Title	Proposal for unique magnitude and amplitude nomenclature
Author	Peter Bormann (formerly GeoForschungsZentrum Potsdam,Telegrafenberg, D-14473 Potsdam, Germany); E-mail: pb65@gmx.net
Version	June 2013; **DOI: 10.2312/GFZ.NMSOP-2_IS_3.2**

page

1 Introduction

Besides location the magnitude is the most frequently determined and important parameter to characterize a seismic source and for earthquake statistics, aimed at assessing seismic activity and hazard, even the most important one. Classical magnitudes are based on the measurement of amplitudes and periods of seismic waves which also allow inferences on the structural and physical properties of the propagation medium. The usefulness of amplitude, period and magnitude data for application and research essentially depends on their long-term availability, homogeneity, reproducibility, compatibility and reliability. But these properties require globally agreed and applied measurement, calculation and data representation (nomenclature) standards. Inconsistencies in these crucial aspects increase data scatter, may even results in systematic biases, wrong inferences and thus strongly reduce the value of such data. This the more so since it has become obvious that no single magnitude is able to characterize the "sizes" of an earthquake in all of their geometric, kinematic and dynamic aspects. Better characterization of different aspects of earthquake size, desirable in order to better anticipate associated earthquake effects, requires a complementary set of magnitude types. Although this is outlined in detail in sections 3.1.2, 3.2 and 3.3 of Chapter 3 we summarize here some of the essential related aspects in order to better appreciate the need for a sufficiently detailed and unambiguous magnitude nomenclature.

The effort by Gutenberg and Richter (1954) to classify in "Seismicity of the Earth" earthquakes of different size by just ONE unspecified magnitude value M was one of the outstanding seismological milestones of the 20th century. It is now recognized, however, that a relative-size classification by a single type of magnitude implicitly presupposes an over-simplified assumption of the similarity of the source process of all earthquakes and thus of their spectra, as, e.g., in Figure 1. The condition of source similarity (see section3.3.1 of Chapter 3) holds only under certain conditions of geometric and dynamic similarity, such as constant stress drop $\Delta\sigma$. But for individual earthquakes $\Delta\sigma$ may vary by several orders of magnitude and thus the corner frequency $\mathbf{f_c \sim(\Delta\sigma)^{1/3}}$ of the source spectrum up to a factor of 10 or even more. This means, however, that for a given static seismic moment or rupture "size" the ratio between released high and low frequency energy and thus the earthquake's potential to cause shaking damage or to generate a tsunami is not constant. Therefore, magnitudes based on amplitudes measured in either the long-period or more medium to short-period range of the source spectrum may be rather different and thus the conclusions with respect to the size or "strength" of an earthquake and its related hazard potential (e.g., Choy and Kirby, 2004; Di Giacomo et al., 2008 and 2010; Bormann and Di Giacomo, 2011).

Abe and Kanamori were aware of this and therefore "decomposed" the Gutenberg-Richter (1954) and later published unspecified M for large earthquakes on the basis of Gutenberg's original note pads and other sources into the original Gutenberg (1945a) 20 s surface-wave magnitude Ms and the more broadband 2-20s body-wave magnitude mB (Gutenberg and Richter 1956) [Abe (1981), (1982), and (1984); Abe and Kanamori (1979) and (1980)]. And the short-period "generic" magnitudes such as teleseismic mb and local ML, which are based on amplitudes at frequencies in the range 0.3 Hz < f < 10 Hz, reveal in their relationship to the long-period event magnitudes even more clearly such hazard relevant shifts in source spectra corner frequencies for equal seismic moments away from or towards frequencies that are of particular interest to earthquake engineers (see Figures 1 and 2 below).

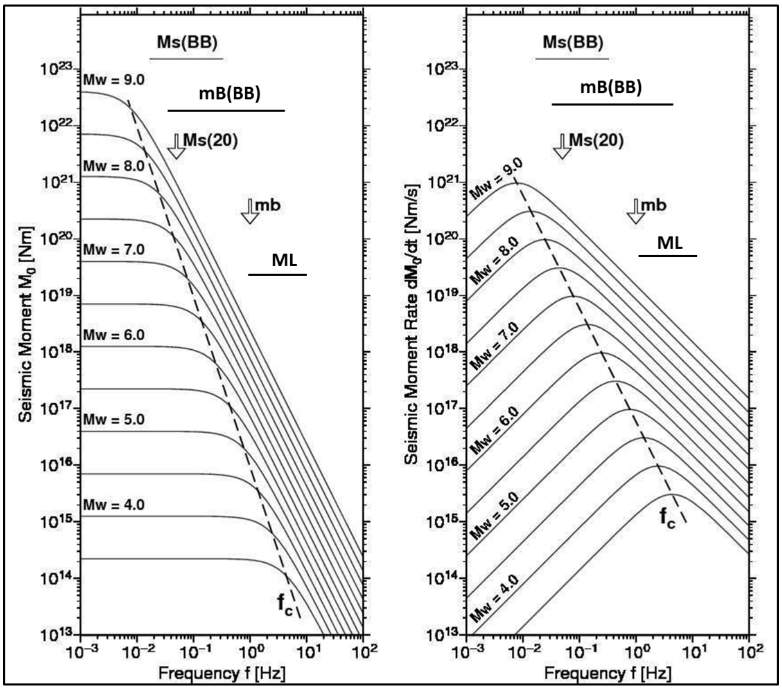

Figure 1 Left: "Source spectra" of a simplified "omega-squared" model, modified according to Bormann et al. (2009). Plotted are the ground displacement amplitudes A for "average" seismic shear sources with constant stress drop $\Delta\sigma$ = 3 MPa as a function of frequency *f*, scaled to seismic moment M_0 and the equivalent moment magnitude Mw. **Right:** The same as left, but for ground motion velocity amplitudes V, scaled to seismic moment rate and Mw.

Note that the maximum of seismic energy $E_S \sim V^2$ is radiated around the corner frequency f_c. The open arrows point to the center frequencies on the abscissa at which the 1 Hz body-wave magnitude m_b and the 20 sec surface-wave magnitude Ms(20), respectively, are determined. The horizontal interval bars mark the range of frequencies within which broadband body- and surface-wave magnitudes mB(BB) and Ms(BB) and the local magnitude ML should be measured.

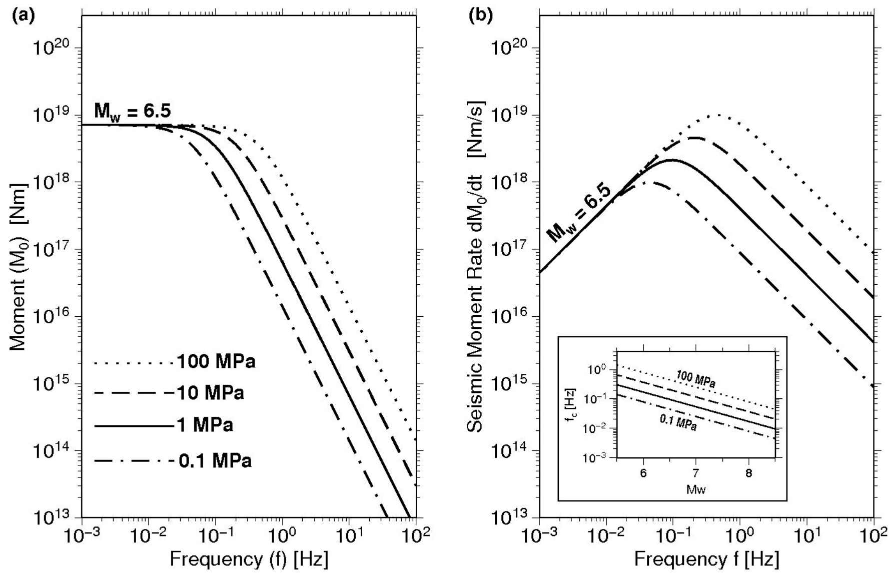

Figure 2 Far-field displacement and (b) velocity source spectra scaled to seismic moment and moment rate, respectively, for a model earthquake with Mw = 6.5 but different stress drop $\Delta\sigma$ in units of MPa. The spectra were calculated based on the same model assumptions as in Figure 1. The inset in Figure 2 (b) shows the variation of the corner frequency f_c obtained according to the Brune (1970, 1971) equation $f_c = c\, v_s\, (\Delta\sigma/M_0)^{1/3}$ in a wider range of Mw for varying $\Delta\sigma$ in increments of one order between 0.1 and 100 MPa. (Copy of Fig. 2, p. 415 in Bormann and Di Giacomo, 2011, J. Seismology, **15** (2), 411-427; © Springer Publishers).

This questions the whole currently still dominating concept of the seismic hazard community of "unifying" magnitudes in earthquake catalogs to moment magnitudes with M_0 being a purely static-geometric parameter of rupture size corresponding to the zero-frequency plateau amplitude in Figure 1. This neglects the "dynamic variability" of the individual rupture process which is reflected, e.g., in the position of the corner frequency towards higher frequencies for equal seismic moment (Figure 2) and in the empirically proven variability of the decay of spectral displacement amplitudes towards higher frequencies with slopes varying between about 1 and 5 for $f \gg f_c$. Moreover, for the majority of instrumentally recorded events no accurate direct seismic moment measurements are available. This necessitates to estimate inferior Mw proxies via often rather noisy empirical correlation relationships between proper Mw with classical magnitudes (see ISC-GEM project: Global Instrumental Earthquake Catalogue (1900-2009), Di Giacomo et al., 2013). No single value magnitude type, including the supposedly non-saturating Mw, will ever allow to quantify both the (geometric) "size" and the seismic radiation efficiency and thus the potential "shaking strength" of an earthquake. Some of the currently common Mw procedures do not even fulfill the primary justification for having Mw as a non-saturating complement/extension to Ms (compare Mwp, Mwb and Mwc in Table 1).

Therefore, future improvements in seismic hazard assessment necessitate a multi-magnitude approach. But this requires a deeper understanding of the physical relevance of the different magnitude scales, of their mutual relationship, as well as more "clean" complementary high quality data that have been measured over long time spans according to internationally agreed standards or otherwise clearly defined procedures, linked to easily accessible documentation published with unique nomenclatures that allows to unambiguously identify and correctly use such data.

The classical generic magnitudes are ML (Richter, 1935), Ms (Gutenberg, 1945a; since 1967 using the IASPEI standard Ms formula according to Vaněk et al., 1962), mB (Gutenberg 1945 b and c) and mb (Engdahl and Gunst, 1966), both using the Gutenberg and Richter (1956) calibration function for mB although mb as a more band-limited and high-frequency magnitude means a physically different thing. According to Figure 1 these "generic" magnitudes cover the range between 3 and 9 reasonably well. They are also the most frequently measured and at data centers collected magnitudes, with the exception of mB. Despite its fundamental importance (see Chapter 3, section 3.2.5.2) the determination of mB had been terminated in most parts of the world with the deployment of the narrowband instrumentation of the World-wide Seismic Standard Network (WWSSN) with peak magnifications between 1 and 2 Hz and 10 to 20 s, respectively (see Chapter 3, Fig. 3.20).

However, the procedures for measuring "generic" mb and Ms have not been so unique as global standards would have required for so widely used magnitudes. Different recording responses, measurement time windows after the P-onset and calibration functions were applied at different agencies or changed with time, resulting in increased data scatter, some systematic distance and/or magnitude-dependent biases and also in mixing of sometimes incompatible data. E.g., in the extreme case of the great Sumatra-Andaman Islands Mw9.3 earthquake of 26 December 2004 the following values for mb were reported by some of the leading seismological agencies: mb(IDC/CTBTO) = 5.7, mb(CENC, China) = 6.4, and mb(NEIC) = 7.2. Such differences for magnitudes of the same type and code name are not acceptable. Less dramatic but still significant are both distance- and magnitude-dependent biases up to 0.3-0.5 m.u. when using the IASPEI standard Ms formula, which had been derived for scaling A/T ratios in a wide range of periods between 2 and about 25 s, for scaling 20 ± 2 s surface waves only. Facts, causes and the effects of lacking standards have been outlined and discussed in detail in Chapter 3.

Besides these classical magnitudes, which have been determined already for decades, mostly from analog records, others, such as the moment magnitude Mw and the energy magnitude Me, require digital broadband recordings and their spectral analysis or integration in the time-domain. Up to now they have been regularly determined only by a few specialized data centers. However, the broader use of these modern magnitude concepts is rapidly growing.

Short-comings of the current procedures to determine and annotate classical and also newly proposed magnitudes are, e.g.:

- Although already earlier IASPEI recommendations, published in the old Manual of Seismological Practice (Willmore, 1979), aimed at
  - expending and homogenizing magnitude measurements and nomenclature,
  - determining magnitudes from all seismic waves and component readings for which calibration functions are available,

- indicating the type of instruments and component on which the parameter readings (amplitudes, periods and/or duration) for a given magnitude value were made,

these recommendations have become common practice only in a few countries;

- Body-wave magnitudes are nowadays determined from *vertical component* P-waves only although Gutenberg and Richter (1956) published body-wave calibration functions Q(Δ, h) for both vertical and horizontal component readings of P and PP as well as for horizontal component readings of S;
- mb has been determined since the 1960s at "western" data centers and most stations and networks only from *short-period* recordings although the body-wave Q-functions have been derived mainly from medium- to long-period, more or less broadband recordings. Only some "eastern" countries, such as the former Soviet Union and its allies, or now in Russia, and in China, have seismograph networks continued to determine the classical Gutenberg and Richter (1956) medium-period broadband magnitude mB (m_B) as well;
- Some other specialized international data centers such as the IDC of the CTBTO use for mb and Ms determination other than the common filter responses, measurement time-windows and/or calibration functions, resulting in the more or less strong incompatibility of their mb and/or Ms values (for comparison of mb(IDC) and mb(NEIC) see Murphy and Barker, 2003; Granville et al., 2002 and 2005; Bormann et al., 2007 and 2009);
- Currently still dominating "generic" magnitude nomenclature provides no hints to data users about such possible incompatibilities of magnitudes of supposedly the "same kind";
- Calculating event mb averages, as done, e.g., at the ISC for many years from such incompatible NEIC and IDC mb data with an average (although magnitude-dependent) bias of about 0.4 m.u. is incorrect;
- Long-term continuity of classical standard magnitudes is a matter of high priority and necessitates proper scaling of modern magnitudes based on digital data with their forerunners that were based on analog data analysis. This has not always been done. Jumps in detection thresholds and catalog completeness due to unknown or not properly documented changes in measurement procedures may result in wrongly inferred changes of the relative frequency of occurrence of weaker and stronger earthquakes and be misinterpreted as changes in the seismic regime and the time-dependent seismic hazard (see case study for Southern California Ml by Hutton and Jones, 1993; also Habermann, 1995). This is not acceptable.

In order to overcome or at least mitigate these problems IASPEI established in 2001 within its Commission on Seismic Observation and Interpretation (CoSOI) a Working Group on Magnitude Measurements (in the following for short termed the WG). It has been entrusted with critically screening the most common procedures of amplitude measurement and magnitude determination practiced at seismic stations and various data centers and proposing measurement and nomenclature standards. Its members were: J. Dewey and P. Bormann (co-chairs), P. Firbas, S. Gregersen, A. Gusev, K. Klinge, B. Presgrave, L. Ruifeng, K. Veith, W.-Y. Kim, H. Patton, R. A. Uhrhammer, I. Gabsatarowa, J. Saul, and S. Wendt. The essential results are summarized below.

2 Seismic parameter data formats

The Willmore (1979) proposal for reporting magnitude parameter data was still based on the classical and costly telegraphic format. Modern seismic networks can provide far more information and low-cost e-mail transmissions and data exchanges via Internet have eliminated the restrictions and high costs of old telex messages. Consequently, as outlined in Chapter 10, most seismic parameter data have been stored and exchanged since at least 1990 in modern formats that are more complete, simpler and usually more transparent than the telegraphic format. But only rather recently agreement has been reached on some modern generally accepted standard formats for reporting parameter data.

A major step forward in this direction was made by the Group of Scientific Experts (GSE) organized by the United Nations Conference on Disarmament. It developed GSE/IMS formats (see Chapter 10, section 10.2.4) for exchanging parametric seismological data in tests of monitoring the Comprehensive Test Ban Treaty (CTBT). Seismological research, however, has a broader scope than the International Monitoring System (IMS) for the CTBT. Therefore, a new **IASPEI Seismic Format** (ISF; http://www.isc.ac.uk/standards/#dataformats), which is compatible with the IMS format but with essential extensions, has been developed and adopted by the Commission on Seismological Observation and Interpretation (CoSOI) of the International Association of Seismology and Physics of the Earth´s Interior (IASPEI) at its meeting in Hanoi, August 2001. Examples for ISF compatible parameter data plots are given in the Information Sheet IS 10.2 and in Table 1 below. Both the International Seismological Centre (ISC) and the USGS National Earthquake Information Center (NEIC) present, exchange and archive their parameter data in the ISF format.

With respect to magnitude data, however, the ISF format limits the length of the magnitude names (nomenclature) to 5 letters/symbols. Further specification is however possible in combination with the related “amplitude phase name” which allows for more letters/symbols.

Since 2001 new developments have been introduced due to technology changes. The introduction of XML, i.e., an Extensible Markup Language, allows to present hierarchic structured data in form of text files and thus enables a platform and implementation independent exchange of data between computer systems, especially via Internet. This again resulted in the requirement of a standard scheme for the representation of seismological parameter data. QuakeML, initiated and maintained by the Swiss Seismological Service, is such a collaborative effort. Detailed documentation and contact addresses are accessible via https://quake.ethz.ch/quakeml/QuakeML. The latest version 1.2 has been released only on 14 Febr. 2013 with the basic event descriptions mostly stable as of this writing but with the related metadata presentation still being under development.

QuakeML does not specify a magnitude or a magnitude name and its length. This is considered to be the duty of other standards. In QuakeML a magnitude name may be arbitrarily long. Rather, QuakeML permits to describe in detail how the amplitudes, periods, duration or other magnitude-relevant parameters have been measured by whom, when, where, and how, i.e., according to which procedure. QuakeML also allows to describe how the station and event magnitudes have been calculated from the measurement parameters, taking into account station counts and azimuthal gaps, the evaluation mode and statistics, how moment tensors have been determined etc. For details see sections 3.5.5 to 3.5.9 in Euchner and Schorlemmer (2013).

This latest development has to be closely followed up further because it might offer a comfortable and flexible complement to the limitations of the fixed ISF magnitude format for allowing the badly needed sufficiently detailed and unique description of the procedure of magnitude determination in the metadata.

3 IASPEI standard magnitudes

By May 2002, the WG reached the following first general understanding:

- the "generic" magnitudes ML, mb and Ms are most common, and related data for their determination are regularly reported by seismic stations and networks/arrays to international data centers;
- these "generic" magnitude names are widely accepted and applied by a diversity of user groups. Therefore, their **names should be kept when reporting magnitude data to a broader public.**
- this nomenclature is also considered to be adequate for many scientific communications, but **on the understanding that these magnitudes have been determined according to well established rules and procedures;**
- the WG realized, however, that different data producers make their related measurements for determining these magnitudes on records with different response characteristics and bandwidths, on different components and types of seismic waves and sometimes also use different period and measurement time windows. This increases data scatter, may produce baseline shifts and prevents long-term stable, unique and reproducible magnitude estimates that are in tune with original definitions, earlier practices and inter-magnitude conversion relationships;
- this situation is no longer acceptable, therefore, the WG felt a **need to introduce an obligatory more "specific" nomenclature** for reporting magnitude, amplitude (and related period) measurement data for databases and for use **in scientific correspondence and publications in which the ambiguity inherent in the "generic" nomenclature might cause misunderstanding;**
- the WG notes that the recently accepted IASPEI Seismic Format (ISF, see section 10.2.5 of Chapter 10) and the flexibility of internet data communication allow such specifications in nomenclature and even complementary remarks to be reported to international data centers, and to store and retrieve such data from modern relational databases.

Therefore, the WG proposed within its mandate:

a) standard measurement procedures for amplitude-based magnitudes that agree as far as possible and reasonable with magnitudes of the same type that have been measured for decades from analog seismograms according to original definitions,

b) that promote the best possible use of the advantages of digital data and processing,

c) a unique nomenclature for these standard magnitudes and related amplitude data which is compatible with the IASPEI Seismic Format (ISF) and allows an unambiguous discrimination between standard and non-standard data;

d) a questionnaire for dissemination (and deposition of the responses) by the ISC to seismic parameter data reporting stations and agencies on their specific procedures for recording and analyzing data relevant for magnitude calculation (see IASPEI, 2013: http://www.iaspei.org/commissions/CSOI/Summary_WG_recommendations_20130327.pdf and Annex 1 in IS 3.4)

with the main aim to

e) minimize bulletin magnitude biases that result from procedure-dependent single-station or network magnitude biases;

f) increase the number of seismological stations and networks with well-defined procedures;

g) avail at the ISC as the final authoritative depositary of the most complete and accurate seismological parameter data set also a directory of all standard and agency-specific procedures and nomenclatures;

h) increase essentially the accuracy, representativeness, homogeneity and long-term global compatibility of magnitude data and their usefulness for seismic hazard assessment and research.

First recommendations for standard magnitude measurement procedures were published by IASPEI (2005). The latest update is posted under IASPEI (2013). The following standard types of magnitudes have been proposed and the procedures of their determination been specified. For more details, also on filter parameters and calibration functions, distance ranges of applicability, admissible deviations etc., see NMSOP-2, Chapter 3, sections 3.2.3.2, 3.2.4, 3.2.5 and IS 3.3:

- Local magnitude **ML** according to the Hutton and Boore (1987) formula measured on simulated Wood-Anderson records according to the parameter specifications of Uhrhammer and Collins (1990);
- Regional magnitude mb(Lg) = **mb_Lg** based on amplitude measurement of the Lg phase in a defined group-velocity window on WWSSN-SP simulated records;
- Short-period body-wave magnitude **mb** by measuring on simulated WWSSN-SP records the largest amplitude with periods < 3 s in the whole P-wave train prior to PP and calibrating it with the Gutenberg and Richter (1956) calibration function for vertical component P waves;
- Broadband body-wave magnitude mB(BB) = **mB_BB** by measuring the largest velocity amplitude in the whole P-wave train on velocity-broadband records in a wide period range between 0.2 s and 30 s and calibrating it as for mb;
- Surface-wave magnitude Ms(20) = **Ms_20** by measuring the largest amplitude in the Rayleigh-wave train on simulated long-period WWSS-LP records at periods between 18 s and 22 s and calibrating A/T with the IASPEI standard Ms formula according to Vaněk et al. (1962) in the distance range between 20° and 160°;
- Surface-wave magnitude Ms(BB) = **Ms_BB** by measuring the largest velocity amplitude in the Rayleigh-wave train on broadband velocity records in a wide range of periods between 3 s and 60 s in the wider distance range between 2° and 160° and calibrating them with the Vaněk et al. (1962) formula for Ms. This formula had in fact been developed on the basis of data in this wider range of period and distances.

With the exception of standard ML, which is measured on single horizontal components, not vector summed but each counted as an individual magnitude datum, all other standard magnitudes are measured on vertical component records only.

For international data exchange and archiving the magnitude names (nomenclature) should be written in the maximum 5-letter code (as above in **bold**) reserved in the ISF format for magnitude data.

In order to associate unambiguously the measured amplitudes and periods with the respective standard magnitudes the following standard nomenclature in the ISF format has been agreed upon for the so-called "amplitude phase names" (which may exceed 5 letters):

IAML, IAmb, IAmb_Lg, IAMs_20, IVmb_BB and IVMs_BB.

I stands for IASPEI International standard, A for displacement amplitude in units of nm and V for velocity amplitude in nm/s.

4 Magnitude and amplitude nomenclature applied by the USGS-NEIC

The USGS/NEIC runs since 2006 its new fully automatic HYDRA location and analysis system. It measures routinely in experimental mode the amplitudes and periods related to all recently recommended IASPEI standard magnitudes according to the filter and measurement procedures outlined in IASPEI (2013) and IS 3.3. These data are presented in the event and station parameter plots according to the recommended standard nomenclature (see previous section) for amplitude phase names and related magnitudes (Table 1).

Additionally, HYDRA measures some agency-specific magnitudes, amongst them several versions of moment magnitude based on broadband body or surface waves (Mwb according to ???, Mwc according to ???, and Mwp according to ???), a time-domain, variable-period surface-wave magnitude Ms(VMAX) for application at regional and teleseismic distances according to a procedure proposed by Bonner et al. (2006) and a not specified average event magnitude M out of all these data (Table 1). All these magnitudes are given in the *maximum 5-letters* ISF format, which required to shorten, e.g., Ms(VMAX) to Ms_VX.

Table 1 Cut-out from an event and station parameter plot in IMS1.0/ISF parameter format produced by the USGS/NEIC HYDRA automatic location and analysis system.

```
BEGIN IMS1.0
MSG_TYPE DATA
MSG_ID 30000Z9N_43 HYDRA_ORANGE

DATA_TYPE BULLETIN IMS1.0:SHORT
The following is an UNCHECKED, FULLY AUTOMATIC LOCATION from the USGS/NEIC Hydra System
Event    15694
   Date       Time        Err   RMS Latitude Longitude  Smaj  Smin  Az Depth
2009/09/29 17:48:13.26   2.94  1.45 -15.5267 -172.0703   6.5   5.8 133  28.4

Magnitude  Err Nsta Author      OrigID
Mb_Lg  6.0 0.5    1 NEIC             0
Ms_VX  8.2 0.1   23 NEIC             0
mb     7.2 0.0  243 NEIC             0
Mwp    7.8 0.0  179 NEIC             0
mB_BB  7.7 0.0  246 NEIC             0
Ms_BB  8.3 0.1  134 NEIC             0
Mwb    7.7 0.0   97 NEIC             0
```

```
Ms_20   8.0 0.0   161 NEIC              0
Mwc     8.1 0.0    71 NEIC              0
M       7.9 0.1 1064 NEIC               0
Mwp     7.9 0.0     4 PMR               0

Sta      Dist  EvAz Phase        Time             Amp     Per  Magnitude    ArrID
KNTN   12.68   1.6 IAmb_Lg  17:55:00.090       7785.9  0.98   Mb_Lg  6.0 BHZIU00
KNTN   12.68   1.6 IVMs_BB  17:56:03.398    2169276.1 10.00   Ms_BB  7.7 LHZIU00
TARA   22.39 317.2 P        17:53:11.829                                 BHZIU00
TARA   22.39 317.2 IAmb     17:53:45.055      12080.1  1.25   mb     7.2 BHZIU00
TARA   22.39 317.2 MMwp     17:53:53.279    1728974.9 41.45   Mwp    7.6 BHZIU00
TARA   22.39 317.2 IVmB_BB  17:54:07.329     206688.6  5.40   mB_BB  7.8 BHZIU00
OUZ    23.45 210.6 P        17:53:22.710                                 HHZNZ10
OUZ    23.45 210.6 IAmb     17:53:47.450      11261.4  1.22   mb     7.3 HHZNZ10
OUZ    23.45 210.6 IVmB_BB  17:53:49.880     314772.2  9.74   mB_BB  8.0 HHZNZ10
OUZ    23.45 210.6 IAMs_20  18:01:02.679       6314.2 20.00   Ms_20  8.1 LHZNZ10
OUZ    23.45 210.6 IVMs_BB  18:02:47.679    3821858.4 16.00   Ms_BB  8.4 LHZNZ10
OUZ    23.45 210.6 AMs_VX   18:02:54.449    6326077.5 15.00   Ms_VX  8.3 LHZNZ10
```

This way of an unambiguous presentation and annotation of magnitude and related amplitude data may serve as a good example for other seismological agencies as well, provided that the data users are somehow guided, e.g., via some explanatory pages that accompany data reports or bulletins and link to relevant documents/publications in which the respective procedures and - hopefully - also the relationship of this type of magnitude to other well established and widely used magnitudes are explained (see next section 5). Regrettably, the parameter data plot in Table 1 does not allow to say in which component the measurement has been made. One just has to know that all above amplitudes and magnitudes have been measured exclusively on the vertical component. However, standard ML should be measured on either the N or E or both components and any teleseismic S-wave amplitude or magnitude measurement, currently still greatly disregarded despite its undoubted scientific importance (see section 6), should preferably be made on horizontal components as well. Even the standard magnitude "amplitude phase names" do not yet account for a differentiation between vertical and horizontal component measurements.

5 Magnitude nomenclature reported to the ISC

The ISC (2013) Bulletin Summary for January-June 2010 includes the description of the upgraded new ISC procedures and the nomenclature for agency-specific magnitudes reported to the ISC. The latter are outlined in detail in Tables 9.6 and 9.7 of the ISC (2013) Bulletin Summary. For the period January-June 2010 **148 agencies contributed 29 different types of magnitudes**. This is due to the different seismological practices both at regional/national and global level in computing magnitudes from a multitude of combinations of wave types, period and amplitude measurement standards, distance ranges, instruments, components, algorithms etc. They are listed along with the agency codes and the number of earthquakes for which these magnitudes have been determined. Their main features are presented in tabulated form together with references to documents in which the procedure and/or data peculiarities are outlined. Table 2 is an abridged sample of the types of magnitudes contained in the ISC Bulletin for the time January-June 2010.

In Table 2 the proper IASPEI standard magnitude names according to the finally in 2011/2013 agreed nomenclature have not yet been used and also not yet been reported to the ISC. However, in a special investigation Bormann et al. (2009) compared for large event data sets in the wide magnitude range 4 < M < 9 all types of traditional Chinese magnitudes, measured at the China Earthquake Network Centre (CENC), with independently measured related IASPEI standard magnitudes. E.g., Ms7 in Table 2 is measured on vertical component records with a WWSSN-LP response, as the standard Ms(20). But, in contrast to the latter, which is measured only at periods between 18 s and 22 s and in the distance range 20°-160°, Ms7 is based on surface-wave displacement amplitude maxima with periods T > 6 s measured in the distance range 3°-177°. Nevertheless, independent Ms7 and Ms(20) for the same events agreed almost perfectly within the tolerance limit of 0.1 m.u. set by the WG. The orthogonal regression relationship is **Ms7 = 0.99Ms_20 + 0.14** with a standard deviation of ± 0.20 m.u.. The latter is typical for high-quality Ms determinations. Thus, Ms7 and Ms_20 are fully compatible and new Ms_20 could be merged with older Ms7 data without any loss in quality or increase in data scatter, which means assured data continuity.

Table 2 Examples of magnitudes reported to the ISC by data contributing seismological stations or agencies for the Summary of the ISC Bulletin January-June 2010 (ISC, 2013). All references cited in the table, and agency abbreviations, are given in ISC (2013) but those typed in *Italics* also in the reference list to this IS.

Magnitude type	Description	References	Comments
M	Unspecified magnitude type		Often related to real or near-real time magnitude estimations
mB	Broad-band body-wave magnitude	*Gutenberg (1945b,c); IASPEI (2005); Bormann and Saul (2008)*	
mb	Short-period body-wave magnitude	*IASPEI (2005)*	Classical mb computed from station between 20°-100° distance
mb1	Short-period body-wave magnitude	IDC (1999) and references therein	Reported only from IDC; it includes also station below 20° distance
mb1mx	Maximum likelihood short-period body-wave magnitude	Ringdal (1976); IDC (1999) and references therein	Reported only from IDC
mbtmp	short-period body-wave magnitude with depth fixed at the surface	IDC (1999) and references therein	Reported only from IDC
mbLg	Lg-wave magnitude	*Nuttli (1973); IASPEI (2005)*	Reported only by MDD and by other North American agencies as MN
Mc	Coda magnitude		
MD (Md)	Duration magnitude	Bisztricsany (1958); *Lee et al. (1972)*	
ME (Me)	Energy magnitude	*Choy and Boatwright (1995)*	Reported only by NEIC
MJMA	JMA magnitude	*Tsuboi (1954)*	Reported only by JMA
ML (Ml)	Local (Richter) magnitude	*Richter (1935); Hutton and Boore (1987)*	
MLSn	Local magnitude calculated off Sn phases	Balfour et al. (2008)	Reported by PGC only for earthquakes west of the Cascadia subduction zone

MLv	Local (Richter) magnitude computed from the vertical component		Reported only by DJA and BKK
MN (Mn)	Lg-wave magnitude	*Nuttli (1973); IASPEI (2005)*	Also reported as mbLg from MDD
MS (Ms)	Surface wave magnitude	*Gutenberg (1945a); Vaněk et al. (1962); IASPEI (2005)*	Classical surface wave magnitude computed from station between 20°-160°
Ms1	Surface wave magnitude including	IDC (1999) and references therein	Reported only by IDC; it includes also stations below 20° distance
ms1mx	Maximum likelihood surface wave magnitude	Ringdal (1976); IDC (1999) and references therein	Reported only by IDC
Ms7	Surface wave magnitude	*Bormann et al. (2007)*	Reported only by BJI and measured in the distance range 3°-177° on records of a Chinese-made seismograph with WWSSN-LP response
MW (Mw)	Moment magnitude	*Kanamori (1977); Dziewonski et al. (1981)*	
Mw(mB)	Proxy Mw based on mB	*Bormann and Saul (2008)*	Reported only by DJA and BKK
Mwp	Moment magnitude from P-waves	*Tsuboi et al. (1995)*	Reported only by DJA and BKK and used for rapid response purposes

Not as perfect is the agreement between Ms(CENC) and Ms(20), measured at different components, period ranges, record responses and with a constant difference in the calibration function (ΔM = 0.25 m.u). And the average differences between other combinations of similar types of magnitude measurement depend on magnitude, ranging from small to large magnitudes for mB(CENC) and mB(BB) from ΔM = -0.3 to 0.0 m.u, for Ms(CENC) and Ms(BB) from ΔM = 0.0 to +0.4 m.u, and for mb(CENC), which is measured only within the first 6 s after the P-wave arrival, the difference to standard mb may reach at the largest earthquakes even -1 m.u. It is just this kind of procedure-dependent data incompatibilities in international data exchange, which the measurement standards aim to eliminate, thus reducing data scatter and improving the global compatibility of magnitude estimates.

This experience from China shows that it is highly desirable that seismic stations/agencies reporting data to the ISC or to other regional or global seismological data centers compare - in conjunction with the introduction of the new IASPEI standard magnitudes - for a sufficiently large and representative set of seismic records from events in a wide range of magnitudes and distances the results of their traditional magnitude procedures with those according to the new IASPEI standard procedures. A suitable representative test data set can be downloaded via IS 3.4, which gives also guidelines for carrying out such a test by using the SEISAN software. If the average absolute differences turn out to be within 0.1 m.u. then the traditional procedure yields in fact IASPEI standard compatible results.

Sometimes this may be the case even if some procedural details, such as the applied filter responses, differ significantly. An example is given in IS 3.3 (Figures 10 and 14) comparing

Ms_20 measured on either SRO-LP or WWSSN-LP responses. Analysis software which has an SRO-LP simulation filter implemented, such as Seismic Handler Motif (SHM), could then be used as an even better alternative for Ms_20 determination, because the measured A and T are within acceptable limits of measurement accuracy identical with those measured on WWSSN-LP records and can thus be reported with the standard amplitude nomenclature IAMs_20. But because of the generally better SNR of SRO-LP records one is able to measure even more surface-wave magnitudes, especially from weaker events. Moreover, also automatic A and T measurements are less error-prone because of the less noisy and thus simpler waveforms in SRO-LP filtered records (see Figure 13 b in IS 3.3). This, however, is not a rule. In other cases of magnitude measurements in other frequency ranges and on other seismic phases already smaller changes in recommended measurement parameters may result in much larger magnitude differences.

In any event, the ISC as the most representative, complete and accurate final depositary of seismological parameter data should be informed by all its data contributing stations/agencies about the details of their procedures for recording, measuring and calibrating their magnitude data. In order to assure sufficient completeness and compatibility of provided information, the IASPEI/CoSOI WG has developed a questionnaire which is annexed to both IASPEI (2013) and (as Annex 2) to IS 3.4. Based on such information and the results of comparative measurements with traditional agency and new IASPEI standard procedures the number of agency specific entries in Table 2 is likely to shrink significantly with the global introduction of the IASPEI (2013) measurement standards.

6 Proposal for a more generalized unique nomenclature for amplitude and magnitude data

In order to assure future IASPEI-authorized standards annotation and reporting of measurements for amplitude-based seismic magnitudes, the WG on magnitude measurements had agreed already a decade ago on the suitability of a more general systematic nomenclature for presenting amplitude and magnitude data in a unique manner (see IS 3.2 in NMSOP-1, in Bormann, 2002 and 2009). It is based on recommendations of the Sub-Commission on Magnitudes of the Commission on Practice made at the Joint General Assembly of the IASPEI/IAVCEI Meeting in Durham 1977. These recommendations aimed at measuring and reporting magnitudes in an unambiguous manner for all seismic phases and from all component readings for which magnitude calibration functions according Richter (1935, 1958), Gutenberg and Richter (1956) and Vaněk et al. (1962) were available (see first bullet-point paragraph on page 4). The reason that Gutenberg and Richter (1956) proposed besides P waves also PP and S for magnitude determination and also amplitude measurements from vertical and horizontal components were that

- medium to long-period PP is usually the largest longitudinal wave in the core shadow of P beyond 100°, up to 180°, allowing more reliable mB event estimates, based on more stations than with P waves alone;
- medium to long-period S is usually the largest secondary body-wave phase after P with amplitudes much larger than that of P and with a radiation pattern about 45° off that of P (see section 3.4.1 of Chapter 3). This again assured more independent magnitude data and, when averaged with those from P wave readings, data that are much less affected by the radiation pattern of the seismic source, which may in the

case of only a few stations with P-wave readings and insufficient azimuthal coverage produce rather biased magnitude estimates;

- teleseismic S-waves have generally their largest amplitudes in the horizontal components, and horizontal PP amplitudes are also relatively large or even larger than those of P, and, because of different take-off angle, also source mechanism dependent. Moreover. at Gutenberg and Richter's times stable long-period vertical component recordings were not yet as commonly available as nowadays.

During recent decades the virtual global seismic network of high-resolution stable broadband recordings has grown tremendously. Therefore, an insufficient number of stations with potential amplitude readings and the need for independent amplitude readings from PP and S has become much less of a problem for a reliable magnitude determination than in the past. However, S-wave amplitude, period and/or ground velocity readings and reporting to the international data centers are still grossly neglected at many observatories/networks (see Chapter 1) although they are highly desirable for improving the shear-wave attenuation model of the Earth down to shorter periods and thus with higher spatial resolution and with larger penetration depths than possible with surface waves. But when measuring S amplitudes they could be used for additional S-wave mB estimates as well with the advantage of reducing possible P-wave station mB biases in the case of inappropriate azimuthal station coverage. But then it would be desirable to clearly differentiate between mB based on P, S and/or PP.

For the original proposal of a more systematic unique magnitude nomenclature see Willmore (1979; p. 124)) and its extension in IS 3.2 of NMSOP-1 (Bormann, 2002 and 2009. An example along these lines has been given for a strong Mongolia earthquake in Tab. 3.1 of Chapter 3.

In view of the now reached agreement on standard measurement procedures and a unique nomenclature for 6 widely determined types of magnitude as well as the general trend to measure related amplitudes, with the exception for ML, on vertical component records only, this proposal may at present appear to be obsolete. In section 5 of this IS it has also been shown that agencies or stations reporting magnitudes to international data centers or publishing them in their bulletins may define their own ISF format compatible magnitude names. They could be unique and unambiguous provided that they are accompanied, as in Table 2, by references to publications/documents which describe in detail the procedures for recording, filtering, measuring, and calibrating these magnitudes, in a similar way as the IASPEI standard magnitudes have been defined in IASPEI (2013) or IS 3.3. Moreover, it has to be assured that other data producers that apply the same procedures use also the same nomenclature. If handled this way then it is indeed the best way to keep data centers and external data users fully informed. This avoids mixing incompatible data and biased conclusions. Precondition is, however, that all data producers really make their agency-specific ways of magnitude determination, hopefully together with some information on how there magnitudes relate to other well established and/or IASPEI standard magnitudes of the same type, publicly available via their national or regional/global data centers (for questionnaire see references in section 5).

Nevertheless, we will give below in Table 3 a few examples for another way of designing unique magnitude names, also for other than the now common phases, components, record responses and calibration functions. It is based on the earlier version presented in I.S 3.2 of NMSOP-1. However, the current upgrade allows also to differentiate between magnitudes based on displacement amplitudes A and broadband velocity amplitudes V and the instrument code is no longer put in brackets. Moreover, since V stands now for velocity the vertical component code is now Z, as in the Gutenberg-Richter (1956) calibrations diagrams.

Further, one has to know that Willmore (1979) presents in Fig. 1.1 the following standard response classes for analog seismographs: Type A (short-period, A1-A4), B (long-period, B1-B3), C (displacement broadband Kirnos), D (velocity broadband 1-100 s), and E (classical Galitzin) besides the classical Wood-Anderson (WA) response. These responses still resemble widely used responses of modern digital records or of common synthetic filter outputs derived therefrom (e.g., A1 = Benioff-SP, A2 = WWSSN-SP, A3 = French APX system, A4 = Russian SKM-3 seismograph; B1 = WWSSN-LP, B2 = French system, B3 _ high-gain HGLP system; C = Kirnos seismograph). The latter has two widely used versions: C1 = SK - corner period of 10 s and C2 = SKD – 25 s, with C1 being a standard filter at CENC for Chinese mB and Ms measurement and C2 being a standard filter in SHM and Pitsa software because of the superiority of C2 records in seismic phase recognition (see Chapter 11). And the Willmore (1979) standard response D covers the main period range of modern velocity broadband seismographs, which is between 1 and 100 s. Therefore, we use these class symbols in order to illustrate the filter/seismograph type specification in the proposed generalized magnitude nomenclature. It may be replaced or complemented by any other unique specified filter/seismograph response symbol. Along these lines we propose in Table 3 just a few magnitude names for readings of maximum amplitudes of different seismic phases made on horizontal or vertical component records of such basic standard types of seismographs/filters and calibration functions and compare them with respective "generic" magnitude names. As a general unique magnitude name we proposes **MXYFC** with

- **M** being the general symbol for magnitude.;
- **X** the symbol name of the seismic phase on which the amplitude and periods for the respective magnitude have been measured, e.g., P, S, PP, Lg, PKP;
- **Y** the component on which amplitude and period have been measured, e.g., N for the north-south, E for the east-west, Z for the vertical and H – for the vectorially combined horizontal component;
- **F** the symbol for the filter/seismograph response on the record of which the amplitude and period have been measured;
- **C** the symbol for the calibration function which has been applied to calculate the respective magnitude based on the measure ground motion amplitudes and periods.

However, in the case that the considered magnitudes have been calculated on the basis of other measurement parameters or procedures such as duration, spectra, waveform fitting and inversion, tsunami run-up or wave height measurements, the MXYFC nomenclature is not appropriate and should better be replaced by MAG (MAgency) or MAU (MAuthor) with reference being available for full procedural details.

Along these lines a few examples are presented in Table 3, using the following additional abbreviations:

A-E seismograph/filter type classes according to their definition in Willmore (1979) and outlined above, with a number added if there are several common types within a given class. E.g., one could give the NEIC PDE filter and the IDC/CTBTO filter used for short-period parameter readings, which differ from A1-A4 (see Figure 3 in IS 3.3) the numbers A5 and A6, respectively.

WA Wood-Anderson horizontal-component seismograph with displacement-proportional response in the period range 0.1 to 0.8 s;

RO stands for the long-period Seismological Research Observatory (SRO-LP) response (see Figure 10 in IS 3.3);

Δ epicentral distance as commonly used in calibration functions;

h hypocentral depth;

L largest (relatively) long-period surface wave

Q at the end of the magnitude name stands for the respective Gutenberg and Richter (1956) calibration function Q(Δ, h) for either PZ, PH, PPZ, PPH, SH (see Figures 1a-c and Table 7 in DS 3.1 and for standard PZ also in tabulated form for all source depths with program description in PD 3.1);

σ at the end of the magnitude name stands for the Prague-Moscow (Vaněk et al., 1962, or Karnik et al., 1962) calibration function σ(Δ) for surface-wave readings of both LZ and LH; recommended as standard by IASPEI and used at both the NEIC and the ISC (in tabulated form as Table 4 in DS 3.1; as standard formula see Chapter 3, Eqs. (3.35 or 3.36)

C Stands for any other specific calibration function, e.g., RI for Richter (1958), HB for Hutton and Boore (1987) or VC for the Veith and Clawson (1972) calibration function P(Δ, h) used at the IDC/DTBTO (for details see DS 3.1).

For magnitudes that have been determined from records of seismographs with other response characteristics than the standards A to D or WA and/or by using calibration functions other than σ(Δ), Q(Δ, h) or local scales properly linked to the original Richter Ml (ML) scale, this should be specified by giving filter type F and C in brackets, i.e., M(F; C), or by adding a complementary comment line with the name of the relevant author/institution or with a link to proper reference and documentation.

Amplitude data for identified seismic phases should be specified and reported to data centers in the following general format for non-IASPEI standard "amplitude phase names": **AXYF or VXYF**:

with A = displacement amplitude in nm or V = velocity amplitude in nm/s
and X, Y and F as defined above, e.g.:

- ASHB2 – horizontal component S-wave displacement amplitude on a WWSSN-LP record;
- APPZC2 – vertical component PP-wave displacement amplitude on a Kirnos SKD record;
- VPZD – vertical component P-wave velocity amplitude on type D record.

In the case that phase name, component, filter type and calibration function can be uniquely described by just one letter, then the general MXYFC nomenclature would perfectly match with the ISF 5-letter magnitude name format. This, however, is not possible for more than single letter phase names such as Lg, PP or PKP, in the case of using more specific responses within a standard response class (such as A1 or C2) and/or calibration functions that require more than one letter to describe them unambiguously. A few such examples have been added to Table 3 too, typed in Italics.

This dilemma remains as long as the most relevant current seismic standard data formats limit the length of magnitude names to 5 letters. A future extension might therefore be considered by IASPEI/CoSOI. As long as this is not the case, however, we can only recommend, that the component information and any specification within a considered response class is conveyed by the related magnitude "amplitude phase name", as shown above. The type of calibration function used for calculating a specific type of magnitude from a compatible set of measured parameter data, however, has then to be documented in the metadata and/or in related generally accessible documentation as it has been done for the current IASPEI standard magnitudes. The same holds if some agency decides to measure amplitudes and periods not at the maximum of the respective phase waveform but within an arbitrarily fixed measurement time window after the phase first arrival, such as the 5.5 s window set by the International Data Centre (IDC) of the Comprehensive Test-Ban Treaty Organization (CTBTO). Such a combination of magnitude and amplitude phase name nomenclature or M(Agency) specification would limit also for non-standard magnitudes their names to match the ISF 5-letters magnitude code, e.g.:

- MPA in conjunction with APZA5 (previous NEIC PDE mb)
- MPPD in conjunction with VPPHD;
- MPPC in conjunction with APPZC2;
- MLgA in conjunction with ALgZA2;
- MPIDC with reference to procedure definition (e.g., section 17.4.2 of Chapter 17).

Table 3 Preliminary proposal for specific magnitudes not measured and/or scaled according the recommended IASPEI (2013) standard and the equivalent "generic" magnitude names. The ambiguity of generic magnitude names is obvious.

Specific	Generic	Description
MPZAQ	mb	P-wave magnitude from short-period narrowband vertical component recordings of type A calibrated with Q(Δ, h) for PZ; **equivalent to standard mb if A2 = WWSSN-SP response** and standard measurement criteria are observed.
MPHCQ	mB	P-wave magnitude from medium-period (more broadband) recordings calibrated with Q(Δ, h) for PH.
MPZDQ	mB	P-wave magnitude from velocity broadband recordings calibrated with Q(Δ, h) for PZ; **equivalent to mB_BB** if standard measurement criteria are observed.
MSHCQ	mB	S-wave magnitude from medium-period (more broadband) recordings calibrated with Q(Δ, h) for SH.
MLZDσ	Ms	Surface-wave magnitude from L readings in vertical component broadband velocity records of type D, calibrated with the IASPEI standard "Prague-Moscow" formula σ(Δ) (cf. Eq. 3.35, or 3.36 in Chapter 3); **equivalent to Ms_BB** if amplitudes are read in the period range 3-60 s.
Mw(Author/Agency), e.g. **MwCMT**	Mw	Non-saturating moment magnitude based on the zero-frequency plateau of the displacement spectrum or other related estimates via signal analysis/inversion in the time domain, e.g., of (Global) Centroid Moment Tensor Project.

Me(Author/Agency) e.g., **MeGS**, **MeGFZ**	Me	Energy magnitude as defined/derived by specific author(s) or institution(s), e.g. Me of the US Geological Survey (Choy and Boatwright, 1995) Me of the GFZ German Research Centre for Geosciences (Di Giacomo et al., 2008)
Mt(Author), e.g. **MtABE**	Mt	Tsunami magnitude as defined/derived by specific author(s) or institutions, e.g. Mt according to Abe (1989)
MPZA6VC	mb	P-wave magnitude measured on short-period vertical component recordings with the CTBTO/IDC narrowband velocity band-pass filter (here abridged as A6), within 5.5 s after the P-wave first onset and calibrated with Veith and Clawson (VC; 1972) calibration curve P(Δ, h).
MPPHCQ	mB	PP-wave magnitude from medium-period (more broadband) recordings calibrated with Q(Δ, h) for PPH.
MLZB1σ or *MLZROσ*	Ms	Rayleigh surface-wave magnitude from L readings in vertical component records of type **B1 = WWSSN-LP**, or SRO-LP, calibrated with the IASPEI standard σ(Δ) (cf. Eq. 3.35, or 3.36 in Chapter 3). **Equivalent with standard Ms_20** if measured at periods between 18-22 s.

In the case that amplitudes have been measured on phases, components and with procedures according to the respective IASPEI magnitude standards (see section 2) then the IASPEI amplitude phase name nomenclature should be used instead, e.g., IAmb_Lg or IVMs_BB. For non-standard agency or author specific magnitudes, however, one should avoid any confusion with traditional generic or new standard magnitudes and generally use capital M as the unique magnitude symbol, followed by phase, component, filter and calibration function symbol as in Tab. 3, or, if this exceeds the 5-letters code, by the proposed abridge version MXF in conjunction with the respective more detailed amplitude phase names A(orV)XFn and the calibration function C specified in the metadata.

7 Author or agency specific magnitude nomenclature

Classical magnitudes based on not strictly standardized procedures still form the majority of available magnitude data for quite some time. This particularly applies to the three "generic" types of magnitudes, ML, mb and Ms. The majority of countries, using ML, have not yet been able to derive their own local/regional calibration functions that are properly scaled and tested with respect to the IASPEI standard. mb data, measured up to now (2013) and contained in national and international data bases, are still more or less a mixture of data measured with slightly different instrument responses within differently fixed or flexible measurement time windows. And also Ms data may differ by up to several tenths of magnitude units depending on the specific Ms procedure applied. Therefore, it is important that the new standards now clearly differentiate between Ms_20 and Ms_BB or any other type of Ms. **Any future use of the undifferentiated generic magnitude symbol Ms would be highly counter-productive**, not so much in publications to a broader public when accuracy matters less but **in any scientific publication and data base with relevance for future research**.

Regrettably, such a clear distinction between old (still mixed and thus more noisy or even incompatible) and new (standardized) ML and mb data is not yet possible because the IASPEI Working Group was unable to agree on specified non-generic IASPEI standard names for ML and mb. This persisting ambiguity between old generic and new standard magnitude data symbols may confuse in future users of both old and new data with respect to their compatibility, unless the distinction can be made on the basis of the related standard amplitude phase names IAML and IAmb for standard ML and mb in contrast to AML and Amb for non-standard versions of these two magnitudes.

For ML data that are used for relevant studies only within the considered regions and less frequent, if ever, for interregional comparison of compatibility (an exception see section 3.2.9.6 in Chapter 3), the generic ML nomenclature may be less of a problem as long as no interregional and border crossing seismic hazard assessment is based on such data. In order to reduce uncertainties in this respect we have presented in Table 2 of DS 3.1 Ml formulas for 16 different regions world-wide together with information on their calibration to either the traditional Richter (1935) scale and Wood-Anderson records or to the new IASPEI standard formula (3.15) in Chapter 3 when using synthetic WA records. Moreover, in both NMSOP-1 (2002 and 2009) and NMSOP-2 (2012/13) we deliberately **use the more general symbol Ml for local magnitudes. It may be changed to ML when the related formula for the region under consideration has been properly scaled to the IASPEI standard formula and procedure.** If not, it should be considered and also denoted as an area- or agency-specific formula MlAG if it is likely to produce average absolute differences > 0.1 m.u. as compared to formula (3.15) in Chapter 3.

The multitude of currently used agency-specific magnitudes may be very confusing for users. Systematic inter-comparison between these formulas and the new IASPEI standards offers the chance to streamline, homogenize and reduce their number by agreeing on the circumstances under which these magnitudes have the same values as their IASPEI counterparts. In fact, in most cases a specific magnitude scale will agree on average with another magnitude scale at some appropriate value, e.g. local scales at some measured input value at a suitable hypocentral distance between about 17 km (Hutton and Boore, 1987) to 100 km (Richter, 1935) (see Fig. 3.30 in Chapter 3), the teleseismic scales mB, Ms and Mw at a common average magnitude value, which is around 6.5 (Fig. 3.70 in Chapter 3; see Utsu, 2002), or the modern moment and energy magnitude scales, Me and Mw, which yield identical values at a constant ratio of released seismic energy to seismic moment (see Chapter 3, section 3.3.3 and Bormann and Di Giacomo, 2011). At other than these scaling values, however, they may differ significantly, depending on local/regional differences in wave attenuation, the difference in the periods and bandwidth at which these magnitudes are measured and/or the difference in the E_S/M_0 ratio of the actual rupture process.

The required uniqueness of magnitude data can principally be assured and documented by a rather short specific magnitude names within the 5-letters ISF code, as in Table 2, yet necessitating a defining documentation in the metadata, which will – hopefully in future – also be complemented by some statistics of the authors/agencies about average absolute or mean/median and standard deviations or trend differences with respect to standard magnitudes, moment magnitudes or other magnitudes of the same type. However, **if it can be proven that agency-specific deviations in procedural details from the recommended standard procedures result in magnitude values that differ in terms of absolute average deviations not more than 0.1 m.u. from the respective standard values then they can be considered and reported as standard magnitudes as well.** Examples are given in section

3.2.3.2 of Chapter 3, in section 5 of IS 3.3 with Figure 14 and in section 5 above with the discussion in conjunction with Table 2. Guidelines with record data for such comparative measurements are given in IS 3.4 together with questionnaires for reporting the results of such a comparison as well as the agency-specific procedures for magnitude measurements to the International Seismological Center (ISC).

New procedures for magnitude measurement are continuously proposed, such as non-saturating broadband P-wave magnitude estimators which take additionally rupture duration into account [e.g., mBc by Bormann and Wylegalla (2005) and Bormann and Saul (2009); the unspecified M by Hara (2007); Mwpd by Lomax and Michelini (2009)], W-phase-based estimates of Mw and moment tensor solution estimates based on the analysis of W phases [see Kanamori and Rivera (2008), Hayes et al. (2009); Chapter 3, section 3.2.8.6] or magnitude estimates based on strong-motion data. Generally, new or modified classical procedures of magnitude determination should be clearly distinguishable from any common "generic" or standardized magnitude and be given unique specific names. Some general rules are recommended:

- If authors or institutions have given to their new magnitudes already unique names with 5 or less letters (such as mBc or Mwpd) these names should be preserved in national or international data bases, bulletins or publications in agreement with the ISF 5-letters magnitude code and links be given to relevant publications for user information;
- If such magnitudes are unspecified, then a code should be added that permits the unambiguous identification of the author, agency and type of magnitude, preferably within the ISF 5-letters restriction, e.g. MHARA or MwWPH for the W-PHase derived Mw, otherwise in an extended form as the related amplitude phase name or as accompanying metadata;
- If author/agency proposed names exceed the ISF 5-letters code one could also try to shorten it in a still comprehensible and unambiguous way, as, e.g., Ms(VMAX) was shortened into Ms_VX in the NEIC Hydra parameter data plots;
- If possible these modifications should be agreed upon between the data centers and authors/agencies so as to assure their unique use also in publications.

8 The role of the ISC in implementing IASPEI standard magnitude measurements and assuring unique amplitude and magnitude nomenclature

The WG on Magnitude measurements was set up by the IASPEI Commission on Seismic Observation and Interpretation (CoSOI) in response to a IASPEI resolution submitted in 2001 by the ISC Governing Council under the chairmanship of A. Dziewonski. Its mandate has been outlined on pages 6 and 7 above. The goals a-d have been achieved with all related documentation on the procedures, standard nomenclature, comparison with non-standard magnitudes, questionnaire on agency-specific procedures etc. being now available, including publications in peer-reviewed journals and related NMSOP-2 items [e.g., Liu et al. (2005; 2006); Bormann et al. (2007; 2009); Bormann and Saul (2008); NMSOP-2, Chapter 3, section 3.2, IS 3.3 and 3.4, DS 3.1; http://nmsop.gfz-potsdam.de.]

With respect to **goal a)** we can now be sure that mB_BB is very close to the original Gutenberg (1945b) and Gutenberg and Richter (1956) body-wave magnitude m = mB, deviating in its original range of definition between 5.5 < mB < 8.5 less than 0.1 m.u. (see Bormann et al., 2009). The same applies when comparing Ms_20 with the classical Gutenberg (1945a) Ms and the traditional NEIC vertical component surface-wave magnitude measured around 20 s (Bormann et al., 2009; Lienkaemper, 1984).

However, Ms_BB is the only surface-wave magnitude that agrees **perfectly** with the Ms formula proposed by Vaněk et al. (1962) which is the official IASPEI standard Ms formula since 1967. Being perfectly scaled to the original Gutenberg Ms (around 20s) that is almost exclusively based on event magnitudes ≥ 6 – 8+, Ms_BB yields however on average for magnitudes 3 < Ms_20 < 6 between 0.4 and 0.1 m.u. larger values than Ms_20. The simple reason is that the Rayleigh wave maxima for these smaller earthquakes, which are preferentially recorded at local to regional distances, rarely occur at periods around 20 s (see Bormann el al., 2009 and Figs. 3.35 and 3.40 in Chapter 3). This also explains the systematic distance-dependent errors found by Herak and Herak (1985) and Rezapour and Pearce (1993) when Ms, calculated with the IASPEI standard formula, is based exclusively on amplitudes measured in the period range between 18 and 22s. Ms_BB also reduces by about ½ the systematic bias of Ms_20 when compared with Mw for Mw < ≈6.5 (Kanamori and Anderson, 1975; Ekström and Dziewonski, 1988; Di Giacomo et al., 2013) as well as the difference between Ms with mb and ML for Mw < 6 (see Chapter 3, Fig. 3.70). Since Ms_BB may be measured down to epicentral distances of 2° and measured at periods as small as 3 s, it agrees in fact rather well with ML at regional distances (see Figure 5, upper right in Bormann et al., 2007, comparing Ml with traditional Chinese Ms that resembles Ms_BB).

ML (Richter, 1935, 1958), mb (Engdahl and Gunst, 1966), and mb(Lg) (Nuttli, 1973, 1985, 1986, 1988) are classical US derived magnitudes. The US members in the WG have taken care of assuring that the related new standards are compatible with these original definitions within about 0.1 m.u.

With respect to **goal b)** it has been proven by implementing the new standards both in fully automatic procedures at the NEIC, in the GFZ-GEOFON SeisComp3 real-time procedures (for mb and mB_BB) as well as in comprehensive off-line interactive data analyses at the China Earthquake Network Center (CENC) and at the Collm (CLL) observatory in Germany that the new standards allow to make best use of the advantages of digital data and processing. Moreover, the new broadband standard magnitudes mB_BB and Ms_BB, that are based on just the single measurement parameter Vmax instead of Amax and T, are even more robust and have a smaller data scatter than the band-limited mb and Ms_20 (see section 3.2.3.2 in Chapter 3 and Table 5 in IS 3.3).

With respect to **goal c)** the new nomenclatures for standard magnitudes and related amplitudes are now available but have been implemented as of May 2013 only in the NEIC Hydra event data plot and in the SEISAN analysis software record plots for magnitude measurements. They are not yet available in the bulletins of the ISC, the NEIC or other agencies and stations.

Concerning **goal d)** the ISC had circulated already years ago the first versions of the IASPEI (2005) WG recommendations and of the questionnaire on current agency-specific magnitude procedures. First answers to the latter by a few stations/agencies, which had also been posted on the ISC website, revealed however some inconsistencies and ambiguities which required a revision of the questionnaire which is now annexed to the IASPEI (2013) WG recommendations as well as to IS 3.4. This necessitates a second effort by the ISC to disseminate to all its data contributors and membership agencies these latest versions together with an urgent request for consideration, implementation and feedback in the context of outlining beforehand to them the future ISC policy in implementing these IASPEI recommendations.

Only when pioneered by the ISC as the singular true global seismological parameter data agency with the self-demand to assure - in close collaboration with IASPEI and CoSOI - the best achievable degree of data completeness, quality and unambiguity, also the other main goals e-h) can be achieved in the years ahead in the very best long-term interests of the global seismological community. This, however, also requires a majority support by the ISC Governing Council, the initiator of the IASPEI resolution and thus of the WG establishment. And this position should be independent on the particular national interests, limiting conditions or current priority tasks under which some of the ISC members or cooperating associates have to run at present their daily operations.

Acknowledgments

The author owes great thanks to his fellow WG members for the many years of fruitful cooperation, and to J. Dewey, D. Storchak and D. Di Giacomo in particular for their critical reading the draft version of this Information Sheet. Their useful comments and editorial recommendations have helped to improve and substantiate the manuscript. J. Saul helped to clarify the representation of magnitude data in the QuakeML format.

References

Abe, K. (1981). Magnitudes of large shallow earthquakes from 1904 to 1980. *Phys. Earth Planet. Interiors*, **27**, 72-92.

Abe, K. (1982). Magnitude, seismic moment and apparent stress for major deep earthquakes. *J. Phys. Earth,* **30**, 321-330.

Abe, K. (1984). Complements to “Magnitudes of large shallow earthquakes from 1904 to 1980”. *Phys. Earth Planet. Interiors*, **34**, 17-23.

Abe, K., and Kanamori, H. (1979). Temporal variation of the activity of intermediate and deep focus earthquakes. *J. Geophys. Res.*, 84, B7, 3589-3595.

Abe, K. (1989). Quantification of tsunamigenic earthquakes by the M_t scale. *Tectonophysics*, **166**, 27-34.

Abe, K., and Kanamori, H. (1980). Magnitudes of great shallow earthquakes from 1953 to 1977. *Tectonophys.*, **62**, 191-203.

Bonner, J. L., Russel, D. R., Harkrider, D. G., Reiter, D. T., and Herrmann, R. B. (2006). Development of a time-domain, variable-period surface-wave magnitude measurement procedure for application at regional and teleseismic distances, part II: Application and Ms-mb performance. *Bull. Seism. Soc. Am.* **96**, 2, 678-696, doi: 10.1785/0120050056.

Bormann, P. (2002; 2009). IS 3.2: Proposal for unique magnitude nomenclature. In: Bormann, P. (Ed.) (2002). *New Manual of Seismological Observatory Practice (NMSOP-1)*, *IASPEI,* GFZ German Research Centre for Geosciences, Potsdam (printed version) or electronic version (2009), IS 3.2, 6 pp., DOI: 10.2312/GFZ.NMSOP_r1_IS_3.2., accessible via http://nmsop.gfz-potsdam.de.

Bormann, P., and K. Wylegalla (2005). Quick estimator of the size of great earthquakes. *EOS, Transactions, American Geophysical Union*, **86** (46), 464.

Bormann, P., and J. Saul (2008). The new IASPEI standard broadband magnitude m_B, *Seismol. Res. Lett.* **79** (5), 699-706.

Bormann, P., and Saul, J. (2009). A fast, non-saturating magnitude estimator for great earthquakes, *Seism. Res. Lett.* **80** (5), 808-816; doi: 10.1785/gssrl.80.5.808.

Bormann, P., and D. Di Giacomo (2011). The moment magnitude M_w and the energy magnitude M_e: common roots and differences. *J. Seismology*, **15**, 411-427; doi: 10.1007/s10950-010-9219-2.

Bormann, P., Liu, R., Ren, X., Gutdeutsch, R., Kaiser, D., Castellaro, S. (2007). Chinese national network magnitudes, their relation to NEIC magnitudes, and recommendations for new IASPEI magnitude standards, *Bull. Seism. Soc. Am.* **97**, 114-127.

Bormann, P., Liu, R., Xu, Z., Ren, K., Zhang, L., Wendt S. (2009). First application of the new IASPEI teleseismic magnitude standards to data of the China National Seismographic Network, *Bull. Seism. Soc. Am.*, **99** (3), 1868-1891; doi: 10.1785/0120080010

Brune, J.N. (1970). Tectonic stress and the spectra of seismic shear waves from earthquakes, J. Geophys. Res., 75, 4997-5009.

Brune, J.N. (1971). Correction, J. Geophys. Res., 76, 5002.

Choy, G. L., and Boatwright, J. L. (1995). Global patterns of readiated seismic energy and apparent stress. *J. Geophys. Res.*, **100**, B9, 18,205-18,228.

Choy, G. L., and Kirby, S. H. (2004). Apparent stress, fault maturity and seismic hazard for normal-fault earthquakes at subduction zones, *Geophys. J. Int.*, **159**, 991-1012.

Di Giacomo, D., Grosser, H., Parolai, S., Bormann P., and Wang, R. (2008). Rapid determination of Me for strong to great shallow earthquakes. *Geophys. Res. Lett.*, **35**, L10308; doi:10.1929/2008GL033505.

Di Giacomo, D., Parolai, S., Bormann P., Grosser, H., Saul, J., Wang, R., and Zschau, J. (2010). Suitability of rapid energy magnitude estimations for emergency response purposes. *Geophys. J. Int.*, **180**, 361-374; doi: 10.1111/j.1365-246X.2009.04416.x.

Di Giacomo, D., Bondár, I., Storchak, D. A., Engdahl, E., R., Bormann, P., and Harris, J. (2013). ISC-GEM: Global Instrumental Earthquake Catalogue (1900-2009), III. Re-computed M_S and m_b, proxy M_W, final magnitude composition and completeness assessment. *Phys. Earth Planet. Int.* (submitted).

Dziewonski, A. M., Chou, T. A., and Woodhouse, J.H. (1981). Determination of earthquake source parameters from waveform data for studies of global and regional seismicity. *J. Geophys. Res*., 86, 2825-2852.

Ekström, G., and Dziewonski, A. M. (1988). Evidence of bias in estimations of earthquake size. *Nature*, **332**, 319-323.

Engdahl, E. R., and Gunst, R. H. (1966). Use of a high speed computer for the preliminary determination of earthquake hypocenters. *Bull. Seism. Soc. Am.,* **56**, 325-336.

Euchner, F., and Schorlemmer, D. (Eds.) (2013). QuakeML – an XML representation of seismological data. Basic event description. Version 1.2 (14 Febr. 2013).

https://quake.ethz.ch/quakeml/docs/REC?action=AttachFile&do=view&target=QuakeML-BED-20130214a.pdf

Granville, J. P., Kim, W.-Y., and Richards, P. G. (2002). An assessment of seismic body-wave magnitudes published by the Prototype International Data Centre. *Seism. Res. Lett.*, **73**(6), 893-906.

Granville, J. P., Richards, . G., Kim, W.-Y., and Sykes, L. R. (2005). Understanding the differences between three teleseismic m_b scales. *Bull. Seism. Soc. Am.*, **95**(5), 1809-1824.

Gutenberg, B. (1945a). Amplitudes of surface waves and magnitudes of shallow earthquakes. *Bull. Seism. Soc. Am.*, **35**, 3-12.

Gutenberg, B. (1945b). Amplitudes of P, PP, and S and magnitude of shallow earthquakes. *Bull. Seism. Soc.* Am., **35**, 57-69.

Gutenberg, B. (1945c). Magnitude determination of deep-focus earthquakes. *Bull. Seism. Soc. Am.*, **35**, 117-130.

Gutenberg, B. (1956). The energy of earthquakes. *Q. J. Geol. Soc*. London, **112**, 1-14.

Gutenberg, B., and Richter, C. F. (1954). Seismicity of the Earth and asscociated Phenomena. 2nd edition, Princeton University Press, 310 pp.

Gutenberg, B., and Richter. C. F. (1956). Magnitude and energy of earthquakes. *Annali di Geofisica*, **9**, 1-15.

Habermann, R. E. (1995). Opinion. *Seism. Res. Lett.*, **66**, 5, 3.

Hara, T. (2007). Measurement of the duration of high-frequency energy radiation and its application to determination of the magnitudes of large shallow earthquakes. *Earth Planets Space* **59**, 227-231.

Hayes, G. P., Rivera, L., and Kanamori, H. (2009). Source inversion of the W-phase: Real-time implementation and extension to low magnitudes. *Seism. Res. Lett.*, 80, 5, 817-822; doi: 10.1/85/gssrl.80.5.817.

Herak, M., and Herak. D. (1993). Distance dependence of M_S and calibrating function for 20 s Rayleigh waves. *Bull. Seism. Soc. Am.*, **83**, 6, 1881-1892.

Hutton, L. K., and Boore, D. M. (1987). The M_L scale in southern California. *Bull. Seism. Soc. Am.*, **77**, 2074-2094.

Hutton, L. K., and Jones, L. M. (1993). Local magnitudes and apparent variations in seismicity rates in Southern California. *Bull. Seism. Soc. Am.*, **83**, 2, 313-329.

IASPEI (2005). Summary of Magnitude Working Group recommendations on standard procedures for determining earthquake magnitudes from digital data. http://www.iaspei.org/commissions/CSOI/summary_of_WG_recommendations_2005.pdf.

IASPEI (2013) Summary of Magnitude Working Group recommendations on standard procedures for determining earthquake magnitudes from digital data.

http://www.iaspei.org/commissions/CSOI/Summary_WG_recommendations_20130327.pdf

http://www.iaspei.org/commissions/CSOI.html#wgmm

ISC (2013). Summary of the Bulletin of the International Seismological Centre, 2010, January-June, **47**(1-6), 187 pp.

Kanamori, H. (1977). The energy release in great earthquakes. *J. Geophys. Res.*, **82**, 2981-2987.

Kanamori, H., and Anderson, D. L. (1975). Theoretical basis of some empirical relations in seismology. *Bull. Seism. Soc. Am.*, **65**, 1073-1095.

Kanamori, H., and Rivera, L. (2008). Source inversion of W phase: speeding up seismic tsunami warning. *Geophys. J. Int.*, **175**, 222-238.

Karnik, V., N. V. Kondorskaya, Ju. Riznitchenko, E. F. Savarensky, S. L. Sobolev, N. V. Shebalin, J. Vanek, and A. Zatopek (1962). Standardization of the earthquake magnitude scale. *Studia geoph. et geod.* **6**, 41-48.

Lienkaemper, J. J. (1984). Comparison of two surface-wave magnitude scales: M of Gutenberg and Richter (1954) and Ms of "Preliminary Determination of Epicenters". *Bull. Seism. Soc. Am.*, **74**(6), 2357-2378.

Lomax, A., and A. Michelini (2009). M_{wpd}: A duration-amplitude procedure for rapid determination of earthquake magnitude and tsunamigenic potential from *P* waveforms, *Geophys.l J. Int.*, **176**, 200-214; doi: 10.1111/j.1365-246X.2008.03974.x.

Liu, R., Chen, Y., Bormann, P., Ren, X., Hou, J., Zou, L., and Yang, H. (2005). Comparison between earthquake magnitudes determined by China seismograph network and US seismograph network (I). Body wave magnitude. *Acta Seismologica Sinica*, **18,** 6, 627-631.

Liu, R., Chen, Y., Bormann, P., Ren, X., Hou, J., Zou, L., and Yang, H. (2006). Comparison between earthquake magnitudes determined by China seismograph network and US seismograph network (II). Surface wave magnitude. *Acta Seismologica Sinica*, **19,** 1, 1-7.

Murphy, J. R., and Barker, B. W. (2003). Revised distance and depth corrections for use in estimation of short-period P-wave magnitudes. *Bull. Seism. Soc. Am.*, **93**, 1746-1764.

Nuttli, O. W. (1973). Seismic wave attenuation and magnitude relations for eastern North America. *J. Geophys. Res.*, **78**, 876-885.

Nuttli, O. W. (1985). Average seismic source-parameter relations for plate-margin earthquakes. *Tectonophysics*, **118**, 161-174.

Nuttli, O .W. (1986). Yield estimates of Nevada Test Site explosions obtained from seismic Lg waves, *J. Geophys. Res.*, **91**, 2137-2151.

Nuttli, O. W. (1988). Lg magnitudes and yield estimates for underground Novaya Zemlya nuclear explosions, *Bull. Seism. Soc. Am.* 78, 873-884.

Okal, E. A., and Talandier, J. (1989). M_m: A variable-period mantle magnitude. J. *Geophys. Res.*, **94**, 4169-4193.

Okal, E. A., and Talandier, J. (1990). M_m: Extension to Love waves of the concept of a variable-period mantle magnitude. *Pure Appl. Geophys.*, **134**, 355-384.

Rezapour, M., and Pearce, R. G. (1998). Bias in surface-wave magnitude M_S due to inadequate distance corrections. *Bull. Seism. Soc. Am.*, **88**, 1, 43-61.

Richter, C. F. (1935). An instrumental earthquake magnitude scale. *Bull. Seism. Soc. Am.*, **25**, 1-32.

Richter, C. F. (1958). Elementary seismology. *W. H. Freeman and Company*, San Francisco and London, viii + 768 pp.

Storchak, D. A., Schweitzer, J., and Bormann, P. (2011). Seismic phase names: IASPEI standards. In: Harsh Gupta (ed.). *Encyclopedia of Solid Earth Geophysics,* Springer, Vol. 2,1162-1173; doi: 10.1007/978-90-481-8702-7.

Tsuboi, C. (1954). Determination of the Gutenberg-Richter´s magnitude of earthquakes occuring in and near Japan. *Zisin.* (*J. Seism. Soc. Japan*), Ser. II, **7**, 185-193.

Tsuboi, S., Abe, K., Takano, K., and Yamanaka, Y. (1995). Rapid determination of M_w from broadband P waveforms. *Bull. Seism. Soc. Am.*, **85**, 2, 606-613.

Uhrhammer, R. A., and Collins, E. R. (1990). Synthesis of Wood-Anderson seismograms from broadband digital records. *Bull. Seism. Soc. Am.*, **80**, 702-716.

Utsu, T. (2002). Relationships between magnitude scales. In: *International Handbook of Earthquake and Engineering Seismology*, *Part A*, edited by W.H.K. Lee, H. Kanamori, P.C. Jennings, and C. Kisslinger, Academic Press, Amsterdam, 733–746.

Vaněk, J., Zapotek, A., Karnik, V., Kondorskaya, N.V., Riznichenko, Yu.V., Savarensky, E.F., Solov'yov, S.L., and Shebalin, N.V. (1962). Standardization of magnitude scales. *Izvestiya Akad. SSSR., Ser. Geofiz.*, **2,** 153-158 (108-111 in the English translation).

Veith, K. F., and Clawson, G. E. (1972). Magnitude from short-period P-wave data. *Bull. Seism. Soc. Am.*, **62**, 435-452.

Willmore, P.L. (1979). Manual of Seismological Observatory Practice. World Data Center A for Solid Earth Geophysics, Report SE-20, September 1979, Boulder, Colorado, 165 pp.; http://www.seismo.com/msop/msop79/inst/inst1.html.