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. - Journal of Seismology, 13, 4, 517-541

DOI: 10.1007/s10950-008-9144-9

Journal of Seismology 13(4): 517-541
DOI 10.1007/s10950-008-9144-9

The unified catalogue of earthquakes in central, northern, and northwestern Europe (CENEC) – updated and expanded to the last millennium

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Received: 11 March 2008 / Accepted: 14 October 2008

Abstract New databases motivate improvements and extensions of the catalogue by Grünthal and Wahlström (J Seismol 7:507-531, 2003a) - G&W03 - of earthquakes in central, northern and northwestern Europe with $M_w \geq 3.50$. Data from over 30 regional catalogues, the ISC and NEIC bulletins for the NE Atlantic Ocean, and many special studies were analysed, largely along the lines of the previous study. Non-tectonic, non-seismic and non-existing as well as duplicate events were identified and removed according to our current stage of knowledge. If not given by the original source, the moment magnitude, M_w, was calculated for each event with a specified epicentral location and a given strength measure (i.e., an original magnitude of any type or, for onshore events only, an intensity). The calculations follow transformation relations derived in the present or in our previous study. The investigated area is subdivided into 22 polygons, in each of which one or more local catalogues, supplemented by data from special studies, are used. If more than one catalogue lists an event, one entry was selected according to a priority algorithm specific for each polygon. If the selected catalogue entry contains more than one strength type, one was selected for the M_w calculation according to another priority scheme. The final catalogue, CENEC, is confined to the time period 1000-2004 and magnitudes $M_w \geq 3.50$. This is an extension of the time period covered by G&W03 (1300-1993). The number of events has increased from about 5,000 to about 8,000. For each entry, available information on the date, time, location (including focal depth), intensity I_0, magnitude M_w, and source (i.e., the local catalogue or special study) are given. The strength type and value from which M_w was calculated are also indicated. The catalogue is available on the website of the GFZ German Research Centre of Geosciences.

Keywords Earthquake catalogue • Europe • Unified moment magnitude

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1 Introduction

Homogeneous earthquake catalogues with high-quality data covering large territories and long historical time spans are lacking for many parts of the Earth. Such data are highly requested for various kinds of seismological studies. Grünthal and Wahlström (2003a, here referred to as G&W03) produced an earthquake cata-

Published online: 13 January 2009

logue for central, northern and northwestern Europe (EEC_CNNW) north of 44°N for events with $M_w \geq 3.50$ in the time frame 1300-1993, with unified M_w. The issue of G&W03 was strongly motivated by the responsibilities at the corresponding GSHAP (Global Seismic Hazard Program) regional centre. It is based on many local earthquake lists and special studies and is available on the homepage of the GFZ German Research Centre of Geosciences (doi: 10.2312/ GFZ.b103-030104 for the respective Scientific Technical Report STR 03/02 (Grünthal and Wahlström, 2003b); doi 10.2312/GFZ. b103-030104_Annex for the seismicity database). The G&W03 catalogue has been very frequently visited and utilized. The update of the present version is strongly demanded by the growing user community of G&W03. The new CEntral, Northern and northwestern European earthquake Catalogue (CENEC) intends to support newly established activities in the frame of the European Seismological Commission to study the roots of the significant European earthquakes before 1900 and produce a catalogue with $M_w \geq 5$ events.

Different to most domestic catalogues, the bulletins from the international seismological data centres, such as the International Seismological Centre (ISC), U.S. National Earthquake Information Center (NEIC) and European Mediterranean Seismological Centre (EMSC) and their predecessors, cover short time periods. The "standard" catalogue for European and Mediterranean earthquakes by Kárník (1996) has high strength thresholds, intensity 7 for the period 1800-1900 (and is still rather incomplete except for the last decades of the 19th century), $M_S = 4.5$ for 1901-1950 and $M_S = 3.8$ for 1951-1990. These sources do not meet the full needs of applications like seismic hazard assessment or long term seismicity studies, especially in areas of relatively low seismic activity, such as Europe north of the Mediterranean region.

The main motivation of our present paper is to keep the many users of our catalogue updated with respect to data sets which have become available since the G&W03 publication. The catalogue also contains data from several additional special studies, mostly of single events. The time period has been extended back in time to the year 1000 and forward to 2004. The addition of the first three centuries certainly does not imply completeness for events with $M_w \geq 3.5$, but it introduces all the available local data uniformly converted to M_w above this threshold for this time period. The area covered has been slightly extended to the north and east.

The new data enabled the improvement of most of the empirical relations between different strength measures. A joint study (Grünthal et al., 2008) is made of the degree of harmonization of M_w which can be achieved by the approach used. The conclusions can provide the basis for future work towards a further harmonized catalogue.

In the frame of this study, non-tectonic, non-seismic and non-existing as well as duplicate events were identified according to our current stage of knowledge.

2 New local catalogues

The new local catalogues for Italy (CPTI Working Group, 2004) and Switzerland (Fäh et al., 2003) are now prime sources in these countries since they contain M_w magnitudes throughout and include updated archival findings on historical key earthquakes. These and the other catalogues or data sets which are new with respect to G&W03 are described below in a country- or region-wise alphabetic order. This is the order of Annex 1, in which all the catalogues are listed in detail. Each catalogue is valid in one or more of 22 polygons (Section 3.1).

- Austria: Data files on the web from ZAMG (2007) from 2000 and on. The time gap between Lenhardt (1996) and ZAMG (2007), i.e., for the period 1996-1999, is covered by SZGRF (2007) data (see below).
- Belgium: Upgrade of the Verbeiren et al. (1995) catalogue by data from the Observatoire Royal de Belgique webpage (ORB, 2007). Historical data have been modified. In the period 1985-1993 the old data have been completely substituted and from 1994 on new data have been introduced.
- Croatia: A new extensive database for Croatia and surrounding countries, including data

from many local sources (Herak et al., 1996). This is the only source for Croatia and Bosnia-Herzegovina and it is used also for Slovenia and Serbia-Montenegro. The previous source for Croatia, used by G&W03 (Živčić, 1994), has been abandoned.

- Czech Republic: Schenková (1993) up to 1984 and Zedník (2005) from 1992 on for use in the Czech Republic. Schenková (1993) is also valid in Poland, but there is no event with $M_w \geq 3.50$.
- Fennoscandia: Upgrade of the Ahjos and Uski (1992) catalogue by data from the Institute of Seismology, University of Helsinki webpage (FENCAT, 2007), including revision of the old data and extension in time after 1991, as the only catalogue for Fennoscandia and the adjacent area (including the Baltic countries) and used also for the North Atlantic Ocean (see below).
- France: Two French catalogues, SisFrance (BRGM-EDF-IRSN, 2008) giving intensities and LDG (2005) M_L magnitudes. Beside France, they are used for the English Channel. The previously used French catalogue by Lambert and Levret-Albaret (1996) has been abandoned.
- Germany: The Gräfenberg Observatory bulletins (SZGRF, 2007) providing first hand data for Germany and, for the period 1996-1999 when no data from the Austrian institute are available, for Austria. These SZGRF data were also used for Poland and the Czech Republic since 1994, but in the Czech Republic Zedník (2005) has higher priority and no SZGRF entries with $M_w \geq 3.50$ are needed.
- Hungary: Two Hungarian earthquake lists, Zsíros (1999) for the time period 1995-1999 and Tóth et al. (2006) from the year 2000 on. These are the only sources for Hungary and Slovakia in these intervals but Zsíros (1999) has no events with $M_w \geq 3.50$. The catalogues are also valid for the Ukraine, but have no entries.
- Iceland: The catalogue for Iceland until 1990 used by G&W03, now available on the webpage as a separate file and renamed IMO (2007a). The catalogue for Iceland from 1991 on from the webpage of the Icelandic Meteorological Office (IMO, 2007b).
- Italy: CPTI Working Group (2004) substituting the only previous source used for Italy (Camassi and Stucchi, 1996). Like its predecessor, the CPTI Working Group (2004) catalogue claims to contain no dependent earthquakes (fore- and aftershocks) and considers no deeper earthquakes. It gives M_w magnitudes and has a threshold at $M_w = 4$. The INGV (2007) data file, for the time period 1983-2004 for Italy. For reasons specified in Section 4, only entries from August 1, 2001 on are used.
- Netherlands: The database from Het Koninklijk Nederlands Meteorologisch Instituut (KNMI, 2006) succeeding Houtgast (1995) after 1993 as the only source for the Netherlands.
- Poland: The published catalogue of historical earthquakes by Guterch and Lewandowska-Marciniak (2002), used also for the Czech Republic. Pagaczewski (1972) is kept as the source for pre-1483 earthquakes.
- Romania: The continued catalogue for Romania from the National Institute for Earthquake Physics (INFP, 2007). Like its predecessor, the Oncescu et al. (1999) catalogue ending in September 1998, it contains M_w magnitudes and has validity also in Serbia-Montenegro and the Ukraine, although lacking events with $M_w \geq 3.50$ in the Ukraine. Both catalogues have validity for, but lack entries in, Moldavia.
- Switzerland: The Swiss ECOS catalogue (Fäh et al., 2003) as the only source used for Switzerland, and providing supplementary data for adjacent parts of Germany and selected events in adjacent parts of France. It has substituted Mayer-Rosa and Baer (1992) used by G&W03. The Fäh et al. (2003) report covers the time period up to 2000 inclusive, but the ECOS catalogue is continuously updated at the ETH homepage and has been used for Switzerland after 2000 (ECOS, 2006). Furthermore, the Swiss Moment Tensor Solutions (2006) database beginning in 1999 has been used. It encompasses practically all of Europe and its entries supersede the calculated M_w entries of any other catalogue (see Section 4).
- United Kingdom: The database from the Brit-

ish Geological Survey (Musson, 2006) succeeding Musson (1994) after 1993 as the only catalogue for the United Kingdom. The Musson (2006) catalogue includes events with $M_L \geq 3$.
- Ukraine: The catalogue by Kondorskaya and Ulomov (1999) for the former Soviet Union, here used as the prime source for Moldavia and the Ukraine up to 1995. It also applies to Belorussia, but has no entries.

The local catalogues which contribute data to CENEC are listed to the catalogue in Annex 1 with the new catalogues highlighted. Many special studies also provide data for the catalogue (Annex 2). Uncertain events were identified as, e.g., fakes, when a corresponding special study or a compatible reference can be cited. However, it is beyond the scope of this study to make a systematic analysis of all the individual entries, e.g., medieval earthquakes, in the local catalogues.

The reporting of local earthquake data to international data centres such as ISC or NEIC is very different on behalf of different domestic seismological agencies. The compilation and unification of local data from most European countries made in this study therefore implies a significant improvement, which is necessary for reliable seismic hazard assessment and other seismicity based analyses. For the North Atlantic Ocean, where for obvious reasons local data are lacking, the reported events by the International Seismological Centre (ISC) have been incorporated to supplement the previous data from the National Earthquake Information Center (NEIC). See also Section 3.1.

3 Study area extent and priorities of the different national catalogues

3.1 Revised polygons and study area

To account for the geographical limitation of the validity of each catalogue and to set priorities where there are two or more catalogues covering a region (e.g., a country), the investigated area is subdivided into 22 polygons (Fig. 1, Annex 3). The overall boundaries are 25°W to the west, 73°N to the north and 44°N to the south, whereas the eastern border is irregular - see Fig. 1. The differences to the G&W03 study are:

- The polygon Fennoscandia (FEN) has been slightly expanded to the north and east to better cover the seismicity distribution.
- Ukraine (UA) and Belorussia (BY) have been expanded to the east to include the whole countries.
- Due to the introduced improved French data from LDG (2005) and SisFrance (BRGM-EDF-IRSN, 2008) both the British and the French catalogues are applied for the English Channel. The French polygon has been extended in the offshore area south of the UK polygon, substituting a previous part of the North Atlantic Ocean and Iceland (AOI) polygon.
- AOI has been extended from 72°N to 73°N latitude to cover more of the seismicity.
- The previous Bosnia and Serbia polygon has split into its two national parts, BIH and YU (see Annex 3), respectively.

3.2 Catalogue-polygon combination priorities

For each polygon, one or more local catalogues are accepted as data sources. Data are also provided by more than 40 special studies, each referring to one or a limited set of events only. Annex 1 summarizes to which polygon(s) the catalogues are associated and Annex 2 summarizes the special studies. For the sake of completeness, this study includes all references used in the catalogue. Annex 3 gives the polygons and their associated catalogues. These are the polygon-catalogue combinations which qualify for the new catalogue. If two or more catalogues are allowed for a polygon, one is selected according to the priority scheme in Annex 3. Exceptions from the validity criteria are made for “mutual border cases”, i.e. when catalogue 1 with validity in polygon P1 has an entry in neighbouring polygon P2, and catalogue C2 with validity in polygon P2 has an entry in P1; in such cases one of the entries is accepted by CENEC. As before, special studies have generally higher priority than the catalogues in most cases.

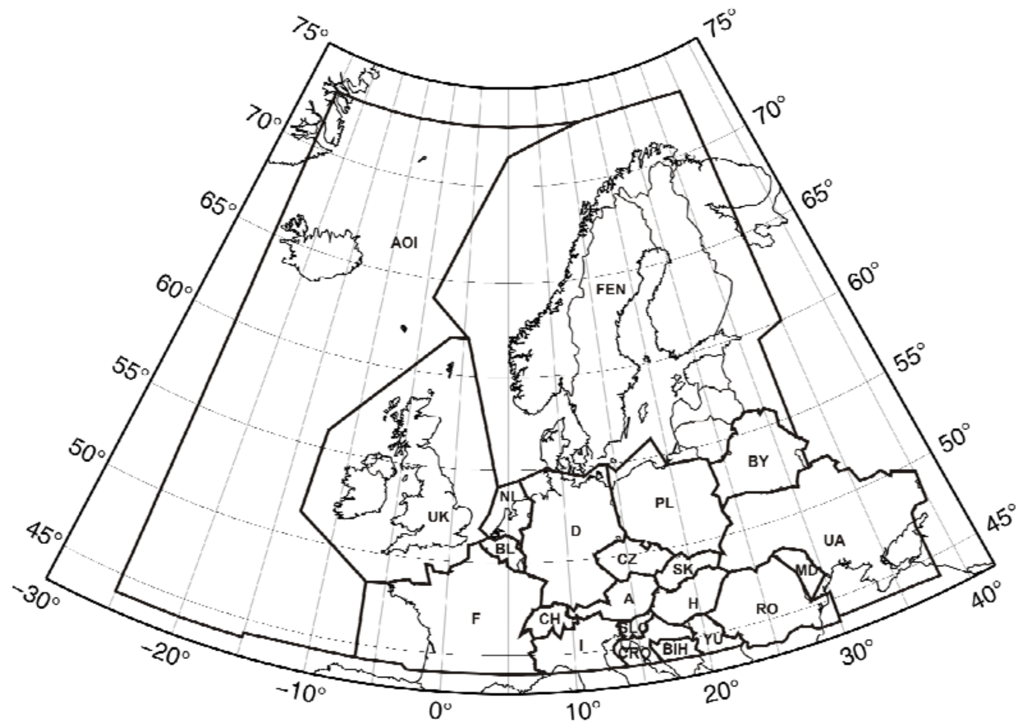

Fig. 1 The polygons accounting for the geographical limitation of the validity of used regional catalogues. To the south, the polygons are cut at latitude 44°N with the exceptions that the southern border of Romania is followed and the border north of the Iberian Peninsula is slightly north of 44°N.

With the many new data sources added to or substituting the previous ones in G&W03, the catalogue-polygon priority scheme has changed in many cases. The full scheme is given in Annex 3.

4 Calculation of the moment magnitude M_w from other event strength types

4.1 Hierarchy of conversions towards M_w

M_w was chosen by G&W03 as the standard magnitude because it is a physically founded measure and most of the ground motion models are given for this parameter. M_w is used also for the present catalogue. Once an entry from a local catalogue, or a special study, has been selected for an event according to the scheme in Annex 3, the next task is to obtain its M_w. If M_w or the seismic moment, M_0, is provided by the original source this is used. M_0 is converted to M_w using the Hanks and Kanamori (1979) relation.

Beside the Romanian catalogue by Oncescu et al. (1999), used already by G&W03 and its continuation (INFP), the new local catalogues for Italy (CPTI Working Group, 2004) and Switzerland (Fäh et al., 2003; ECOS, 2006), give M_w for all entries. So does the Kondorskaya and Ulomov (1999) catalogue used for Eastern Europe. The new Fennoscandian catalogue, FENCAT (2007), gives M_w (originally from Bergen University) for some events. Several special studies also give M_w magnitudes. As mentioned in Section 2, M_w magnitudes from Swiss Moment Tensor Solutions (2006) have been inserted to entries of all catalogues and special studies. So have supplementary M_w values from the European-Mediterranean Regional Centroid Moment Tensors project (Pondrelli et al., 2002, 2004, 2007).

The new Icelandic data file (IMO, 2007b) gives a moment magnitude which is not compatible with the Hanks and Kanamori M_w (S. Jakobsdottir, pers. communication). To convert to M_w, we have made a regression with M_w from ISC for overlapping events, resulting in the relation

$$M_{w,ISC} = 0.612\ M_{w,IMO07} + 2.63 \qquad \sigma = 0.43 \ldots 0.61 \qquad (1)$$

The large standard deviation σ indicates that the relation between M_w and M_L is not stringent. This and all the following relations in this paper are based on the chi-square maximum likelihood regression technique, presented by Stromeyer et al. (2004). This approach pays special attention to the errors affecting the input data. For Eq. (1), the same error is assumed for all values. The uncertainties of this and all following relations are given in terms of the 68% confidence bounds for a predicted value. This measure depends on the residuals between the model and the input data, and the covariance of the regression parameters. The difference between the regression relation and its 68% confidence bounds is approximately one standard deviation σ of a predicted magnitude. For Eq. (1), $\sigma = 0.43$ and 0.61 denote the lower and upper bounds. The detailed dependence of σ on $M_{w,IMO07}$ is given in Annex 4.

The remaining vast majority of the local catalogues do not provide M_w (or M_0), which thus has to be derived. A scheme is established showing the transformation relations and the hierarchy of strength types from which M_w is calculated for the different catalogues (Annex 5). Where available, local transformation relations were tested and used. However, the majority of the necessary relations had to be derived by G&W03 and in the present study. Magnitude data are given priority to intensity data. Special attention is paid to the historical earthquakes, which are often the largest ones in an area. Their strengths can originally be given in terms of macroseismic parameters only (see Section 4.3). The relations to obtain M_w derived in the present study are given in detail in Sections 4.2 and 4.3; the other relations used are given directly in Annex 5.

If M_w (or M_0) does not exist for an entry of a special study, it is calculated from an algorithm valid in the polygon where the event is located.

4.2 M_w from other magnitude types

4.2.1 M_w derived from M_L

M_L is by far the most frequent magnitude type in our database. In many cases, it is the only magnitude given. A well constrained relation derived by Stromeyer et al. (2004) based on data from 164 earthquakes in central Europe with original seismic moments was used by G&W03, who demonstrated its applicability to the local catalogues in central Europe. The positive feedback the authors received on this relation confirms its general usefulness in the seismological practice.

For the present study, the set could be expanded to 221 M_w-M_L data pairs, many of them filling the previous gap between $M_L = 3.5$ and 5. The new regression relation, assuming the same but unknown error in both magnitude types, reads (Fig. 2a):

$$M_w = 0.0376\, M_L^2 + 0.646\, M_L + 0.53 \qquad \sigma = 0.29 \ldots 0.34 \qquad (2)$$

The dependence of σ on M_L is given in Annex 4.

The new M_L data for Eq. (2) come primarily from earthquakes after 1993 and are combined mostly with M_w from Swiss Moment Tensor Solutions (2006). Some special studies also provide data for the regression. The shape of relation (2) is very similar to the previous equation, although due to the large covariance the parameters of the two equations are rather different. Since the relation between M_w and M_L is of key importance for our study, it is compared in Fig. 2b with our previous version. The difference is less than or about 0.1 for the range $M_L \geq 1$.

In the Herak et al. (1996) catalogue, which is used for several of the Balkan countries (see Annex 1), all magnitudes (not only M_L) are unreliable for events before 1908 according to M. Herak (2005, personal communication). Therefore, entries before 1908 are all based on intensities (Section 4.2) in our updated version.

The new M_w and M_L data in FENCAT (2007) fit excellently to Eq. (2). The standard deviation for the new data with respect to this equation is 0.31, which is in agreement with that for the regression data of Fig. 2a. Equation (2) is therefore applied also to FENCAT (2007) entries.

Since the M_L values of the French catalogue LDG (2005) are generally larger than those in other catalogues for the corresponding events, a regression of M_L from SZGRF (2007) on M_L from LDG (2005) was performed for French earthquakes yielding the relation below for $M_L < 4.65$ (Fig. 3). For larger magnitudes, the few available data do not seem to indicate a significant deviation between the two M_L sets:

$M_L[\text{calc}] = 1.310\ M_{L,LDG} - 1.44$
$\sigma = 0.40 \ldots 0.51$ for $M_L < 4.65$
$M_L[\text{calc}] = M_{L,LDG}$ for $M_L \geq 4.65$. (3)

Again the same but unknown error is assumed in all input values. The dependence of σ on M_L is given in Annex 4. Each equation is combined with Eq. (2) to give compatible M_w values for $M_{L,LDG}$ magnitudes.

The INGV (2007) catalogue gives M_L and/or M_d magnitudes for each event. We give M_L the higher priority. By comparing the M_L magnitudes with M_w from Swiss Moment Tensor Solutions (2006), there is an obvious systematic change in the M_L values from August 2001 on. The regression equation including only events since August 2001reads (Fig. 4a):

$M_w = 0.906\ M_L + 0.65 \quad \sigma = 0.21 \ldots 0.22,$ (4)

assuming the same error in all input values. The detailed σ-M_L dependence is given in Annex 4. Equation (4) is applied to INGV (2007) entries from August 2001 on.

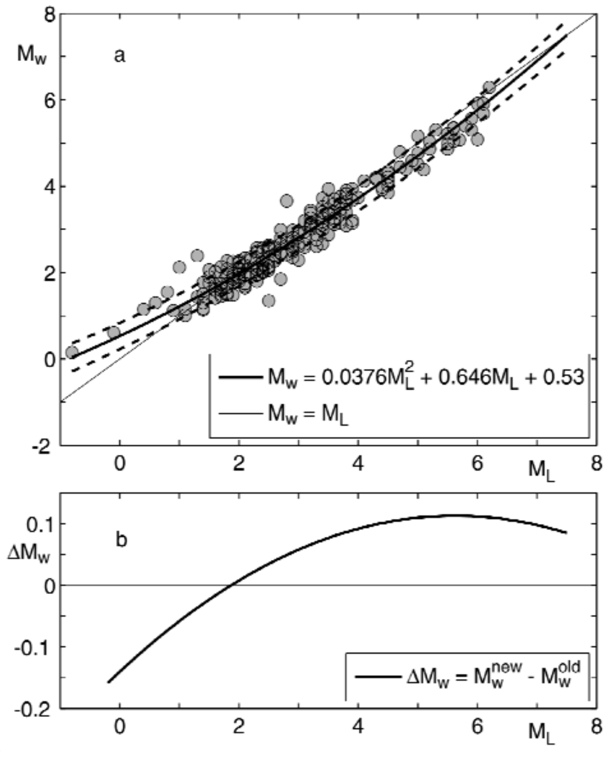

Fig. 2 **a)** The updated M_w-M_L relations for central Europe based on data in G&W03 extended by new data as explained in Section 4.1 (in total 221 data points; the *dashed lines* denote the 68% confidence bounds), Eq. 2; **b)** comparison of the new and old (G&W03) M_w-M_L relations

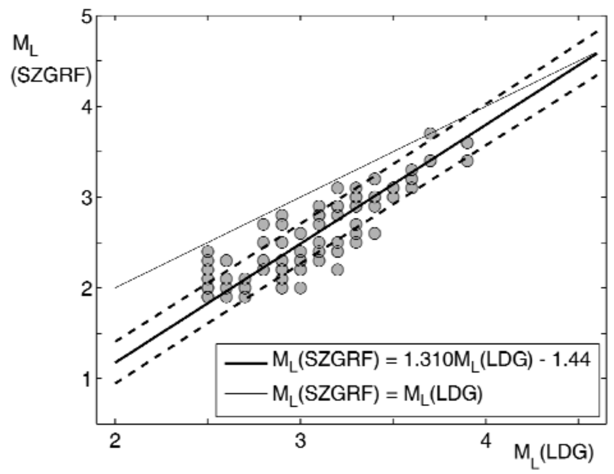

Fig. 3 Regression of M_L data from SZGRF (2007) vs. M_L data from LDG (2005) for earthquakes in France in 1994-2004 (93 data points), Eq. 3 for $M_L < 4.65$. For $M_L \geq 4.65$, M_L (SZGRF) = M_L (LDG) is set (the *dashed lines* denote the 68% confidence bounds)

4.2.2 M_w from M_S

For North Atlantic Ocean earthquakes, ISC data have been added to the previous data sets. Where M_w is given by ISC this is used, otherwise M_S. For M_S magnitudes from ISC and NEIC, a global transformation relationship derived from graphs by Utsu (2002) is applied:

$M_w = 10.85 - \text{SQRT}\ (73.74 - 8.38\ M_S).$ (5)

This equation is valid in the range of all our data, which does not exceed $M_S = 7$.

4.2.3 M_w from m_b

The Fennoscandian catalogue by Ahjos and Uski (1992) and its update called FENCAT (2007) both have m_b magnitudes for many events. For North Atlantic Ocean events, m_b from NEIC is used when M_S is not given (from G&W03). To calculate M_w from m_b in these catalogues, again a global transformation relationship based on graphs by Utsu (2002) was derived:

$M_w = 8.17 - \text{SQRT}\ (42.04 - 6.42\ m_b).$ (6)

This relation is valid for the range of all our data, which does not exceed $m_b = 6$.

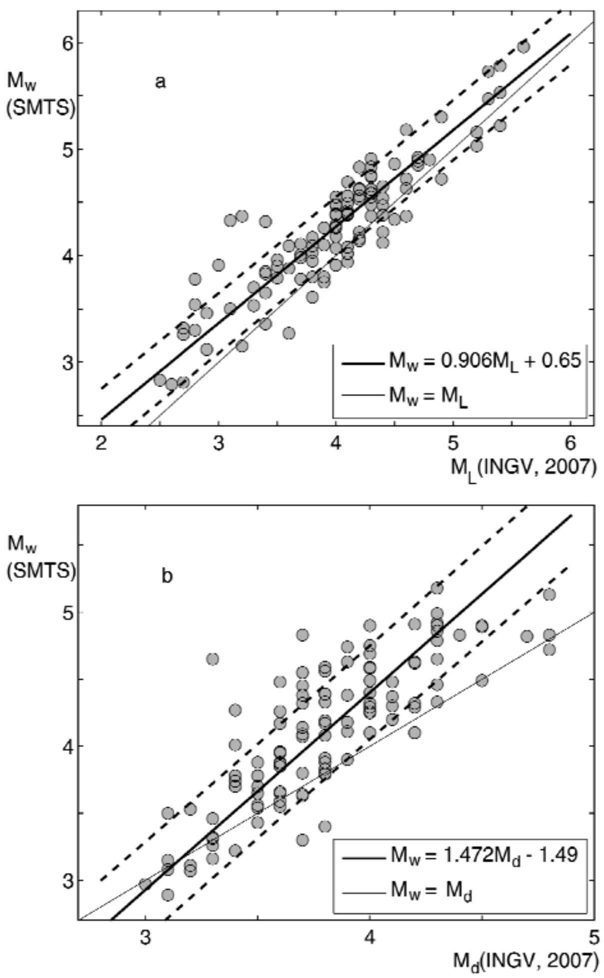

Fig. 4 Regressions of M_w data from Swiss Moment Tensor Solutions (2006) on INGV (2007) local magnitude data (M_L and M_d): **a)** M_w-M_L with data since August 2001 (110 data points), Eq. 4; b) M_w-M_d (119 data points), Eq. 7 (the *dashed lines* denote the 68% confidence bounds)

4.2.4 M_w from M_d

Like for Ahjos and Uski (1992), the new Fennoscandian catalogue, FENCAT (2007), assumes the duration magnitude to be equal to M_L except for offshore events, when it is not applied.

The INGV (2007) catalogue contains many entries where M_d is given as the only strength parameter. We have performed a regression of M_w from Swiss Moment Tensor Solutions (2006) on M_d from INGV (2007), with the result (Fig. 4b):

$$M_w = 1.472\ M_d - 1.49 \quad \sigma = 0.20 \ldots 0.22. \qquad (7)$$

This relation is valid for the range of all our data, which does not exceed $M_d = 4$. The same error has been assumed in all M_w and M_d values and the detailed dependence of σ on M_d is given in Annex 4. This equation is applied to INGV (2007) entries from August 2001 onward.

4.2.5 M_w from M_m

Besides M_L, Herak et al. (1996) also gives macroseismic magnitudes, M_m. We assume that these are calibrated to M_L, i.e.:

$$M_L = M_m \qquad (8)$$

and then apply Eq. (2). As mentioned above, magnitudes before 1908 are not trusted according to the local authors and therefore not used.

In other catalogues giving M_m, the intensity is also given and is the entity used for the M_w calculation.

4.3 Empirical relations between M_w and macroseismic parameters

Most of the catalogues use the epicentral or maximum intensity as the strength measure for their historical or pre-instrumental parts. In exceptional cases only isoseismals are given, which usually provide a good basis for the conversion to magnitudes. Another very useful macroseismic database for conversions into magnitude types are the sets of intensity data points IDP. However, also this type of information is lacking almost entirely for the $M_w \geq 3.5$ databases which are at our disposal for this project. As already described in G&W03, approaches based on individual intensity observation data to calculate M_w in general failed due to limitations in the direct transferability of such approaches.

We do not differentiate between intensities assigned according to different 12-degree scales. Different routines and subjective components in the evaluation of macroseismic data play a larger role than the differences between the scales.

The M_L vs. I_0 and h equation by Herak (1995, see Annex 5) is applied to all entries in the Herak et al. (1996) catalogue before 1908, the period when magnitudes are unreliable (see above), and to events as from 1908 where no M_L or M_m is given. The Herak et al. (1996) catalogue contains

I_0 or (exclusive) I_{max} for each felt event. Since many I_{max} values occur from epicentres on land, this relation is used for I_0 and I_{max}. The Herak (1995) equation is also now applied to the Živčić (1993) catalogue entries. Equation (2) is authorized for the subsequent transformation from M_L to M_w.

An attempt to lump together all the instrumental time data from the local catalogues to derive an M_L-I_0 relation resulted in a large scatter and was abandoned (G&W03). However, such a relation was successfully derived for each of the local catalogues for Austria, Belgium, Fennoscandia, Germany (Grünthal, 1988, 1991; Leydecker, 1986, 1996) and the Netherlands under the assumption that the M_L data have an error of 0.3 and intensities of 0.5 (only the ratio 3/5 controls the regression). Using only events with a focal depth of 5 km or larger, the error in the depth is negligible in the applied chi-square regression technique (see Stromeyer et al., 2004). The regression equations read:

Austria: $M_L = 0.787\ I_0 + 1.19 \log h - 1.44$
$\sigma = 0.36 \ldots 0.38,$ (9)

Belgium and The Netherlands:
$M_L = 0.696\ I_0 + 1.06 \log h - 0.60$
$\sigma = 0.48 \ldots 0.57,$ (10)

Fennoscandia:
$M_L = 0.848\ I_0 + 0.76 \log h - 1.41$
$\sigma = 0.44 \ldots 0.48,$ (11)

Germany: $M_L = 0.810\ I_0 + 0.49 \log h - 0.85$
$\sigma = 0.39 \ldots 0.44.$ (12)

For each equation, the detailed dependence of the prediction error σ of M_L on I_0 and h is given in Annex 4. The regressions are shown in Fig. 5. The data sets are from 1963 and later except for Austria where no magnitudes are reliable before 1991 (W. Lenhardt, 2006, personal communication).

Equations (11) and (12) were applied also to several catalogues of adjacent areas, as specified in Annex 5. Each of Eqs. (9), (10), (11) and (12) is combined with an M_w-M_L relation to calculate M_w (Annex 5).

For the other catalogues, existing local formulae are used to convert I_0 to M_L, if needed (some catalogues give magnitudes for all events). This applies to the catalogues below and the corresponding equations are given in Annex 5.

Herak's (1995) formula is applied to the Herak et al. (1996) and Živčić (1993) entries. The French relation by Levret et al. (1994) is applied to the SisFrance entries (BRGM-EDF-IRSN, 2008) and to the few entries in France from Fäh et al. (2003) used for the catalogue, under consideration of Eq. (3) for transformation to M_w.

The formula given by Zsíros (1983) is used for the conversion of entries in the Zsíros et al. (1990) and Zsíros (1994) catalogues. Again, Eq. (2) is used for the M_L to M_w conversion. Labak (1998) gives a relation to convert I_0 to M_S (Annex 5).

When calculating a magnitude from an intensity, a default value of 10 km is set for the focal depth if this is not given. This is valid for all relations, whether derived in this study – Eqs. (9), (10), (11) and (12) – or already existing.

5 Entries of the Catalogue

After the data selection and editing described above, the catalogue consists of about 8,000 tectonic earthquakes. They are the events inside the 22 polygons in the time period 1000-2004 with $M_w \geq 3.50$. The epicentres of the catalogue entries with classes of M_w are plotted in Fig. 6.

A histogram showing the event frequency in different magnitude classes is given in Fig. 7. This should not be interpreted as a magnitude-frequency distribution, since it does not consider the data completeness with time. The analysis of the completeness of the data with time is a separate complex problem and part of, e.g., probabilistic seismic hazard assessments (PSHA). The magnitude dependent data completeness is a function of cultural historical conditions, which, obviously, vary considerably over the study area of this catalogue. To provide the reader with an impression of the completeness of certain magnitudes, not yet published PSHA shows that for SW Germany $M_w = 3.5$ is complete since about 1825 and $M_w = 6$ since about 1250.

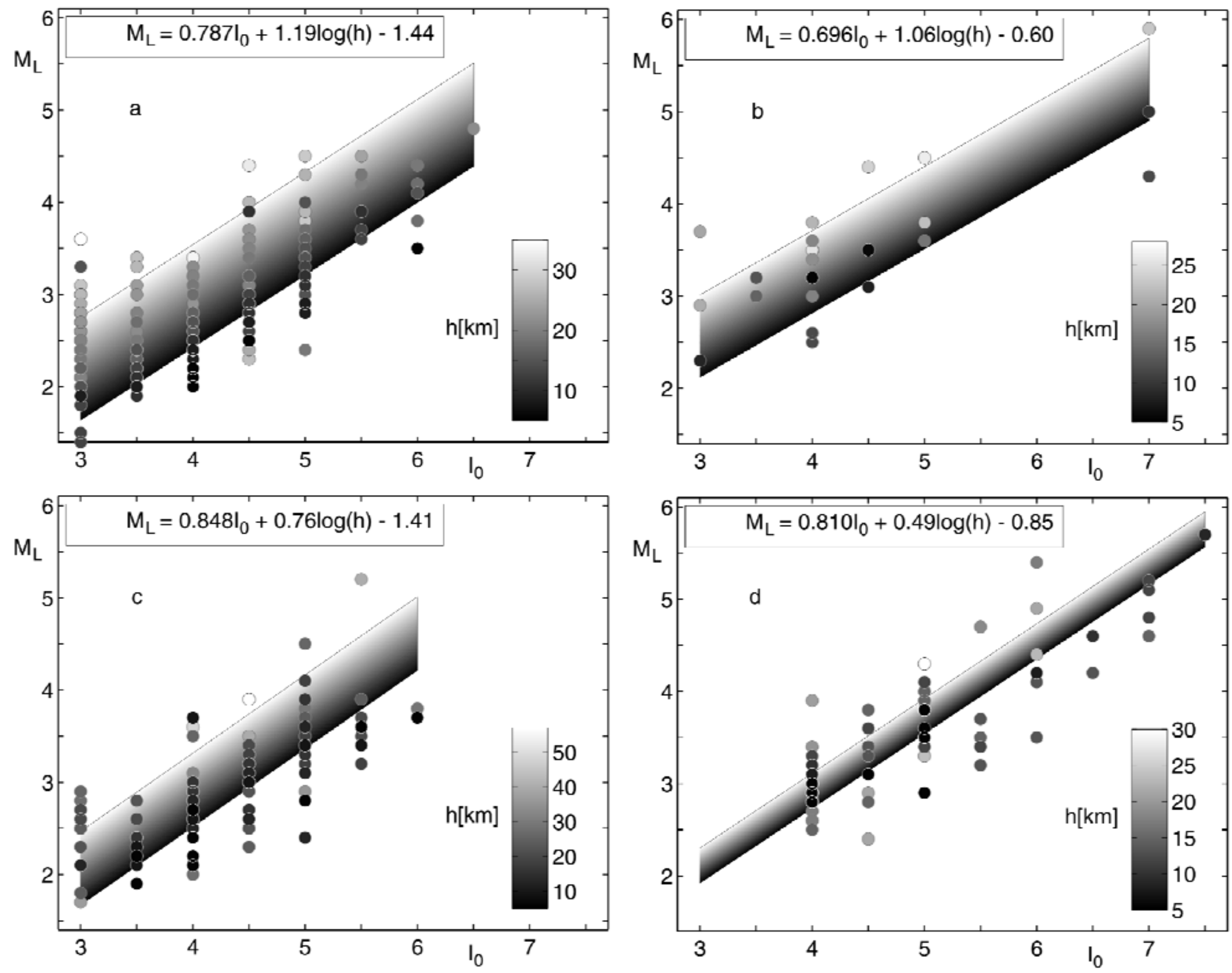

Fig. 5 Regression of M_L vs. I_0 and h for earthquakes in **a)** Austria (311 data points), **b)** Belgium and The Netherlands (27 data points), **c)** Fennoscandia (116 data points), and **d)** Germany (82 data points), Eqs. 9, 10, 11, and 12, respectively. The range of *grey colours* for the data points and regression lines refers to the range of source depths

The largest events (M_w) in different geological areas are shown in Table 1. Compared with G&W03, there are changes due to new references, or new magnitude transformation formulae and different cut-off magnitudes for the selection of events.

The catalogue is available under the doi:10.2312/GFZ.CENEC-2008 (electronic version of the seismicity database CENEC 2008 for Europe north of 44°N). The following information is given in the Catalogue:

- *Origin Time.* Year, month, day, hour and minute, specified to the smallest unit given by the original source. Time period 1000-2004. Generally, the original data have been kept, i.e., no attempt to standardize GMT and local times, Julian and Gregorian dates, etc. is made for the historical events. However, the different timings were checked with respect to duplets.
- *Location.* Epicentral coordinates and, if given, focal depth.
- *Intensity,* I_0. If given by the original source.
- *Magnitude,* M_w *with original magnitude entry* from which it has been calculated according to the scheme of Annex 5. No entry means calculated from intensity.
- *Reference.* The local catalogue (Annex 1) or special study (Annex 2). Only one reference is listed for each entry, although the parameters are sometimes taken from different sources, e.g., when not all parameters have been reassessed in a special study.

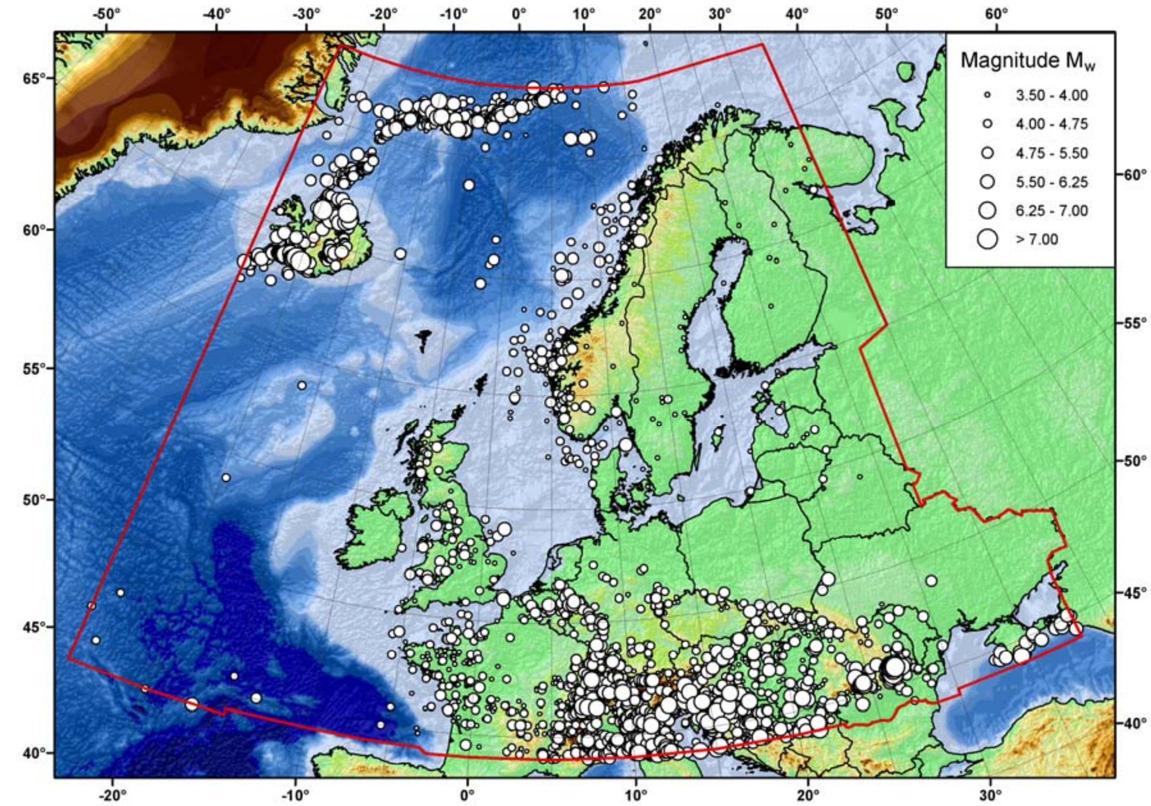

Fig. 6 Epicentres of the catalogue entries, about 8,000 events with $M_w \geq 3.50$ in the time period 1000-2004. The *red line* denotes the outer border of the polygons

Discussion and conclusions

It has been a long and non-trivial work to compile, edit, scrutinize and homogenize all the data in the large database and then to make the final selection of the entries for the catalogue. The elimination of entries concerns duplications and various types of fakes.

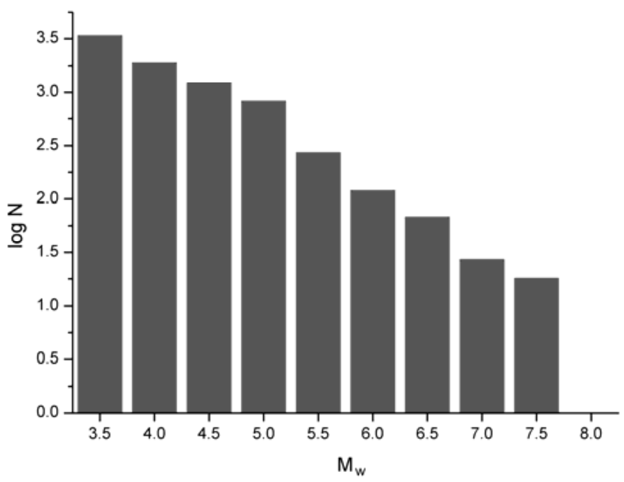

Fig. 7 Frequency of the earthquakes of the catalogue in half magnitude classes. The events in the polygon AOI are excluded

The new catalogue has some 8,000 entries, i.e., about 60% more than the old one. The main contributing factors to the increase are the inclusion of the time periods 1994-2004 (some 1700 events) and 1000-1299 (some 60 events), the extension of the area to the north and east (some 90 events), and above all the introduction of the many new data sources. On the other hand, a number of events in the previous catalogue have also been discarded as fakes or duplicates; especially the new Italian and Swiss catalogues are rigorous in this respect. There are also a few events which have had their location or magnitude changed in a way that they no more qualify for the catalogue; others have been shifted in time of the order of minutes, hours, days or months. A special case is made up by events where the date has been changed by 10-11 days (Julian to Gregorian calendar); especially Fäh et al. (2003) has converted many events from the old Swiss catalogue to the Gregorian time frame. We have been searching and identifying duplicates among entries of different catalogues

Table 1. The largest earthquakes (M_w) in different geological areas.

Area	year	mo	day	hr	lat N	lon E/W	M_w	I_0	ref	locality and country code	
Vrançea (since 1700)	1738	6	11	10	45.7	26.6	7.7	IX-X	Oncescu et al. (1999)		RO
	1802	10	26	10	45.7	26.6	7.9		Oncescu et al. (1999)		RO
	1838	1	23	18	45.7	26.6	7.5	IX	Oncescu et al. (1999)		RO
	1940	11	10	1	45.8	26.7	7.7	IX-X	Oncescu et al. (1999)		RO
	1977	3	4	19	45.8	26.8	7.4	IX	Oncescu et al. (1999)		RO
Alpine region	1201	5	4	10	46.9	13.5	6.6	IX	ZAMG (2007)	Katschberg region	A
	1348	1	25	17	46.5	13.5	6.8	X	Hammerl and Lenhard (1997)	Gemona	I
	1356	10	18	21	47.5	7.6	6.9	IX	ECOS (2006)	Basel	CH
	1511	3	26	14	46.2	13.4	6.9	IX	Fitzko et al. (2005)	Prov. Udine	I
	1695	2	25	5	45.8	12.0	6.6	IX-X	CPTI Working Group (2004)	Asolo	I
Variscian Europe	1382	5	21	14	51.3	2.0	5.9	VIII	Melville et al. (1996)	North Sea	UK
	1692	9	18	14	50.8	4.8	6.2	VIII	Alexandre et al. (2008)	Verviers	B
	1756	2	18	8	50.8	6.5	5.9	VIII	Meidow (1995, 2001)	Düren	D
	1878	8	26	9	50.9	6.6	5.7	VIII	Meidow (1995, 2001)	Tollhausen	D
	1911	11	16	21	48.2	9.0	5.7	VIII	Kunze (1986)	Albstadt	D
	1931	6	7	0	54.1	1.5	5.9		Musson (1994, 2006)	North Sea	UK
Fennoscandia	1759	12	22	0	57.7	11.1	5.6		FENCAT (2007)	Kattegat	DK/S
	1819	8	31	13	66.4	14.4	5.8	VII	FENCAT (2007)	Lurøy	N
	1866	3	9	1	65.2	6.0	5.7		FENCAT (2007)	Norwegian Sea	N
	1894	7	23	5	67.9	13.3	5.4	VII	FENCAT (2007)	Lofoten	N
	1904	10	23	10	59.2	10.5	5.4	VII	FENCAT (2007)	Oslo Fiord	N/S
North Atlantic Ocean and Iceland	1784	8	14	16	64.0	-20.5	7.1		IMO (2007a, b)	S Iceland	IS
	1910	1	22	7	66.5	-17.0	7.1		IMO (2007a, b)	N Iceland	IS
	1912	5	6	18	63.9	-20.0	7.0		IMO (2007a, b)	S Iceland	IS
	1951	6	6	16	71.3	-9.7	7.0		NEIC	Jan Mayen	N
	1963	3	28	0	66.3	-19.6	7.0		IMO (2007a, b)	N Iceland	IS

The Alpine region encompasses the polygons Italy, Switzerland, Austria, Slovenia, Croatia, Bosnia, Serbia, Hungary and Slovakia; Variscian Europe encompasses the polygons United Kingdom, the Netherlands, Belgium and Luxemburg, France and Germany; Fennoscandia encompasses the land and coastal areas inside the polygon Fennoscandia.

with 10-11 days time shift. However, different historical CENEC entries may refer to different calendars. Such minor time shifts in the historical time are irrelevant for seismic hazard assessments and seismicity studies. A file under the URL http://seismohazard.gfz-potsdam.de* shows (a) fake events of various kinds before 1800 and (b) questionable duplets before 1900. Especially for the latter list, detailed analysis in future projects may give clarifying information.

It is often hard to discriminate between probable and possible duplicates, even if a careful consideration of similarities and differences in time, location and intensity is made. In the most obvious cases, the duplicates in the database have been flagged and do not show up in the version made public. The rule has been to keep the multiple entries in suspicious but not convincing cases, which does not guarantee, however, that single "unique" entries for an event could occasionally have been deleted. It was beyond the scope of this study to provide an inventory of the original sources of such events in a Europe-wide frame.

A critical part of any catalogue compiled of data from different local sources is the harmonization of magnitudes. The G&W03 catalogue like the present one contains unified M_w magnitudes for all events, but an absolute harmonization can hardly be achieved. Further credibility in this respect is provided in the adjoining Grünthal et al. (2008) study. By extending the M_w-M_L relation for Central Europe also to Fennoscandia and eastern Central Europe, a further step towards a harmonization has been taken. For Fennoscandia, this has implied generally slightly higher M_w values. M_w values for Italy and Switzerland are among those which now are generally higher than in G&W03 due to the new respective catalogues.

In many statistical seismicity studies over smaller or larger areas, data from global catalogues like the ISC or NEIC bulletins are adapted. If these data were generally good, homogeneous, and had non-tectonic events separated, studies like the present one would be superfluous. It should not come as a surprise to the reader that this is not the case. A comparison was made between the entries in our database and those of ISC and NEIC, for a selection of areas and time intervals. Generally, ISC has a better coverage than NEIC and it would suffice to concentrate the comparison of our data to ISC. The findings are:

- For Belgium and The Netherlands, the local catalogues have slightly less events than ISC, but the local agency selection is likely more critical.
- There is a good correlation between our database and ISC for the United Kingdom.
- For Hungary and Slovakia, we made a more thorough comparison of the ISC data with our database for the period January to June 2004. There are hundreds of events within the area 46-50°N, 16-23°E, encompassing also parts of several neighbouring countries (see Fig. 1). Most events are from the Zedník (2005) catalogue, where in turn the vast majority likely are non-tectonic although this is not marked. We have considered this source unreliable for events outside the Czech Republic. For the specified time and space frames, we have 26 earthquakes in our databank. Only one of these has a magnitude, $M_w \geq 3.50$ and qualifies for the catalogue. 15 of these events are also given by ISC but only one of these (the event in our catalogue) has been reviewed (by ISC). Of the 18 events reviewed by ISC, on the other hand, 14 are mining induced. Three more are probable rockbursts according to the local sources used by us. Only the single event in our catalogue remains as an earthquake of all the ISC entries. It is obvious from this comparison that using the ISC catalogue we come across non-analyzed and erroneously discriminated (as to event type) entries and at the same time we miss a lot of earthquakes, let be of smaller size.

The quality of the ISC bulletin has proved to be very different in different parts of Europe. A further drawback of the ISC catalogue is that the different local magnitude scales (M_L or duration) are not harmonized. It is obvious that

* Following the link „Projects" and then „Earthquake catalogues".

continued scrutinized and edited data from local catalogues, especially in some areas, significantly improve the database and in practice are inevitable in order to create a reliable foundation for seismic hazard and seismicity studies.

In conclusion, the use and editing of the individual local catalogues are advantageous compared to a "blind" acceptance of the global databases. There is also no benefit in supplementing ISC and/or NEIC data where local catalogues exist. For our catalogue, data from ISC and NEIC have only been used where no domestic catalogue exists, i.e., for Atlantic Ocean events.

The catalogue will be useful for applications in many fields of seismicity and in seismic hazard assessment, especially in the case of large scale projects of probabilistic seismic hazard assessment. The update of the database, including a further temporal extension as well as a spatial extension to southern Europe and the Mediterranean area for larger magnitude events, is a continued effort, which will be undertaken also in the frame of ongoing European projects.

Acknowledgements We are very grateful to all the colleagues who have provided their data for its use on internet platforms or in form of publications. Special thanks to B. Feignier (LDG), M. Herak (Department of Geophysics, University of Zagreb), K. Klinge (BGR/SZGRF), J. Lambert (BGRM), R. Musson (BGS), M. Nicolas (LDG), Z. Schenková (IRSM), M. Uski (Institute of Seismology, University of Helsinki) and T. Zsíros (Seismological Observatory, Hungarian Academy of Science) with all of whom we were in personal contact about the local data. We are thankful for the support from Aon Re Global. The technical staff of our section contributed in various steps of the data processing.

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Annex 1 Local catalogues and associated polygons (cf. Annex 3 and Fig. 1).

Country/area of main application	Catalogue	Notation	Associated polygons
Austria	Lenhardt (1996), ZAMG (2007)	ZAMG, *ZAMG07*	Austria (A)
Belgium and Luxemburg	Verbeiren et al. (1995), ORB (2007)	ORB, *ORB07*	Belgium and Luxemburg (BL), Germany (D) - western part
Belorussia	Boborikin et al. (1993)	Bob	Belorussia (BY), Fennoscandia (FEN)
Croatia	Herak et al. (1996)	*HHM*	Croatia (CRO), Bosnia/Herzegovina (BIH), Slovenia (SLO), Serbia/Montenegro (YU)
Czech Republic	Schenková (1993),	*CAS*	Czech Republic (CZ), Poland (PL)
	Zedník (2005)	*GFU*	Czech Republic
Estonia	Nikonov (1992)	Nik	Fennoscandia
Fennoscandia	Ahjos and Uski (1992), FENCAT (2007)	FEN, *FEN07*	Fennoscandia, North Atlantic Ocean and Iceland (AOI)
Fennoscandia, southern part	Wahlström and Grünthal (1994)	WG	Fennoscandia
France	BRGM-EDF-IRSN (2008), LDG (2005)	*SisFrance, LDG*	France (F), United Kingdom (UK)
Germany	Grünthal (1988, 1991)	Gru, Gru91	Germany and adjacent area, inside 49.6°N-54.8°N, 9.5°E-15.5°E
	Leydecker (1986, 1996)	Ley, Ley96[a]	Germany outside 49.6°N-54.8°N, 9.5°E-15.5°E, Austria, France
	SZGRF (2006)	*GRF*	Germany, Austria, Czech Republic, Poland
Hungary	Zsíros et al. (1990), Zsíros (1994)	Zsi, Zsi94	Hungary (H), Ukraine (UA)
	Zsíros (1999), Tóth et al. (2006)	*Zsi99, Tot*	Hungary, Slovakia (SK), Ukraine
Iceland	IMO (2007a, b)	IMO, *IMO07*	North Atlantic Ocean and Iceland
Italy	CPTI Working Group (2004), INGV (2007)	*CPTI04, INGV*	Italy (I)
Netherlands	Houtgast (1995), KNMI (2006)	Hou, *KNMI*	Netherlands (NL)
Poland	Pagaczewski (1972)	Pag	Poland
	Guterch and Lewandowska-Marciniak (2002)	*GLM*	Poland, Czech Republic
Romania	Oncescu et al. (1999), INFP (2007)	Onc, *INFP*	Romania (RO), Moldavia (MD), Serbia/Montenegro, Ukraine
Slovakia	Labak (1998)	Lab	Slovakia
Slovenia	Živčić (1993)	ZivS	Slovenia
Switzerland	Fäh et al. (2003)	*ECOS*	Switzerland (CH), France (selected events), Germany – western part
	ECOS (2006)	*ECOS06*	Switzerland
United Kingdom	Musson (1994, 2006)	Mus, *Mus06*	United Kingdom
The former U.S.S.R. (selected areas)	Kondorskaya and Shebalin (1982)	KSh	Ukraine
	Kondorskaya and Ulomov	*KU*	Ukraine, Moldavia, Belorussia
Worldwide	ISC bulletins, NEIC bulletins	*ISC*, NEIC	North Atlantic Ocean and Iceland

New catalogues cf. to G&W03 are marked in italics.
In addition, Pondrelli et al. (2002, 2007) and Swiss Moment Tensor Solutions (2006) contribute M_w data for events in all Europe since 2000.
[a] Before 1982 Ley96 is given when the corresponding Ley entry is revised.

Annex 2 Special studies contributing to the catalogue.

Notation	Special study	Notation	Special study
Aho83	Ahorner (1983)	GruP	Grünthal, G., pers. comment
AhoP	Ahorner, L., pers. communication	GruRA	Grünthal, G., renewed analysis
Alx08	Alexandre et al. (2008)	GS01	Grünthal and Schwarz (2001)
Alx90[a]	Alexandre (1990)	Hin05	Hinzen (2005)
Alx94	Alexandre (1994)	HL97	Hammerl and Lenhardt (1997)
AP83	Ahorner and Pelzing (1983)	KMM57	Kárník et al. (1957)
AP85	Ahorner and Pelzing (1985)	Kun86	Kunze (1986)
Arv91	Arvidsson et al. (1991)	LenP	Lenhardt, W., pers. communication
AS04	Amstein and Schwarz (2004)	Mei01	Meidow (2001)
AWK92	Arvidsson et al. (1992)	Mei95	Meidow (1995)
Ben06	Benn et al. (2006)	Mel96	Melville et al. (1996)
Bon84	Bonamassa et al. (1984)	MG92	Meier and Grünthal (1992)
Cam94	Camelbeeck et al. (1994)	NG95	Neunhöfer and Grünthal (1995)
Car05	Cara et al. (2005)	OGS	OGS (2006)
EiG94	Eisinger and Gutdeutsch (1994)	PEM01	Pondrelli et al. (2001)
FG96	Fischer and Grünthal (1996)	Pet05	Pettenati et al. (2005)
FGS01	Fischer et al. (2001)	PHW94	Prinz et al. (1994)
Fit05	Fitzko et al. (2005)	Sch98	Schneider (1998)
GF00	Grünthal and Fischer (2000)	SchP	Schneider, G., pers. communication
GF02b	Grünthal and Fischer (2002)	SV87	Schneider and Vogt (1987)
GF98	Grünthal and Fischer (1998)	VG94	Vogt and Grünthal (1994)
GF99	Grünthal and Fischer (1999)	Vog91	Vogt (1991)
GFV99	Grünthal et al. (1999b)	Vog93a	Vogt (1993a)
GHK99	Gutdeutsch et al. (1999)	Vog93b	Vogt (1993b)
GM95	Grünthal and Meier (1995)	VogP	Vogt, J., pers. communication
Gru05	Grünthal (2005)	ZsiP	Zsíros, T., pers. communication
Gru08	Grünthal et al. (2008)		

[a] From this reference only selected mapped events are included and assigned I_0 = V-VI, corresponding to M_w = 3.8, if no intensity is given.

Annex 3 Polygons and the hierarchy (left to right) of local catalogues to which they are associated for different time periods.

Polygon	Country/area	Time period	Local catalogue
A	Austria	-1981	ZAMG, Ley
		1982-1993	ZAMG
		1994-1995	ZAMG, GRF
		1996-1999	GRF
		2000-2004	ZAMG07
AOI	North Atlantic Ocean and Iceland	-1990	IMO, ISC, NEIC, FEN07, FEN
		1991-July 2003	IMO07, ISC, FEN07
		Aug. 2003-2004	IMO07, FEN07
BIH	Bosnia/Herzegovina	-2004	HHM
BL	Belgium and Luxemburg	-1984	ORB07, ORB
		1985-2004	ORB07
BY	Belorussia	-1988	Bob
CH	Switzerland	-2000	ECOS
		2001-2004	ECOS06
CRO	Croatia	-2004	HHM
CZ	Czech Republic	-1984	CAS, GLM, Gru[a]
		1985-1991	Gru91[a]
		1992-2004	GFU
D	Germany inside the area 49.6°N-54.8°N, 9.5°E-15.5°E	-1984	Gru
D	Germany outside the area 49.6°N-54.8°N, 9.5°E-15.5°E	-1981	Ley/Ley96, ORB07, ORB, ECOS
		1982-1993	Ley96
		1994-2004	GRF
F	France	-1961	SisFrance, Ley/Ley96, ECOS[b]
		1962-2003	LDG, SisFrance
		2004	LDG
FEN	Fennoscandia, Balticum, Kola Peninsula and adjacent waters	-1984	WG, Nik, Bob, FEN07, FEN
		1985-1991	FEN07, FEN
		1992-2004	FEN07
H	Hungary	-1986	Zsi
		1987-1994	Zsi94
		1995-1999	Zsi99
		2000-2004	Tot
I	Italy	-2001, July	CPTI04
		2001, Aug.-2004	INGV
MD	Moldavia	-1995	KU
NL	Netherlands	-1993	Hou
		1994-2004	KNMI
PL	Poland	-1482	Pag
		1483-1995	GLM
		1996-2004	GRF
RO	Romania	-1998, Sep.	Onc
		1998, Oct.-2004	INFP
SK	Slovakia	-1994	Lab

Annex 3 (continued)

Polygon	Country/area	Time period	Local catalogue
		2000-2004	Tot
SLO	Slovenia	-1981 1982-2004	ZivS, HHM HHM
UA	Ukraine	-1974 1975-1986 1987-1995 1998, Oct.- 2004	KU, KSh, Zsi, Onc KU, Zsi KU INFP
UK	United Kingdom and adjacent waters	-1961 1962-1993 1994-2004	Mus, SisFrance Mus, LDG Mus06, LDG
YU	Serbia/Montenegro	-1998, Sep. 1998, Oct.-2004	Onc, HHM INFP, HHM

Missing time periods have been inspected but lack entries. Special studies usually have preference over the local catalogues.

[a] Part of polygon inside the area 49.6°N-54.8°N, 9.5°E-15.5°E (with first priority).

[b] Selected events.

Annex 4 Full error equations for the regressions of this study ($\sigma \approx$ 68% prediction error).

Eq. no.	Error range (σ)	Error equation
1	0.43 - 0.61	$\sigma^2 = (3.16\ M_{w,IMO07}^2 - 28.3\ M_{w,IMO07} + 80.9) \times 10^{-2}$
2	0.29 - 0.34	$\sigma^2 = (0.97\ M_L^4 - 12.4 M_L^3 + 58.4 M_L^2 - 120 M_L + 921) \times 10^{-4}$
3	0.40 - 0.51	$\sigma^2 = (0.44\ M_{L,LDG}^2 - 2.71\ M_{L,LDG} + 8.98) \times 10^{-2}$
4	0.21 - 0.22	$\sigma^2 = (0.17\ M_L^2 - 1.39 M_L + 10.53) \times 10^{-2}$
7	0.20 - 0.22	$\sigma^2 = (0.88\ M_d^2 - 6.72 M_d + 25.04) \times 10^{-2}$
9	0.36 - 0.38	$\sigma^2 = (11.2\ I_0^2 + 0.761\ I_0 \log h + 127\ \log^2 h - 87.7\ I_0 - 242\ \log h + 1611) \times 10^{-4}$
10	0.48 - 0.57	$\sigma^2 = (8.57 \cdot I_0^2 - 3.01 \cdot I_0 \log h + 141.4 \cdot \log^2 h - 71 \cdot I_0 - 273 \cdot \log h + 525) \times \cdot 10^{-3}$
11	0.44 - 0.48	$\sigma^2 = (4.74\ I_0^2 - 1.26 I_0 \log h + 44.4\ \log^2 h - 39.2\ I_0 - 82.9\ \log h + 317) \times 10^{-3}$
12	0.39 - 0.44	$\sigma^2 = (2.82\ I_0^2 + 3.99\ I_0 \log h + 57.2\ \log^2 h - 31.1\ I_0 - 132\ \log h + 293) \times 10^{-3}$

Annex 5 Algorithms for calculation of M_w for the different local catalogues. Originally given M_w (or M_0) values, and derived M_w values from entries in special studies, usually have the highest priority. The equations refer to Section 4, and full equations are quoted from Grünthal and Wahlström (2003a) /G&W03/ or another study. The focal depth, h, is in km and the default value is 10 km.

Catalogue	Priority	Origial size entity	Algorithm	Reference	Comment
Lenhardt (1996), ZAMG (2007)	1	M_L	Eq. (2)		M_L not used before 1991 (Section 4.2)
	2	I_0	Eq. (9) + Eq. (2)		
Verbeiren et al. (1995), ORB (2007)	1	M_L	Eq. (2)		
	2	I_0	Eq. (10) + Eq. (2)		
Boborikin et al. (1993)	1	I_0	Eq. (11) + Eq. (2)		
Herak et al. (1996)	1	M_L	Eq. (2)		Original M_L and M_m used only from 1908 on (Section 4.1)
	2	M_m	Eq. (8) + Eq. (2)		
	3	I_0	$M_L = 0.72\ I_0 + 1.28\ \log h - 1.13$ (standard errors of estimates = 0.38 for M_L, 0.53 for I_0 and 0.30 for $\log h$) + Eq. (2)	Herak (1995)	
	4	I_{max}	$I_0 = I_{max}$ + treat like I_0	Section 4.2	
Schenková (1993)	1	M_L	Eq. (2)		
	2	I_0	Eq. (12) + Eq. (2)		
Zedník (2005)	1	M_L	Eq. (2)		
	2	I_0	Eq. (12) + Eq. (2)		
Nikonov (1992)	1	I_0	Eq. (11) + Eq. (2)		
Ahjos and Uski (1992), FENCAT (2007)	1	M_L	Eq. (2)		
	2	M_S	$M_w = M_S$	GW03	
	3	m_b	Eq. (6)		
	4	I_0	Eq. (11) + Eq. (2)		
	5	M_d	$M_L = M_d$ + Eq. (2)	GW03	M_d not used for offshore events and reference PAN events
Wahlström and Grünthal (1994)	1	M_L	Eq. (2)		
	2	I_0	Eq. (11) + Eq. (2)		
BRGM-EDF-IRSN (2008)	1	I_0	$M_L = 0.44\ I_0 + 1.48\ \log h + 0.48$ + Eq. (3) + Eq. (2)	Levret et al. (1994)	
LDG (2005)	1	M_L	Eq. (3) + Eq. (2)		
Grünthal (1988)	1	M_L	Eq. (2)		
	2	I_0	Eq. (12) + Eq. (2)		
Grünthal (1991)	1	M_L	Eq. (2)		

Annex 5 (continued)

Catalogue	Priority	Origial size entity	Algorithm	Reference	Comment
Leydecker (1986, 1996)	1	M_L	Eq. (2)		
	2	I_0	Eq. (12) + Eq. (2)		
SZGRF (2007)	1	M_L	Eq. (2)		
Zsíros et al. (1990), Zsíros (1994)	1	M_L	Eq. (2)		
	2	I_0	$M_L = 0.6\ I_0 + 1.8$ logh - 1.0 + Eq. (2)	Zsíros (1983) after Gutenberg and Richter (1942); Zsíros, personal communication	
Zsíros (1999), Tóth et al. (2006)	1	M_L	Eq. (2)		
IMO (2007a)	1	M_L	$\log M_0 = 17.5 + 1.3\ M_L$ + $2/3 \log M_0 - 10.7$	Agustsson, personal communication; Hanks and Kanamori (1979)	
IMO (2007b)	1	$M_{w,IMO07}$	Eq. (1)		
CPTI Working Group (2004)					M_w given
INGV (2007)	1	M_L	Eq. (4)		
	2	M_d	Eq. (7)		
Houtgast (1995)	1	M_L	Eq. (2)		
	2	I_0	Eq. (10) + Eq. (2)		
KNMI (2006)	1	M_L	Eq. (2)		
Pagaczewski (1972)	1	I_0	Eq. (12) + Eq. (2)		
Guterch and Lewandowska-Marciniak (2002)	1	M_L	Eq. (2)		
	2	I_0	Eq. (12) + Eq. (2)		
Oncescu et al. (1999), INFP (2007)					M_w given
Labak (1998)	1	M_L	Eq. (2)		Labak (1998) applies different formulae for different geographical subregions – see G&W03 for details
	1	M_S	$M_w = M_S$	G&W03	
	2	I_0	$M_S = 0.55\ I_0 + 0.95$ + $M_w = M_S$	Labak (1998); G&W03	
Živčić (1993)	2	I_0	$M_L = 0.72\ I_0 + 1.28 \log h - 1.13$ + Eq. (2)	Herak (1995)	
Fäh et al. (2003) for Switzerland ECOS (2006) for Switzerland					M_w given
Fäh et al. (2003) for France (selected events)	1	I_0	$M_L = 0.44\ I_0 + 1.48 \log h + 0.48$ + Eq. (3) + Eq. (2)	Levret et al. (1994)	

Annex 5 (continued)

Catalogue	Priority	Original size entity	Algorithm	Reference	Comment
Fäh et al. (2003) for Germany	1	I_0	Eq. (12) + Eq. (2)		
	2	M_L	Eq. (2)		
Musson (1994, 2006)	1	M_L	Eq. (2)		
Kondorskaya and Shebalin (1982)	1	I_0	Eq. (11) + Eq. (2)		
Kondorskaya and Ulomov (1999)					M_w given
ISC bulletins	1	M_S	Eq. (5)		
NEIC bulletins	1	M_S	Eq. (5)		
	2	m_b	Eq. (6)		