



ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

ARCHIVIO ISTITUZIONALE DELLA RICERCA

Alma Mater Studiorum Università di Bologna Archivio istituzionale della ricerca

Inhomogeneity of macroseismic intensities in Italy and consequences for macroseismic magnitude estimation

This is the final peer-reviewed author's accepted manuscript (postprint) of the following publication:

Published Version:

Inhomogeneity of macroseismic intensities in Italy and consequences for macroseismic magnitude estimation / Vannucci G.; Lolli B.; Gasperini P.. - In: SEISMOLOGICAL RESEARCH LETTERS. - ISSN 0895-0695. - STAMPA. - 92:4(2021), pp. 2234-2244. [10.1785/0220200273]

This version is available at: <https://hdl.handle.net/11585/841155> since: 2021-12-09

Published:

DOI: <http://doi.org/10.1785/0220200273>

Terms of use:

Some rights reserved. The terms and conditions for the reuse of this version of the manuscript are specified in the publishing policy. For all terms of use and more information see the publisher's website.

(Article begins on next page)

This item was downloaded from IRIS Università di Bologna (<https://cris.unibo.it/>).
When citing, please refer to the published version.

This is the final peer-reviewed accepted manuscript of:

Gianfranco Vannucci; Barbara Lolli; Paolo Gasperini, *Inhomogeneity of Macroseismic Intensities in Italy and Consequences for Macroseismic Magnitude Estimation*, *Seismological Research Letters* (2021) 92 (4): 2234–2244.

The final published version is available online at:
<https://doi.org/10.1785/0220200273>

Rights / License:

The terms and conditions for the reuse of this version of the manuscript are specified in the publishing policy. For all terms of use and more information see the publisher's website.

This item was downloaded from IRIS Università di Bologna (<https://cris.unibo.it/>)

When citing, please refer to the published version.

1 **Inhomogeneity of macroseismic intensities in Italy and consequences for macroseismic**
2 **magnitude estimation**

3

4

5

6 **Gianfranco Vannucci¹, Barbara Lolli¹ and Paolo Gasperini^{1,2}**

7

8 **¹Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Bologna**

9 **²Dipartimento di Fisica e Astronomia, Università di Bologna**

10

11

12

13

Declaration of Competing Interests:

14

The authors acknowledge there are no conflicts of interest recorded.

15

16

17 **Abstract**

18

19 We show that macroseismic intensities assessed in Italy in the last decade are not homogeneous
20 with those of the previous periods. This is partly related to the recent adoption of the European
21 Macroseismic Scale (EMS) in place of the Mercalli Cancani Sieberg (MCS) scale used up to
22 about one decade ago. The underestimation of EMS with respect to MCS is about a half of a
23 degree on average and even more significant if the MCS intensities are estimated according to
24 the approach developed for the quick evaluations of damage by macroseismic seismologists of
25 the Italian Department of Civil Protection. We also show the inhomogeneity over time of the
26 average differences between instrumental and macroseismic magnitudes computed from
27 intensity data, indicating an average overestimation of magnitudes of about 0.3 units for the
28 instrumental ones before year 1960 and of about 0.2 units for the macroseismic ones after such
29 date. This is consistent with previous studies that hypothesized the incorrect calibration of
30 mechanical recording seismometers operating in Italy and in the surrounding countries before
31 the introduction of the standard electromagnetic seismometers from the beginning of 1960s.
32 For such reasons, the magnitudes of pre-instrumental earthquakes in the CPTI15 seismic
33 catalog, used for the most recent seismic hazard assessment in Italy, might be overestimated
34 on average by about 0.1-0.2 magnitude units.

35

36 **Introduction**

37

38 Even if nowadays high-quality instrumental data are available for any significant earthquake,
39 in Italy macroseismic intensities are still systematically collected since the first hours after the
40 shock. The first aim is to provide the Italian Department of Civil Protection with a
41 comprehensive picture of the damage to localities shaken by the earthquake in order to better
42 organize assistance and recovery procedures, but another possible use of such data is to derive
43 empirical relationships, useful to estimate the magnitude of pre-instrumental earthquakes. In
44 order to fulfill this second objective, it is necessary that present intensity assessments be
45 homogeneous with those made for past earthquakes.

46 Macroseismic intensity is a tool to estimate the level of ground motion, based on the
47 classification of earthquake effects collected by on-site surveys and online questionnaires, for
48 contemporary events, or by the retrospective analysis of archive documents and paper
49 questionnaires, for past earthquakes.

50 Starting from the seminal work by Mercalli (1902) a twelve-degrees scale is the standard for
51 macroseismic intensity assessment in Europe. Since then, many other efforts were made to
52 improve such scale. Among them we cite Sieberg (1912, 1932) who, based also on the
53 suggestions of Cancani (1904), defined the Mercalli-Cancani-Sieberg (MCS) scale (see Ferrari
54 and Guidoboni, 2000 and Vannucci et al., 2015, for English translations of the original German
55 version), Medvedev et al. (1967) and Medvedev (1977), who defined the Medvedev-Sponeuer-
56 Karnik (MSK) scale and more recently Grünthal (1993, 1998), who defined the European
57 Macroseismic Scale (EMS). Note that, in the following, with EMS we will always refer to the
58 EMS-98 version (Grünthal, 1998).

59 The aim of the modifications over time of the macroseismic scale was to make it clearer and
60 easier to be applied to the changing anthropic environment and building stock without altering

61 its internal consistency (Grünthal, 1998). Hence, in principle, intensity estimates made by
62 different scales should coincide to each other at least on average and then after the introduction
63 of a new improved scale, a reclassification of earlier intensity assessments should be avoided
64 (Grünthal, 1998). Some of the authors of the EMS (Musson et al., 2010) later suggested the
65 need to reassess the data using the scale that one wishes to have the data expressed in. But they
66 also acknowledged that, in practice, this may not always be possible.

67 The homogeneity of intensities estimated using different scales is the implicit assumption made
68 by the compilers of the Italian macroseismic database DBMI15 (Locati et al., 2019), which
69 merges more than 123000 macroseismic observations made by different authors using different
70 scales. For example DBMI15 collects MCS intensities from the Catalogo dei Forti Terremoti
71 Italiani (Boschi et al., 2000, Guidoboni et al. 2007) and the macroseismic bulletin of the INGV
72 (e.g. Spadea et al., 1983, Gasparini et al. 2011), MSK intensities from Barbano et al. (1980)
73 and Azzaro et al. (2000) and EMS intensities from Tertulliani et al. (2012) and Rossi et al.
74 (2019).

75 The homogeneity of intensity estimates is also the basic assumption for computing intensity
76 prediction equations (e.g. Pasolini et al., 2008, Rotondi et al., 2016) to be used in intensity-
77 based seismic hazard assessment (e.g. Albarello and Mucciarelli, 2002, D'Amico and
78 Albarello, 2008, Gómez Capera et al., 2010) and for calibrating empirical relationships for the
79 computation of magnitudes of pre-instrumental earthquakes (Bakun and Wentworth, 1997,
80 Gasperini et al., 1999, 2010).

81 Hence, a possible approach to evaluate the homogeneity of intensity estimates in Italy is the
82 comparison between instrumental magnitudes and magnitudes derived from intensity data as
83 provided by the Catalogo Parametrico dei Terremoti Italiani (CPTI15) compiled by Rovida et
84 al. (2020) (see data and resource section) for seismic hazard assessment computations.

85

86 **Homogeneity of magnitudes reported by the CPTI15 catalog**

87

88 In Fig. 1 we show the average differences over time intervals of five years between the
89 magnitudes of Italian earthquakes computed using macroseismic methods ($M_{w_{macro}}$) and
90 instrumentally ($M_{w_{instrum}}$), from the CPTI15 catalog (Rovida et al., 2020). We excluded from
91 the comparison the earthquakes that occurred at Mt. Etna, Mt. Vesuvius, Ischia Island and
92 Campi Flegrei because in such volcanic areas the magnitudes reported in the CPTI15 catalog
93 are computed using specific relationships (Azzaro et al., 2011), different from those used for
94 the rest of the catalog (Rovida et al., 2020). We also excluded from analysis the time intervals
95 1900-1904 and 2015-2019 because of the small number of data (less than 5 events in each time
96 period).

97 We can see that from the beginning of the 20th century to 1960-1964, $M_{w_{macro}}$ underestimates
98 $M_{w_{instrum}}$ by about 0.3 magnitude units (m. u.) on average. After such date, the opposite occurs
99 and, on average, $M_{w_{macro}}$ overestimates $M_{w_{instrum}}$ by about 0.2 m.u. up to the last reported time
100 interval 2010-2014 when again $M_{w_{macro}}$ underestimates $M_{w_{instrum}}$ by about 0.2 m.u. Based on
101 the error bars, corresponding to the standard errors (1σ) of the mean differences, we can argue
102 that most average differences are significantly different from 0 and significantly different
103 among each other (in the statistical sense).

104 A naive interpretation in terms of building resistance to the earthquake shaking would be that
105 in Italy the buildings were definitely stronger before 1960-1964 (lower intensities) than in the
106 successive period (higher intensities) and that only since 2010 they almost returned being as
107 robust as in the early 20th century. This interpretation is not reasonable and different causes
108 must be adduced to explain such behavior.

109 The macroseismic magnitudes included in the comparison are homogeneously computed based
110 on a calibration of empirical relationships made by the BOXER code (hereinafter BOXER)

111 (Gasperini et al., 1999, 2010, see data and resource section) using a set of 354 earthquakes of
112 the CPTI15 catalog from 1903 to 2013 for which both reliable macroseismic data and an
113 instrumental magnitude were available (Rovida et al. 2020).

114 However, the accuracy and the calibration of instrumental magnitudes is not the same over
115 time. In particular, as the first definitions of magnitude date back to the seminal works by
116 Richter (1935) for ML and by Gutenberg and Richter (1942) for Ms and mb, it is clear that, for
117 earthquakes that occurred before such papers were published, magnitudes were computed
118 retrospectively by analyzing seismograms recorded tens of years before by instruments that
119 were no longer in operation at the time of the magnitude computations. This prevented a
120 possible verification of the instrumental calibration and in particular of the dynamic
121 magnification factor at different frequencies.

122 Almost all the instrumental magnitudes reported by the CPTI15 catalog from 1900 to 1960 are
123 surface-waves magnitudes Ms coming from the dataset compiled by Margottini et al. (1993)
124 on the basis of a careful reading of bulletins and seismograms.

125 We can note that the change point at 1960-1964 in Fig. 1 about corresponds to the date of
126 deployment of the World Wide Standardized Seismic Network (WWSSN), the first network of
127 well calibrated seismic stations at the global scale which was originally designed to monitor
128 the nuclear-weapon tests (Oliver and Murphy, 1971).

129 The WWSSN stations were all equipped with two sets of standard electromagnetic
130 seismometers (at short and medium period respectively) that were accurately calibrated using
131 shacking tables (Peterson and Hutt, 2014). Then their dynamic instrumental response is known
132 with high accuracy and the Ms and mb magnitudes computed using them are clearly accurate.
133 Conversely the characteristics and in particular the dynamic magnification of the mechanical
134 recording seismometers used in many seismic stations of the World prior to the installation of
135 the WWSSN were established only theoretically, based on mechanical considerations. Among

136 such mechanical instruments, the most common in Italy and in the surrounding countries was
137 the damped inverted pendulum designed by Emil Wiechert at the beginning of the 20th century
138 (Wiechert, 1903a, 1903b) and of which 150 instruments were manufactured by the Spindler
139 and Hoyer Company in Göttingen (Germany). In Italy, about a dozen of stations equipped with
140 a 200 kg horizontal Wiechert seismometer were operating up to the end of the 1970's.

141 The dynamic magnification of the Wiechert seismometer at different frequencies can be
142 calculated using a theoretical formula, whose validity was questioned by Herak et al. (1996,
143 1998) on the basis of a comparison with a modern seismometer installed for reference at the
144 same site in Zagreb (Croatia). They found that the real magnification of the Wiechert
145 seismometer installed at such site, at frequencies of interest for M_s computations (0.05 Hz),
146 could be significantly underestimated by the theoretical formula by a factor of 2, producing an
147 overestimation of M_s up to 0.3 m.u. Although such discrepancy appears to have affected
148 different instruments in different ways and will have varied over time (Allegretti et al., 2000),
149 we may argue that some systematic bias might affect M_s computed by mechanical instruments
150 in Italy and surrounding countries before the standard electromagnetic seismometers were
151 introduced since the beginning of 1960s.

152 This bias might well explain the observed negative difference between macroseismic and
153 instrumental magnitudes before 1960 in Fig. 1. The overestimation of $M_{W_{macro}}$ with respect to
154 $M_{W_{instrum}}$ between 1960 and 2009 could be explained instead by the contribution of the
155 overestimated M_s in the period before 1960 to the calibration of BOXER empirical formulas
156 (Gasperini et al., 1999, 2010) used by Rovida et al. (2020) to compute macroseismic
157 magnitudes in CPTI15. This suggests that future calibrations of BOXER empirical formulas
158 could exclude earthquakes that occurred before 1960.

159 We can note in Fig. 2 that both discrepancies have a reduced impact on the preferred (default)
160 magnitude reported by the CPTI15 catalog in the 20th century, which is obtained as weighted

161 average between the macroseismic and instrumental magnitudes. In fact, for the default
162 magnitude of the CPTI15 catalog the weights (computed as the inverse of the respective
163 squared errors) are generally larger for macroseismic magnitudes before 1960 (when errors of
164 instrumental magnitudes are larger) and for instrumental magnitudes after 1960 (when errors
165 of instrumental magnitudes are smaller). However, from the differences observed between
166 macroseismic magnitudes and well calibrated instrumental magnitudes from 1960 to 2009, we
167 can argue that CPTI15 magnitudes in previous centuries might be overestimated up to 0.2 m.
168 u. owing to the bias induced by poorly calibrated M_s on BOXER empirical relations.
169 Concerning the negative differences between macroseismic and instrumental magnitudes after
170 2009 (Fig. 1), we can confidently exclude that it is due to a poor calibration of instrumental
171 magnitudes. In fact, in the last decade, M_w from moment tensor inversion, whose accuracy is
172 of the order of 0.1 m.u. or smaller (Gasparini et al., 2012), are available for almost all Italian
173 earthquakes with $M_w > 4.0$ and even for many of the smaller ones (Lolli et al., 2020). Hence
174 the only possible explanation, which we will discuss in detail in the following section, is that,
175 from about 2010, something changed in the estimation of intensity in Italy and in particular
176 that intensity was somehow underestimated with respect to the previous periods.

177

178 **Homogeneity of intensity estimates in Italy**

179

180 Looking at the papers and macroseismic reports collecting macroseismic data of earthquakes
181 that occurred from 2010 to present, we can note that the majority of them uses the EMS scale
182 (Azzaro et al., 2012, 2014, Bernardini and Ercolani, 2011, Bernardini et al., 2011, Tertulliani
183 et al., 2012) in place of the MCS scale, which was the mostly used one in the previous period
184 (e. g. Boschi et al., 2000, Galli and Camassi, 2009, Gasparini et al., 2011).

185 We already noted above that in principle, the use of the EMS in place of the MCS scale should
186 not change the estimated intensity, on average at least. However, this would appear not to be
187 the case in Italy.

188

189 ***Comparison between EMS and MCS intensities***

190 A demonstration of the difference between the EMS and the MCS scale is given by the work
191 of Graziani et al. (2015) for the 2012 Pianura Emiliana earthquake sequence. They compared
192 the cumulative (collected after both the strongest shocks of the sequence) EMS intensities
193 estimated considering the whole building stock at the various localities by Tertulliani et al.
194 (2012) with the cumulative MCS intensities they estimated by only considering the old town
195 centers (OTC) of the same localities where the building types were more similar to those
196 existing at the time when Sieberg (1912, 1932) defined the MCS scale. They also made a
197 further experiment of estimating MCS intensities by only considering the monumental
198 buildings (MON) to simulate what might happen when analyzing an ancient earthquake for
199 which historical sources only mention such building types.

200 Note that MCS, different from EMS and MSK, does not provide an explicit classification of
201 building vulnerabilities. The definitions of MCS degrees (see Vannucci et al., 2015) sometimes
202 mention stone and wooden buildings or that buildings were poorly or solidly built but in most
203 cases the definitions generically refer to buildings or houses without any further indication of
204 the material they are made or their robustness. In no cases are reinforced concrete buildings
205 mentioned by the MCS definitions.

206 If EMS and MCS were equivalent, intensities should coincide with each other, at least on
207 average. Graziani et al. (2015) found instead that EMS are smaller than MCS (OTC) by 0.6
208 degrees on average. Moreover, the macroseismic magnitude computed by BOXER (Gasparini
209 et al., 1999, 2010) using EMS is 0.28 m.u. smaller than that computed using MCS (OTC)

210 (Table 1). The differences would be even larger with respect to MCS (MON) but the practice
211 of using monumental building for intensity estimates is strongly discouraged (Grünthal, 1998)
212 and the majority of the macroseismic researchers do not really estimate an intensity when the
213 only information available is on monumental buildings (like churches and bell towers) because
214 the latter are known to be more vulnerable than ordinary buildings.

215 However, if we make the same comparison between EMS and MCS intensity estimates taken
216 from other papers published in the last decade we do not obtain the same difference but rather
217 a substantial coincidence between EMS and MCS (Table 2). Even the comparison of
218 magnitudes computed by BOXER (Gasperini et al., 1999, 2010) using the intensity estimates
219 made by the two scales shows a substantial coincidence (Table 2 and Table S1 of the
220 supplemental material). This means that, apart from the data reported in the paper by Graziani
221 et al. (2015), EMS and MCS intensities estimated in Italy appear substantially equivalent.

222 However, we can note that, contrary to Graziani et al. (2015), none of papers providing MCS
223 intensities in the last decade (Galli et al., 2012a, 2012b, 2017, Arcoraci et al., 2012, 2013, Rossi
224 et al., 2019) mention the need of excluding from the computation of the percentage of damage
225 the buildings made using modern building techniques like for example reinforced concrete.
226 Actually, such building type is intrinsically earthquake resistant even if it is not specifically
227 designed for seismic loads. In modern Italian localities reinforced concrete structures constitute
228 almost one third of the total building stock whereas at the time of the formulation of the MCS
229 scale it was almost non-existent in Italy (Table 3). Reinforced concrete buildings were probably
230 almost not existing elsewhere too as, different from other building types like stone or wooden
231 frame, they are never mentioned by the definitions of the MCS scale (Sieberg, 1912, 1932).

232

233 ***Discussion on the Galli et al. MCS intensity assignments***

234 Among the papers providing MCS intensities in the last decade, Galli et al. (2012a, 2012b,
235 2017) explicitly indicate that all buildings (included those in reinforced concrete) were
236 considered in the analysis as the main scope of their survey was to provide the Italian Civil
237 Protection Department (DPC), to which some of the authors belong, with a complete picture
238 of the damage in the shaken area. In particular, they declare to adopt the specific approach
239 formulated by Molin (2003, 2009) for estimating the MCS intensity. Both the latter papers are
240 in Italian but a brief English description of the methodology can be found in Galli et al. (2012a)
241 It is worth noting that in the introduction of Molin (2009), which is an internal report of the
242 DPC, one can read literally that the MCS scale “is to be considered inadequate for scientific
243 purposes” and then it is only useful to quickly provide the information directly related to the
244 damage, which are required by the DPC.

245 Actually, the criteria proposed by Molin (2009) correspond to a complete reorganization of
246 degrees from 5 to 12 in terms of 5 levels of building damage severity, from slight damage to
247 total collapse, which the author affirms are implicitly used in the MCS scale and have been
248 kept substantially the same in the successive macroseismic scales. In Fig. S1 of the
249 supplemental material we reproduce the original table (3) of Molin (2009), listing the 5 levels
250 of damage, and our English translation of the same.

251 Molin (2009) assigns to each degree of the scale different fractions (5%, 25%, 50%, 75%,
252 100%) of involved buildings for the 5 levels of damage severity, more or less in accord with
253 the original MCS definitions (see in Fig. S2 of supplemental material the reproduction of the
254 original table (4) of Molin, 2009 and our English translation). The author then argues that some
255 inconsistencies exist in the progression of percentages of damage between the various degrees
256 of the MCS scale and, to regularize them, adds a further degree between 5 and 6 (named 5-6)
257 and fills the fractions of damage allegedly missed by Sieberg (1912, 1932) according to a
258 regular scheme (see in Fig. S3 of supplemental material the reproduction of the original table

259 (5) of Molin, 2009 and our English translation; the same table is also reported by Galli et al,
260 2012a).

261 Although we can understand the reasons of such reorganization of the scale (in order to make
262 easier and faster the estimation of intensity in the first hours and days after the earthquake) it
263 is evident that it represents a totally new scale that does not strictly correspond to the MCS
264 defined by Sieberg (1912, 1932) and also differs from the MCS scale applied by other research
265 groups in Italy (e. g. Ferrari and Guidoboni, 2000).

266 In fact, in Table 2 we can note that, contrary to other papers showing a substantial equivalence
267 between EMS and MCS, the MCS intensities estimated by Galli et al. (2012a, 2012b) for the
268 2012 Pianura Emiliana earthquakes underestimate the EMS intensities by Tertulliani et al.
269 (2012) by about 0.2-0.3 degrees.

270 Moreover, in Table 4 we show that a similar average underestimation affects the MCS
271 estimates by Galli et al. (2017) for the 2016 Central Italy sequence with respect to MCS
272 intensities estimated by Rossi et al. (2019) for the same sequence. However, the macroseismic
273 magnitudes of the shocks of 24/8/2016 and 26/10/2016 computed using the dataset by Galli et
274 al. (2017) are larger (0.14 m.u.) than those computed using the dataset by Rossi et al. (2019).

275 To investigate on this apparent contradiction, in Fig. 3 we show the average differences (lines)
276 between MCS estimates by Rossi et al. (2019) and those made by Galli et al. (2017) at the same
277 localities with given MCS intensity estimated by Rossi et al. (2019) (black line) and by Galli
278 et al. (2017) (grey line). The underestimation of Galli et al. (2017) mainly concerns intensities
279 between 6.5 and 8.5, which on average are lower than those of Rossi et al. (2019) of about a
280 half degree. Conversely for intensity 9 or larger, the estimates by Galli et al., (2017) are on
281 average larger than those of Rossi et al. (2019) (Fig. 3). This overestimation of higher
282 intensities is also reflected by larger epicentral intensities of Galli et al., (2017) with respect to
283 Rossi et al. (2019), as computed by BOXER for the shocks of 24/8/2016 (10.5 vs 10) and of

284 26/10/2016 (9 vs 8) (see I_0 in Table S1 of supplemental material). Considering the role of
285 epicentral intensity in the method used by BOXER to compute the magnitude (see Gasperini
286 et al., 1999, 2010), this explains why the macroseismic magnitudes of the two shocks are larger
287 for the dataset by Galli et al. (2017) even if the MCS intensities are smaller on average than
288 the dataset by Rossi et al. (2019).

289

290 *Comparison of EMS intensity assessment made by different groups*

291 In Table 5 we can see that EMS intensities estimated for the shock of the 24 August 2016 by
292 Zanini et al. (2016) are substantially equivalent to those estimated by Rossi et al. (2019).
293 Similarly, the macroseismic magnitudes computed using the two datasets are also close to each
294 other. Hence, we can argue that, contrary to the MCS scale, the application of the EMS to
295 recent earthquakes does not present particular inhomogeneities.

296

297 **Discussion and conclusions**

298

299 We have shown that the macroseismic intensities of Italian earthquakes that occurred in the
300 last decade are underestimated with respect to previous periods. This is partly related to the
301 adoption of the European Macroseismic Scale (EMS, Grünthal, 1998) by most researchers in
302 place of the Mercalli Cancani Sieberg (MCS) scale (Sieberg, 1912, 1932) that was the most
303 used scale until around 2009, but also to the questionable practice of including modern
304 buildings made of reinforced concrete (almost non-existing at the time of the formulation of
305 the MCS scale) in the percentages of damage when using the MCS scale.

306 The underestimation of EMS intensities with respect to MCS ones is about a half of a degree
307 on average as demonstrated by the comparison made by Graziani et al. (2015) between EMS
308 and MCS intensities obtained by only considering the old centers of towns where most of the

309 buildings date back to the early decades of the 20th century, when the MCS scale was
310 formulated by Sieberg (1912, 1932).

311 The underestimation is even more significant if considering the MCS estimated according to
312 the approach proposed by Molin (2009). In fact, the latter intensities are on average about 0.3
313 degrees lower than standard EMS estimates and then about 0.8 degrees lower than MCS
314 intensities estimated, according to Graziani et al. (2015) by properly considering only the
315 building types existing at the time of the formulation of the scale by Sieberg (1912, 1932). Note
316 that Molin (2009) explicitly affirms that such approach, also adopted by Galli et al. (2012a,
317 2012b, 2017), was developed only for rapidly providing the Italian Department of Civil
318 Protection with a quick map of damage just after the occurrence of a strong earthquake.

319 Such inhomogeneities, concerning both EMS and MCS intensities estimated in the last decade,
320 may bias the calibration of empirical relationships used to compute the magnitude of pre-
321 instrumental earthquakes (Gasperini et al., 1999, 2010, Rovida et al., 2020). Hence, we suggest
322 that in future calibrations of such relationships it will be better to exclude the data of
323 earthquakes that occurred in the last decade.

324 We also found that instrumental magnitudes of earthquakes that occurred before 1960-1964
325 (mostly M_s computed by recordings of mechanical instruments) are overestimated with respect
326 to magnitudes computed from macroseismic data by about 0.3 m.u. on average.

327 Based on the result shown by Herak et al. (1996, 1998), we may attribute such overestimation
328 to a possible underestimation of the dynamic magnification of mechanical instruments
329 operating in Italy and surrounding countries up to about the beginning of the 1960's. Hence,
330 we could also suggest that in future calibrations of macroseismic magnitude relationships, the
331 data of earthquakes that occurred before 1960 (when well calibrated electromagnetic
332 seismometers started to be installed in Italy and all over the World) be excluded.

333 We can guess that, due to such inhomogeneities, the macroseismic magnitudes of earthquakes
334 that occurred before the instrumental era, reported by the CPTI15 catalog (Rovida et al., 2020)
335 used for seismic hazard assessment in Italy, might be overestimated up to about 0.2 m.u. This
336 finding is supported by a quick recalibration of the BOXER coefficients for magnitude
337 computation using only the earthquakes, already used for the calibration of CPTI15 (Rovida et
338 al., 2020), but occurred only in the time interval from 1960 to 2009 (in all 251 events). The
339 macroseismic moment magnitudes computed using such revalued coefficients result on
340 average lower than that reported by CPTI15 by 0.144 ± 0.003 m.u.

341 The observed discrepancy between EMS and MCS intensities might be surprising based on the
342 premises of the EMS (Grünthal, 1998), which explicitly excluded the need of reclassifying all
343 past intensity estimates using the new scale. We must note however that the EMS does not
344 derive directly from the MCS scale but rather from the MSK scale (Medvedev et al., 1967,
345 Medvedev, 1977). The latter has been widely used in north-eastern Europe, in Indian
346 subcontinent, as well as in USSR since 1960-1970 but has not widely used in Italy where it had
347 been applied almost only to earthquakes of Sicily (Barbano et al., 1980, Azzaro et al., 2000).
348 Hence it is possible that, during the time, MSK had lost its strict connection to MCS, or to the
349 way in which MCS is applied in Italy (e.g. Ferrari and Guidoboni, 2000) so that the EMS,
350 which derives from MSK, is not anymore compatible with most of the Italian database of MCS
351 intensities DBMI15 (Locati et al, 2019).

352 To rebuild a homogeneous intensity dataset, two options are available: a) a complete
353 revaluation from the original sources of all intensities in DBMI15 (more than 100,000), using
354 the EMS or b) a revaluation of only the MCS intensities of the earthquakes of the last decade
355 (and maybe also of the future ones) according to the criteria proposed by Graziani et al. (2015).
356 That is, by excluding from the computation of percentages of damage, the buildings made using

357 reinforced concrete or other modern building techniques. We defer to macroseismic researchers
358 the choice between such two options.

359

360 **Data and resource**

361 The BOXER code for the computation of macroseismic epicenter and magnitude according to
362 Gasperini et al. (1999, 2010) can be downloaded at <https://emidius.mi.ingv.it/boxer/> (last
363 accessed July 2020).

364 CPTI15 catalog (Rovida et al., 2020) data are collected at: https://emidius.mi.ingv.it/CPTI15-DBMI15/download_CPTI15.htm (last accessed July 2020).

366 Italian Census data (ISTAT, 2011) are collected at [http://dati-](http://dati-censimentopopolazione.istat.it/Index.aspx?lang=en#)
367 [censimentopopolazione.istat.it/Index.aspx?lang=en#](http://dati-censimentopopolazione.istat.it/Index.aspx?lang=en#), (last accessed July 2020).

368 EMS and MCS intensities by Bernardini et al. (2003) are collected at:
369 http://www.ingv.it/quest/images/rilievimacrosismici/xlsx/INGV_QUEST_2003-09-14.xlsx,
370 (last accessed July 2020).

371 MCS intensities by D'Amico et al. (2009) are collected at:
372 http://www.ingv.it/quest/images/rilievimacrosismici/xlsx/INGV_QUEST_2009-03-14.xlsx,
373 (last accessed July 2020).

374 EMS and MCS intensities by Arcoraci et al. (2012) are collected at:
375 http://www.ingv.it/quest/images/rilievimacrosismici/xlsx/INGV_QUEST_2012-01-25.xlsx,
376 (last accessed July 2020).

377 EMS and MCS intensities by Arcoraci et al. (2013) are collected at:
378 http://www.ingv.it/quest/images/rilievimacrosismici/xlsx/INGV_QUEST_2013-06-21.xlsx,
379 (last accessed July 2020).

380 EMS and MCS intensities by Castellano et al. (2018) are collected at:
381 http://www.ingv.it/quest/images/rilievimacrosismici/xlsx/INGV_QUEST_2018-08-16.xlsx,
382 (last accessed July 2020).

383 Supplemental material for this article includes figures S1, S2 and S3, reproducing Tables 3, 4
384 and 5 respectively of Molin (2009) and their English translations and Table S1, listing
385 parameters computed for all intensity dataset considered.

386

387 **Acknowledgements**

388 The authors thank Filippo Bernardini, Graziano Ferrari, Paolo Galli, Laura Graziani and
389 Andrea Tertulliani for thoughtful comments and suggestions after the reading an earlier version
390 of the manuscript. We also thank two anonymous referees for thoughtful comments and
391 suggestions and for the careful check of our use of English language. This paper benefitted
392 from funding provided by the European Union within the ambit of the H2020 project RISE
393 (No. 821115).

394

395 **References**

396

397 Albarello, D., and D. Mucciarelli (2002). Seismic hazard estimates using ill-defined
398 macroseismic data at site, *Pure Appl. Geophys.* 159, 1289-1304.

399

400 Allegretti, I., D. Herak, M. Herak, and S. J. Duda (2000). Consistency of magnitudes of the
401 largest earthquakes of the first half of the 20th century determined on the basis of Göttingen
402 and Zagreb Wiechert seismograms, *Studia geoph. et geod.*, 44, 13-25.

403

404 Arcoraci L., Berardi M., Brizuela B., Castellano C., Del Mese S., Graziani L., Maramai A.,
405 Rossi A., Sbarra M., Tertulliani A., Vecchi M., Vecchi S., Bernardini F., Ercolani E. (2012).
406 Rilievo macrosismico degli effetti del terremoto del 25 gennaio 2012 (Pianura Padana).
407 Rapporto tecnico QUEST, Istituto Nazionale di Geofisica e Vulcanologia (INGV), Roma, 9
408 pp., doi: 10.13127/QUEST/20120125 (in Italian).

409

410 Arcoraci L., Bernardini F., Brizuela B., Ercolani E., Graziani L., Leschiutta I., Maramai A.,
411 Tertulliani A., Vecchi M. (2013). Rapporto macrosismico sul terremoto del 21 giugno 2013
412 (ML 5.2) in Lunigiana e Garfagnana (province di Massa-Carrara e di Lucca) (aggiornato al 30
413 giugno 2013). Rapporto tecnico QUEST, Istituto Nazionale di Geofisica e Vulcanologia
414 (INGV), Roma, 5 pp. doi: 10.13127/QUEST/20130621 (in Italian).

415

416 Azzaro R., Barbano M.S., Antichi B., Rigano R. (2000). Macroseismic catalogue of Mt. Etna
417 earthquakes from 1832 to 1998. *Acta Vulcanologica*, 12, 1-2, 3-36 + CD

418

419 Azzaro R., D'Amico S., Tuvè T. (2011). Estimating the Magnitude of Historical Earthquakes
420 from Macroseismic Intensity Data: New Relationships for the Volcanic region of Mount Etna
421 (Italy), *Seism. Res. Lett.*, 82/4, 533-544, doi: 10.1785/gssrl.82.4.533.

422

423 Azzaro R., D'Amico S., Scarfi L., Tuvè T. (2012). Aggiornamento al rilievo macrosismico
424 degli effetti prodotti dal terremoto del Pollino del 26 ottobre 2012 alle ore 01:05 locali.
425 Rapporto tecnico QUEST, Istituto Nazionale di Geofisica e Vulcanologia (INGV), Roma, 5
426 pp., doi: 10.13127/QUEST/20121026.01 (in Italian).

427

428 Azzaro R., D'Amico S., Mostaccio A., Scarfi L., Tuvè T., Manni M. (2014). Terremoti con
429 effetti macrosismici in Sicilia orientale nel periodo Gennaio 2009 - Dicembre 2013. Quaderni
430 di Geofisica, 120, INGV, Roma, 57 pp, [http://istituto.ingv.it/l-ingv/produzione-](http://istituto.ingv.it/l-ingv/produzione-scientifica/quaderni-di-geofisica/archivio/quaderni-di-geofisica-2014/)
431 [scientifica/quaderni-di-geofisica/archivio/quaderni-di-geofisica-2014/](http://istituto.ingv.it/l-ingv/produzione-scientifica/quaderni-di-geofisica/archivio/quaderni-di-geofisica-2014/) (in Italian).

432

433 Bakun, W. H., and C. M. Wentworth (1997). Estimating earthquake location and magnitude
434 from seismic intensity data, *Bull. Seismol. Soc. Am.*, 87/6, 1502-1521.

435

436 Bernardini F., Camassi R., Castelli V., Ercolani E., Frapiccini M., Vannucci G., Giovani L.,
437 Tertulliani A. (2003). Rilievo macrosismico degli effetti prodotti dalla sequenza sismica
438 iniziata il 14 settembre 2003 (Appennino Bolognese). Rapporto tecnico QUEST, Istituto
439 Nazionale di Geofisica e Vulcanologia (INGV), Bologna, 10 pp., doi:
440 10.13127/QUEST/20030914 (in Italian).

441

442 Bernardini F., Ercolani E., Del Mese S. (2011). Rapporto macrosismico sul terremoto torinese
443 del 25 luglio 2011. Rapporto tecnico QUEST, Istituto Nazionale di Geofisica e Vulcanologia
444 (INGV), Roma, 5 pp. doi: 10.13127/QUEST/20110725 (in Italian).

445

446 Bernardini F., Ercolani E. (2011). Rilievo macrosismico degli effetti prodotti dal terremoto del
447 17 luglio 2011 nella Pianura Padana lombardo-veneta (province di Rovigo, Mantova, Modena
448 e Ferrara). Rapporto tecnico QUEST, Istituto Nazionale di Geofisica e Vulcanologia (INGV),
449 Roma, 6 pp. doi: 10.13127/QUEST/20110717_(in Italian).

450

451 Barbano M.S., Cosentino M., Lombardo G., Patané G. (1980). Isoleismal maps of Calabria
452 and Sicily earthquakes (Southern Italy). CNR-PFG, pubbl. 341, Catania, 116 pp.

453

454 Boschi E., Guidoboni E., Ferrari G., Mariotti D., Valensise G., Gasperini P. (eds), 2000.
455 Catalogue of Strong Italian Earthquakes from 461 B.C. to 1997. *Annali di Geofisica*, 43, 4,
456 609-868.

457

458 Cancani, A. (1904). Sur l'emploi d'une double echelle sismique des intensités, empirique et
459 absolute, G. Beitr., *Erganzungsband* 2, 281-283 (in French).

460

461 Castellano C., Del Mese S., Fodarella A., Graziani L., Maramai A., Tertulliani A., Verrubbi V.
462 (2018). Quest- Rilievo Macrosismico Per I Terremoti Del Molise Del 14 E 16 Agosto 2018.
463 Zenodo, doi: 10.5281/ZENODO.1405385 (in Italian).

464

465 D'Amico, V., and D. Albarello (2008). SASHA: A computer program to assess seismic hazard
466 from intensity data, *Seismol. Res. Lett.* 79, 663-671.

467

468 D'Amico S., Mostaccio A., Tuvè T. (2009). Rapporto macrosismico preliminare sul terremoto
469 etneo del 14/03/2009 - ore 10:26 locali. Rapporto tecnico QUEST, Istituto Nazionale di
470 Geofisica e Vulcanologia (INGV), Catania, 2 pp., doi: 10.13127/QUEST/20090314 (in
471 Italian).

472

473 Ferrari, G., and E. Guidoboni (2000). Seismic scenarios and assessment of intensity: some
474 criteria for the use of the MCS scale, *Annali di Geofisica*, 43/4, 707, 720.

475

476 Galli P., and Camassi R. (eds.), 2009. Rapporto sugli effetti del terremoto aquilano del 6 aprile
477 2009. Rapporto tecnico QUEST, DPC-INGV, Roma, 12 pp. doi: 10.13127/QUEST/20090406
478 (in Italian).

479

480 Galli, P., Castenetto, S., Peronace E. (2012a). May 2012 Emilia earthquakes (MW 6, northern
481 Italy): macroseismic effects distribution and seismotectonic implications. *Alpine and
482 Mediterranean Quaternary*, 25, 2, 105-123, 2279-7327.

483

484 Galli, P., Castenetto, S., Peronace, E. (2012b). The MCS macroseismic survey of the Emilia
485 2012 earthquakes. *Ann. Geophys.*, 55, 4, 663,672, doi: 10.4401/ag-6163.

486

487 Galli, P., Castenetto, S., Peronace, E. (2017). The macroseismic intensity distribution of the 30
488 October 2016 earthquake in central Italy (Mw 6.6): Seismotectonic implications. *Tectonics*,
489 36, doi: 10.1002/2017TC004583.

490

491 Gasparini C., Conte S., Vannucci C. (ed), 2011. Bollettino macrosismico 2001-2005. Istituto
492 Nazionale di Geofisica e Vulcanologia, Roma. CD-ROM (in Italian).
493
494 Gasperini, P., Bernardini, F., Valensise, G., Boschi, E. (1999). Defining seismogenic sources
495 from historical earthquake felt reports. *Bull. Seismol. Soc. Am.* 89, 94-110.
496
497 Gasperini, P., Vannucci, G., Tripone, D., Boschi, E. (2010). The location and sizing of
498 historical earthquakes using the attenuation of macroseismic intensity with distance. *Bull.*
499 *Seismol. Soc. Am.* 100, 2035-2066, doi: /10.1785/0120090330.
500
501 Gasperini, P., B. Lolli, G. Vannucci, and E. Boschi (2012). A comparison of moment
502 magnitude estimates for the European-Mediterranean and Italian regions, *Geophys. J. Int.*, 190,
503 1733-1745, doi: 10.1111/j.1365-246X.2012.05575.x.
504
505 Gómez Capera, A. A., V. D'Amico, C. Meletti, A. Rovida, and D. Albarello (2010). Seismic
506 Hazard Assessment in Terms of Macroseismic Intensity in Italy: A Critical Analysis from the
507 Comparison of Different Computational Procedures, *Bull. Seismol. Soc. Am.*, 100/4, 1614-
508 1631, doi: 10.1785/0120090212.
509
510 Graziani, L., Bernardini, F., Castellano, C., Del Mese, S. Ercolani, E., Rossi, A., Tertulliani,
511 A., Vecchi M. (2015). The 2012 Emilia (Northern Italy) earthquake sequence: an attempt of
512 historical reading. *J. Seismol.*, 19, 371-387, doi: 10.1007/s10950-014-9471-y.
513

514 Grünthal, G. (ed.) (1993). European Macroseismic Scale 1992 (up-dated msk-scale), *Conseil*
515 *de l'Europe. Cahiers du Centre Européen de Géodynamique et de Séismologie*, 7,
516 Luxembourg, 79 pp.

517

518 Grünthal, G. (ed.) (1998). European macroseismic scale 1998, *Conseil de l'Europe. Cahiers*
519 *du Centre Européen de Géodynamique et de Séismologie*, 13, Luxembourg, 99 pp.

520

521 Guidoboni E., Ferrari G., Mariotti D., Comastri A., Tarabusi G., Valensise G. (2007).
522 CFTI4Med, Catalogue of Strong Earthquakes in Italy (461 B.C.-1997) and Mediterranean Area
523 (760 B.C.- 1500). INGV-SGA. <http://storing.ingv.it/cfti4med/>.

524

525 Gutenberg, B., and C. F. Richter (1942). Earthquake magnitude, intensity, energy, and
526 acceleration, *Bull. Seismol. Soc. Am.* 32, 163-191.

527

528 Herak M., Allegretti I., Herak D. and Duda S.J., (1996). Calibration of the Wiechert
529 seismographs relative to a reference seismometer. *Geofizika*, 13, 31-59.

530

531 Herak M., Allegretti I., Herak D. and Duda S.J. (1998). Numerical modeling of the observed
532 Wiechert seismograph magnification, *PAGEOPH*, 152, 539-550.

533

534 Locati M., Camassi R., Rovida A., Ercolani E., Bernardini F., Castelli V., Caracciolo C.H.,
535 Tertulliani A., Rossi A., Azzaro R., D'Amico S., Conte S., Rocchetti E., Antonucci A. (2019).
536 Database Macrosismico Italiano (DBMI15), versione 2.0. Istituto Nazionale di Geofisica e
537 Vulcanologia (INGV). <https://doi.org/10.13127/DBMI/DBMI15.2> (in Italian with English
538 description).

539 Lolli B., Randazzo D., Vannucci G. and P. Gasperini. The HOMogenized instrUMENTal
540 Seismic catalog (HORUS) of Italy from 1960 to present, *Seismol. Res. Lett.* 91, 3208–3222,
541 doi: 10.1785/0220200148
542

543 Margottini, C., N. N. Ambraseys, and A. Screpanti (1993). La magnitudo dei terremoti italiani
544 del XX Secolo, E.N.E.A. Internal Publication, Rome, 57 pp (in Italian).
545

546 Medvedev (1977). Seismic intensity scale MSK 76, *Publ. Inst. Geophys. Pol. Acad. Sc.*, A-
547 6(117), 95-102.
548

549 Medvedev, S.V., W. Sponheuer and V. Karnik (1967). Seismic intensity scale version MSK
550 1964, *Publ. Inst. Geodynamik*, **48**, Jena.
551

552 Mercalli, G. (1902): Sulle modificazioni proposte alla scala sismica De Rossi-Forel, *Bollettino*
553 *della Società Sismologica Italiana*, **8** (1902-1903), 184-191 (in Italian).
554

555 Molin, D. (2003). Considerazioni sull'eventuale adozione in Italia della scala macrosismica
556 europea (EMS- 1998), In: GNGTS - Atti del 22° convegno nazionale/06.21, ISBN/ISSN:88-
557 900385-9-4, 11 pp. (in Italian).
558

559 Molin, D. (2009). Rilievo macrosismico in emergenza. Rapporto interno del Dipartimento della
560 Protezione Civile, Ufficio Valutazione, prevenzione e mitigazione del rischio sismico, 13 pp,
561 (in Italian).
562

563 Musson, R.M.W., Grünthal, G. and Stucchi, M., 2010 The comparison of macroseismic
564 intensity scales. *J Seismol* 14, 413-428, doi: 10.1007/s10950-009-9172-0
565
566 Oliver J., and Murphy L.M. (1971). WWNSS-Seismology's global network of observing
567 stations: *Science*, v. 174, p. 254-261, doi, 10.1126/science.174.4006.254
568
569 Peterson J. Hutt C. R. (2014). World-Wide Standardized Seismograph Network-A user's guide,
570 U.S. Geol. Surv. Open-File Rept. 2014-1218, 74 pp.
571
572 Pasolini C, Albarello D, Gasperini P, D'Amico V, Lolli B (2008) The attenuation of seismic
573 intensity in Italy part II: modeling and validation. *Bull Seism Soc Am* 98:692-708.
574 doi:10.1785/0120070021
575
576 Richter, C. F. (1935). An instrumental earthquake magnitude scale, *Bull. Seismol. Soc. Am.*
577 25, 1-31.
578
579 Rotondi, R., E. Varini, and C. Brambilla (2016). Probabilistic modelling of macroseismic
580 attenuation and forecast of damage scenarios, *Bull Earthquake Eng*, 14, 1777-1796
581 doi 10.1007/s10518-015-9781-7.
582
583 Rossi, A., A. Tertulliani, R. Azzaro, L. Graziani, A. Rovida, A. Maramai, V. Pessina, S.
584 Hailemichael, G. Buffarini, F. Bernardini, R. Camassi, S. Del Mese, E. Ercolani, A. Fodarella,
585 M. Locati, G. Martini, A. Paciello, S. Paolini, L. Arcoraci, C. Castellano, V. Verrubbi, M.
586 Stucchi (2019). The 2016-2017 earthquake sequence in Central Italy: macroseismic survey and

587 damage scenario through the EMS-98 intensity assessment. Bull Earthquake Eng 17, 2407-
588 2431, doi: 10.1007/s10518-019-00556-w.

589

590 Rovida, A., M. Locati, R. Camassi, B. Lolli, and P. Gasperini (2020). The Italian earthquake
591 catalogue CPTI15, Bull. Earthq. Eng., 18, 2953-2984, doi: 10.1007/s10518-020-00818-y.

592

593 Sieberg, A. (1912): Über die makroseismische Bestimmung der Erdbebenstärke. Ein Beitrag
594 zur seismologische Praxis, *G. Gerlands Beiträge zur Geophysik*, 11 (2-4), 227-239 (in German).

595

596 Sieberg, A. (1932): Erdebeben, in *Handbuch der Geophysik*, Vol. 4, (B. Gutenberg Ed.), 552-
597 554 (in German).

598

599 Spadea M.C., Vecchi M., Del Mese S., 1983. Bollettino macrosismico 1981. Istituto Nazionale
600 di Geofisica, Roma, 10 pp. (in Italian).

601

602 Tertulliani, A., Arcoraci, L., Berardi, M., Bernardini, F., Brizuela, B., Castellano, C., Del Mese,
603 S., Ercolani, E., Graziani, L., Maramai, A., Rossi, A., Sbarra, M., Vecchi, M. (2012). The
604 Emilia 2012 sequence: a macro-seismic survey. *Ann. Geophys.* 55 (4), 679-687, doi:
605 10.4401/ag-6140.

606

607 Vannucci, G., D. Tripone, P. Gasperini, G. Ferrari, and B. Lolli (2015). Automated assessment
608 of macroseismic intensity from written sources using the fuzzy sets, Bull. Earthquake Eng., 13,
609 2769-2803, doi: 10.1007/s10518-015-9759-5.

610

611 Wiechert, E. (1903a). Theorie der automatischen Seismographen, Weidmansche
612 Buchhandlung, Berlin, pp.128 (in German).

613

614 Wiechert, E. (1903b). Ein astatisches Pendel hoher Empfindlichkeit zur mechanischen
615 Registrierung von Erdbeben. Physikalische Zeitschrift, No. 28, 821-832 (in German).

616

617 Zanini M.A., Hofern L., Faleschini F., Zampieri P., Fabris N. and Pellegrino C. (2016).
618 Preliminary macroseismic survey of the 2016 Amatrice seismic sequence. Ann. of Geophys.,
619 59, Fast Track 5, doi: 10.4401/ag-7172

620

621

622

Author's addresses

623 Gianfranco Vannucci

624 Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Bologna, Via D. Creti, 12, I-40128,

625 Bologna, Italy, email: gianfranco.vannucci@ingv.it

626

627 Barbara Lolli

628 Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Bologna, Via D. Creti, 12, I-40128,

629 Bologna, Italy, email: barbara.lolli@ingv.it

630

631 Paolo Gasperini

632 Dipartimento di Fisica e Astronomia, Università di Bologna, Viale Berti Pichat, 8, I-40127,

633 Bologna, Italy, email: paolo.gasperini@unibo.it

634

635

636
637

638

639

Tables

640 Table 1 - Comparison between macroseismic parameters computed by BOXER (Gasperini et
641 al., 2010) using EMS and MCS intensities collected after the sequence of 20-29 May 2012
642 (May 2012) in the Pianura Emiliana.

<i>Date</i>	<i>Time</i>	<i>N</i>	$I_{EMS}-I_{MCS}$	$Dist_{macro}$	$\Delta M_{W_{macro}}$	<i>Datasets</i>
May 2012		33	-0.591 ± 0.046	0.1	-0.28	Tertulliani et al. (2012) (EMS) Graziani et al. (2015) (MCS OTC)
May 2012		33	-1.125 ± 0.110	6.9	-0.53	Tertulliani et al. (2012) (EMS) Graziani et al. (2015) (MCS MON)

643 *N* number of localities with intensity data used for the comparison, $I_{EMS}-I_{MCS}$ average
644 differences between EMS and MCS intensities, $Dist_{macro}$ and $\Delta M_{W_{macro}}$ distances between
645 macroseismic epicenters (in km) and differences between macroseismic magnitudes from EMS
646 and MCS intensities respectively. MCS OTC and MCS MON refer to intensities assigned by
647 only considering the buildings in old town centers and the monumental buildings respectively
648 (see main text for details).

649

650 Table 2 - Comparison between macroseismic parameters computed by BOXER (Gasperini et
 651 al., 2010) using EMS and MCS intensities collected by various authors.

<i>Date</i>	<i>Time</i>	<i>N</i>	$I_{EMS}-I_{MCS}$	$Dist_{macro}$	$\Delta M_{W_{macro}}$	<i>Datasets</i>
14/09/2003	21:42	133	-0.233±0.026	2.8	-0.06	Bernardini et al. (2003)
14/03/2009	09:26	20	0.050±0.034	0.7	0.06	Azzaro et al. (2014) (EMS) D'Amico et al. (2009) (MCS)
25/01/2012	08:06	25	-0.060±0.033	0.0	-0.01	Arcoraci et al. (2012)
20/05/2012	02:03	23	0.174±0.087	3.2	-0.04	Tertulliani et al. (2012) (EMS) Galli et al. (2012a,b) (MCS)
May 2012		67	0.291±0.047	1.8	0.23	Tertulliani et al. (2012) (EMS) Galli et al. (2012a,b) (MCS)
21/06/2013	10:33	27	-0.093±0.038	0.0	-0.02	Arcoraci et al. (2013)
24/08/2016	01:36	167	-0.102±0.028	1.0	0.01	Rossi et al. (2019)
26/10/2016	19:18	66	0.023±0.023	0.0	0.01	Rossi et al. (2019)
30/10/2016	06:40	320	-0.053±0.015	1.6	0.00	Rossi et al. (2019)
Aug-Oct 2016		425	-0.073±0.013	0.9	0.01	Rossi et al. (2019)
18/01/2017	10:14	66	-0.023±0.023	2.1	0.17	Rossi et al. (2019)
Aug 2018		15	-0.067±0.045	0.0	-0.22	Castellano et al. (2018)
All (average)		1354	-0.057±0.025	1.2	0.01	

652 *N* number of localities with intensity data used for the comparison, $I_{EMS}-I_{MCS}$ average
 653 differences between EMS and MCS intensities, $Dist_{macro}$ and $\Delta M_{W_{macro}}$ distances (in km)
 654 between macroseismic epicenters and differences between macroseismic magnitudes from
 655 EMS and MCS intensities respectively. If the Datasets column reports only one reference, the
 656 authors assessed both the MCS and EMS intensities for the given earthquake. Cumulative
 657 intensities evaluated for the sequences of 20-29 May 2012 shocks or 24 August-30 October
 658 2016 shocks or the 14-16 August 2018 shocks are indicated with May 2012, Aug-Oct 2016 and
 659 Aug 2018, respectively.

660

661 Table 3 - Number of buildings in Italy as a function of building type (RC=Reinforced concrete)
 662 and epoch from the last Italian Census (ISTAT, 2011, see data and resource section)

Building period	Total	RC		Masonry		Other	
1918 and before	1832504	0	0.0%	1725486	94.2%	107018	5.8%
1919-1945	1327007	77122	5.8%	1149082	86.6%	100803	7.6%
1946-1960	1700836	303903	17.9%	1212279	71.3%	184654	10.9%
1961-1970	2050833	676242	33.0%	1087428	53.0%	287163	14.0%
1971-1980	2117651	907046	42.8%	863668	40.8%	346937	16.4%
1981-1990	1462767	737632	50.4%	467821	32.0%	257314	17.6%
1991-2000	871017	455906	52.3%	251721	28.9%	163390	18.8%
2001-2005	465104	247516	53.2%	125719	27.0%	91869	19.8%
2006 and after	359979	189328	52.6%	92773	25.8%	77878	21.6%
Total	12187698	3594695	29.5%	6975977	57.2%	1617026	13.3%

663

664

665 Table 4 - Comparison between macroseismic parameters computed by BOXER (Gasparini et
 666 al., 2010) using MCS intensities collected for the same shocks by different authors (Datasets).

<i>Date</i>	<i>Time</i>	<i>N</i>	$I_{MCSGalli} - I_{MCSRossi}$	$Dist_{macro}$	$\Delta M_{W_{macro}}$	<i>Datasets</i>
24/08/2016	01:36	131	-0.214±0.038	0.8	0.14	Galli et al. (2017) Rossi et al. (2019)
26/10/2016	19:18	10	-0.300±0.153	7.6	0.18	Galli et al. (2017) Rossi et al. (2019)
30/10/2016	06:40	175	-0.329±0.048	6.6	-0.04	Galli et al. (2017) Rossi et al. (2019)
All (average)		316	-0.280±0.051	5.0	0.09	

667 *N* number of localities with intensity data used for the comparison, $I_{MCSGalli} - I_{MCSRossi}$ average
 668 differences between MCS intensities, $Dist_{macro}$ and $\Delta M_{W_{macro}}$ distances (in km) between
 669 macroseismic epicenters and differences between macroseismic magnitudes respectively.

670

671

672

673 Table 5 - Comparison between macroseismic parameters computed by BOXER (Gasparini et
 674 al., 2010) using EMS intensities collected for the same shocks by different authors (Datasets).

<i>Date</i>	<i>Time</i>	<i>N</i>	$I_{EMSZanini} - I_{EMSRossi}$	$Dist_{macro}$	$\Delta M_{W_{macro}}$	<i>Datasets</i>
24/08/2016	01:36	95	-0.011±0.077	1.6	-0.03	Zanini et al. (2016) Rossi et al. (2019)

675 *N* number of localities with intensity data used for the comparison, $I_{EMSZanini} - I_{EMSRossi}$ average
 676 differences between EMS intensities, $Dist_{macro}$ and $\Delta M_{W_{macro}}$ distances between macroseismic
 677 epicenters (in km) and differences between macroseismic magnitudes respectively.

679

680

681
682
683
684
685
686
687
688
689
690
691
692
693
694
695
696
697
698
699

Figure captions

Figure 1- Average difference between macroseismic ($M_{w_{macro}}$) and instrumental ($M_{w_{instrum}}$) magnitudes (solid line) and number of earthquakes used for the comparison (grey bars) over five-year time intervals from the CPTI15 catalog. The dotted lines indicate the average differences in the intervals 1905-1959 and 1960-2009. Error bars indicate the standard errors (1σ) of the mean differences. Earthquakes in volcanic areas of Mt. Etna, Mt. Vesuvius, Ischia Island and Campi Flegrei are excluded (see text).

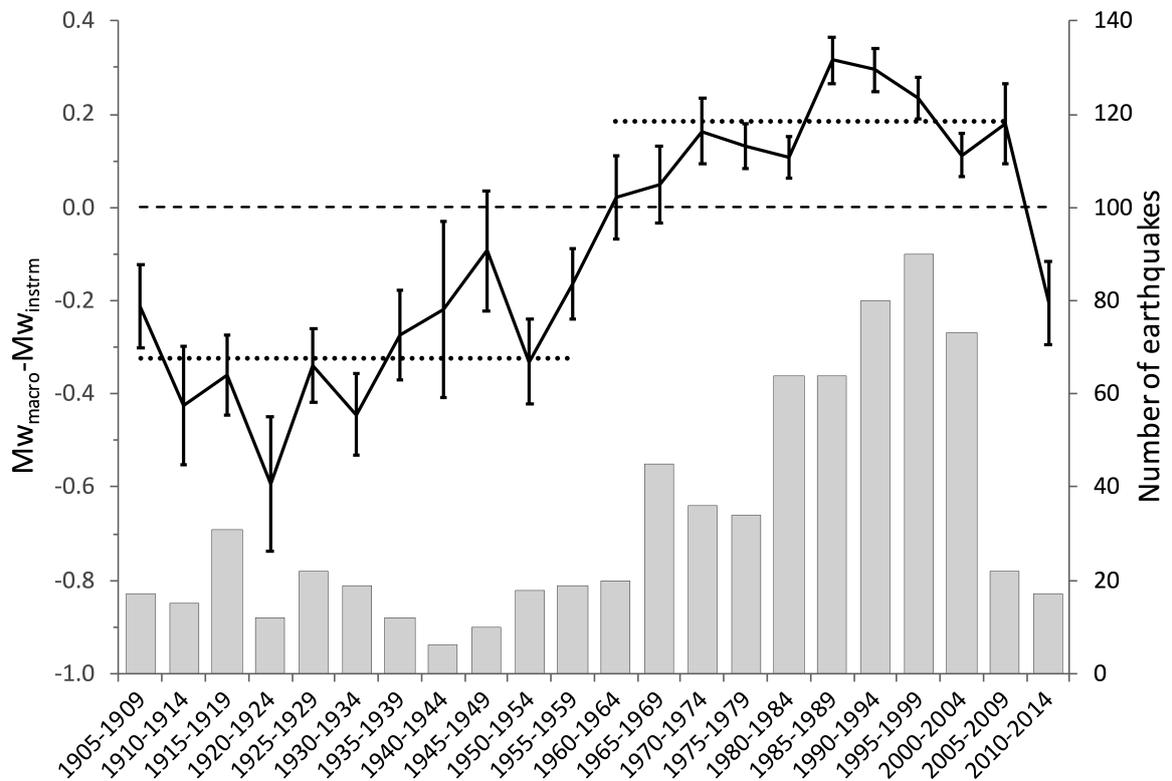
Figure 2 - Same as Fig. 1, but for differences between default ($M_{w_{default}}$) and macroseismic ($M_{w_{macro}}$) magnitudes (a) and between default ($M_{w_{default}}$) and instrumental ($M_{w_{instrum}}$) magnitude (b) over five-year time intervals from the CPTI15 catalog. Earthquakes in volcanic areas of Mt. Etna, Mt. Vesuvius, Ischia Island and Campi Flegrei are excluded (see text).

Figure 3 - Average differences (lines) between MCS intensities for the Central Italy 2016 sequence estimated by Rossi et al. (2019) and by Galli et al. (2017) and numbers of localities (bars) with given MCS intensity estimated by Rossi et al. (2019) (black) and by Galli et al. (2017) (grey).

700

Figures

701



702

703 Figure 1- Average difference between macroseismic (Mw_{macro}) and instrumental ($Mw_{instrum}$)

704 magnitudes (solid line) and number of earthquakes used for the comparison (grey bars) over

705 five-year time intervals from the CPTI15 catalog. The dotted lines indicate the average

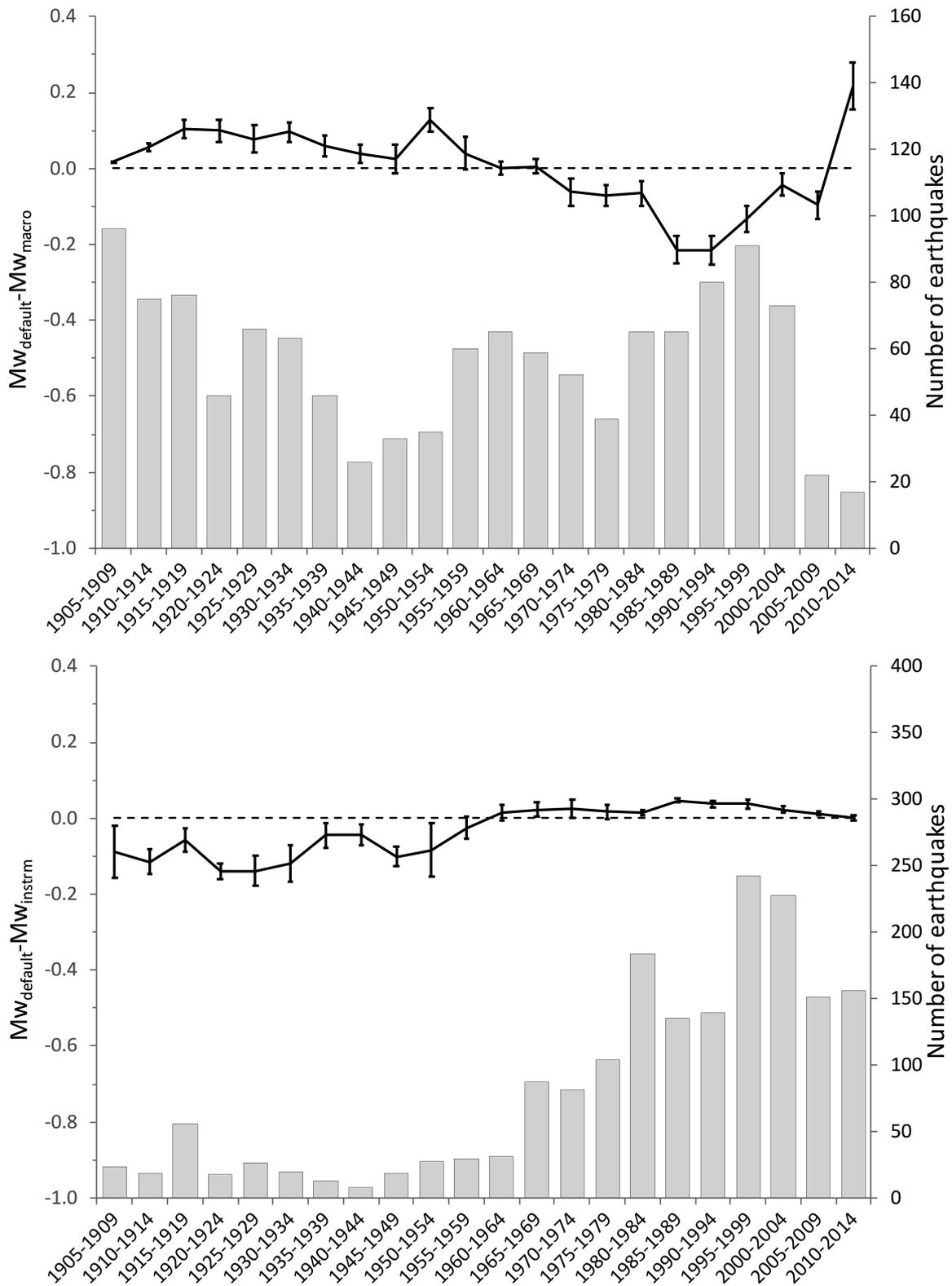
706 differences in the intervals 1905-1959 and 1960-2009. Error bars indicate the standard errors

707 (1σ) of the mean differences. Earthquakes in volcanic areas of Mt. Etna, Mt. Vesuvius, Ischia

708 Island and Campi Flegrei are excluded (see text).

709

710



711

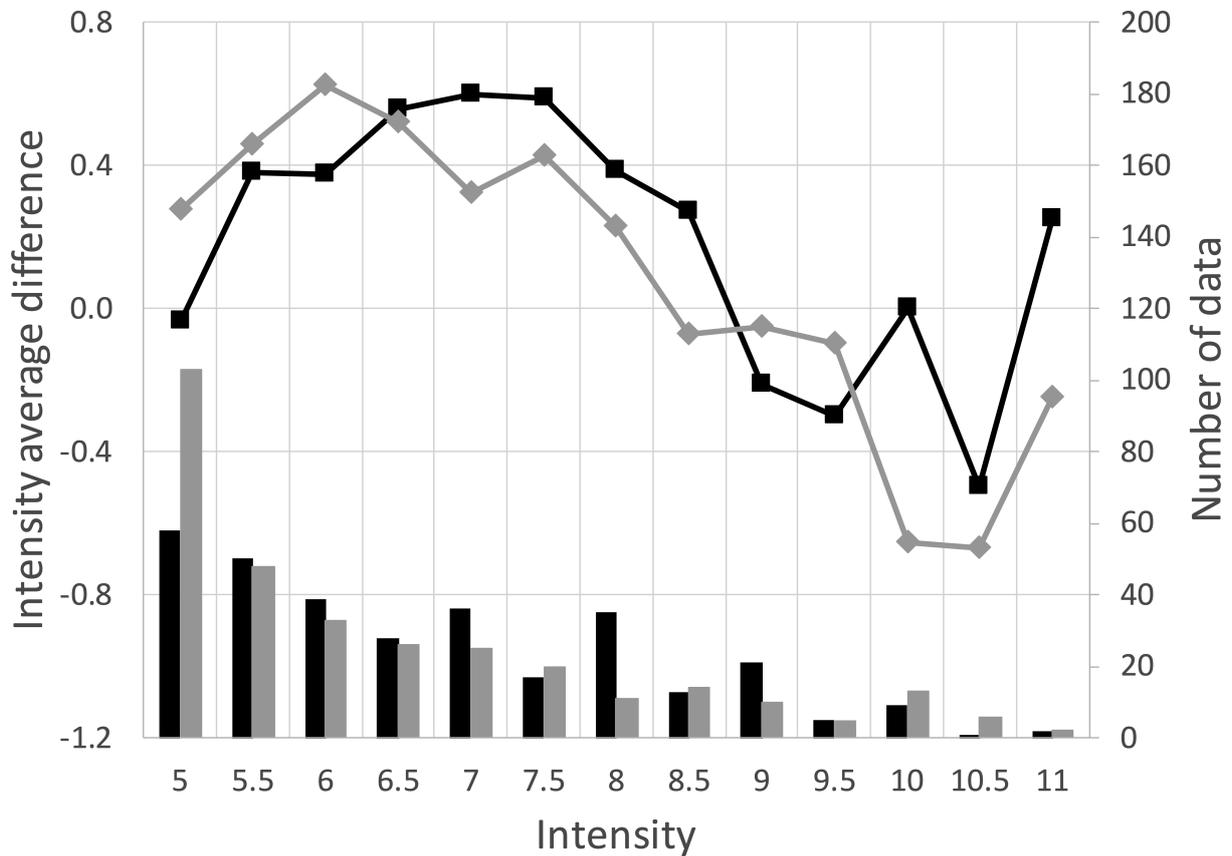
712 Figure 2 - Same as Fig. 1, but for differences between default (Mw_{default}) and macroseismic

713 (Mw_{macro}) magnitudes (a) and between default (Mw_{default}) and instrumental (Mw_{instrum})

714 magnitude (b) over five-year time intervals from the CPTI15 catalog. Earthquakes in volcanic
 715 areas of Mt. Etna, Mt. Vesuvius, Ischia Island and Campi Flegrei are excluded (see text).

716

717



718

719 Figure 3 - Average differences (lines) between MCS intensities for the Central Italy 2016
 720 sequence estimated by Rossi et al. (2019) and by Galli et al. (2017) and numbers of localities
 721 (bars) with given MCS intensity estimated by Rossi et al. (2019) (black) and by Galli et al.
 722 (2017) (grey).