



Completeness and calibration of the Italian Seismological Instrumental and Parametric Database (ISIDE) before 16 April 2005

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Abstract

The Italian Seismological Instrumental and Parametric Database (ISIDE) is the recipient of earthquake data collected in real-time by the Istituto Nazionale di Geofisica e Vulcanologia (INGV), and used by the studies of earthquake forecasting and seismic hazard assessment in Italy in the last decade. When it went online, following a significant improvement of the seismic acquisition system of INGV, it was including only data since the second fortnight of April 2005. About ten years later, the data since the beginning of 1985 suddenly appeared without any prior notice than the updating of the starting date of the dataset. However, the characteristics of the added data appeared clearly different from the following period both in terms of the numbers of located earthquakes and of types of magnitudes provided. After having analyzed the numerical consistency and the calibration of magnitudes of ISIDE as a function of time from 1985 to 15 April 2005, we can say that such a dataset is incomplete and poorly calibrated compared to other catalogs of Italian seismicity (CSTI, CSI, and HORUS) available for the same period. Hence, we suggest not using it as is for statistical analyses of Italian seismicity. However, it provides some magnitudes that are missed by other catalogs and thus might be used for improving such catalogs.

Keywords Earthquake data · Earthquake magnitude · Seismic catalog completeness · Chi-square regression method

Introduction

According to the page <http://terremoti.ingv.it/iside> (last accessed on August 2023) of the website of the Istituto Nazionale di Geofisica e Vulcanologia (INGV), “*The Italian Seismological Instrumental and Parametric Database (ISIDE), version 1.0 contains the parameters of earthquake locations performed by the surveillance service of INGV Rome. It consists of hundreds of thousands of events occurred in the Italian region in the time frame between 01-01-1985 and today.*”.

The data from ISIDE were directly or indirectly used by almost all studies of the last decade aimed at the statistical

forecasting of Italian seismicity (e.g., Schorlemmer et al. 2010; Marzocchi et al. 2014; Murru et al. 2014; Gulia et al. 2016; Lombardi 2019) and also used for compiling the seismic catalog (Rovida et al. 2020) for the latest probabilistic seismic hazard assessment of the Italian area (Meletti et al. 2021).

However, the characteristics of such dataset are rather variable and not well documented, particularly before 16 April 2005 when a substantial improvement of the INGV seismic acquisition system and database took place (Amato and Mele 2008). Since that date, more than 95% of magnitudes indicated as preferred by ISIDE are local magnitudes ML computed by synthetic Wood–Anderson (WA) waveforms (e.g., Uhrhammer and Collins 1990), whereas, before that date, more than 99% are duration magnitudes Md based on the length of the coda. The calibration of the ISIDE magnitudes since 16 Apr 2005 with respect to Mw was already analyzed by Gasperini et al. (2013) and Lolli et al. (2020), which found reasonable homogeneity and notable completeness.

Up to about 2014, the only data provided by ISIDE before 16 April 2005 were that of the Bollettino Sismico Italiano (BSI) of the INGV since 1 January 2002, also available at

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<http://bollettinosismico.rm.ingv.it/>. Unfortunately, the latter site is not accessible anymore, even if it is still mentioned by the site guide of the INGV Earthquake List page at <http://terremoti.ingv.it/en/help> (last accessed on January 2024). Since about 2014, the data concerning earthquakes since 1 January 1985 suddenly appeared without any evident announcement on the website. From the same approximate date, even the data from 2002 to 15 April 2005 was slightly different both in terms of the total numbers of events (4837 vs. 4831) and of the values of earthquake parameters (location, origin time, and magnitude) of some tens of earthquakes.

The locations and magnitudes of Italian earthquakes from 1981 to 1996 are also provided by the *Catalogo Strumentale dei Terremoti Italiani* (CSTI) Version 1.1 (CSTI Working Group 2003) and from 1981 to 2002 by the *Catalogo della Sismicit  Italianiana* (CSI) Version 1.1 (Castello et al. 2006) (see Data and Resource section). The former is the result of the relocation of hypocenters using uniform criteria and the recomputation of magnitudes according to Gasperini (2002) using an integrated dataset of arrival times, amplitudes, and durations obtained by merging the data of the INGV National Seismic Network (RSN) and of other Italian regional and local networks for earthquakes from 1981 to 1996. For building the CSI, Castello et al. (2006) made the same work of network merging and earthquake relocation for the interval 1997 to 2002, according to Chiarabba et al. (2005), and recomputed the magnitudes as described by Castello et al. (2007). The CSI also relocated the hypocenters and recomputed the magnitudes in the period 1981 to 1996, using the same set of arrival times and durations collected for the CSTI. However, owing to different selection criteria adopted, CSI reports about 2000 earthquakes more than CSTI (because the latter has more restrictive selection criteria based on the maximum distance from the closest station and the maximum azimuthal gap), and about 11,000 magnitudes less than CSTI (because all the amplitudes and many durations used by CSTI were considered unreliable and thus discarded by the authors of CSI) (see Table 1). For such reasons, Gasperini et al. (2013) and Lolli et al. (2020), to build a homogeneous catalog from 1981 to 1996, only considered the data of CSTI and ignored those of CSI in the same period, except for about 350 synthetic WA ML of

1996 earthquakes computed from broadband recordings of the Mednet network (Boschi et al. 1994).

Gasperini et al. (2013) and Lolli et al. (2020) calibrated the amplitude and duration magnitudes provided by various catalogs from 1981 to the present with respect to moment magnitude M_w , using an integrated dataset (IMW) built by combining M_w taken from various online resources (see Gasperini et al. 2012, and Lolli et al. 2020 for details). Lolli et al. (2020) also describe the implementation in near real time of a homogenized catalog (called HORUS) in terms of M_w , made available on a public website (see Data and Resource section).

In the following, we analyze the data provided by ISIDE in various periods from 1 January 1985 to 15 April 2005 to evaluate their numerical consistency and magnitude calibration and compare them with the other seismic catalogs available for the same periods. We also compare the frequency-magnitude distributions (FMD, Gutenberg and Richter 1944) of various datasets.

We subdivide the analysis over three periods: 1985 to 1996, 1997 to 2002, and 2003 to 15/04/2005 corresponding to those covered by the alternative datasets mentioned above (CSTI, CSI, and BSI, respectively). To calibrate the magnitudes, we compute regressions of ISIDE magnitudes with the M_w from the IMW dataset using the Chi-Square (CSQ) regression method (Stromeyer et al. 2004), which considers the uncertainties of both regressed magnitudes. We estimate such uncertainties (reported in Table 2) according to Gasperini et al. (2013) and Lolli et al. (2020).

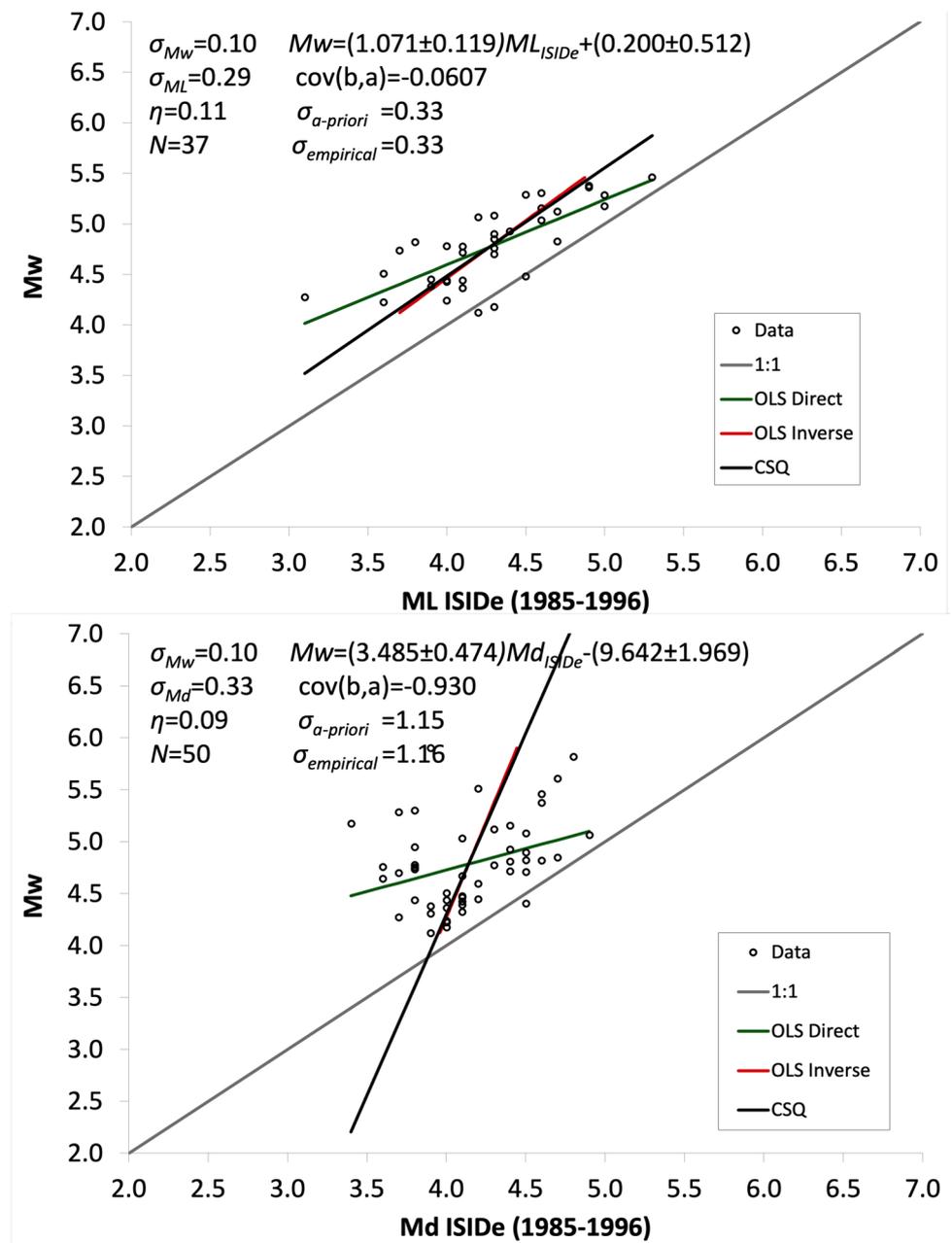
Table 1 Numbers of locations and magnitudes in various datasets and time intervals (within the “Italy” spatial window: Latitude 35–49, Longitude 5–20)

	ISIDE		CSTI		CSI		HORUS	
	Loc	Mag	Loc	Mag	Loc	Mag	Loc	Mag
1985–1996	24,290	22,026	39,956	29,521	41,896	17,981	39,987	29,558
1997–2002	20,611	20,598	–	–	42,925	20,029	42,952	20,027
2003–15/04/2005	4837	4837	–	–	–	–	4865	4865
16/04/2005–2022	364,226	363,977	–	–	–	–	364,348	364,009

Table 2 Empirical standard deviations of regression residuals ($\sigma_{\text{empirical}}$), M_w average uncertainties ($\bar{\sigma}_{M_w}$), and ML and Md adjusted uncertainties (σ_{ML} , σ_{Md}) for different time intervals and datasets

	$\bar{\sigma}_{M_w}$	$\sigma_{\text{empirical ML}}$	σ_{ML}	$\sigma_{\text{empirical Md}}$	σ_{Md}
1985–1996	0.10	0.325	0.29	1.163	0.33
1997–2002	0.07	0.306	0.34	0.312	0.19
2002–15/04/2005	0.07	0.289	0.28	0.322	0.21

Fig. 1 Regressions of moment magnitude M_w with local magnitude M_L (top panel) and duration magnitude M_d (bottom) from ISIDe for the time interval 1985–1996



1985–1996

The results of CSQ regressions are shown in Fig. 1 and Table 3. The number of data pairs available is 37 for Mw-ML and 50 for Mw-Md. For Mw-ML, the slope of the linear regression is rather close to 1, and, based on the Student's t-test (Table 3), we cannot reject the H_0 hypothesis ($\beta = 1$) of 1:1 scaling between Mw and ML. Hence, to convert ML to Mw it would be sufficient to apply to ML a constant shift of $+0.500 \pm 0.049$ corresponding to the average difference between Mw and ML. We can note, however, that such a difference is rather large if compared to that determined in

the period 1981–1996 by Gasperini et al. (2013) for CSTI (0.15 ± 0.05 , using 24 Mw-ML magnitude pairs). Despite the longer time interval, for the CSTI dataset, the number of data is smaller than ours. Hence, we can argue that the MLs reported by ISIDe in this time interval are mainly based on amplitudes of short-period stations (mostly vertical), which were not well-calibrated (see Gasperini 2002 for a thorough discussion on the calibration of such amplitude magnitudes) and that for such reason were discarded by the compilers of CSI. For Md (Fig. 1 bottom panel), the distribution of data is rather sparse and would imply a very large regression slope which is not very realistic.

Table 3 Results of regressions of Mw with ML and Md in various time intervals

Dataset	N	α (intercept)	β (slope)	s.l. ($H_0: \beta=1$)	Δ	s.l. ($H_0: \Delta=0$)
1985–1996 ML	37	0.200 ± 0.512	1.071 ± 0.119	0.55	0.500 ± 0.049	< 0.01
1985–1996 Md	50	-9.642 ± 1.969	3.485 ± 0.474	< 0.01	–	–
1997–2002 ML	110	0.932 ± 0.156	0.874 ± 0.039	0.02	–	–
1997–2002 Md	102	-2.178 ± 0.363	1.620 ± 0.089	< 0.01	–	–
2002–2005/04/15 ML*	39	-0.462 ± 0.288	1.127 ± 0.067	0.06	0.08 ± 0.03	–
2002–2005/04/15 Md*	24	-1.472 ± 0.503	1.456 ± 0.134	< 0.01	–	–
2002–2005/04/15 ML	77	0.216 ± 0.214	1.002 ± 0.052	0.96	0.226 ± 0.033	< 0.01
2002–2005/04/15 Md	51	-1.505 ± 0.450	1.482 ± 0.117	< 0.01	–	–

N is the number of data pairs, Δ is the average difference between Mw and ML or Md, s.l. indicates the significance level of the Student's t-test of equality. Bold types for s.l. < 0.05 indicate that the corresponding H_0 hypothesis of equality can be confidently rejected. * From Gasperini et al. (2013)

Also note that the locations provided by ISIDe in the interval 1985–1996, within the “Italy” window (Latitude 35–49, Longitude 5–20) used for selections by the Earthquake List page of the INGV website, are much less than those provided by both CSTI and CSI (Table 1) within the same spatial window. This is because the latter catalogs located the earthquakes also using the arrival times from regional and local networks whereas ISIDe only uses the data of the RSN of the INGV.

The number of magnitudes is much lower than that of CSTI but higher than that of CSI due to the choice made by the CSI compiler to discard all the amplitudes and durations provided by the regional and local networks as unreliable, while CSTI considers and uses them all, using the calibrations carried out by Gasperini (2002).

From Table 1, we can also see that the HORUS catalog has some tens of locations/magnitudes more than CSTI. This is due to the addition of earthquakes (mostly offshore or in neighboring countries but within the “Italy” spatial window) not located by the RSN but reported by online moment tensor catalogs.

In Table 4 and in Figs. S1, S2, S3, and S4 of supplementary information, we show the results of the analysis of the FMD for the four datasets (ISIDe, CSTI, CSI, and HORUS). To avoid spatial incompleteness due to the lack of seismic stations in sea-covered areas, we limited such analyses to earthquakes located inland within the Italian

national borders (see numbers of data in Table S1 of supplementary information). To draw the plots and choose the completeness magnitude thresholds, we adopted the same approach as Gasperini et al. (2013) and Lolli et al. (2020).

The b -value of ISIDe dataset is decidedly larger than usual (1.392 ± 0.020), and the completeness threshold M_c is significantly higher than other catalogs, so confirming a worse magnitude calibration and a lower completeness of ISIDe with respect to CSTI, CSI, and HORUS catalogs. In summary, the data of ISIDe from 1985 to 1996 is less numerous and then less complete than CSTI, CSI, and HORUS catalogs and has poorly calibrated magnitudes, hence we suggest not using it for statistical analysis of Italian seismicity.

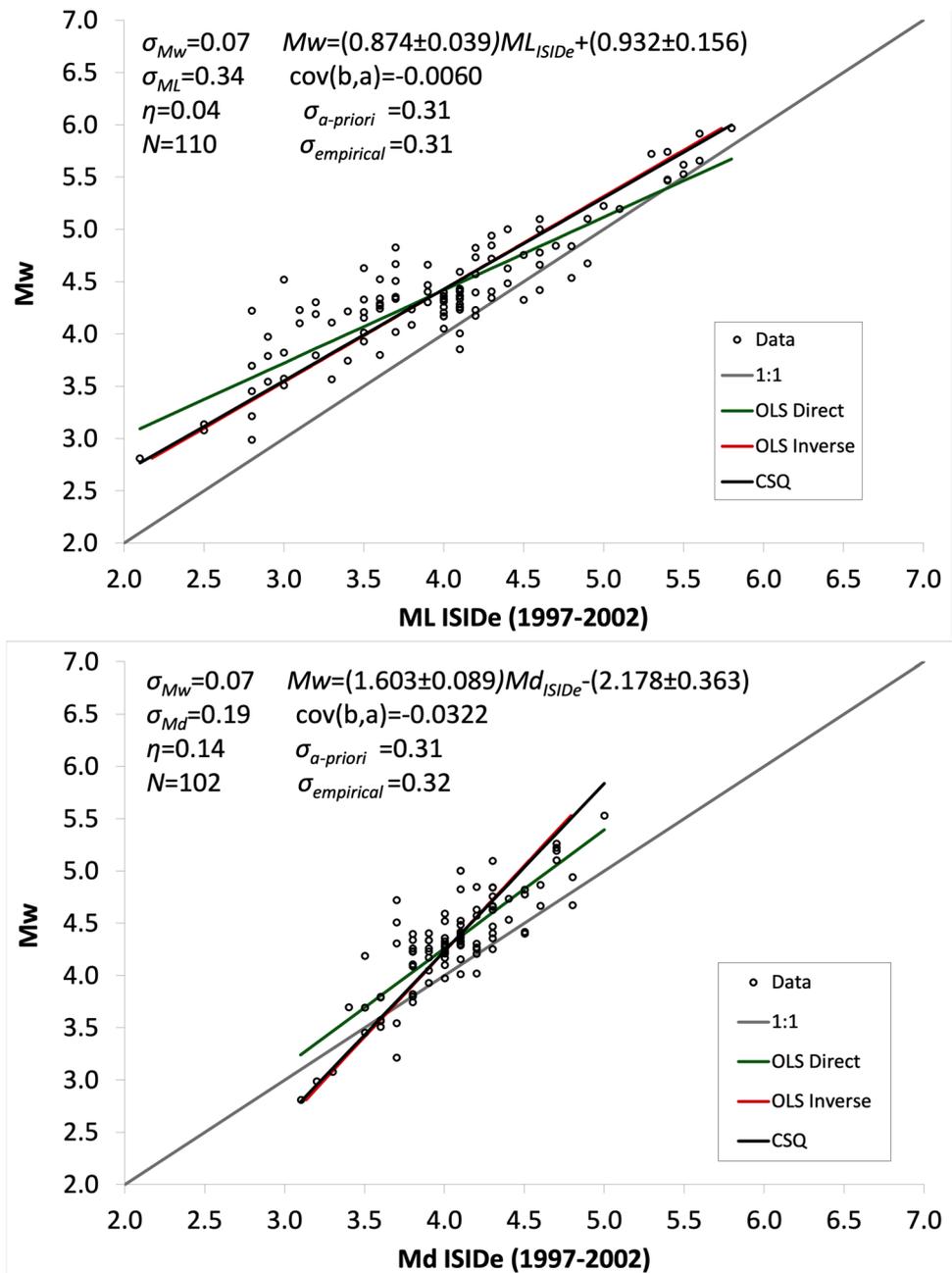
1997–2002

The results of CSQ regressions are shown in Fig. 2 and Table 3. The number of data pairs available is 110 for Mw-ML and 102 for Mw-Md. For this period, we can confidently reject the H_0 hypothesis ($\beta=1$) of 1:1 scaling between Mw and ML (Table 3). Hence, to convert ML to Mw, the linear relation with the coefficients resulting from the regression (Table 3) should have to be applied. This apparently contradicts the results of Gasperini et al. (2013) who in the same period for the CSI data found instead a 1:1 scaling

Table 4 Completeness thresholds M_c and frequency-magnitude distribution b -values for various datasets and periods

	ISIDe		CSTI 1.1		CSI 1.1		BSI		HORUS	
	M_c	b -value	M_c	b -value	M_c	b -value	M_c	b -value	M_c	b -value
1985–1996	2.7	1.392 ± 0.020	2.4	1.062 ± 0.015	2.4	1.050 ± 0.017	–	–	2.4	1.004 ± 0.014
1997–2002	2.6	1.257 ± 0.016	–	–	2.2	0.941 ± 0.013	–	–	2.5	0.942 ± 0.013
2003–15/04/2005	2.5	1.451 ± 0.040	–	–	–	–	2.5	1.435 ± 0.039	2.2	0.931 ± 0.030
16/04/2005–2022	1.8	1.068 ± 0.004	–	–	–	–	–	–	1.8	1.035 ± 0.004

Fig. 2 Same as Fig. 1 for the time interval 1997–2002



between Mw and ML. We can argue that even in this case ISIDe ML is mostly based on amplitudes of short-period stations, which are not well-calibrated, whereas for the CSI, the ML magnitudes (named MIMDN) were all computed using synthetic WA amplitudes of well-calibrated broadband stations.

Even the coefficient of the regression of Mw with respect to Md is significantly different from 1 and thus would imply that to convert Md to Mw, the linear relation resulting from the regression should have to be applied. Even in this case the results apparently contradict those of Gasperini et al. (2013) for CSI in the same period, which indicates a 1:1

scaling between Mw and Md. We can argue that this is because, for computing Md, ISIDe used the formula of Console et al. (1989), whereas CSI applied the new formula derived by Castello et al. (2007), which is better calibrated with respect to ML. This interpretation is confirmed by the computed regression coefficients between Mw and ISIDe Md that are similar to that of the relationship computed by Gasperini et al. (2013) for the interval from 16/04/2005 to 2010 ($\alpha = -1.905 \pm 0.205$, $\beta = 1.718 \pm 0.050$), during which ISIDe Md was based on the Console et al. (1989) formula.

We also note that the number of locations provided by ISIDe from 1997 to 2002 is less than half of those provided

by the CSI, while the magnitudes are 500 more (Table 1). We again can explain such discrepancies as due to the absence of arrival times from regional and local networks in ISIDE and to the discarding of all amplitude data by CSI. Even for this interval, the HORUS catalog has some tens of locations more than CSI (probably offshore or in neighboring countries). However, it has two magnitudes less than CSI (instead of some tens more) because HORUS does not use the mb magnitudes (about 50) provided by CSI for intermediate and deep earthquakes in this time interval.

In Table 4 and in Figs. S5, S6 and S7 of supplementary information, we show the results of the analysis of the FMD for the three datasets (ISIDE, CSI, and HORUS) limited to inland earthquakes.

Also for this time window, the b -value of ISIDE dataset is decidedly larger than usual (1.257 ± 0.016) and the completeness threshold M_c is significantly higher than other catalogs, thus confirming a worse magnitude calibration of ISIDE and lower completeness compared to CSI and HORUS catalogs. In summary, even the locations of ISIDE from 1997 to 2002 are less complete compared to CSI and HORUS catalogs, and the magnitudes are poorly calibrated, hence we suggest not using them for statistical analysis of Italian seismicity. However, as CSI (and even HORUS) lack many magnitudes due to the choices made by the authors of CSI, we could hypothesize that future work could integrate the ML provided by ISIDE into HORUS, by first applying the calibration of Gasperini et al. (2002) and then converting them to M_w according to Lolli et al. (2020). The same work could also consider the mb provided by CSI for intermediate and deep earthquakes and convert them into M_w according to, for example, the relationships between mb and M_w derived by Lolli et al. (2023).

2003–15/4/2005

In Fig. 3 and Table 3, we show the results of CSQ regressions for the slightly wider time interval 2002–15/04/2005, because this was the interval considered by Gasperini et al. (2013) to calibrate the regressions used by them and later by Lolli et al. (2020) to build their homogeneous catalogs in the time interval 2003–15/04/2005. The number of data pairs available for the regression is 77 for M_w -ML and 51 for M_w -Md. For M_w -ML, the linear regression coefficient is close to 1, and, based on the Student's t -test (Table 3), we cannot reject the H_0 hypothesis ($\beta = 1$) of 1:1 scaling between M_w and ML. Hence, to convert ML to M_w it would be sufficient to apply a constant shift of 0.226 ± 0.033 . This result is fairly coherent with what was obtained by Gasperini et al. (2013) who also found a 1:1 scaling between M_w and ML but with a smaller average difference (0.08 ± 0.03). Comparing the distributions of data pairs in Fig. 3 with

that reported in Fig. 9 by Gasperini et al. (2013), we can note some more data (77 vs. 39), particularly at magnitudes lower than 4 and a wider dispersion around the regression line ($\sigma = 0.29$ vs. $\sigma = 0.20$ of Gasperini et al. 2013). We must note that the BSI dataset used at the time by Gasperini et al. (2013) only included ML computed by synthetic WA waveforms from broadband stations of the Mednet network, whereas we can argue that some ML reported by ISIDE are based on amplitudes of short-period stations which, as noted above, are not particularly well-calibrated.

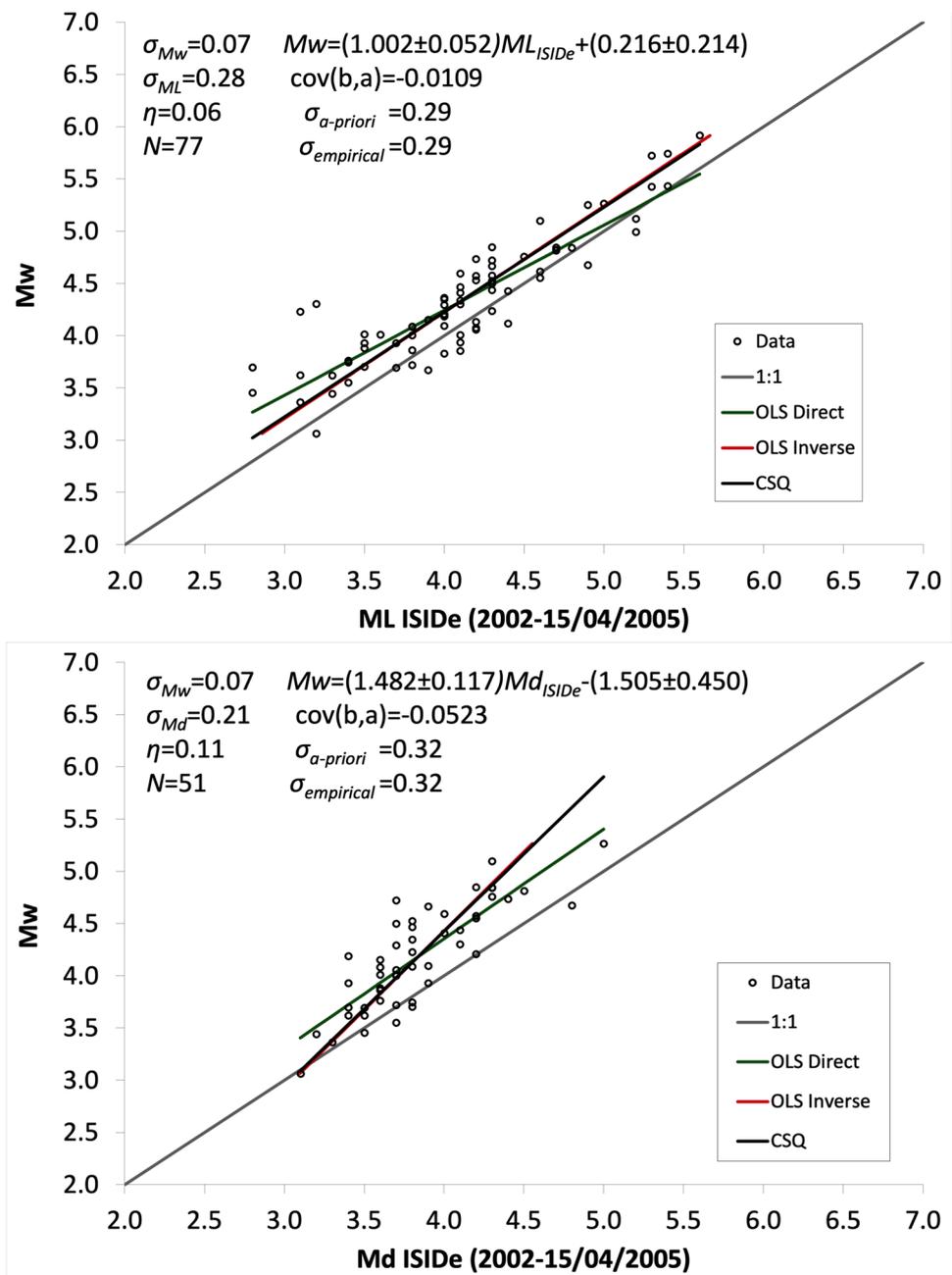
The coefficients of the regression of M_w with respect to Md are very similar to that obtained by Gasperini et al. (2013) (Table 3), even if the number of data pairs we use is more than twice. The reason for such an increase in data is that in the BSI dataset used by Gasperini et al. (2013), only one magnitude, the preferred one between ML and Md, was provided for each earthquake, whereas ISIDE now reports both if available. As for many earthquakes for which an M_w is available, only the ML from broadband data was provided by BSI, many associations M_w -Md were lost by Gasperini et al. (2013).

We can see in Table 1 that for this time interval, the number of locations exactly corresponds to the number of magnitudes for both ISIDE and HORUS datasets because an ML and/or an Md magnitude is provided for all earthquakes. Even for this period, we can see that the HORUS catalog has some tens of locations/magnitudes more than ISIDE.

In Table 4 and in Figs. S8 and S9 of supplementary information, we show the results of the analysis of the FMD for the two datasets (ISIDE and HORUS) limited to inland earthquakes within the Italian national borders. In Fig. S10 of supplementary information, we also plot for completeness of information the FMD of the original BSI dataset which appears very similar to that of ISIDE.

The b -values of ISIDE and BSI datasets are decidedly higher than usual (1.451 ± 0.040 and 1.435 ± 0.039 , respectively), and the completeness thresholds M_c are higher than HORUS catalog. However, this is probably due to the greater slope of the frequency-magnitude distribution rather than a real lack of data. In summary, the data of ISIDE from 2003 to 15/04/2005 does not differ much from the BSI dataset calibrated by Gasperini et al. (2013) but includes some Md magnitudes more because BSI provides only one magnitude between ML and Md. Even considering that the data set calibrated by Gasperini et al. (2013) is no longer available online, it could be reasonable in the future to use such data from ISIDE for the construction of the homogeneous catalog HORUS in this period.

Fig. 3 Same as Fig. 1 for the time interval 2002–15/04/2005



16/4/2005–2022

Even if this time interval is outside the one analyzed in this work, we want to underline here that, unlike the previous periods, the numerical consistency and calibration of the ISIDe data starting from the second fortnight of April 2005 are absolutely excellent, making it one of the best world seismic datasets to test seismic forecasting methods. This is clearly evidenced by the low magnitude completeness threshold ($M_c = 1.8$), the straightness of the FMD (Fig. S11 of the supplementary information), and the b

value close to 1 (Table 4). The differences compared to the homogenized HORUS catalog (Fig. S12 of the supplementary information) mainly concern the fact that most magnitudes in ISIDe are ML while in HORUS they were converted to proxy Mw for improving homogeneity with true Mw estimates.

Conclusions

We analyzed the numerical consistency of seismic locations and magnitudes and the calibration of magnitudes provided by the online database ISIDE of the INGV from 1 January 1985 to 15 April 2005.

1. From 1985 to 1996, the number of earthquakes is much less than that provided for the same period by CSTI V1.1 (CSTI Working Group 2003) and CSI V1.1 (Castello et al. 2006), and the number of magnitudes is less than that provided by CSTI V1.1. Moreover, the calibration of both ML and Md appears rather poor. For these reasons, we suggest not considering ISIDE data and using instead CSTI V1.1 or HORUS (which is based on CSTI data) in this time interval.
2. From 1997 to 2002, the number of earthquakes is much less than that provided by the CSI V1.1, and also the calibrations of both ML and Md are rather poor. Thus, we suggest not considering ISIDE locations and using CSI V1.1 or HORUS (which is based on CSI data) in this time interval. However, as ISIDE reports ML from short-period stations which have been discarded by Castello et al. (2006) in compiling CSI, it could be useful in the future to calibrate and use them for integrating the magnitudes reported by HORUS in this time interval.
3. From 2003 to 15/04/2005, the data of ISIDE are only slightly different from that of the BSI dataset analyzed by Gasperini et al. (2013) and used by Lolli et al. (2020) to build HORUS in this time interval. As the BSI is not anymore available online at the site <http://bollettinosismi.co.rm.ingv.it/>, it could be useful in the future to consider ISIDE data for this period for integrating HORUS magnitudes, even if some specific calibration will be necessary.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s11600-024-01395-3>.

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Data availability ISIDE is available at <https://webservices.ingv.it/> (last accessed August 2023) and at <http://terremoti.ingv.it> (Last accessed August 2023). CSTI V1.1 is available at https://emidius.mi.ingv.it/CSTI/Versione1_1/ (Last accessed August 2023). CSI V1.1 is available at <https://csi.rm.ingv.it> (Last accessed August 2023). HORUS (HOMogenized instrUMENTal Seismic) catalog is available at <http://horus.bo.ingv.it> (Last accessed August 2023).

Declarations

Conflict of interest The authors declare no competing interests.

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