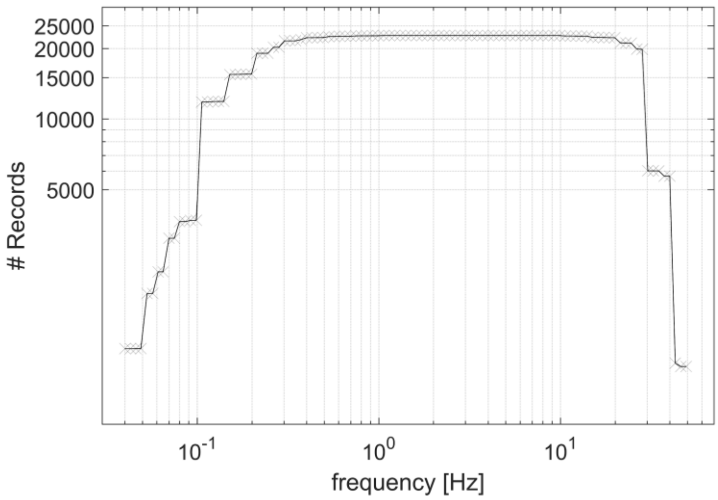


Figure 5. Number of FAS records versus frequency.

The number of records relative to the lowest frequencies (<lower than 0.5Hz) dramatically decreases to about 1000 samples, corresponding to about 4% of the entire dataset. Similarly, we observe a significant reduction of the number of records at frequencies larger than 30Hz. However, the latter behavior is not critical for the usability of the acceleration response spectral (SA) values. Following NGA-West2, SA can be considered valid up to frequency of 100 Hz, even if the low-pass filter applied had a much lower corner frequency (Ancheta et al. 2014). Douglas and Boore (2011) showed that this apparent contradiction can be explained by the fact that SA are often controlled by ground

accelerations associated with much lower frequencies than the natural frequency of the oscillator.

3.1 Data statistics

The magnitude-distance distribution is given in Figure 6, grouped by style of faulting (SoF). The moment magnitude is available for 68% of the data. Local magnitude M_L is used when M_w is not provided; in the few cases of missing both M_w and M_l, the surface magnitude M_s is considered. In the following, we will refer to a generic "Magnitude" or "M" which corresponds to the mixed magnitude obtained according to the above described procedure. In Figure 6 the distance is the Joyner-Boore distance (R_{JB}), if available, otherwise the epicentral distance (R_{EPI}).

You have already introduced these metrics, so just use the acronyms.

Since we selected events with at least an estimation of magnitude higher than 4.0, regardless the type (moment, local or surface), the flatfile includes also data related to moment magnitudes smaller than this threshold. The distance metric related to fault geometry (R_{JB}) is relevant only for events with M>5.5 and are available for 2,145 records, corresponding to about 9% of the total recordings.
Data are well sampled in the magnitude range 3.5÷6.5 and for epicentral distance up to 300 km. There is also a significant number of records related to strong events with magnitude comprises between 6.0 and 7.8, corresponding to 6% of the records. Indeed, it includes some major events with magnitude larger than 7.0, such as Mw 7.4 1990 Rudbar earthquake in Iran (9 records), and the two 1999 earthquakes in Turkey of Mw 7.6 Izmit (19 records) and Mw 7.3 Duzce (21 records). We also report in Figure 6 the marginal distribution of SoF, showing that the most of the events with M≤3.5 are not associated to a defined focal mechanism (undefined mechanism, U).

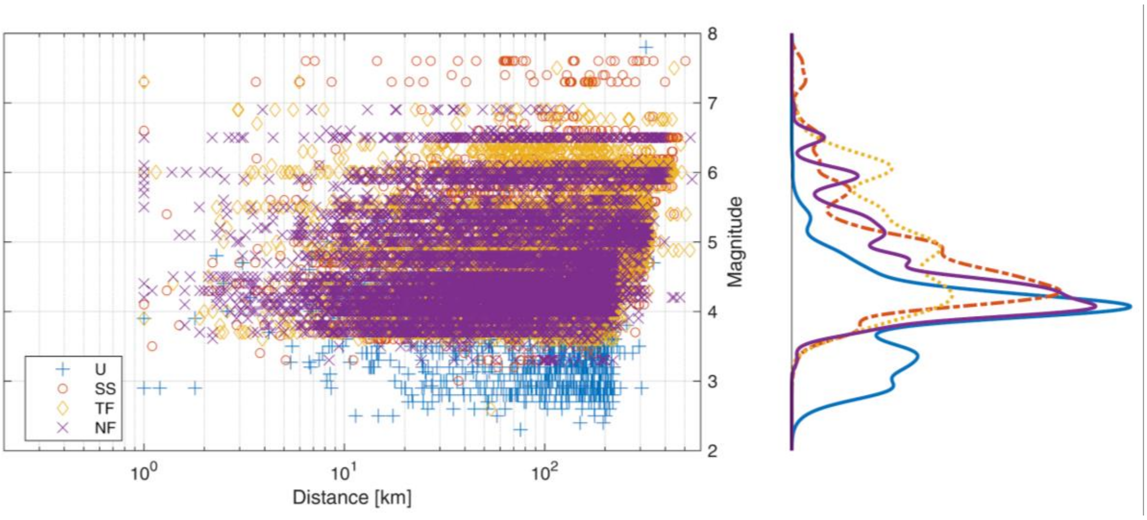


Figure 6. Magnitude vs distance (R_{JB} if available otherwise R_{EPI}) scatter plot of recordings in the flatfile grouped by style of faulting with related marginal distributions. U: undefined; SS: strike-slip; TF: thrust; NF: normal. The records at zero distance (R_{JB}=0) are plotted at 1km.

Figure 7 shows the histograms of magnitude (a), epicentral distance (b), focal depth (c) and SoF (d). The majority of the data are in the magnitude range 3.5-4.5 (about 70%), highlighting the dominance of small-size events (Figure 7a). A not negligible amount of data (7%) is also available at magnitudes around 6.0, due to the contribution of Italian events. Most of the data are relative to distances larger than 150km (about 30%); 4% and 37% of records correspond to distances shorter than 10km and 60km, respectively (Figure 7b). The distribution of recordings in terms of depth intervals (Figure 7c) shows that the most of the data have focal depth lower than 30 km, corresponding to about 88% of the total records in the flatfile, thus indicating a predominance of shallow crustal events in the dataset. Indeed, about 2,700 records (12%) corresponds to deeper events.
Looking at the focal mechanisms distribution in Figure 7d, the records associated to Normal Faulting (NF) events are predominant (43%) with respect to Thrust (TF, 23%) and Strike-Slip (SS, 16%). Totally, the focal mechanisms have been provided for the about 82% of the total number of records.

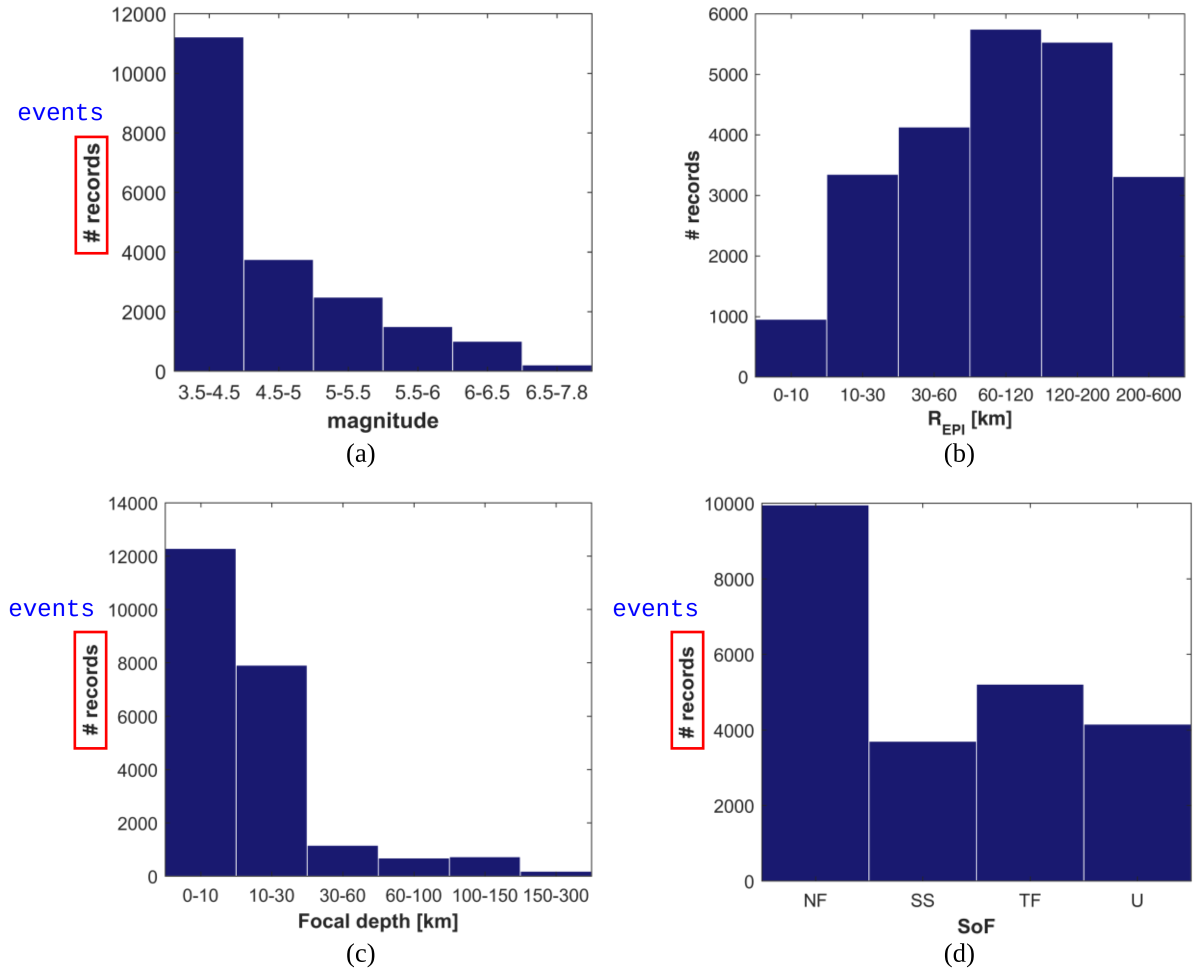


Figure 7. Histogram of (a) magnitude, (b) epicentral distance, (c) focal depth and (d) style of faulting (SoF).

Figure 8 shows the histogram of data with reference to the site categories of EC8. Direct shear wave velocity measurements (V_S profile) from geophysical prospections are available for 474 stations, corresponding to 24% of the recording sites (blue bars in Figure 8). In the other cases, the site category was inferred from surface geology information (52%) or it was estimated on the basis of the $V_{S,30}$ calculated from slope. More than 1,000 recording stations are classified as class EC8-B (about 52%), about 400 in class EC8-A (26%) and 550 in class EC8-C (21%). Few stations (about 2%) are classified as EC8-D and EC8-E.

topographic slope

Suggestion: You can add VS,30 ranges for each site class for those who are not familiar with EC8 site classes.

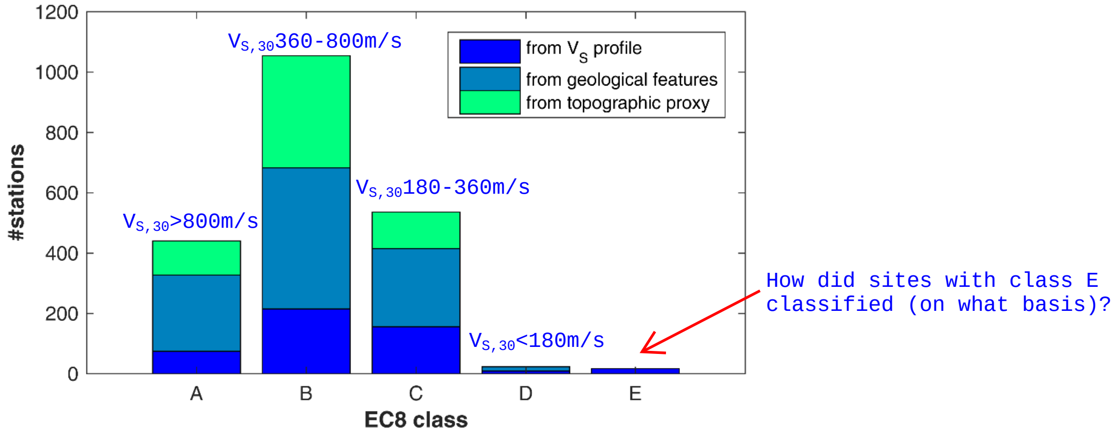
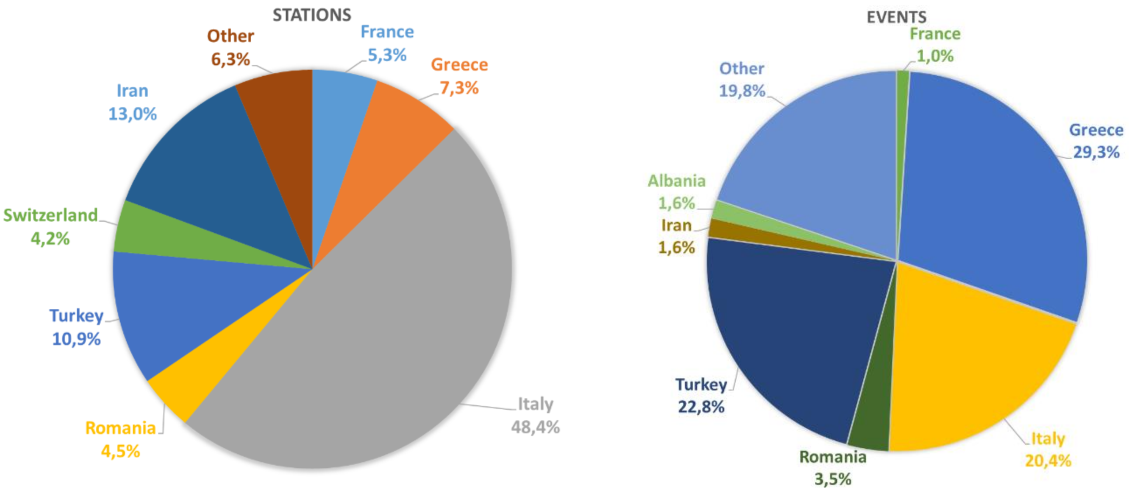


Figure 8. Distribution of strong motion stations as a function of EC8 site classes.

3.2 Spatial distribution of events and stations

ESM flatfile includes recordings of earthquakes occurred in Europe and Middle East in 38 different countries: Figure 9 shows the percentages of stations (a) and events (b) for the major contributing countries.



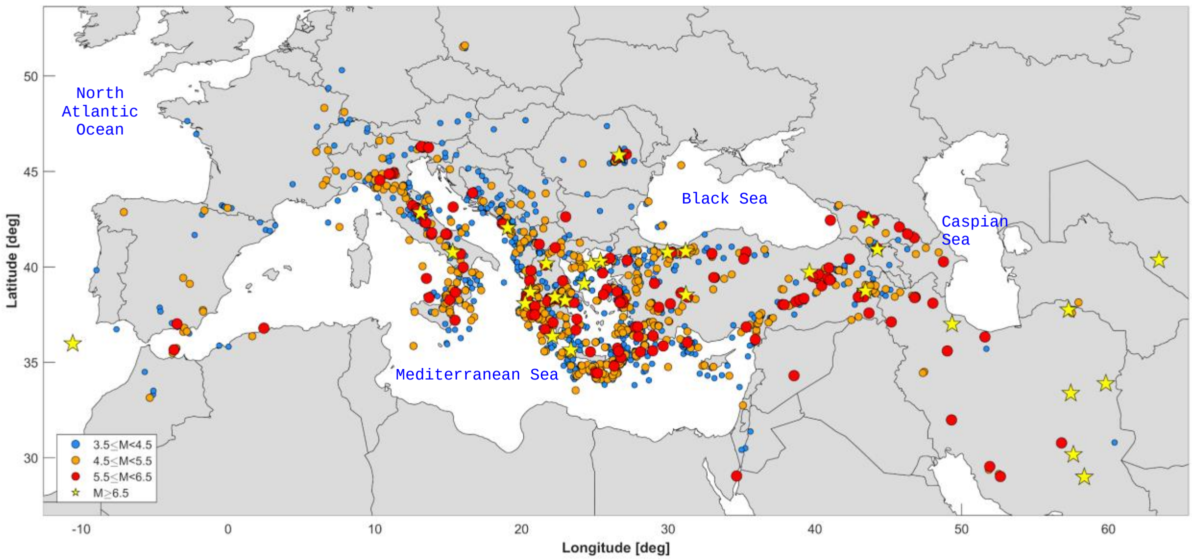
(a) (b)

Figure 9. Pie-chart of the distribution of (a) stations and (b) events within the flatfile table

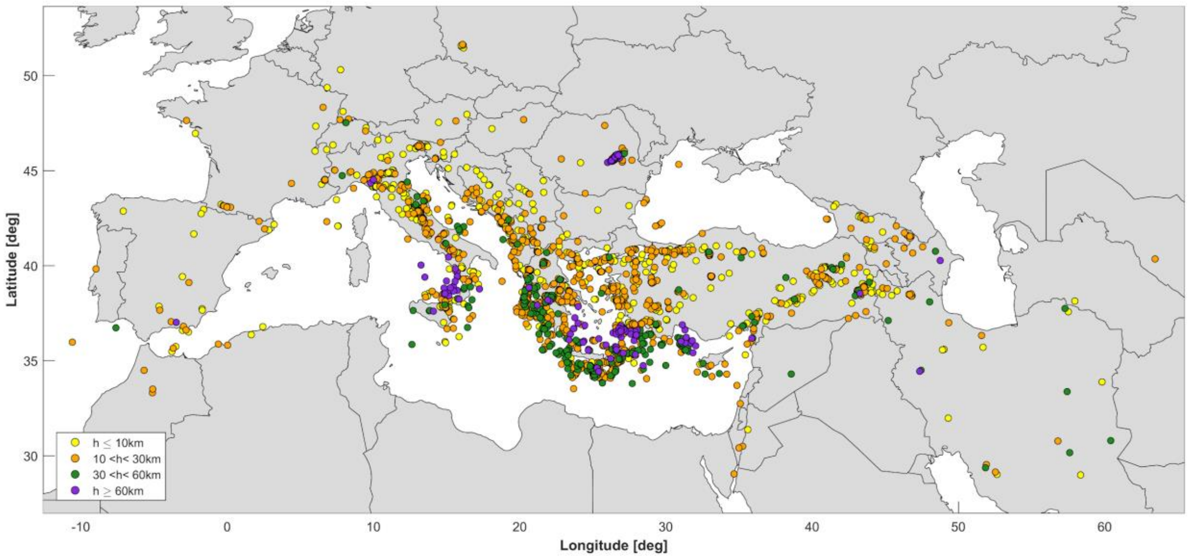
from!

Italian strong motion recording sites, mainly relative to RAN (Italian Strong Motion Network, managed by Italian Civil Protection Department) and RSN (Italian Seismic Network, managed by *Istituto Nazionale di Geofisica e Vulcanologia*), are about half of the total number of stations (Figure 9a). Turkish stations were made available offline up to 2007 by AFAD (Prime Ministry Disaster & Emergency Management Presidency Earthquake Department) which manages the TR-NSMN (National strong motion Network of Turkey); KOERI (Kandilli Observatory and Earthquake Research Institute, Bosphorus University) strong motion stations are instead available on EIDA. Iranian stations belong to the Iranian Strong Motion Network managed by BHRC (Road, Housing & Urban Development Research Center). The amount of strong motion stations of the remaining countries ranges from about 1% to 7%; the complete list of the contributing network is available at ESM flatfile website. Earthquakes occurred in Italy, Turkey and Greece contribute to about 70% of the total events (Figure 9b).
The maps of the earthquakes are shown in Figures 10, with respect to magnitude (a) and depth (b).

I would recommend adding at least name of major water bodies in the map (e.g. mediterranean sea)



(a)



(b)

Figure 10. Maps of earthquakes in ESM dataset color coded according to (a) magnitude and (b) depth intervals.

Figure 10a shows that moderate-to-high seismicity countries, as Italy, Greece, Turkey and Romania, are characterized by a significant number of events with magnitude larger than 5.5 (red circles and yellow stars). Moreover, as expected, low-to-moderate seismicity countries, as France, Switzerland and Germany, contribute with smaller magnitudes events (mostly M<5.5).
Shallower events (h < 30km) are almost uniformly distributed in the most European seismic countries, including the Balkans. Deepest events (h > 60 km) mainly occurred in the subduction Hellenic (Southern Greece and Crete Island) and Tyrrhenian Arcs (Southern Italy), Southern Turkey and in the Vrancea region (Eastern Romania).
Figure 11 shows the magnitude versus epicentral distance scatter plot for the most contributing countries. Table 1 reports the main subset characteristics of each abovementioned country, in terms of number of records (*# recs*), stations (*# stats*) and events (*# evs*), especially in the intervals which are significant for hazard assessment (e.g. M>5.0 and distance < 50km).

Table 1. Characteristics of the ESM flatfile subsets for the main contributing countries.

Countries	***# recs***	***# evs***	***# stats***	***# stats with $V_{S,30}$***	***mean # recs/evs***	***# recs M > 5.0***	***# recs dist ≤ 50km***	***# recs h ≤ 30km***
Italy	13591	443	1000	202	31	3591	5611	12947
Turkey	1622	496	225	114	3	472	372	1563
Greece	3766	637	151	37	6	904	668	3146
Romania	1201	76	93	0	16	224	219	161
Iran	336	34	269	24	10	324	69	290
Others	2498	493	342	94	5	366	310	2082

The distribution is almost uniform in the magnitude range 3.5-6.5 and for distances larger than 5km for Italy, Greece and Turkey. Romania is mainly characterized by lower magnitudes earthquakes (M<5.0), while Iranian contribution is dominated by stronger seismic events (M>6.0). The majority of the records and stations refers to Italy, while most of the earthquakes occurred in Greece (about 30%), despite the limited number of stations, compared to Italy. The Italian events are on average sampled by more than 30 recordings, due to the increasing development of the national networks and the installation of temporary stations during the main seismic sequences. Several stations are accompanied by a shear wave velocity profile, especially in Italy and Turkey; the latter has about 50% of the recording sites characterized by an in-situ measurement. A significant number of recordings at distance lower than 50km is available in Italy (about 40%); in the other contributing countries, the percentage is instead around 20%.

It is very unusual to show Magnitude values on a logarithmic scale. I would suggest using a linear scale for magnitude.

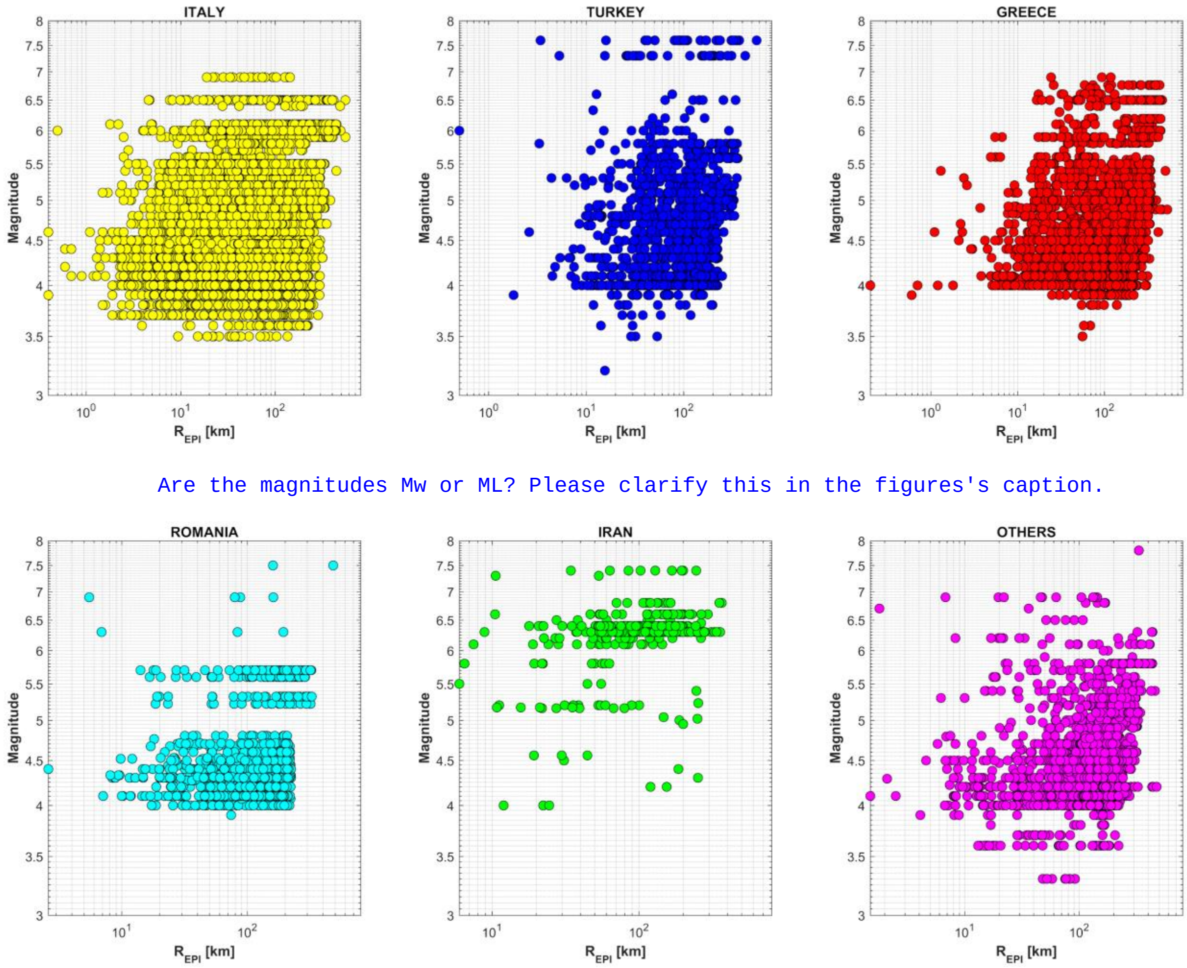
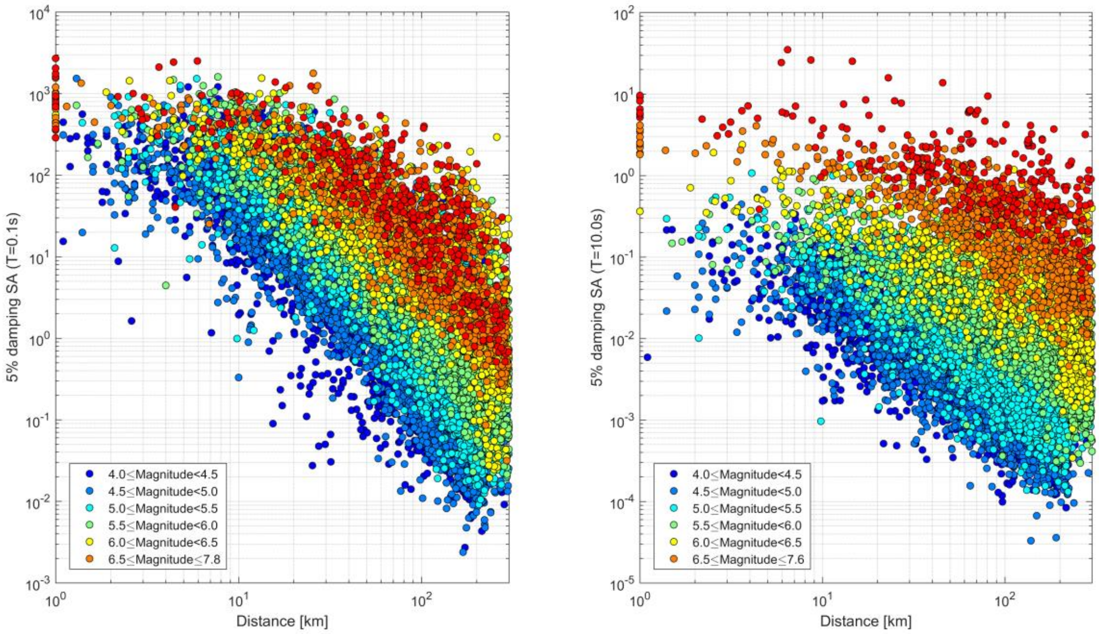


Figure 11. Distribution of magnitude versus epicentral distance (R_{EPI}) for the main contributing countries.

3.3 Distribution of intensity measures

Figure 12 reports the distribution of SA at periods 0.1s and 10s, as a function of Joyner-Boore distance for several classes of magnitudes. For those events with M<5.5 lacking of fault model, the epicentral distance is used.



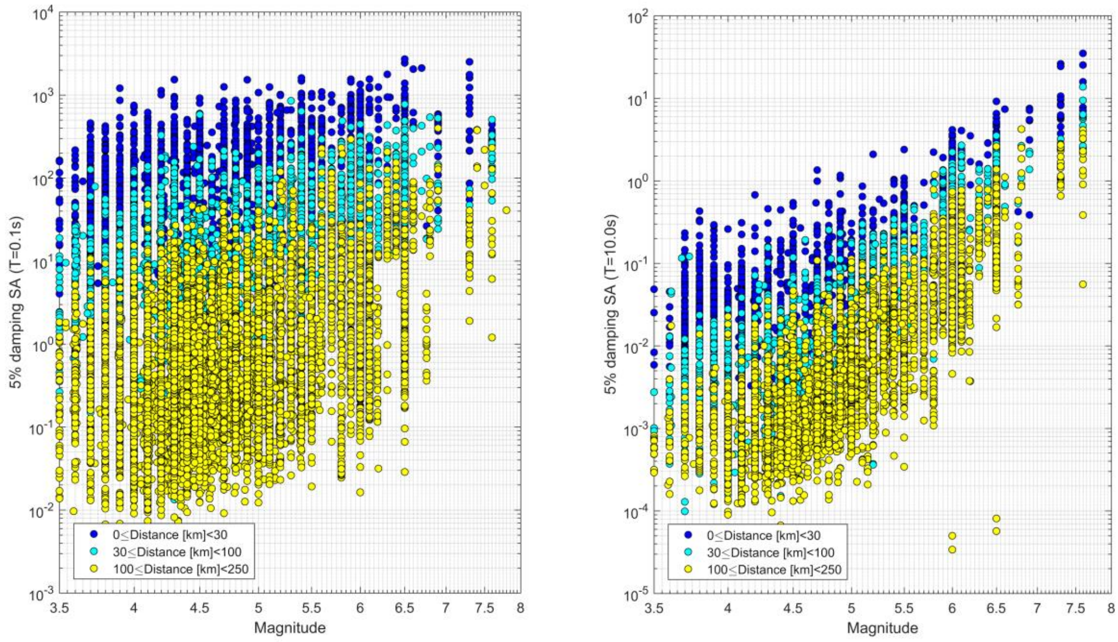
(a) (b)

Figure 12. Distribution of spectral acceleration (SA) ordinates at periods 0.1s (a) and 10s (b) as a function of distance (i.e. R_{JB} if available otherwise R_{EPI}); Data are colored according to different ranges of magnitudes (i.e. M_w if available, otherwise M_L).

Please provide appropriate references for these phenomenon.

The flatfile data are able to reproduce the ground motion attenuation with distance, including the saturation in the proximity of the fault, and the scaling with magnitude. At high frequencies (T=0.1s in Figure 12a), the distance scaling is found to be magnitude-dependent and the anelastic attenuation is also noticeable. At low frequencies (T=10s in Figure 12b) the number of data within the usable frequency bandwidth is about the half of the total recordings; the observations show lower attenuation with distance, compared to T=0.1s, and larger scatter, particularly at higher magnitudes.

Figure 13 reports the distribution of same SA ordinates of Figure 12 as a function of magnitude for different classes of distances. The data at higher frequency are sparser, that reflected in higher variability of the existing ground motion models, with a peak at 0.1s (Lanzano et al. 2016); moreover, the spectral ordinates at 0.1s are slightly correlated with magnitude, especially for shorter distances, where a saturation effect is noticeable after 5.5. A stronger magnitude dependence is found for spectral ordinates at longer periods, where a saturation of the SA ordinates is observed at M larger than 6.5. In both cases, the data exhibit a large scatter at the smaller magnitudes, mainly due to large variability of the stress-drop associated to small earthquakes (Oth et al. 2017; Bindi et al., 2018b) or to a reduced accuracy of their metadata (Lanzano et al. 2017).



a) b)

Figure 13. Distribution of ground-motion parameters as a function of magnitude (i.e. M_w if available, otherwise M_L): spectral acceleration (SA) ordinates at periods 0.1s (a) and 10s (b). Data are colored according to different ranges of distances (R_{JB}-R_{epi}).

3.4 Comparison with RESORCE

The number of common records between the ESM and RESORCE flatfiles is about 2,000, relative to 715 events. About 3,000 records contained in RESORCE were not included in ESM, since we removed records i) with duration shorter than 8s, ii) missing one of the three components and iii) from stations without coordinates. In general, ESM reviewed the Mw values of 173 RESORCE events, while 46 events still not have an estimate of M_w in both databases. Only 17 events have M_w in RESORCE but not in ESM.

In Figure 14, we compare the metadata associated to ESM and RESORCE records in terms of epicentral distance (a), magnitude (b), focal depth (c) and fault geometry (d). Figure 14a shows a good agreement in terms of epicentral distance between the two datasets, because about 95% of the records show differences less than 10 km, except for few records mainly due to change in earthquake location. Figure 14b shows the comparison between RESORCE and ESM in terms of magnitude M, as previously defined in §3.1, and EMEC moment magnitude. Main differences are observed at smaller magnitudes (M<5.5), where the M estimates of ESM are generally lower than RESORCE. The EMEC data, which are not available for all the events in common with RESORCE, are unbiased and less scattered, because the moment magnitudes were manually reviewed. Six events have differences between 1 and 1.5 units, due to a more accurate estimates of moment magnitude.

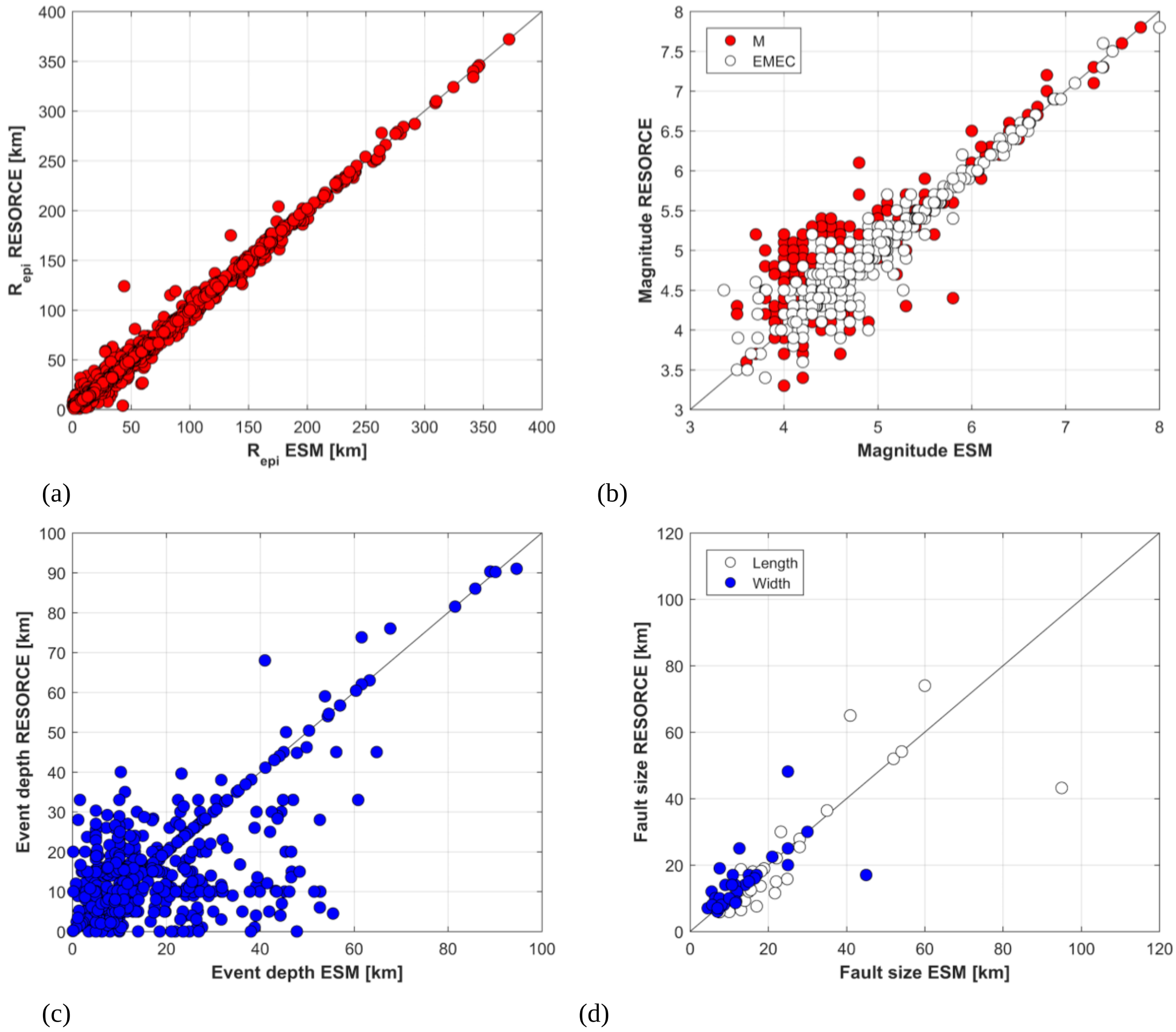


Figure 14. Comparison between ESM and RESORCE metadata: a) epicentral distance; b) magnitude; c) focal depth; d) fault geometry. ESM magnitude M is M_w, if available, otherwise M_L or M_S, when M_w and M_L are missing.

Relevant differences are observed for focal depth in Figure 14c, especially for the shallow crustal earthquakes. In general, the earthquake depth is a location parameter often poorly constrained, and thus significant differences can be observed among different authoritative sources. The main source for the focal depth in ESM is the ISC bulletin (http://www.isc.ac.uk), which collects the data from over 130 agencies worldwide and provides them online soon after being received. The policy for ESM flatfile compilation is to use only the ISC reviewed data, available after 24 months. As consequence, the table does not contain unrealistic zero depth events, as reported in RESORCE database. About 22% of the events show differences larger than 10 km. In particular, several Greek events from ISESD database (mainly occurred before 1999), with a focal depth lower than 10km in RESORCE, have values larger than 30km in ESM. After the review of event metadata in ESM, events with shallow active crustal tectonic regime were re-classified as subduction in areas where deep seismicity can be expected.

The comparison for fault geometry (Figure 14d) is evaluated both for the length and the width of the rupture plane of 62 events with with M > 5.5. In few cases, we observe significant differences (larger than 20km), related to the strongest events in the dataset such as the M_w 7.3 1978 Tabas (Iran), the M_w 7.3 2011 Van (Turkey) and the M_w 7.6 1999 Izmit (Turkey) earthquakes, due to a careful revision after publication of more recent literature studies.

time-averaged shaer wave velocity in the top 30m

Figure 15 shows the comparison of the station metadata in terms of measured average shear-wave velocity (V_{S30}) in ESM and RESORCE. Several V_{S30} estimates in RESORCE were not included in ESM, since the measurements without traceable reference have been disregarded (Felicetta et al.

On page 6, V_{S30} has been introduced. So, you can simply use the acronym throughout the text without reintroducing it. Also, please use a consistent acronym (i.e. $V_{S,30}$ or V_{S30})

Please be consistent in using the same formatting style for reporting units. Either attach the unit to a value or consider a space. You can check the guidelines for publication.

2017). Differences larger than 250 m/s are found for some Italian recording station (Figure 15), after that new and more accurate geophysical measurements have been included in ESM. This is the case of STR (Sturno) station, which recorded the mainshock of M_w 6.9 1980 Irpinia earthquake: the V_{S30} changes from 1122 m/s (site class A) to 382 m/s (site class C), after more recent in-situ investigations. V_{S30} values of BBN (Bibbiena) and BRC (Barcis) have a significant increment from about 400 m/s to 1000 m/s. The station metadata of the strong-motion stations in Italy have been improved and enriched, since several research projects was promoted after 2006, when ITACA (ITalian ACcelerometric Archive funded by Italian Department of Civil Protection) database was born (Pacor et al. 2011b).

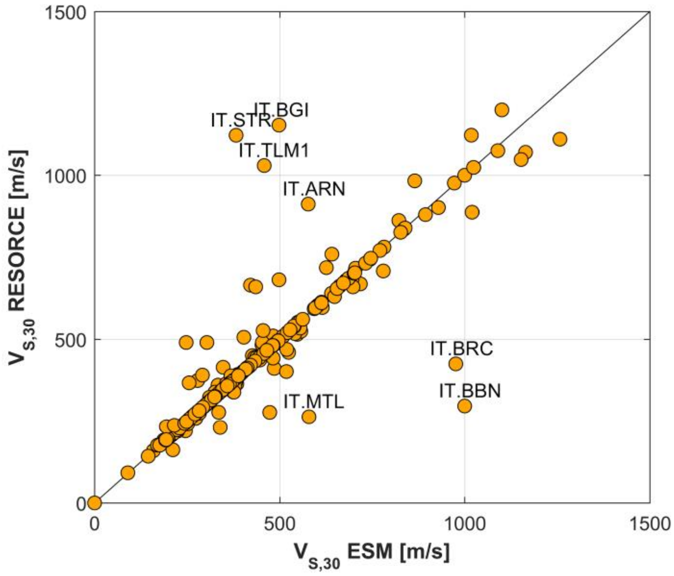


Figure 15. Differences in ESM and RESORCE measured shear wave velocity ($V_{S,30}$). The names of the stations with differences larger than 250 m/s are shown.

4. CONCLUSIONS

The paper describes the main features of the latest version (released in March 2018) of the ESM flatfile, a parametric table derived from Engineering Strong Motion Database. The flatfile revises the strong motion parameters and metadata included in previous databases (ISESD and RESORCE) and provides 10,000 additional strong-motion recordings until 2016. The metadata were extended and improved, including the manually reviewed parameters of events and stations from national and international authoritative sources (e.g. ISC, INGV) and the results of the most recent studies (e.g. in terms of site characterizations and fault geometries).

The total number of three-component recordings is about 23,000 from more than 2,000 events of different tectonics regimes, although mainly related to shallow active crustal regions. The flatfile provides peak parameters, duration, integral parameters and amplitudes of acceleration and displacement response spectra, as well as Fourier spectra ordinates.

One of the goals of the ESM flatfile is to create a standard for the dissemination of waveform metadata and parameters for engineering seismology applications in Europe, similarly to NGA-West in the United States. A significant effort in the compilation of the flatfile has been spent in the metadata revision in order to make them traceable including specific fields for the references of each metadata (i.e. event, source and station).

The data collected in the flatfile can be used for development of ground motion models and seismic engineering applications, such as selection of existing GMPEs for hazard assessment, calibration of new GMPEs for different tectonic regimes in Europe and Middle East and regionalization of the GMPEs for several European countries. In addition, the flatfile can be used for the estimation of the systematic source, site and path effects from the residual decomposition to implement the non-ergodic approach for the seismic hazard assessment. Thanks to the large amount of records in the recent 2016-2017 Central Italy seismic sequence, the flatfile allowed to study the ground-motion features in terms

Please provide a reference.

of directivity effects and in near fault conditions (Luzi et al. 2017).
We plan to periodically release the flatfile, whereas specific releases can be expected after future significant seismic sequences. The inclusion of additional metadata (i.e. event tectonic regimes, event stress drop, site fundamental frequencies) should be discussed within the engineering seismology community, depending on future research developments.

5. DATA AND RESOURCES

In the file "ec8_code_method.txt"
- The word "Rayleigh" is misspelled as "Raleigh".
- Also, two acronyms are used for the "Spectral analysis of surface waves", one is "SASW" and the other is "S".

The web interface http://esm.mi.ingv.it/flatfile-2018/index.php provides the access to the flatfile (version 2018), derived from the Engineering Strong Motion database (http://esm.mi.ingv.it/). Registered users can access to the ESM flatfile web page and save the parametric table on their personal computer. If you are already registered on ESM web processing (http://esm.mi.ingv.it/processing/), you can use the same username and password. From the main web page the user can download the flatfile in a .zip format (including the three tables and the field dictionaries), the user manual and the list of contributing networks. The dictionaries for several table fields are also provided as text file. A complete list of references is provided in the 'Reference.txt' dictionary for all the table fields.
Shell-script applications are provided to the users ('filter_gmpe_table.sh') for querying the parametric table according to several criteria (e.g. metadata selection over the event, station, and network classes) and to extract specific features of interest (e.g., intensity measures).
The ESM strong motion flatfile (version 2018) can be cited as "Lanzano G, Puglia R, Russo E, Luzi L, Bindi D, Cotton F, D'Amico M, Felicetta C, Pacor F & ORFEUS WG5 (2018). ESM strong motion flatfile 2018. Istituto Nazionale di Geofisica e Vulcanologia (INGV), Helmholtz-Zentrum Potsdam Deutsches GeoForschungsZentrum (GFZ), Observatories & Research Facilities for European Seismology (ORFEUS), PID: 11099/ESM_flatfile_2018. The Persistent IDentifier (PID) can be resolved at http://hdl.handle.net/ (if you select "Don't Redirect to URLs", the proxy will display the handle record). The ESM strong-motion flat-file 2018 is licensed under the terms of the "Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0)" License.

6. ACKNOWLEDGMENTS

In the file "ref.txt", from line 474 to the end of the document, some acronyms are used which their meanings are unclear. Please either introduce them or remove them from the file.

The European project EPOS (European Plate Observing System Implementation Phase) and its coordinator Massimo Cocco (INGV) are acknowledged by the Authors for supporting and funding the preparation of the Engineering Strong Motion (ESM) flatfile. This work is possible thanks to the European Integrated Data Archive (EIDA) and Observatories and Research Facilities for European Seismology (ORFEUS) Working Group 5 (acceleration and strong-motion data) communities for providing open data to the community. The institutions and researchers which provided local databases, original waveforms, or metadata in the ESM Database were fully acknowledged in the paper of Luzi et al. (2016). The work of Steffi Lammers (GFZ) was essential to introduce the EMEC magnitudes in the flatfile. We thank Sinan Akkar (Bogazici University, Istanbul) and M. Abdullah Sandikkaya (Hacettepe University, Ankara) for the careful review of the first release of the flatfile (version 2017). We wish to thank Donat Fäh (ETH-Zürich), Cécile Cornou (Université Grenoble Alpes) and Giovanna Cultrera (INGV) for providing us the information to update the site metadata after the first release in Swiss, France and Italy, respectively. The web interface of the ESM flatfile (2018 version) was designed and implemented by Istituto Nazionale di Geofisica e Vulcanologia (INGV), thanks to the work of our colleagues Emiliano Russo and Massimo Fares.

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Figure 1

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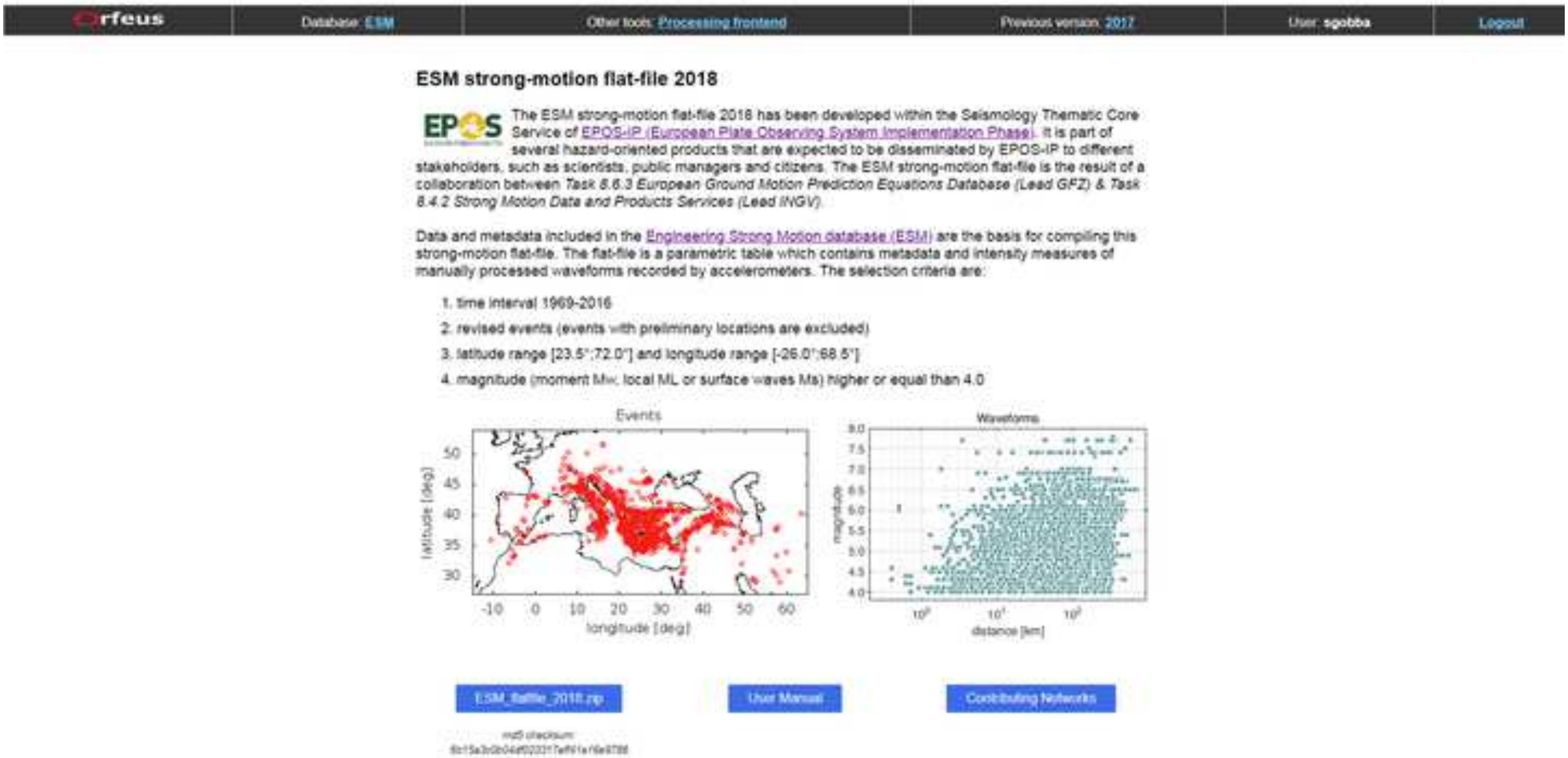

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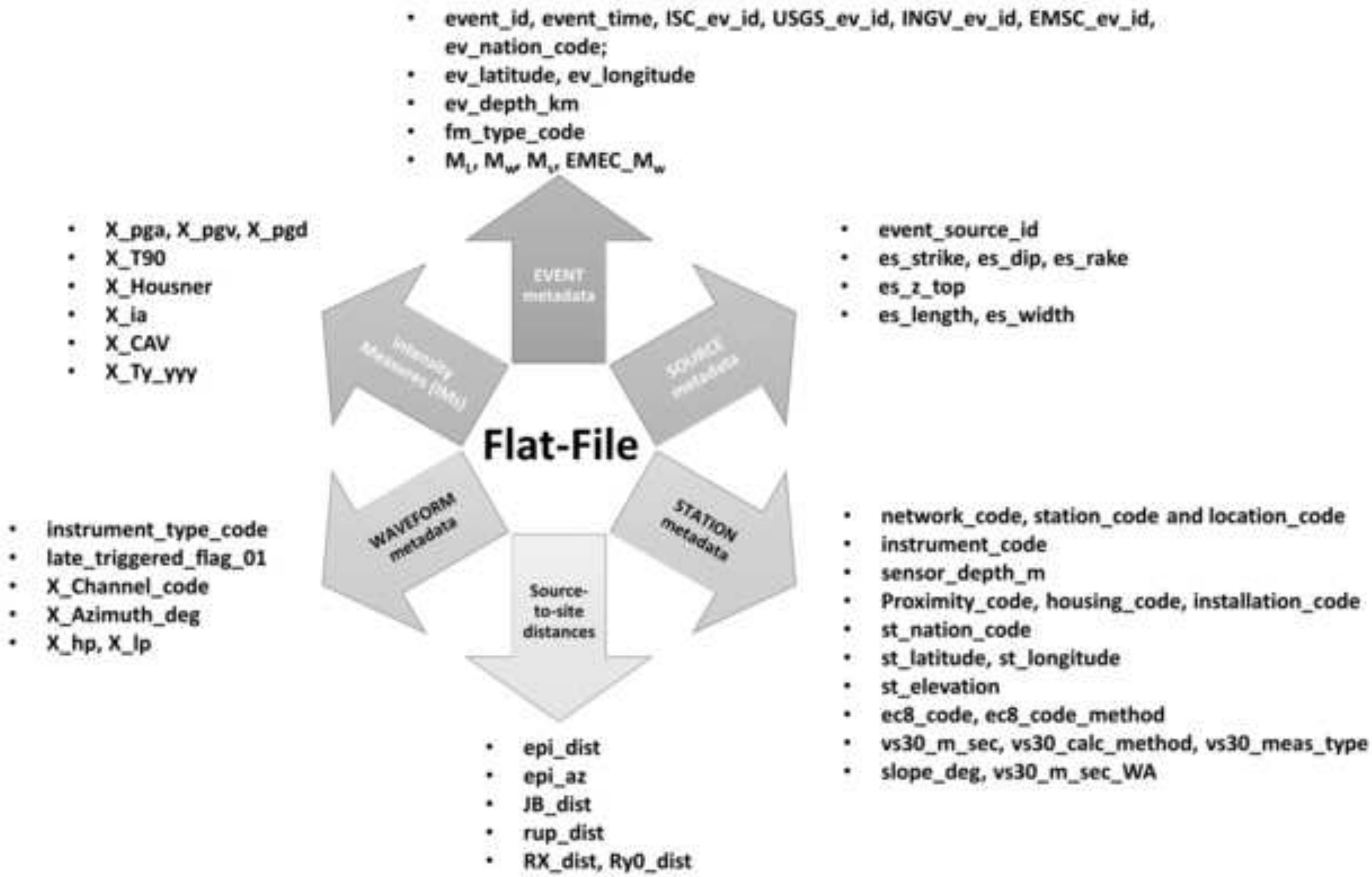

Figure 3

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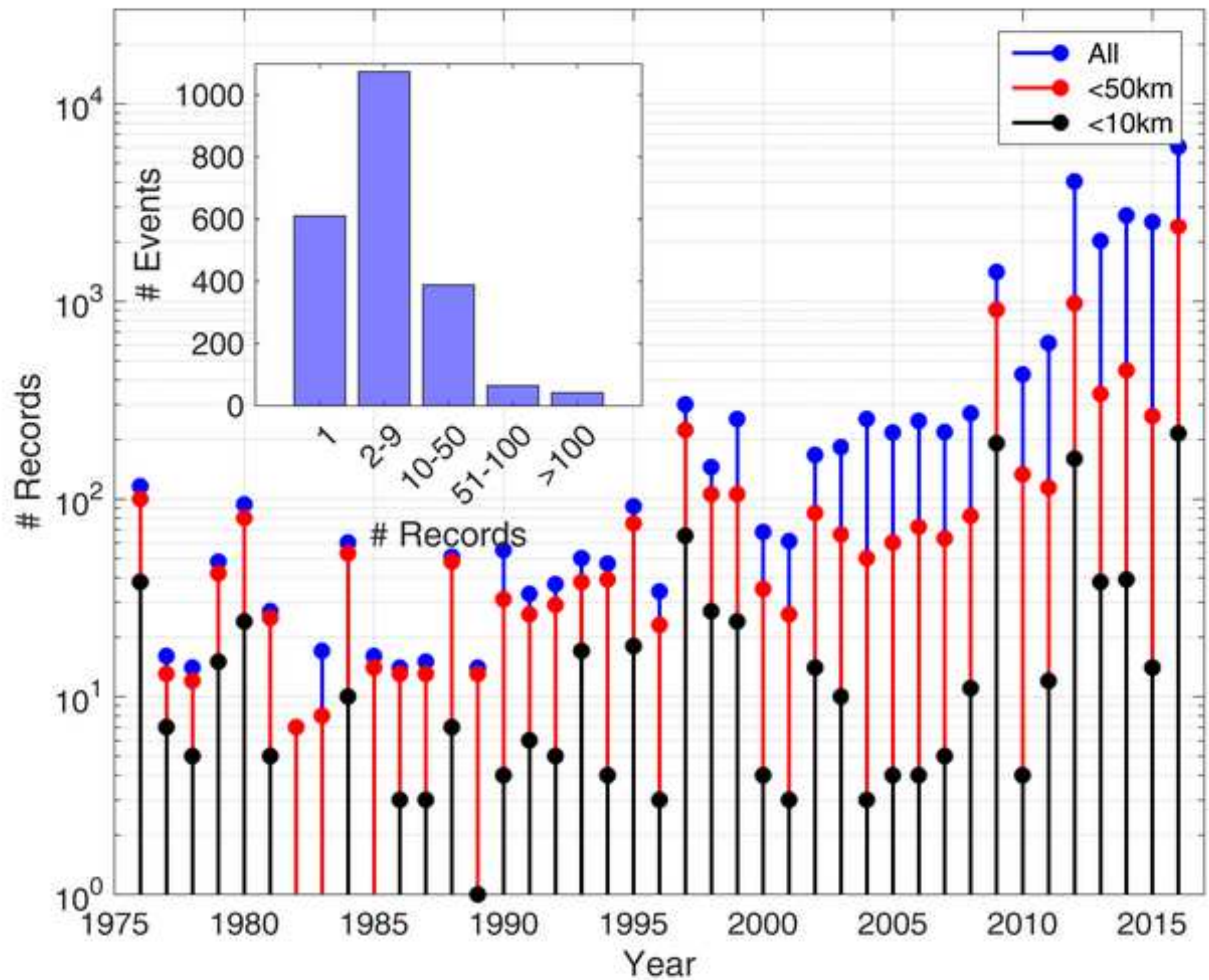

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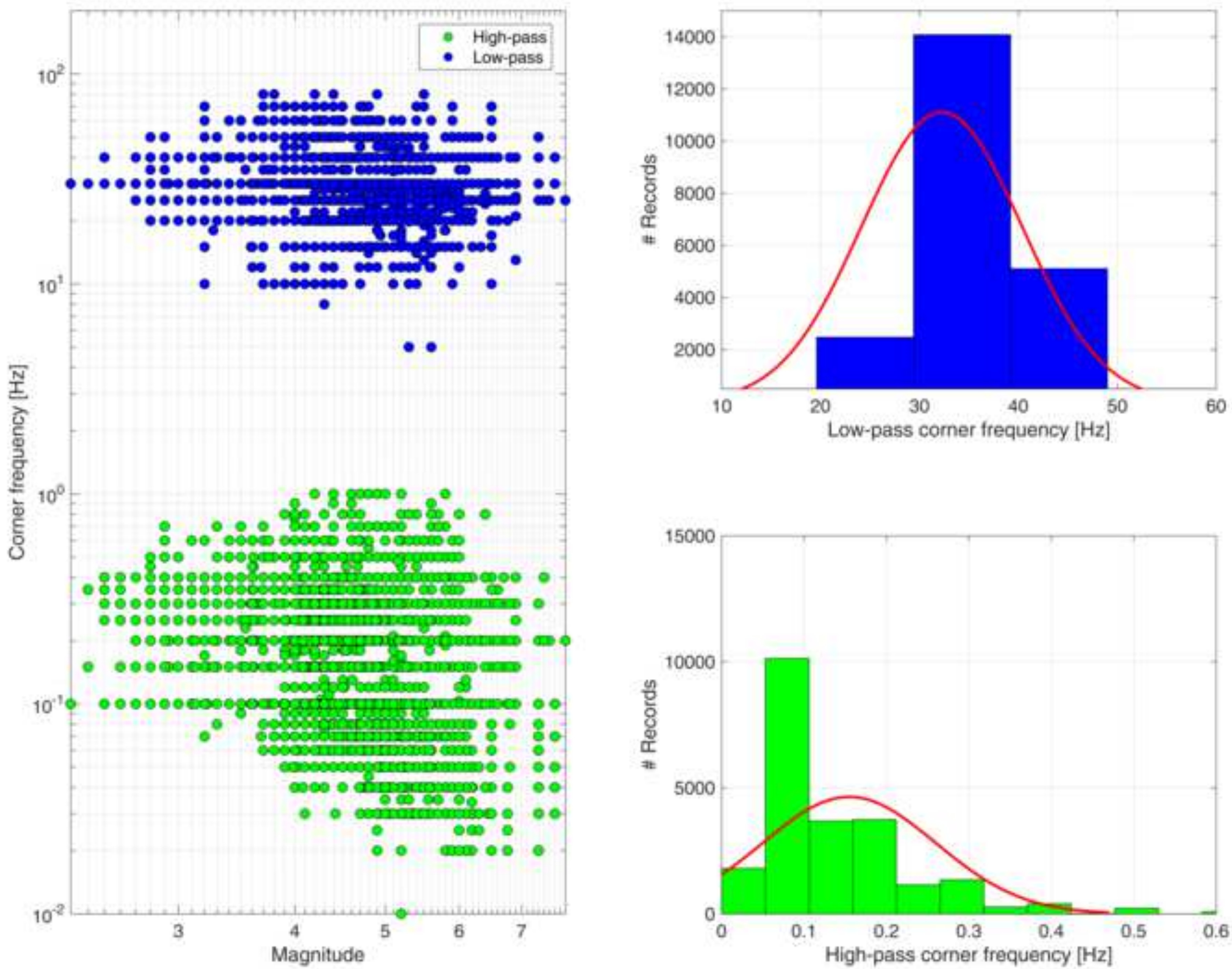

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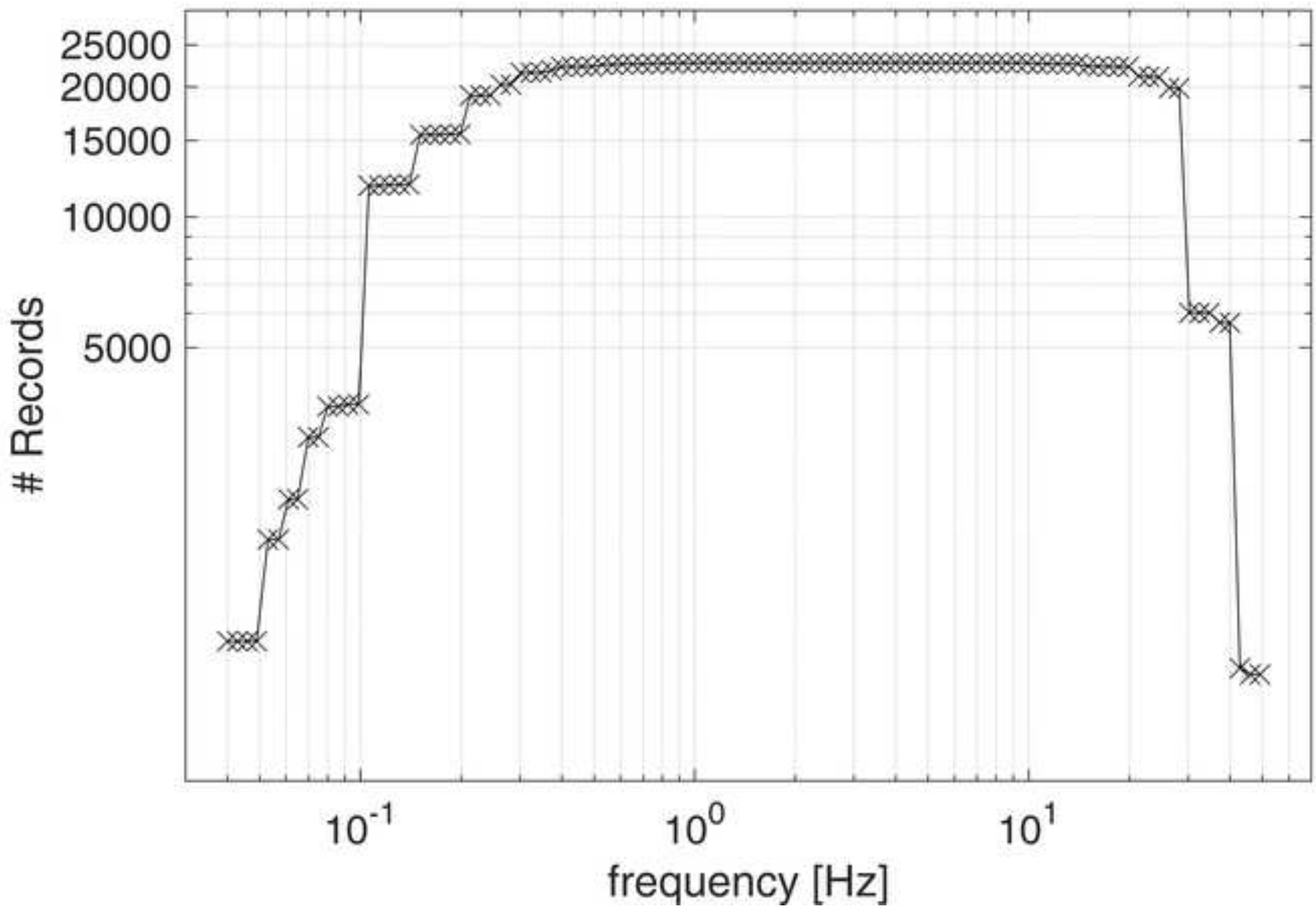

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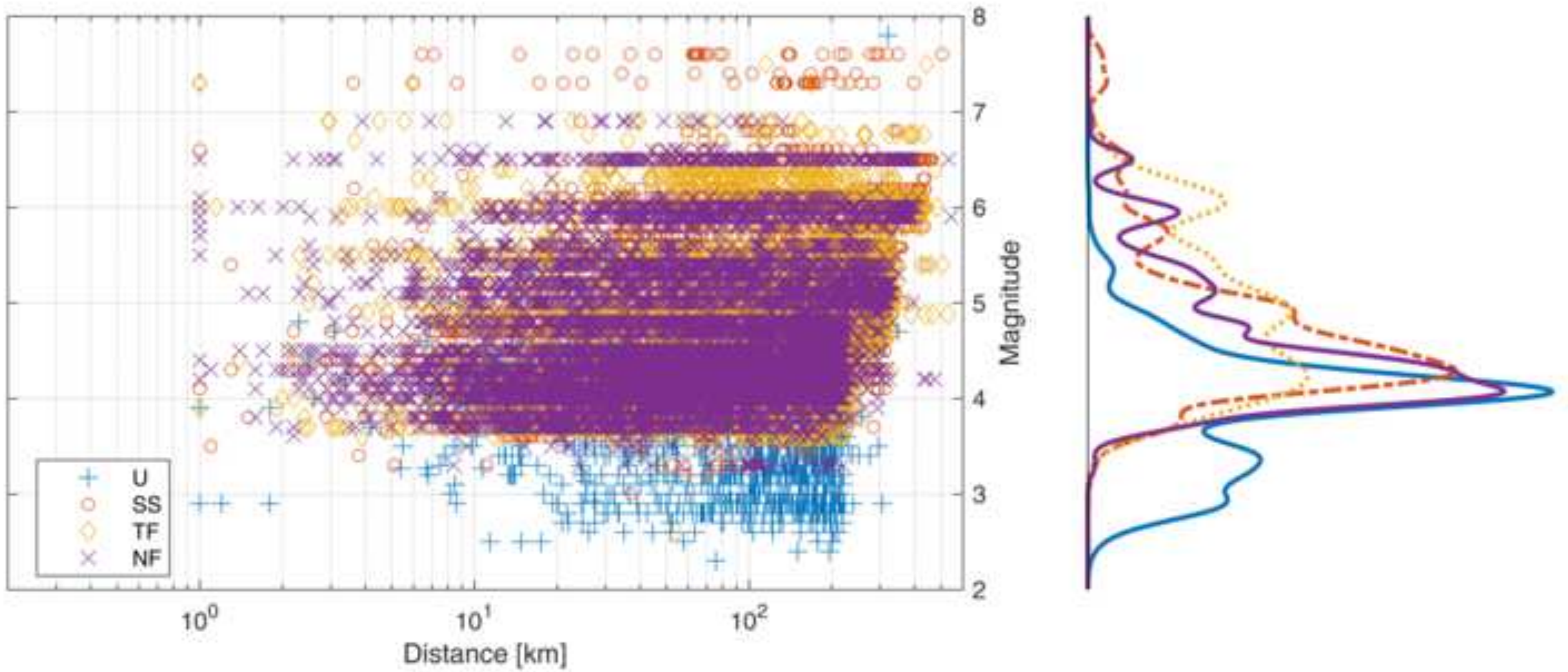

Figure 7a

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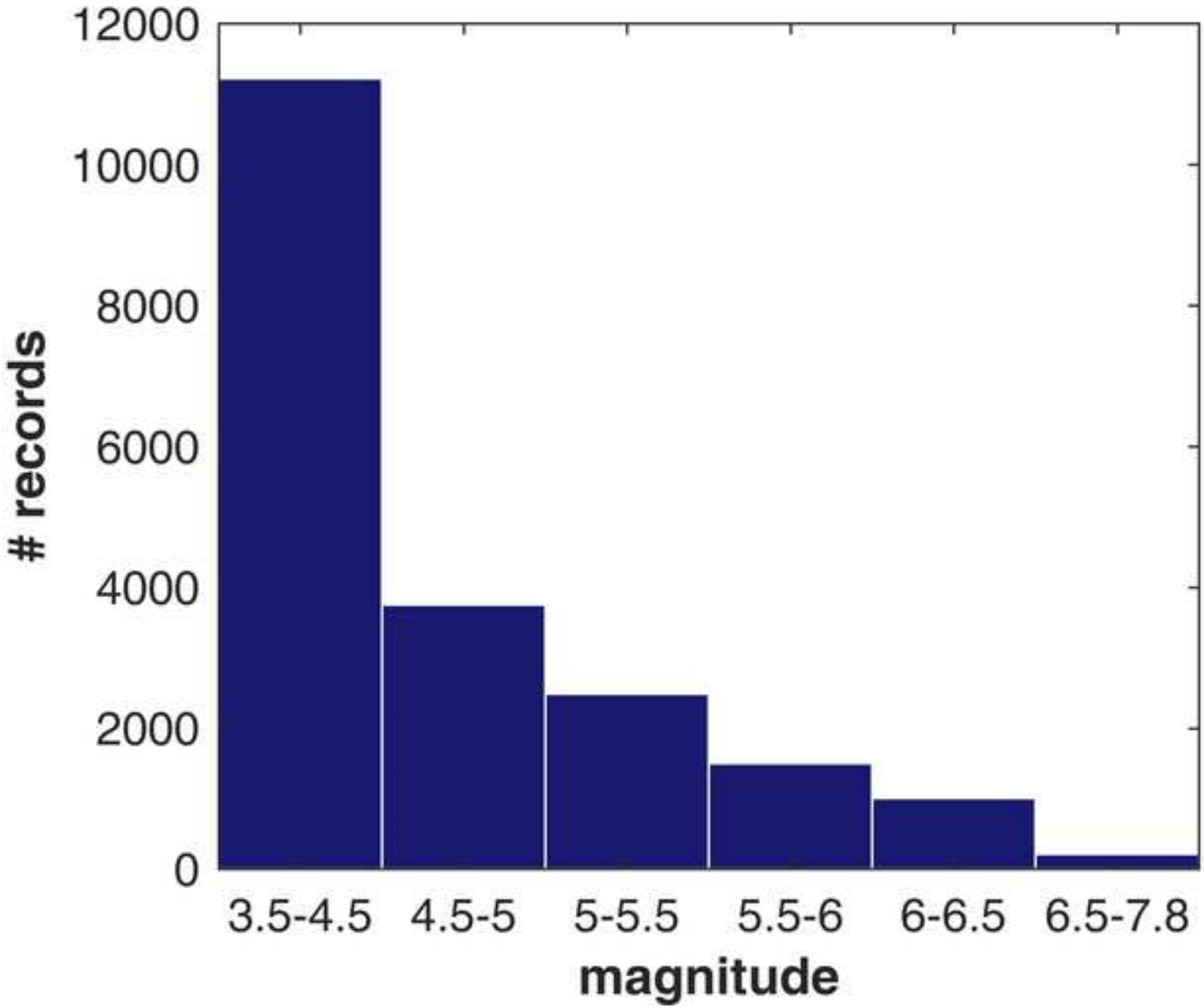

Figure 7b

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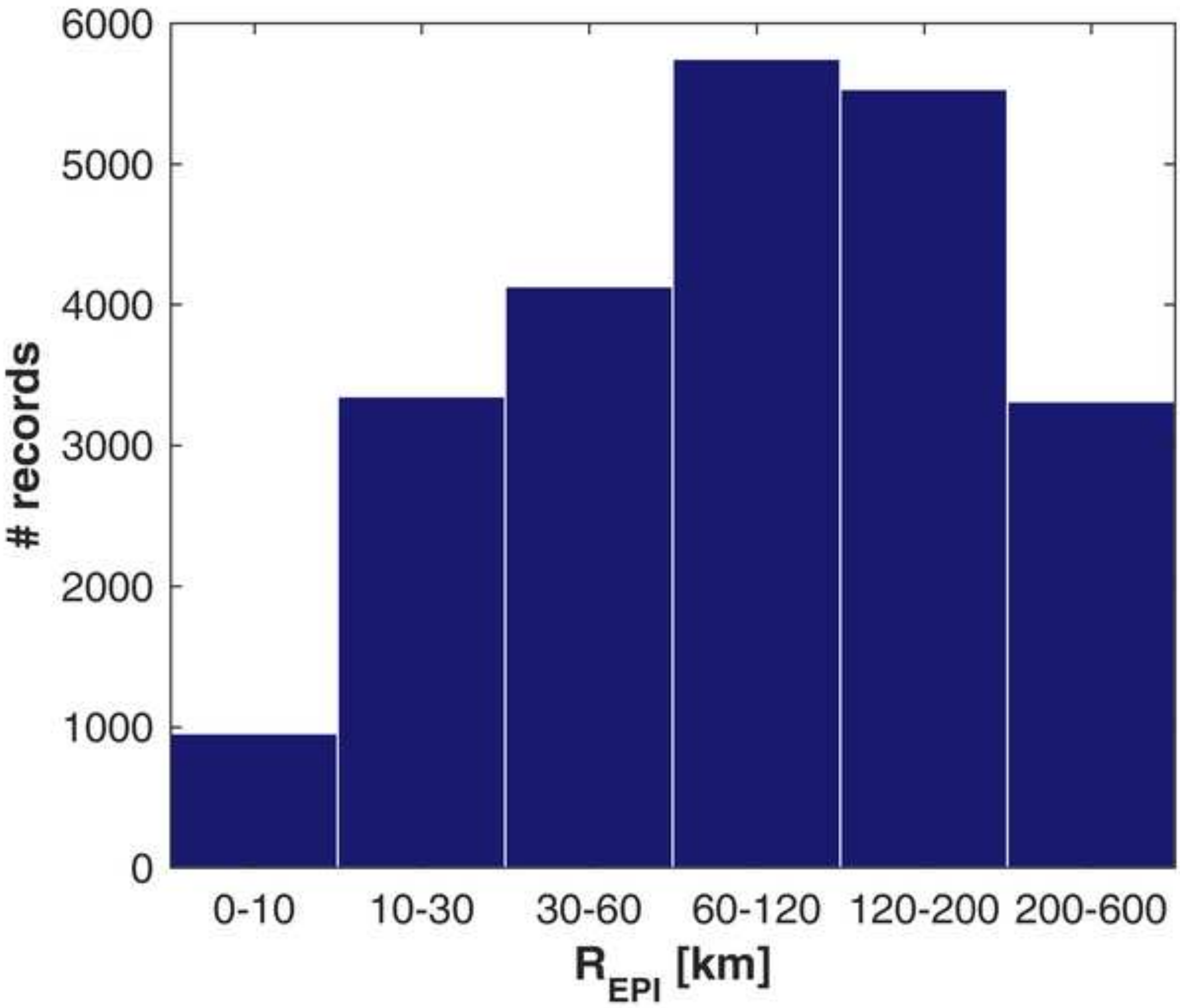

Figure 7c

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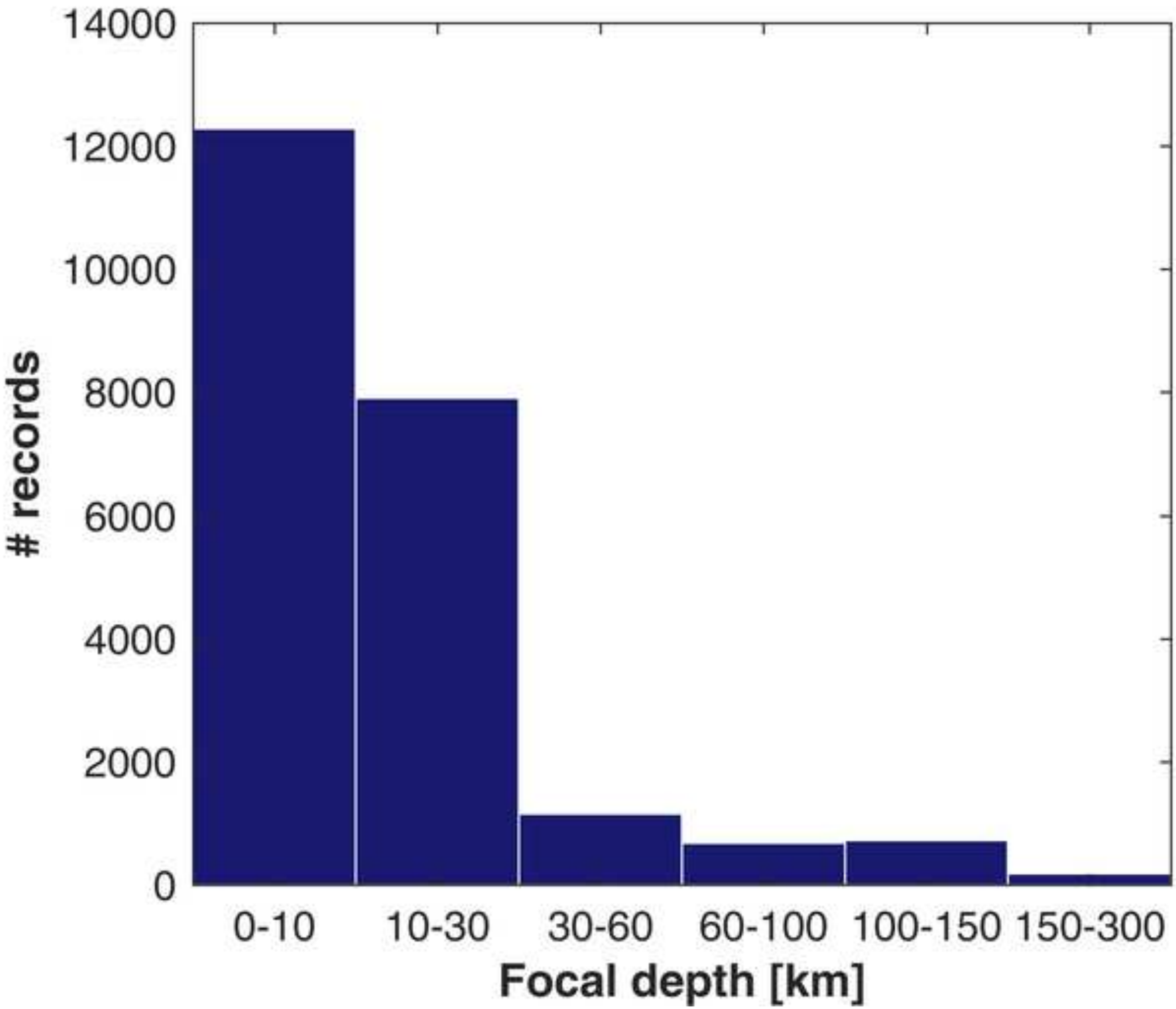

Figure 7d

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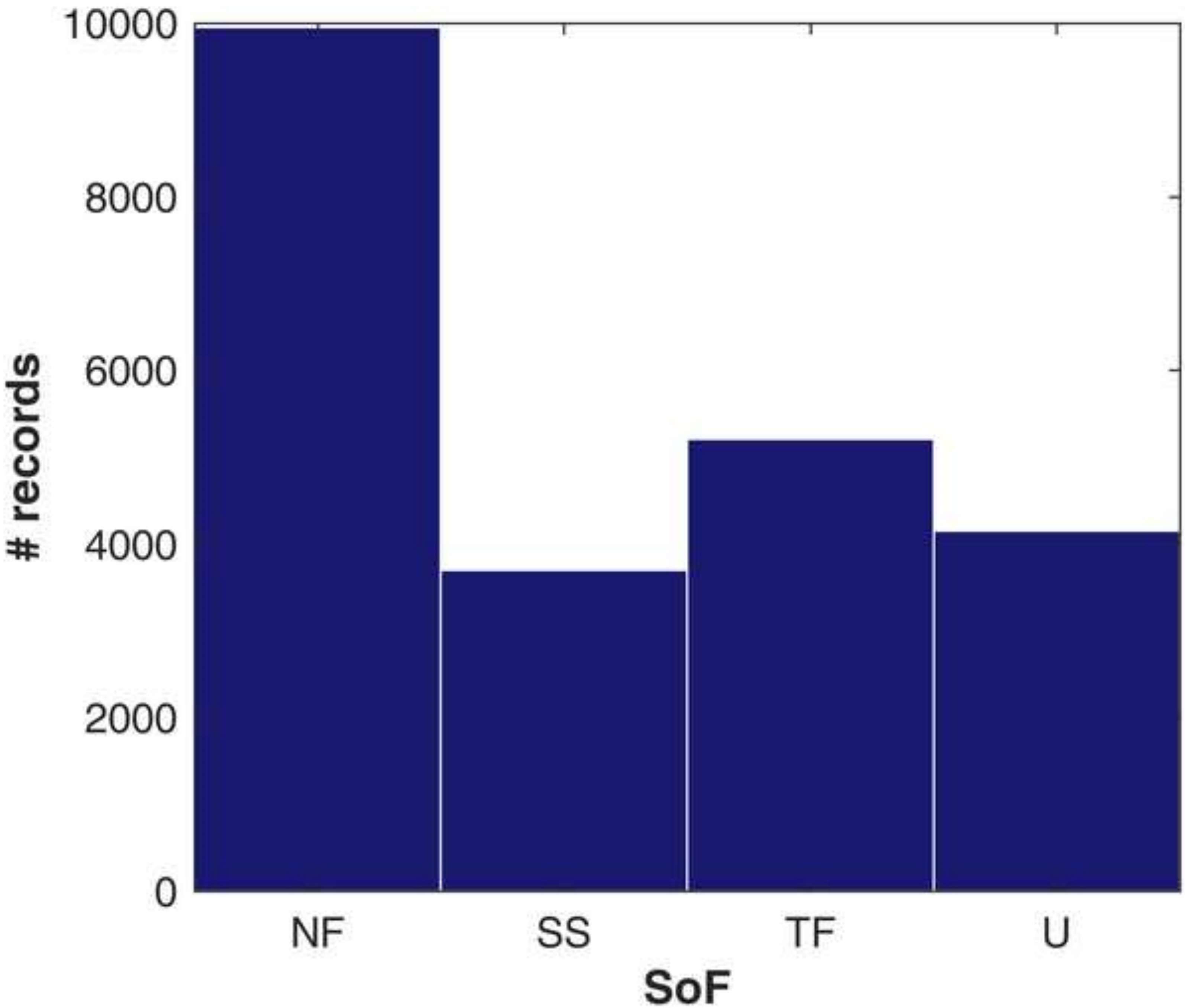

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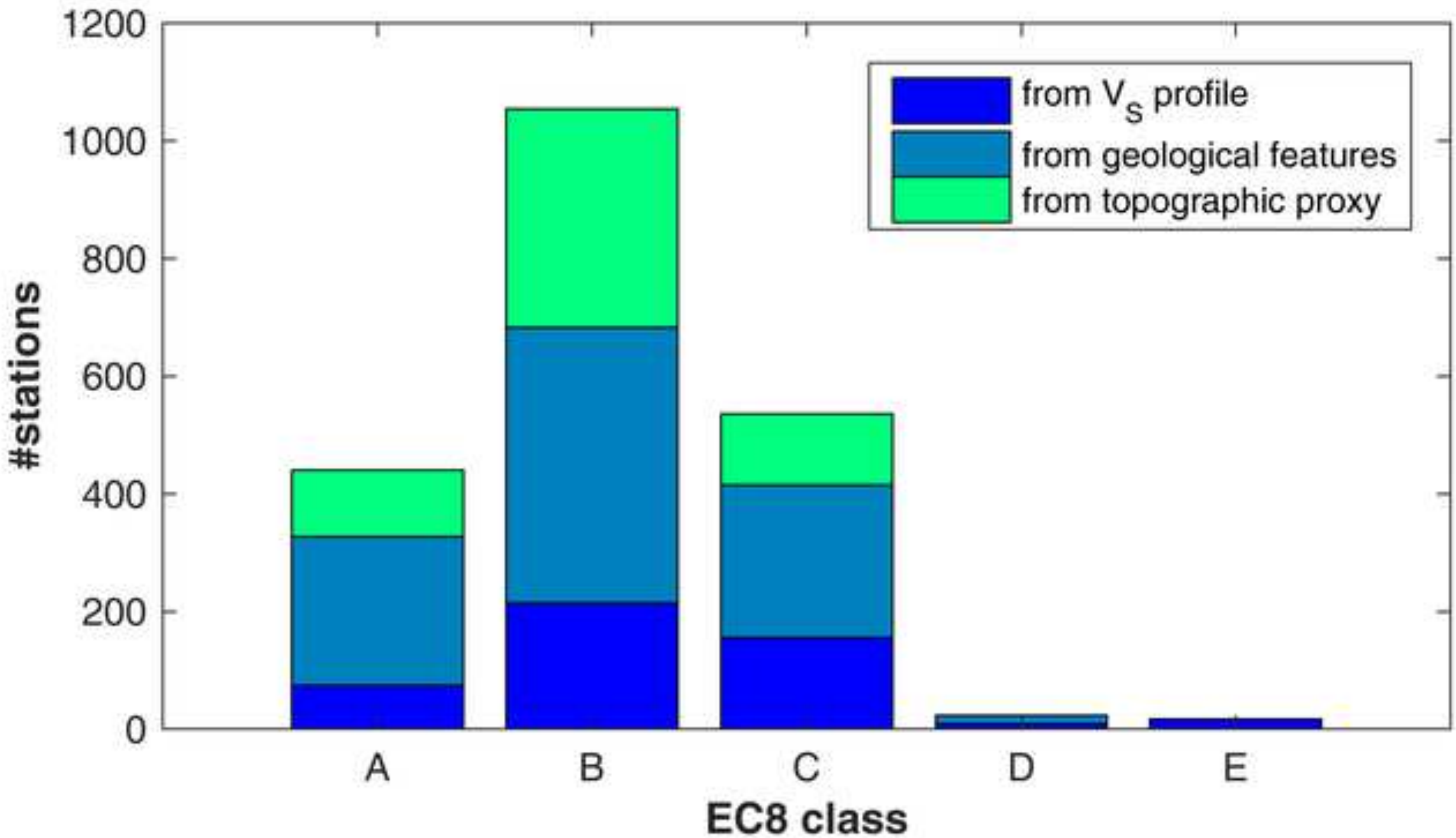

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Figure 9a

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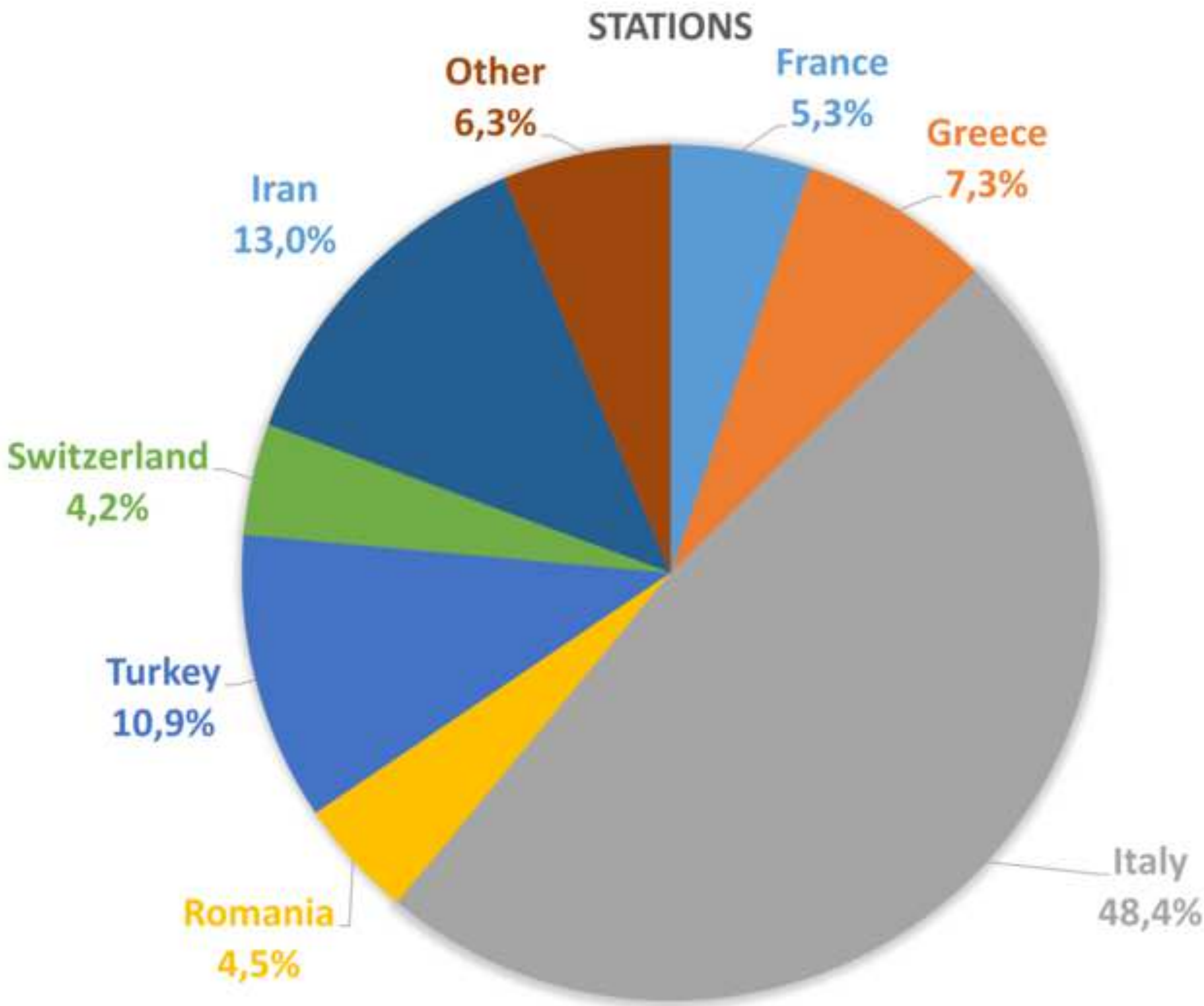

Figure 9b

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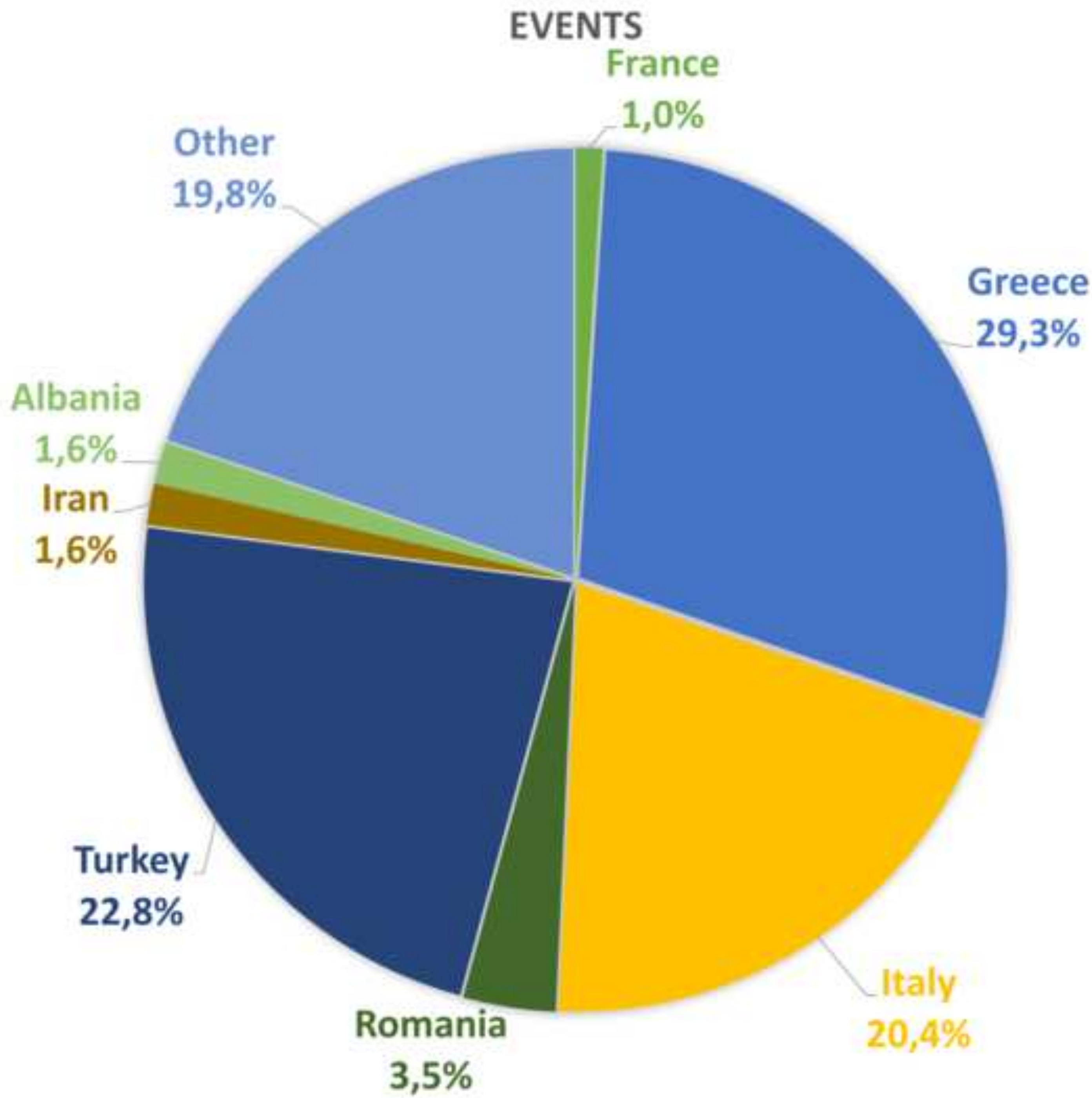

Figure 10a

Click here to download colour figure Figure_10a.png

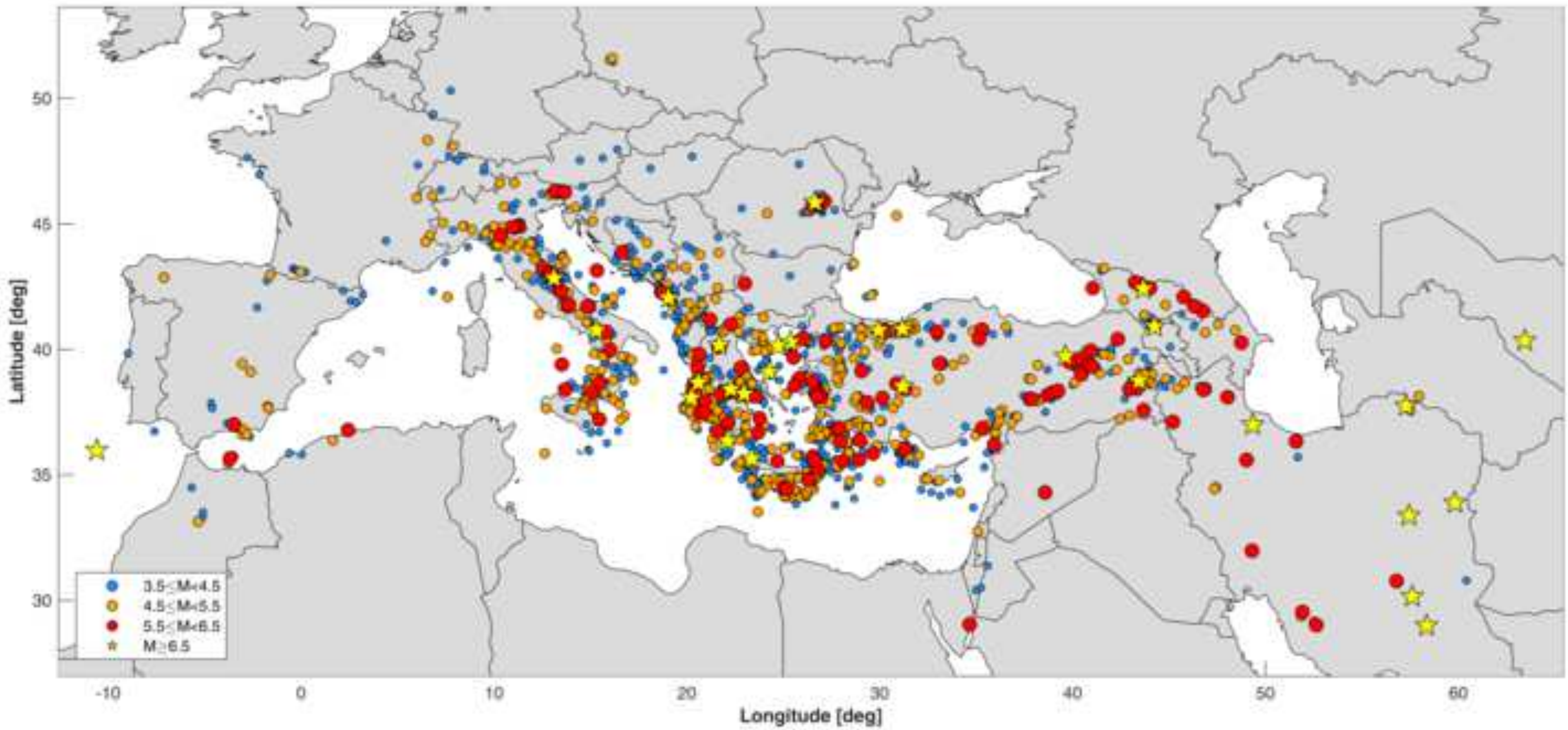

Figure 10b

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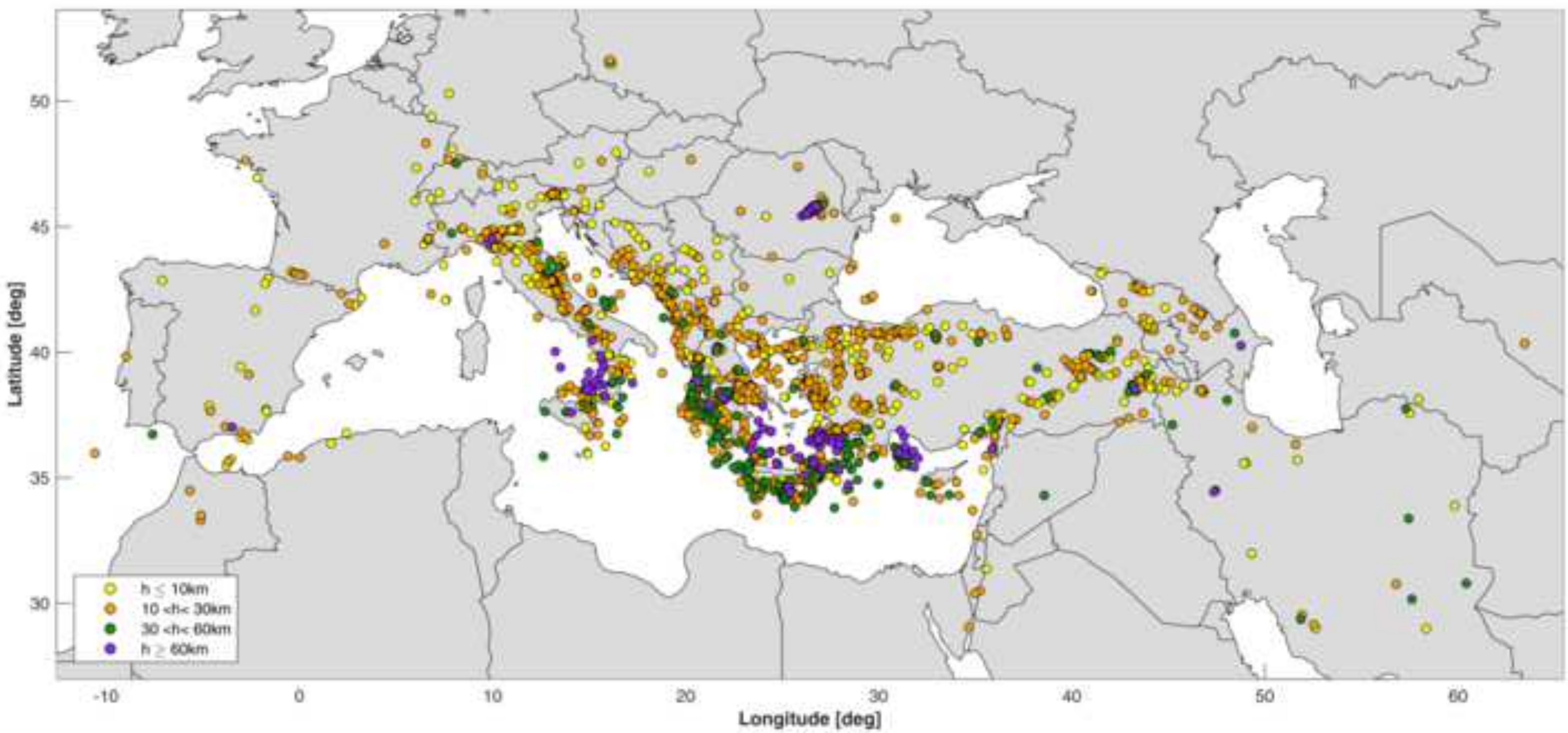

Figure 11

Click here to download colour figure Figure_11.png

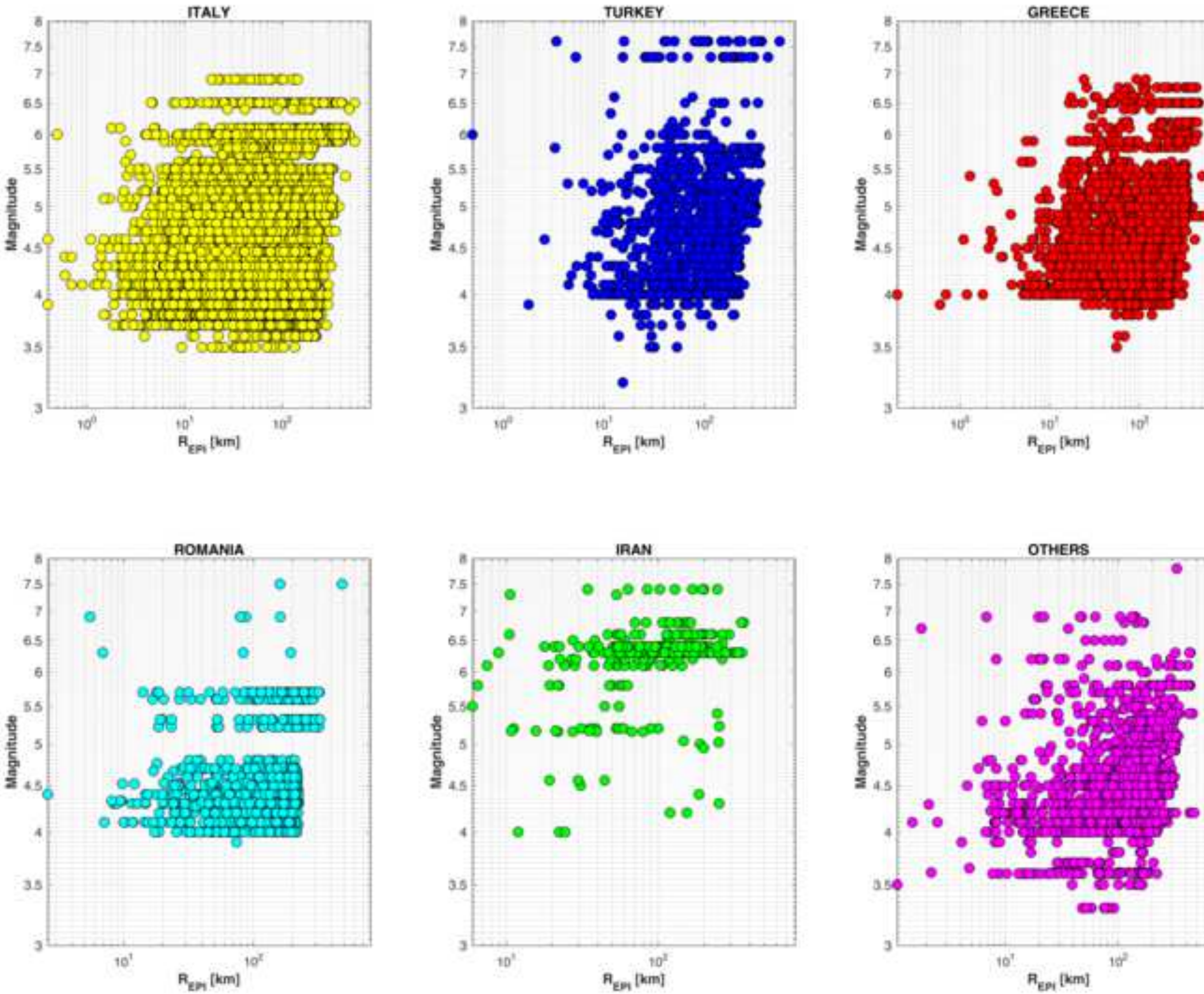

Figure 12a

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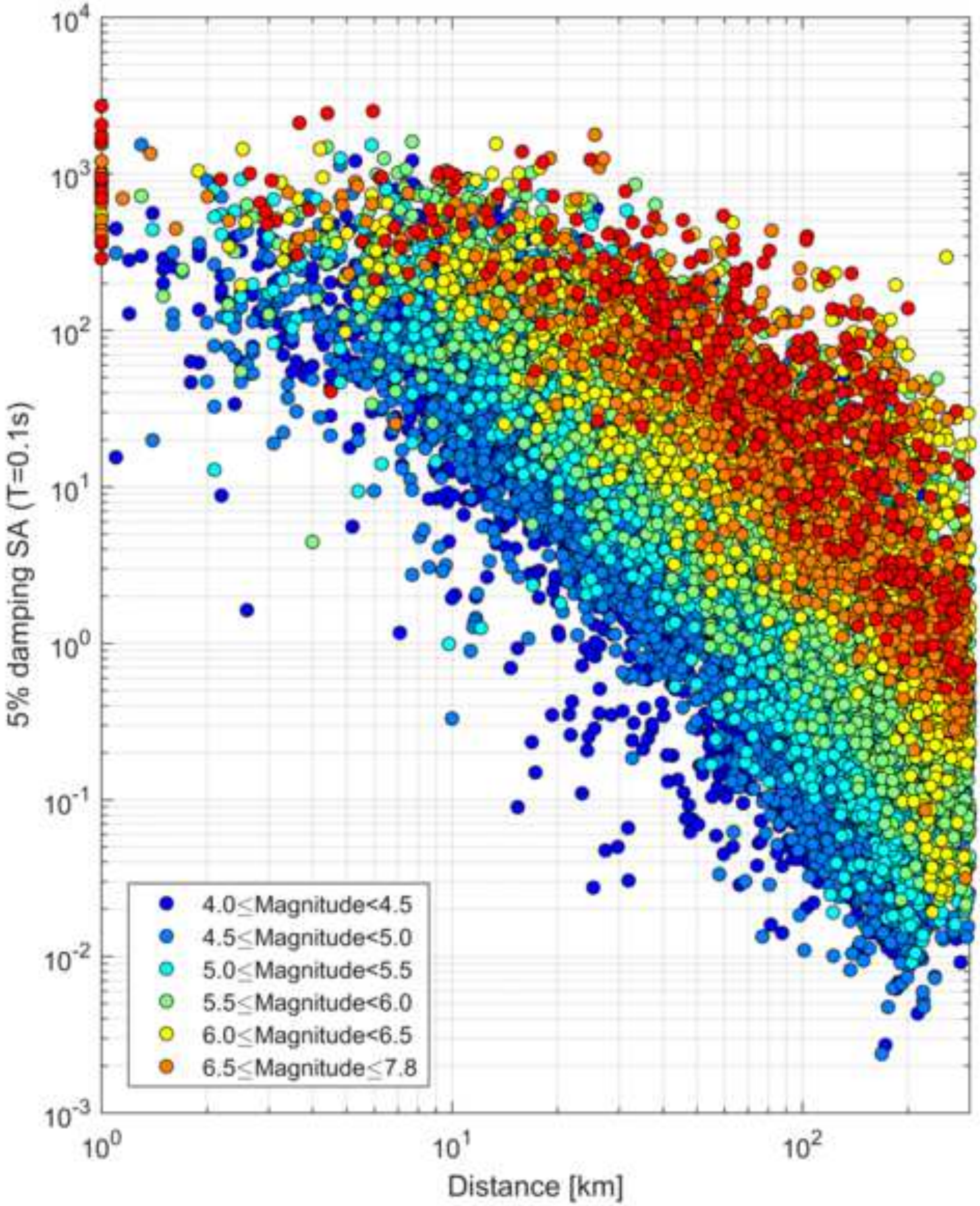

Figure 12b

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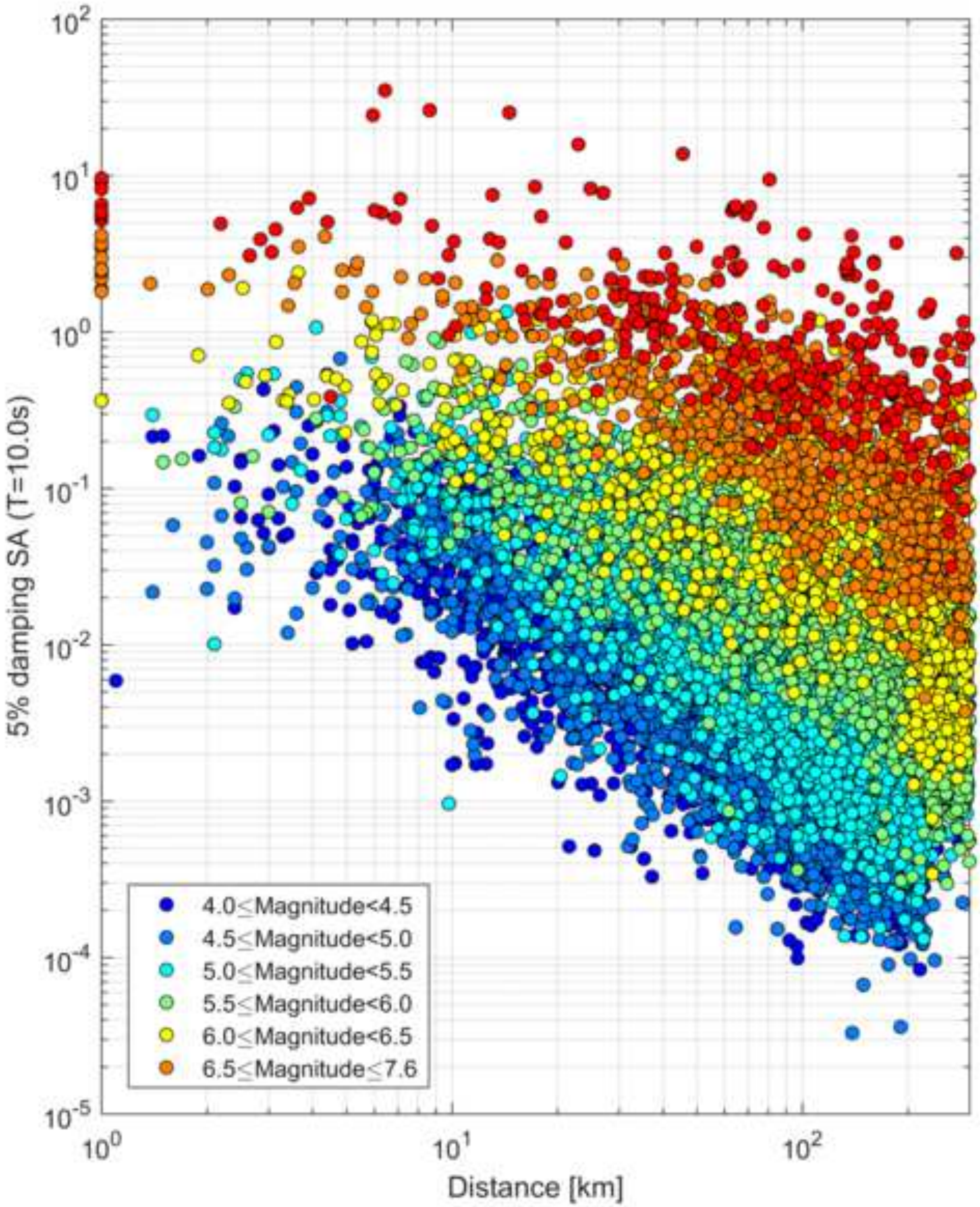

Figure 13a Click here to download colour figure Figure_13a.png

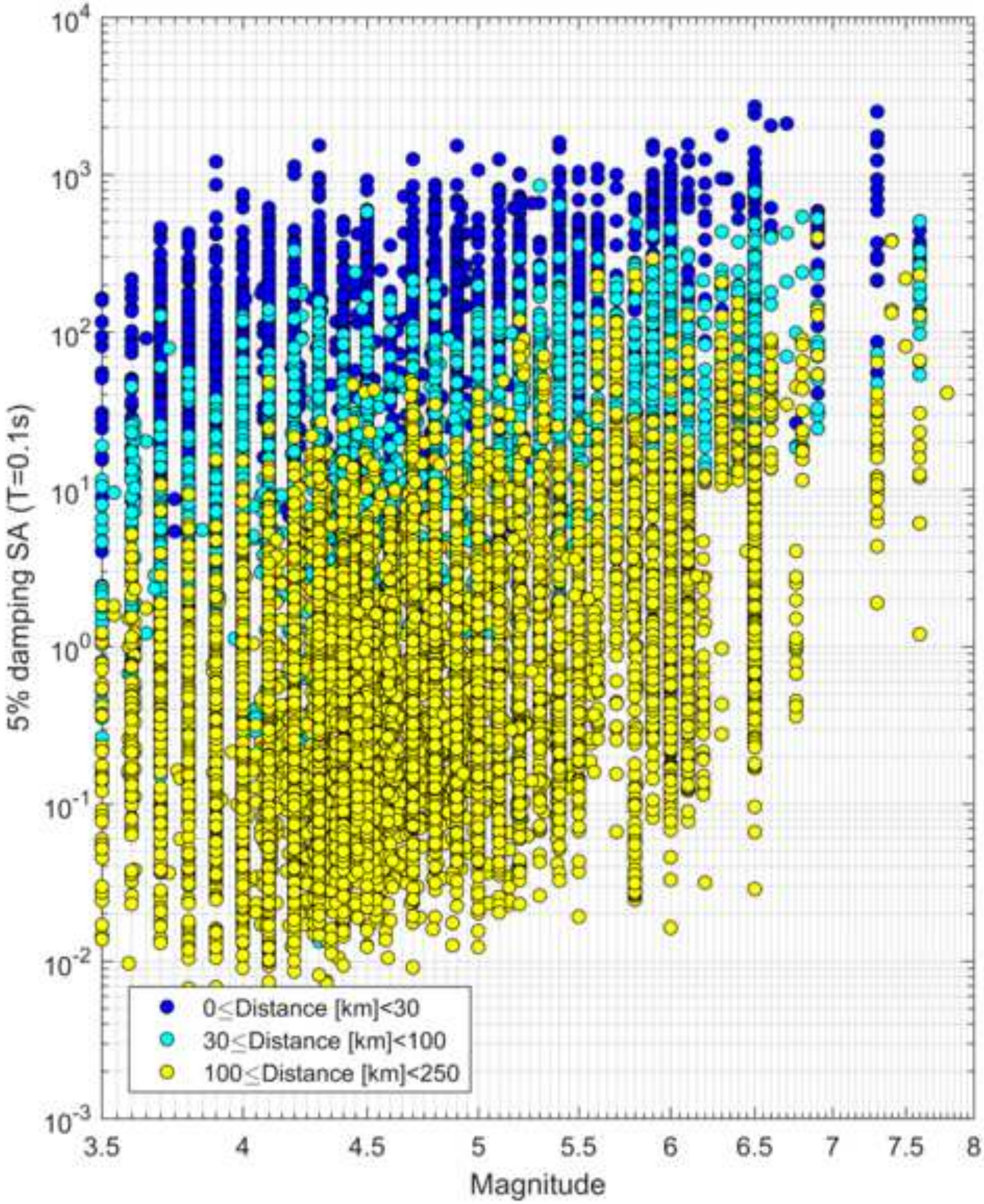

Figure 13b

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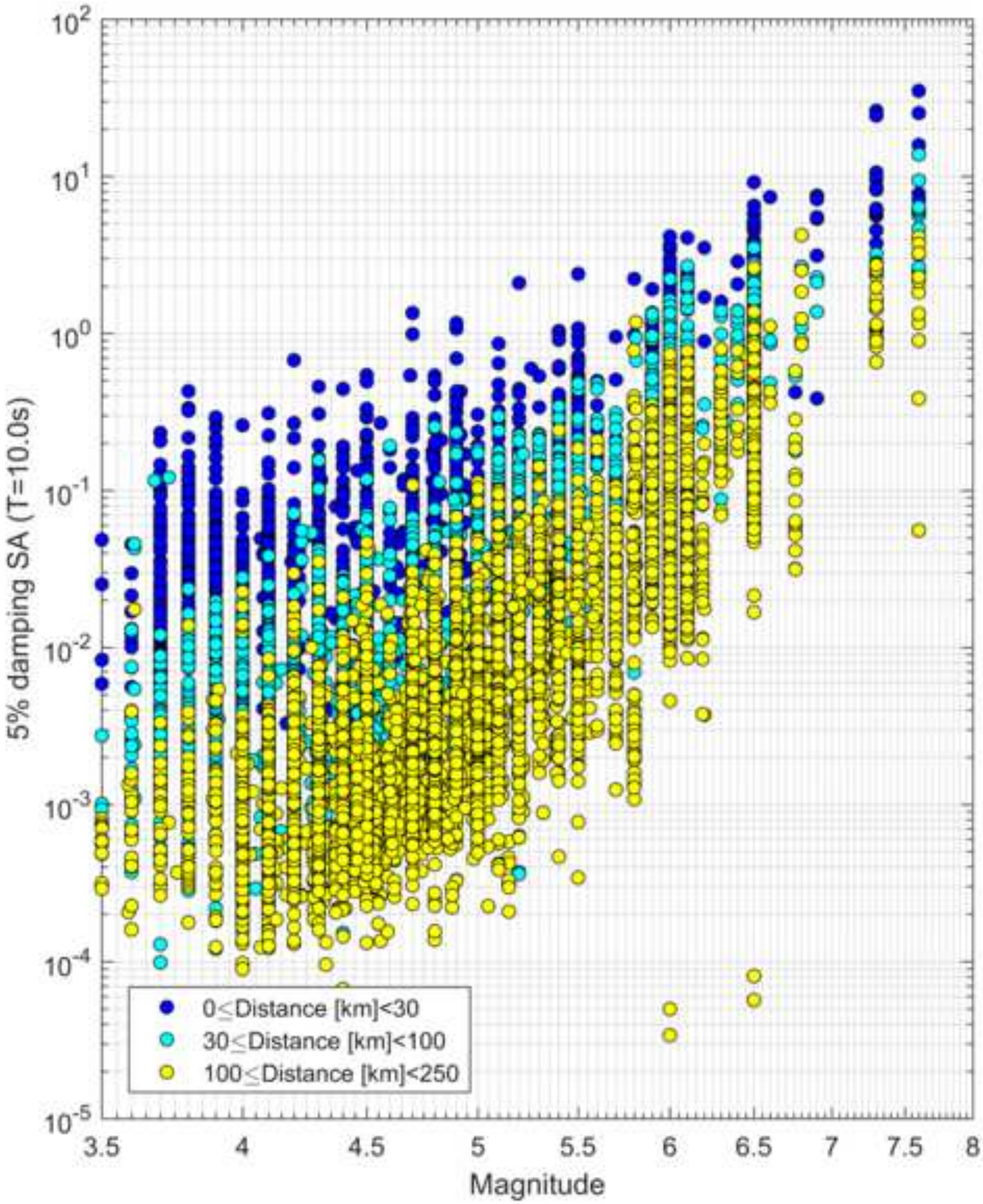

Figure 14a

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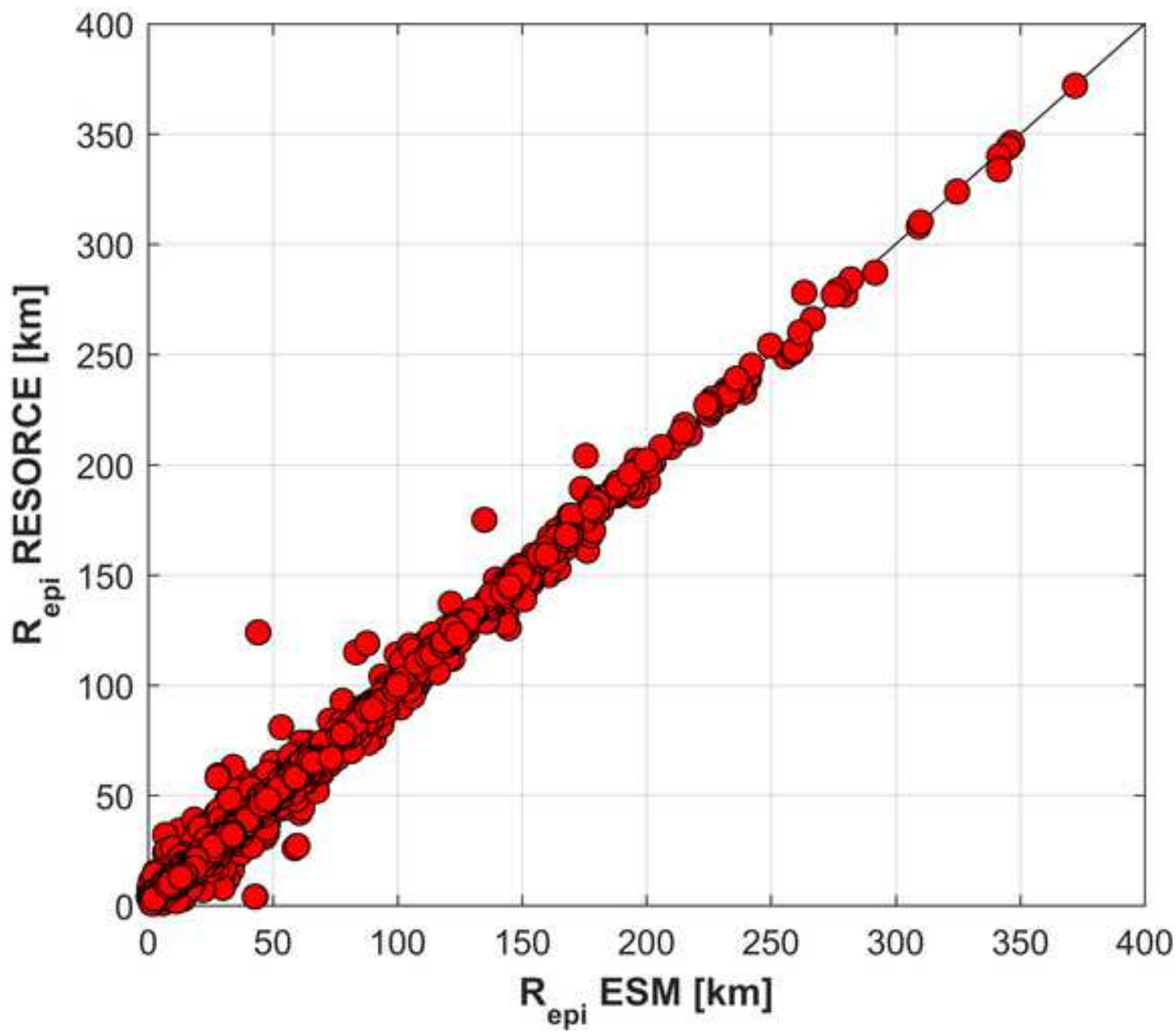

Figure 14b

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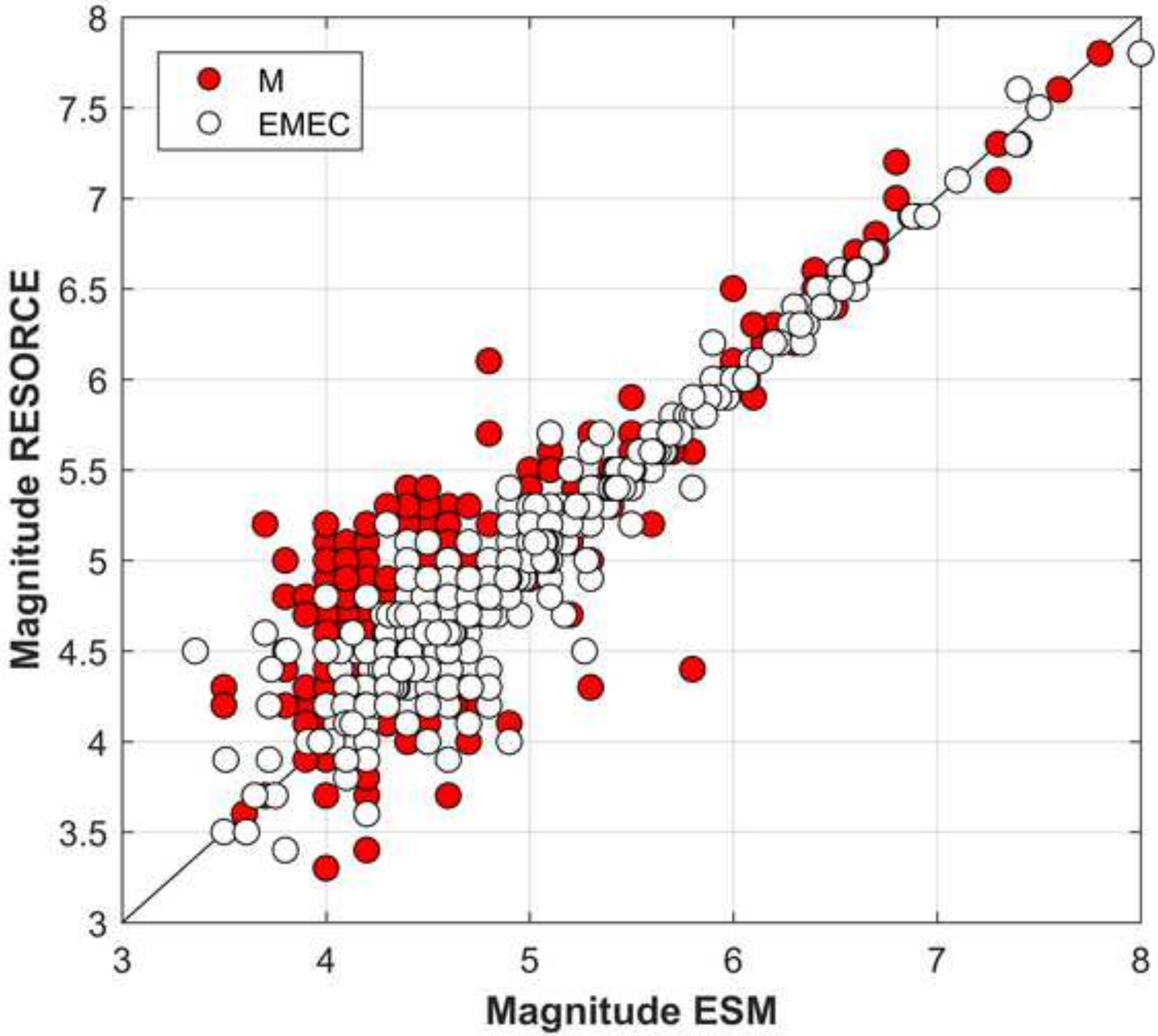


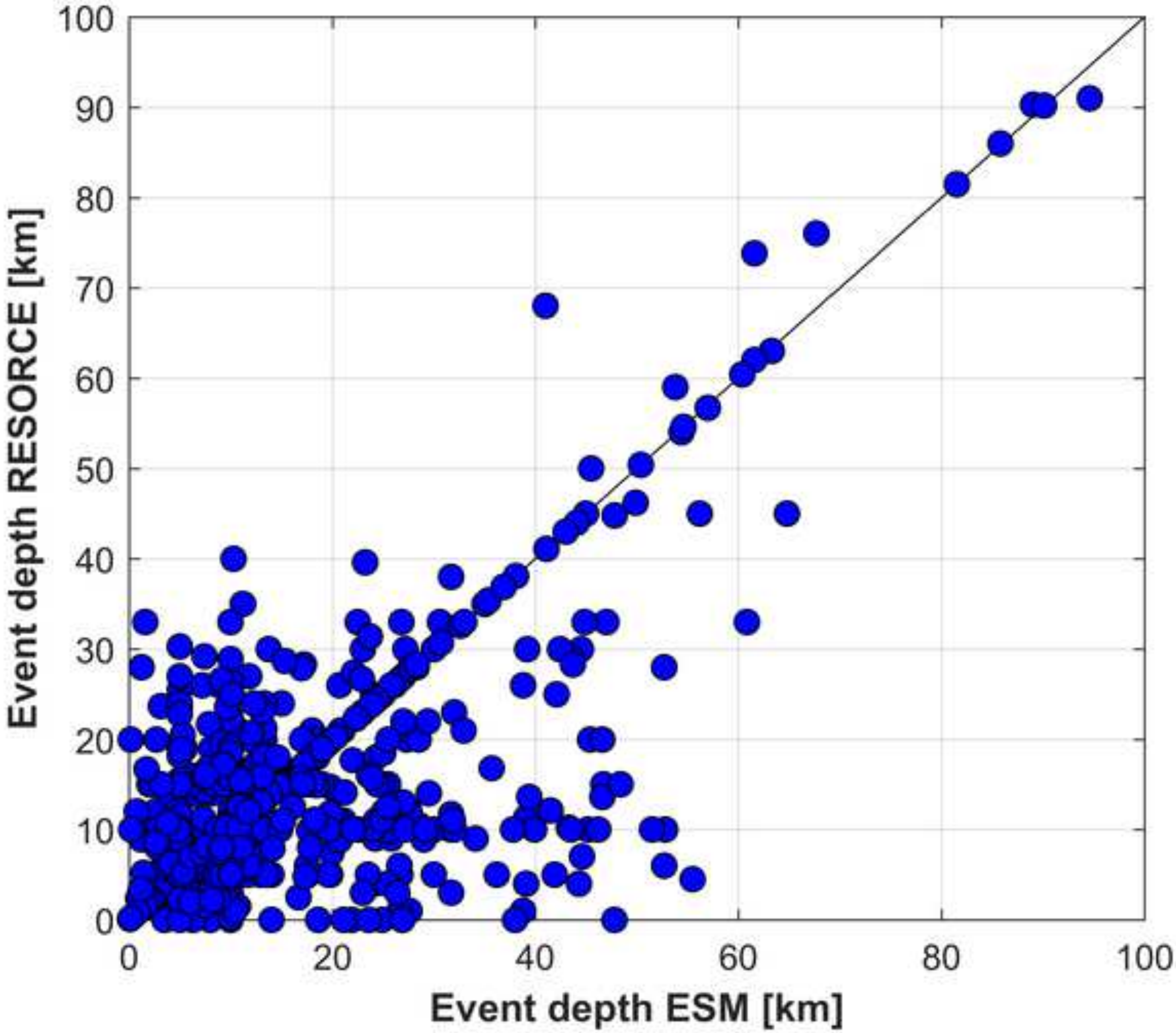

100
90
80
70
60
50
40
30
20
10
0
Event depth RESORCE [km]
0
20
40
60
80
100
Event depth ESM [km]

Figure 14d

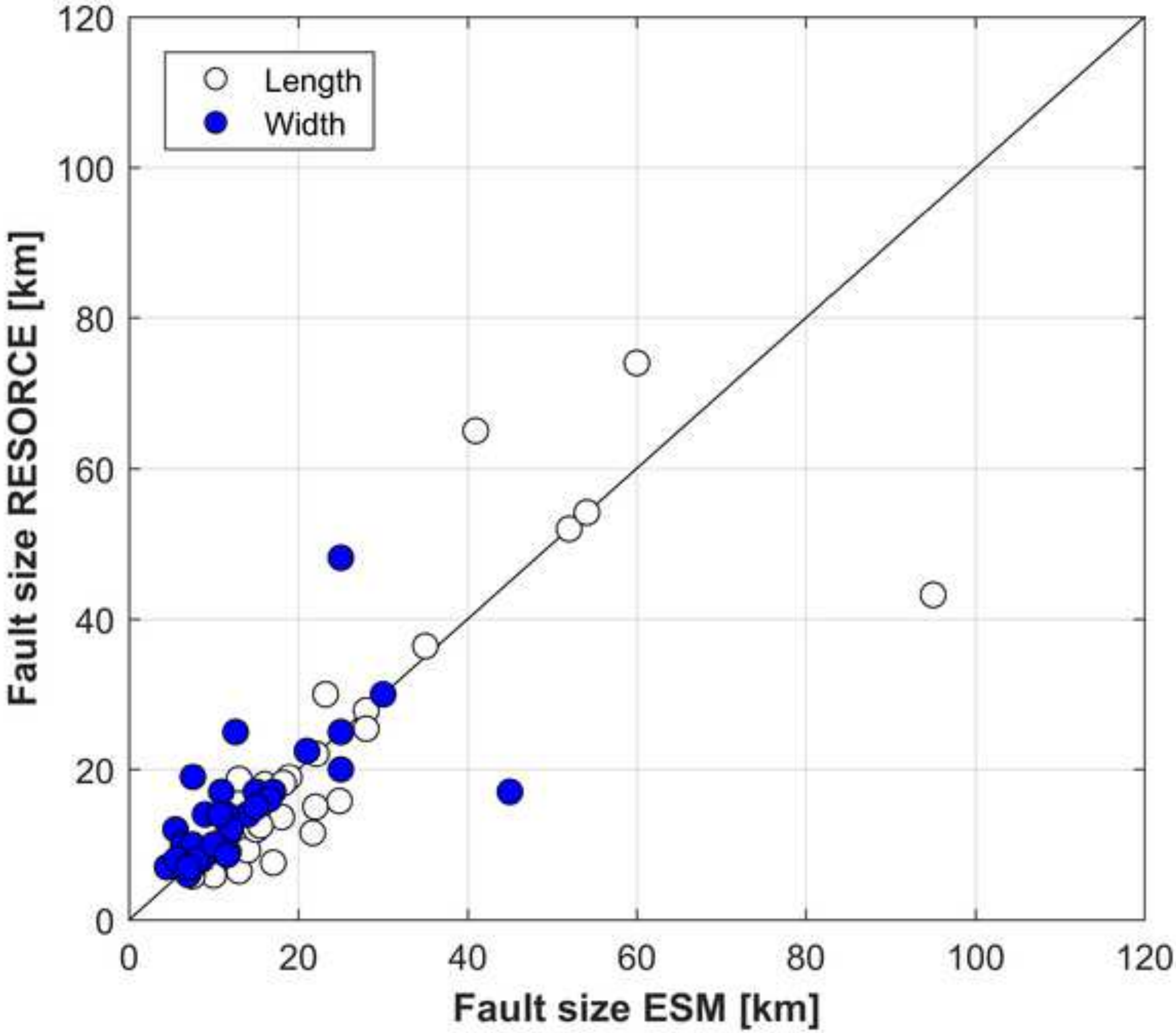
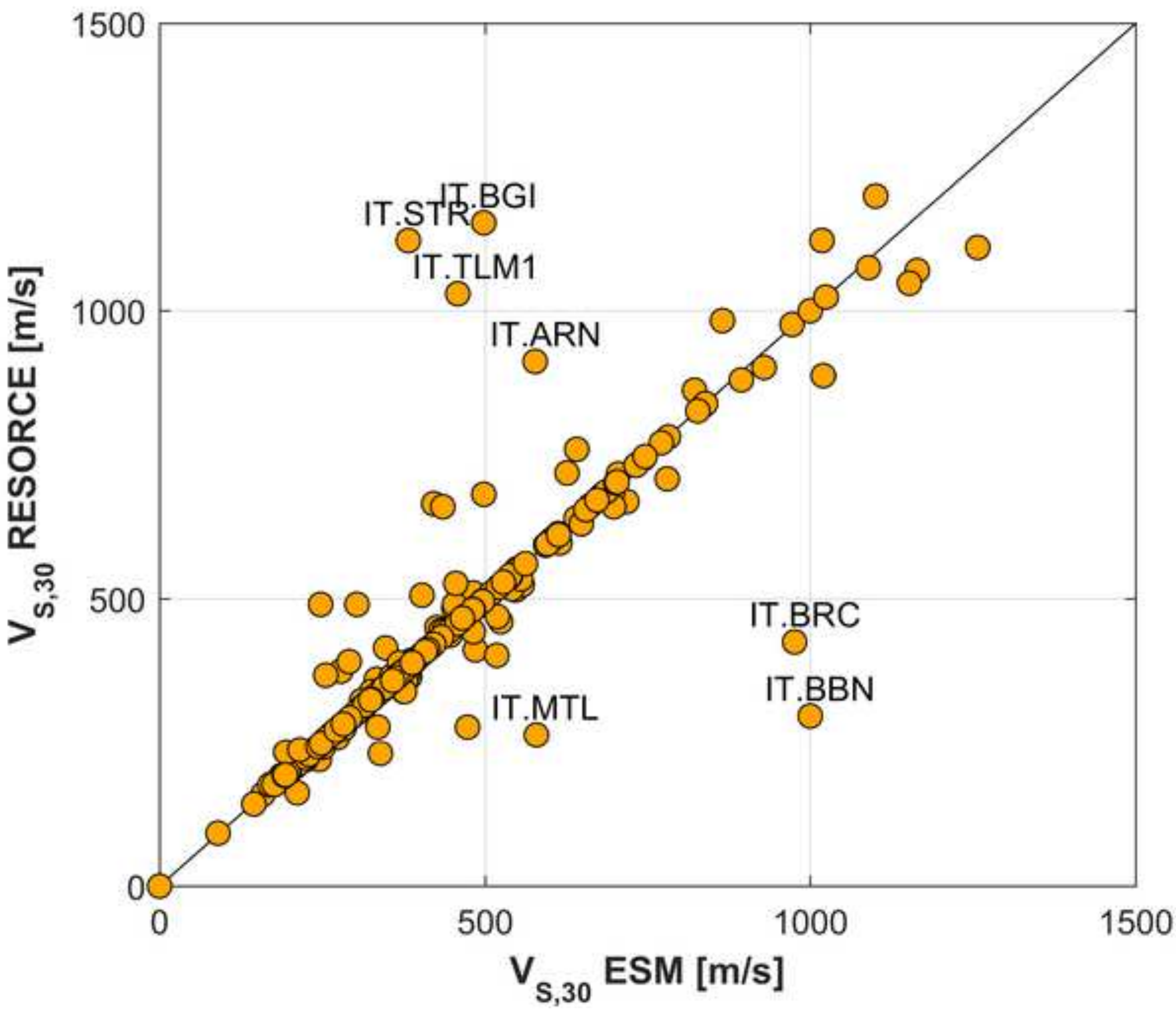

Length
Width
Fault size RESORCE [km]
Fault size ESM [km]
0
20
40
60
80
100
120

Figure 15


1500
1000
500
0
0
500
1000
1500
V S,30 RESORCE [m/s]
V S,30 ESM [m/s]
IT.BGI
IT.STR
IT.TLM1
IT.ARN
IT.BRC
IT.BBN
IT.MTL