



HAL
open science

Harmonization check of within the central, northern, and northwestern European earthquake catalogue (CENEC)

Gottfried Grünthal, Dietrich Stromeyer, Rutger Wahlström

► **To cite this version:**

Gottfried Grünthal, Dietrich Stromeyer, Rutger Wahlström. Harmonization check of within the central, northern, and northwestern European earthquake catalogue (CENEC). *Journal of Seismology*, 2009, 13 (4), pp.613-632. 10.1007/s10950-009-9154-2 . hal-00535491

HAL Id: hal-00535491

<https://hal.science/hal-00535491>

Submitted on 11 Nov 2010

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Harmonization check of M_w within the central, northern, and northwestern European earthquake catalogue (CENEC)

Gottfried Grünthal · Dietrich Stromeyer ·
Rutger Wahlström

Received: 18 August 2008 / Accepted: 15 January 2009 / Published online: 3 March 2009
© Springer Science + Business Media B.V. 2009

Abstract Large data sets covering large areas and time spans and composed of many different independent sources raise the question of the obtained degree of harmonization. The present study is an analysis of the harmonization with respect to the moment magnitude M_w within the earthquake catalogue for central, northern, and northwestern Europe (CENEC). The CENEC earthquake catalogue (Grünthal et al., J Seismol, 2009) contains parameters for over 8,000 events in the time period 1000–2004 with magnitude $M_w \geq 3.5$. Only about 2% of the data used for CENEC have original M_w magnitudes derived directly from digital data. Some of the local catalogues and data files providing data give M_w , but calculated by the respective agency from other magnitude measures or intensity. About 60% of the local data give strength measures other than M_w , and these have to be transformed by us using available formulae or new regressions based on original M_w data. Although all events are thus unified to M_w magnitude, inhomogeneity in the M_w obtained from over 40 local catalogues and data files and 50 special studies is inevitable. Two different approaches have been followed to

investigate the compatibility of the different M_w sets throughout CENEC. The first harmonization check is performed using M_w from moment tensor solutions from SMTS and Pondrelli et al. (Phys Earth Planet Inter 130:71–101, 2002; Phys Earth Planet Inter 164:90–112, 2007). The method to derive the SMTS is described, e.g., by Braunmiller et al. (Tectonophysics 356:5–22, 2002) and Bernardi et al. (Geophys J Int 157:703–716, 2004), and the data are available in greater extent since 1997. One check is made against the M_w given in national catalogues and another against the M_w derived by applying different empirical relations developed for CENEC. The second harmonization check concerns the vast majority of data in CENEC related to earthquakes prior to 1997 or where no moment tensor based M_w exists. In this case, an empirical relation for the M_w dependence on epicentral intensity (I_0) and focal depth (h) was derived for 41 master events, i.e., earthquakes, located all over central Europe, with high-quality data. To include also the data lacking h , the corresponding depth-independent relation for these 41 events was also derived. These equations are compared with the different sets of data from which CENEC has been composed, and the goodness of fit is demonstrated for each set. The vast majority of the events are very well or reasonably consistent with the respective relation so that the data can be said to be harmonized with respect to M_w ,

G. Grünthal (✉) · D. Stromeyer · R. Wahlström
GFZ German Research Centre for Geosciences,
Section 2.6 Earthquake Hazard and Stress Field,
Telegrafenberg, D-14473 Potsdam, Germany
e-mail: ggrue@gfz-potsdam.de

but there are exceptions, which are discussed in detail.

Keywords Earthquake catalogue · Europe · Moment magnitude M_w · Harmonization check

1 Introduction

Earthquake catalogues covering different national catalogues meet the challenge how a harmonization of the strength measure could be achieved. It is a well-known fact that magnitudes can differ substantially between national seismological agencies. Not least is this the case with local M_L and duration based (M_d) scales. Although a general problem in regional earthquake cataloguing, previous studies attempting to quantify the harmonization are not known to the authors.

The particular task of this study is to analyse the compatibility and reached harmonization of the M_w values given in different local catalogues contributing to a regional data base or derived from other strength parameters in these. The regional seismicity data file, which is the subject of this analysis, is the catalogue of earthquakes in central, northern, and northwestern Europe (CENEC) by Grünthal et al. (2009). CENEC contains about 8,000 earthquakes with $M_w \geq 3.50$ and covers Europe north of the Mediterranean region (N of 44°N; Fig. 1). The objective of the new catalogue is to provide a harmonized strength measure in terms of M_w , a goal one can approach but hardly fully realize since it is based on many sub-regional, national, and local earthquake catalogues or data files and also numerous special studies on certain events or sets of events.

This study aims at quantifying the compatibility of the sets of M_w values in CENEC, based on

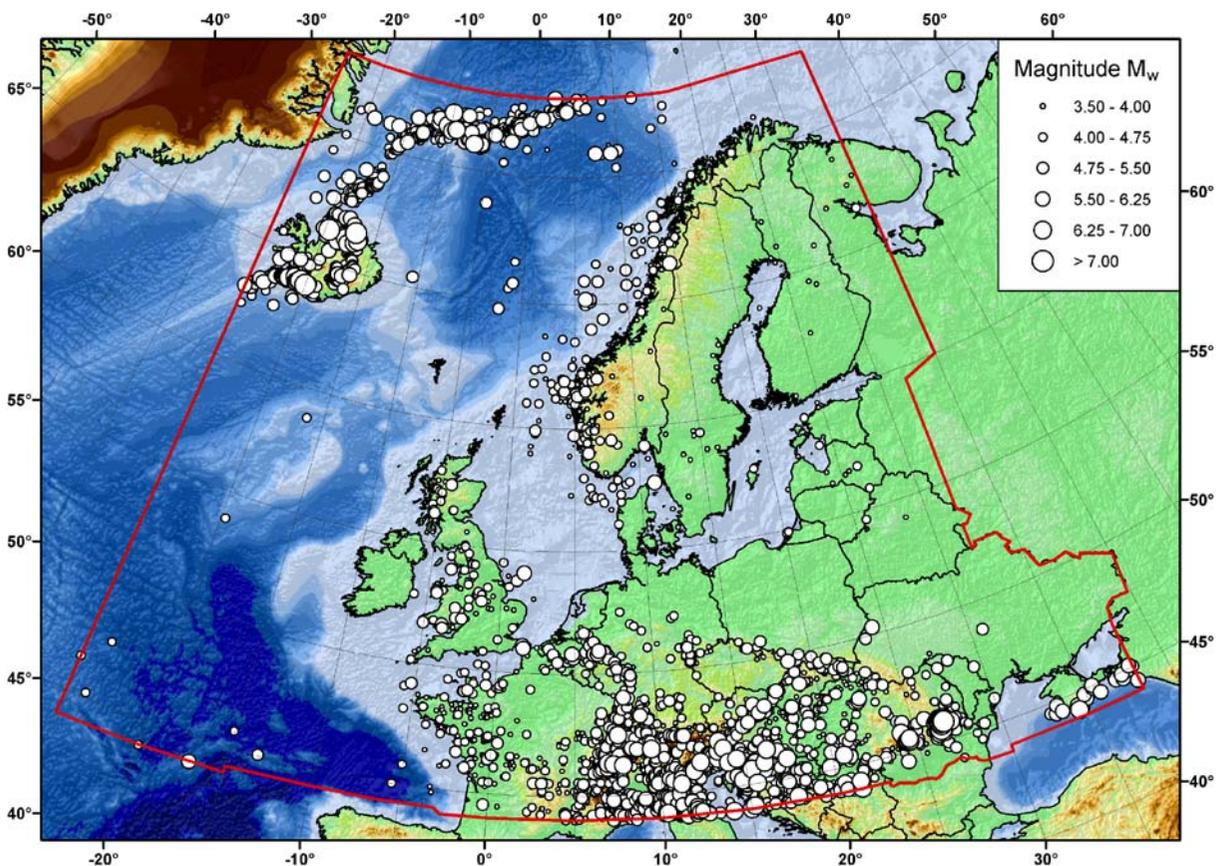


Fig. 1 Epicentre map according to the CENEC catalogue, which encompasses the study area of this paper

the different earthquake catalogues, which have been calculated from different other magnitude types or intensity. About 60% of the CENEC M_w entries have been calculated using regressions or existing local transformation formulae derived or selected by Grünthal et al. (2009). For most of the remaining events, “original” M_w given in the national catalogues, such as the Italian, Romanian, or Swiss, has also been calculated from other magnitude concepts or intensity. Thus, only about 2% of the CENEC entries have truly original M_w determined directly from digital records or are subject of special studies with M_w derived, e.g., from intensity data points. Such data, i.e., the M_w after Pondrelli et al. (2002, 2007) available since 1997 and the Swiss moment tensor solutions (2006) (SMTS) available since 1999, together with the M_w from special studies, have the highest rank in the priority scheme of CENEC.

For the data to be of value in various seismological studies, notably seismic hazard, it is important not only that the catalogue contains the same type of magnitude, in our case M_w , but that this is harmonized. Of special concern is the

long-term behaviour of the pre-instrumental parts of the catalogues. Firstly, we compare M_w values from truly original, i.e., moment tensor based, data sources with (1) M_w given by the local catalogues and data files and (2) M_w calculated from other strength measures in the local catalogues and data files according to a hierarchy of empirical relations. Secondly, a relation of M_w vs. intensity and focal depth is established based on original, high-quality parameter data, the so-called master events (Section 3). This relation, based on 41 events, is then compared with the individual M_w data in or derived from the different national catalogues to evaluate and quantify the degree of harmonization. A depth-independent equation is also derived based on the same 41 events and compared with the individual data.

2 Comparison of original and calculated M_w values

The first type of harmonization check treats original M_w , i.e., based on moment tensor solutions by

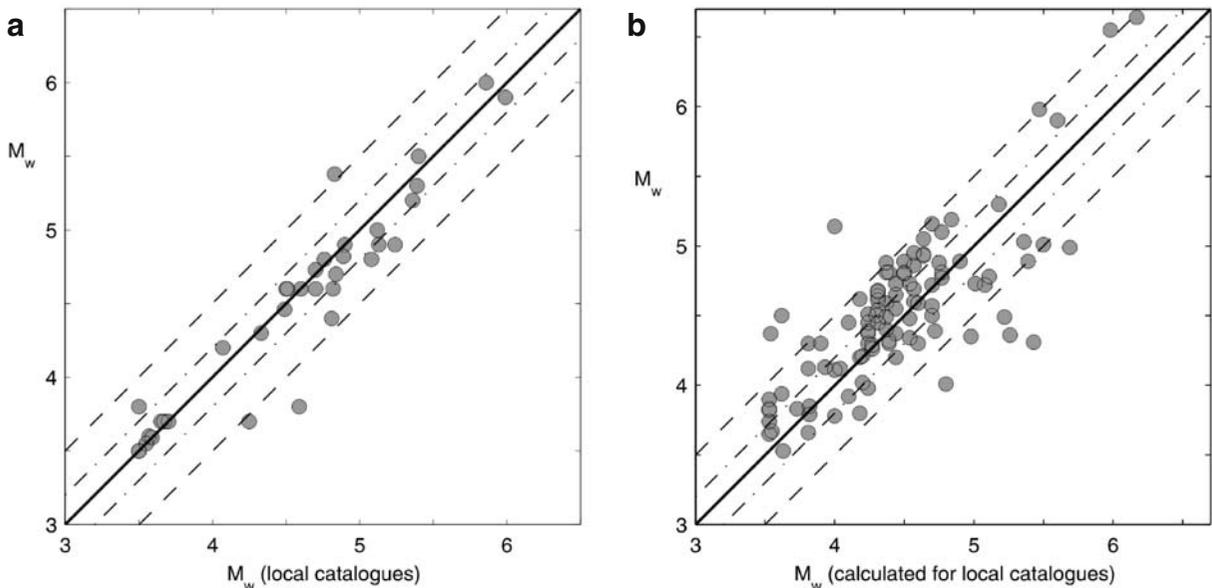


Fig. 2 **a** M_w from moment tensor solutions (SMTS and Pondrelli et al. 2002) vs. M_w given by local catalogues and data files used in CENEC. The M_w values of SMTS and Pondrelli et al. (2002) are given in CENEC, having higher hierarchy rank than the ones in the local catalogues. **b** M_w

from moment tensor solutions (SMTS and Pondrelli et al. 2002, 2007) vs. M_w calculated from other strength measures according to the algorithms for the local catalogues in CENEC established by Grünthal et al. (2009)

Pondrelli et al. (2002, 2007) and the Swiss moment tensor solutions, available since 1997 and 1999, respectively.

We first compare these high-quality M_w values with the M_w provided by several national catalogues, i.e., CPTI Working Group (2004),

Table 1 Central European earthquakes with original seismic moment determined and related to intensity and focal depth to derive the master event relations, Eqs. 1 and 2

Date	Lat	Lon	Locality and country code		M_w	I_0	Depth (km)
1911 November 16	48.22	9.00	Albstadt	D	5.7	8	10
1913 July 20	48.23	9.01	Albstadt	D	5.0	7	11
1935 June 27	48.04	9.47	Saulgau	D	5.4	7.5	9
1938 June 11	50.78	3.58	Zulzich-Nukerke	B	5.3	7.5	19
1943 May 2	48.27	8.98	Albstadt	D	4.9	7	9
1943 May 28	48.27	8.98	Albstadt	D	5.3	8	9
1951 March 14	50.65	6.72	Euskirchen	D	5.1	7.5	9
1969 February 26	48.29	9.01	Albstadt	D	4.4	7	8
1970 January 22	48.28	9.03	Albstadt	D	4.9	7	8
1971 September 29	47.10	9.00	Glarus	CH	4.3	7	10
1976 May 6	46.36	13.27	Friuli	I	6.4	9.5	17
1976 September 15	46.35	13.14	Friuli	I	6.0	8.5	11
1978 September 3	48.28	9.03	Albstadt	D	5.1	7.5	7
1980 July 15	47.67	7.48	Sierentz	F	4.1	6.5	12
1983 September 11	48.32	9.04	Albstadt	D	3.0	5	8
1983 November 8	50.63	5.51	Liège	B	4.8	7	6
1992 April 13	51.16	5.95	Roermond	NL	5.3	7	18
1998 April 12	46.31	13.66	Bovec	SLO	5.4	7.5	16
2000 January 20	50.61	7.09	Ahrweiler	D	3.4	5	10
2000 July 11	48.00	16.50	Ebreichsdorf	A	4.4	6.5	13
2000 July 11	48.00	16.50	Ebreichsdorf	A	3.9	5	22
2001 February 23	46.14	7.03	Martigny-Ville	CH	3.6	5	5
2001 July 1	47.70	16.10	Pitten	A	4.1	5.5	16
2002 June 2	45.66	14.21	Pivka	SLO	3.9	5	9
2002 July 22	50.87	6.20	Alsdorf	D	4.6	6	16
2002 September 22	52.53	-2.16	Dudley	UK	4.3	5.5	14
2002 September 30	46.34	13.55	Bovec	SLO	3.9	5	11
2003 February 22	48.37	6.64	Rambervillers	F	4.8	6.5	10
2003 May 31	45.87	15.20	Novo Mesto	SLO	3.7	5.5	11
2003 July 21	47.20	14.30	Murau	A	4.0	6	11
2003 August 9	46.99	16.60	Magyarszecsöd	H	3.8	5.5	8
2003 October 29	47.57	11.91	Wörgl	A	3.7	5.5	6
2004 June 21	47.50	7.70	Arlesheim	CH	3.4	5	22
2004 July 12	46.30	13.60	Bovec	SLO	5.2	6.5	7
2004 July 14	46.34	13.57	Bovec	SLO	3.7	5	7
2004 October 1	47.39	15.17	Leoben	A	3.7	6	10
2004 December 5	48.08	8.04	Waldkirch	D	4.6	6	9
2005 January 14	46.29	14.03	Bohiniska Bistrica	SLO	3.9	5	10
2005 January 14	46.23	14.05	Bohiniska Bistrica	SLO	3.8	5	10
2005 September 6	47.24	11.70	Wattener Lizum	A	3.1	5	8
2008 February 27	53.38	-0.21	Market Rasen	UK	4.6	6.5	22

References for events with $M_w \geq 3.5$ before 2005 are given in the Grünthal et al. (2009) catalogue. For the other events, the references are: 1983 September 11 Langer (1986), 2000 January 20 Hinzen (2003), 2004 June 21 ECOS06 (see Grünthal et al. 2009, Annex 1), 2005 January 14, two events, GRF (ibid.), 2005 September 6 ZAMG07 (ibid.), 2008 May 7 R. Musson, pers. communication

Oncescu et al. (1999), INFP (2007), ISC (1904–2003), Fäh et al. (2003), and ECOS (2006; Fig. 2a). Altogether, there are 37 data pairs in CENEC. Seventy-six percent of the data pairs are within the ± 0.2 and 91% within the $\pm 0.5 M_w$ unit bounds. This shows that the sets with original M_w are largely compatible with M_w in the catalogues mentioned. The M_w according to SMTS and ECOS, Pondrelli et al. (2002, 2007) and CPTI Working Group (2004), respectively, are not identical although provided by the same respective agency.

In a second comparison, the original SMTS and Pondrelli et al. (2002, 2007) M_w values are checked against M_w values of the local catalogues calculated from other strength measures according to dependent algorithms established by Grünthal et al. (2009; Fig. 2b). There are 100 data pairs, with 94 original M_w entries from SMTS, five from Pondrelli et al. (2002) and one from Pondrelli et al. (2007). Fourteen events with calculated $M_w < 3.5$ are not included in this data

set, although they occur in CENEC since SMTS or Pondrelli et al. (2002, 2007) have $M_w \geq 3.5$. On the mean, the calculated M_w are 0.08 units lower than the original. Thirty-eight of the 100 data pairs are within the ± 0.2 and 88 within the $\pm 0.5 M_w$ unit bounds. Twelve of the data pairs are thus outliers with the calculated M_w more than 0.5 units different from the original. Five of the outliers are from IMO07, three from LDG, two from ISC, and one each from IMO and INGV (cf. Table 2 with respect to the used notation of national catalogues).

3 Master event relation

Any harmonization study requires a data set with which the investigated data can be compared. The relative test criterion is in our case a set of 41 earthquakes with carefully determined parameters, i.e., the seismic moment or moment magnitude, M_w , the maximum or epicentral intensity, I_{max} or I_0 , and the hypocentral depth h (Table 1).

Since the target area of this study is the same as for CENEC, we select the master events from the region which is central to this catalogue and has a sufficient level of seismic activity. Thus, the master events are from Austria, Belgium, France, Germany, Hungary, Italy, Netherlands, Slovenia, Switzerland, and United Kingdom.

The lower magnitude threshold for the master events is $M_w = 3$. The largest earthquake in the area, where the master events have been taken, is the Friuli earthquake of May 6, 1976 with an original $M_w = 6.4$.

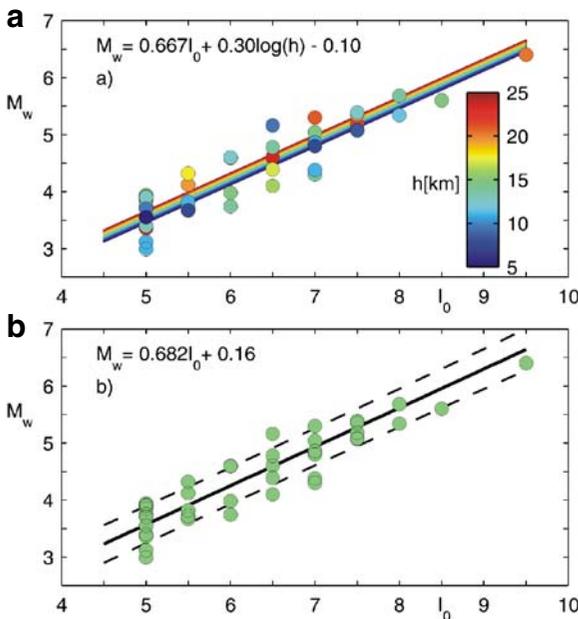


Fig. 3 Master event regressions and used data points. **a** Depth dependent relation, Eq. 1; **b** depth-independent relation, Eq. 2. Dashed lines show the 68% confidence bounds of the latter relation, whereas the confidence bounds for the depth dependent relation cannot be visualized in a simple manner

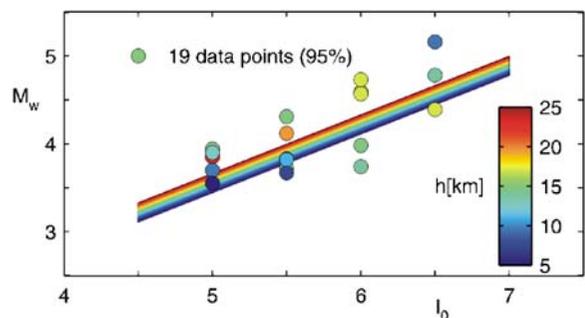


Fig. 4 Comparison of M_w (SMTS) – I_0 data pairs of CENEC with the depth dependent master event relation

Table 2 Comparison of the national catalogue data with the master event relations

Country/area	Catalogue	Notation (from Grünthal et al. 2009)	Number of events		Percent of data within 95% confidence range		Mean/standard deviation of ΔM_w		Figure
			With <i>h</i>	Without <i>h</i>	With <i>h</i>	Without <i>h</i>	With <i>h</i>	Without <i>h</i>	
Austria	Lenhardt (1996); ZAMG (2007)	ZAMG, ZAMG07	165	2	100	100	-0.09/0.12	-0.05/0.07	5
Belgium and Luxembourg	Verbeiren et al. (1995); ORB (2007)	ORB, ORB07	12	40	83	90	-0.05/0.43	-0.05/0.38	6
Bosnia-Herzegovina, Croatia, Serbia-Montenegro, and Slovenia	Herak et al. (1996)	HHM	123	137	90	97	-0.10/0.38	-0.02/0.20	7a
Slovenia	Živič (1993)	ZivS	160	30	100	100	-0.02/0.15	-0.05/0.04	7b
Czech Republic	Schenkova (1993); Zedník (2005)	CAS, GFU	3	4	100	100	-0.03/0.24	-0.16/0.10	8
Fennoscandia	Ahjos and Uski (1992); FENCAT (2007)	FEN, FEN07	58	17	98	71	0.02/0.22	0.54/0.31	9
France	BRGM-EDF-IRSN (2008); LDG (2005)	SisFrance, LDG	-	360	-	100	-/-	0.07/0.13	10a
Germany	Grünthal (1988, 1991); Leydecker (1986, 1996); SZGRF (2007)	Gru, Gru91, Ley, Ley96, GRF	36	13	81	100	0.20/0.42	0.06/0.11	10b
Hungary	Zsiros et al. (1990); Zsiros (1994, 1999); Zsiros et al. (2006)	Zsi, Zsi94, Zsi99, Tot	36	135	94	99	-0.08/0.32	-0.08/0.09	12
Italy	CPTI Working Group (2004)	CPTI04	-	582	-	66	-/-	0.54/0.31	13
Netherlands	Houtgast (1995); KNMI (2006)	Hou, KNMI	5	12	100	92	0.05/0.27	0.10/0.35	14
Poland	Guterch and Lewandowska-Marciniak (2002)	GLM	2	23	100	100	0.08/0.04	0.02/0.05	15
Romania	Onescu et al. (1999); INFP (2007)	Onc, INFP	111	2	77	100	0.25/0.46	0.01/0.34	16
Slovakia	Labak (1998)	Lab	27	88	100	100	0.07/0.15	0.01/0.15	17
Switzerland	Fäh et al. (2003); Fäh et al. (2003); ECOS (2006)	ECOS before 1975 ECOS from 1975 on, ECOS06	82	348	43	95	0.83/0.50	0.38/0.20	18a
Ukraine	Kondorskaya and Ulomov (1999); Kondorskaya and Shebalin (1982)	KU, KSh	8	-	88	-	0.35/0.34	-/-	18b
United Kingdom	Musson (1994, 2006)	Mus, Mus06	59	17	88	88	-0.10/0.08	-/-	19a
							0.18/0.39	0.02/0.39	20

The intensities of the master events since 1992 have been carefully determined using the European Macroseismic Scale, EMS-98 (Grünthal 1998), or its test version, the EMS-92 (Grünthal 1993). What concerns the general compatibility of good quality assignments of intensities according to different 12-degree scales, we refer to Musson et al. (2009). In our study, only earthquakes with an intensity of I_0 or $I_{max} \geq 5$ were considered. Intensity V coincides roughly with the chosen

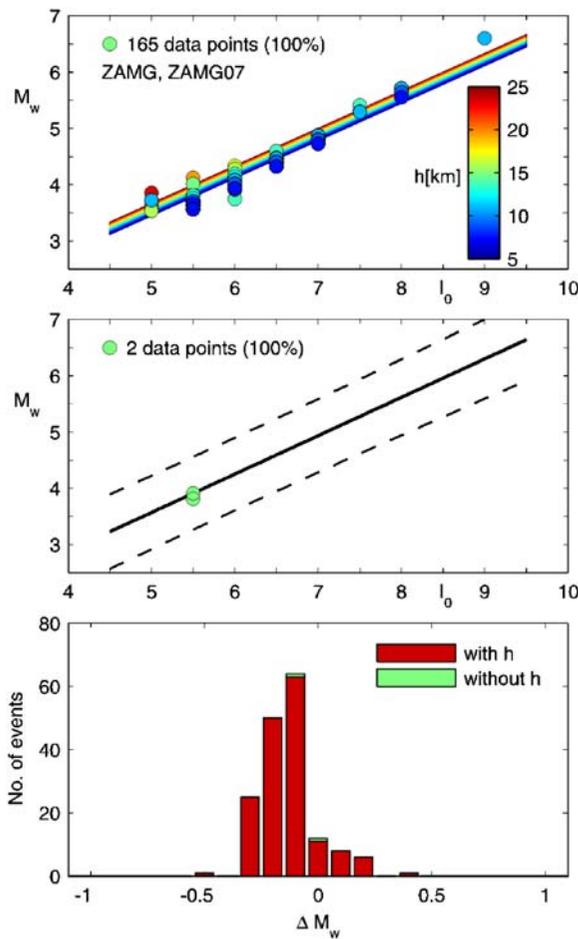


Fig. 5 Comparison of the local catalogue data for Austria to the master event relations: Eq. 1 data with depth (*top*) and Eq. 2 data without depth (*centre*). The share of events within the 95% confidence limits is given in each of the plots (here 100% in both cases). The depth-independent plot additionally shows the 95% confidence limits. The *bottom* figure shows the histogram of ΔM_w . This description and the legends of the plots are valid also for Figs. 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, and 20, although in a few cases, there are data only for one of the M_w - I_0 plots

magnitude threshold of $M_w = 3$. Further criteria to select master events related to high-quality intensities are either the availability of macroseismic maps with intensity data points, which allows to confirm the reliability of the I_0 (I_{max}) value, or that the macroseismic data evaluation was made by a scientist, assuring a good quality I_0 (I_{max}) assignment. The epicentre or meizoseismal area must not be offshore. A minimum focal depth of 5 km was chosen to avoid a bias in the I_{max} reading due to the areal density of localities in the considered parts of Europe.

A chi-square regression of M_w on I_0 and h was performed for the 41 selected events. This provides a general possibility to introduce individual errors for the used data. Since the errors are not precisely known for the individual data

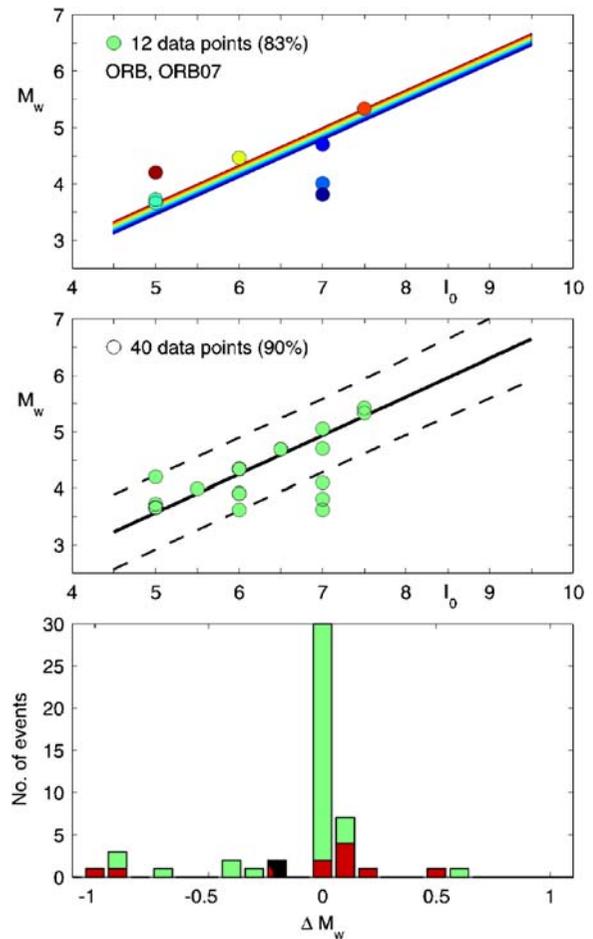


Fig. 6 Belgium, Luxemburg (see caption to Fig. 5)

points, however, we set a general error in intensity of 0.25 and in M_w of 0.15 for events from 2000 onward and 0.30 for events before 2000. The 0.15 value was obtained by Braunmiller et al. (2005) for Swiss earthquakes, but it is valid for all Swiss moment tensor solutions SMTS for M_w (J. Braunmiller, pers. communication). The influence of the error in source depth is negligible if $\sigma(h) < h$ (Stromeyer et al. 2004). This is a further reason to consider depths of 5 km and larger only.

The chi-square regression of M_w on I_0 and h with respect to the master events yields

$$M_w = 0.667 I_0 + 0.30 \log(h) - 0.10$$

$$\sigma = 0.31 \dots 0.37 \quad (1)$$

The obtained relation is valid in the applied ranges of I_0 and h (see Table 1). In Fig. 3a, the relation is plotted together with the input data. The error σ (the 68% confidence interval) of M_w predicted by Eq. 1 depends on the regression error and the uncertainties of the three estimated regression parameters. Its variation with I_0 and h is small compared with the accuracy of the used magnitude data.

For many data sets to be tested, only a few or no h values exist. To be able to check also the data without depth assignment, a regression for the 41 master events omitting h yields

$$M_w = 0.682 I_0 + 0.16 \quad \sigma = 0.32 \dots 0.36 \quad (2)$$

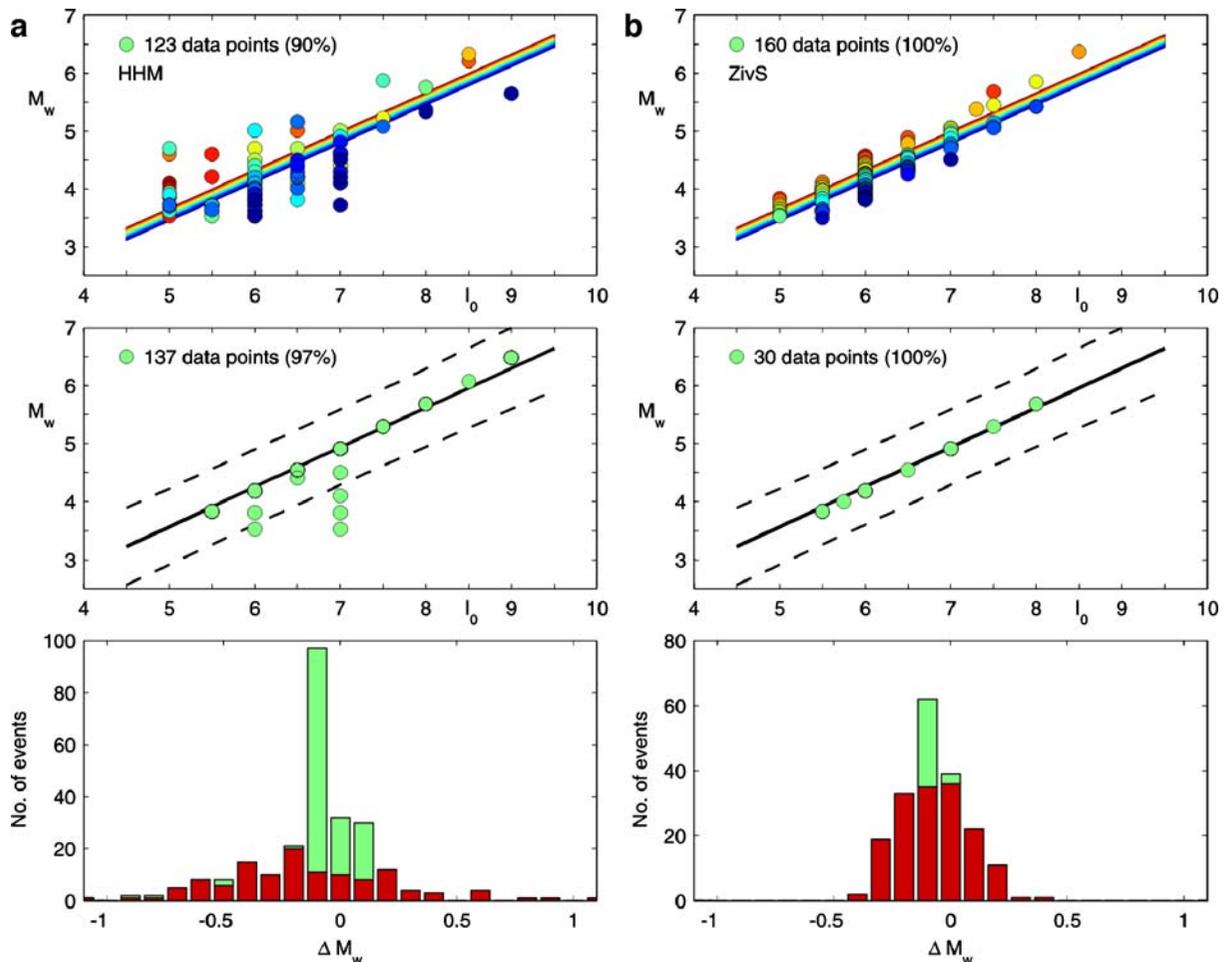


Fig. 7 **a** Bosnia-Herzegovina, Croatia, Serbia-Montenegro, and Slovenia (see caption to Fig. 5). **b** Slovenia – ZivS catalogue (see caption to Fig. 5)

Figure 3b shows this relation and its 68% confidence bounds for a new predicted magnitude. The similarity of the prediction errors σ of Eqs. 1 and 2 demonstrate the weak depth dependence of the data.

4 Statistical test criterion for comparing data sets with the master event relation

The statistical test for our harmonization check is a comparison between appropriate data sets in CENEC with the master event relations. We do not argue that the two empirical relations between the parameters of the master events are valid for the whole area of CENEC, rather we perform a relative test of how the relation of the earthquake

parameters M_w , I_0 and in one case h for each local catalogue in CENEC agrees with the master event relations.

To quantify the performance, we choose the 95% confidence interval of Eqs. 1 and 2 as reference and count the number of catalogue entries in these regions. This is done separately for the data points with and without an assigned depth h . Additionally, the mean and the standard deviation of the differences ΔM_w between the local catalogue entries and the master event relations are calculated.

Before the results for the different national data sets are discussed, we check how the truly original M_w entries in CENEC (which have the highest priority) behave with respect to the master event relations. There are 19 entries with such

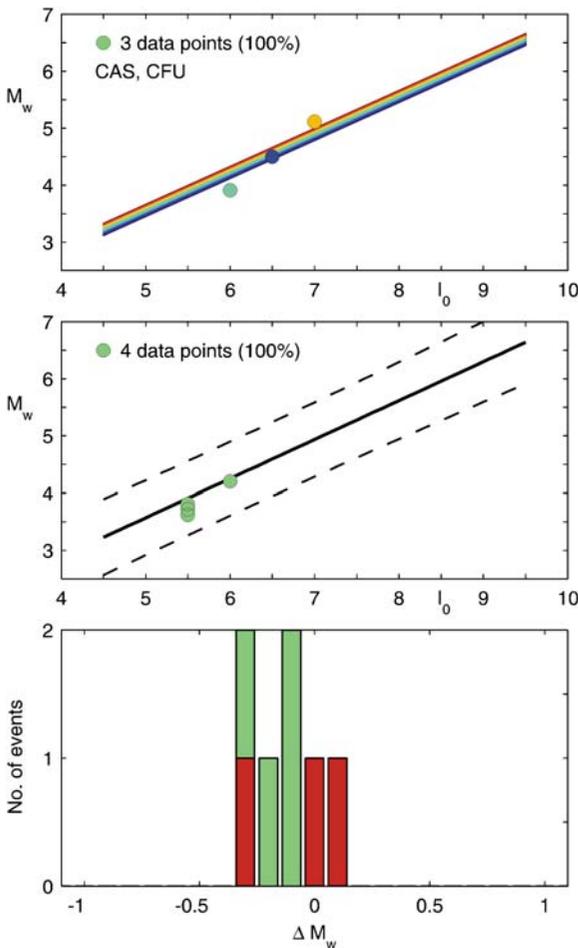


Fig. 8 Czech Republic (see caption to Fig. 5)

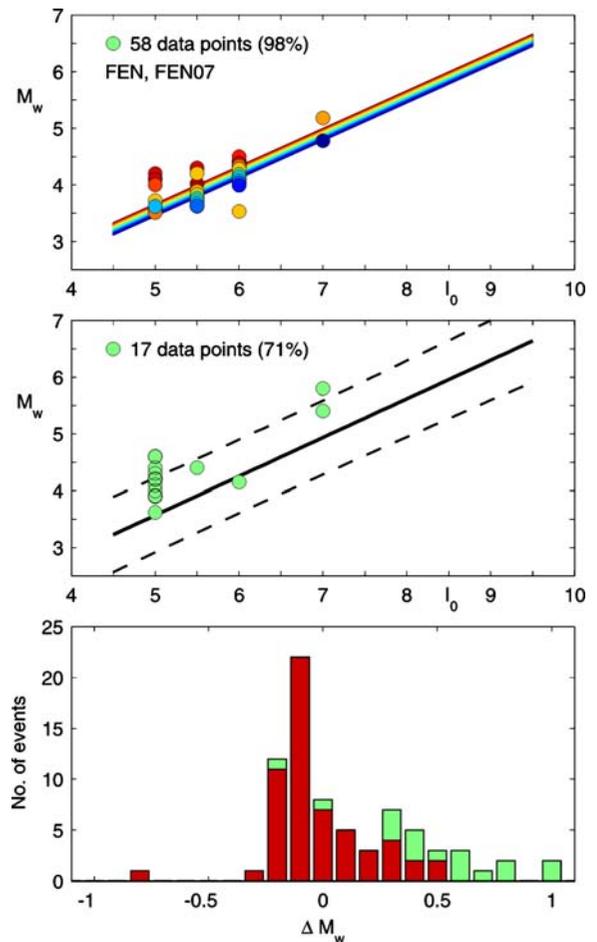


Fig. 9 Fennoscandia (see caption to Fig. 5)

high-quality M_w , all from SMTS, which have an I_0 of 5 or larger and a focal depth between 5 and 25 km according to the national data. Depicted against the range of the master event relation in Fig. 4, the test of the goodness of fit reveals that 95% of the data are within the 95% confidence limit.

5 Comparison of the master event relation with local catalogue data

Different national parts of the CENEC database (Table 2) are tested against the derived master event relations, Eqs. 1 and 2, for the degree of harmonization. Data after 2004, the final year of

CENEC, have been added where available. It is checked to what extent the M_w from each of the national parts of the CENEC catalogue are in agreement with the M_w according to the master event fit as a function of I_0 and h , Eq. 1, and only I_0 , Eq. 2, respectively. This is of special concern since the majority of the significant earthquakes in the different parts of the CENEC study area have intensity as the only strength parameter. Solely events with epicentre onshore and an original I_0 entry in the respective national catalogue are used. The data are restricted to $M_w \geq 3.5$, $I_0 \geq 5$, and $5 \leq h \leq 25$ km, as for the master events. The comparisons, both with and without considering the focal depth, are described below. Consequently, data whose M_w originate in a special

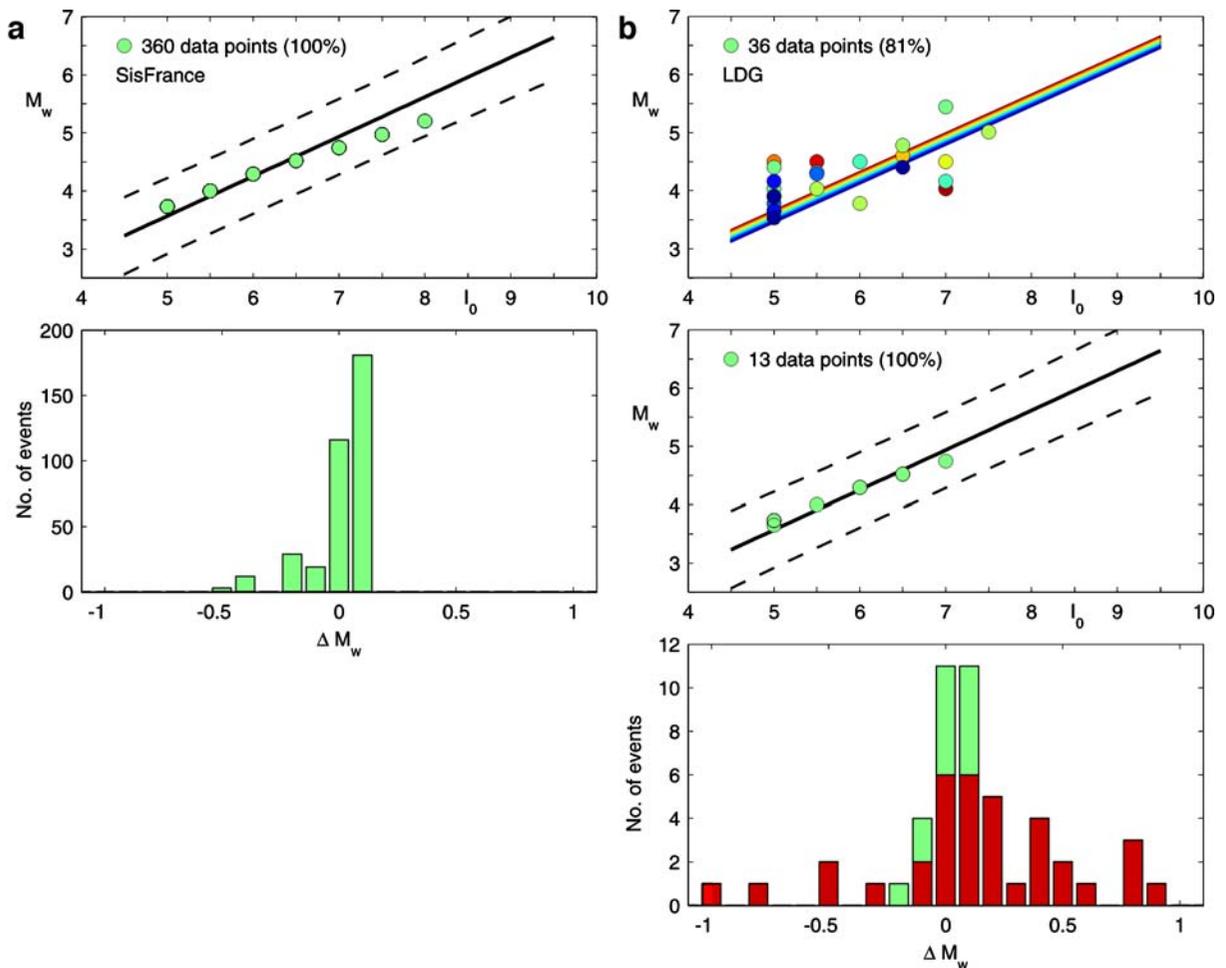


Fig. 10 a France – SisFrance catalogue (see caption to Fig. 5). b France – LDG catalogue (see caption to Fig. 5)

study or in any of the SMTS or Pondrelli et al. (2002, 2007) data bases are not part of the test.

The local NE European catalogues by Boborikin et al. (1993), Nikonov (1992), Pagaczewski (1972), and Wahlström and Grünthal (1994) in the Grünthal et al. (2009) catalogue have too few data to be tested. The IMO (2007a, b; Iceland) and INGV (2007; Italy) catalogues give no intensities. Contributions from ISC (1904–2003) and NEIC (1917–1999) bulletins are lacking intensities in our area of application, the Atlantic Ocean. The test results for all other catalogues used by Grünthal et al. (2009) are described below and shown in the Figs. 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, and 20. In these descriptions, we make use of the acronyms of the catalogues (see Table 2).

5.1 Austria

The Austrian earthquake data files ZAMG and ZAMG07 provide M_L , I_0 , and h . For the reference of these and other abbreviated local catalogue notations, see Table 2. Only two events are lacking a h value. The comparison of the data with the two versions of the master event relation is shown in Fig. 5. The upper part contains the 165 data with h , which have a 100% coincidence with the master event relation within the 95% confidence limits. The ascent in the data is almost the same as for the master events. In the intensity range up to $I_0 = 6$, M_w seems to be slightly underestimated with respect to the master events. The two data points lacking a h value are in good agreement with the reference

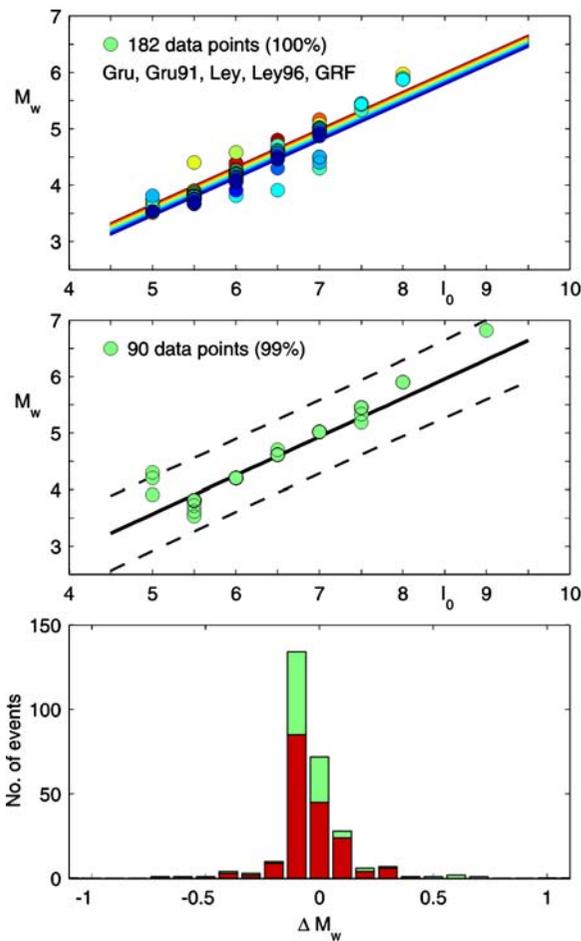


Fig. 11 Germany (see caption to Fig. 5)

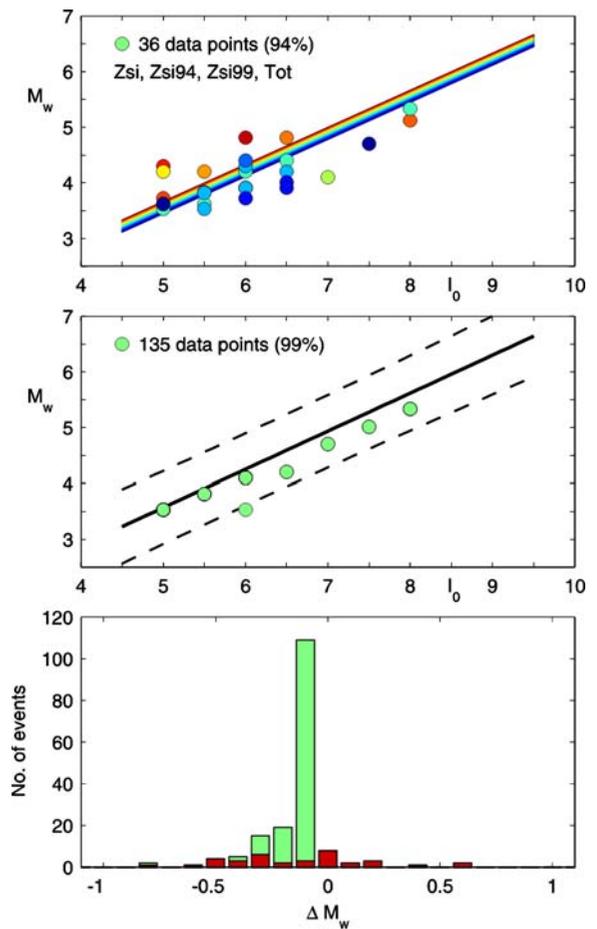


Fig. 12 Hungary (see caption to Fig. 5)

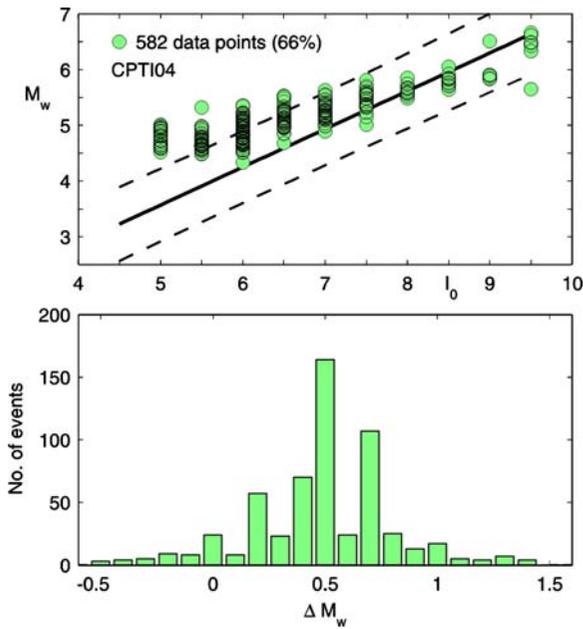


Fig. 13 Italy (see caption to Fig. 5)

relation. This is illustrated in the lower part of Fig. 5.

5.2 Belgium, Luxembourg

The scarce data above the set parameter thresholds from the data files for Belgium and Luxembourg ORB and ORB07 show a quite good coincidence with the master events (Fig. 6). Eighty-three percent of the data with h and 90% without h are within the 95% confidence bounds. The mean values of the differences ΔM_w of the M_w values of the local data from the master event relations are negligible (Table 2), but the standard deviations of ΔM_w are somewhat greater than the prediction errors σ of Eqs. 1 and 2, respectively.

5.3 Bosnia-Herzegovina, Croatia, Serbia-Montenegro, and Slovenia (lat. $\geq 44^\circ\text{N}$)

The HHM catalogue is the major data source for Bosnia-Herzegovina, Croatia, and Serbia-Montenegro and is also used for some events in Slovenia (Fig. 7a). One hundred twenty-three data points from this source provide focal depth and

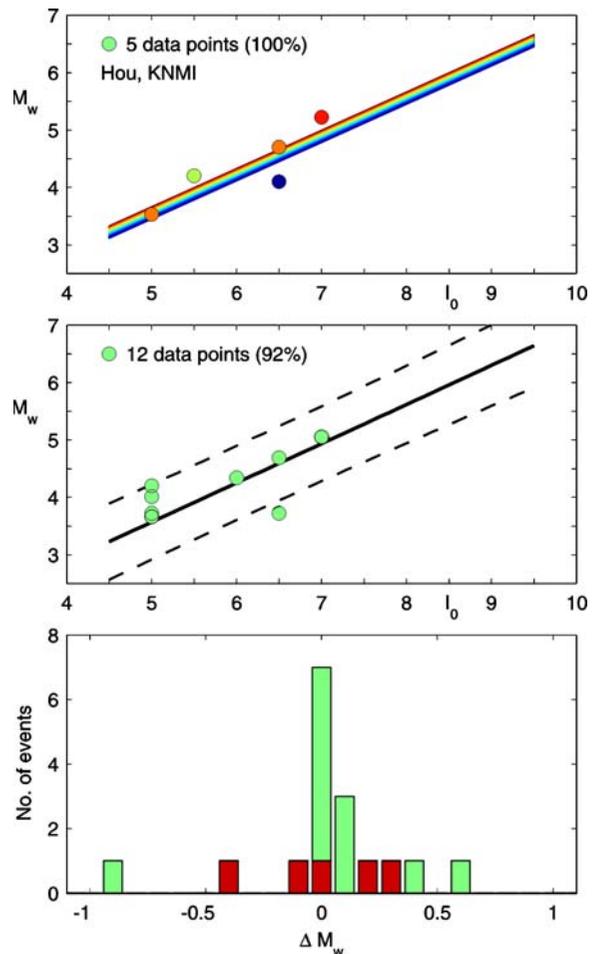


Fig. 14 Netherlands (see caption to Fig. 5)

intensity values. Ninety percent of these data are within the 95% confidence bounds of the master event relation. The ascent of the data is almost the same as those for the master events. For the 137 events without h , 97% of the data are within the 95% master event confidence limits.

For Slovenia, ZivS is the main data source. The 190 data points from this catalogue exhibit an excellent coincidence with the master events (Fig. 7b) in that all data with and without h , respectively, are within the 95% confidence bounds.

5.4 Czech Republic

We have only seven data points above the given parameter thresholds. Therefore, the data from

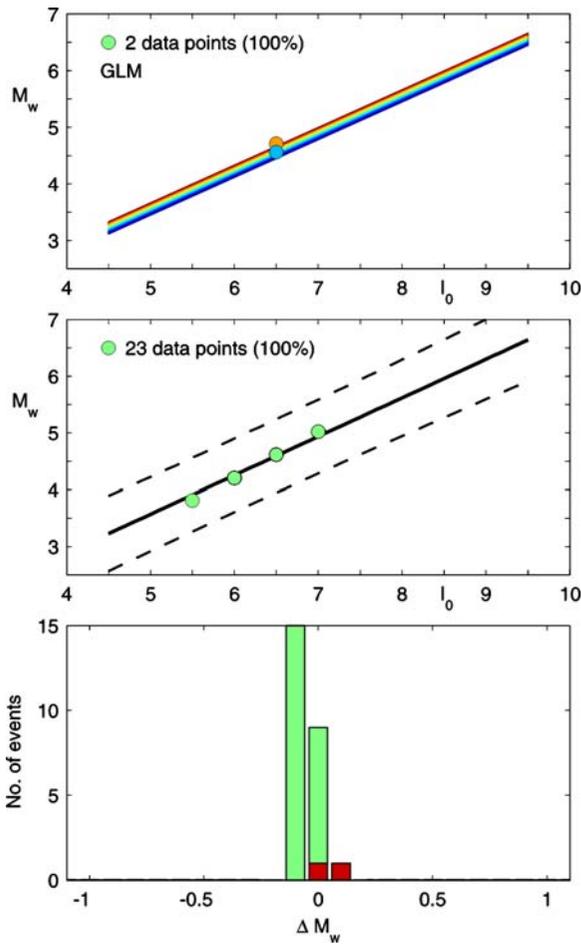


Fig. 15 Poland (see caption to Fig. 5)

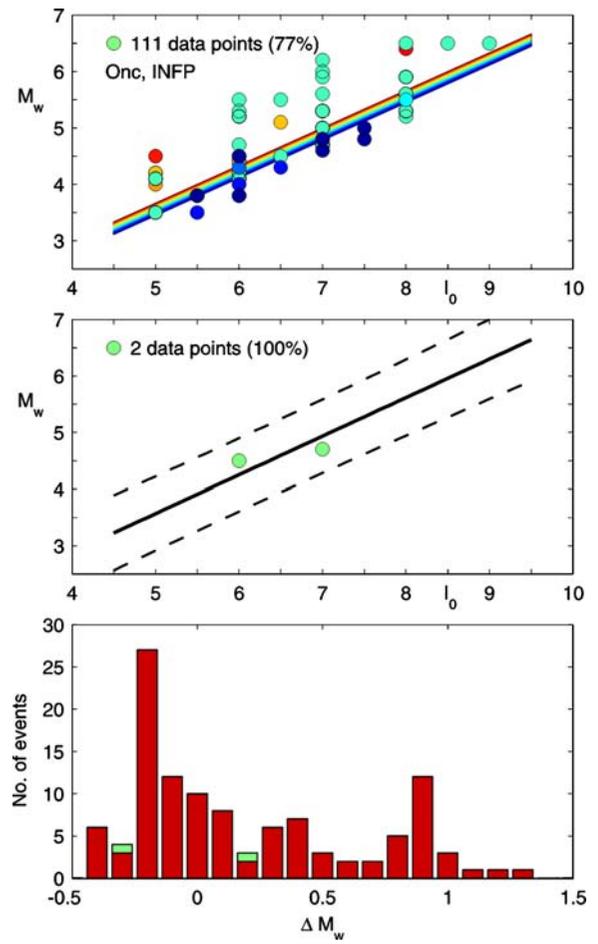


Fig. 16 Romania (see caption to Fig. 5)

the two catalogues for the Czech Republic CAS and GFU are treated together. All data with and without h , respectively, fall within the 95% confidence limits (Fig. 8).

5.5 Fennoscandia sensu lato (Denmark, Finland, Norway, Sweden, the Baltic republics, and adjacent areas)

Although the onshore data for Fennoscandia from the data sets FEN and FEN07 show a distinct scatter, 98% of them with h and 71% without h are within the 95% confidence bounds. The ascent of the M_w-I_0 behaviour is slightly steeper than that of the master event relations (Fig. 9). There is a tendency of either underestimated intensities

or overestimated M_w for the data without h . A closer look shows that the two $I_0 = 7$ events, in 1819 and 1904, as well as four of the five most “anomalous” events with $I_0 = 5$ and 5–5.5, are located in coastal regions of Norway, with possibly incomplete intensity data. This may explain the relatively low intensities with respect to the master event relation. The more modern data which contain h show better agreement with the master event relations.

5.6 France (lat. $\geq 44^\circ\text{N}$)

The French data consist of two quite different data types, the SisFrance data (Fig. 10a), represented in terms of I_0 only, and LDG data (Fig. 10b)

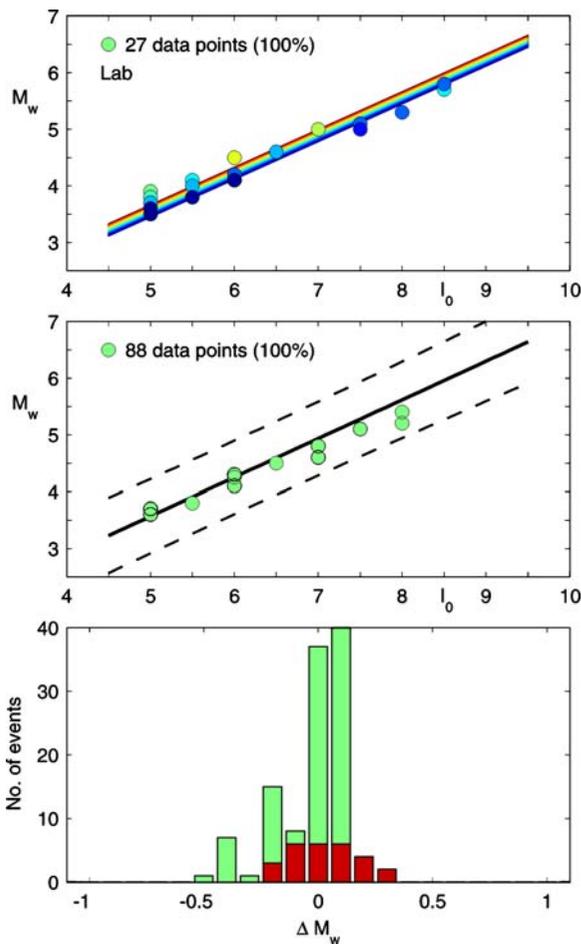


Fig. 17 Slovakia (see caption to Fig. 5)

starting in 1962, giving only M_L . The corresponding M_w have been calculated with the procedures described in Grünthal et al. (2009). The SisFrance data, where h is lacking throughout, are within the 95% confidence bounds of the corresponding master event relation, but show a distinctly different ascent, which originates in the used relation between M_L , I_0 , and h by Levret et al. (1994). For LDG, intensities from SisFrance have been used. The LDG data with depth assignments show a scatter around the master event curve, with 81% of the data being within the 95% confidence bounds, resulting in a slight underestimation of M_w especially at larger magnitudes. The data without depth values behave as the SisFrance entries.

5.7 Germany

The different data sets for Germany (Table 2) behave similarly and have been processed jointly. The 182 data points with h are all within the 95% confidence bounds of the master events (Fig. 11). A similar behaviour is shown by the 90 data points without h , 99% of which are within the 95% confidence limits.

5.8 Hungary

The main Hungarian data sources (Table 2) also show a similar M_w - I_0 - h behaviour. Ninety-four percent of the 36 data points with h and 99% of the 135 without h are within the 95% confidence limits. The generated M_w are mostly underestimated by about 0.1 magnitude units (Fig. 12).

5.9 Italy (lat. $\geq 44^\circ\text{N}$)

The Italian data in CENEC have two sources. The M_w -based CPTI04 is used up to July 2001 and have no h values. The M_L - and M_d -based INGV (2007) data used from August 2001 on provide h values but no intensities, and therefore, as stated above, this catalogue is not part of this study.

The CPTI04 data agree well with the master event relation for intensities $I_0 \geq 7$ (Fig. 13). For $I_0 < 7$, the corresponding M_w values are distinctly higher. The lower ascent in the M_w - I_0 relation for the CPTI04 data is obvious. Sixty-six percent of the data are within the 95% confidence bounds. The mean of ΔM_w is 0.54. The part of Fig. 2 applying to CPTI04 data is in good agreement with the M_w values from SMTS and Pondrelli et al. (2002).

5.10 Netherlands

The scarce data in CENEC for the seismically not very active Netherlands are shown in Fig. 14. They are from the Hou catalogue and its successor file KNMI. There are only five data points with a h value which fulfil the parameter criteria. All of them are in the 95% confidence limits. Ninety-two percent of the 12 data points, which are lacking a h value, are in the 95% confidence limits. The mean values of ΔM_w are not greater than 0.1.

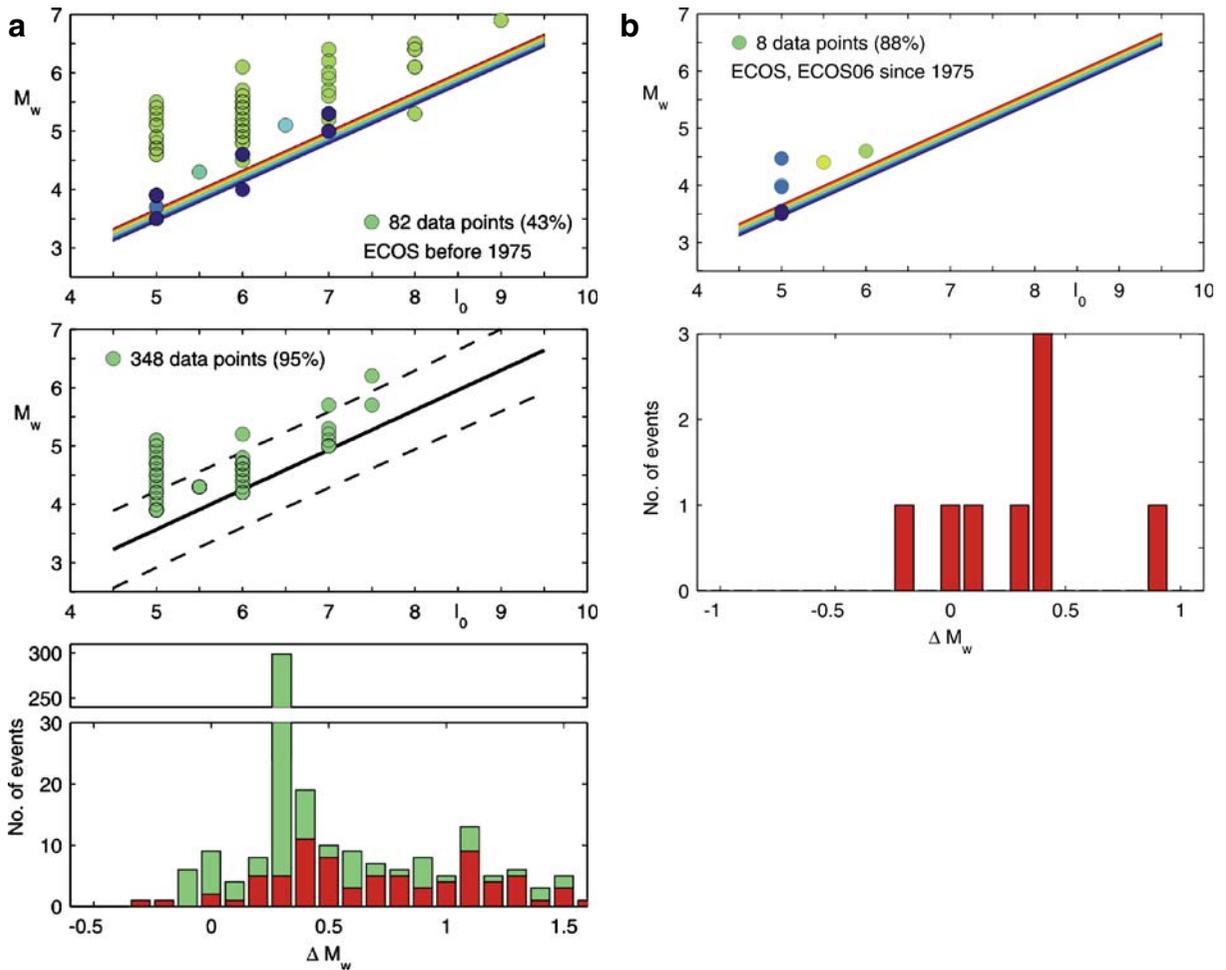


Fig. 18 **a** Switzerland before 1975 (see caption to Fig. 5). **b** Switzerland since 1975 (see caption to Fig. 5)

5.11 Poland

Also in Poland, the seismic activity due to natural tectonic events is very minor. There are only two data points in GLM with h . They coincide very well with the master event curve. Twenty-three data points exist without h . Also they agree very well with the corresponding master event relation (Fig. 15).

5.12 Romania

From the Romanian data in CENEC, the Onc catalogue, and its continuation INFP, there are 111 data points with a h value in the selected range

(Fig. 16). Seventy-seven percent are within the 95% confidence limits. The mean of ΔM_w is 0.25, indicating higher values of the data with respect to the master events. The ascent in the Romanian M_w-I_0 data is fully compatible with the master event relation. Only two data points are lacking h . They both fall within the 95% confidence bounds.

5.13 Slovakia

From the Lab data file for Slovakia, 27 data points with h and 88 data points without h fulfil the parameter criteria (Fig. 17). The scatter in the data

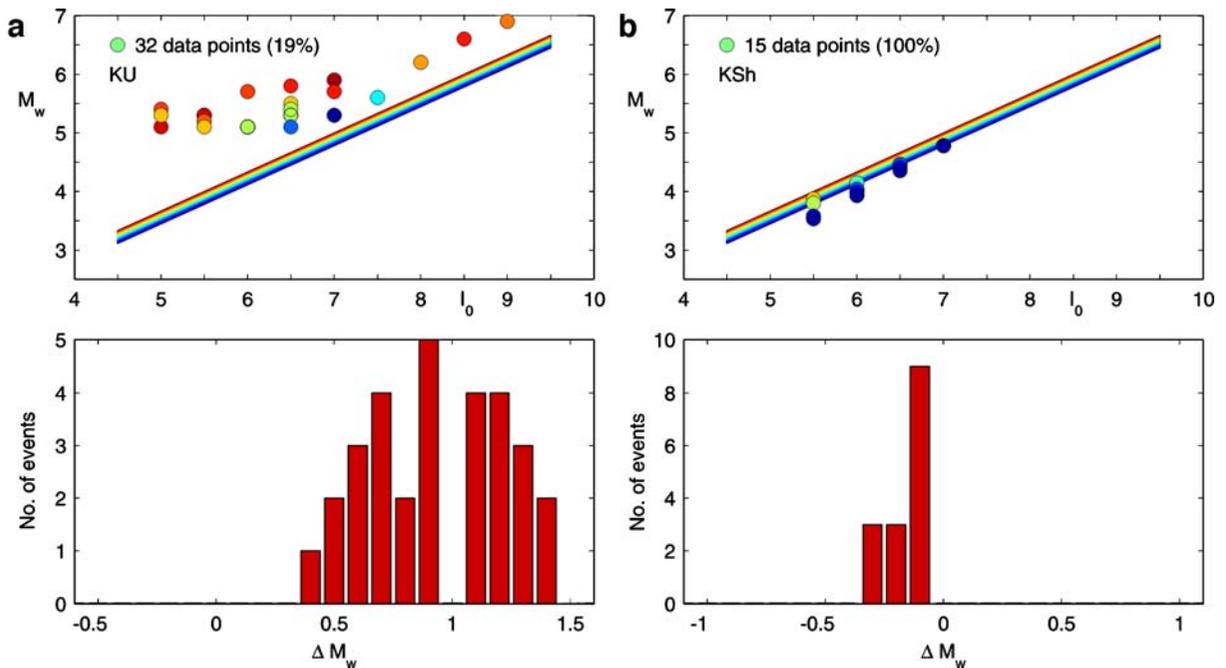


Fig. 19 **a** Ukraine – KU catalogue (see caption to Fig. 5). **b** Ukraine – KSh catalogue (see caption to Fig. 5)

is very low, and all data in both sets are within the 95% confidence bounds. The mean values of ΔM_w are nearly zero.

5.14 Switzerland

The ECOS catalogue for Switzerland and its continued data file ECOS06 (from 2001 onward) are calibrated for M_w and therefore used without modification in CENEC. A characteristic increase of completeness and reliability of the ECOS data approximately since 1975 could be achieved, connected to the high-sensitive telemetry seismic array. According to the descriptions of the ECOS catalogue by Fäh et al. (2003), it is motivated to differentiate between the time period before 1975 (Fig. 18a) and that from 1975 onward (Fig. 18b). The part of Fig. 2 applying to Switzerland shows that the M_w values from SMTS are not identical with those from Fäh et al. (2003) and its continuation ECOS06 in each case, although they all originate from the same agency (ETH Zurich). However, the overall agreement is good.

In the period before 1975, there are 82 data points with h and 348 data points without h in the considered parameter range. Only 43% of the data with h are within the 95% confidence limits, but 95% of those without h .

In the data set with h , there is a clear overestimation of M_w with respect to the master events, with a mean deviation of 0.83. There are, e.g., seven events of $M_w \geq 5.0$ in the upper part of Fig. 18a with an I_0 of 5 and also seven events of $M_w \geq 5.5$ with an I_0 of 6. In the data set without h , there is a large peak of almost 300 events with $\Delta M_w = 0.3$, which is not distinguishable in the centre plot of Fig. 18a due to overlapping data points.

The period since 1975 has eight data points, all with h and all except one point within the 95% confidence limits. The mean shift is reduced to 0.35.

Since the data sets from the two periods behave quite differently, conclusions based only on one part, e.g., in seismic hazard assessment, may be biased.

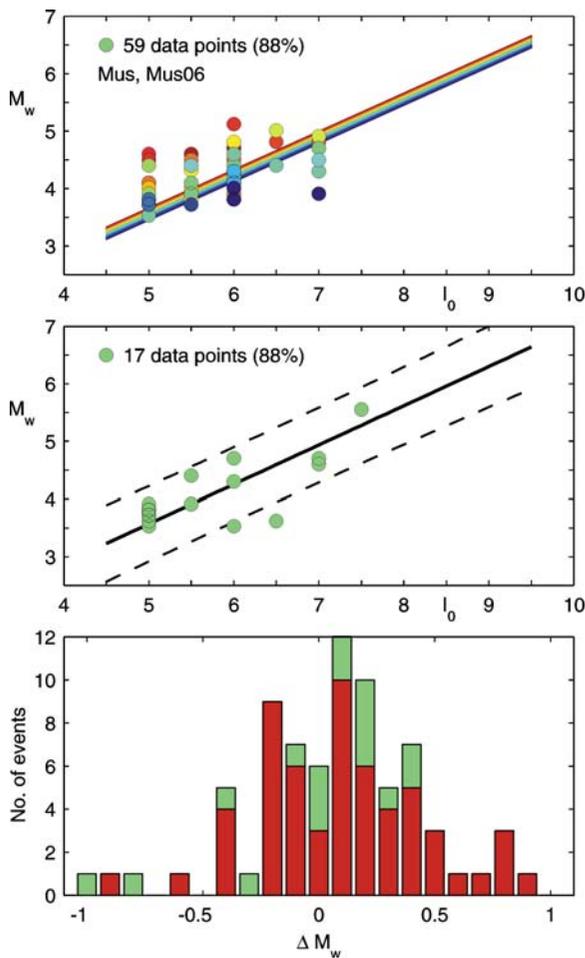


Fig. 20 United Kingdom (see caption to Fig. 5)

5.15 Ukraine

The entries for the Ukraine encompass mainly two data sources, KU and KSh. The KU catalogue has the highest priority, it is calibrated in M_w , and has a lower threshold of $M_w = 5.1$. The KSh catalogue, which requires a conversion to M_w , is used in CENEC for smaller events. The entries of both catalogues have h values. The KU data show a clear overestimation of M_w with respect to the master events. Only 19% of the data are within the 95% confidence bounds (Fig. 19a). On the contrary, the fit between the converted KSh data with the master event relation is excellent

(Fig. 19b), with all data within the 95% confidence range with a slight underestimation of M_w by 0.10 magnitude units.

The different behaviour of M_w in the two data files requires attention in using them jointly in different studies. A further calibration of KU is recommended.

5.16 United Kingdom

The data for the United Kingdom Mus and Mus06 show a fairly large scatter around the master event relations. Of the 59 data points providing h values, 88% are within the 95% confidence limits (Fig. 20). The mean of ΔM_w is 0.18. Eighty-eight percent of the 17 data points without h values are within the 95% confidence bounds. The mean of ΔM_w here is 0.02. The ascent in the M_w-I_0 plot of the data coincides very well with that of the master events.

Table 2 summarizes the comparison of the data from the national catalogues to the two master event relations. It shows the number of events in each national file, the respective percentage of data within the 95% confidence range, and the mean and the standard deviation of ΔM_w . For the data with h , 15 national catalogues out of 18, and for the data without h , 15 catalogues out of 17, have more than 80% of the data points within the 95% confidence range. We judge this as a good overall degree of a harmonization of CENEC. However, some of the national catalogues with original M_w have parts which do not behave as the selected master events. These are the CPTI04 data up to July 2001, the Onc/INFP data with h , the ECOS data with h before 1975, and the KU data above $M_w = 5.1$. Of the catalogues with calculated M_w , only the FEN/FEN07 data without h fall below the 80% limit.

6 Discussion and conclusions

Based on the results presented in this study, harmonization tests of seismicity data bases composed of different independent data sets should

inevitably be introduced. Moreover, such tests should be quantitative. We propose and apply here two different tests to check the degree of harmonization in the earthquake catalogue for Europe north of 44°N (CENEC), focusing on M_w values.

Harmonization tests could quantify the reliability of other parameters than M_w or target the degree of identification of, e.g., fake quakes in regional long-term seismicity data files, to give just a few examples of multifarious harmonization tests.

We have performed two test types with respect to M_w in the CENEC data set: Firstly, the comparison of M_w values from truly original, i.e., moment tensor based, data sources with (1) M_w given by the local catalogues and data files and (2) M_w calculated from other strength measures in the local catalogues and data files. Secondly, based on 41 earthquakes in different parts of central Europe, all with high-quality data – the master events – the relations $M_w = 0.667 I_0 + 0.30 \log(h) - 0.10$ (1) and $M_w = 0.682 I_0 + 0.16$ (2) were derived. Comparing the different data sets contributing to CENEC with these relations, using the percentage of data falling within a 95% confidence range as the measure, 11 sets out of 18 have a very good to excellent fit (>90% of the data) to Eq. 1 and 14 sets out of 18 to Eq. 2. A perfect fit according to this measure (99–100% agreement) is obtained for nine and 11 of these sets, respectively, and a fair to good fit (70–90% agreement) for three sets relative to Eq. 1 and one set to Eq. 2. There is a poor fit (<70%) only for two sets compared to Eq. 1 – ECOS/ECOS06 (Switzerland before 1975) and KU (Ukraine) – and one set compared to Eq. 2 – CPTI04 (Italy). The users of the data files with poor fit should be aware that the M_w values show a different behaviour than those from the data which are more compatible to the master events. Either the master event relation is not applicable in the anomalous cases or the values should be calibrated to conform with the others. It is beyond the scope of this study to elaborate this in more detail and to apply any adjustments. For the vast majority of the data sets and events, the tests show a harmonized catalogue over large areas and time spans, suitable to use, e.g., in large-scale seismic hazard studies.

Acknowledgement We are thankful for the support from the Aon Re Global.

References

- Ahjos T, Uski M (1992) Earthquakes in northern Europe in 1375–1989. *Tectonophysics* 207:1–23. http://www.seismo.helsinki.fi/bulletin/list/catalog/Scandia_clean.html /as in 2003; cf. FENCAT (2007)
- Bernardi F, Braunmiller J, Kradolfer U, Giardini D (2004) Automatic regional moment tensor inversion in the European-Mediterranean region. *Geophys J Int* 157:703–716. doi:10.1111/j.1365-246X.2004.02215.x
- Boborikin AM, Gareckij RG, Emeljanow AP Cildvee ChCh, Cuvejedis PI (1993) Sowremennoye sostoyaniye seismitsheskich nablyudeniyy i ich obobshtsheniyy. In: Semletryasseniya Belarussi i Pribaltiki, Minsk, Belorussia, pp 29–40
- Braunmiller J, Kradolfer U, Baer M, Giardini D (2002) Regional moment tensor determination in the European–Mediterranean area; initial results. *Tectonophysics* 356:5–22. doi:10.1016/S0040-1951(02)00374-8
- Braunmiller J, Deichmann N, Giardini D, Wiemer S, the SED Magnitude Working Group (2005) Homogeneous moment-magnitude calibration in Switzerland. *Bull Seismol Soc Am* 95:58–74. doi:10.1785/0120030245
- BRGM-EDF-IRSN (2008) Base de données SisFrance des séismes historique en France. <http://www.sisfrance.net>
- CPTI Working Group (2004) Catalogo parametrico dei terremoti Italiani, versione 2004 (CPTI04). Istituto Nazionale di Geofisica e Vulcanologica, Milan, Italy. <http://emidius.mi.ingv.it/CPTI04/>
- ECOS (2006) Data file of the Swiss Federal Institute of Technology Zurich. The Swiss Seismological Service, Zurich, Switzerland. http://histserver.ethz.ch/simplequery_e.html (since 2001)
- Fäh D, Giardini D, Bay F, Bernardi F, Braunmiller J, Deichmann N, Furrer M, Gantner L, Gisler M, Isenegger D, Jimenez MJ, Kästli P, Koglin R, Masciadri V, Rutz M, Scheidegger C, Schibler R, Schorlemmer D, Schwarz-Zanetti G, Steimen S, Sellami S, Wiemer S, Wössner J (2003) Earthquake catalogue of Switzerland (ECOS) and the related macroseismic database. *Ecolae Geol Helv* 96:219–236. http://histserver.ethz.ch/simplequery_e.html (up to 2000)
- FENCAT (2007) Data file of the Institute of Seismology, University of Helsinki, Helsinki, Finland. http://www.seismo.helsinki.fi/bulletin/list/catalog/Scandia_clean.html
- Grünthal G (1988) Erdbebenkatalog des Territoriums der Deutschen Demokratischen Republik und der angrenzenden Gebiete von 823 bis 1984. Akademie der Wissenschaften der DDR, Zentralinstitut für Physik der Erde 99, 38 pp + Appendix, 139 pp
- Grünthal G (1991) Data file continuing the earthquake catalogue by Grünthal (1988) for the years 1985–

1991. GeoForschungsZentrum Potsdam, Potsdam, Germany
- Grünthal G (ed) (1993) European macroseismic scale 1992. Cahiers du Centre Européen de Géodynamique et de Séismologie 7, Centre Européen de Géodynamique et de Séismologie, Luxembourg, Luxembourg 79 pp
- Grünthal G (ed) (1998) European macroseismic scale 1998 (EMS-98). Cahiers du Centre Européen de Géodynamique et de Séismologie 15, Centre Européen de Géodynamique et de Séismologie, Luxembourg, Luxembourg 99 pp
- Grünthal G, Wahlström R, Stromeyer D (2009) The unified catalogue of earthquakes in central, northern, and northwestern Europe (CENEC) – updated and expanded to the last millennium, *J Seismol*. doi:10.1007/s10950-008-9144-9
- Guterch B, Lewandowska-Marciniak H (2002) Seismicity and seismic hazard in Poland. *Folia Quat* 73:85–99
- Herak M, Herak D, Markušić S (1996) Revision of the earthquake catalogue and seismicity of Croatia, 1908–1992. *Terra Nova* 8:86–94 / + Data file until 2004/
- Hinzen KG (2003) Source parameters of the ML 3.8 earthquake on January 20, 2000 near Meckenheim, Germany. *J Seismol* 7:347–357. doi:10.1023/A:1024510932145
- Houtgast G (1995) Aardbevingen in Nederland. Koninklijk Nederlands Meteorologisch Instituut, De Bilt, The Netherlands 179, 166 pp
- IMO (2007a) Data file of the Icelandic Meteorological Office, Reykjavik, Iceland for large earthquakes up to 1990. <http://hraun.vedur.is/ja/yomislegt/storskjalif.html>
- IMO (2007b) Data file of the Icelandic Meteorological Office, Reykjavik, Iceland for earthquakes with $M_L \geq 3$ from 1991. <http://hraun.vedur.is/cgi-bin/sellib?>
- INFP (2007) Data file of the National Institute for Earth Physics, Bucharest, Romania. <http://www-old.infp.ro/catal.php>
- INGV (2007) Data file of Istituto Nazionale di Geofisica e Vulcanologia, Milan, Italy
- ISC Bulletins International Seismological Centre (previously International Seismological Summary) bulletins (1904–2003) Newbury, United Kingdom. <http://www.isc.ac.uk/search/index.html>
- KNMI (2006) Data file of Het Koninklijk Nederlands Meteorologisch Instituut, De Bilt, The Netherlands. <http://www.knmi.nl/seismologie/tectonische-bevingen-nl> and <http://www.knmi.nl/seismologie/tectonische-bevingen-regio>
- Kondorskaya NW, Shebalin NW (1982) New Catalogue of strong earthquakes in the USSR from ancient times through 1977. World Data Center A for Seismology SE-31, Boulder, U.S., 608 pp
- Kondorskaya NV, Ulomov VI (1999) Special earthquake catalogue of Northern Eurasia from ancient times through 1995 (SECNE). Joint Institute of Physics of the Earth (JIPE), Russian Academy of Sciences, Moscow, Russia
- Labak P (1998) Data file of the Geophysical Institute, Slovak Academy of Sciences, Bratislava, Slovakia
- Langer H (1986) Seismotektonische Herdparameter und Ausbreitungseffekte bei Mikroerdbeben im Bereich der westlichen schwäbischen Alb. Berichte des Instituts für Geophysik der Universität Stuttgart, Nr. 2, 113 pp
- LDG (2005) Data file of the Laboratoire de Détection et de Géophysique, Bruyères-le-Châtel, France
- Lenhardt W (1996) Data file of the Zentralanstalt für Meteorologie und Geodynamik, Hauptabteilung für Geophysik, Vienna, Austria
- Levret A, Backe JC, Cushing M (1994) Atlas of macroseismic maps for French earthquakes with their principal characteristics. *Nat Hazards* 10:19–46. doi:10.1007/BF00643439
- Leydecker G (1986) Erdbebenkatalog für die Bundesrepublik Deutschland mit Randgebieten für die Jahre 1000–1981. *Geol Jb E36*, 83 pp
- Leydecker G (1996) Data file updating and continuing (until 1994) the earthquake catalogue by Leydecker (1986). Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany
- Musson RWM (1994) Earthquake catalogue of Great Britain and surroundings. British Geological Survey, Edinburgh, United Kingdom, Technical Report WL/94/04, Seismology Series, 99 pp
- Musson RWM (2006) Data file of the British Geological Survey, Edinburgh, United Kingdom for events with $M_L \geq 3$
- Musson RWM, Grünthal G, Stucchi M (2009) The comparison of macroseismic intensity scales. *J Seismol* (in review)
- NEIC bulletins U.S. National Earthquake Information Center bulletins (1917–1999) U.S. Geological Survey, World Data Center A for Seismology, Boulder, U.S. <http://neic.usgs.gov/neis/epic>
- Nikonov AA (1992) Distribution of maximum observed tremors and zones of possible occurrence of earthquakes in Estonia. *Izvestiya Earth Phys* 28: 430–434
- Oncescu MC, Marza VI, Rizescu M, Popa M (1999) The Romanian earthquake catalogue between 984–1997 /+ Data file until September 1998/. In: Wenzel F, Lungu D (eds) Contributions from the first international workshop on Vrancea Earthquakes, Bucharest, Romania, November 1–4, 1997. Kluwer, Boston, pp 43–48
- ORB (2007) Data files of the Observatoire Royale du Belgique, Brussels, Belgium. <http://www.astro.oma.be/SEISMO/index.php?>
- Pagaczewski J (1972) Catalogue of earthquakes in Poland in 1000–1970 years. Publications of the Institute of Geophysics, Polish Academy of Sciences, Warsaw, Poland, 61 pp
- Pondrelli S, Salimbeni S, Morelli A, Ekström G, Boschi E (2007) European–Mediterranean regional centroid moment tensor catalogue: solutions for years 2003 and 2004. *Phys Earth Planet Inter* 164:90–112. doi:10.1016/j.pepi.2007.05.004
- Pondrelli S, Morelli A, Ekström G, Mazza S, Boschi E, Dziewonski AM (2002) European–Mediterranean regional centroid-moment tensors: 1997–2000. *Phys Earth Planet Inter* 130:71–101. doi:10.1016/S0031-9201(01)00312-0

- Schenkova Z (1993) Earthquake catalogue for Czechoslovakia. *Pure Appl Geophys* 119:1077–1092 /+ Data file until 1984/
- Stromeyer D, Grünthal G, Wahlström R (2004) Chi-square regression for seismic strength parameter relations, and their uncertainties, with applications to an M_w based earthquake catalogue for central, northern and northwestern Europe. *J Seismol* 8:143–153. doi:10.1023/B:JOSE.0000009503.80673.51
- Swiss moment tensor solutions (2006; SMTS) Moment tensor solutions from the Schweizerischer Erdbebendienst (SED), Zurich, Switzerland. <http://www.seismo.ethz.ch/mt>
- SZGRF (2007) Gräfenberg Seismological Central Observatory bulletins, Erlangen, Germany. <http://www.szgrf.bgr.de/bulletins.html>
- Tóth L, Mónus P, Zsíros T, Kiszely M, Czifra T (2006) Data file of the GeoRisk Ltd., Budapest, Hungary. <http://www.georisk.hu>
- Verbeiren R, Camelbeek T, Alexandre P (1995) Data file of the Observatoire Royale du Belgique, Brussels, Belgium
- Wahlström R, Grünthal G (1994) Seismicity and seismotectonic implications in the southern Baltic Sea area. *Terra Nova* 6:149–157. doi:10.1111/j.1365-3121.1994.tb00648.x
- ZAMG (2007) Data file on the webpage of the Zentralanstalt für Meteorologie und Geodynamik, Hauptabteilung für Geophysik, Vienna, Austria. http://www.zamg.ac.at/erdbeben/beben_archiv/jahresberichte/index.php
- Zedník J (2005) Catalogs of regional seismic events – Czech Regional Seismological Network. Geophysical Institute, Czech Academy of Sciences, Prague, Czech Republic
- Živčič M (1993) Data file “earthquakes of Slovenia” of the seismology and geology office. Environmental Agency of the Republic of Slovenia, Ljubljana
- Zsíros T (1994) Data file of the Seismological Observatory, Geodetic and Geophysical Research Institute, Hungarian Academy of Sciences, Budapest, Hungary
- Zsíros T (1999) Data file of the Seismological Observatory, Geodetic and Geophysical Research Institute, Hungarian Academy of Sciences, Budapest, Hungary
- Zsíros T, Mónus P, Tóth L (1990) Hungarian earthquake catalogue (456–1986). Seismological Observatory, Geodetic and Geophysical Research Institute, Hungarian Academy of Sciences, Budapest, Hungary, 182 pp