

Seismotectonic setting and seismic hazard in the Etna region: constraints for the definition of the seismic input for microzonation

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Abstract

This paper defines the seismotectonic and seismic hazard background used to establish the seismic input for Level 3 Seismic Microzonation (SM3) and Active and Capable Fault (ACF) studies in the Etna area. The analysis integrates over 400 years of historical macroseismic records from the Catalogo Macrosismico dei Terremoti Etnei (CMTE) with a robust instrumental dataset from the 2000-2026 period. The definition of the seismic input was based on the identification of the most impacting events for each municipality through a critical analysis of the “site seismic histories”: i) regional scenario, for municipalities dominated by purely tectonic events, reference spectra were defined according to Italian seismic code NTC18 and considering return period of 475 years; ii) volcano-tectonic scenario, for municipalities close to local seismogenic faults, a “volcanic” scenario spectrum was defined based on a representative M5 earthquake at R = 3 km, using the December 26, 2018, Fleri earthquake as a reference. The introduction of this spectrum was required because earthquake recordings in volcanic areas show distinctive spectral features, with larger amplitudes in the intermediate period range. Spectrum-compatible sets of seven accelerograms were selected using the REXELweb tool for three representative target spectra (NTC18), as well as for this additional scenario spectrum. In this way, the variability of the seismic input is better represented, as the selected accelerogram sets include recordings from both tectonic and volcano-tectonic events.

Keywords: Volcano-tectonic earthquakes; Seismotectonics; Seismic input; Earthquake Spectra; Mt. Etna

1. Introduction

This paper describes the seismotectonic and seismic hazard background that led to the definition of the seismic input to be adopted for Level 3 Seismic Microzonation (SM3) studies in the volcanic region of Mt. Etna. The relevance of this kind of analysis in this area derives from its high exposure to strong ground shaking due to both regional tectonic earthquakes and local volcano-tectonic events (Azzaro et al., 2013b). In fact, the Etna region – as a large part of eastern Sicily – suffers the effects of large earthquakes ($M > 7$), the strongest of which occurred in January 1693

and December 1908 with epicentres, respectively, in the southeastern sector of the island and in the Messina Strait (Barbano and Rigano, 2001; Barbano et al., 2005; Rovida et al., 2022). As a result of this seismicity, the Catania area and the eastern flank of Etna experienced extensive damage and destruction, while the western and northern sectors of the volcano were relatively less struck (Azzaro et al., 1999; Barbano et al., 2001).

On the other hand, volcano-tectonic earthquakes, although lower in magnitude ($M_{\max} \approx 5.4$) than regional events, also cause heavy damage and even destruction, albeit over limited areas (Azzaro, 2004). This is due to the shallow hypocentral depths of the sources, typically not exceeding 4 km (Azzaro et al., 2017) and to the strong attenuation of seismic energy within a very few kilometers of distance from the epicenter (Azzaro et al., 2006; Lanzano and Luzi, 2020; Tusa et al., 2020). As a result, the damage effects are concentrated in narrow zones, generally 2-8 km long and 1-2 km wide, astride the causative faults. Furthermore, the strongest shallow earthquakes ($M > 3.5$) produce coseismic surface faulting (Azzaro, 1999), a circumstance that has significant implications for land management policies and it is the subject of specific studies aimed to define and characterize the Active and Capable Faults (ACF) in this volcanic area (Peronace et al., this volume).

These features pose specific challenges for local-scale seismic hazard assessment and represent the main motivation for detailed SM3 analyses. In particular, despite the relatively limited spatial extent of the study area, the seismic input is not uniform across the municipalities due to differences in source-to-site distance and in the relative contribution of tectonic and volcanic sources. This required a careful analysis of the seismic history of each locality to define representative seismic scenarios and the associated reference spectra.

In seismic microzonation studies, the seismic input is defined as a set of acceleration time histories at engineering bedrock, to be used in numerical simulations of local seismic response (Gruppo di Lavoro MS, 2008). The selected ground motions must be consistent with the seismic hazard at the site, typically expressed in terms of response spectra derived from probabilistic analyses or scenario-based approaches. In volcanic environments, however, the definition of seismic input is particularly challenging due to the limited availability of strong-motion recordings representative of shallow volcano-tectonic events and to the specific characteristics of the associated ground motion (Lanzano and Luzi, 2020; Ramadan et al., 2023).

To address these issues, the seismic input adopted in this study was defined using a spectrum-compatible approach, whereby sets of recorded accelerograms are selected to match reference target spectra within prescribed tolerances (Gruppo di Lavoro MS, 2008; Iervolino et al., 2010). Following the standard approach adopted in Italian seismic microzonation studies, the code-based target spectra were defined according to NTC18 by selecting a return period of 475 years as the reference hazard level for urban planning purposes. However, in the Etna area, this standard input was integrated with an additional spectrum derived from a specific volcano-tectonic scenario, in order to account for the distinctive spectral features of shallow seismic sources in volcanic environments. This integration allows the selected accelerogram sets to better represent the variability of the seismic input, including ground motions from both tectonic and volcano-tectonic events.

The selection of accelerograms was performed using the REXELweb tool (Sgobba et al., 2019), which allows querying multiple accelerometric databases (ITACA, Felicetta et al., 2023; ESM, Mascandola et al., 2026; NESS2, Sgobba et al., 2021) and identifying sets of records compatible with the target spectra.

Based on the extensive dataset of the earthquake catalogue – including historical macroseismic records spanning several centuries and instrumental recordings collected through the dense monitoring network operating since the late 1980s – as well as substantial geological and tectonic studies available for the Etna region, this study defines the key elements of the seismotectonics framework relevant to the SM3 and ACF analyses. Particular attention is devoted to the definition of the seismic input, including the identification of representative seismic scenarios and the selection of spectrum-compatible accelerograms for local seismic response analyses.

2. Seismotectonic background

The need for specific SM3 and ACF analyses in a volcanic region such as Etna arises from the peculiar seismotectonic characteristics of this area, which are ill-suited to being addressed with the “traditional” guidelines. This observation is not merely a scientific consideration, but it has significant practical implications for land management in terms of seismic risk issues. The huge literature of seismological, geophysical and geological studies, promoted also by more than 40-years of multi-disciplinary monitoring data, has improved the understanding of the seismotectonic framework to a very detailed level (e.g. Azzaro et al., 2012, 2013b; Scarfi et al., 2025). In the following, we propose a synthesis of

the main elements and input data representing the common base for the analyses and guidelines produced in the “Etna ACF_SM3 Project”.

2.1 Volcano-tectonic seismicity

Seismic activity at Etna frequently occurs as earthquake sequences and seismic swarms that characterise different phases of volcanic activity, as well as individual shocks related to the activity of the numerous active faults that cross its flanks. This activity is extremely well documented by two earthquake catalogues specifically compiled for this area, covering overall more than 400 years of the volcano’s history. The long-term seismicity is represented by the historical macroseismic catalogue of Etnean earthquakes [CMTE], that includes the intensity data for 1,845 earthquakes with associated parameters, in the time-span 1633-2026. It provides a clear view of major seismicity in the densely urbanised sectors of the volcano, highlighting the causative relationships with the dense network of ACFs crossing these areas. For the purposes of this study, we considered the events above the threshold of diffuse damage ($I_0 \geq VII$ EMS; Grünthal, 1998), whose representation through the “Site Seismic Histories” – the chronological sequence of the seismic events that struck a given locality and the associated intensity – is particularly useful to identify the most impacting earthquakes (see Section 3.1). A more specific characterisation of the recent seismicity is given by the Mt. Etna Seismic Catalogue 2000-2026 (EtnaSC_2000_2026), compiled through the instrumental data acquired by the local seismic network of INGV-Osservatorio Etneo. This homogeneous and rich dataset (more than 23,000 events) exploits the important technological upgrade implemented since the mid-2000s, with 40 digital stations equipped with broad-band sensors. Selected weak- and strong-motion recordings constitute the robust dataset on which other specific seismological analyses have been carried out for SM3 (Tarchini et al., this volume; Laurenzano et al., this volume).

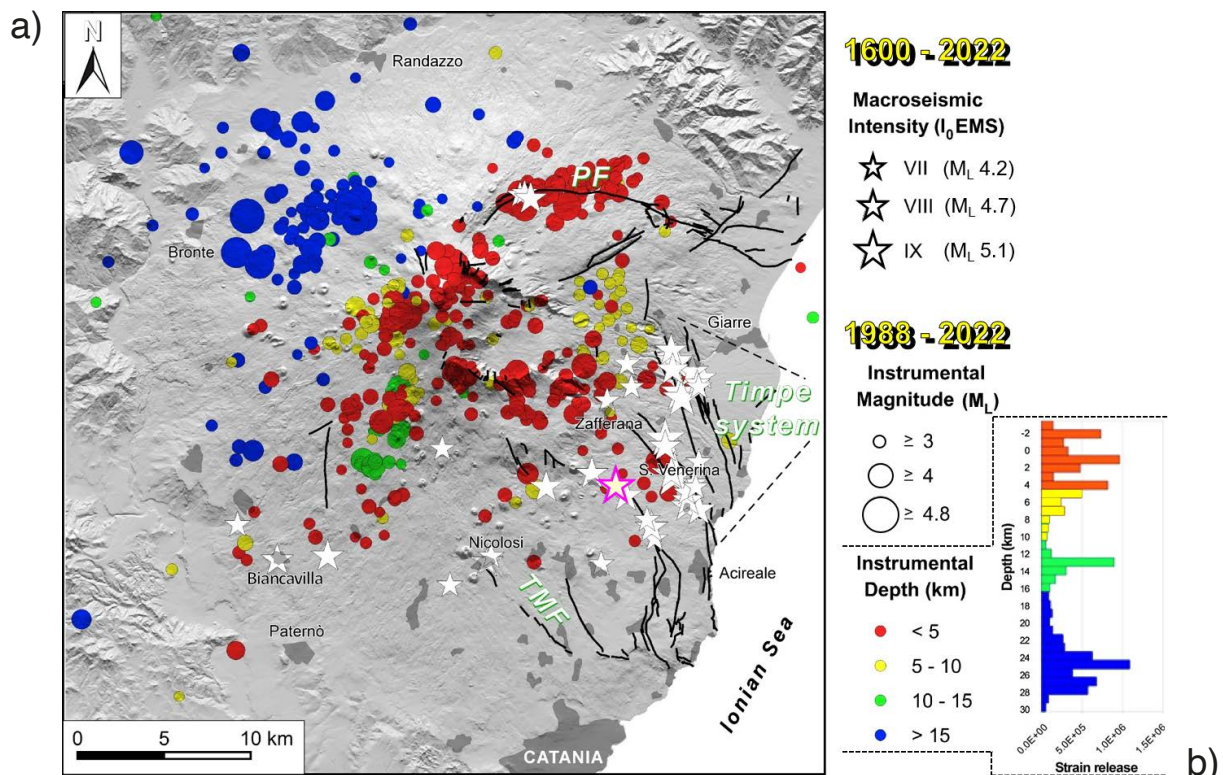


Figure 1. (a) Distribution of the main historical earthquakes from CMTE (white stars) and recent instrumental seismicity recorded by the INGV-Osservatorio Etneo stations (colored circles, data from <https://www.ct.ingv.it/index.php/monitoraggio-e-sorveglianza/banche-dati-terremoti/terremoti>). (b) Depth distribution in 1-km bins vs seismic strain release of $M \geq 3$ earthquakes (instrumental data). Faults are in black (modified from Azzaro et al., 2012); abbreviations: PF, Pernicana Fault; TMF, Tremestieri Fault. The purple star indicates the 2018 earthquake used as a reference event for the seismic input.

The integration of both the catalogues provides, in Fig. 1a, a complementary view of the overall distribution of major seismicity at Etna. The macroseismic data highlight the location of damaging events and their severity of damage expressed in terms of intensity, whereas the instrumental data describe the real distribution of $M > 3$ earthquakes (not damaging events) taking into account the hypocentral depth.

The strongest historical earthquakes ($VIII \leq I_0 \leq IX$ EMS, white stars) are mostly located in the lower eastern flank of the volcano, which is crossed by the dense network of active faults of the Timpe system. The high occurrence and intensity of these events determines this area as that most exposed to seismic hazard of the Etna region (see Section 3). Table 1 summarizes the strongest events occurring from 1800 to today, and their causative faults: 12 major earthquakes with $M \geq 4.7$, that means, overall for this seismotectonic district, one severe earthquake every ~ 18 years. To the north, a cluster of damaging events is located at the westernmost termination of the Pernicana Fault (PF) whereas other earthquakes are scattered across the southern flank (Biancavilla-Nicolosi area).

Table 1. Strong earthquakes generated by the Timpe faults in the last centuries (data from CMTE). The intensity of grade VIII EMS represents the threshold of heavy damage. Note that the S. Tecla and Moscarello faults have not generated strong earthquakes for several decades.

Data	Seismogenic fault	Epicentral area	Epicentral intensity EMS (I_0)	Magnitude (M_L)
11/07/1805	Moscarello	Fondo Macchia	VIII-IX	4.9
19/07/1865	Moscarello	Fondo Macchia	IX	5.1
19/08/1865	S. Tecla	S.M. Ammalati	VIII	4.7
17/06/1879	S. Venerina	Bongiardo	VIII-IX	4.9
08/08/1894	Fiandaca	Mazzasette	VIII-IX	4.9
15/10/1911	Moscarello	Fondo Macchia	VIII-IX	4.9
08/05/1914	S. Tecla	Linera	IX-X	5.4
19/03/1952	S. Tecla	Linera	VIII-IX	4.9
21/04/1971	Moscarello	Fondo Macchia	VIII	4.7
25/10/1984	Fiandaca	Fleri	VIII	4.4
29/10/2002	S. Venerina	Bongiardo	VIII	4.5
26/12/2018	Fiandaca	Mazzasette	VIII	4.8

On the other hand, the instrumental data clearly show that Etna seismicity is not equally distributed in the volcanic region, with a larger number of events occurring in the central sector. This is even more evident in terms of hypocentral distribution, with substantially four depth classes (Fig. 1b): the shallowest events ($H < 5$ km, red circles) affect the eastern and central sectors (rift-zones and summit craters) of the volcano as well as the Pernicana Fault (Alparone et al., 2013); intermediate events ($5 \leq H < 17$ km, yellow and green circles) are widely scattered throughout the central sector, and mark the processes of magma migration in the crust up to the shallow plumbing system (Firetto Carlino, 2022); the deepest events ($H \geq 17$ km, blue circles) are mainly confined in the north-western sector of the volcano, and are generally related to tectonic compressive processes of the Eurasia-Africa convergence (Scarfì et al., 2025).

The existence of different seismogenic levels beneath Etna indeed has direct implications on the seismic hazard characterisation. Briefly, we note that: i) the more significant seismic release is confined in the first 4 km b.s.l. (Fig. 1b, in red), where the strong damaging earthquakes are located and reach magnitudes up to M_L 5.4.; ii) the depth range 17-30 km, although capable of generating magnitudes up to M_L 4.8 and overall significant values of strain particularly in the north-western sector of the volcano, does not produce damaging earthquakes (only strong felt areas) because of the attenuation of ground motion (Langer et al., 2016). This distinction and different behaviour has implications in terms of ground motion models (GMM) selection to be used in this area, and the depth of 4-5 km represents the level dividing the shallower GMM domain from the deeper one (Tusa and Langer, 2016; see also Tarchini et al., this volume).

2.2 Seismogenic faults

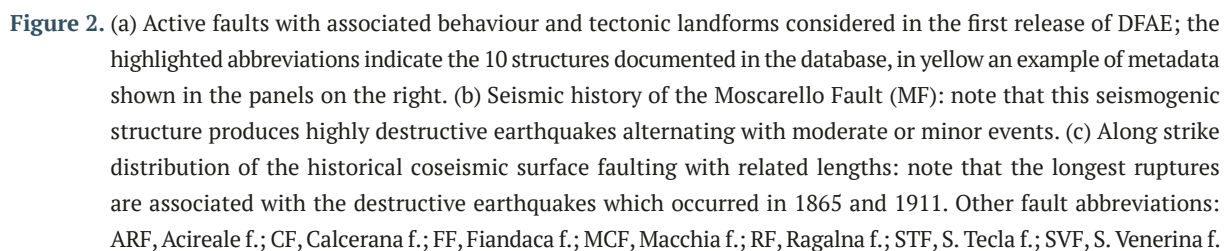
The Etna region is crossed by a dense network of active volcano-tectonic features and faults that are strictly connected to each other (Azzaro et al., 2012), whose activity responds to magma-induced stress and local geodynamic processes. Without addressing the role of the first-order tectonic structures involved in kinematics of the unstable flank (Azzaro et al., 2013a and references therein), we focus here on the key characteristics of the seismogenic faults relevant for the project, and in particular to for the ACF analyses.

Faults at Etna move through complex and strongly heterogeneous rupture mechanisms: different sections of the same fault exhibit either stick-slip behaviour (earthquake-related slip) or stable-sliding behaviour (aseismic creeping), but in some cases coseismic slip and creep can alternate along the same fault segment (Azzaro, 2004). This feature implies that faults result segmented and, when modelling seismic sources for hazard or damage scenarios, they should not be considered for the whole length but only for the segments “radiating” the seismic input.

A second important feature is that fault activity produces prominent surface faulting effects, either due to coseismic displacements or to creep (Rasà et al., 1996; Azzaro, 1999, 2004). These phenomena frequently cause significant ground deformations along strike, including scarp formation, open fractures and aligned hollows, that cause extensive damage to the infrastructures (buildings, roads, water/gas pipes) (Azzaro et al., 1998; Blumetti et al., 2007). The impact on the ACF characterisation is heavy: the areas exposed to the disruptive effects of surface faulting exhibit different extensions depending on the nature of the displacement. In case of earthquake, coseismic ruptures can reach significant lengths along the causative fault, up to 6-8 km, and widths up to 300 m across the fault trace, with a predominant fracturing in the hangingwall (see the features produced by the 2018 earthquake in Tortorici et al., 2021; Tringali et al., 2021; Azzaro et al., 2022). Differently, fault creep produces localised ground ruptures, and damage effects remain limited to the cultural features astride the dislocation lines.

Last but not least, the morphological expression of the tectonic elements plays a key role in the overall structural framework. Since the intrinsically high re-surfacing of a volcanic environment, where lava-flows of different ages may totally or partially cover the fault scarps, each structure exhibits different morphological features along strike. At Etna, three tectonic landforms have been recognised (Azzaro et al., 2012): i) exposed faults, with a clear trace expressed by linear scarps, fresh fault plane and evident vertical offset; ii) buried faults, with a degraded trace masked at a different degree by lava-flows crossing the escarpment or deviated/dammed by counterslope fault planes; iii) hidden faults, without a clear fault scarp but, at most, an extremely smoothed scarplet; they are recognisable in the field by newly formed, short-lived fracture fields following an earthquake or creep episode. These categories are also relevant for ACF applications (see Peronace et al., this volume). In fact, the decreasing level of precision in mapping the fault trace of exposed-buried-hidden sections determines zones more or less wide to comply with the regulations for urban planning according to the SM3 criteria. Nevertheless, the occurrence of recent earthquakes that rupture hidden fault sections provides an extraordinary opportunity to verify and update the mapping of these structures, which is essentially based on the interpretation of historical data (Azzaro, 1999); the most recent and explanatory case is represented by the 2018 M4.9 earthquake of the Fiandaca Fault (Civico et al., 2021; Romagnoli et al., 2021).

The above seismo- and morphotectonic characterisation has been adopted as a reference framework for the “Etna ACF_SM3 Project”. Based on the original dataset of the “Volcano-tectonic map of Mt. Etna” (Azzaro et al., 2012), fault metadata and related cartography have been verified and implemented through new field surveys and analyses of unpublished data and recent literature. This revised and updated dataset led to the publication of a new thematic on-line repository, the “Etnean Active Faults Database” [DFAE]. It is based on a webGIS that reports the interactive mapping of the tectonic elements (Fig. 2) linked with the relevant metadata (seismotectonic behaviour,



3. Seismic hazard

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territory Since the regulatory framework for the local-scale SM3 analysis at Etna is still based on the previous national seismic hazard map MPS04 (MPS Working Group, 2004; Stucchi et al., 2011), we have to define representative seismic scenarios by considering reference spectra consistent with the seismic hazard at the site as well as with the seismic history of the localities of interest. Figure 3a shows PGA values with 10% PoE in 50 years for the whole of Sicily: the eastern sector of the island is characterized by the highest PGA values expected, determined by a number of strong regional earthquakes (1169, 1542, 1693, 1780, 1908) which struck this part of the island in the past. As for the Etna area (blue box in Fig. 3), it is characterized by PGA values in the range 0.125-0.250 g. Although the grid resolution of the national map cannot capture the extreme spatial variability necessary for detailed SM3 analyses at the volcano scale (Fig. 3b), it is nevertheless evident that the highest PGAs are distributed on the eastern flank, with peak values up to 0.250 g in the zone encompassing the municipalities of Zafferana, Acireale and Nicolosi. Conversely, the western flank exhibits lower PGA values, in the range 0.125-0.175 g.

In the last decades, knowledge of the key elements relevant for hazard has significantly increased at Etna – historical and instrumental earthquake catalogues, attenuation models, structural maps, seismotectonic models – allowing to define the input parameters of hazard in a great detail (Azzaro et al., 2017). This process has evolved in various research projects, at first through the probabilistic approach based on the “site seismic histories” (Albarelo and Mucciarelli, 2002; D’Amico and Albarelo, 2008), that can exploit at best the huge macroseismic dataset available for this volcanic region (Azzaro et al., 2016; D’Amico et al., 2025a), and subsequently through the Cornell conceptual approach according to both Poissonian and time-dependent seismicity occurrence models (Azzaro et al., 2013a; Peruzza et al., 2017). The results indicate that for short-medium exposure times (10, 30 years), the expected PGA or intensity due to volcano-tectonic seismicity can even equal or exceed the shaking predicted in 50 years (Gomez Capera et al., 2010; Meletti et al., 2021; Cito et al., 2022), and that the role of site effects due to geological heterogeneity is significant (Panzera et al., 2016).

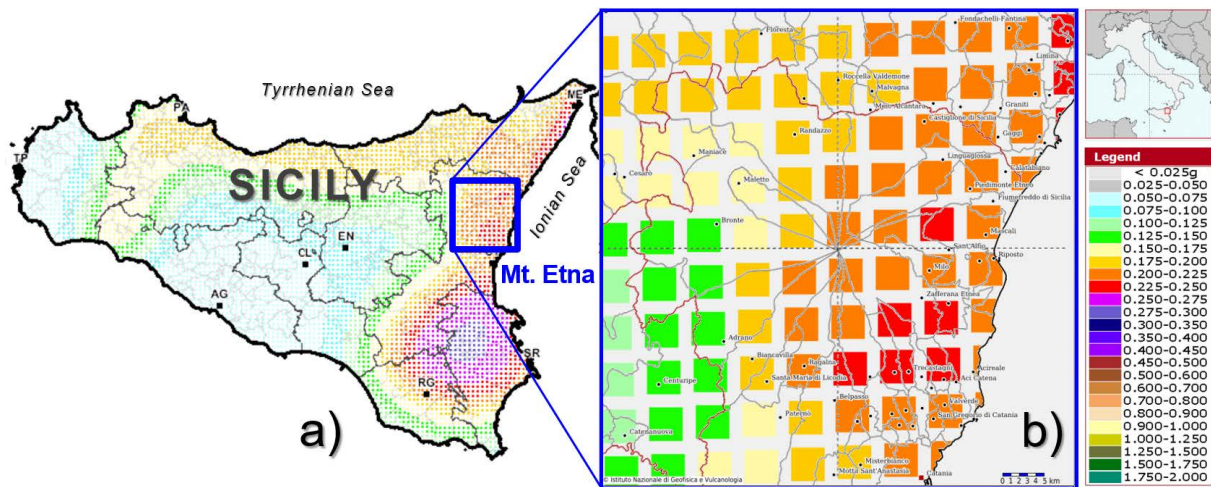


Figure 3. (a) Seismic hazard model MPS04 for Sicily. (b) Detail of Mt. Etna region. Color scale represents expected PGA values with a 10% probability of exceedance in 50 years; the grid has an inter-nodal distance of 5 km (data from <http://esse1-gis.mi.ingv.it/>).

In Fig. 4 we show the intensity values calculated with 10% PoE in 10, 30 and 50 years, obtained through the “site seismic history” approach without taking into account the contribution given by the regional earthquakes. The highest intensities are expected along the faults of the Timpe system, ranging from grade VIII EMS (severe damage) for an exposure time of only 10 years, to grade IX EMS (destruction) for a period of 30 years, finally reaching grade X EMS (total destruction) for 50 years. At the shorter exposure time (10 years), in particular, we can also appreciate the contribution of the Tremestieri (TMF) and Pernicana (PF) faults in producing widespread damage (grade VII EMS) in the areas of Nicolosi and of the “Etna Nord” ski station.

Finally, it is noteworthy that the southern and western flanks of the volcano, although crossed by other fault systems, are characterised by lower intensity (VI EMS, slight damage) related to volcano-tectonic events, that basically represents the attenuation of the seismic input originating from the local seismic sources in the eastern sector.

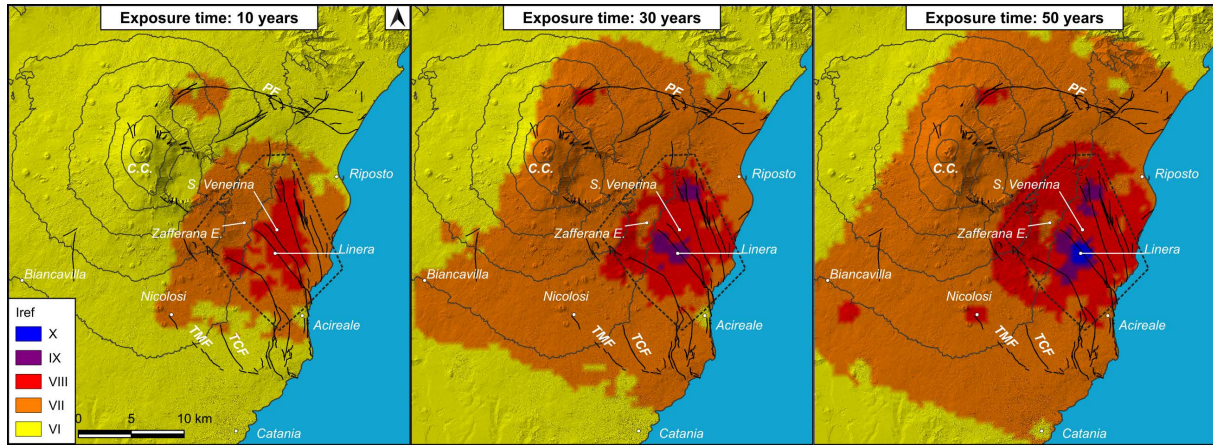


Figure 4. Seismic hazard maps for the volcano-tectonic seismicity of Mt. Etna, expressed in terms of expected intensity (I_{ref}) with an exceedance probability of 10% and calculated for different exposure times (from D’Amico et al., 2025a). Maps are based on historical-macroseismic data, following the “site seismic history” approach; faults are in black (modified after Azzaro et al., 2012); other abbreviations as in Fig. 2.

This confirms that in these sectors as well as in the northern flank of Etna, the hazard due to the volcano-tectonic earthquakes only can be considered negligible.

The above framework, combined with the analysis of site seismic histories, forms the basis for selecting the reference earthquakes to be used for the seismic input in the SM3 analysis.

3.1 Reference earthquakes for the seismic input definition

Since the Etna region is exposed to the effects of both regional tectonic earthquakes and local volcano-tectonic seismicity, the event associated with the most severe effects in the municipality under consideration was identified as the reference earthquake, herein defined as the event used to determine the seismic input for the corresponding SM3 characterization. This was achieved through the critical analysis of the “site seismic histories”, namely the set of macroseismic intensities reported for a given locality in the Italian Macroseismic Database (DBMI15), integrated with the most updated data from CMTE. Figure 5 shows an example of two typologies of seismic histories referring to Etnean localities differently exposed to the earthquake effects, even at a short distance from each other. Pedara exhibits very high intensity values determined by regional earthquakes whereas the macroseismic effects due to volcano-tectonic events are trivial (I_{max} V-VI EMS) albeit frequent. Conversely, Santa Venerina is characterised by an extremely high number of macroseismic observations related to local earthquakes, producing both high and moderate intensity values. Although we cannot exclude the incompleteness of its seismic history before the 19th century, it is evident the contribution of the local seismogenic sources next to this locality (for details see Azzaro et al., 2013b).

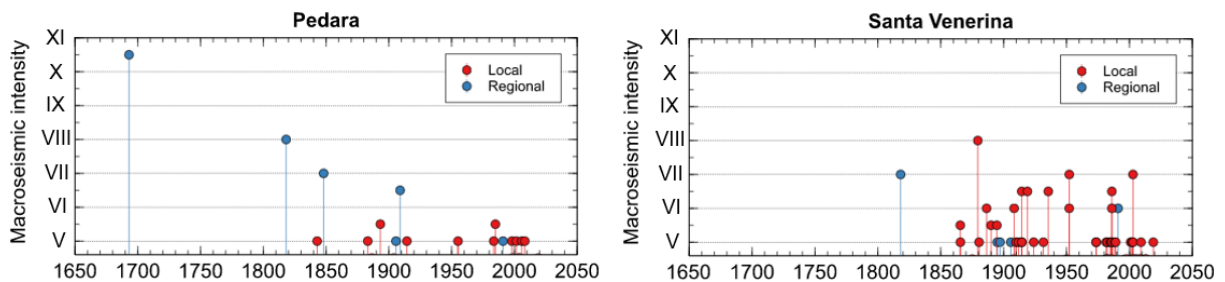


Figure 5. Example of two Etnean localities characterised by seismic histories governed by macroseismic effects due to regional vs volcano-tectonic earthquakes.

A general view of the area distribution of the cumulative macroseismic effects deriving from the local earthquakes in the Etna region, is given in Fig. 6a. We note that the highest values, up to degree IX EMS, are concentrated in the eastern flank of the volcano – the densely populated area between Acireale, Zafferana, Santa Venerina and Sant'Alfio – while some spots of lower intensity degrees (VII or VIII EMS) characterise the northern and southern sectors. Conversely, the piedmont parts of the volcano as well as the metropolitan area of Catania, are not affected by significant macroseismic effects ($I_{\max}$ V EMS).

In conclusion, when the site seismic history of a municipality (municipal capital) is dominated by intensity values caused by regional tectonic events – whatever they may be located – the input spectrum is the one defined by the national seismic hazard map MPS04 (MPS Working Group, 2004), otherwise a reference spectrum has been defined for a volcano-tectonic earthquake considered representative of Etna's seismicity.

Figure 6b and Table 2 show the municipalities interested by the SM3 studies, indicating whether the reference earthquake selected for the definition of the seismic input is regional or local. Note that the areas subject to seismic microzonation include not only the urbanized zones of the municipal capitals, but also several hamlets that represent important residential settlements. The site seismic histories of municipal capitals and related hamlets listed in Table 2 are reported in the Appendix 1.

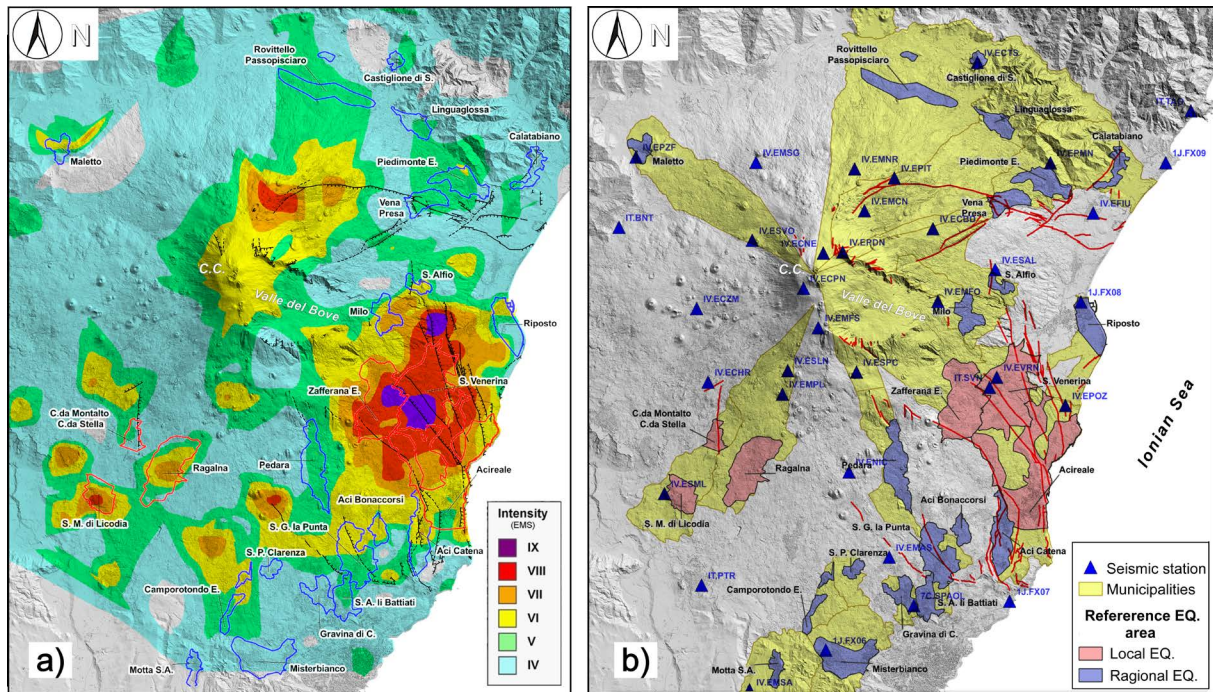


Figure 6. (a) Maximum intensities observed in the Etna region from 1633 to 2026, due to volcano-tectonic seismicity. The map is obtained by the seismic histories of the 386 localities in the macroseismic database of CMTE, taking the highest intensity value inside a circle with radius of 1 km (in grey, areas not covered by intensity data points). SM3 zones and related reference earthquakes (local vs. regional) are also plotted. (b) Municipalities of the Etna region under study (in yellow) and distribution of the seismic stations used for the analysis. Urbanized zones (municipal capitals and hamlets) subject to SM3 analyses are in red or blue depending on the earthquake assumed as a reference event.

The volcano-tectonic earthquake to be selected as a reference for the local-scale seismic input, should represent a significant event both in terms of damage severity and spatial extent of the affected area. Although the seismic history of the Timpe fault system is rich of strong or destructive shocks (see Table 1), most of these events occurred in the pre-instrumental era and this entails a certain degree of uncertainty in the definition of the relevant parameters such as the magnitudes, estimated through the Intensity-Magnitude relationship (D'Amico et al., 2025b), and the hypocentral depths, which remain undetermined although indeed shallow ($H \leq 4$ km). In order to better constrain the seismic source to be used as a reference, we therefore selected the December 26, 2018 earthquake (star with fuchsia border

Table 2. Reference earthquakes for the municipalities under study.

Municipalities and hamlets	Regional reference earthquake	Volcano-tectonic reference earthquake (Fleri, 2018)
Aci Bonaccorsi	Target 1-SVN	
Aci Catena	Target 1-SVN	
Acireale and southern hamlets	Target 1-SVN	
Acireale, northern hamlets	Target 1-SVN	Target 4-RLS23
Calatabiano	Target 2-CPR	
Camporotondo	Target 2-CPR	
Castiglione di Sicilia, Moio, Passopisciaro, Rovittello	Target 2-CPR	
Gravina di Catania	Target 1-SVN	
Linguaglossa	Target 1-SVN	
Maletto	Target 3-MBN	
Milo	Target 1-SVN	
Misterbianco	Target 3-MBN	
Motta S. Anastasia	Target 3-MBN	
Pedara	Target 1-SVN	
Piedimonte, Vena, Presa	Target 1-SVN	
Ragalna	Target 1-SVN	Target 4-RLS23
Riposto	Target 1-SVN	
S. Agata lì Battiati	Target 2-CPR	
S. Giovanni la Punta	Target 1-SVN	
S. Maria di Licodia, C.da Montalto, C.da Stella	Target 1-SVN	Target 4-RLS23
S. Pietro Clarenza	Target 2-CPR	
S. Venerina	Target 1-SVN	Target 4-RLS23
S. Alfio	Target 1-SVN	
Zafferana Etnea	Target 1-SVN	Target 4-RLS23

in Fig. 1a), which is the most significant event occurred at Etna in the last 75 years in terms of both damaged area (Azzaro et al., 2020b) and extension and complexity of coseismic faulting phenomena (Tortorici et al., 2021; Tringali et al., 2021; Azzaro et al., 2022) relevant for the characterisation of ACF issues (see Peronace et al., this volume).

Table 3. Instrumental parameters of the earthquake of December 26, 2018, 02:19 UTC (from Alparone et al., 2022). The moment magnitude (M_w) value is from CPTI15.

Long	Long	Depth (km)	M_L	M_w
37.644	15.116	-0.29	4.8	5.0

In addition to well constrained instrumental earthquake parameters (Table 3), strong-motion recordings are also available. In particular, the closest accelerometric station – S. Venerina (SVN), part of the Italian National Accelerometric Network (RAN) – recorded a peak acceleration (PGA) equal to 0.56 g at a distance of ca. 5 km. It should be stressed that this station is positioned orthogonally to the causative Fiandaca fault, that is in the direction of maximum attenuation with distance (Azzaro et al., 2006, 2013b). The role of anisotropic spreading is important at Etna, and should be considered to simulate the near-field shaking produced by this type of event. Nevertheless, the observed high PGA value at SVN also reflects site amplification effects, as the stations in this sector of the volcano tend to amplify the seismic shaking (see Tarchini et al., this issue; Laurenzano et al., this issue).

4. Seismic input

4.1 Selection of accelerograms

Different approaches can be adopted for the selection and generation of accelerograms within the framework of Seismic Microzonation (Gruppo di Lavoro MS, 2008). In the present study, the seismic input was defined through a spectrum-compatible selection of recorded ground motions, so as to preserve the characteristics of real seismic signals (Bommer and Acevedo, 2004; Iervolino et al., 2010). For dynamic soil analyses, the input consists of a set of acceleration time histories at the reference site, selected such that their mean response spectrum matches the target spectrum within prescribed tolerance limits over a given range of vibration periods, thus ensuring consistency with the reference hazard conditions (Gruppo di Lavoro MS, 2008; Iervolino et al., 2010).

The selection of accelerograms is commonly based on recorded ground motions, given the wide availability of national and international strong-motion databases, with scaling factors applied where appropriate to meet target intensity levels. However, in the Etna area, recordings representative of shallow volcano-tectonic events remain limited (Tarchini et al., this issue), particularly for magnitudes comparable to the reference volcanic scenario ($M \approx 5$). Consequently, the selection cannot rely exclusively on recordings from similar events and is primarily governed by spectral compatibility with the target spectra, while additional constraints are imposed on magnitude, distance, and overall spectral properties of the ground motions.

The selection was carried out using the REXELweb tool (Sgobba et al., 2019), which allows defining sets of accelerograms compatible with different target spectra, including both code-based and user-defined spectra. In particular, this feature enables the construction of spectrum-compatible sets not only for standard hazard conditions but also for the volcanic scenario spectrum adopted in this study.

REXELweb queries and integrates records from multiple accelerometric databases (ESM, ITACA, NESS2.0) and automatically identifies combinations that satisfy spectral compatibility criteria under user-defined constraints (e.g., magnitude, distance, site class). The records available in these databases are processed using homogeneous procedures and are associated with high-quality metadata (Puglia et al., 2018), ensuring consistency and reliability of the selected datasets.

4.2 Target spectra

As previously discussed, the seismic hazard affecting the municipalities located on the Etna flank is primarily controlled by regional seismicity. According to the Italian guidelines for seismic microzonation (Gruppo di Lavoro MS, 2008) and subsequent regulatory updates (e.g., Ordinances No. 24/2017 and 55/2018), this contribution is adequately represented by the national seismic hazard model MPS04 (Stucchi et al., 2011).

Following standard practice in microzonation studies, the reference spectra were defined in terms of code-based response spectra corresponding to a return period of 475 years (i.e., 10% probability of exceedance in 50 years) (Fig. 7a). For each municipality, the seismic input is typically represented by a set of seven accelerograms whose mean response spectrum is compatible with the corresponding target spectrum. The use of multiple accelerograms provides a simple way to account for the aleatory variability of the seismic input, while acknowledging that the limited availability of representative records may lead to an incomplete representation of possible ground motion scenarios.

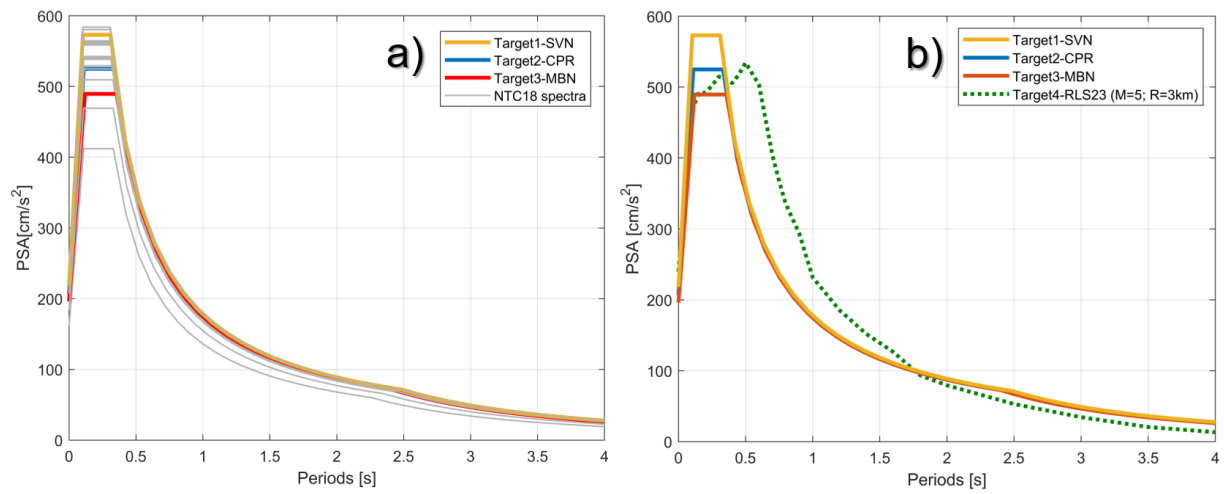


Figure 7. Regulatory UHS (Uniform Hazard Spectra) for a return period of 475 years. a) Target spectra for the 23 municipalities (in grey), with three selected targets for the municipalities of Santa Venerina (Target 1, yellow), Camporotondo (Target 2, blue) and Misterbianco (Target 3, red). b) The spectra of the three municipalities compared with those predicted by the RLS23 (Ramadan et al., 2023) GMM for $M_w = 5.0$ and $R_{hyp} = 3$ km.

The spectra associated with the 23 municipalities show similar shapes, mainly differing in amplitude. The MPS04 deaggregation results (Stucchi et al., 2011) suggest that the seismic hazard in the Mt Etna area is controlled by relatively nearby sources, generally located within about 20 km from the sites, and characterized by similar spectral properties. Additional checks based on the BMSE (Best Matching Scenario Earthquake) approach of Paolucci et al. (2024) did not show major differences among the municipalities in terms of representative magnitude-distance scenarios. The average magnitude is approximately $M 5.8$ from disaggregation, while it shifts towards larger values, around $M 6.5$, when the BMSE procedure is applied.

Given the limited variability among the spectra, the municipalities were grouped into three representative target spectra (Fig. 7b), selected as envelopes of the observed spectral shapes. The grouping was performed by ensuring that the deviation between each individual code-based spectrum and the corresponding target spectrum does not exceed approximately 10% over the period range of interest. The assignment of each municipality to one of the three target spectra (Target 1, Target 2, Target 3) is reported in Table 2. This simplification allows reducing the number of input conditions while preserving the main differences in seismic demand across the study area.

In addition to the code-based spectra, a volcanic scenario spectrum was defined for municipalities located in proximity to active structures, where shallow volcano-tectonic events may significantly contribute to ground shaking. This spectrum was derived considering a representative earthquake with magnitude $M \approx 5$ at a distance of $R \approx 3$ km, consistent with the seismotectonic framework described in the previous sections.

The definition of the volcanic scenario spectrum was based on ground motion prediction models specifically developed for volcanic environments. In such contexts, ground motion is characterized by high amplitudes at short distances, rapid attenuation, relatively long signal duration, and persistent low-frequency energy content (Lanzano

and Luzi, 2020; Tusa et al., 2020; Ramadan et al., 2023). As a result, the corresponding response spectra may differ significantly from those associated with regional tectonic seismicity. In this study, the volcanic scenario spectrum was computed using the model proposed by Ramadan et al. (2023) (RLS23), which was calibrated using recordings from different volcanic districts in Italy, including Mt. Etna, the Aeolian Islands and Ischia, and is therefore suitable for application to the study area. This GMM was also used as a reference predictive model for estimating empirical amplification factors in the study by Laurenzano et al. (in this issue).

RLS23 provides predictions of peak ground acceleration (PGA), peak ground velocity (PGV), and 5%-damped spectral acceleration (SA) over a wide period range ($T = 0.01$ – 5 s), as a function of magnitude, source-to-site distance, and site conditions classified according to EC8. The model adopts the geometric mean of the horizontal components and is calibrated for magnitudes approximately between 3.5 and 4.9 and distances up to about 100 km.

A comparison between the three target spectra and the volcanic scenario spectrum is shown in Fig. 8b, highlighting the differences in spectral shape and amplitude between regional and local contributions, particularly in the period range between $T = 0.2$ s and $T = 1.5$ s. For this reason, the volcanic scenario spectrum was considered in addition to NTC spectra for the municipalities located in areas where the shaking of volcano-tectonic earthquakes prevails.

4.3 Selection criteria

Each input set consists of 7 accelerograms, in agreement with standard microzonation practice (Gruppo di Lavoro MS, 2008). The analyses were carried out considering one horizontal component of motion separately. With reference to site conditions, records were selected primarily from stations classified as EC8 class A, representative of reference bedrock conditions, also including sites where the classification is inferred from geological or topographic information. When necessary, records from classes B and C were also considered. This choice does not significantly affect the selection, as spectral compatibility constrains the shape of the response spectra, reducing the influence of site class (Baraschino et al., 2019). In addition, it should also be noted that site classifications derived from geological or topographic data are often affected by significant uncertainty, also for soil category attribution.

The magnitude and distance ranges were defined to be consistent with the seismic scenarios considered. For tectonic conditions, magnitudes in the range $M_w \approx 5.5$ – 6.6 , derived from MPS04 disaggregation and BSME analyses, were considered, while for volcanic scenarios the selection focused on magnitudes $M_w \approx 4.5$ – 6.0 . Magnitude was expressed in terms of moment magnitude (M_w) and/or local magnitude (M_L), depending on data availability. Source-to-site distances were constrained within 0–50 km for tectonic scenarios and within 0–20 km for volcanic scenarios, as ground motion in the volcanic environment of Mt. Etna is strongly attenuated with distance (i.e., Lanzano and Luzi, 2020; Tusa et al., 2020). No constraints were imposed on the focal mechanism, as its influence on ground motion is generally secondary compared to magnitude and source-to-site distance (Acunzo et al., 2014). Only high-quality digital recordings were considered. In particular, late-triggered records (i.e., recordings starting from the S-wave phase) were excluded to ensure high quality of the input signals. Spectral compatibility was verified over the period range $T = 0.0$ – 2.0 s, extended to short periods to ensure consistency with peak ground acceleration values. Tolerance limits were set to +30% and –10%, in agreement with the Italian seismic code (NTC2018) and microzonation guidelines (Gruppo di Lavoro MS, 2008). No scaling of the records was applied in the selection procedure, in order to preserve the original characteristics of the ground motions. The ASCII files of the accelerograms obtained from the selections made using Roxelweb, are available in Appendix 2. Details are available in the Data Availability statement section.

4.4 Results

Figure 8 shows the spectra of the selected accelerograms, their average, and the reference spectrum for the four targets under consideration. In all cases, the average score is less than 0.13, indicating excellent agreement between the average spectrum of the set and the target spectrum (values ≤ 0.2 indicate a reliable selection).

However, there are cases of records whose spectral trends deviate from the average, exhibiting very significant peaks over short periods: this is the case for the record obtained from Target 1 selection (Fig. 8a), relative to station 109 of the Icelandic SM network, which recorded a regional earthquake with a peak exceeding 1.8 g at $T = 0.05$ s; the Target 2 selection (Fig. 8b) also includes the recording from station VAZ, belonging to the Iranian I1 network, with a peak at very short periods of almost 1.2 g. In other cases, no selected records with anomalous trends are observed.

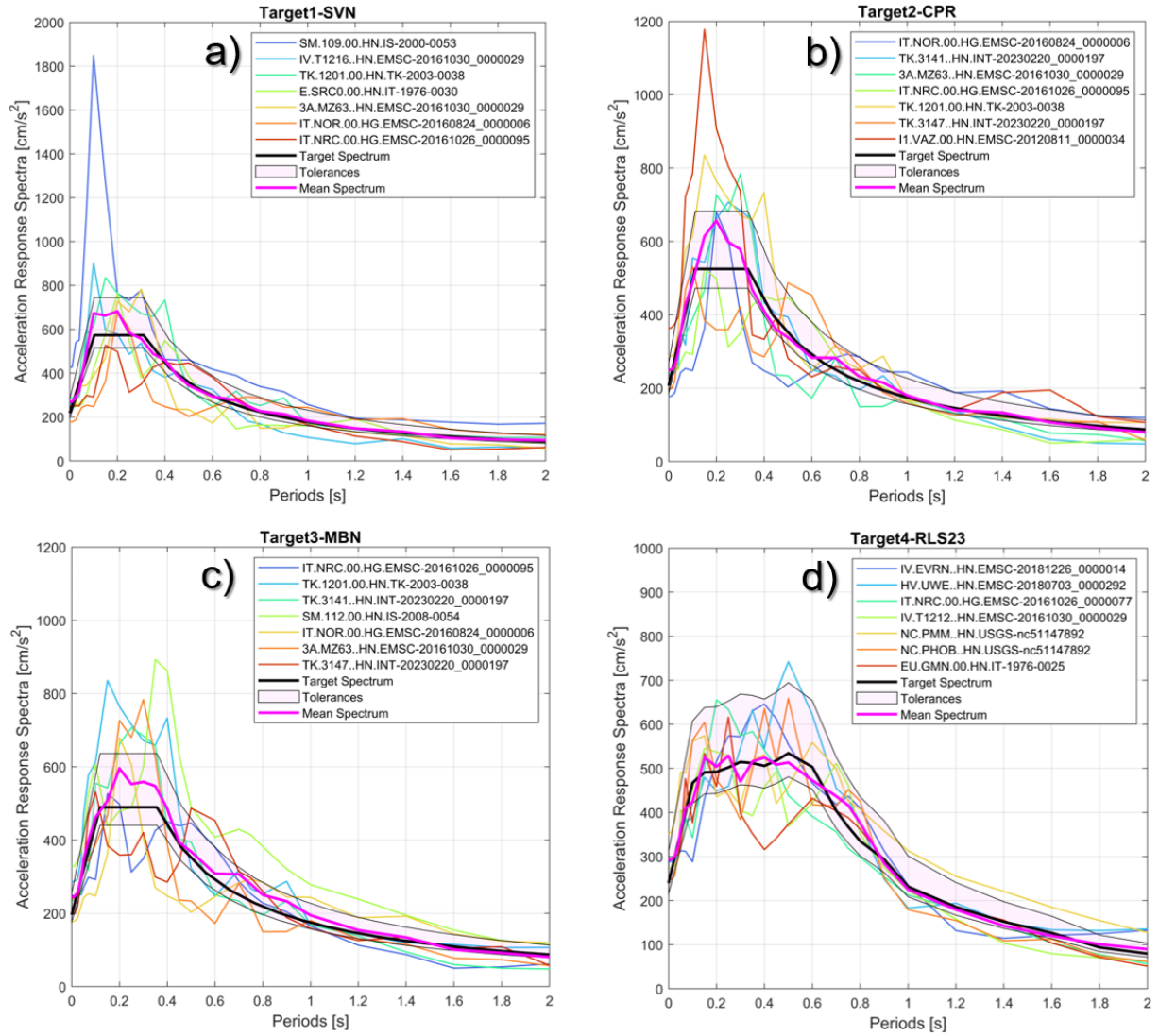


Figure 8. Spectra of the selected accelerograms (coloured), the average spectrum (magenta) and target spectrum (black), with associated tolerance for spectral compatibility: (a) Target 1 (NTC18 Santa Venerina); (b) Target 2 (NTC18 Camporotondo); (c) Target 3 (NTC18 Misterbianco); (d) Target 4 (prediction of RLS23 GMM for $M_w = 5.0$ and $R_{hyp} = 3$ km).

Table 4 lists the records obtained from the four selections, along with some relevant metadata (magnitude, distance, event depth, $V_{s,30}$, PGA, component). The last column also shows the target corresponding to each waveform. A very strong similarity can be observed between the NTC target spectra, as four waveforms recur in three selections; two others were obtained from two spectral matches (Targets 2 and 3). In contrast, the waveforms from the selection with the scenario spectrum (Target 4) are different from the NTC ones, confirming that they are representative of a peculiar seismicity.

With regard to the target regulatory spectra, it is noted that all the selected accelerograms were recorded within 35 km of the epicenter, although more than half of those selected have a $R_{epi} < 20$ km. Furthermore, the moment magnitudes of the events corresponding to the recordings range from 5.9 to 6.6 (approaching the upper limit of the selection range). The depths of the events are between 4 and 12 km below sea level, indicating a range typical of crustal seismicity, and at its lower limit also consistent with volcano-tectonic seismicity ($h = 4.2$ km). The selected events include a number of significant earthquakes that have occurred in Italy over the last 50 years, such as one of the major aftershocks (3rd main shocks) of the Friuli sequence of 15 September 1976 (M_w 6.0) and the three strongest earthquakes of the 2016–2017 central Italy sequence, namely the Amatrice earthquake (24 August 2016, M_w 6.0), the Visso earthquake (26 October 2016, M_w 5.9) and the Norcia earthquake (30 October 2016, M_w 6.6). The list also

includes two earthquakes that occurred in Turkey: the Bingöl earthquake of 1 May 2003 (M_w 6.4) and an aftershock of the devastating 2023 Turkey-Syria earthquake sequence, which occurred on 20 February with a magnitude of M_w 6.3. There were also two strong earthquakes in Iceland, with similar characteristics (both strike-slip earthquakes, both involving pairs of strong events occurring just a few days apart), which occurred in the seismic zone of southern Iceland on 21 June 2000 (M_w 6.5) and 29 May 2008 (M_w 6.3). Finally, the mainshock of the Ahar-Varzaqan sequence (Iran-Azerbaijan), which occurred on 11 August 2012 (M_w 6.4), has also been included in the selection.

Table 4. List of recordings selected as input for numerical analyses, along with some basic metadata. M: VS30 measured; I: VS30 inferred from proxy; N: north-south horizontal component; E: east-west horizontal component; 2,3: generic horizontal component. Target 1: NTC18 Santa Venerina; Target 2: NTC18 Camporotondo; Target 3: NTC18 Misterbianco; Target 4: predictive scenario for $M_w = 5.0$ and $R_{hyp} = 3$ km. Note that negative focal-depth values indicate locations above sea level.

Event time	Depth [km]	M_w	Net code	Station code	EC8 class	$V_{s,30}$ [m/s]	Method $V_{s,30}$	Repi [km]	PGA [cm/s ²]	Comp	Target
2000-06-21	8.7	6.5	SM	109	B			17.8	426	2	1
2016-10-30	6.2	6.6	IV	T1216	B			10.3	260	E	1
1976-09-15	11.3	6.0	E	SRC0	A			15.8	245	E	1
2016-08-24	8.1	6.0	IT	NOR	B	423	M	15.6	177	N	1/2/3
2016-10-30	6.2	6.6	3A	MZ63	B	562	M	28.3	239	E	1/2/3
2016-10-26	2.1	5.9	IT	NRC	B	498	M	13.6	248	E	1/2/3
2003-05-01	10.7	6.4	TK	1201	B	382	I	11.6	286	E	1/2/3
2023-02-20	10.0	6.3	TK	3141	B	414	I	29.6	235	E	2/3
2023-02-20	10.0	6.3	TK	3147	B	372	I	28.9	198	N	2/3
2012-08-11	8.7	6.4	I1	VAZ	B	475	M	34.9	364	2	2
2008-05-29	4.2	6.3	SM	112	A			4.3	328	3	3
2018-12-26	-0.3	5.0	IV	EVNR	C	298	M	5.3	295	E	4
2018-07-03	-0.1	5.3	HV	UWE	A			1.8	288	E	4
2016-10-26	3.4	5.5	IT	NRC	B	498	M	11.2	295	E	4
2016-10-30	6.2	6.6	IV	T1212	A			11.6	273	N	4
2004-09-28	8.1	6.0	NC	PMM	B	654	I	19.6	350	E	4
2004-09-28	8.1	6.0	NC	PHOB	B	376	M	11.7	247	N	4
1976-09-11	4.3	5.6	EU	GMN	B	445	M	9.4	294	E	4

The focal mechanisms of the selected events (not shown in the table) are both dip-slip (normal faulting earthquakes in central Italy and reverse in Friuli) and strike-slip (all events outside Italy), indicating the marginal role of the style of faulting in the selection. All the events considered in these selections are primarily of tectonic origin, although there is a link between local volcanism and earthquakes occurring in Iceland.

The station sites identified through spectral matching with regulatory targets mainly fall into the EC8 B subsoil category (rigid soils), with $V_{S,30}$ values – whether measured or inferred – in the range 370–570 m/s. There are two stations classified as Category A (rock), mainly assigned on the basis of surface geology (Branca et al., 2011). It should be noted that stations SM.109 and SM.112 are located in volcanic environments, and the stratigraphic profiles typically show a succession of Quaternary basaltic lavas interrupted by thin sedimentary or pyroclastic layers (Rahpeyma et al., 2016; Darzi et al., 2024). The PGA values range from 0.17 g to 0.43 g, averaging 0.27 g, 0.254 g and 0.249 g for Targets 1, 2 and 3, respectively. The values reflect the decreasing level of shaking from Target 1 to 3 and are consistent with the anchor accelerations in the regulatory spectrum, which range from 0.2 to 0.22 g.

For the scenario spectrum of the volcano-tectonic event, the selection of accelerograms includes recordings with moment magnitudes ranging from 5.0 to 6.6, which exceed the reference value for scenario prediction (M_w 5.0), in order to ensure compatibility even at longer periods. The distances are on average shorter, almost all within 12 km, and the depths of the events do not exceed 8 km.

It is interesting to note that two records related to volcano-tectonic earthquakes were included in the selection: the Santa Venerina record (station code EVRN, IV network) of the Fleri earthquake on Mt Etna (see Section 3.1), with a magnitude and distance consistent with the scenario earthquake; a recording from the Hawaiian Islands (network code HV, station code UWE) relating to an earthquake that occurred on 3 July 2018 with a magnitude of M_w 5.3 and a very short distance ($R_{epi} = 1.8$ km), which also has characteristics similar to the reference scenario. It should be noted that both events occurred at depths below mean sea level: this is common in earthquakes in volcanic areas, which are very shallow on topographies where the elevation exceeds the depth of the event. The other earthquakes are all of tectonic origin and include: two recordings relating to events in central Italy, namely the Norcia earthquake (30 October 2016, M_w 6.6) and an aftershock of the Visso earthquake (26 October 2016, M_w 5.5); a recording of an aftershock from the 1976 Friuli sequence (earthquake of 11 September 1976, M_w 5.6); two recordings of the Parkfield earthquake in California, which occurred on 28 September 2004 with M_w 6.0. Again, the focal mechanisms include all types of faulting (strike-slip, normal dip-slip and reverse). The recording stations are located on EC8-A (2 stations) and EC8-B (4 stations) sites. The EVRN station, which is included in the selection, was initially classified as category B based on the correlation with proxy; following characterisation as part of the Seismic Microzonation project, it was reclassified as category EC8-C, as on soft soil with a $V_{S,30} = 298$ m/s (Tarchini et al., this issue). The PGA values of the selected recordings show very little variability, ranging between 0.25 and 0.350 g, with an average value of 0.29 g, which is similar to the PGA value of the RSL23 spectrum, which is approximately 0.25 g.

Figure 9 shows some examples of selected waveforms: two for selections with regulatory spectra as their targets (Fig. 9a–b), and two for the volcano-tectonic scenario spectrum (Fig. 9c–d). The representative waveforms for the selections with Targets 1, 2 and 3 are those of a Turkish earthquake recorded by station 3141 of the TK network and that of an earthquake in central Italy recorded by the temporary station (MZ63) of the 3A network, installed for seismic microzonation purposes (Cara et al., 2019). The recordings exhibit a marked high-frequency component, but also a non-negligible low-frequency component, which is particularly noticeable in the signal from central Italy, which, after 30 seconds, shows a signal with a very well-defined mono-frequency carrying wave.

In the case of selection using the scenario spectrum, Figs. 9c and 9d show the two waveforms of volcano-tectonic earthquakes, namely the IV.EVRN and HV.UWE records. In both cases, low-frequency waves characteristic of volcanic earthquakes are clearly visible. These are often characteristic of near-source impulse records or of those exhibiting surface waves in the trace. The difference between IV.EVRN and HV.UWE is that the former also has a non-negligible high-frequency component, whereas in the case of the Hawaiian record, this appears almost entirely absent (this is also evident in the spectral form in Fig. 9d, which shows a peak at $T = 0.6$ s). Among the other Target 4 records, the Norcia (IT.NRC) record is also noteworthy, as it exhibits a profile with velocity inversions similar to those observed at sites in volcanic areas, albeit of a different origin, and is located near a basin, often showing traces of surface waves in the records (Luzi et al., 2019).

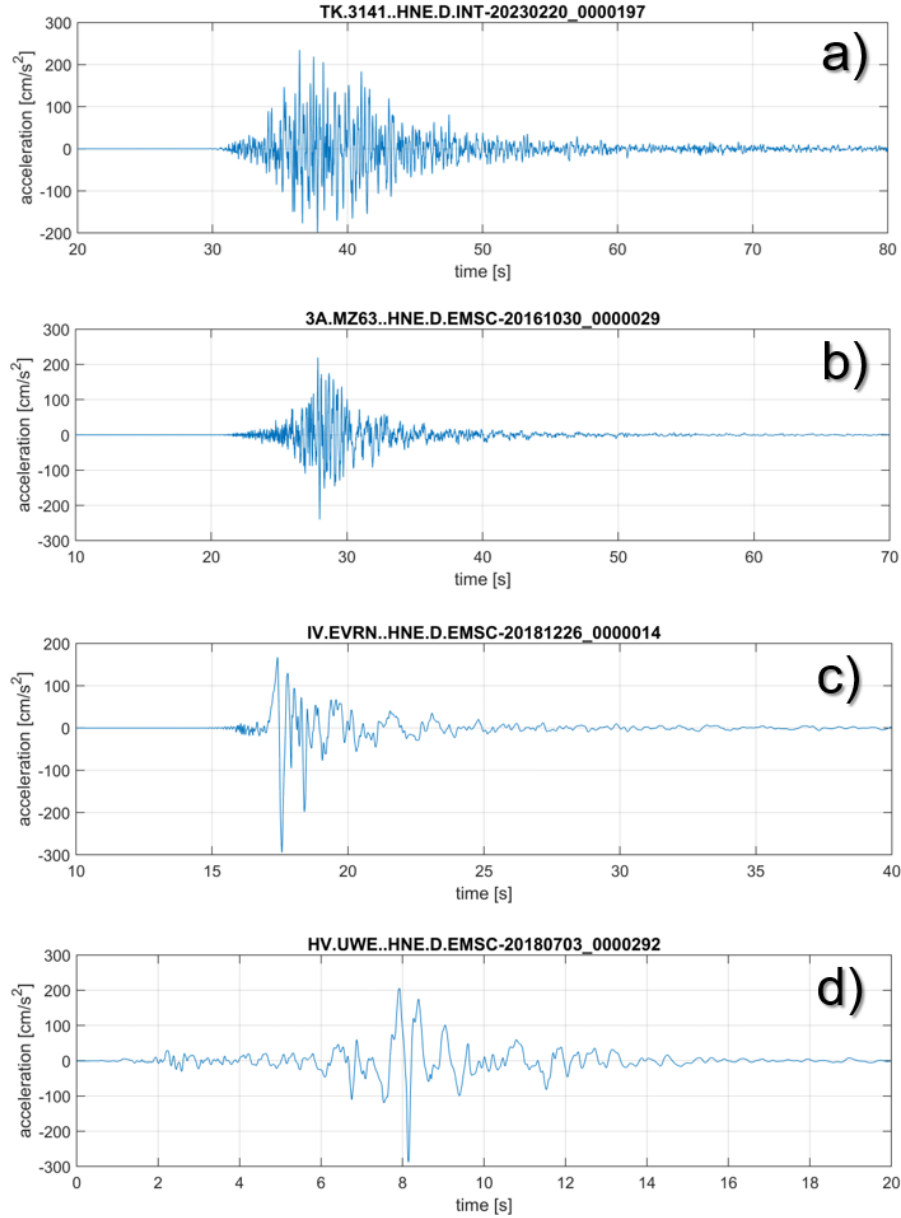


Figure 9. Examples of waveforms obtained from selections of: (a, b) target spectra from the NTC18 standard; (c, d) target scenario spectrum from the GMM prediction for $M_w = 5.0$ and $R_{hyp} = 3$ km.

5. Conclusions

This study provided an integrated seismotectonic and seismic hazard framework aimed at defining the reference seismic input for SM3 and ACF investigations in the Mt. Etna region. The complex coexistence of regional tectonic structures and shallow volcano-tectonic sources poses a major challenge for local seismic hazard and risk assessment, which cannot be adequately captured through the standard approaches only. A crucial role has been played by the rigorous exploitation of over 400 years of historical macroseismic records from the CMTE catalogue: in a volcanic environment characterized by frequent but highly localized and destructive events, historical macroseismic data represent one of the most reliable tools for reconstructing local seismic histories.

The combined analysis of the seismic histories and the local seismotectonic framework made it possible to identify municipalities where volcano-tectonic earthquakes play a dominant role in the expected ground motion scenarios, thus supporting the definition of ad-hoc target spectra specifically representative of the local seismic context. Accordingly, the target spectra adopted for SM3 analyses were derived from reference earthquake scenarios representative of both regional tectonic and shallow volcano-tectonic events.

For the municipalities mainly affected by the macroseismic effects of regional tectonic earthquakes, the seismic input was represented through code-based spectra consistent with the NTC18 prescriptions, and associated with a return period of 475 years. Owing to the limited variability among the corresponding spectra, the municipalities were grouped into three representative target spectra, allowing a simplification of the input conditions while preserving the differences in seismic demand across the study area. For the municipalities located close to active seismogenic structures, the standard code-based approach was integrated with an additional volcanic scenario spectrum derived from a representative shallow earthquake ($M_w \approx 5$, $R_{hyp} \approx 3$ km), calibrated on the seismotectonic characteristics of the Etna region and based on the RLS23 ground motion model. The introduction of this additional spectrum was motivated by the peculiar spectral characteristics of volcano-tectonic ground motions, which are characterized by stronger amplitudes in the intermediate-period range and a rapid attenuation with distance. The selection of accelerograms was performed through the REXELweb platform, ensuring consistency between the selected records and the target spectra over the period range relevant for engineering applications. The resulting datasets include recordings from both tectonic and volcanic environments, thus improving the representation of the variability of the seismic input expected in this area.

Overall, the adopted methodology provides a coherent and physically grounded framework for defining the seismic input at Etna. The proposed strategy therefore represents a useful reference for seismic microzonation studies in other volcanic areas in Italy, where the seismic hazard used for regulatory purposes does not fully account for the contribution of shallow volcano-tectonic earthquakes.

Data and sharing resources. Data used in this study were obtained from the following online resources:

- CMTE: Azzaro, R. and S.D'Amico (2026). Macroseismic Catalogue of Etnean Earthquakes (CMTE2), version 2.0, 1633-2026 [Data set], Istituto Nazionale di Geofisica e Vulcanologia (INGV), doi:10.13127/cmte.2.
- CPTI15: Rovida, A., M. Locati, R. Camassi, B. Lolli, P. Gasperini and A. Antonucci (2022). Italian Parametric Earthquake Catalogue (CPTI15), version 4.0 [Data set], Istituto Nazionale di Geofisica e Vulcanologia (INGV), doi:10.13127/CPTI/CPTI15.4.
- DBMI15: Locati, M., R. Camassi, A. Rovida, E. Ercolani, F. Bernardini, V. Castelli, C. H. Caracciolo, A. Tertulliani, A. Rossi, R. Azzaro, S. D'Amico and A. Antonucci (2022). Italian Macroseismic Database (DBMI15), version 4.0 [Data set]. Istituto Nazionale di Geofisica e Vulcanologia (INGV), doi:10.13127/dbmi/dbmi15.4.
- DFAE: Azzaro, R. and S.D'Amico (2026). Etnean Active Fault Database, [Data set], Istituto Nazionale di Geofisica e Vulcanologia (INGV), <https://www.ct.ingv.it/macro/fdae>.
- EtnaSC_2000_2026: joined version of:
 - 2000-2010: Alparone, S. C., V. Maiolino, A. Mostaccio, A. Scaltrito, A. Ursino, G. Barberi et al. (2015). Mt. Etna Seismic Catalog 2000-2010 [Data set], Istituto Nazionale di Geofisica e Vulcanologia (INGV) – Osservatorio Etneo. doi:10.13127/etnasc/2000_2010.
 - 2011-2013: Alparone, S. C., G. Barberi, G. Di Grazia, E. Giampiccolo, V. Maiolino, A. Mostaccio, C. Musumeci, A. Scaltrito and A. Ursino (2020). Mt. Etna Seismic Catalog 2011-2013 (Version 1) [Data set], Istituto Nazionale di Geofisica e Vulcanologia (INGV). doi:10.13127/etnasc/2011_2013.
 - 2014-2016: Alparone, S. C., G. Barberi, G. Di Grazia, E. Giampiccolo, V. Maiolino, A. Mostaccio, C. Musumeci, A. Scaltrito, T. Tuvè and A. Ursino (2020). Mt. Etna Seismic Catalog 2014-2016 (Version 1) [Data set], Istituto Nazionale di Geofisica e Vulcanologia (INGV). doi:10.13127/etnasc/2014_2016.
 - 2017-2019: Alparone, S. C., G. Barberi, G. Di Grazia, E. Giampiccolo, V. Maiolino, A. Mostaccio, C. Musumeci, A. Scaltrito, T. Tuvè and A. Ursino (2022). Mt. Etna Seismic Catalog 2017-2019 (Version 1) [Data set], Istituto Nazionale di Geofisica e Vulcanologia (INGV). doi:10.13127/etnasc/2017_2019.
 - 2020-2026: Barberi, G., G. Di Grazia, F. Ferrari, M. Firetto Carlino, E. Giampiccolo, V. Maiolino, A. Mostaccio, C. Musumeci, A. Scaltrito, M. Sciotto, G. Tusa, T. Tuvè and A. Ursino (2020). Mt. Etna Revised Seismic Catalog from 2020 (EtnaRSC2020) (Version 1) [Data set], Istituto Nazionale di Geofisica e Vulcanologia (INGV). doi:10.13127/etnasc/etnarsc2020.

Data availability statement. The selection results are available in the electronic supplements of this article. For each target spectrum, a .zip file is provided containing: i) 7 acceleration time histories in the 'WAVEFORMS_SET' directory in DYNA 1.2 ASCII format (64 lines of header and acceleration values, in cm/s^2); ii) AVAILABLE_COMBINATIONS.json which reports the available combinations identified by the SET_ID; iii) METADATA_TABLE_SET_X.json which displays

the table containing data and metadata for the selected spectrum combination (identified by the SET_ID); iv) SUMMARY.txt containing a summary of the parameters used for selection.

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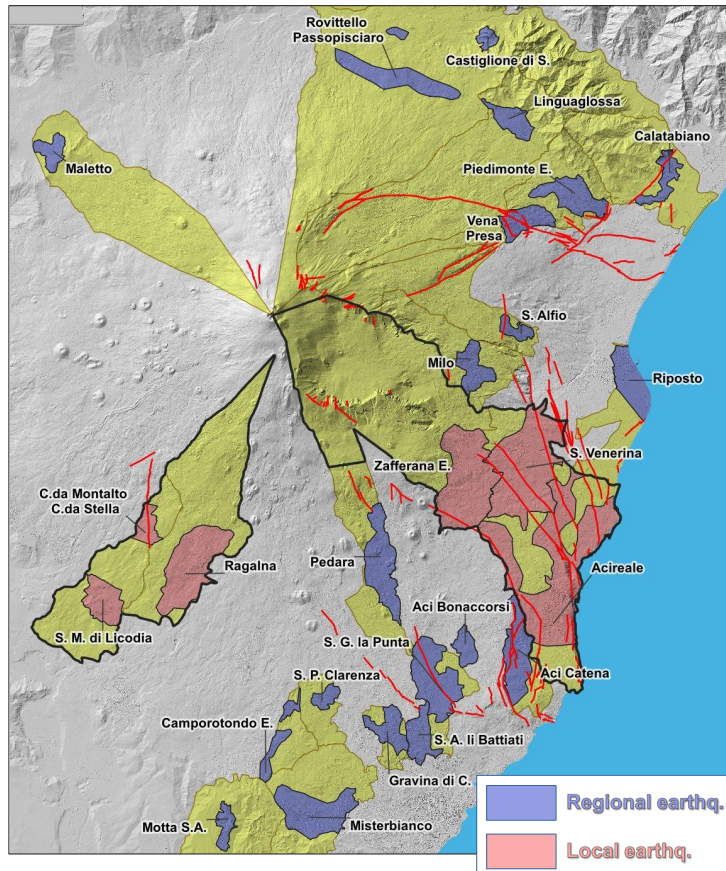
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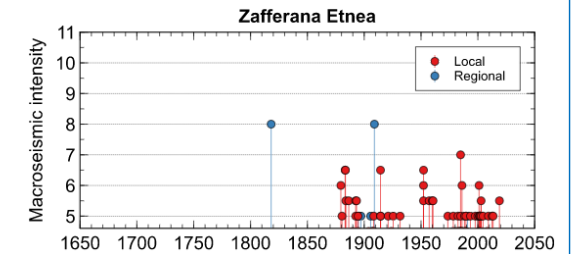
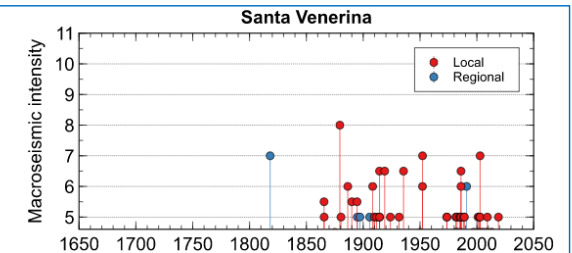
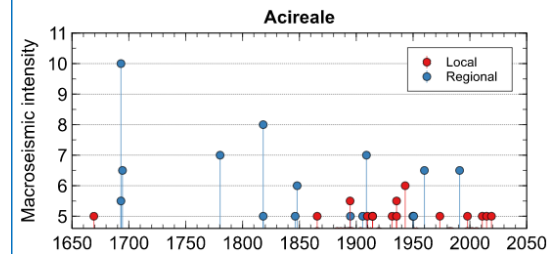
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Appendix 1.

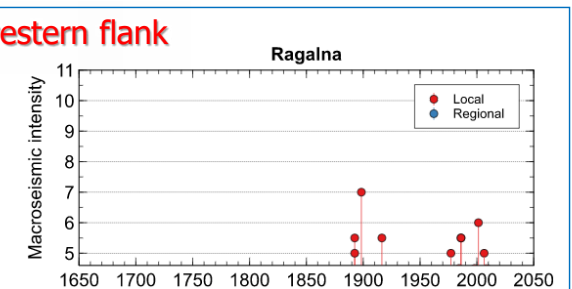
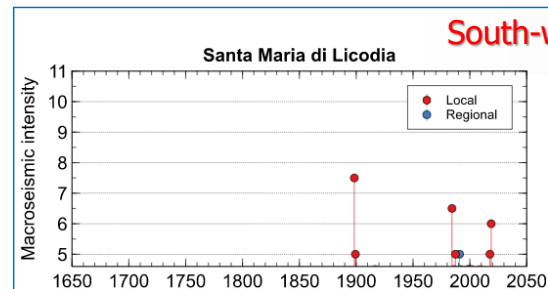
Municipalities investigated by the SM3 analysis: volcano-tectonic earthquake



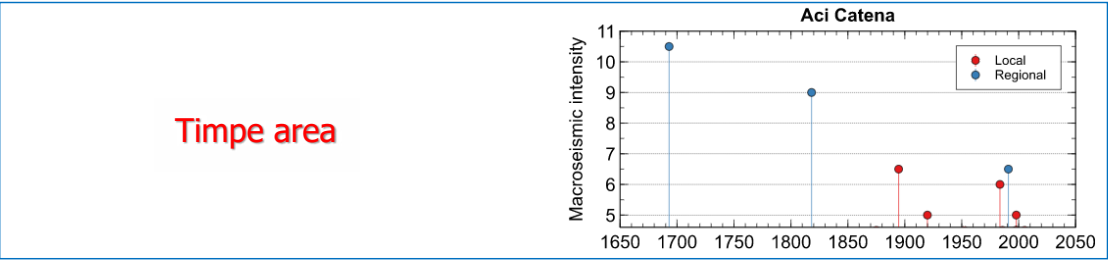
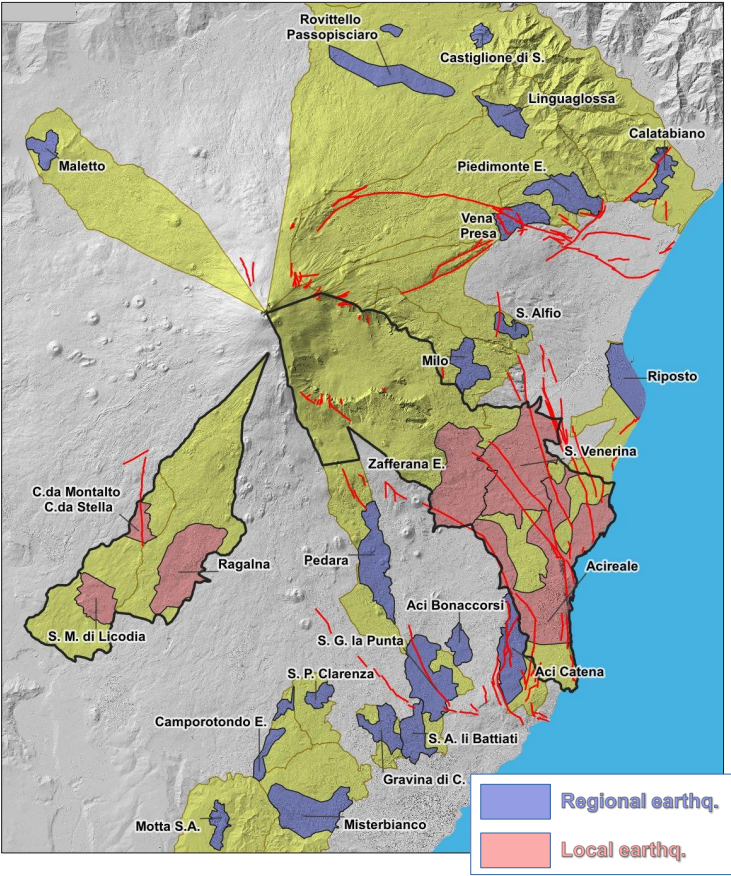
Timpe area



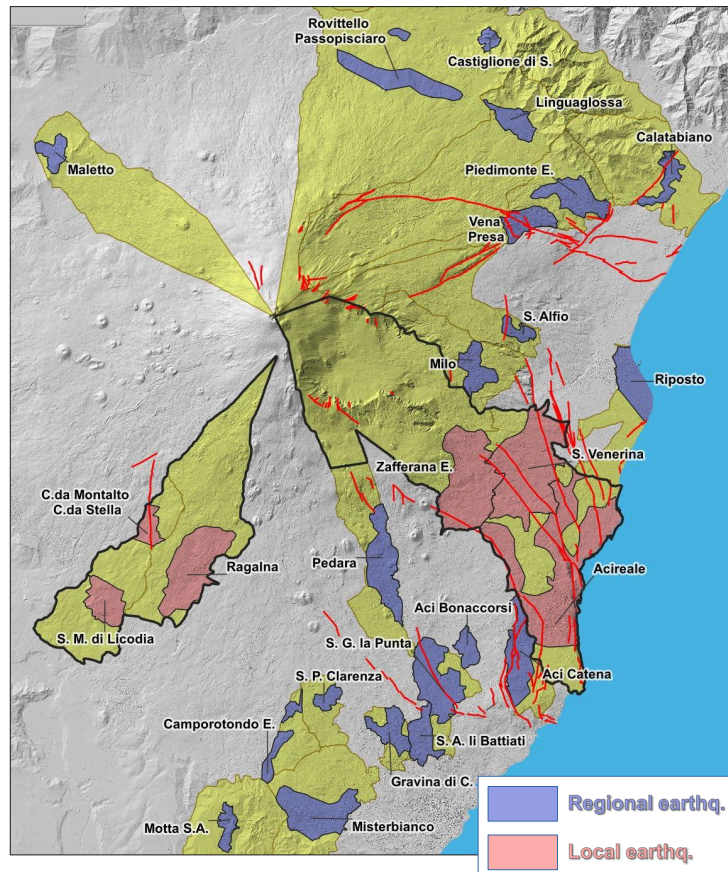
South-western flank



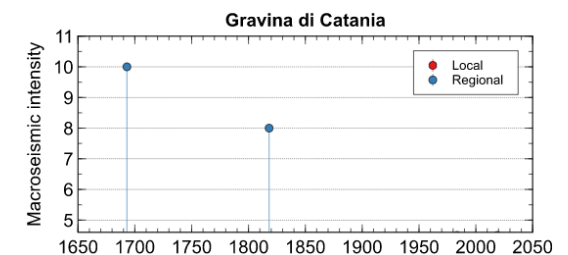
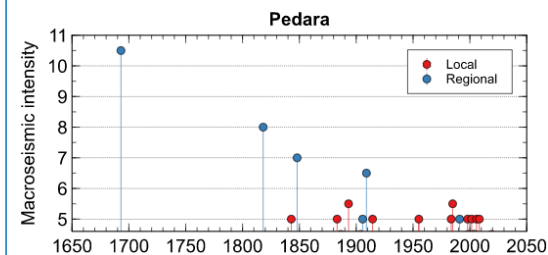
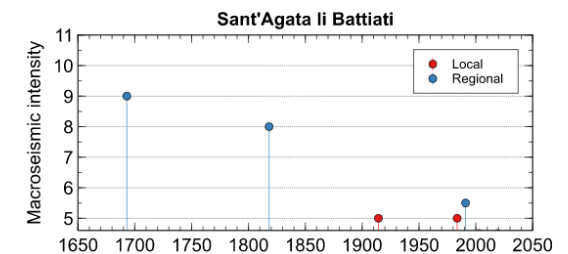
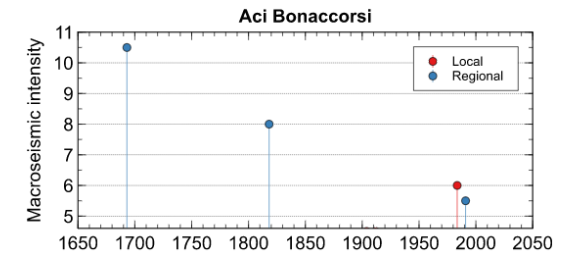
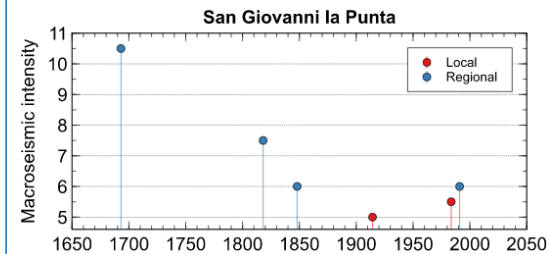
Municipalities investigated by the SM3 analysis: volcano-tectonic earthquake



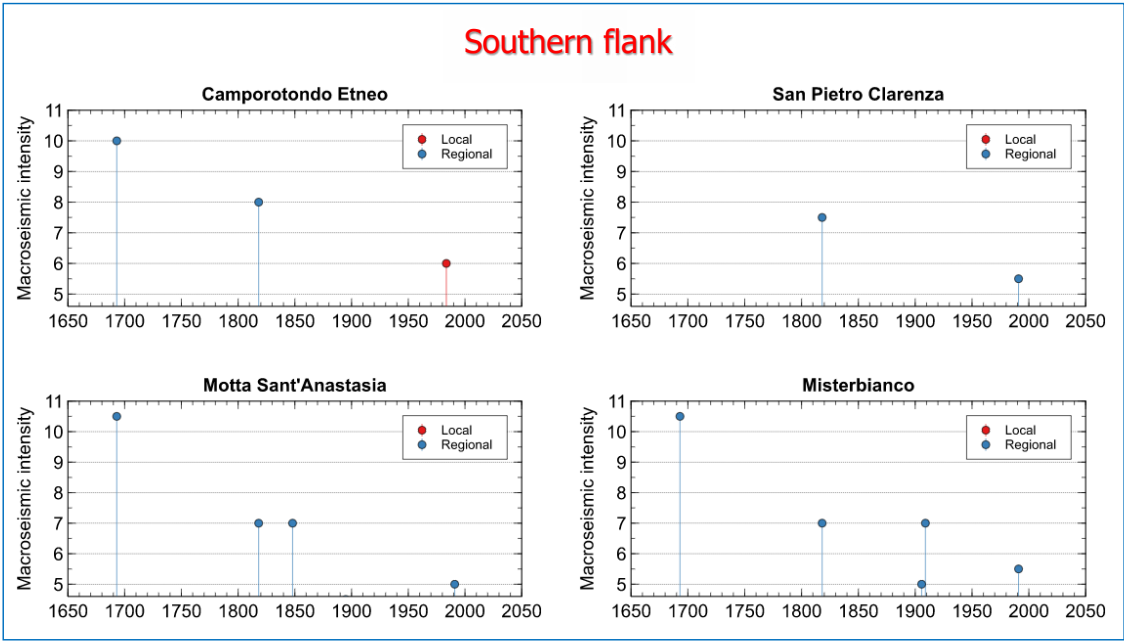
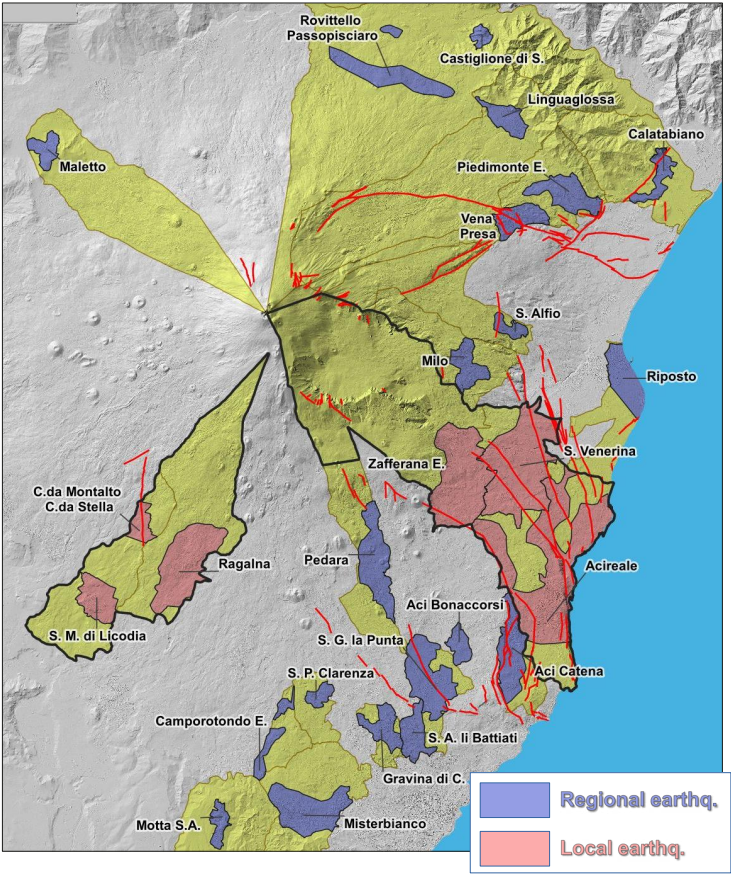
Municipalities investigated by the SM3 analysis: volcano-tectonic earthquake



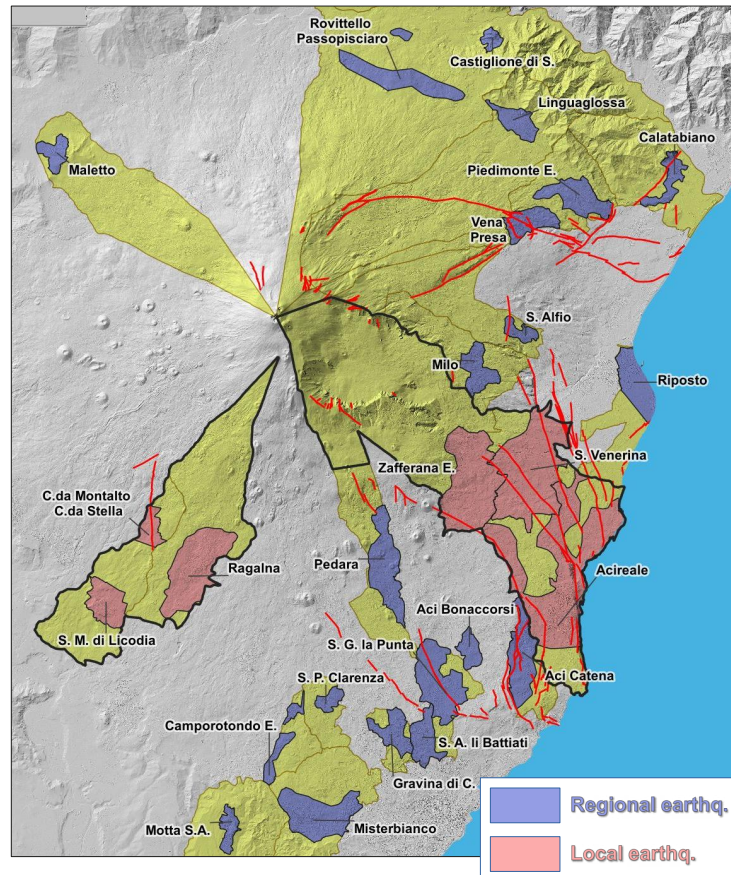
South-eastern flank



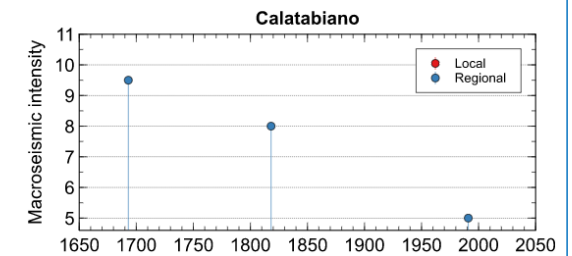
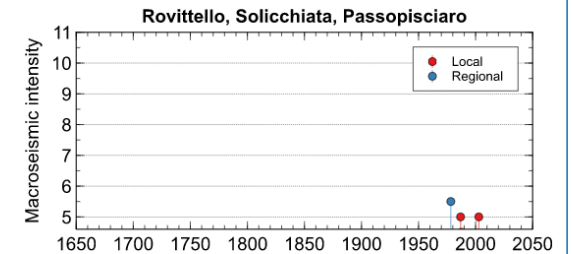
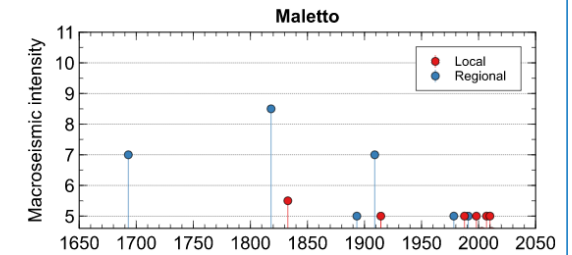
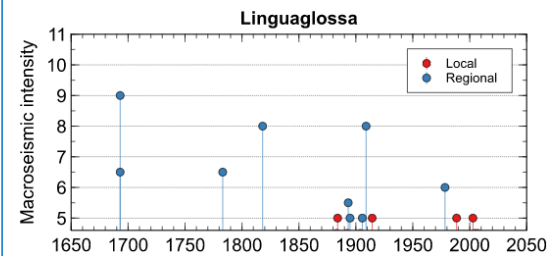
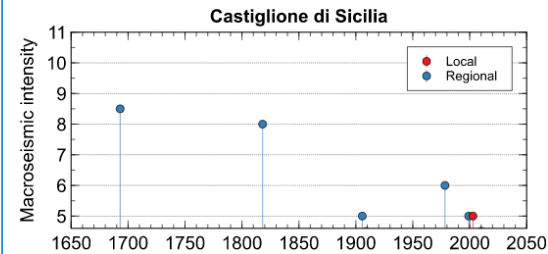
Municipalities investigated by the SM3 analysis: regional earthquake



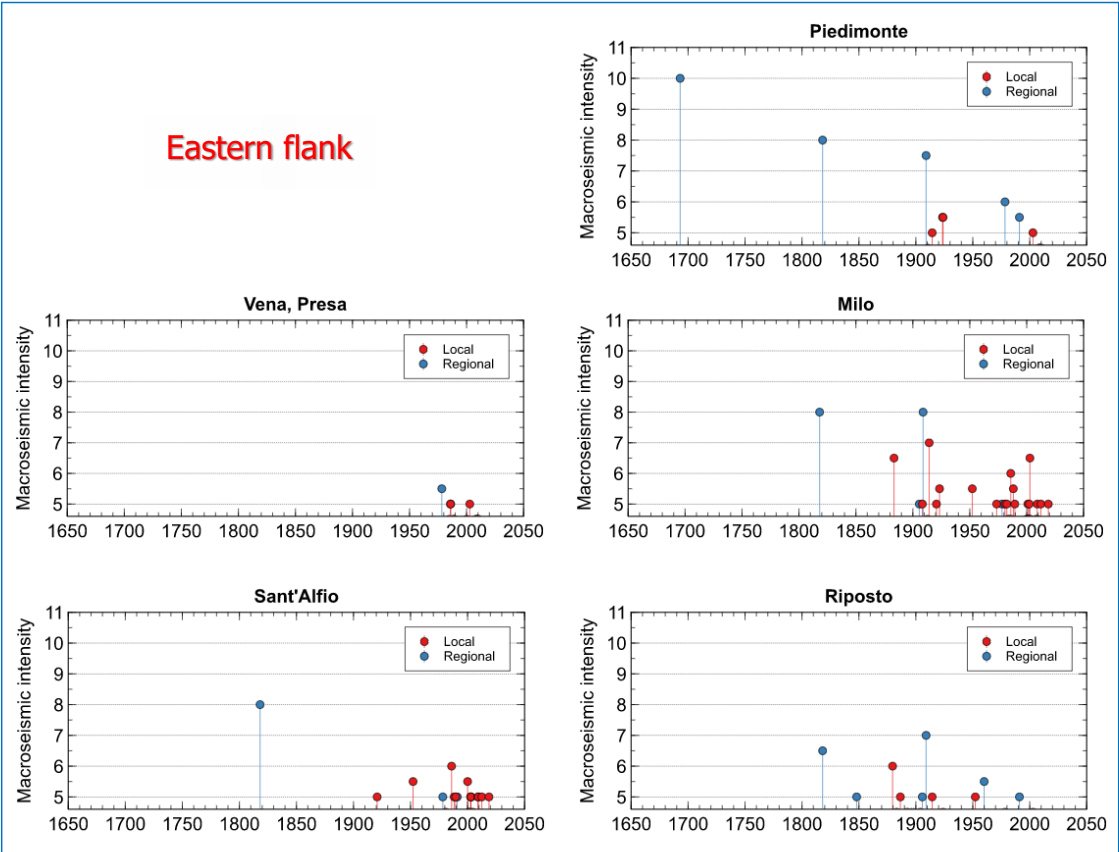
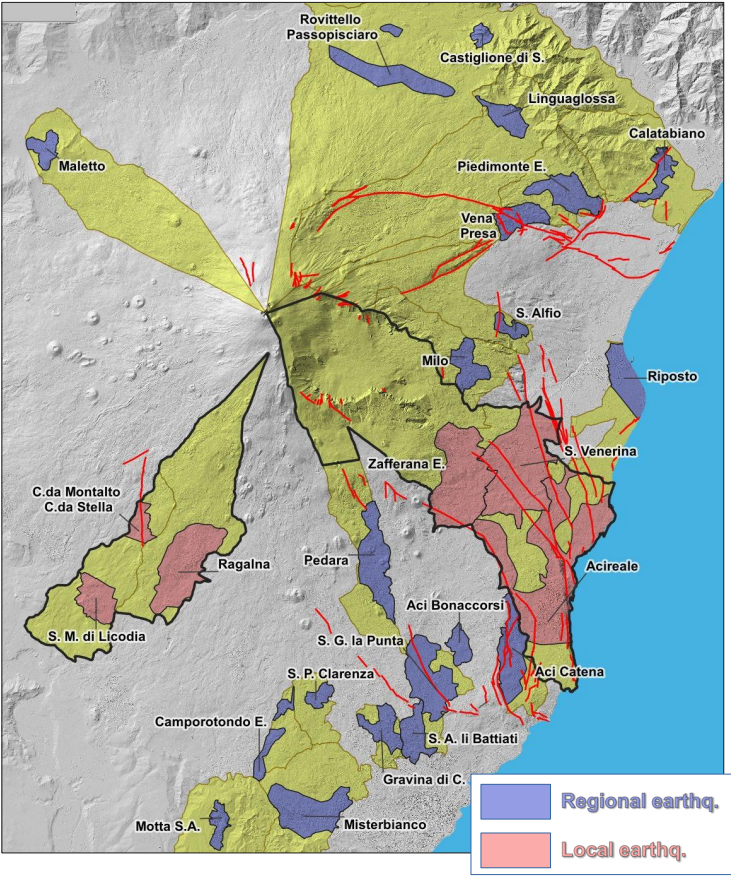
Municipalities investigated by the SM3 analysis: regional earthquake



Northern flank



Municipalities investigated by the SM3 analysis: regional earthquake



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