



# Updating the macroseismic intensity database of 19th century damaging earthquakes in Greece: a case study in Samos Island

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## Abstract

Sources containing descriptive information on earthquake effects in Greece from the period 1800–1899 are analysed and EMS-98 macroseismic intensities are assigned, aiming at the enrichment of the number of macroseismic datapoints contained in the Hellenic Macroseismic Database (HMDB.UoA). Based on the information provided by the analysis, intensities were re-assigned for all events reported in the sources. Compared to the MDPs presented in the Hellenic Macroseismic database, the total number of MDPs from the present study is more than double. Similar procedure was applied to the 19th century Samos and surrounding areas earthquakes including all macroseismic intensity degrees. For the case study of Samos, two macroseismic intensity data sets are presented: the damaging ( $I_{EMS98} > 6$ ) and the non-damaging ones. The macroseismic parameters of one new earthquake were determined and the seismic history of the island showed that two earthquakes, probably similar to the 30 October 2020 Samos event, occurred in the 19th century. New earthquakes improve the seismic history and increased MDPs number allow for more accurate parameters assessment.

**Keywords** Historical earthquakes · Macroseismic intensity data points · Seismic history · Samos island

## Introduction

The value of historical earthquake data for studying long-term seismicity in Greece is illustrated through a considerable number of destructive earthquakes in the 19th century. Although the area was tectonically active, the seismic history of Greece is not uniformly documented throughout the centuries, due to the availability of the historical sources. 19th century was dominated by the historical events that took place in the area: the Greek War of Independence in 1821, recognition of the autonomy of the Greek state from the Ottoman Empire in 1828 and recognition of Greece as a fully independent kingdom in 1832, in the Treaty of Constantinople.

Earthquakes were present throughout the 19th century in the daily life of Greeks, in parallel to all other catastrophes (the war of Independence, strife, other natural phenomena, etc.). In most cases, earthquakes struck the already vulnerable buildings, leaving thousands of dead and injured (e.g. the earthquakes of Chios 1881 and Filiatra 1886). Contemporary literary sources often report earthquake damage together with damage due to other building deterioration causes, e.g. ageing, weathering, neglect and military operations, or the consequence of more than one earthquake (Ambraseys 2009). Particularly, in the first half of the century, these causes were not independent from each other, mainly in sparsely populated rural areas of the country.

Collapse or structural damage to ordinary buildings was a usual phenomenon, even in the case of moderate magnitude onshore earthquakes, which occurred some months or even a couple of years after a large earthquake. The poor living standards of the people and weak economy of the country did not allow for proper repair of damage. Loss of life was another result of the high vulnerability building stock exposed to earthquakes, in relation to the population density and time of earthquake occurrence. On the contrary, simple structures, such as temples and free-standing columns of the

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antiquity or bell-towers and minarets usually responded to earthquake shaking with non-structural damage.

This paper aims in contributing to the study of 19th century earthquakes in Greece by re-visiting the damaging ( $I_X > 6$ , i.e. non-negligible damage in the European Macroseismic Scale, EMS-98) events of this period through careful insight of a number of sources, with special reference to the events occurred at Samos Island.

Taking into consideration that seismic hazard assessment is highly influenced by historical earthquakes, their consequences studied here, and therefore physical risks (damage to buildings) of the pre-1900 period may be used as a comparison to recent data.

## State of the art

Historical earthquake catalogues provide parameters, which are highly dependent on the primary sources used for intensity assignment. The amount and quality of information related to one earthquake will influence the number and quality of its macroseismic intensity data points (MDPs) and hence the uncertainties associated to its parameters. It has been therefore considered vital to work towards accumulating and storing sufficient number of MDPs from as many as possible sources for the historical earthquakes under investigation. Since the 19th and throughout the 20th century, macroseismic information reported from various localities is listed for each earthquake (e.g. Kárník 1969; Papazachos and Papazachou 2003). In the last decades, efforts have been devoted to the identification and georeferencing of these localities, along with the search for more sources of macroseismic information, leading to the development of MDP databases. There are many examples of macroseismic databases compiled at regional or state level; among others, the Algerian Homogenized Macroseismic Database (Harbi et al. 2015), the Tunisian Homogenized Macroseismic Database (Kharrat et al. 2019), the macroseismic intensity database for the Republic of Georgia (Varazanashvili et al. 2018), and many others.

In Europe, the “Archive of Historical Earthquake Data” (AHEAD platform) supplies, after elaborations carried out during the EU NERIES project, NA4 module “a Distributed Archive of Historical Earthquake Data”, a considerable number of historical earthquakes dataset. Published MDPs and background information are available in AHEAD inventory (Locati et al. 2014; Rovida and Locati 2015), following the philosophy of continuous updating with new data, which is the objective of historical earthquake research. AHEAD is a portal allowing the presentation of data from other databases, such as France with SISFRANCE (BRGM, IRSN,

EDF) by Scotti et al. (2004), Switzerland with ECOS (SED-ETHZ) by Fäh et al. (2011), Italy with ASMI by Rovida et al. (2017), Spain with the Base de Datos macroseismic (IGN) by Solares and Rodríguez (2002), etc. Greece with the Hellenic Macroseismic Database (HMDB.UoA, <http://macroseismology.geol.uoa.gr>) and the Macroseismic Data of Southern Balkan area by ITSAK, as well as a number of online macroseismic archives from other countries in the European region.

The Hellenic Macroseismic Database (Kouskouna and Sakkas 2013) was compiled following the criteria established in NERIES project and hosted 1178 historical earthquakes with 2141 MDPs of the period 1000–1899 from the eastern Aegean area, central and southern Greece and Ionian Islands. As HMDB is a contributor, many of these events are hosted in AHEAD. The majority of them occurred in the 19th century: 1081 events with 1933 MDPs, out of which 74 events with maximum intensity  $I_{X,EMS-98} > 6$ . It is noted here that many of these earthquakes are not located in Greece, but they affected places in the country. The earthquakes included in HMDB.UoA followed certain criteria concerning the transparent methodologies of historical earthquakes investigation and the availability of MDPs assigned according to the European Macroseismic Scale 1998 (EMS-98; Grünthal et al. 1998) from published studies of various authors. According to the philosophy of all European macroseismic databases, HMDB follows the “one-to-one” philosophy, that is one study entry per event. At its compilation stage, HMDB did not accommodate full coverage of the large events in the area of Greece. Therefore, it is considered here vital to enrich it with more significant historical earthquakes and their MDPs, by exploiting a number of related seismological studies and compilations.

Greek historical earthquakes are included in the catalogues of Galanopoulos (1960, 1961) Kárník (1969) and Shebalin et al. (1974). Papazachos and Papazachou (2003) collected and elaborated the damaging historical and instrumental period earthquakes of the Southern Balkan region. SHEEC, the most recent earthquake catalogue for historical earthquakes in Europe (Stucchi et al. 2013) compiled in the frame of the European Commission project “Seismic Hazard Harmonization in Europe” (SHARE), covers the time window 1000–1899. In this catalogue, the broader European region is sub-divided into 22 macro-areas, with Greece belonging mainly to the Aegean macro-area (BAS), as well as to the East Adriatic-Ionian and Southern Balkans (BAI) macro-areas. In SHEEC, the parameters of historical earthquakes in Europe were re-assessed; the MDPs provided by Papazachos and Papazachou (2003), Taxeidis (2003) and Sakellariou et al. (2010) were used for the Greek earthquakes.

## Investigation of sources

The purpose of this study is to provide macroseismic intensities of the damaging 19th century earthquakes in Greece. Intensities are assigned for the studies providing only textual descriptions of earthquake effects. Although certain published studies deliver MDPs for a considerable number of events, re-assignment of intensities is considered indispensable for homogeneity reasons. In both cases, reported localities are identified and georeferenced and the corresponding intensities are assigned using EMS-98.

It is noted that a similar study carried out by Albini (2020) concentrates in the time period 1815–1864 in the Ionian islands. This study presents four unknown earthquakes, as a result of archival research of the author, with assigned EMS-98 intensities for 8 MDPs.

In what follows, the sources used for analysis are presented in detail. The presenting order of the studies is based on their amount of data used.

**Ambraseys (2009):** In this paper, the main source for systematic search for earthquake records and intensity assignment is the seismological study by Ambraseys (2009), presenting detailed descriptions on the earthquakes in the Mediterranean and Middle East from the antiquity up to 1899, as a result of an in-depth study of numerous primary, contemporary sources. Within his texts, the author offers detailed descriptive information on the earthquake effects, such as damage, vulnerability and exposure to earthquakes, identifies spurious or fake events that might be the result of mistaken interpretation of other natural phenomena, introduces historical earthquakes that are not listed in the parametric catalogues, and provides additions and clarifications to the date and time of occurrence of the earthquakes.

It is emphasized that the author states clearly whether an earthquake was damaging or not and if the existence of the earthquake is verified in more than one source. Many significant earthquakes are described in detail, allowing for accurate intensity assignment and providing a considerable number of MDPs. In few cases, a damaging earthquake is reported in a couple of lines, escorted with a comment, such as “but details are lacking”. In such short texts, it is not straightforward whether damage was structural or non-structural, as information is limited to “heavy damage to some houses”, “a few houses fell”, or “the earthquake caused some damage”, and therefore an intensity range (e.g. 6–7 in EMS-98) was assigned to accommodate uncertainties. In other cases, even for events reported as damaging in the parametric catalogues, Ambraseys clears up the situation by mentioning “the shock caused no damage ...” or “it is not mentioned in other sources”, commenting on possible inaccuracies.

In principle, the study lists aftershocks and their effects at the end of the text dedicated to the mainshock. However, due to their importance, in some cases main aftershocks with considerable effects are presented as separate earthquakes, similarly to twin events. This procedure is adopted in the present paper, thus including damaging foreshocks and aftershocks, always keeping in mind that their effects are cumulative (e.g. 1 August and 25 October 1870, Fokis; 20 and 27 April 1894, Locris). In the descriptive texts, the epicentral area and the time of the earthquake occurrence, usually converted to local western from Ottoman time are provided for most events and used in this study.

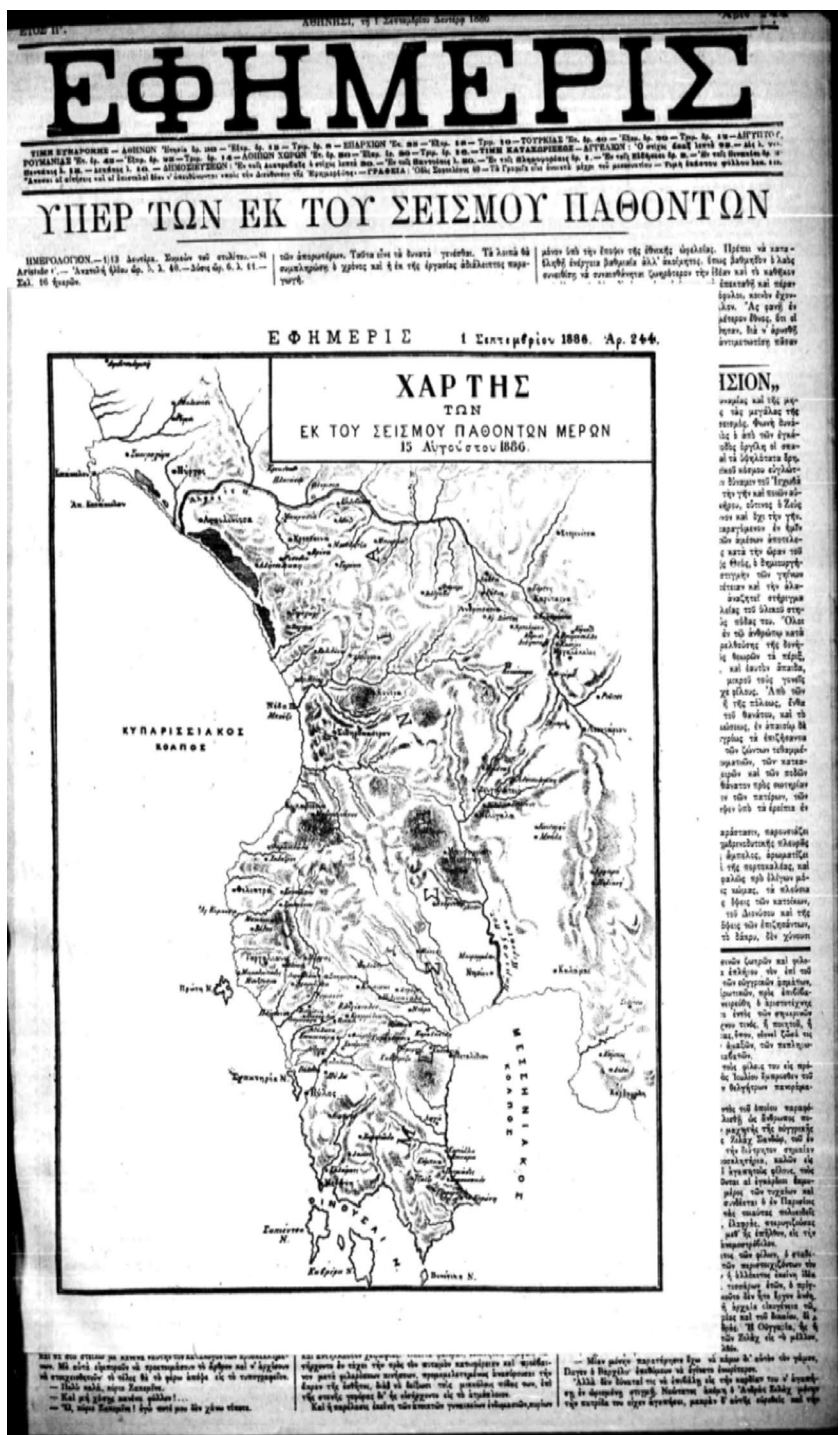
The result of this procedure is the identification of certain “unknown” historical earthquakes. The term unknown is used here in quotation marks, as some of them are actually known to researchers, having already been mentioned in seismological studies or reports, but have not been included in the parametric historical earthquake catalogues, such as SHEEC (Stucchi et al. 2013) and Papazachos and Papazachou (2003).

The majority of events in Ambraseys (2009) were shallow depth, whereas six offshore events were of intermediate depth. In the present study special care is taken to flag the spurious events with effects similar to those of an earthquake, as well as the fake events (clearly stated in the text). Earthquakes with only seismogeological effects are not taken into account.

**Schmidt (1879):** For the period after 1800, Schmidt elaborated his earthquake catalogue based on original sources derived mainly from correspondence with travellers, observers and consuls in the Eastern Mediterranean area and from contemporary press in Athens, Istanbul, Izmir, etc. This study is a main source for parametric Greek earthquake catalogues (e.g. Papazachos and Papazachou (2003), as well as non-parametric (e.g. Ambraseys 2009).

**Galanopoulos (1953):** This study is a catalogue of earthquake effects in Greece for the period 1879–1892 (in German). The author’s intention is to continue Schmidt’s (1879) work for another 13 years, until the systematic macroseismic information listing of earthquakes in Greece is taken over by the *Annales de l’Observatoire National d’Athènes* in 1893. Based mainly on newspaper reports from 16 Athens newspapers (e.g. *Asty*, *Chronos*, *Akropolis*) and contemporary sources, the author provides the event date, time and lists the detailed earthquake effects and his brief comments for each locality listed in tables, accompanied by the corresponding sources. Intensities are assigned in Mercalli–Cancani–Sieberg scale (MCS) in many cases. The table format used does not allow a detailed analysis of information and commenting found in Ambraseys (2009), but it proves extremely helpful for intensity assignment. Galanopoulos (1953) is the source

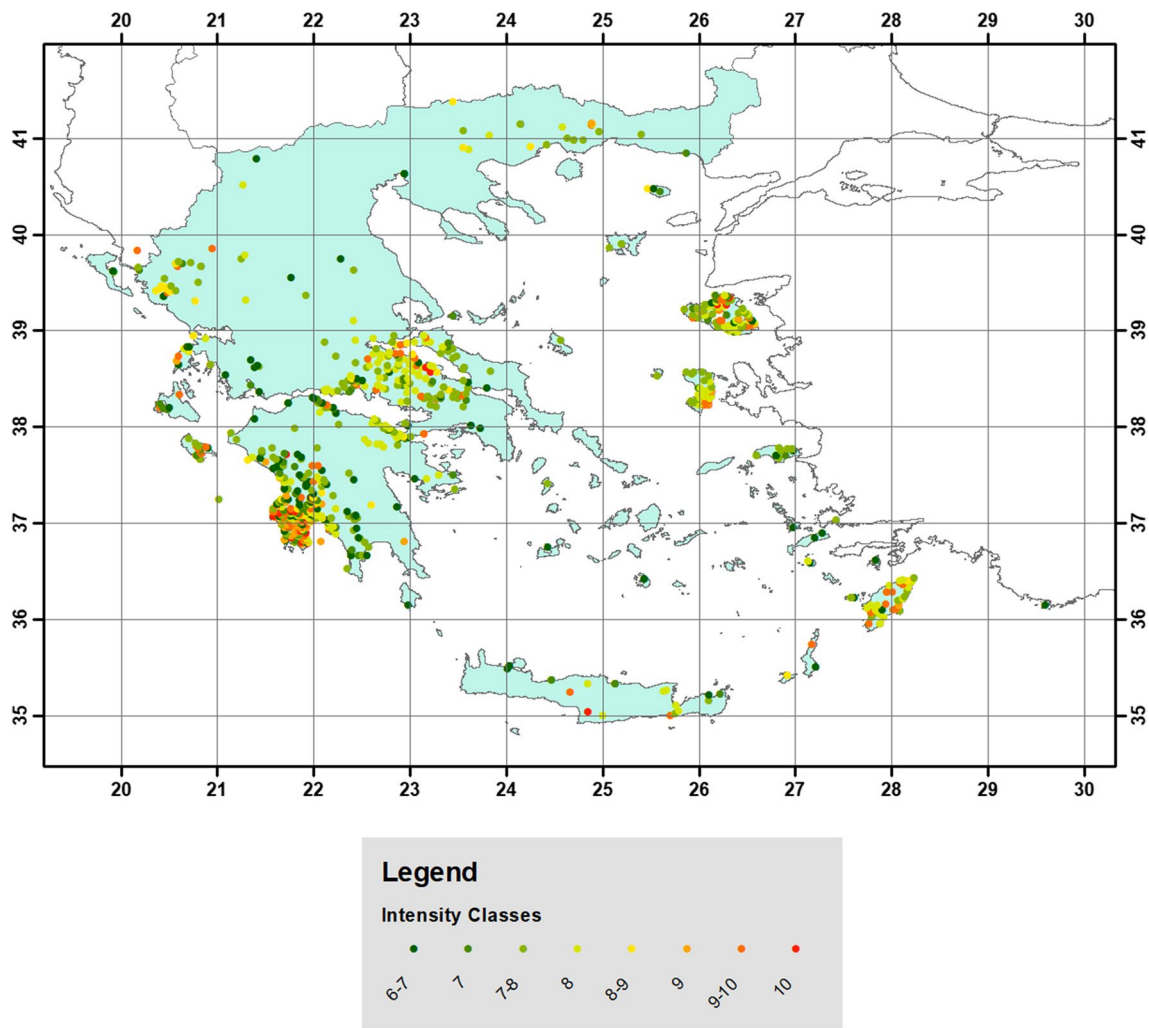
**Fig. 1** Front page of the Athens newspaper “Efimeris” of 1 September 1886 (O.S.) with a map of the SW Peloponnese affected localities as a result of the 15 August 1886 Filiatra earthquake (O.S.). Source: Digital Library of the Greek Parliament (<https://library.parliament.gr/Ψηφιακή-Βιβλιοθήκη/Εφημερίδες-και-Περιοδικά/>)



for some earthquakes in the Eastern Aegean Region in the study of Taxeidis (2003) and the Southern Peloponnese 1885, 1886 and 1899 earthquakes study by Sakellariou and Kouskouna (2014).

Annales de l’Observatoire National d’Athènes (1899, 1903): This bulletin is published in French by the National Observatory of Athens. It contains all earthquakes in the territory of the Greek state, as it was at that time period.

Therefore, earthquakes the areas Epirus, Macedonia, West Thrace, the Eastern Aegean Islands, the Dodecanese and Crete are not listed. Detailed macroseismic information is provided by a large number of local observers appointed by the Observatory, responsible for submitting their reports via telegram. This source is used by Taxeidis (2003) and Sakellariou and Kouskouna (2014).



**Fig. 2** Distribution of EMS-98 intensities > 6, assigned in the present study, for the 19th century earthquakes in Greece

Stamatiadis (1886): Stamatiadis acted as observer of the earthquakes in the broader area of Samos, which he published in the local newspaper “Samiaka”. His work is one of the main sources of Taxeidis (2003).

Kantartzis (1867): In his hand-written notes, the author gives a detailed analysis of the 1867 Lesbos earthquake, acting as the main source for the analysis of Taxeidis (2003).

Mitzopoulos (1900): The study is a detailed contemporary report of the 1899 Kyparissia earthquake, used by Sakellariou and Kouskouna (2014).

Galanopoulos (1940): The study is a detailed report based on contemporary accounts and Athens newspapers (e.g. Efimeris, Chronos, Akropolis) for the 1885 Messinia earthquake, used by Sakellariou and Kouskouna (2014).

Galanopoulos (1941): The study is a detailed report based on contemporary accounts and newspapers (e.g. Chora, Efimeris in Athens and Arcadia in Tripolis, Peloponnese) for the 1886 Filiatra earthquake, used by Sakellariou and Kouskouna (2014).

Stefanidis (1898): The detailed notes of Stefanidis on the 1898 Balikeshir earthquake are the only source of the Taxeidis (2003) analysis of the event.

Baratta (1901): This study focuses on the historical earthquakes of Italy. It acted as source of information on felt effects of the 1886 Filiatra earthquake in Italy by Sakellariou and Kouskouna (2014).

**Table 1** Comparison of number of MDPs of 19th century damaging earthquakes in Greece presented in the Hellenic Macroseismic Database (HMDB, <http://macroseismology.geol.uoa.gr>) to those assigned in this study

YYYY MM DD HH MM	MDPs (HMDB)	MDPs (This study)
1817 10 31	2	2
1820 03	1	1
1831 04 < 03	3	1
1845 10 11 14	15	18
1845 11 01 05 30	1	3
1846 06 25 10	1	5
1856 11 25 11 37	2	5
1859 08 21 11 30	18	26
1865 07 22 23 23	8	18
1865 10 11 03 42	1	6
1865 10 23	1	1
1865 11 12 da	1	4
1866 01 19	1	2
1866 01 22 12 30	2	1
1867 03 07 17 58	109	117
1867 03 28 23	1	5
1867 07 22 15 05	1	3
1868 05 16 04 28	1	5
1869 04 18 05 55	1	10
1873 01 13 10 30	4	10
1873 02 01 01 13	6	13
1873 02 01 01 23	1	1
1875 07 07 23 28	2	3
1875 11 05 09 52	4	8
1877 10 13 08 46	3	3
1881 04 03 13 35	61	72
1881 04 11 08 00	1	1
1881 04 11 19 15	1	1
1881 04 11 19 17	1	1
1882 04 01 17 13	3	4
1883 10 15 15 53	16	28
1886 06 05 14 05	1	6
1886 08 27 23 27	190	352
1886 09 04 04	5	5
1886 11 27	1	1
1886 11 27 09 57	6	6
1887 05 14 05 39	7	8
1887 07 17 07 40	1	33
1889 10 26 01 19	32	43
1889 11 21 17 50	3	4
1890 05 26	3	3
1891 05 11 20 13	1	9
1892 01 09 08 15	8	10
1892 12 27	1	1
1892 12 27 07 00	1	1
1893 03 12 16	3	3

**Table 1** (continued)

YYYY MM DD HH MM	MDPs (HMDB)	MDPs (This study)
1894 04 20 17 16	38	113
1894 04 27 19 45	28	75
1898 01 29 17	41	41

## The macroseismic data points

After thorough study of the Ambraseys (2009) earthquake texts, macroseismic effects leading to EMS-98 macroseismic intensity assignment were evaluated. In many cases, the study provides in detail information on damage to buildings, as well as construction types, for vulnerability class identification. Damage may be described as structural or non-structural, heavy or “slight/some” and, for the thoroughly studied earthquakes, the description is more specified and may directly correspond to the effects listed in each damage grade of the EMS-98 scale.

Macroseismic intensity in EMS-98 was assigned following the considerations and guidelines for historical earthquakes (Grünthal 1998, Sect. 3). The information on vulnerability provided in Ambraseys (2009) leads to the general conclusion that throughout the rural areas class A dominated during the 19th century and in major towns class A and B, with limited possible existence of class C. It was often observed that the houses destroyed or damaged by an earthquake, especially in remote localities, were not repaired immediately after the earthquake, until another found them already more vulnerable.

The sources mentioned in the previous section are used for EMS-98 intensity assignment of the earthquakes in the corresponding time periods. The saturation effect mentioned in the scale (Grünthal 1998) was not avoided when most local buildings were of vulnerability class A and already destroyed from previous earthquakes or neglected.

Assigned intensity values correspond to a considerable number of localities throughout the country, with MDPs from localities whose traditional place names refer to a set of small settlements in a limited area (MS), such as a whole island, e.g. Samos. In these cases, information does not strictly refer to the place name; intensity and coordinates are assessed, but the code should represent a warning to the user, as this intensity value, corresponding to a number of localities and not a single one, may be higher. However, no better interpretation can be provided. In addition, some MDPs refer to monasteries, which are taken into account as single (isolated), standing-alone buildings (IB). In such cases, intensity assignment is not compatible with the statistical meaning of intensity. However, these MDPs were not

**Table 2** Parameters of the damaging earthquakes of Samos island in the 19th century assessed in the SHARE European Earthquake Catalogue SHEEC (Stucchi et al. 2013)

YYYY	MM	DD	HH	MM	Locality	Lat (°N)	Lon (°E)	$I_0$	$M_w$	Root	MDPs	$I_x$	CCode
1846	6	25	10		Samos	37.757	26.976	7–8	6.0	Taxeidis (2003)	1	7–8	PAPA003
1865	10	11			Samos	37.757	26.976	6–7	5.8	ITSAK (2003)	2	7	PAPA003
1868	5	3			Pagondas	37.670	26.820	6–7	5.8	ITSAK (2003)	2	7	PAPA003
1873	2	1	1	13	Samos	37.729	26.938	7–8	6.2	Taxeidis (2003)	6	7–8	PAPA003
1875	7	5			Samos	37.757	26.976	5	5.4	ITSAK (2003)	1	5	PAPA003
1877	10	13	8	46	Kokkari	37.768	26.908	8	6.2	Taxeidis (2003)	4	8	
1877	10	14	19	35	Kokkari	37.774	26.874	7	5.9	Taxeidis (2003)	2	7	PAPA003
1892	12	27	7		Samos	37.757	26.976	7	5.9	Taxeidis (2003)	1	7	
1893	3	12			Samos	38.062	26.555	6	5.9	Taxeidis (2003)	3	6–7	PAPA003

**Table 3** Macroseismic parameters assessed in this study for the 15 May 1868 Samos event with the four methods of MEEP package. Adopted solutions (Centroid and MEEP) are marked in bold

Method	Lat (°N)	Lon (°E)	$\pm$	$M_w$	$\pm$	h (km)
<b>Centroid</b>	<b>37.917</b>	<b>26.925</b>	<b>24.8</b>	<b>6.6</b>	<b>0.6</b>	<b>20</b>
<b>MEEP</b>	<b>37.717</b>	<b>26.899</b>	<b>7.2</b>	<b>7.2</b>	<b>0.5</b>	<b>20</b>
Bakun	37.684	25.505	121.8	13.5	0.6	–
Pairwise	37.445	27.058	31.9	7.2	0.8	–

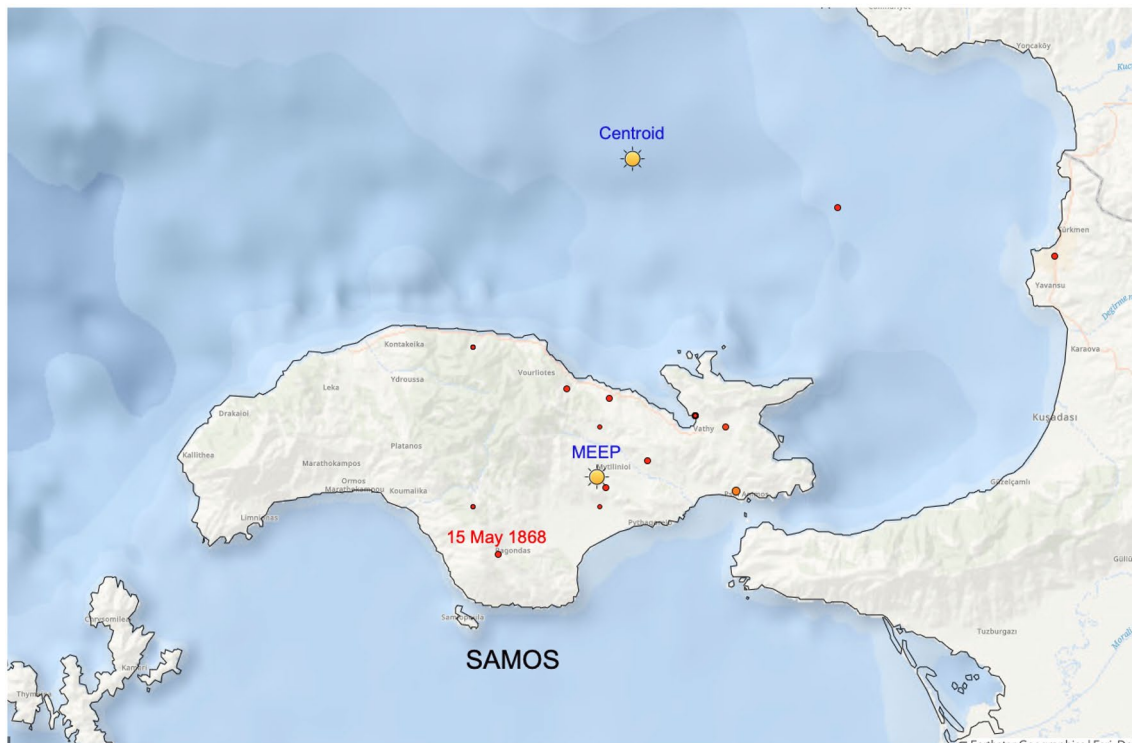
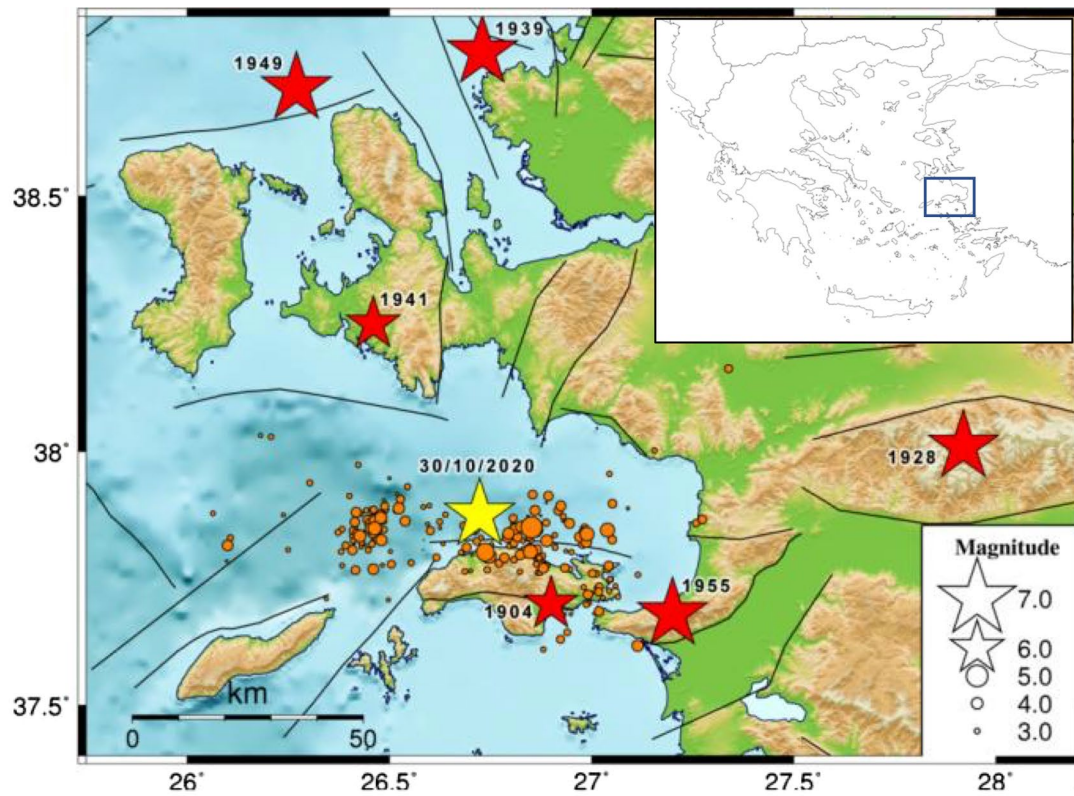
used for earthquake parameters determination (Locati et al. 2014). Damage to monumental buildings was reported from Athens in two cases. It is worth noting that many localities, mainly small villages, appear once in the database with one intensity value throughout the century. Several were deserted or abandoned after the earthquake that destroyed them (DL), and do not exist today. In terms of seismic history, they are not exploitable. However, many main towns present a significant seismic history which may be used for hazard assessment.

The majority of localities in Greece are main or smaller towns and villages. Assigning coordinates for main towns was a straightforward procedure, in agreement with the definition given in EMS-98, that, firstly, the settlement is large enough for a statistically significant sample to be obtained, without being unduly affected by small-scale local peculiarities (such as for isolated buildings) and secondly, that it is not so large that genuine local variations are not blurred over. The latter is overcome by the fact that in the 19th century, and in view of the socio-economic situation of Greece at that time, main towns were not largely populated (metropolitan) areas. For example, before the Greek Revolution of 1821, the population of Athens consisted of approx. 10,000, as opposed to less than 300,000 in the beginning of the 20th century.

As Greece underwent several changes throughout the 19th century, it is a common case that the same locality

appears with more than one names in the sources and, consequently, in the intensity database. A crucial problem for avoiding duplications of localities was their identification. In the beginning of the 19th century, Turkish and Arbëreshë (from southern Albania) names dominated, in particular for smaller towns and villages, which were gradually Hellenized or altered for easier pronunciation, and finally renamed in Greek. For example, Basta became Vasta and renamed Platy, or Chasan Pascha became Chasambasa and renamed Aristodeimeio. Fortunately, in several cases, Ambraseys (2009) supplies both the old and the new name. For the remainder, a useful tool for name identification was the 1923 Census Report for municipalities, towns and settlements of Greece (Lexicon 1923). Figure 1 presents a newspaper extract of damage distribution map compiled after the 1886 Filiatra earthquake, where the contemporary place names may be identified.

The final number of damaging events from the period 1800–1899 identified in this study, with maximum intensity  $I_{EMS-98} > 6$  in Greece is 151 with 2544 MDPs (Table S1), corresponding to EMS-98 intensity range 1–10. 2057 MDPs (1125 with  $I_{EMS-98} > 6$ ) are located in Greece (Fig. 2). The procedure followed and the quality and quantity of analysed sources leads to the assumption that this dataset may be considered complete, with regard to EMS-98 intensities  $> 6$ . The comparison of these numbers to the data available in HMDB

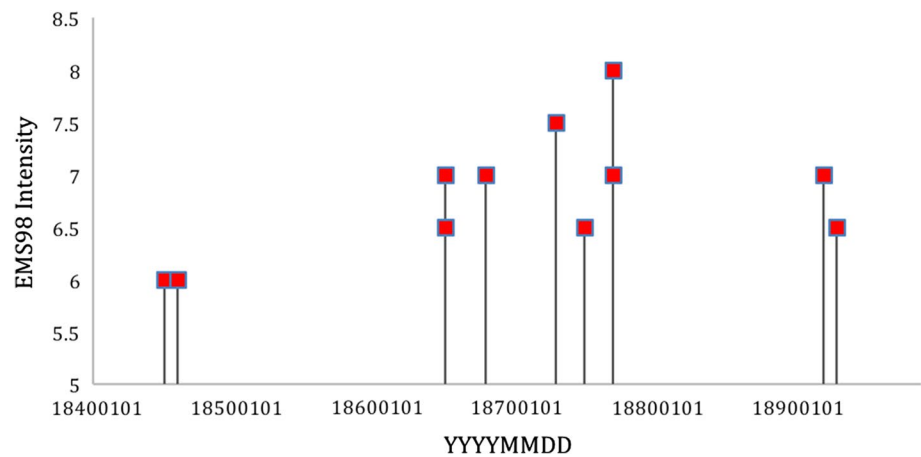


**Fig. 3** Top: Epicentre of the 30 October 2020 mainshock (yellow star), its aftershocks (orange circles) and large events ( $M_W \geq 6.0$ ) of the instrumental period (red stars) in the broader area of Samos (from Papadimitriou et al 2020). Inset box: Location of Samos. Bottom: Historical earthquakes of Samos (SHEEC, Stucchi et al. 2013).

The epicentre of 15 May 1868 earthquake from SHEEC (red dot) and from this study (yellow sun) for Centroid and MEEP methods (extract from the Seismotectonic Atlas of Greece v1.0, <http://www.geophysics.geol.uoa.gr/atlas.html>, Kassaras et al. 2020)



**Fig. 4** Seismic history of Samos island in the 19th century, with EMS-98 intensities  $\geq 6$  assigned in the present study



shows that 49 out of the total 151 events are included in HMDB and proves the necessity of this effort (Table 1).

### Case study: the seismic history of Samos

The island of Samos belongs to the broader area of Eastern Aegean, at the transition zone of deformation, with Anatolia microplate moving to the WSW and the opening of the nearby Izmir Bay and Gulf of Kuşadası, which are bounded by parallel E-W striking normal faults (e.g. Mascle and Martin 1990).

Earthquakes have been present in the history of the island since the 3rd century BC, with archaeological studies providing evidence for a damaging earthquake on 201–297 BC at Pythagoreio, the main town of the island in the antiquity. Another event, on 47 AD, struck the main towns of Asia Minor and the Eastern Aegean islands, including Pythagoreio, also evidenced also by epigraphic material discovered in Samos. Seventeen centuries later, chronicles describe a severe earthquake on 18 June 1751 that destroyed churches and houses at Chora and Vathy, as well as Kusadasi and nearby villages at the opposite coast. A violent earthquake is again reported from Samos on 1 August 1766 (Taxeidis 2003).

By the 19th century, newspapers are the main source of information on remarkable earthquakes in the Eastern Mediterranean. Specifically in Samos, the literary editor of the homonymous newspaper Epameinondas Stamatiadis, published systematically and in detail all the earthquakes felt and affecting Samos. At the opposite coast, the newspaper “Amaltheia” in Smyrna, complements the seismic history with its detailed reports. Therefore, the volume of accounts has increased drastically in this century, as opposed to the previous time periods. Regarding the Eastern Mediterranean and Middle East historical seismicity, Ambraseys (2009) notes that this increase of sources decreases in the 20th century, “as instrumental, electronic or other mechanical

reporting of events has grown, and news is increasingly disseminated by radio and television, a parallel decline is visible in both the volume and the quality of documentary and descriptive accounts of earthquakes”. In the period 1800–1899, local newspaper material on earthquake effect is enriched by European (occidental) sources, as well as unpublished archival records (e.g. Albini 2020). For Greece, the Ottoman archival material is also particularly useful, at least as far as damage is concerned, to know the cost for repairs or reconstruction, in order to assess the degree of damage, as well as church and monastery records (Taxeidis 2003; Kouskouna and Makropoulos 2004). For all such material, careful consideration of dating and timing of the reported earthquakes is absolutely necessary.

Samos experienced more than 350 local and regional earthquakes in the 19th century. Table 2 shows the parameters of events included in SHEEC (Stucchi et al. 2013). Thorough investigation of the macroseismic effects of the Samos earthquakes is carried out in this study, in parallel to the published MDPs in HMDB. Table S2, elaborated (a) in the first part of this study and (b) in HMDB, presents the MDPs of all the events experienced in Samos. The reason for such a detailed dataset is that Stamatiadis, the main source of information, was based in Samos and dedicated systematic efforts for registering all earthquake activity. It is noted that a number of these earthquakes are aftershocks of the damaging events. Further investigation on these earthquakes may uncover a variety of earthquake epicentral areas.

The total number of MDPs for the damaging historical earthquakes in Samos are presented in Table S2. For the event of 15 May 1868, the 6 MDPs (3 on Samos and 3 in Turkey, Tables S1, S2) allowed for macroseismic estimation of parameters, using the MEEP package developed by Musson and Jimenéz (2008). This package associates magnitude with intensity and combines the MEEP, Centroid or Boxer (Gasperini et al. 1999, 2010), minimizing residuals (Bakun and Wentworth 1997), and pairwise comparison (Shumila 1994) methods for joint epicentre and magnitude

determination. The geometrical spreading factor ( $k$ ), scaling constant ( $C$ ) attenuation factor ( $Q$ ) and absorption coefficient ( $\alpha$ ) values from Kouskouna et al. (2020) are adopted in this study for parameters estimation (epicentre, equivalent  $M_W$  and focal depth).

The solutions for all methods used in the package is given in Table 3. Centroid and MEEP methods are adopted as they provide the lowest uncertainties. The uncertainties of these solutions are considered satisfactory, taking into account the low number of MDPs and the unavoidable subjectivity of macroseismic data. The equivalent  $M_W$  by both methods is within the limit for the maximum expected magnitude in the area. Moreover, the epicentral solution of Centroid method coincides with the 30 October 2020 event (Fig. 3).

The overall macroseismic information in terms of MDPs elaborated in this study for the 19th century damaging earthquakes in Samos is expressed through its seismic history (Fig. 4 and Table S2). Based on this information, it is concluded that the island experienced in total 456 EMS-98 intensities  $\geq 3$ , at least twice EMS-98 intensity 7–8 or 8 (heavily damaging, many buildings of vulnerability A suffer damage of grade 4; a few of grade 5 and a few of vulnerability B suffer damage of grade 4, i.e. nearly or totally collapsed) and four times intensity 7 (damaging, a few buildings of vulnerability A suffer damage of grade 4, i.e. nearly collapsed). Many of the damaging events were equally damaging in Izmir, a fact implying that an event similar to the 2020 one has probably occurred in the 19th century.

## Conclusions

Historical earthquake catalogs and inventories of their supporting datasets are usually open to re-compilation and updating at regular time intervals, as long as new seismological studies appear, or unpublished material on earthquake effects is discovered. The present study deals with the first option: a number of sources are exploited for the validation of damaging 19th century earthquakes in Greece.

A total number of 151 damaging events is analysed in the present study. Assignment and re-assignment of macroseismic intensities performed here leads to a total number of 2,544 MDPs, out of which 1,125 with  $I_{\text{EMS-98}} > 6$  are located in Greece. The dataset of intensity  $I > 6$  in the 19th century may be considered complete, but a large number of MDPs of lower intensity is also present in this dataset. The results of this study aim to be incorporated in the Hellenic Macroseismic Database.

On the occasion of the recent 30 October 2020 Samos earthquake, the seismicity of the island in the period 1800–1899 is approached with macroseismic methods, as a case study. The analysis showed that, most probably, a

similar earthquake occurred at least twice in the 19th century. Such information aims at improving the knowledge of long-term seismicity and seismic hazard of Samos.

Consequently, the seismic hazard of a number of regions shown in instrumental hazard maps of Greece, which reflects the lack of long-term observations, may improve with the inclusion of 100 years of seismicity, i.e. the 19th century.

**Supplementary information** The online version contains supplementary material available at <https://doi.org/10.1007/s11600-021-00608-3>.

## Declarations

**Conflict of interest** The corresponding author has no conflicts of interest to declare that are relevant to the content of this article.

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