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ORIGINAL ARTICLE

# The 7 and 11 May 1984 earthquakes in Abruzzo-Latium (Central Italy): reappraisal of the existing macroseismic datasets according to the EMS98

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**Abstract** The aim of this paper is to provide a complete and reliable macroseismic knowledge of the events that stroke a large area in Central Italy on 7 and 11 May 1984. Previous studies, together with original accounts integrated with new and unpublished information, have been gathered and examined in order to re-evaluate macroseismic intensities in terms of the European Macroseismic Scale (EMS98). New intensity maps have been compiled; the total number of localities with available information for both the shocks increases from 1254 of the previous study to 1576. On the basis of the new dataset, the macroseismic magnitude of the first shock is $M_W$ 5.6 which is lower than the previous macroseismic computation ($M_W$ 5.7). Moreover, the topic of assessing macroseismic intensity in the presence of multiple shocks has been also investigated, proposing an unconventional approach to presenting the macroseismic data: an overall picture of the cumulative effects produced by all the seismic sequence is given to support a partial but faithful reconstruction of the second shock. This approach is inspired by the common experience in interpreting historical seismic sequences and gives a picture of the impact of the 1984 events on the territory.

**Keywords** EMS98 · 1984 Latium-Abruzzo (Central Italy) seismic sequence · Multiple damaging earthquakes · Cumulative intensity

## 1 Introduction

The role of macroseismology in retrieving and reinterpreting information coming both from historical and recent accounts on earthquakes is presently experiencing a new flourishing period. During the last 10 years, the attention to macroseismic data has grown and the scientific community acknowledges its essential contribution to seismic hazard assessment and seismic catalogues completeness. Nevertheless, the seismic catalogues are the result of collections of earthquakes whose studies show rather different levels of accuracy. For this reason, macroseismic data at the base of all those studies should be continuously reviewed and improved, including additional information, in order to get the best possible accuracy.

Having this in mind, we focus our attention on the May 1984 earthquake sequence in Central Italy that was one among others in the catalogues needing a revision.

On 7 May 1984, a $M_W$ 5.9 (instrumental) earthquake occurred in an area at the border of Latium, Abruzzo and Molise regions (Central-Southern Italy), largely felt in Central and Southern Italy, as the onset of a sequence

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lasted several weeks (Milano and Di Giovambattista 2011). The mainshock was followed by an important aftershock on 11 May 1984, $M_W$ 5.5 (Rovida et al. 2016).

The 7 May shock provoked widespread moderate damage, worsened, in some cases, by the aftershock of 11 May.

In spite of the limited impact in terms of damage, this seismic sequence produced a large impression on people and media because it occurred 3.5 years after the devastating magnitude 7 Irpinia (Southern Italy) event (December 1980), whose memory was still vivid and whose damage was still unrepaired. In fact, the areas that experienced the 1980 and 1984 earthquakes partially overlapped. The 1984 earthquakes damaged particularly small mountain villages, whose building stock was old and not well maintained.

The most recent macroseismic study of the 1984 Abruzzo-Latium seismic sequence is that of Guidoboni et al. (2007) (hereinafter, GUAL07). The authors gathered and acknowledged intensity values assigned by different studies using different methodologies. This approach necessarily entails to acquire issues or inaccuracies from each of the studies, sometimes contradicting one another. This state of the art revealed that a thorough revision of the macroseismic datasets of the 7 and 11 May earthquakes was necessary. The object of the present work is to carefully revise the intensity dataset and to propose a new macroseismic field in terms of EMS98 (Grünthal 1998).

## 2 Summary of the accounts of the 7 and 11 May 1984 earthquakes

The May 1984 earthquake sequence is known in the seismological literature with various denominations: Abruzzo Apennine earthquake, Val Comino (from the name of the locality closer to the epicentre), Southern Latium, Abruzzo national park and others (see Westaway et al. 1989; Pace et al. 2002).

Soon after the events, several seismological groups performed independent macroseismic field surveys, using different scales and procedures. GUAL07 made a synthesis of the data coming from such surveys, and their study is the reference source used for the two main shocks included in the Parametric Catalogue of Italian Earthquakes (Rovida et al. 2016).

GUAL07 took into consideration three kinds of accounts: (1) the macroseismic field surveys by Frezzotti et al. (1995) (hereinafter, FRE95), (2) the Spadea and Vecchi (1985) dataset (hereinafter, BMING) and (3) reports from press agencies (ANSA 1984).

FRE95 carried out a field survey in the damaged area while, for the far field localities, they collected information and data by means of phone interviews to officers of local municipalities. FRE95 distinguished the effects caused by the two shocks and assessed Mercalli-Cancani-Sieberg (MCS) intensity values to 369 localities for the 7 May event and 342 for the 11 May one. For the localities with $I > 5.5$ MCS, a short description of buildings damage was provided.

BMING compiled the intensity maps combining the accounts from the direct survey carried out after the 11 May event (Scalera et al. 1984) together with the macroseismic questionnaires filled in by Italian Carabinieri Corp local stations. At that time, according to an official agreement between the Istituto Nazionale di Geofisica and the Carabinieri Corp, soon after an earthquake, the Carabinieri compiled questionnaire forms based on the Medvedev-Sponheuer-Karnik (MSK) and MCS scales to report the earthquake effects observed within their jurisdiction area. The filled-in forms provided information on people perception, effects on objects inside buildings and information on building damage. Environmental effects and information on the building stock were also provided. An example of original questionnaire form (Favali et al. 1980) is shown in the Electronic Supplement (Online Resource 1).

Like FRE95, also BMING distinguished the effects caused by the two shocks assessing MSK intensity values to 703 localities for the 7 May shock and 710 localities for the 11 May event.

The final data were published in the monthly bulletin as a mere list of intensity values, since the reports of the field survey and the accounts from macroseismic questionnaires were never issued.

GUAL07 gathered information from FRE95, combining them with press news (ANSA 1984) and assessing final MCS intensities. For those localities not included in FRE95 or not quoted in press reports, mostly in the range of intensity between not felt (NF) and 5, GUAL07 picked the MSK intensity values coming from BMING not explaining how they moved from MSK to MCS intensity values. Finally, for some localities, the intensity value was assessed on the basis of ANSA reports only. The final result is an extremely non-homogeneous dataset composed of 912 localities, with a maximum assessed intensity as 8 MCS for the 7 May shock, and 342 localities, with a maximum intensity as 7 MCS for the 11 May event. With regard to this last one, GUAL07 assessed intensities on the basis of FRE95 records only, whereas neither BMING dataset nor ANSA reports were taken into account (Fig. 1).

None of the mentioned studies considered the possible cumulative effects due to repeated earthquakes, while in contrast, the damage effects caused by the two shocks have been separated.

## 3 Methodology and analysis

As illustrated above, the GUAL07 dataset of the May 1984 seismic sequence is based on a non-homogeneous data collection: our intent was to achieve a reliable macroseismic knowledge of the events. To this purpose, we followed four steps: (1) we collected all available original accounts on the effects of the two main events; (2) we gathered new information in order to get the most accurate picture, especially for those localities with a scant description of earthquake effects; (3) we reinterpreted the bulk of the accounts in order to build a new dataset in terms of EMS98; and (4) we provided a picture of the impact of the whole sequence on the territory, also by estimating the cumulative effects on the building stock as the result of multiple shocks.

Our work started by collecting and examining all the available sources used by GUAL97 (FRE95, BMING, ANSA). During the scrutiny, some minor inaccuracies found in the datasets, such as misplaced and/or duplicated localities and intensity estimation based on single buildings, have been amended. During the first steps of the work, the hugest task was recovering and classifying more than 1400 BMING 12-page booklets containing the questions about the earthquake effects on people and structures.

To collect new information, newspapers and local histories have been scrutinized looking for additional data. In particular, we examined local and national editions of the newspapers published from 8 May 1984 to the end of the month (Corriere Adriatico 1984; Corriere della Sera 1984; Il Giornale d'Italia 1984; Il Messaggero 1984; Il Tempo 1984; Paese Sera 1984; Repubblica 1984; Resto del Carlino 1984; Gazzetta di Chieti 1984). A few local histories resulted useful with new data (D'Andrea 1987; Antonelli 1993; Mancini 1994; Zullo 1996; Le Donne 2000; Rea and Simeone 1999; Tavernese 2012). At the end of the scrutiny, new accounts for about 150 localities have been gathered and added to the bulk of the available reports.

As third step, we reinterpreted the gathered dataset, identifying and extracting, from the description of the effects, the quantitative elements necessary for the evaluation of EMS98 intensities (percentages of buildings for the different vulnerability classes and damage grades). In this frame, the most demanding task was the reformulation of BMING questionnaires, according to the EMS98. This was accomplished through a simple code which extracted the diagnostic elements in terms of EMS98 from all the answers reported in the questionnaire forms.

Finally, we followed some constraints to adhere, as far as possible, to the EMS98 guidelines. First of all, we assumed that the building stock of the affected localities

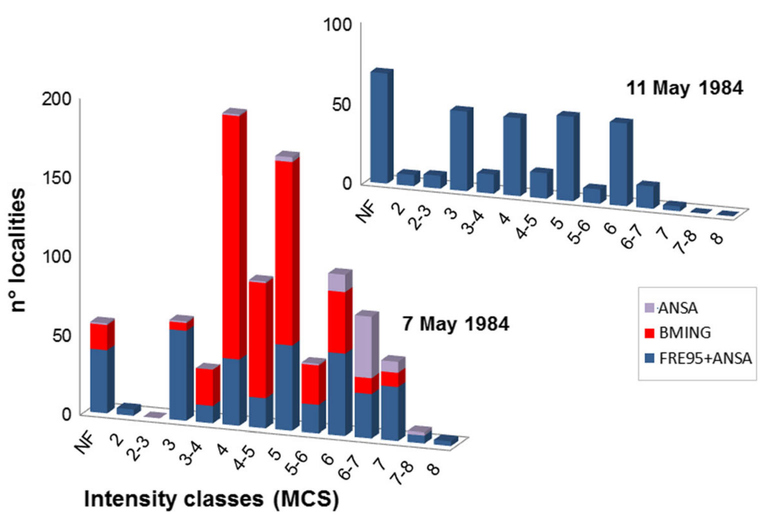


**Fig. 1** Frequency of Guidoboni et al. (2007; GUAL07) intensities for the May 7 and May 11 earthquakes. The histograms also show the original datasets used to build the final GUAL07 collections

by the 1984 earthquakes was well represented by vulnerability classes A, B and C of the EMS98 and that these classes may be identified with the corresponding A, B and C of the MSK scale used in the questionnaires. In fact, it is correct to presume that in the 1984 earthquake area, buildings with moderate-to-high earthquake-resistant design (types D and E) were almost inexistent.

During the intensity evaluation, we strive to avoid doubtful intensity assignments, as recommended by the EMS98 guidelines; nevertheless, since in some cases the available information was not detailed enough to discriminate between two intensity degrees, an uncertain intensity value has been assigned, meaning that the data could be interpreted equally well as one or the other intensity value.

The fourth step, namely the choice of estimating the cumulative effects of the sequence, derives from the difficulties we encountered in evaluating the increment of damage caused by the second shock, especially when we use the EMS98. The issue of evaluating repeated damaging earthquakes is very common, inasmuch almost every strong event is followed by aftershocks capable to cause additional damage. The practice to assess intensity (epicentral and maximum) to the aftershocks is quite diffused and acknowledged by seismic catalogues compilers. Nevertheless, we believe that it is quite complicated to isolate the macroseismic effects of multiple damaging earthquakes that take place in a short period after the main shock (see Tertulliani et al. 2012) because, by its own nature, a permanent damage to a structure cannot slip back. Consequently, an observer cannot avoid evaluating the impact of more than one earthquake as a whole. This is not true below intensity 5, where the intensity is based on transient effects on objects and on humans.

Recent literature has investigated how the seismic behaviour of buildings already damaged by previous earthquakes may vary (among the others Aschheim and Black 1999; Di Sarno 2013; Mouyiannou et al. 2014). However, the question of how this variation can influence the assessment of macroseismic intensity is almost neglected in the literature. The EMS98 (Grünthal 1998) gives a hint for this topic by evidencing that buildings already damaged "can behave very poorly, so that a relatively weak aftershock can cause disproportionate amounts of damage (including collapses)". Specifically, if a building with a class C vulnerability sustains a damage of grade 3 during the first shock, what kind of seismic residual resistance will it show during a further earthquake? Should it be moved to class B or A vulnerability? In the same way, we cannot quantify the damage evolution in terms of intensity degree: if a building sustains a damage of grade 2 after the first shock and, at the end of the sequence, shows an overall damage of grade 4, how can this increase be quantified?

Grimaz and Malisan (2016) explored the influence of cumulative damage on EMS98 macroseismic intensity assignment, evidencing through simulations that the changes in vulnerability, for the buildings that suffered a specific damage in a prior shock, are particularly possible in case of structural damage. Nevertheless, the assessment of the contribution due to single aftershocks is still unsolved.

In general, in terms of building shaking, the combination of a main shock and aftershocks can be considered equivalent to a very long-duration earthquake (Li et al. 2012), so we assumed to estimate the intensity of the 11 May earthquake only when we were confident to evaluate the real contribution of that shock. Generally, this was the case of undamaged localities during the first shock or localities for which the shaking of the second shock produced only transient effects (on people and objects). To give the general picture, we assessed also the cumulative effects of the sequence, assigning an intensity value that is representative of the overall result of repeated shocks on building stock.

## 4 Discussion

### 4.1 The 7 May 1984 earthquake (mainshock)

The result of the scrutiny enriched the accounts of about 150 localities, and after the revision of the first shock data, the number of localities with useful information slightly increased from 912 to 915.

Figure 2 shows how GUAL07 MCS intensity values have been reevaluated using the EMS98: in particular, the effect of the reevaluation from GUAL07 to present work (PW) in the intensity range between 5 and 7. The number of localities with assigned intensity 5 has significantly increased, mostly due to the adoption of the EMS98 scale. In fact, according to the EMS98, buildings start to get damaged at intensity 5, whereas in the MCS scale, the evidence of slight damage is expected to begin from intensity 6. Furthermore, more than half of the 6 MCS values have been downgraded to intensity 5 EMS98, as well as most of the intensities of 5–6 MCS. During the revision, we also found that 20 sites assessed with ≥6 MCS intensity in GUAL07 were based on

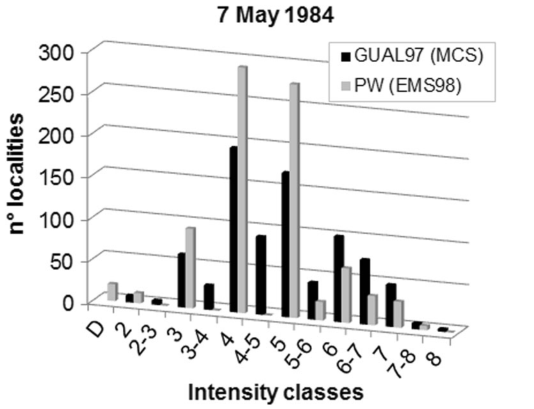


**Fig. 2** *Black columns* represent GUAL07 MCS intensity classes, and *grey columns* show the present work (*PW*) new values in EMS98

rather vague-sounding accounts like "The earthquake provoked unspecified widespread damage". In these cases, we adopted the generic assignment damage (D) to notify the damage occurrence that is impossible to describe in terms of EMS98 diagnostics.

In Fig. 3, a comparison between the frequency intensities of GUAL07 dataset and PW dataset is shown. Intensity classes are expressed in the MCS scale for GUAL97 and in the EMS98 scale for PW. The EMS98 intensities are generally lower than those recorded in GUAL07: the maximum intensity is 7–8 EMS98 in five sites, and intensity points with $I \geq 7$ dropped from 60 to 36. The complete list of the assessed intensities is available in the electronic supplement (Online Resource 2).

Figure 4 shows the new intensity map of the 7 May earthquake. The macroseismic epicentral parameters were also determined from the new dataset using the code Boxer (Gasperini et al. 2010). Being the intensities generally lowered, the new macroseismic magnitude is now decreased to $M_W$ 5.6 with respect to the one computed from the GUAL07 dataset ($M_W$ 5.7). In Table 1, the computed macroseismic magnitudes and epicentral coordinates are listed.

## 4.2 The 11 May 1984 aftershock and the cumulative intensity assessment.

Regarding this earthquake, GUAL07 took into consideration only the FRE95 accounts, related to 342 localities, in which ANSA and BMING were omitted. We integrated this dataset with accounts coming from the BMING questionnaires as well as information from press reports. As a result, the new dataset consists of 661 localities.

As outlined above, FRE95 discriminated the damage contribution of the second shock from the first one, assessing intensity values on the basis of descriptions like "general worsening of preexisting damage" or "new cracks occurred". These descriptions do not allow to estimate the damage evolution after the second shock; therefore, we took the decision of evaluating the intensity of the 11 May earthquake only for sites for which we were confident to assess the effective contribution of the shock. All localities presenting a generic worsened scenario were omitted and are indicated in the electronic supplement table (Online Resource 2) as not assigned (NA). The outcome of this unconventional way of data reading is an intensity map of 506 localities, all outside

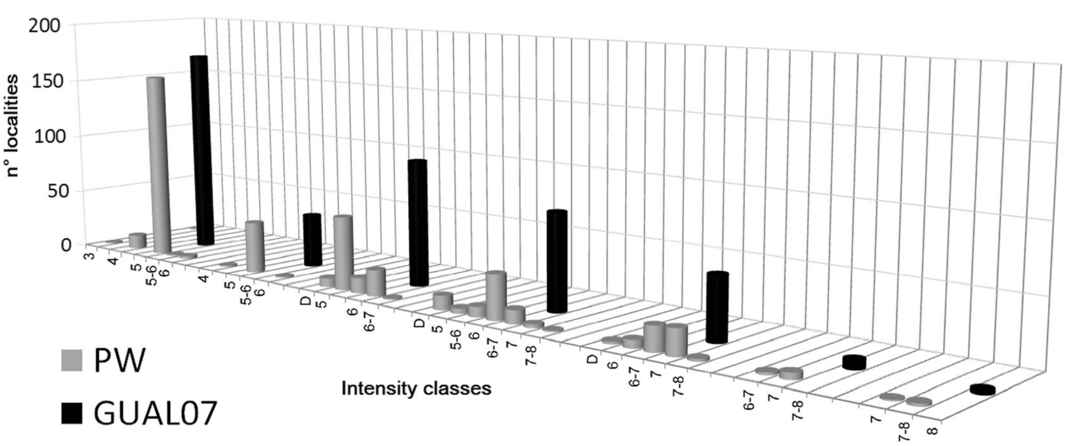


**Fig. 3** Comparison between the frequency intensities of GUAL07 dataset (*black columns*) and PW (*grey columns*) dataset for the 7 May earthquake. Intensity classes are expressed in the MCS scale for GUAL97 and in the EMS98 scale for PW

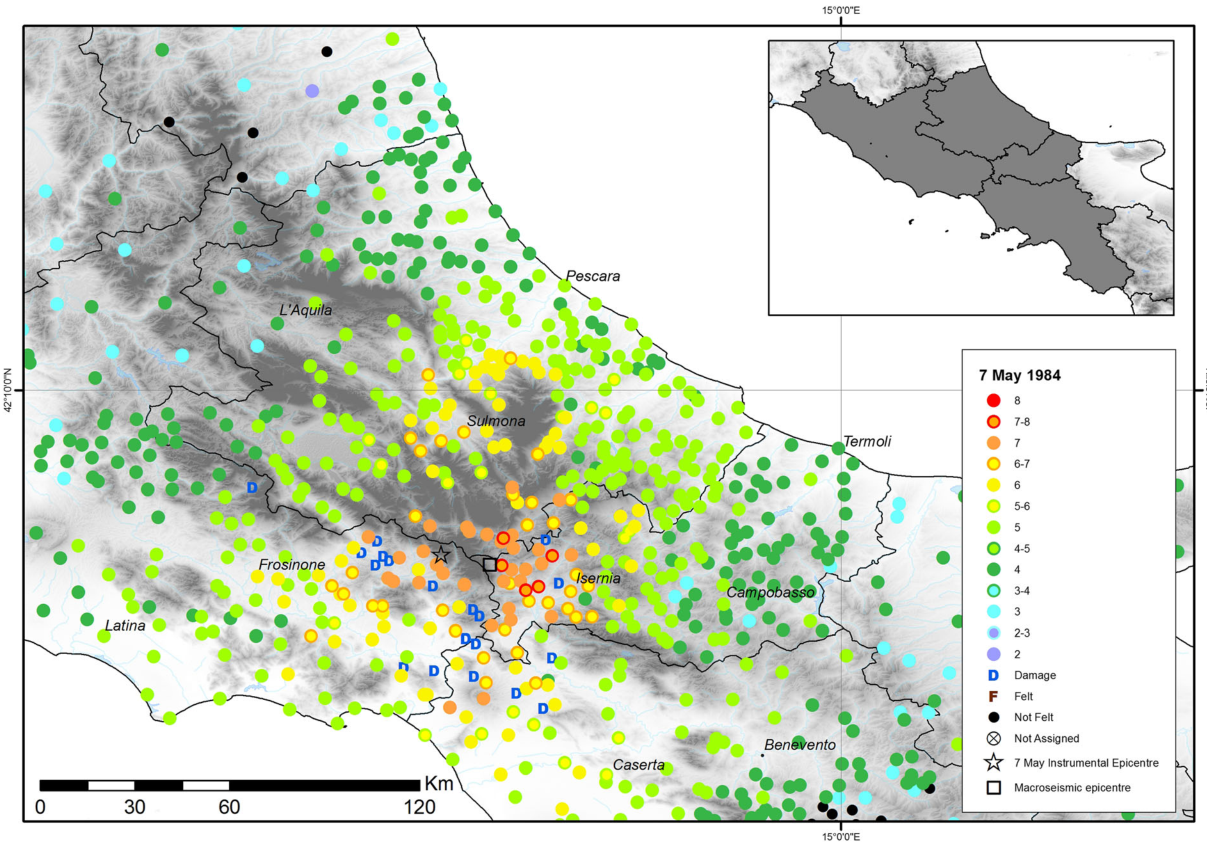


**Fig. 4** EMS98 intensity map of the 7 May 1984 event. The *black square* is the new macroseismic epicentre computed by the Boxer code (Gasperini et al. 2010)

the epicentral area and with intensity <6, apart from a few exceptions (Fig. 5). We decided, in fact, not to assign an intensity value to the other 156 localities (crossed circles in Fig. 5) placed within and close the epicentral area, because we were not able to distinguish the 11 May shock contribution in the intensity estimation.

Nevertheless, in order to display the picture of the effects due to the whole sequence, we also evaluated the intensity degree for all localities on the basis of the aggregate effects due to both events. Where it was possible to assess the intensity for the 7 and 11 May separately, we choose the maximum value. The assessed intensities are available in the electronic supplement. Figure 6 shows the cumulative intensity map after all experienced earthquakes, while in Table 1, epicentral and maximum intensity values are reported. From a comparison between Figs. 4 and 6, it is evident that in most localities, the sum of the effects due to the repeated shocks was not enough to produce any increase of intensity value.

This kind of reading reminds the interpretation of historical seismic sequences, for which only an overall description of the effects is often available, not allowing to discriminate the contribution of the single shocks. The result, albeit cannot be used to infer seismological parameters of the source (magnitude, location, fault dimension), nevertheless gives a picture of the seismic impact on the territory useful for a comparison with historical earthquakes that occurred in the same area (see, for example, Graziani et al. 2015).

## 5 Conclusive remarks

A detailed appraisal of all original accounts integrated with new and unpublished information was carried out in order to re-evaluate macroseismic intensities in terms of EMS98. The total number of localities with available information of both the shocks increases from 1254 to 1576. The second shock is now documented by

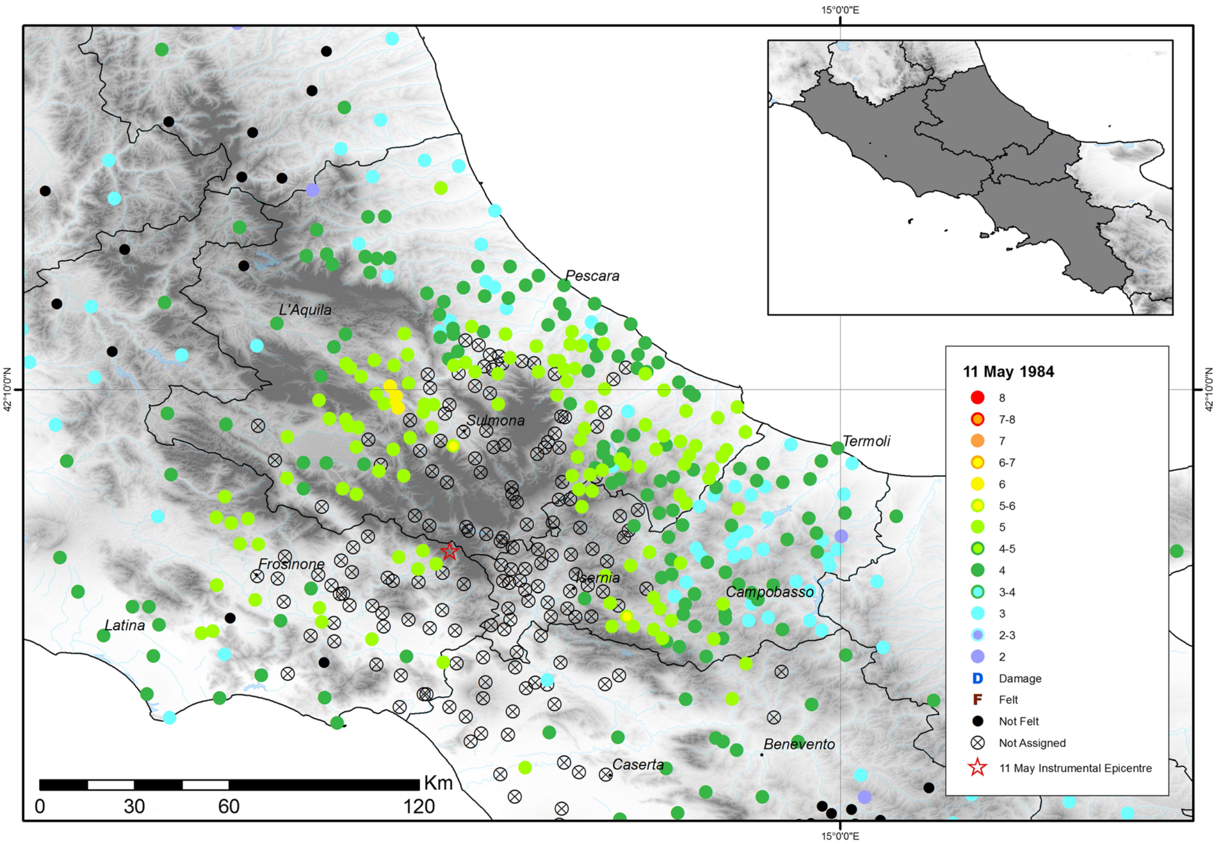


**Fig. 5** EMS98 intensity map of the 11 May 1984 event. *Crossed circles* indicate localities for which an intensity value was not assigned

approximately the same number of intensity points of the first one. The two main shocks are supported by the same quality of primary sources, and all intensities are assessed using the same macroseismic scale, namely EMS98. The maximum mainshock intensity is 7–8 EMS98, and the intensity points with $I \geq 7$ EMS98 are 36. New macroseismic epicentral parameters have also been determined using the code Boxer (Gasperini et al. 2010). The computed macroseismic magnitude resulted $M_W$ 5.6 vs the macroseismic $M_W$ 5.7 quoted in the catalogue.

Concerning the second shock, namely the main aftershock, we realized that the superimposition of the effects did not allow to assess its maximum intensity, being impossible to separate the damage caused by the 11 May event from the preceding one. For the same reason, we were not able to assess the intensity of many localities. In order to overcome the problem, we propose an unconventional way of interpreting macroseismic data of this seismic sequence. We assessed the second shock intensity only if the effects of the shaking in a given locality were referred definitely to the second

**Table 1** Synthesis of the epicentral parameters of the 7 May 1984 earthquake

| | Latitude | Longitude | $M_W$ | $I_0$ EMS98 |
|---|---|---|---|---|
| Old macroseismic parameters | 41.667 | 14.057 | 5.7 | 8 |
| New macroseismic parameters | 41.670 | 14.001 | 5.6 | 7–8 |
| Cumulative | | | | 7–8 |

Instrumental parameters are from Rovida et al. (2016), and old and new macroseismic parameters are computed by the Boxer code (Gasperini et al. 2010). The last row shows the only cumulative intensity assessed after 11 May 1984 as in the present work. In all cases, $I_0 = I_{max}$

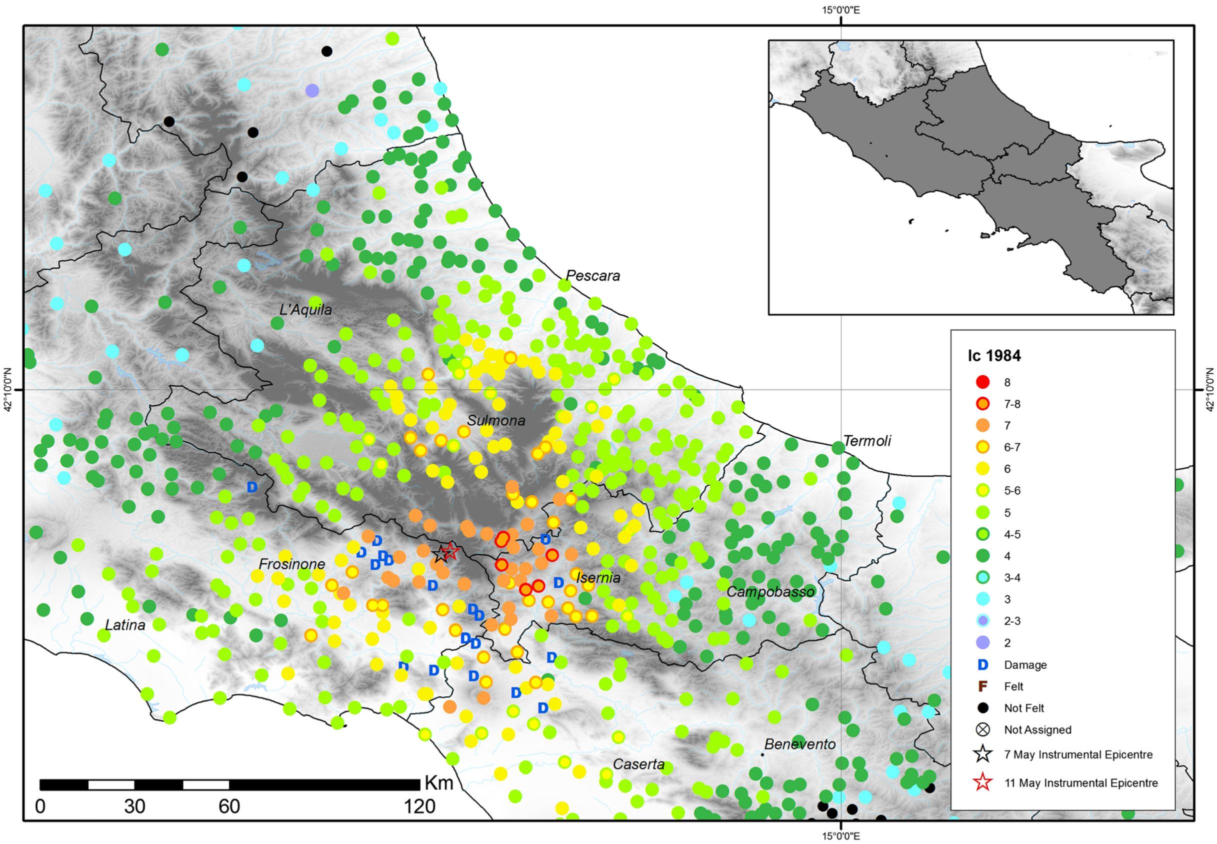


**Fig. 6** Cumulative intensity map of the May 1984 sequence

shock itself. Otherwise, we provide a cumulative intensity which represents the result of repeated shocks. Ultimately, we can affirm that part of the dataset of the 1984 sequence was implicitly based on observations unavoidably cumulative, from which it was not possible to infer a complete picture of the second shock.

Our outcome, although it cannot be referable to the source characteristics nor to PGA correlations, gives the reader an idea of the impact of the phenomenon on the territory hence suitable for comparison with the seismic history of the area under exam. Similar pictures can, in fact, be deduced from reports of historical seismic sequences for which the attention was often focused on the major effects due to the mainshock, omitting details about the effects produced by aftershocks. The topic of assessing macroseismic intensity in the presence of multiple shocks recurs for many other seismic sequences quoted in the seismic catalogues. Considering that macroseismic intensities are extensively used for civil protection purposes and hazard maps, it is evident how the assessment of multiple shocks intensity is a crucial issue. In our work, we tried to give an answer to this issue proposing an unconventional reading aimed to display all available information. Nevertheless, we believe that this issue should be faced and codified by the seismological community to reach a shared vision in order to deal with the intensity data of seismic sequences.

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