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The European-Mediterranean Earthquake Catalogue (EMEC) for the last millennium

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Abstract The catalogue by *Grünthal et al.* (J Seismol 13:517–541, 2009a) of earthquakes in central, northern, and north-western Europe with $M_w \geq 3.5$ (CENEC) has been expanded to cover also southern Europe and the Mediterranean area. It has also been extended in time (1000-2006). Due to the strongly increased seismicity in the new area, the threshold for events south of the latitude 44°N has here been set at $M_w \geq 4.0$, keeping the lower threshold in the northern catalogue part. This part has been updated with data from new and revised national and regional catalogues. The new Euro-Mediterranean Earthquake Catalogue (EMEC) is based on data from some 80 domestic catalogues and data files and over 100 special studies. Available original M_w and M_0 data have been introduced. The analysis largely followed the lines of the *Grünthal et al.* (J Seismol 13:517–541, 2009a) study, i.e., fake and duplicate events were identified and removed, polygons were specified within each of which one or more of the catalogues or data files have validity, and existing magnitudes and intensities were converted to M_w. Algorithms to compute M_w are based on relations provided locally, or more commonly on those derived by *Grünthal et al.* (J Seismol 13:517–541, 2009a) or in the present study. The homogeneity of EMEC with respect to M_w for the different constituents was investigated and improved where feasible. EMEC contains entries of some 45,000 earthquakes. For each event, the date, time, location (including focal depth if available), intensity I_0 (if given in the original catalogue), magnitude M_w (with uncertainty when given), and source (catalogue or special study) are presented. Besides the main EMEC catalogue, large events before year 1000 in the SE part of the investigated area and fake events, respectively, are given in separate lists.

Keywords Earthquake catalogue • European Mediterranean region • Unified moment magnitude

1 Introduction

A homogeneous earthquake catalogue with harmonized moment magnitude data with sufficiently low thresholds covering the European-Mediterranean area and long historical time spans up to recent times has been lacking so far. The earthquake catalogue presented here fills this gap. It covers the western part of the Eurasian plate with the seismically highly active plate boundaries, including the Mid-Atlantic ridge down to the Azores, extends in the south to Africa north of the Sahara, in the north to the Arctic Sea, and in the east to the Levant, eastern Turkey, and the Caucasus. This areal coverage gave the name to the catalogue: EMEC - The European-Mediterranean Earthquake Catalogue.

EMEC represents the spatial and temporal extension of CENEC, the unified catalogue of earthquakes in central, northern, and north-western Europe with a threshold of $M_w = 3.5$ (*Grünthal et al.* 2009a, denoted *GWS09* below), which in turn was an improvement, and expansion in time and space, of the *Grünthal and Wahlström* (2003) catalogue. While CENEC has a southern and western extension to 44°N and 25°W, EMEC goes far beyond these spatial limitations. Temporally CENEC covers about one millennium, i.e., from AD 1000 up to 2004, although for some regions, notably and obviously

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the Atlantic Ocean, the time period of data is significantly shorter. EMEC starts generally also in AD 1000 and extends up to 2006. In certain parts of the central and eastern Mediterranean region, the data allow a start earlier than 1000. Thus earthquakes in the studied area in the years 300-999, located south of latitude 40°N and east of 10°E, and with magnitude $M_w \geq 6.0$, are included in a special file. For several of the domestic catalogues used in CENEC, we could make use of their new versions.

As a suitable magnitude threshold, $M_w = 4.0$ has been chosen for the new area, considering the generally much higher seismic activity. Still a few catalogues and special studies have thresholds above 4. The threshold for the northern part, latitude 44°N and above, remains $M_w = 3.5$ as in *GWS09*. Difficulties in the catalogue preparation began already in accessing several of the catalogues. The conversion of the different strength types in the many catalogues and special studies to M_w was challenging. Special studies denote specific publications with respect to a particular or several earthquakes and usually contain more precise data than the catalogues show. The conversions to M_w were based on local relations or on regressions developed by *GWS09* or in the present study. Although all the area, i.e., the part covered by CENEC and the new extended part, is investigated in a similar way, the description of the analysis is given in more detail for the new, southern part.

As in the previous study, all original data from the different sources were incorporated into a database, including not only tectonic earthquakes but also induced events, explosions, and suspected other non-seismic events of different kinds. A more elaborate technique than described by *Grünthal and Wahlström* (2003) has been applied for the event type discrimination and is described in Chapter 6. The EMEC catalogue is an excerpt from the database of tectonic earthquakes starting in year 1000 or in a limited area even earlier, located within the polygons covering the described area (Chapter 2), and with M_w magnitudes above the specified respective thresholds. If more than one catalogue lists an event, a priority algorithm, described in Chapter 2, decides which entry has been selected for EMEC. EMEC contains about 45,000 earthquakes.

The efforts to generate a homogeneous earthquake catalogue have been concentrated on the harmonization of magnitudes, since no uniform reference system exists for this parameter. There are not only different types of magnitudes, but moreover quite different approaches how, e.g., M_L was/is determined throughout the Euro-Med region, countries or agencies. The other parameters to describe an earthquake are date/time, epicentral location, and depth. Differences in the entries from the Julian and the Gregorian calendars have been carefully observed to avoid duplications. So have different local times used by different sources in some cases. However, the time of the preferred entry has been kept. The precision of timing is decreasing towards historical periods. The exact timing of a millennium of data is not of utmost importance in seismicity studies. An extensive search for fake events includes, besides identifying non-seismic events, corrections of time and location where needed. Besides this, the harmonization is focussed on magnitudes (M_w). A special chapter is dedicated to the uncertainty of parameters.

The completeness of events is homogeneous for certain time periods only. The completeness is not only depending on the magnitude but also substantially vary from region to region. Although the completeness analysis is not part of earthquake cataloguing this issue is attended to in Section 10.

EMEC and its earlier versions have already been the basis for a number of European or regional research projects. To these belong (1) the probabilistic assessment of the tsunami hazard for the coastal regions of the Mediterranean (*Sørensen et al.* 2012) as part of the European project TRANSFER, (2) the probabilistic seismic hazard assessments (PSHA) for Europe in the frame of the project NERIES as a new hybrid zoneless approach (*Chan and Grünthal* 2010), (3) the time-independent and the long-term time-dependent PSHA for the Levant (*Grünthal et al.* 2009c), and (4) the generation of a preliminary European earthquake model for the public private partnership project GEM (*Grünthal et al.* 2010). A version of EMEC representing an earlier processing status has been made available for the European PSHA project SHARE, namely 18,996 events in the time period 1900-2006, representing > 78% of the total number of events used for this project (cf. Chapter 3.2).

2 The catalogues, special studies, and polygons

Most European countries started compiling their own national electronic earthquake bulletins in the late 1970s and early 1980s, when appropriate computer techniques became available. They were often supplied as printed earthquake lists and/or computer files, and were and are subject to regular or sporadic updates. The some 80 catalogues contributing data to EMEC, as well as the ISC/ISS (below referred to as ISC only) and NEIC bulletins used mostly for part of the Atlantic Ocean, are listed in Table 1. The characteristics of the contributing catalogues are described below.

Special studies on individual earthquakes, earthquake sequences or the seismic activity in more lim-

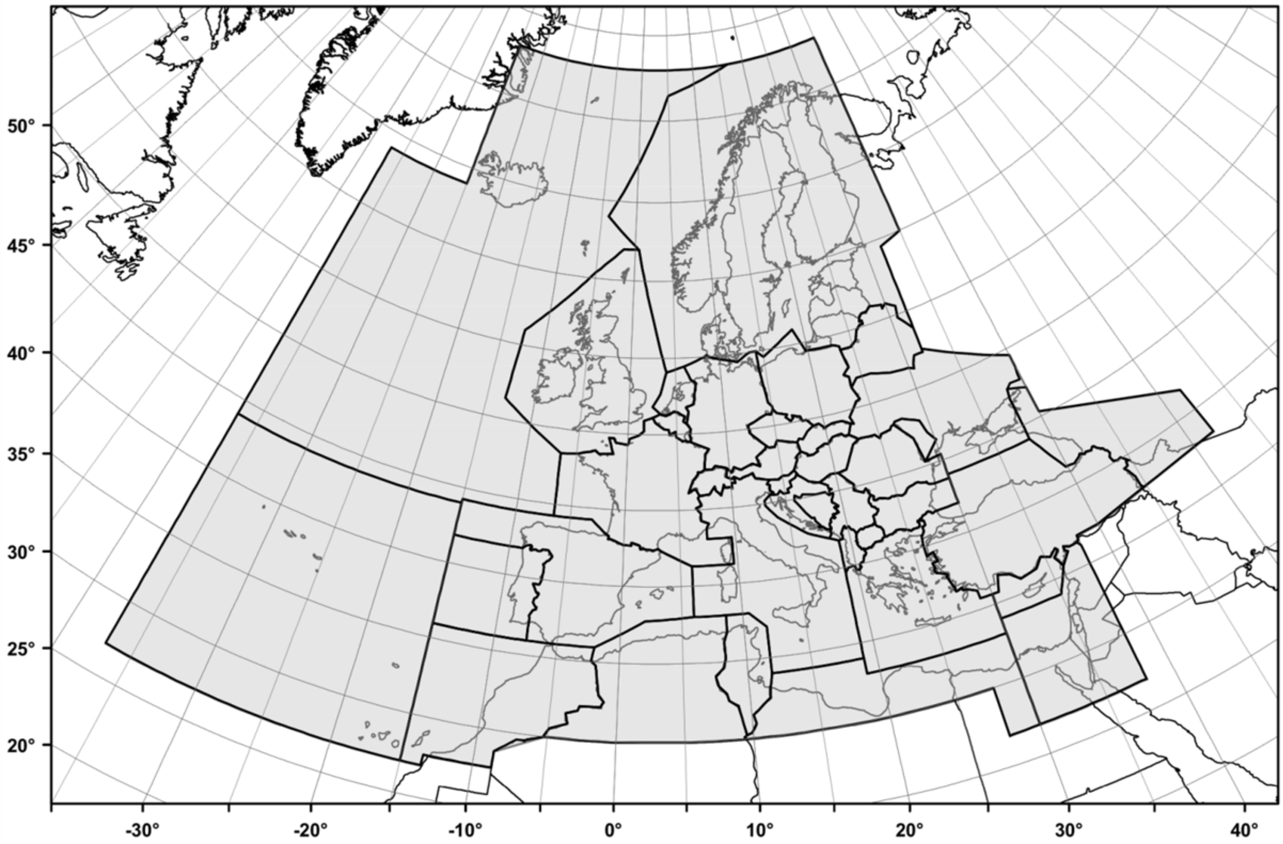

Figure 1. The polygons used for the generation of EMEC. Within each polygon, a certain hierarchy of local catalogues is valid. For details, we refer to the text.

ited geographical areas and time spans give improved and sometimes extended information. The special studies are listed in Table 2.

The investigated area was subdivided into 37 polygons (Table 3; Fig. 1). These are geographical regions which often follow national borders within which respective domestic catalogues have a priority position. Compared to the *GWS09* study, five polygons, which were cut at 44°N latitude, Bosnia/Herzegovina, Croatia, France, Italy, and Serbia/Montenegro, were now extended to cover larger areas. The North Atlantic and Iceland polygon has been extended westward to encompass all the ridge.

Each catalogue has validity in one or more polygons (see Table 1). In each polygon, data from one or more of the catalogues are allowed according to a hierarchy schedule, which can differ for different time periods depending on the span and reliability of the data sets (Table 3). There are many entries in the data file which do not qualify for the catalogue due to the criteria specified in Table 3. Almost all such entries are duplicated by those in allowed catalogues or in special studies. The latter usually have priority over the catalogues.

Exceptions from the catalogue-polygon assignments have been made for events near polygon borders, notably where an entry of catalogue C1 valid in polygon P1 occurs in polygon P2, whereas an entry for the same event of catalogue C2 valid in polygon P2 occurs in polygon P1. In this case, one of the entries C1 or C2 is allowed. The most notable of these cases is described in Table 3.

In the search for duplicates, special attention was paid to (1) events with entries in more than one polygon, (2) differences between universal and local time (up to several hours), and (3) differences between the Julian and the Gregorian calendars (10 to 12 days) for historical earthquakes. Other data cleaning tasks were performed similarly to *Grünthal and Wahlström* (2003) and *GWS09*.

For several applications of the catalogue, it may be useful to consider also significant earthquakes before the principal starting year of EMEC. These are especially earthquakes within the highest magnitude classes of certain regions. We consider here events before year 1000 in the Aegean region, Cyprus, Sicily, and the Levant.

3 The southern extension of the CENEC area

The EMEC catalogue is, as its forerunners, consistently based on unified M_w magnitudes. Where M_w data are not given in the catalogues, they had to be derived. Irrespective of the magnitude threshold of any individual catalogue, $M_w = 4.0$ is the lower cut-off for events appearing in the southern part of EMEC, i.e., at latitudes south of 44°N.

3.1 Catalogues based entirely on moment tensor solutions

The backbone for the M_w harmonization are two European data sets based entirely on moment tensor solutions – here called the original M_w. These are the European-Mediterranean Regional Centroid Moment Tensor Solutions (RCMTS) by *Pondrelli et al.* (2002, 2004, 2007, 2011) from 1997 and on, and the Swiss Moment Tensor Solutions (SMTS) from 1999 and on. These M_w magnitudes have highest priority for the most modern part of EMEC (since 1997) and are the basis for harmonization checks. They have been combined with the other parameters of the catalogue. SMTS rank before RCMTS. The two data sets are fully compatible as illustrated in Fig. 2. Harvard Central Moment Tensor Solutions (HCMTS) provide M_w magnitudes to many ISC bulletins events and are therefore introduced for the Mid-Atlantic ridge. HCMTS are also congruent with RCMTS and SMTS data.

3.2 National and regional catalogues in terms of M_w

Several of the national and regional catalogues give M_w magnitudes for all events, namely (countrywise alphabetically following Table 1) *Hamdache et al.* (2010) for Algeria, *Papaioannou* (2001) for the eastern Mediterranean area, *Papazachos et al.* (2003, 2009) and *Roumelioti et al.* (2010, 2011) for Greece, *Martínez Solares* (2003) and *Stich et al.* (2010) for Iberia, *CPTI Working Group* (2004, 2008) for Italy, *Peláez et al.* (2007) for Morocco, *Oncescu et al.* (1999) and *INFP* (2009) for Romania, *Turkish GSHAP catalogue* (2000), *Ambraseys* (2002), and *Kalafat et al.* (2009, 2010) for Turkey, and *Kondorskaya and Ulomov* (1999) for areas of the former USSR. There are also M_w for events from IGN starting in 2004 taken from the EMSC webpage - see Section 3.3. All these sources provide data for the surroundings of the main cataloguing regions as well and have often been used for EMEC also there (see Table 1). Sporadic M_w magnitudes are also given by the ISC bulletins, which are applied for the areas in the Atlantic Ocean, and as supplementary source also, e.g., in the south-eastern Mediterranean. The degree of harmonization in M_w reached by these catalogues is not always sufficient. This is discussed in Chapter 7.

From the *Hamdache et al.* (2010) file, several longitudes (E instead of W) have been corrected. For the project SHARE (cf. Chapter 1), it was agreed to use data from the University of Athens by K. Makropoulos for Greece instead of those mentioned above. These data are not publicly available and therefore not used for EMEC. Their number encompass only approximately one third of that from the sources we used here. *Ambraseys* (2002) gives M_0, from which M_w is calculated with the *Hanks and Kanamori* (1979) relation. The two Italian catalogues, except for the limited region mentioned below, are restricted to presumed main shocks with $M_w \geq 4$. At least for the older events, the M_w values in the catalogues were assigned by local transformation relations. For modern time data, original M_w from RCMTS and SMTS were compared with each of the M_w sets above which have corresponding data. The outcome is shown in Section 7.1.

Hamdache et al. (2010) provide data for the whole period of the EMEC catalogue. *Papaioannou* (2001) covers 1896-1980, *Papazachos et al.* (2003) up to 1999, *Papazachos et al.* (2009) since 2000, *Roumelioti et al.* (2010) since1969, *Roumelioti et al.* (2011) in 2006, *Martínez Solares* (2003) 1396–1899, and *Stich et al.* (2010) since 2005. The *CPTI Working Group* (2004, 2008) catalogues give data for Italian earthquakes up to 2002 and 2006, respectively. In the time period 1000-1900, *CPTI Working Group* (2008) give data only in a region of central Italy (see Table 3) and *CPTI Working Group* (2004) were used only outside this region. After 1900, the *CPTI Working Group* (2008) data were used, and since August 2001 also *INGV* (2007) (see Section

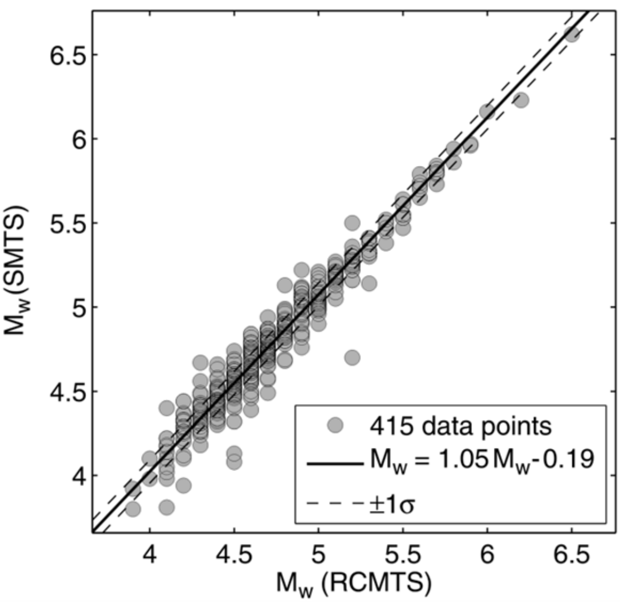

Figure 2. Comparison of M_w of the Swiss Moment Tensor Solutions (SMTS) with M_w from the European-Mediterranean Regional Centroid Moment Tensor Solutions (RCMTS) by *Pondrelli et al.* (2002, 2004, 2007, 2011).

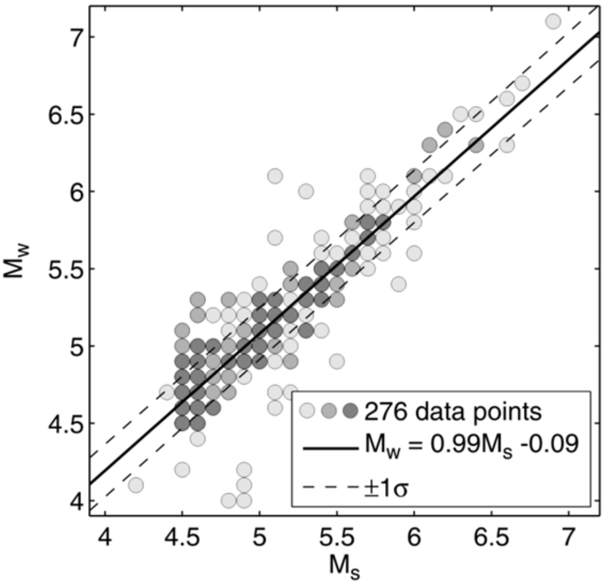

Figure 3. Comparison of M_w from *Papazachos et al.* (2003) vs. M_S from *Sulstarova et al.* (2000). The different grey-shading symbols represent, with increasing darkness, one, two, and three or more data points.

3.3). The *Peláez et al.* (2007) catalogue was used for the time interval 1045-1799 and *Oncescu et al.* (1999) cover the time period up to October 1998, when it is continued by *INFP* (2009). The *Turkish GSHAP catalogue* (2000) has data up to 1999. It has strong similarities to *Papazachos et al.* (2003) for the events west of longitude 30.5°E and we applied it only for Turkey east of 30.5°E up to 1899. The *Ambraseys* (2002) catalogue gives data up to 1999, the *Kalafat et al.* (2010) catalogue for the years 1900-2005, and for 2006 the data were from *Kalafat et al.* (2009). Finally, *Kondorskaya and Ulomov* (1999) provide data up to 1995.

3.3 National and regional catalogues requiring conversion to M_w

M_w is not given for the vast majority of the national and regional catalogues, nor for many special studies. Therefore, M_w has to be derived from other strength measures. The derivation for the different catalogues and special studies is described below. The validity ranges for all derived and used relations are congruent with the data to which they are applied, with only a few data marginally outside the ranges. An exception is the Icelandic catalogues - see Section 7.1.

The algorithms for the calculation of M_w and the hierarchy of strength types from which it is calculated are shown in Table 4. As seen in Table 4, magnitude data have priority over intensity data, but special attention is paid to the historical earthquakes, where often only the intensity is given. So, the *Glavcheva* (2004) and *BRGM-EDF-IRSN* (2010) catalogues for Bulgaria and France, respectively, and the *Guidoboni and Comastri* (2005) catalogue contain intensities only.

The transformation relations to M_w are given below. Where reliable local formulae exist, these were used, but the majority of the relations were derived either by *GWS09* or in the frame of the present study. Where feasible, a direct comparison with corresponding original M_w values by RCMTS and SMTS was made. These relations are described country- or region-wise in alphabetical order. For relations derived in this study, validity ranges and uncertainties in terms of the 68% confidence bounds for a predicted value based on the chi-square maximum likelihood regression technique presented by *Stromeyer et al.* (2004) are given.

The *Sulstarova et al.* (2000) catalogue for Albanian earthquakes contains events up to 2000, and gives I_0 and M_S magnitudes for each event. The few available original M_w data do not provide a useful M_w-M_S relation, and the conversion to M_w was made by:

$$M_w = 0.995M_S + 0.09 \qquad 4 \le M_S \le 7 \qquad (1)$$
$$\sigma = 0.17 - 0.18$$

obtained by regression of *Papazachos et al.* (2003) M_w vs. *Sulstarova et al.* (2000) M_S (Fig. 3). The uncertainty 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 relation (1), σ = 0.17 and 0.18 denote the lower and upper bounds, respectively.

The *Harbi et al.* (2010) catalogue for eastern Algeria has been paid special cleaning attention, since a certain portion of events have interchanged longitudes (W instead of E; cf. *Hamdache et al.* 2010, Section 3.2 above). Besides an early event lacking size specification, the list of "cleaned" events starts in 1767 and extends beyond 2006. It includes some distinct historical events and gives intensities and various types of magnitudes. We converted intensities to M_w applying:

$$M_w = 0.6\, I_{max} + 0.96 \qquad (2)$$

from *Mezcua* (2002), but only to the onshore events assuming epicentral intensity. Relation (2) is only valid for focal depths down to 30 km, but we apply it also to events where no depth is assigned. Actually, there is just one event for which M_w cannot be calculated due to this restriction. Many events have M_S magnitudes, and the non M_S type magnitudes have been converted to M_S. We converted to M_w

using the relations:

$$M_w = 0.796\ M_S + 1.280 \quad \text{for } M_S \geq 5.4 \qquad (3)$$
$$= 0.585\ M_S + 2.422 \quad \text{for } M_S < 5.4$$

by *Bungum et al.* (2003) derived for southern Europe. As for several of the formulae suggested below, the applicability of relations (3) is not proven, but will be tested in the homogenization process of Chapter 7.

Nunes et al. (2004) presented a catalogue for the Azores Islands area for the period 1915-1998. Since the magnitudes are unreliable (J. Batlló, personal communication, 2010), they are taken from *Borges et al.* (2007) or from ISC bulletins. Although normally given highest priority (see Table 3), the *Nunes et al.* (2004) solutions are substituted by the ISC bulletins ones also for the locations in cases where the latter is based on many readings and the two solutions differ considerably.

Glavatović (2009) provided a preliminary catalogue for the Balkans, compiling various sources. M_L magnitudes are given for all events and for each sub-catalogue one of two given transformation formulae from M_L to M_w is applied (see Table 4). This catalogue is related to the BSHAP project on the harmonization of seismic hazard maps for the western Balkan countries, a NATO SPS programme. The Glavatović catalogue contains a certain number of duplicates and other inconsistencies, which required some cleaning, including leaving some parts out. It has still been worthwhile to include it in EMEC, since the catalogue covers a large area, for parts of which we have only poor coverage by other sources. It is given the lowest priority in the polygons in which it is applied.

The *Glavcheva* (2004) catalogue contributes events in Bulgaria in the time period 1750-1904. M_w values were calculated from:

$$M_w = 0.0376\ M_L^2 + 0.646\ M_L + 0.53 \qquad (4)$$
$$\sigma = 0.29 - 0.34$$

derived by *GWS09* for earthquakes in Central Europe sensu lato, after the relation:

$$M_L = 0.72\ I_0 + 1.28 \log(h) - 1.13 \qquad (5)$$

from *Herak* (1995), with standard errors of estimates 0.38 for M_L, 0.53 for I_0, and 0.30 for $\log(h)$, was applied to obtain M_L magnitudes. Since relation (4) is very similar to those for quite different parts of the globe, e.g., California (*Uhrhammer et al.* 1996) and western USA (*Bollinger et al.* 1993), cf. *Grünthal and Wahlström* (2003), we feel encouraged to apply it for other regions in Europe as well. The lack of data in recent years prevents a comparison of the Glavcheva catalogue with original M_w data. This is the case also for several of the catalogues mentioned below. h in relation (5) denotes focal depth in km and is set at 10 km if no value is given.

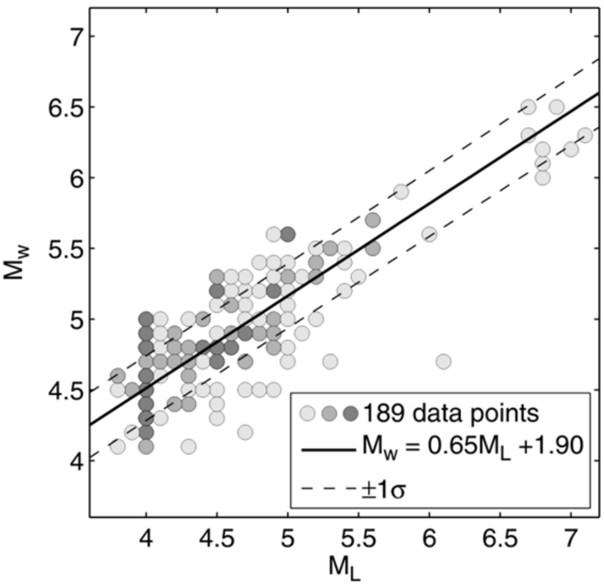

Figure 4. Comparison of M_w from *Kalafat et al.* (2010) vs. M_L from *Godzikovskaya* (2001). For symbol representations, see Fig. 3.

Godzikovskaya (2001) lists events in the Caucasus from AD 50 to 1997. This catalogue was also used as a supplementary source for eastern Turkey. Lacking original M_w data, the conversion to M_w was made by:

$$M_w = 0.65\ M_L + 1.90 \qquad 4 \leq M_L \leq 7 \qquad (6)$$
$$\sigma = 0.23 - 0.24$$

obtained by regression of M_w from *Kalafat et al.* (2010) vs. *Godzikovskaya* (2001) M_L (Fig. 4). Admittedly, the quality of the M_w and M_L of the 189 data pairs is not perfect, but to use this relation seems to be the best way to treat these data. From 1998 and on, data for the Caucasus were taken from ISC bulletins.

The *Shebalin et al.* (1998) catalogue for central and south-eastern Europe is applied, in this study, only for Bulgaria and Macedonia. It contains entries up to 1989. I_0 and M_S values are provided for all events and we have used the intensities and the relations (4) and (5) for the conversion to M_w.

From the *Herak et al.* (1996) catalogue up to 2004 and intended mainly for Croatia, but extended also to several neighbouring countries on the Balkans (see Table 1), original I_0, I_{max}, and M_L values were all used to convert to M_w. Before 1908, only intensities were considered reliable (see *GWS09*), and from 1908 to 2004, M_L has priority over intensity. Epicentral intensity (I_0) or (exclusive) maximum felt intensity (I_{max}) is provided for each felt event. Since many I_{max} values are given also for events located on land, we make no distinction with I_0 and apply relations (5) and (4) for the M_w calculation whatever intensity type is given. Lacking M_L, M_m has also been used occasionally, and is assumed to have been calibrated with M_L so that identity of the values can be set. The conversion of M_L to M_w follows relation (4).

A catalogue for Cyprus giving intensities was presented by *Galanopoulos and Delibasis* (1965). It extends up to 1963. The relation:

$$M_S = 0.63\ I_0 + 0.91 \qquad 5 \leq I_0 \leq 11 \qquad (7)$$
$$\sigma = 0.70 - 0.74$$

was obtained by regression of data from *Feldman and Amrat* (2007) for the eastern Mediterranean region and combined with relations (3) to yield M_w. *Ambraseys and Adams* (1993) give M_S and/or m_b magnitudes for earthquakes in the Cyprus area in the time period 1890-1990. M_S was converted to M_w applying relations (3) and m_b was converted to M_w with:

$$M_w = 8.17 - \mathrm{SQRT}(42.04 - 6.42\ m_b) \qquad (8)$$

derived by *GWS09* after *Utsu* (2002) based on global data. *Papazachos and Papaioannou* (1999) give M_S magnitudes for earthquakes in the eastern Mediterranean area, notably Cyprus, in the time period 1896-1997. Relations (3) were used for the magnitude conversion. The earthquakes listed by *Ambraseys et al.* (1994) with epicentres in the SE Mediterranean area polygon were also used in this study. The events occurred in the time period up to 1992 and each event has an M_S, m_b, and/or I_0 value. The conversion to M_w was performed using relations as already described above (see Table 4 for details).

For France we could make use of updated catalogue versions provided by *BRGM-EDF-IRSN* (2010) and *LDG* (2011). The conversions for the catalogues *LDG* (2005) and *LDG* (2011) data followed the routines in *GWS09*, i.e.:

$$M_L = 1.310\ M_{L(LDG)} - 1.44$$
$$\sigma = 0.40 - 0.51 \qquad \text{for } M_{L(LDG)} < 4.65 \qquad (9)$$
$$= M_{L(LDG)} \qquad \text{for } M_{L(LDG)} \geq 4.65$$

considering the difference between $M_{L(LDG)}$ by *LDG* (2005) and other Central European M_L magnitudes, combined with relation (4). The *LDG* (2005) catalogue contains $M_{L(LDG)}$ entries for events in 1962-2004. The *LDG* (2011) catalogue was used after 2004. The conversion to M_w for intensity data from *BRGM-EDF-IRSN* (2010) was made by the depth independent master event relation for Central European crustal events given by *Grünthal et al.* (2009b), i.e.:

$$M_w = 0.682\ I_0 + 0.16 \qquad (10)$$

The *IGN* (2005) catalogue for Iberia, Maghreb, and the nearby water areas of the Atlantic and the Mediterranean, contains epicentral, I_0, and maximum felt, I_{max}, intensities, as well as m_b and regional m_bLg magnitudes, all of which were transformed to M_w. The updated *IGN* (2010) version has only I_0 and m_bLg to convert to M_w. However, many historical events listed by these catalogues, although located, lack a strength measure and therefore are not entries in EMEC. Irrespective of which of the two types of intensities is denoted by *IGN* (2005), we strictly used only intensities from land located events for the transformation applying relation (2). m_b magnitudes were converted to M_w with relation (8) and m_bLg with:

$$M_w = 0.311 + 0.637\ m_bLg + 0.061(m_bLg)^2 \qquad (11)$$

from *Rueda and Mezcua* (2002). M_w magnitudes from IGN for the years 2004-2006 published on the EMSC webpage have substituted the calculated ones, if not given by SMTS or RCMTS (cf. Section 3.2).

The catalogues for the Catalonian part of Iberia (*IGC* 2009a, b) span the time periods from 1152 to 1995, and from 1996 and on, respectively. The first catalogue contains epicentral intensities which were converted to M_w by relation (2) (recommendation from J. Batlló, personal communication, 2010). The second part contains M_L, which has only a minimal difference from m_bLg (J. Batlló, personal communication, 2010) and so relation (11) can be applied.

F. Carrilho (personal communication, 2009) gives M_L magnitudes for events in Portugal and surroundings for the years 1961-2000. This is an improved and extended version of the catalogue by *Carrilho et al.* (2004). The identity relation $M_w = M_L$ is suitable for the conversion to M_w (S. Vilanova, personal communication, 2010).

For Italy *INGV* (2007) is used as one source for earthquakes from August 2001 and on, giving M_L and/or M_d magnitudes. These were converted to M_w using the relations:

$$M_w = 0.906\ M_L + 0.65 \qquad \sigma = 0.21 - 0.22 \qquad (12)$$

and

$$M_w = 1.472\ M_d - 1.49 \qquad \sigma = 0.20 - 0.22 \qquad (13)$$

respectively, both derived by *GWS09*. We refrain from using *INGV* (2007) data before August 2001 for reasons given by *GWS09*. The other sources used for Italy have given M_w (see Section 3.1.2).

The Levant area is especially rich in historical data, still it is a complex task to organize them in a suitable manner. From the *Khair et al.* (2000) catalogue up to 1999, M_S magnitudes and intensities were converted to M_w magnitudes. M_L is also given, but never when M_S is lacking (whereas the opposite can be the case). Only very few original M_w are available for this area. Therefore, we had to follow an approach based on relations, which are not calibrated with respect to local data of this region (for details see Table 4). Nevertheless, the resulting M_w values seem to be reasonable.

Abdallah et al. (2004) provides M_L magnitudes for events in the Levant area in the time period 1900 and on. Visualizing original M_w vs. M_L a very scattered picture is obtained, i.e., even for this instrumental part no local relation could be derived. Therefore, M_L was converted to M_w using relation (4).

The *Sbeinati et al.* (2005) catalogue is focused on Syria. It has events in the time period up to 1899. However, only about 20% of the events have a specified location. These and only these events have M_S and I_0 values. Only M_S was used for the M_w conversion, performed according to relations (3).

From the *Ambraseys* (2006) catalogue of large events, $M_S \geq 7$, in different areas, those in the SE Mediterranean area polygon are picked. The catalogue also lists many events in Turkey, but here we have many other sources (see above). The M_S values were converted to M_w applying relations (3).

The catalogues by *Feldman and Amrat* (2007), *Khair et al.* (2000), and *Sbeinati et al.* (2005) all list large events in the SE Mediterranean area polygon and the eastern part of the Turkey polygon, *Feldman and Amrat* (2007) also in Cyprus. Most M_w magnitudes calculated from the *Feldman and Amrat* (2007) entries of earthquakes in these polygons, in the time up to 1899, are based on M_L, but where M_S is given this has top priority. If no magnitude is provided, I_0 was used for the conversion. For M_S, relations (3), for M_L:

$$M_S = 1.37\, M_L - 2.19 \qquad 4.7 \leq M_L \leq 7.4 \qquad (14)$$
$$\sigma = 0.32 - 0.39$$

obtained by regression of data from *Feldman and Amrat* (2007) combined with relations (3), and for I_0, relation (7) combined with relations (3), were used for the transformations to M_w.

The area of Libya, western Egypt, and Tunisia is problematic with respect to the availability of local seismicity data. For Libya we could at least use several publications by Ambraseys. M_S and/or m_b are given for catalogued events in Tripolitania, Libya, in 1900-1976 (*Ambraseys* 1984), and relations (3) and relation (8), respectively, are applied. M_S magnitudes from *Ambraseys* (1994) for all Libya in the time period 1900-1990 were converted with relations (3). Also some events in *Ambraseys et al.* (1994; see above) fall in the Libya and western Egypt polygon. Lacking access to more local data, also data from ISC bulletins were used for the polygon Libya and western Egypt.

For the Mediterranean area, *Guidoboni and Comastri* (2005) provide intensities for earthquakes in the time period 1000-1500. This reference was applied in the SE Mediterranean area, Cyprus, and Turkey polygons. Maximum felt intensities are listed and we assume them to be equal to epicentral intensity and so applied relation (7) to convert to M_S followed by relations (3) to obtain M_w.

Ambraseys (2009) thorough investigation of earthquakes in the Mediterranean and Middle East is mainly qualitative. Where earthquake parameters are given – M_S in a few isoseismal maps for events in the twelfth century – these have been included with the highest priority.

For the part of the Atlantic Ocean west of longitude 15°W, which belongs to this study, i.e., the polygon AOC (Fig. 1), no local bulletins exist besides that for the Azores Islands region treated above. Therefore, the data from ISC bulletins were used. The first event in this area occurred in 1921 (ISS). The M_S magnitude is given for the vast majority of the events and was transformed to M_w, when this was lacking, using:

$$M_w = 10.85 - \mathrm{SQRT}(73.74 - 8.38\, M_S) \qquad (15)$$

derived by *GWS09* after *Utsu* (2002) based on global data. When neither M_w nor M_S is given, m_b was transformed to M_w with relation (8).

4 Innovations in the northern part

Updates of the catalogues and data files from agencies used for the part of Europe treated by *GWS09* (CENEC) have been incorporated in EMEC (Table 1). Some of the new data are continuations in time beyond 2004, the final year of CENEC, whereas others, besides a plain continuation, comprise revisions of earlier events. In excess to the catalogues encompassing also parts south of 44°N and therefore mentioned in Chapter 3, the updates include Austria (*ZAMG* 2009), Belgium (*Camelbeeck* 2009), Fennoscandia (*FENCAT* 2009), France (*BRGM-EDF-IRSN* 2010; *LDG* 2011), Germany (*SZGRF* 2010), Hungary (*Georisk* 2009), the Netherlands (*KNMI* 2009), Switzerland (*Fäh et al.* 2011), and UK (*Musson and Sargeant* 2007). The new UK catalogue contains only main shocks and is supplemented by the two catalogues used by *GWS09*. Some of the catalogues also apply to adjacent polygons (see Table 1). The *Fäh et al.* (2011) catalogue gives more realistic magnitude assessments for historical key earthquakes compared with its forerunner *Fäh et al.* (2003). Thus the 1356 Basel earthquake has M_w = 6.9 in *Fäh et al.* (2003) and M_w = 6.6 in *Fäh et al.* (2011). The new value is the same as determined by *Grünthal and Wahlström* (2003) in their catalogue for Europe north of 44°N. M_w = 6.6 for the Basel earthquake is possibly still a conservative value. *Fäh et al.* (2011) is applied in two and nine cases in Germany and France, respectively.

Newly introduced catalogue-polygon combinations (see Tables 1 and 3) compared to *GWS09* are *Herak et al.* (1996) in Austria, the Hungarian catalogues in Romania, *Oncescu et al.* (1999)/*INFP* (2009), and *Kondorskaya and Shebalin* (1982) both in Moldavia, and *Kalafat et al.* (2009, 2010) in Ukraine.

The transformation formulae of *GWS09* have been kept (Table 5) except where the harmonization is defective (see Chapter 7). An exception is Iceland, where the *IMO* (2007b) data contain a local M_w magnitude which has proved unreliable and therefore has been excluded. M_w magnitudes have now, like in the first Icelandic catalogue (*IMO* 2007a), been calculated exclusively from M_L (see Section 7.1). For the *Živčić* (1993) catalogue, the formula for M_L to M_w conversion by *INGV* (2007) is now used following a recommendation by M. Živčić (personal communication, 2009).

5 Special studies

As mentioned in Chapter 2, special studies generally have priority over catalogues. Many special studies give M_w or M_0. It is assumed that sufficient effort has been made to obtain credible values and these are adopted here. Special studies giving M_w have priority over those not giving M_w. For special studies lacking M_w, conversions are performed using formulae applied to catalogues valid in the polygons in which the corresponding events are located. The references of all special studies are listed in Table 2.

6 Fake events

The CENEC catalogue is accompanied by a list of fake events. This is included in the electronically available download, where the selection criteria of the events are also specified. The identification of fakes was part of this study. If not published somewhere else, the fake events are referenced as "renewed analysis (GruRA)". Thus every entry in the list has been individually tested as to its status as a fake. Erroneous information on place, date, or magnitude, mistaken storms, rock falls, landslides, etc. are causes for an event to be classified as fake. Events which have been listed on separate days by different sources due to the difference between the Julian and Gregorian calendars are not indicated in the fake list, nor are entries which differ in time or place if neither of them can be verified as wrong, also no shifts of only one day. Of course, only one of the entries is included in the catalogue in such cases. The sources used for the fake list are given in connection with the list if not appearing in the main reference list.

A principal problem with most fake lists is that they normally do not state why an event is classified as a fake nor to which source they belong. The event could be (1) non-seismic, e.g., confused with a storm or a collapse not connected with an earthquake, (2) seismic but with changed time, location, and/or magnitude compared to a previous solution, or (3) a duplicate. The sign errors in longitude for several events in the *Hamdache et al.* (2010) and *Harbi et al.* (2010) catalogues (Sections 3.2 and 3.3, respectively) are corrected in the EMEC catalogue, but not included in the fake list.

A problem with suspected duplicates is that, particularly for historical events, it is often hard to determine if two or more entries belong to the same event or not. A first judgment has to be based on a composite comparison of location, time, and strength. For example, entries with quite different location and magnitude, but similar time of occurrence, are cases where such a decision can be difficult. A final judgment can only be made on the basis of studying contemporary sources.

Although induced events cannot be denoted as fake events, there are a few cases where catalogues interpret induced events as tectonic earthquakes. Known such cases do not enter the EMEC catalogue.

7 Harmonization of M_w

Following the algorithms presented above the EMEC catalogue could be unified with respect to M_w. It remains to demonstrate the harmonization in terms of M_w reached for the different parts. Similar to *Grünthal et al.* (2009b) we perform these tests along two lines: (1) comparison of given and calculated M_w with original M_w; (2) comparison of the M_w relation to I_0 and h (focal depth), and to I_0 only. Each of these tests was accomplished for every catalogue, data permitting. Only data from events in the allowed polygons according to Table 1 were used in all tests. In addition, calculated M_w values for the largest events have been compared with those of

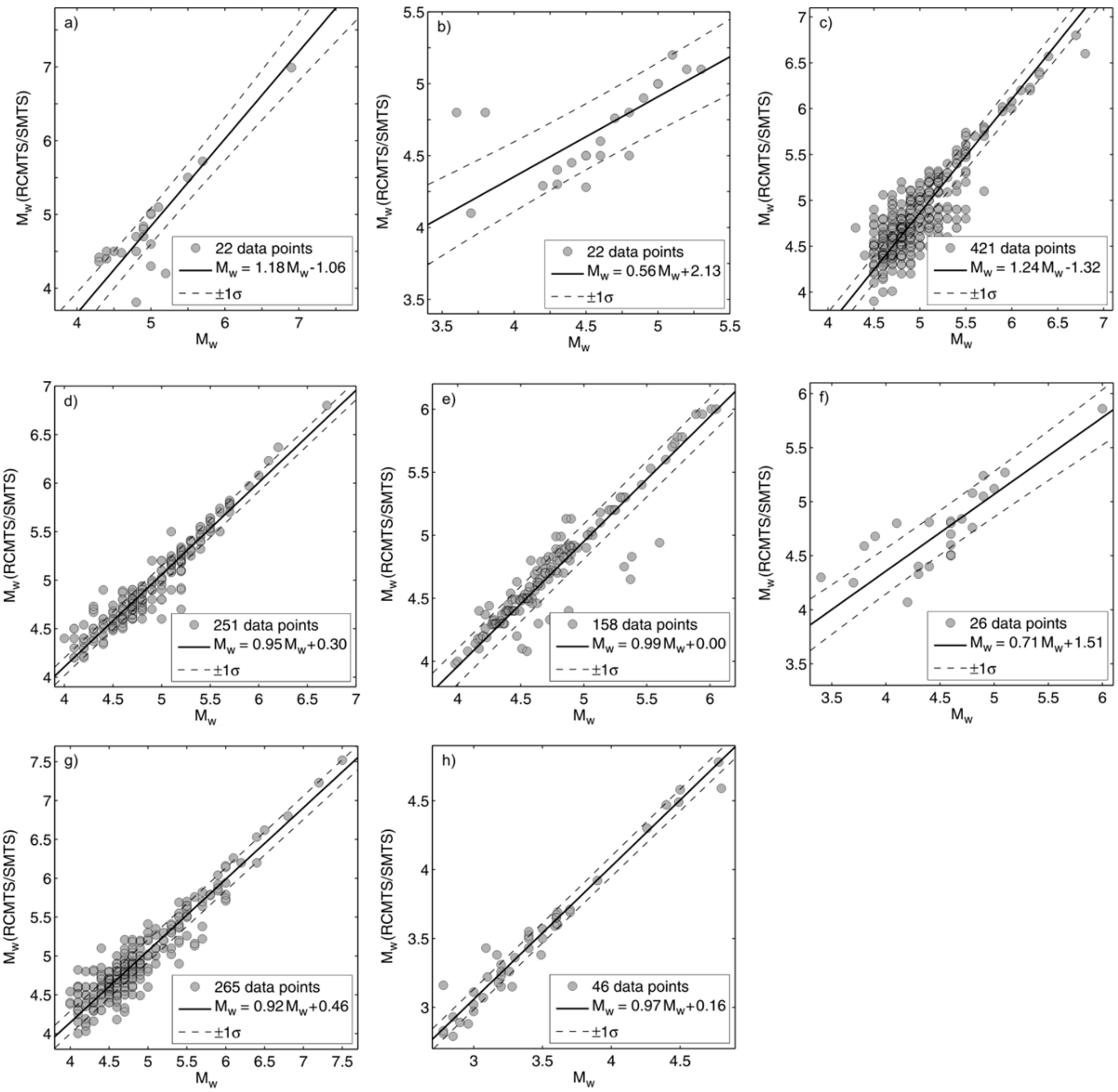

Figure 5. Original M_w from RCMTS and SMTS vs. M_w given for entries in the catalogues by **a** *Hamdache et al.* (2010), **b** *Papaioannou* (2001), **c** *Papazachos et al.* (2003, 2009), **d** *Roumelioti et al.* (2010, 2011), **e** *CPTI Working Group* (2004, 2008), **f** *Oncescu et al.* (1999) and *INFP* (2009), **g** *Kalafat et al.* (2009, 2010), and **h** *Fäh et al.* (2011). The comparisons of data are shown to illustrate the goodness of fit. The relation for each catalogue is given only in order to quantify the fit, but is not used to derive M_w. The data in Fig. 5a, b, and f are not satisfactory due to lack of data. These graphs include data up to 2008 to underpin our interpretations.

Engdahl and Villasenõr (2002) and a good fit was found.

7.1 M_w- M_w calibrations

Visualization was performed for original moment-tensor M_w from RCMTS and SMTS vs. each of the M_w sets of Section 3.2 which have more than 20 data points. This applies to *Hamdache et al.* (2010), *Papaioannou* (2001), *Papazachos et al.* (2003, 2009), *Roumelioti et al.* (2010, 2011), *Stich et al.* (2010), *CPTI Working Group* (2004, 2008), *Oncescu et al.* (1999)/*INFP* (2009), and *Kalafat et al.* (2009, 2010). From the CENEC part of the area, an analogous graph could be made only for the *Fäh et al.* (2011) catalogue. The obtained graphs, Fig. 5a-h, show that the M_w sets from the various catalogues are not much different from the respective original M_w sets. To make it clear, these figures illustrate the achieved calibration and are not used to derive any M_w. In order to increase the significance of the figures, also the data for the years 2007-2008 (i.e., after the year of termination of EMEC) were added. All graphs of

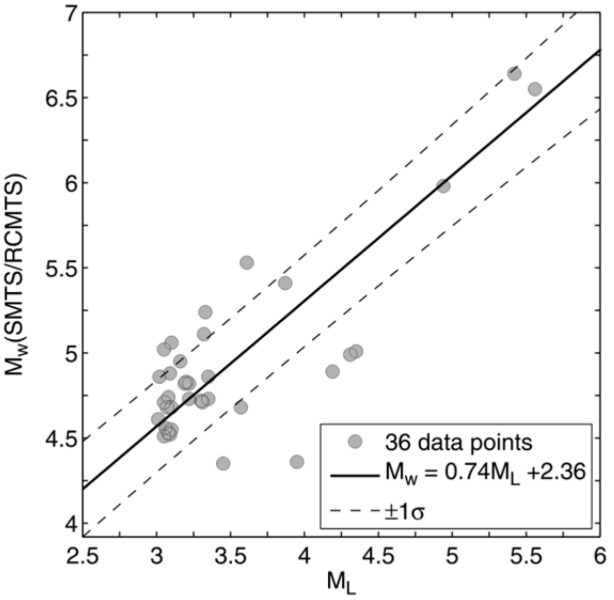

Figure 6. Original M_w from RCMTS and SMTS vs. M_L from the *IMO* (2007b) catalogue.

Fig. 5, which are based on a sufficient number of data, show a very good fit. Only those with less than 30 data pairs (Fig. 5a, b, f) have a less convincing fit.

The data by *Camelbeeck et al.* (2010) and *Musson and Sargeant* (2007) include only one and two M_w entries, respectively, above the threshold magnitude with corresponding (almost identical) SMTS magnitude. *FENCAT* (2009) has corresponding values only for a few offshore events.

The only adjustment carried out was for the Icelandic catalogues (*IMO* 2007a, b). A new relationship with original M_w vs. M_L illustrated in Fig. 6 was introduced (cf. Table 5):

$$M_w = 0.74\, M_L + 2.36 \qquad 3 \le M_L \le 5.6 \qquad (16)$$
$$\sigma = 0.27 - 0.32$$

This is the only relation of this study which has been extrapolated outside the range of the data used for the regression for a significant number of events. However, the extrapolation is in accordance with similar linear equations covering a large magnitude range.

7.2 Intensity based calibrations

For intensity based calibrations we generated, analogous to *Grünthal et al.* (2009b), graphs of M_w vs. epicentral intensity, I_0, and focal depth, h, and M_w vs. I_0, respectively, for each catalogue with available data. Some catalogues provide data for only one of the graphs. Each figure also includes the respective master event relations provided by *Grünthal et al.* (2009b), i.e., with and without the h term. Since these were derived for crustal events, the depth data are restricted to the range of 5-25 km. An implicit assumption for the comparisons is that the intensity assignments do not differ significantly for the various catalogues. The correlations are good to excellent in most cases, implying that the harmonization with respect to M_w magnitudes is good. Figure 7a-d give examples. It has to be stressed that such a comparison does not imply that the master event relation is valid for all these regions, i.e., such tests are intended to be relative only with respect to internal consistency. Obviously, the agreement for the *Sulstarova et al.* (2000) and *Sbeinati et al.* (2005) catalogues is not so good (Fig. 7a, d), for *Shebalin et al.* (1998) it is excellent (Fig. 7b), and for *IGN* (2010) relatively good (Fig. 7c).

8 Entries of the EMEC catalogue

After the data processing, selection, and harmonization check described above, the EMEC catalogue, which consists of some 45,000 tectonic earthquakes beginning in the year 1000 - or in some areas earlier (see Chapter 2) - and ending in 2006, has been extracted from the database. More than 400 of the entries are from special studies. The epicentres located within the study area are depicted in Fig. 8a, b. While Fig. 8a shows all catalogued earthquakes in EMEC, Fig. 8b is restricted to those with $M_w \geq 6.0$ which gives a clearer picture for high seismicity regions such as the eastern Mediterranean area.

The EMEC catalogue is available at the home page of the GFZ German Research Centre for Geosciences: [http://www.gfz-potsdam.de/EMEC and dx.doi.org/10.2312/GFZ.EMEC, respectively] where the following information is given:

- *Origin time.* Year, month, day, hour, and minute, specified to the smallest unit given by the original source. Generally, the original data have been kept, i.e., no attempt is made to standardize GMT and local times, Julian and Gregorian dates, etc. However, the different timings were considered in the search for duplicates.
- *Location.* Epicentral coordinates and, if given, focal depth.
- *Intensity*, I_0. Epicentral or (if assumed similar to epicentral) maximum intensity if given by the original source.
- *Magnitude*, M_w, with uncertainty where available (cf. next chapter), and type and value of original entry from which it was calculated according to the algorithms of Tables 4 and 5.
- *Reference*. The national or regional catalogue (Table 1) or special study (Table 2). Only one reference is listed for each entry, although the pa-

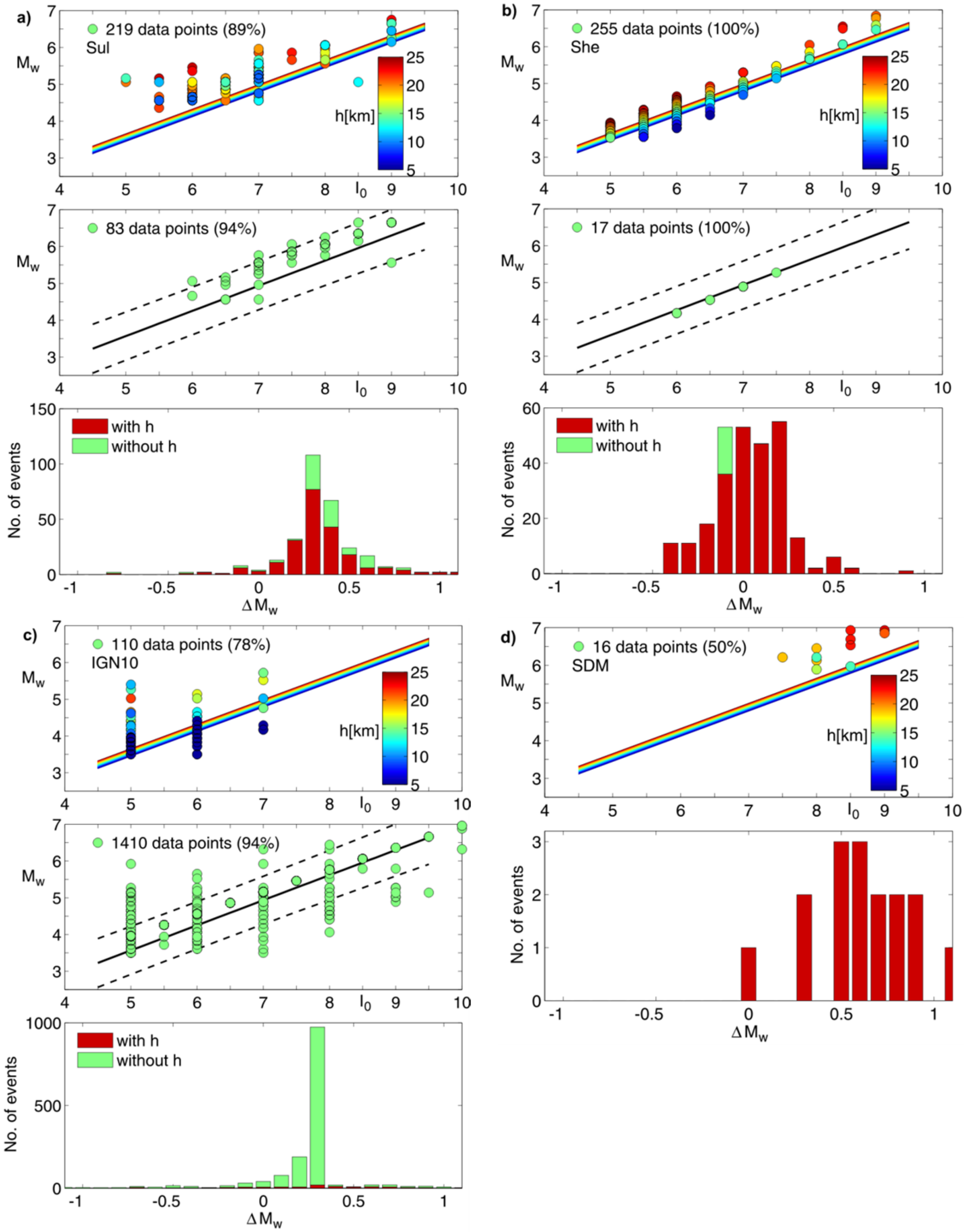

Figure 7. Preferred M_w values (original, given or calculated) drawn vs. given I_0 and h values (top graph), and vs. I_0 values only (centre graph), for different local national and regional catalogues ($M_w \geq 3.5$; $I_0 \geq 5$): **a** *Sulstarova et al.* (2000), **b** *Shebalin et al.* (1998), **c** *IGN* (2010), and **d** *Sbeinati et al.* (2005; only data with depths). The lines refer to the master event relations derived by *Grünthal et al.* (2009b). The depth distribution of the data and regression lines are indicated by different colours (top graph). The rate of data points within one standard deviation from the relations is indicated. The bottom graph shows the distribution of the difference in M_w between the points and the lines

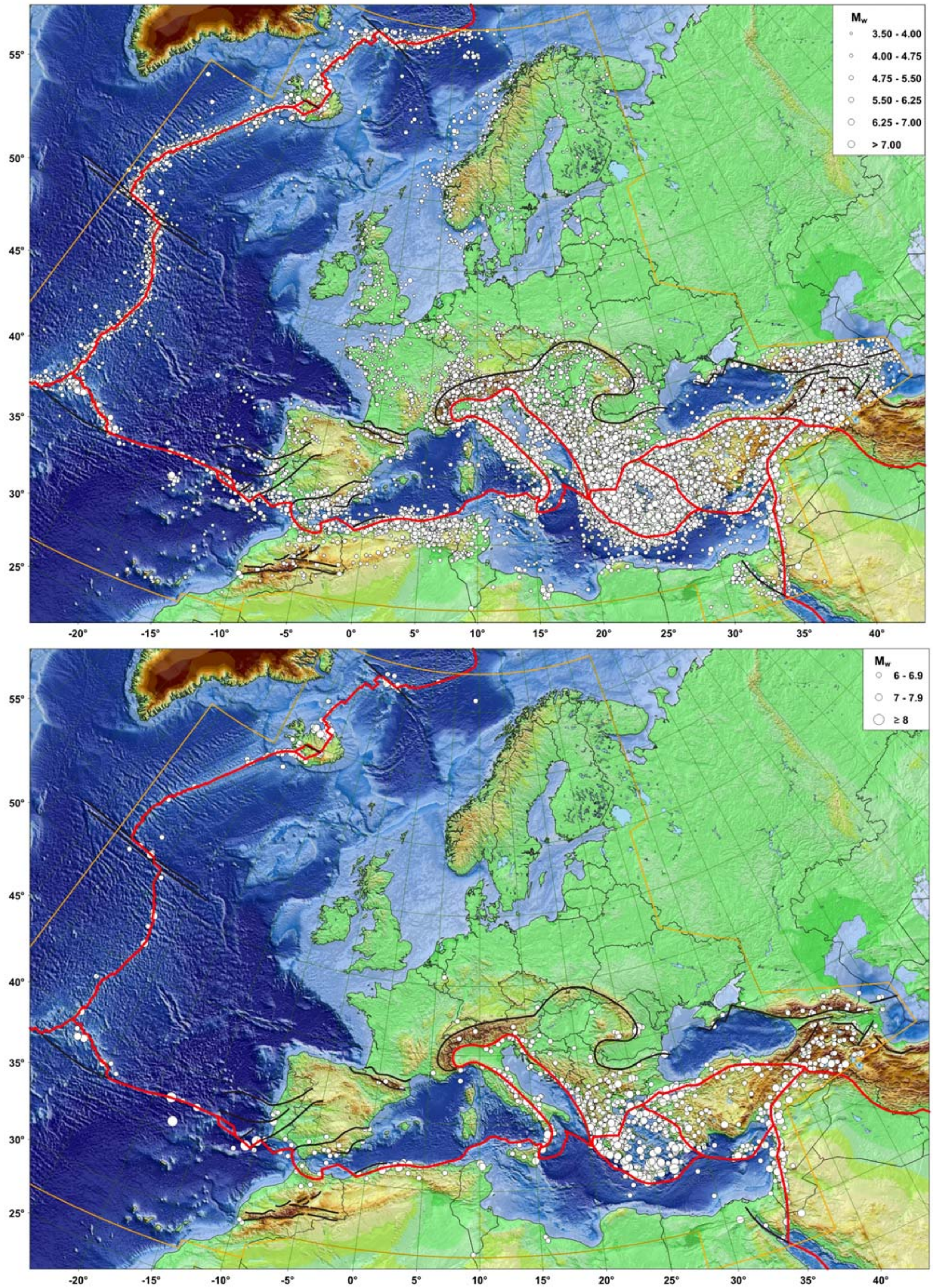

Figure 8. Epicentre map of the EMEC catalogue. **a** All events. **b** Events with $M_w \geq 6.0$. The buff-coloured polygon delineates the study area. The plate boundaries, in red, are according to *Bird* (2003) with modifications in the area of Gibraltar and further west up to 15°W after *Jiménez-Munt and Negredo* (2003) and *Zitellini et al.* (2009) as well as in the N-Atlantic and Iceland after *Byrkjeland et al.* (2000) and *Tsikalas et al.* (2012). The black lines represent other selected first-order tectonic elements.

rameters were sometimes taken from more than one source, e.g., when an M_w value from RCMTS or SMTS was included. A special case is posed by the focal depths of the *Papazachos et al.* (2003) entries, which all were taken from *Burton et al.* (2004), since *Papazachos et al.* (2003) did not publish depths.

9 Uncertainties

Qualitative or quantitative uncertainties have been incorporated into some parametric earthquake catalogues since their advent. One of these is the catalogue by *Grünthal* (1988) with uncertainty classes for location, depth, and intensity for all earthquakes with these parameters. Unfortunately, this has not become standard and only about 15% of the original catalogues which were used for EMEC contain uncertainties for epicentre location, about 25% for depth and less than 40% for a strength measure, most commonly intensity. Only a small fraction of them presents uncertainties for all events. The information on uncertainties is thus incomplete. Moreover, the expressions of uncertainties vary considerably. Some catalogues give estimated actual values, and these can relate to one or (as for *Fäh et al.* 2011) two standard deviations, whereas others just indicate ranges of the uncertainty as quality classes.

What concerns a big set of original M_w readings in EMEC, the Swiss moment tensor solutions (SMTS), their uncertainties are in the range of 0.1-0.2 (*Braunmiller et al.* 2005; Braunmiller, personal communication, 2007). M_w values resulting from a conversion have, of course, larger uncertainties. Modern catalogues used for EMEC which provide M_w and include uncertainty assignments are the Swiss (*Fäh et al.* 2011), Greek (*Papazachos et al.* 2003), and Italian (*CPTI Working Group* 2004, 2008) catalogues. We include in the EMEC database the uncertainties for M_w provided by these catalogues.

Fäh et al. (2011) give sporadic uncertainties in M_w for 11% of the events in the period before 1975. In the period 1975–2006, 95% of the events with M_w have an uncertainty assigned. This is always < 0.4 units and for 34% of the cases with uncertainty this is ≤ 0.2.

The Greek catalogue gives no individual uncertainty assignments. For each event, in the instrumental part, i.e., the period 1911-1999, the uncertainty in M_w is estimated at 0.25, and in the historical period at 0.35 when the number of available macroseismic data points is ≥ 10 and at 0.5 otherwise.

The Italian catalogues provide uncertainty assignments for de facto all events. In *CPTI Working Group* (2004), all assignments are < 0.35, also in the historical time. For the most recent decades, 90% of the events have an uncertainty ≤ 0.2. There is a remarkable difference in the *CPTI Working Group* (2008) M_w uncertainty assignments. Here several tens of events have values in the range of 0.5-1.02, and in the recent decades only some 45% have uncertainties ≤ 0.2. Thus an adjustment to more realistic values (cf. *Fäh et al.* 2011) has been done.

In the total about 45% of the entries in EMEC have uncertainties in M_w. About 90% of these are in the *Papazachos et al.* (2003) catalogue, i.e., are not individually assigned. The assessment of uncertainties in EMEC according to a harmonized rigorous procedure which would provide realistic estimates event by event is beyond the scope of this study.

10 Conclusions and discussion

It has been a long and non-trivial work to compile, edit, scrutinize, and harmonize all the data in the large database and then to develop the rules according to which the entries in the EMEC catalogue have been selected. This includes the identification of duplicates and various types of fakes and induced events.

Some 80 national or regional catalogues from all Europe and the Mediterranean region and close to 100 special studies form the basis for EMEC. All these data have been incorporated into a database, where the different entries to one and the same earthquake constitute a so called event family. According to a strict hierarchy algorithm one member of such an event family is picked as the entry for EMEC. Altogether there are some 45,000 entries in EMEC from over 700,000 entries in the entire database.

A critical part of the cataloguing based on numerous sources is the check whether the common strength measure, here in terms of M_w, has reached a sufficient level of harmonization. Different tests have shown that the vast majority of data agree well. The magnitudes from a few sources required a rigorous modification, i.e., recalculation. Some minor parts are still not perfect or not possible to fully check. A novelty compared to *GWS09* is that very small focal depths of crustal tectonic earthquakes, often poorly constrained, as sometimes given in catalogues together with magnitudes M_L, are not acknowledged. Such magnitude-depth combinations would lead to intensity values which were not observed. Thus only originally given depths of 3 km or greater for M_w = 3.5-3.9 events, 5 km or greater for M_w = 4.0-4.4 events, and 7 km or greater for $M_w \geq 4.5$ events are given in the catalogue and are used in formulae where a depth term is part of the calculation of M_w from intensity.

Fake events in historical times are given in a special list on our web page. Besides identified non-seismic events, the list includes entries with errone-

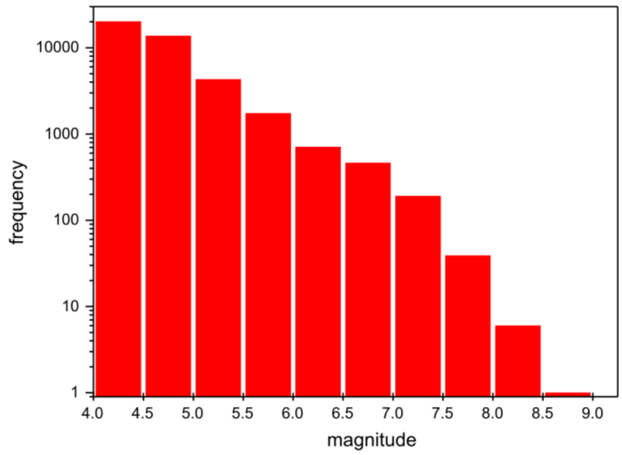

Figure 9. Frequency of the earthquakes of the EMEC catalogue in half-magnitude classes.

ous date or location as well as duplicates. It can sometimes be hard to determine if an entry is a fake or not, and if two or more entries belong to the same event or not (duplicates).

Induced or triggered events are not a subject of EMEC, but are included in the large database. Most domestic catalogues which contain such data denote them as such - but not all of them. Mining areas, as well as those where natural gas and oil are or were exploited, are well-known, which facilitated the withdrawal of such events. Other types of induced events can occur in enhanced geothermal systems, be due to water reservoirs, or are interpreted as rain triggered (e.g., *Hainzl et al.* 2006). Sometimes it is difficult to distinguish, if an event is tectonic or induced. This issue has even been subject of scientific dispute. There are a few instances where catalogues classify induced events as tectonic earthquakes. They are not included in the EMEC catalogue.

As mentioned already in Section 1, the assessment of data completeness with time is not part of earthquake cataloguing. However, this issue is briefly discussed here. A completeness analysis is part of the data pre-processing for the calculation of the parameters of frequency-magnitude relations. Usually the completeness analysis is made for declustered data, where foreshocks and aftershocks have been removed. The data completeness with time is not only strongly magnitude dependent but changes considerably from region to region in Europe and the Mediterranean area. The completeness of earthquake data depends on the way records (historical, pre-instrumental, or instrumental) were made, stored, have survived with time, and were retrieved for the cataloguing. The way notations have been made on earthquakes in pre-instrumental times depends on cultural-historical aspects. A comprehensive completeness analysis for the Euro-Med region is therefore an ambitious task in itself. The first step is to define the areas with common cultural-historical background, which, e.g., for Germany, are two or three depending on the chosen approach. This means that different experts might have different views alone with respect to this sub-task. The next step is to select a suitable approach to determine the completeness. Different approaches can result in differing completeness patterns. Often these methods do not provide an uncertainty range.

Completeness analyses on the basis of EMEC, or its preliminary versions, have been performed for the entire Euro-Med region and for selected areas (*Grünthal et al.* 2010; *Chan and Grünthal* 2010; *Sørensen et al.* 2012; *Hakimhashemi and Grünthal* 2012). Figure 8a, b shows the geographical distribution of epicentres. Figure 8a depicts all the epicentres of EMEC. The seismicity is basically concentrated along the plate boundaries and to some extent associated with other first-order tectonic elements. The highest seismic activity is observed along the Aegean arc and the northerly adjoining boundaries of microplates, in the western Balkans, Italy, northern Algeria, and southern Iberia, as well as in the east in the Caucasus and along the Dead Sea fault zone. North of the Mediterranean most of the seismicity is bounded by the border fault of the Alpide belt, with the Alpine chain in the west and the Carpathian chain with the Vrancea region in the east. North of the Alpide belt the Rhine area has the highest concentration of seismicity. The Mid-Atlantic ridge including the Azores Islands and Iceland is another well documented zone of high seismicity.

An even clearer association of seismicity with active tectonic structures is shown in Fig. 8b, which is restricted to earthquakes with $M_w \geq 6.0$. Apart from a few exceptional cases the $M_w \geq 6.0$ seismicity is associated with the Alpide belt and other plate boundaries. This figure also shows that the vast majority of $M_w \geq 7.0$ events is connected with the plate boundaries, particularly the Aegean subduction.

A histogram displaying the number of events in EMEC in different magnitude classes is given as Fig. 9. Obviously this should not be misinterpreted as the frequency-magnitude relation of complete data.

Only some of the basic data for EMEC consider uncertainties of key parameters of the events. The national and regional catalogues which provide uncertainties use quite different criteria; some give explicit values whereas others indicate them in quality classes. Uncertainty assignments of modern catalogues are discussed and where available for M_w they are included in EMEC. The assessment of uncertainties event by event in EMEC is beyond the scope of this study.

The availability of earthquake catalogues or data files has rather decreased than increased during the last years. Certain catalogue agencies providing their files on the web over the years have closed their URL. Restrictions and commercialization are increasing. Other online versions change their entries permanently or frequently. Some agencies at least announce that new versions will become available online at a certain time of the year, or associate a version with a date. Others shift a rather limited time window covering the most recent data only. In short, we cannot guarantee that the files we refer to are still available, or still contain exactly the set of earthquakes we have used at the given URL. The years we give to the respective references at least indicate from what time we have made use of them.

Frozen parametric catalogues are preferred sources. We provide our frozen catalogue version with the guarantee of its permanent availability - including the errors which are unavoidable in any earthquake cataloguing, especially for larger regions and long-time spans.

The main purpose of the EMEC catalogue is to provide a database for seismic hazard calculation, but it can also be used for various kinds of seismicity studies. Its earlier versions have already been successfully applied in numerous projects, some of them mentioned in Chapter 1. This publication should be the basis for its further use. Since catalogue work is a never-ending task, future studies might point out how this catalogue can be improved and sophisticated.

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Table 1 National and regional catalogues and data files and their associated polygons

Country/area of main application	Catalogues	Notation	Associated polygons
Albania	Sulstarova et al. (2000)	Sul	Albania (AL)
Algeria	Harbi et al. (2010) eastern part; Hamdache et al. (2010) northern part	HPP10; Ham	Algeria (DZ), Tunisia (TN); Ham also Morocco (MA)
Austria	Lenhardt (1996); ZAMG (2009)	ZAMG; ZAMG09L	Austria (A)
Azores Islands	Nunes et al. (2004)	NFO	East Atlantic Ocean and Canaries (AOC)
The Balkans	Glavatović (2009)	Gla	Albania, Bosnia/Herzegovina (BIH), Bulgaria (BG), Croatia (CRO), Macedonia (MK), Serbia/Montenegro (YU), Slovenia (SLO)
Belgium, Luxemburg	Verbeiren et al. (1995); ORB (2007); Camelbeeck (2009)	ORB; ORB07; Cam	Belgium and Luxemburg (BL); ORB07 and Cam also Germany (D) western part
Belorussia	Boborikin et al. (1993)	Bob	Belorussia (BY), Fennoscandia (FEN)
Bulgaria	Glavcheva (2004)	Gleva	Bulgaria
The Caucasus	Godzikovskaya (2001)	God	Caucasus (CAU), Turkey (TR) east of 30.5°E
Central and south-eastern Europe	Shebalin et al. (1998)	She	Bulgaria, Macedonia
Croatia	Herak et al. (1996)	HHM	Croatia, Austria, Bosnia/Herzegovina, Macedonia, Slovenia, Serbia/Montenegro
Cyprus	Galanopoulos and Delibasis (1965); Ambraseys and Adams (1993); Papazachos and Papaioannou (1999); Papaioannou (2001)	GD; AA; PP; Pou	Cyprus (CY); PP, Pou also SE Mediterranean area (SEM) and Turkey east of 30.5°E
Czech Republic	Schenková (1993); Zedník (2005)	CAS; GFU	Czech Republic (CZ)
Egypt, Arabia, Red Sea	Ambraseys et al. (1994)	AMA	SE Mediterranean area, Libya and western Egypt (LWE)
Estonia	Nikonov (1992)	Nik	Fennoscandia
Fennoscandia	Wahlström and Grünthal (1994) southern part; FENCAT (2009);	WG; FEN09	Fennoscandia; FEN09 also North Atlantic Ocean and Iceland (AOI)
France	LDG (2005, 2011); BRGM-EDF-IRSN (2010)	LDG; LDG11; SisF10	France (F), United Kingdom (UK); Spain (E) only when there is a corresponding IGC1, IGC2, or IGN10 entry in polygon F (see Iberian Peninsula entries)
Germany	Grünthal (1988, 1991); Leydecker (1986, 1996); SZGRF (2010)	Gru; Gru91; Ley; Ley96; GRF	Gru, Gru91: Germany and adjacent area, inside 49.6°N–54.8°N, 9.5°E–15.5°E
			Ley, Ley96: Germany outside this area, Austria, France; in 1992–1993 (Ley96) also inside this area
			GRF: Germany, Austria, Czech Republic, Poland

Table 1 (continued)

Country/area of main application	Catalogues	Notation	Associated polygons
Greece	Papazachos et al. (2003) (Burton et al. 2004 used for focal depths); Papazachos et al. (2009); Roumelioti et al. (2010, 2011)	Pap; Pap09; RKB10; RKB11	Greece (GR); Pap, Pap09, RKB10 also Albania, Macedonia, and Turkey west of 30.5°E; Pap, Pap09 also BG
Hungary	Zsíros et al. (1990); Zsíros (1994), Zsíros (1999); Tóth et al. (2006); Georisk (2009)	Zsi; Zsi94; Zsi99; Tot; Georisk	Hungary (H), Romania (RO), Ukraine (UA); Zsi99, Tot, Georisk also Slovakia (SK)
Iberian Peninsula	Martínez Solares (2003); IGN (2005, 2010); IGC (2009a, b) Catalonia; Carrilho F (personal communication, 2009) Portugal; Stich et al. (2010)	MzS; IGN; IGN10; IGC1; IGC2; CNP; SMM	MzS: Spain
			IGN: Algeria, Morocco, Tunisia. Applied only if lat. <32°N or lon. >6°E, i.e., outside the area covered by the IGN10 catalogue
			IGN10, SMM: Spain, Algeria, Morocco, Portugal (P)
			IGC1, IGC2: Spain
			CNP: Portugal, Morocco, Spain
Iceland	IMO (2007a, b)	IMO; IMO07	North Atlantic Ocean and Iceland
Italy	CPTI Working Group (2004, 2008); INGV (2007)	CPTI04; CPTI08; INGV	Italy (I)
The Levant	Khair et al. (2000); Abdallah et al. (2004); Sbeinati et al. (2005); Ambraseys (2006); Feldman and Amrat (2007)	KKP; AFS; SDM; Amb06; FA	SE Mediterranean area; KKP, SDM, FA also Turkey east of 30.5°E; AFS, FA also Cyprus
Libya	Ambraseys (1984, 1994)	Amb84; Amb94	Libya and western Egypt
Mediterranean area	Guidoboni and Comastri (2005); Ambraseys (2009)	GC; Amb09	Cyprus, SE Mediterranean area, Turkey east of 30.5°E
Morocco	Peláez et al. (2007)	Pel	Morocco, Algeria, Portugal, Spain
The Netherlands	Houtgast (1995); KNMI (2009)	Hou; KNMI09	The Netherlands (NL)
Poland	Pagaczewski (1972); Guterch and Lewandowska-Marciniak (2002)	Pag; GLM	Poland (PL); GLM also Czech Republic
Romania	Oncescu et al. (1999); INFP (2009)	Onc; INFP	Romania, Bulgaria, Moldavia (MD), Serbia-Montenegro, Ukraine
Slovakia	Labak (1998)	Lab	Slovakia
Slovenia	Živčić (1993)	ZivS	Slovenia
Switzerland	Fäh et al. (2011)	ECOS-09	Switzerland (CH), Austria; selected events in France and western Germany
Turkey	Turkish GSHAP Catalogue (2000); Ambraseys (2002); Kalafat et al. (2009, 2010)	TR-GSHAP; Amb02; Kal; KOERI	Turkey; TR-GSHAP only east of 30.5°E; Amb02 only west of 30.5°E; KOERI also SE Mediterranean area, Cyprus, and Ukraine
United Kingdom	Musson (1994, 2006); Musson and Sargeant (2007)	Mus; Mus06; MS	United Kingdom
The former USSR	Kondorskaya and Shebalin (1982); Kondorskaya and Ulomov (1999)	KSh; KU	Moldavia, Ukraine; KU also Turkey east of 30.5°E

Table 1 (continued)

Country/area of main application	Catalogues	Notation	Associated polygons
Worldwide	ISC bulletins (ISS before 1964); NEIC bulletins	ISC; NEIC	North Atlantic Ocean and Iceland; ISC also Belorussia, the Caucasus, East Atlantic Ocean and the Canaries, Libya and western Egypt, and SE Mediterranean area

Table 2 Special studies contributing to the Catalogue

Notation	Special study
AA98	Ambraseys and Adams (1998)
Aho83	Ahorner (1983)
AhoP	Ahorner L, personal communication
AJ00	Ambraseys and Jackson (2000)
AKC10	Aktuğ et al. (2010)
Alb04	Albini (2004)
Alt05	Altinok et al. (2005)
Alx08	Alexandre et al. (2008)
Alx90	Alexandre (1990)[1)]
Amb01a	Ambraseys (2001a)
Amb01b	Ambraseys (2001b)
Amb01c	Ambraseys (2001c)
Amb01d	Ambraseys (2001d)
Amb97	Ambraseys (1997)
AP04	Albini and Pantosti (2004)
AP83	Ahorner and Pelzing (1983)
AP85	Ahorner and Pelzing (1985)
AR10	Albini and Rovida (2010)
Arv91	Arvidsson et al. (1991)
AS04	Amstein and Schwarz (2004)
AVA91	Ambraseys et al. (1991)
AWK92	Arvidsson et al. (1992)
Bak97	Baker et al. (1997)
Bat10	Battlo' et al. (2010)
BB03	Bezzeghoud and Borger (2003)
BBG05	Bernardi et al. (2005)
Ben04	Benetatos et al. (2004)
Ben06	Benn et al. (2006)
BLO10	Bungum et al. (2010)
Bor07	Borges et al. (2007)
Buf05	Buforn et al. (2005)
BUM91	Buforn et al. (1991)
Cam10	Camelbeeck et al. (2010)
Cam94	Camelbeeck et al. (1994)
Car03	Cara (2003)
CAS08	Cara et al. (2008)
CSD11	Chevrot et al. (2011)
Dew90	Dewey (1990)
Din02	Dineva et al. (2002)
EiG94	Eisinger and Gutdeutsch (1994)

Table 2 (continued)

Notation	Special study
Erc10	Ercolani et al. (2010)
FGS01	Fischer et al. (2001)
Fit05	Fitzko et al. (2005)
Fre11	Fréchet et al. (2011)
GBM06	Gutscher et al. (2006)
GBM08	Goded et al. (2008)
GCT94	Guidoboni et al. (1994)[2)]
GF02b	Grünthal and Fischer (2002)
GF98a	Grünthal and Fischer (1998a)
GF98b	Grünthal and Fischer (1998b)
GF99	Grünthal and Fischer (1999)
GFS04	Gisler et al. (2004)
GFV99	Grünthal et al. (1999)
GHK99	Gutdeutsch et al. (1999)
GM95	Grünthal and Meier (1995)
Gru05	Grünthal (2005)
Gru08	Grünthal et al. (2008)
GruRA	Grünthal G, renewed analysis
GS01	Grünthal and Schwarz (2001)
Ham11	Hammerl (2011)
Hin05	Hinzen (2005)
HL97	Hammerl and Lenhardt (1997)
HMM11	Harbi et al. (2011)
KL03	Kiratzi and Louvari (2003)
Kli99	Klinger et al. (1999)
KMM57	Kárník et al. (1957)
Kon10	Konstantinou (2010)
Kun86	Kunze (1986)
LH10	Lenhardt and Hammerl (2010)
LK01	Louvari and Kiratzi (2001)
LKP99	Louvari et al. (1999)
Lou00	Louvari (2000)

Table 2 (continued)

Notation	Special study
Lou01	Louvari et al. (2001)
Mei01	Meidow (2001)
Mei95	Meidow (1995)
MG92	Meier and Grünthal (1992)
Mil98	Milutinović (1998)
NG95	Neunhöfer and Grünthal (1995)
OGS06	OGS (2006)
Oli08	Olivera et al. (2008)
Pan00	Panagiotou (2000)
Per09	Perea (2009)
Pet05	Pettenati et al. (2005)
PHW94	Prinz et al. (1994)
Pin09	Pino et al. (2009)
Sch98	Schneider (1998)
SchP	Schneider G, personal communication
SG11	Schellbach and Grünthal (2011)
Sha08	Shaw et al. (2008)
Sti05	Stich et al. (2005)
TB11	Teves-Costa and Batlló (2011)
Tib01	Tibi et al. (2001)
Van10	Vannucci et al. (2010)
VF07	Vilanova and Fonseca (2007)
VG94	Vogt and Grünthal (1994)
Vog91	Vogt (1991)
Vog93a	Vogt (1993a)
Vog93b	Vogt (1993b)
Vog96	Vogt (1996)
VogP	Vogt J, personal communication
YB99	Yilmazturk and Burton (1999)
Zil05	Zilberman et al. (2005)
ZsiP	Zsíros T, personal communication

Table 3 Polygons and the hierarchy of catalogues to which they are associated for different time periods

Polygon	Country/area	Time period	Local catalogue
A	Austria	-1981	ZAMG09L, ZAMG, Ley, Ley96, HHM, ECOS-09
		1982-1993	ZAMG09L, ZAMG, Ley96, HHM, ECOS-09
		1994-1995	ZAMG09L, ZAMG, GRF, ECOS-09
		1996-2006	ZAMG09L, GRF, ECOS-09
AL	Albania	-1968	Sul, Pap
		1969-1999	RKB10, Sul, Pap
		2000-2006	RKB10, Pap09, Gla
AOC	East Atlantic Ocean and the Canaries	-1998	NFO, ISC
		1999-2006	ISC
AOI	North Atlantic Ocean and Iceland	-1990	IMO, ISC, NEIC, FEN09
		1991-2006	IMO07, ISC, FEN09
BG	Bulgaria	-1904	Gleva, Onc, She, Pap, Gla
		1905-1990	Onc, She, Pap, Gla
		1991-Sep. 1998	Onc, Pap, Gla
		Oct. 1998-1999	INFP, Pap, Gla
		2000-2006	INFP, Pap09, Gla
BIH	Bosnia/Herzegovina	-2004	HHM, Gla
		2005-2006	Gla
BL	Belgium and Luxemburg	-1899	ORB07, ORB
		1900-1984	Cam
		1985-2006	Cam, ORB07
BY	Belorussia	-1983	Bob, ISC
		1984-2006	ISC
CAU	Caucasus	-1997	God
		1998-2006	ISC
CH	Switzerland	- 2006	ECOS-09
CRO	Croatia	-2004	HHM
		2005-2006	Gla
CY	Cyprus	-1499	Amb09, GC, GD, FA
		1500-1889	GD, FA
		1890-1895	AA, GD, FA
		1896-1899	Pou, PP, AA, GD, FA
		1900-1963	Pou, PP, AA, AFS, KOERI, GD
		1964-1990	Pou, PP, AA, AFS, KOERI
		1991-1997	Pou, PP, AFS, KOERI
		1998-2005	Pou, AFS, KOERI
		2006	Pou, AFS
CZ	Czech Republic	-1984	CAS, GLM, Gru[a)]
		1985-1991	GFU; Gru91[a)]
		1992-1993	GFU
		1994- 2006	GFU, GRF
D	Germany inside the area 49.6°N-54.8°N, 9.5°E-15.5°E (eastern part)	-1984	Gru
		1985-1991	Gru91
		1992-1993	Ley96
		1994-2006	GRF

Table 3 (continued)

Polygon	Country/area	Time period	Local catalogue
D	Germany outside the area 49.6°N-54.8°N, 9.5°E-15.5°E (western part)	-1899	Ley/Ley96, ORB07, ECOS-09[c)]
		1900-1981	Ley/Ley96, Cam, ECOS-09[c)]
		1982-1984	Ley96, Cam
		1985-1993	Ley96, Cam, ORB07
		1994-2006	GRF, Cam
DZ	Algeria	-1799	Pel, HPP10, Ham, IGN10, IGN[b)]
		1800-2004	HPP10, Ham, IGN10, IGN[b)]
		2005	SMM, HPP10, Ham, IGN10, IGN[b)]
		2006	SMM, HPP10, Ham, IGN10
E	Spain	-1799	IGC1, Pel, IGN10, MzS, SisF10[d)]
		1800-1899	IGC1, IGN10, MzS, SisF10[d)]
		1900-1960	IGC1, IGN10, SisF10[d)]
		1961	IGC1, IGN10, CNP, SisF10[d)]
		1962-1995	IGC1, IGN10, CNP, LDG[d)], SisF10[d)]
		1996-2000	IGC2, IGN10, CNP, LDG[d)], SisF10[d)]
		2001-2002	IGC2, IGN10, LDG[d)], SisF10[d)]
		2003-2004	IGC2, IGN10, LDG[d)], SisF10[d)]
		2005-2006	SMM, IGC2, IGN10, LDG11[d)], SisF10[d)]
F	France	-1961	SisF10, Ley/Ley96, ECOS-09[c)]
		1962-1981	LDG, SisF10, Ley/Ley96
		1982-1993	LDG, SisF10, Ley96
		1994-2004	LDG, SisF10
		2005-2006	LDG11, SisF10
FEN	Fennoscandia, Balticum, Kola Peninsula, and adjacent waters	-1984	WG, Nik, Bob, FEN09
		1985-1988	Nik, Bob, FEN09
		1989-2006	FEN09
GR	Greece	-1968	Pap
		1969-1999	RKB10, Pap
		2000-2005	RKB10, Pap09
		2006	RKB10, RKB11, Pap09
H	Hungary	-1986	Zsi
		1987-1994	Zsi94
		1995-1999	Zsi99
		2000-2005	Tot
		2006	Georisk
I	Italy	-1900	CPTI04
		1000-1900[5)]	CPTI08, CPTI04
		1901-July 2001	CPTI08
		Aug. 2001-2006	CPTI08, INGV
LWE	Libya and western Egypt	-1899	AMA
		1900-1963	AMA, Amb94, Amb84
		1964-1976	AMA, Amb94, Amb84, ISC
		1977-1990	AMA, Amb94, ISC
		1991-1992	AMA, ISC
		1993-2006	ISC

Table 3 (continued)

Polygon	Country/area	Time period	Local catalogue
MA	Morocco	-1799	Pel, Ham, IGN10, IGN[f)]
		1800-1960	Ham, IGN10, IGN[f)]
		1961-2000	Ham, IGN10, IGN[f)], CNP
		2001-2004	Ham, IGN10, IGN[f)]
		2005	SMM, Ham, IGN10, IGN[f)]
		2006	SMM, Ham, IGN10
MD	Moldavia	-1977	KU, KSh, Onc
		1978-1995	KU, Onc
		1996-Sep. 1998	Onc
		Oct. 1998-2006	INFP
MK	Macedonia	-1968	Pap, HHM, She, Gla
		1969-1990	RKB10, Pap, HHM, She, Gla
		1991-1999	RKB10, Pap, HHM, Gla
		2000-2004	RKB10, Pap09, HHM, Gla
		2005-2006	RKB10, Pap09, Gla
NL	The Netherlands	-June 1906	Hou
		July 1906-2006	KNMI09
P	Portugal	-1799	Pel, IGN10
		1800-1960	IGN10
		1961-2000	CNP, IGN10
		2001-2004	IGN10
		2005-2006	SMM, IGN10
PL	Poland	-1482	Pag, Gru[a)]
		1483-1984	GLM, Gru[a)]
		1985-1991	GLM, Gru91[a)]
		1992-1993	GLM
		1994-1995	GLM, GRF
		1996-2006	GRF
RO	Romania	-1986	Onc, Zsi
		1987-1994	Onc, Zsi94
		1995-1998, Sep.	Onc, Zsi99
		1998 Oct.-1999	INFP, Zsi99
		2000-2005	INFP, Tot
		2006	INFP, Georisk
SEM	SE Mediterranean area	-1499	Amb09, Amb06, SDM, KKP, GC, FA, AMA
		1500-1895	Amb06, SDM, KKP, FA, AMA
		1896-1899	Pou, PP, SDM, KKP, FA, AMA
		1900-1963	Pou, PP, KKP, AMA, AFS, KOERI
		1964-1992	Pou, PP, KKP, AMA, AFS, KOERI, ISC
		1993-1997	Pou, PP, KKP, AFS, KOERI, ISC
		1998-2005	Pou, AFS, KOERI, ISC
		2006	Pou, AFS, ISC
SK	Slovakia	-1994	Lab
		1995-1999	Zsi99
		2000-2005	Tot
		2006	Georisk

Table 3 (continued)

Polygon	Country/area	Time period	Local catalogue
SLO	Slovenia	-1981	ZivS, HHM
		1982-2004	HHM
		2005-2006	Gla
TN	Tunisia	- 2005	HPP10, Ham, IGN
		2006	HPP10, Ham
TR	Turkey, lon. ≤ 30.5°E	-1899	Amb02, Pap
		1900-1968	Amb02, KOERI, Pap
		1969-1999	Amb02, KOERI, RKB10, Pap
		2000-2005	KOERI, RKB10, Pap09
		2006	Kal, RKB10, Pap09
TR	Turkey, lon. > 30.5°E	-1499	Amb09, SDM, KKP, GC, FA, TR-GSHAP, God, KU
		1500-1895	SDM, KKP, FA, TR-GSHAP, God, KU
		1896-1899	Pou, PP, SDM, KKP, FA, TR-GSHAP, God, KU
		1900-1995	KOERI, Pou, PP, KKP, God, KU
		1996-1997	KOERI, Pou, PP, KKP, God
		1998-1999	KOERI, Pou
		2000-2005	KOERI, Pou
		2006	Kal, Pou
UA	Ukraine	-1899	KU, KSh, Zsi, Onc
		1900-1977	KU, KSh, Zsi, Onc, KOERI
		1978-1986	KU, Zsi, Onc, KOERI
		1987-1994	KU, Zsi94, Onc, KOERI
		1995	KU, Zsi99, Onc, KOERI
		1996-Sep. 1998	Zsi99, Onc, KOERI
		Oct. 1998-1999	Zsi99, INFP, KOERI
		2000-2005	Tot, INFP, KOERI
		2006	Georisk, INFP
UK	United Kingdom and adjacent waters	-1961	MS, Mus, SisF10
		1962-1993	MS, Mus, LDG
		1994-2004	MS, Mus06, LDG
		2005	MS, Mus06, LDG11
		2006	MS, LDG11
YU	Serbia/Montenegro	-1998, Sep.	Onc, HHM, Gla
		1998, Oct.-2004	INFP, HHM, Gla
		2005-2006	INFP, Gla

[a] Part of polygon inside the area 49.6°N–54.8°N, 9.5°E–15.5°E (with first priority)
[b] IGN is applied only if lat. <32°N or lon. >6°E, i.e., outside the area covered by the IGN10 catalogue
[c] Selected events
[d] An LDG, LDG11, or SisF10 entry in the polygon E (Spain) enters EMEC only if there is a corresponding IGC1, IGC2 or IGN10 entry in the polygon F (France)
[e] CPTI08 data in the region 41.5°N–43.5°N, 11°E–15°E; CPTI04 outside this region
[f] IGN is applied only if lat. <32°N, i.e., outside the area covered by the IGN10 catalogue

Table 4. Algorithms for calculation of M_w for the different catalogues - the southern part (the relations refer to Section 3.3). Original M_w (or M_0) values usually have highest priority. In formulae containing the focal depth, h = 10 km is set if no value is given

Catalogue	Priority	Original size entity	Algorithm	Reference/Comment
Sulstarova et al. (2000)	1	M_S	Relation (1)	
Harbi et al. (2010)	1	M_S	Relations (3)	
	2	I_0	$I_{max} = I_0$ & Relation (2)	
Hamdache et al. (2010)	1	M_w		
Nunes et al. (2004)	1	M_w		All magnitudes are taken from Borges et al. (2007) or ISC bulletins
	2	M_S	Relation (15)	
	3	m_b	Relation (8)	
Glavatović (2009)	1	M_L	Croatia: $M_w = 0.408 + 0.930 \cdot M_L$ $\sigma = 0.209$	Glavatović B, personal communication
			Other polygons: $M_w = 0.474 + 0.933 \cdot M_L$ $\sigma = 0.215$	Glavatović B, personal communication
Glavcheva (2004)	1	I_0	Relation (5) & Relation (4)	
Godzikovskaya (2001)	1	M_L	Relation (6)	
Shebalin et al. (1998)	1	I_0	Relation (5) & Relation (4)	
Herak et al. (1996)	1	M_L	Relation (4)	M_L and M_m not used before 1908
	2	M_m	$M_L = M_m$	
	3	I_0	Relation (5)	
	4	I_{max}	$I_0 = I_{max}$	
Galanopoulos and Delibasis (1965)	1	I_0	Relation (7) & Relations (3)	
Ambraseys and Adams (1993)	1	M_S	Relations (3)	
	2	m_b	Relation (8)	
Papazachos and Papaioannou (1999)	1	M_S	Relations (3)	
Papaioannou (2001)	1	M_w		
Ambraseys et al. (1994)	1	M_S	Relations (3)	
	2	m_b	Relation (8)	
	3	I_0	Relation (7)	
LDG (2005)	1	M_{Lf}	Relations (9) & Relation (4)	
LDG (2011)	1	M_{Lf}	Relations (9) & Relation (4)	
BRGM-EDF-IRSN (2010)	1	I_0	Relation (10)	
Papazachos et al. (2003)	1	M_w		
Papazachos et al. (2009)	1	M_w		
Roumelioti et al. (2010)	1	M_w		
Roumelioti et al. (2011)	1	M_w		
Martínez Solares (2003)	1	M_w		
IGN (2005)	1	m_b	Relation (8)	
	2	m_bLg	Relation (11)	
	3	I_0	$I_{max} = I_0$ & Relation (2)	
	4	I_{max}	Relation (2)	
IGN (2010)	1	m_bLg	Relation (11)	
	2	I_0	$I_{max} = I_0$ & Relation (2)	
IGC (2009a)	1	I_0	Relation (2)	
IGC (2009b)	1	M_L	$m_bLg = M_L$ & Relation (11)	

Table 4. (continued)

Catalogue	Priority	Original size entity	Algorithm	Reference/Comment
Carrilho, pers. communication (2009)	1	M_L	$M_w = M_L$	
Stich et al. (2010)	1	M_w		
CPTI Working Group (2004)	1	M_w		
CPTI Working Group (2008)	1	M_w		
INGV (2007)	1	M_L	Relation (12)	M_L and M_d not used before August 2001
	2	M_d	Relation (13)	
Khair et al. (2000)	1	M_S	Relations (3)	
	2	I_0	Relation (7)	
Abdallah et al. (2004)	1	M_L	Relation (4)	
Sbeinati et al. (2005)	1	M_S	Relations (3)	
Ambraseys (2006)	1	M_S	Relations (3)	
Feldman and Amrat (2007)	1	M_S	Relations (3)	
	2	M_L	Relation (14)	
	3	I_0	Relation (7)	
Ambraseys (1984)	1	M_S	Relations (3)	
	2	m_b	Relation (8)	
Ambraseys (1994)	1	M_S	Relations (3)	
Guidoboni and Comastri (2005)	1	I_0	Relation (7) & Relations (3)	
Ambraseys (2009)	1	M_S	Relations (3)	
Peláez et al. (2007)	1	M_w		
Oncescu et al. (1999)	1	$\mathrm{M_w}$		
INFP (2009)	1	M_w		
Turkish GSHAP Catalogue (2000)	1	M_w		
Ambraseys (2002)	1	M_0	Hanks and Kanamori (1979)	
Kalafat et al. (2009)	1	M_w		
Kalafat et al. (2011)	1	M_w		
ISC bulletins	1	M_w		
	2	M_S	Relation (15)	
	3	m_b	Relation (8)	

Originally given M_w (or M_0) values, and derived M_w values from entries in special studies, usually have the highest priority. In formulae containing the focal depth, a default value of 10 km is set if no value is given

Table 5. Algorithms for calculation of M_w for the different catalogues - the northern part (when not quoted as "this study", the relations refer to the GWS09 study). Original M_w (or M_0) values usually have highest priority. In formulae containing the focal depth, h = 10 km is set if no value is given

Catalogue	Priority	Original size entity	Algorithm	Reference/Comment
Lenhardt (1996), ZAMG (2009)	1	M_L	Relation (2)	
	2	I_0	Relation (9)	
Verbeiren et al. (1995), ORB (2009), Camelbeeck (2009)	1	M_L	Relation (2)	
	2	I_0	Relation (10)	
Boborikin et al. (1993)	1	I_0	Relation (11) & Relation (2)	

Table 5. (continued)

Catalogue	Priority	Original size entity	Algorithm	Reference/Comment
Lenhardt (1996), ZAMG (2009)	1	M_L	Relation (2)	
	2	I_0	Relation (9)	
Verbeiren et al. (1995), ORB (2009), Camelbeeck (2009)	1	M_L	Relation (2)	
	2	I_0	Relation (10)	
Boborikin et al. (1993)	1	I_0	Relation (11) & Relation (2)	
Herak et al. (1996)	1	M_L	Relation (4) of this study	M_L and M_m not used before 1908
	2	M_m	$M_L = M_m$	
	3	I_0	Relation (5) of this study	
	4	I_{max}	$I_0 = I_{max}$	
Schenková (1993)	1	M_L	Relation (2)	
	2	I_0	Relation (12)	
Zedník (2005)	1	M_L	Relation (2)	
	2	I_0	Relation (12)	
Nikonov (1992)	1	I_0	Relation (11) & Relation (2)	
FENCAT (2009)	1	M_L	Relation (2)	
	2	M_S	$M_w = M_S$	Grünthal and Wahlström (2003)
	3	m_b	Relation (6)	
	4	I_0	Relation (11)	
	5	M_d	$M_L = M_d$	Grünthal and Wahlström (2003)
Wahlström and Grünthal (1994)	1	M_L	Relation (2)	
	2	I_0	Relation (11)	
LDG (2005, 2011)	1	M_{Lf}	Relations (9) & Relation (4) of this study	
BRGM-EDF-IRSN (2010)	1	I_0	Relation (10) of this study	
Grünthal (1988)	1	M_L	Relation (2)	
	2	I_0	Relation (12)	
Grünthal (1991)	1	M_L	Relation (2)	
Leydecker (1986, 1996)	1	M_L	Relation (2)	
	2	I_0	Relation (12)	
SZGRF (2010)	1	M_L	Relation (2)	
Zsíros et al. (1990), Zsíros (1994)	1	M_L	Relation (2)	
	2	I_0	$M_L = 0.6\ I_0 + 1.8\ \log h - 1.0$	Zsíros (1983) after Gutenberg and Richter (1942); Zsíros T, personal communication
Zsíros (1999), Tóth et al. (2006), Georisk (2009)	1	M_L	Relation (2)	
IMO (2007a, b)	1	M_L	Relation (16) of this study	
CPTI Working Group (2004, 2008)	1	M_w		
INGV (2007)	1	M_L	Relation (12) of this study	M_L and M_d not used

Table 5. (continued)

Catalogue	Priority	Original size entity	Algorithm	Reference/Comment
	2	M_d	Relation (13) of this study	before August 2001
Houtgast (1995)	1	M_L	Relation (2)	
	2	I_0	Relation (10)	
KNMI (2009)	1	M_L	Relation (2)	
Pagaczewski (1972)	1	I_0	Relation (12) & Relation (2)	
Guterch and Lewandowska-Marciniak (2002)	1	M_L	Relation (2)	
	2	I_0	Relation (12)	
Oncescu et al. (1999), INFP (2009)	1	M_w		
Labak (1998)	1	M_L	Relation (2)	
	2	M_S	$M_w = M_S$	
	3	I_0	$M_S = 0.55\ I_0 + 0.95$	Labak (1998) Labak (1998) applies different formulae for different geographical subregions – see Grünthal and Wahlström (2003) for details
Živčić (1993)	1	M_L	Relation (12) of this study	see Chapter 4
	2	I_0	Relation (5) of this study	
Fäh et al. (2011)	1	M_w		
Musson (1994, 2006)	1	M_L	Relation (2)	
Musson and Sargeant (2007)	1	M_w		
Kondorskaya and Shebalin (1982)	1	I_0	Relation (11) & Relation (2)	
Kondorskaya and Ulomov (1999)	1	M_w		
ISC bulletins	1	M_W		
	2	M_S	Relation (15) of this study	
	3	m_b	Relation (8) of this study	
NEIC bulletins	1	M_S	Relation (5)	
	2	m_b	Relation (6)	