Plan of activities of the new IASPEI Working Group on Magnitude Measurements

1. Background

The Working Group (WG) on Magnitude Measurements of the IASPEI Commission on Seismological Observation and Interpretation was begun in 2001 as an outgrowth of the Commission meeting in Hanoi. K. Shedlock, U.S. Geological Survey, was the initial chairwoman. In 2002 J. Dewey was the new chairman. P. Bormann joined J. Dewey as cochairman following the 2009 IASPEI meeting in Cape Town. Chairmen Bormann and Dewey announced in 2013 that they would be resigning their positions at the time of the CoSOI meeting in Gothenburg. The CoSOI suggested to continue a Magnitude WG and asked the former chairmen to help with the transition to a restructured Magnitude WG. In 2014 Domenico Di Giacomo (International Seismological Centre, ISC) has joined the WG as new chairman with the task of re-organizing the WG so that it will continue and expand its activities.

The mission of the WG is to set up standards for magnitude measurements (IASPEI standards) that should be implemented by regional and global networks in routine operations. The WG proposed such standards in a preliminary report to the CoSOI in 2005 (http://www.iaspei.org/commissions/CSOI/summary_of_WG_recommendations_2005.pdf), and the standards were accepted by the Commission, pending testing of the standards in operational mode. The current more elaborate 2013 formulation of the standards may be accessed at http://www.iaspei.org/commissions/CSOI/Summary_WG_recommendations_20130327.pdf. They are functionally almost equivalent to the standards adopted in 2005 but they specify, besides stylistic editing of the text, the standard filter responses to be applied, address ambiguities recognized since 2005, agree on the nomenclature with which standard magnitudes and their related amplitude and period data should be reported, give reasons for agency-specific modifications of the recommended standard procedures, hint to several slightly adjusted procedures so as to be more easily implemented with current analysis software or so as to extend the domain over which a particular magnitude can be determined and provide a questionnaire for the detailed and unambiguous Documentation of Agency/Station Magnitude Procedures. Additional complementary details and data have been published by Bormann and Dewey (2012). Appendix A lists the WG achievements and related publication from WG members and colleagues.

During the 2013 Gothenburg meeting the WG and the CoSOI commission recognized the need of continuing the WG in order to 1) see the IASPEI standards fully implemented at several data centers and/or in software packages such as SeisComp, Antelope, etc. 2) achieve goals that became recognized in recent years, as explained later in this document. With the unanimous adoption of IASPEI resolution No. 1 the 2013 IASPEI General Assembly at Gothenburg recognized the importance of the magnitude standards proposed by the WG and the CoSOI (also published in second edition of the New Manual of Seismological Observatory Practice, NMSOP2, available at http://nmsop.gfz-potsdam.de), recommends to station operators and data centers to adopt these standards in day to day operations, and encourages the developers of waveform processing programs to incorporate these standards within their software packages.

2. Membership as from 2014

Membership of the group in July 2013 (former WG) was as follows: Peter Bormann (co-chairman), Jim Dewey (co-chairman), Irina Gabsatarova, Søren Gregersen, Alexander A. Gusev, Won-Yon Kim, Liu Ruifeng, Howard Patton, Bruce Presgrave, Joachim Saul, Bob Uhrhammer, and Siegfried Wendt.

The new WG is composed by: Domenico Di Giacomo (chairman), Allison Bent, Peter Bormann, Jim Dewey, Aleksey Emanov, Gavin Hayes, Alberto Michelini, Lars Ottemöller, Liu Ruifeng, Joachim Saul and Siegfried Wendt. The members of the WG are selected as representatives of different communities/agencies involved in magnitude measurements and/or analysis software developments. New members may join the WG in the future. Colleagues of the WG members are also encouraged to cooperate with the WG in order to achieve the best results possible within the plans of the WG.

3. Goals of the WG

The restructured WG aims at achieving various goals in the coming years. Some of these goals were developed by the former WG during 2002-2013 while others came up only recently and were not part of the agenda of the former WG. Additional goals may be added in the future as new requests may come up from the seismological community.

a. Publish in a reviewed journal an article on the IASPEI magnitudes: although several sections in the NMSOP-2 and other publications (see Appendix A) cover many aspects of the IASPEI standards on magnitude determination, there is still be the need of investigating features of the IASPEI magnitudes by analyzing a large global earthquake dataset (i.e., several thousands of earthquakes worldwide) recorded by the current (and growing) seismic network of broadband stations. This goal can be achieved if IASPEI magnitudes are systematically computed on a routine basis at least on a global scale and over a long period of time.

b. Gather and organize relevant documentation on the procedures used by seismological agencies in magnitude computation: seismological agencies operating at various scales (global, regional, local) often use not well documented procedures to compute different magnitudes which are reported in the ISC Bulletin (www.isc.ac.uk/iscbulletin). The WG and the ISC aim at engaging various agencies in order to make available online the most important features of the magnitude procedures run by various agencies. The ISC will have a leading role for this task as it is most comprehensive and final depository of seismological parameter data.

c. Develop more detailed standard nomenclature for Mw: in the recent years there has been a great proliferation of different types of Mw that may have significant differences from each other yet are all labeled as "Mw". This is due both to different procedures and the introduction of moment tensor inversion at regional scale from an increasing number of agencies. Therefore the WG aims at establishing a clear nomenclature for the various Mw currently computed in order to allow the user to better understand the procedure used to obtain Mw. Besides, comparisons of the newly computed Mw from regional networks with other magnitudes need to be investigated.

d. Establish a way of identifying IASPEI magnitudes and related measurements reported in seismological bulletins: the nomenclature established by the WG for identifying IASPEI magnitudes and related measurements is not fully implemented yet at several agencies. The WG and in particular the ISC aim at engaging agencies and software developers to implement the IASPEI standards in their operations and to support the ISC to identify IASPEI magnitudes and related measurements.

e. Cross-check magnitudes computed by different agencies: with the exception of the publications by Liu *et al.* (2005 and 2006) and Bormann *et al.* (2007 and 2009), there has not yet been a systematic, large-scale, effort by researchers from a number of national and regional centers to cross-check magnitudes computed by different agencies for the same earthquake in order to understand the reasons for discrepancies that are larger than 0.1 magnitude unit. The same applies to investigating the differences between the same type of magnitudes determined at identical stations or network data analysis centers for the same earthquakes when applying both their traditional (or "non-standard") and the new IASPEI standard procedures, respectively. Magnitude differences between standard and "non-standard" procedures can be due, among others, to the following reasons:

a. differences in applied filter parameters (e.g., a 2 Hz filter instead of the WWSSN-SP filter may increase the SNR allowing, therefore, the mb computation of intermediate to deep earthquakes);
b. variable measurement time windows;
c. different calibration functions;
d. software and/or instrument changes, which alone may introduce time dependent changes.

Further investigations are required in this sense. In particular, the WG shall try to identify and address time dependent variations for magnitudes available over long periods of time and to establish a way to identify magnitudes that deviate from standard practice. This task, therefore, is also tied to the progress of task b). The seismological community would benefit from this work by having a clearer background about the specifics (and limitations) of the magnitudes listed in regional/ global catalogues.

Finally, if time and resource permit, it would be interesting to study discrepancies between manual (seismologist using an interactive software) and automatic solutions and to develop a robust algorithm for amplitude measurements in noisy data and when the signal is not nearly sinusoidal and to compare results with standard amplitude measurements.

f. <u>Development/revision of regional calibration curves for mb, mB_BB and Ms_BB</u>: body-wave magnitudes are currently computed for distances > 20 deg since the complexity of the Earth structure at shorter distances makes quite difficult the application of a simple calibration curve valid for the entire Earth. However, regional calibration curves can be developed and their use would be important for rapid magnitude determinations in realtime procedures. For Ms_BB much more data in different geodynamic settings need to be gathered in order to either justify or revise for those regions the current global calibration curve which is used down to 2 degrees. The WG shall cooperate with various agencies to investigate this aspect. A modernized version of the Gutenberg-Richter $Q(\Delta, h)$ functions has been developed at the GFZ and extended down to 5 degrees using a global average. Such functions may be used as starting point for developing functions for specific regions.

g. Development of PKP calibration curves: PKP recordings can be a useful complement for mb computation. In Europe, for example, there are excellent recording conditions for earthquakes in the South West Pacific Ocean: at station CLL in Germany and for distances between 145 and 155 degrees PKP signals could be analyzed for about 20-30% of the events, even with small magnitude. PKP curves for station CLL are already available in the NMSOP. The next step will be to obtain calibration curves for PKP branches using a regional network and, eventually, the global seismic network.

h. Develop standards for a short-period velocity broadband mb based on Vmax: this point has been suggested by former co-chairman Peter Bormann and can be achieved thanks to the work started at INGV and GEOFON.

i. Investigate the use of MLg(f) as an Lg magnitude: this point is of particular importance for continental paths over which the Lg phase is recorded at predominant periods significantly less than 1s.

j. Develop standard procedures for coda-magnitude: this point was suggested by former WG member Howard Patton, who notes that "in the area of nuclear test monitoring, coda magnitudes have supplanted mb(Lg) as the measurement of preference".

k. Establish a standard procedure for computing the K-class: for several decades the Kclass has been computed for local and regional earthquakes occurring in the area of the former Soviet Union territory. However, the measurement and calibration procedures need to be modernized and standardized so as to make the K-class values computed for different regions compatible amongst each other and comparable with respective logEs seismic energy and related Me calculations based on teleseismic records from worldwide earthquakes only (see IS 3.7 of NMSOP-2). K-class values should then also be compared with other magnitudes in order to better evaluate their potential as proxy measure of the energy released by earthquakes. However, one should be aware that the currently common teleseismic Me formula scales logEs, estimated from velocity broadband P-wave records, to band-limited 20 s surface-wave magnitude Ms. This may result in significant differences between such Me estimates and those based on short-period local/regional K measurements. In order to better understand the reason for such possible differences it is recommended to calculate local/regional Me also via a recently proposed formula (Bormann et al. 2000; Bormann 2014 submitted) which scales K = logEs to P-wave based broadband mB instead. The logEs-mB scaling has been the originally been the only and by good reason preferred energy-magnitude scaling proposed by Gutenberg and Richter (1956).

l. Investigations on the effect of the unbalanced geometry of the global seismic network on magnitude determination: the number of digital stations world-wide has increased dramatically, so that it is not unusual for the agencies such as NEIC or ISC to have several thousand amplitude/period observations for a single, moderately strong, earthquake. At the NEIC, this situation has led to consideration of computing magnitudes only for a preferred subset of the overall station set, with preferred stations being selected on the basis of such criteria as geographic location, station sensitivity and reliability, or the extent to which current observations would continue a long-running data set. Such considerations call for systematic studies on the effects of the station coverage on magnitude determination.

m. Establish standards for routine estimation or quantification of the source duration of earthquakes: after the great 2004 Sumatra earthquake procedures to rapidly estimate the duration of the earthquake rupture were introduced. Being an important measure to detect and discriminate in a short time after the earthquake occurrence potentially disastrous tsunami-genic and tsunami earthquakes, such procedures are important for tsunami early warning systems. The source duration would be an important parameter to characterize the earthquake source and, therefore, IASPEI standards for routine computation of source duration should be established. However, to accomplish this task feasibility studies need to be carried out over a large dataset in order to explore the benefits and limitations of various procedures, in particular below magnitude 6.

n. Set up an advisory forum: this would be a platform on the IASPEI website that could be used for various purposes. Probably the more important would be for individuals or groups who are computing new versions of magnitudes and wish their magnitudes to be consistent with magnitudes computed worldwide. They may use the forum for exchanging information with the WG. The forum can also be used for discussions or other topics (see, e.g., task n.).

o. Establish IASPEI standards for Signal-to-Noise Ratio (SNR) computation: there is no consensus on how SNR should be computed for amplitude measurements within procedures designed for magnitude computation. SNR should be a parameter systematically provided along with the amplitude and the period. Since magnitudes are computed over different frequency ranges, spectral SNR offers the possibility of providing the SNR within the relevant frequency limits of a magnitude type. The forum could be used for discussing a standard for SNR computation for magnitude measurements.

Appendix A: 2002-2013 accomplishments of the Magnitude WG or accomplishments by others that pertain to the standards proposed by the WG

1. The WG fulfilled its original charge to define standards ("IASPEI Standard Procedures") for making measurements from digital data to be used in calculating widely-used magnitudes.

2. The IASPEI Standard Procedures have been posted online for a number of years, so that a Google search for "IASPEI magnitudes" highlights as first choice the Summary of Procedures that is posted on the ISC website.

3. The IASPEI magnitudes, and their relationships to other magnitudes, have been exhaustively analyzed in Chapter 3 and associated Information Sheets, Exercises, and Datasheets of the New Manual of Seismological Observatory Practice, version 2 (NMSOP-2).

4. The NEIC has implemented the IASPEI procedures in experimental mode for over six years, and since 2009 most NEIC-computed and published mb, Ms (Ms_20), ML, and mb_Lg are computed by the IASPEI recommended procedures.

5. The IASPEI Procedures are implemented in the widely-used seismic analysis package SEISAN.

6. Several WG members and their colleagues have published papers in journals or in the New Manual of Seismological Observatory Practice 2 that are devoted to, or that strongly emphasize, the IASPEI magnitudes. These are listed below, in approximate chronological order.

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.

Bormann, P., R. Liu, X. Ren, R. Gutdeutsch, D. Kaiser, and S. Castellaro (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. and J. Saul (2008). The New IASPEI Standard Broadband Magnitude mB. *Seism. Res. Lett.*, **79**, 698-705.

Bormann, Peter, Ruifeng Liu, Zhiguo Xu, Kexin Ren, Liwen Zhang, and Siegfried Wendt (2009). First application of the new IASPEI teleseismic magnitude standards to data of the China National Seismographic Network, *Bull. Seism. Soc. Am.*, **99**, 1868-1891.

Bormann, Peter and Joachim Saul (2009). Earthquake magnitude, in Encyclopedia of Complexity and Systems Science, A. Meyers (Editor), Springer, Heidelberg-New York, Vol. 3, 2473-2496.

Bormann, P., D. Di Giacomo, and J. Saul (2010). Is there a need to redefine Mw and Me on the basis of modern Es and magnitude data? Poster presented at the 32nd ESC General Assembly, Montpellier, France.

Bormann, P. (2011). Earthquake magnitude. In: Harsh Gupta (ed.): Encyclopedia of Solid Earth Geophysics, Springer, 207-218; doi: 10.1007/978-90-481-8702-7.

Bormann, P. (2012). Magnitude calibration formulas and tables, comments on their use and complementary data, Data-Sheet 3.1, in Bormann, P. (Ed.) New Manual of Seismological Observatory Practice (NMSOP-2), 19 p. (available at http://bib.telegrafenberg.de/publizieren/vertrieb/nmsop/, last accessed December 2013).

Bormann, P. (2012). Magnitude determinations, Exercise 3.1, in in Bormann, P. (Ed.) New Manual of Seismological Observatory Practice (NMSOP-2), 8 p. (available at http://bib.telegrafenberg.de/publizieren/vertrieb/nmsop/, last accessed December 2013).

Bormann, P., J. Dewey, and the IASPEI/CoSOI Working Group on Magnitude Measurement (2012). The new IASPEI standards for determining magnitudes from digital data and their relation to classical magnitudes, Information Sheet 3.3, in Bormann, P. (Ed.) New Manual of Seismological Observatory Practice (NMSOP-2), 44p. (available at http://bib.telegrafenberg.de/publizieren/vertrieb/nmsop/, last accessed December 2013).

Bormann, P. and S. Wendt (2012). Preliminary guidelines for using the IASPEI standard magnitude reference data set, Information Sheet 3.4, in Bormann, P. (Ed.) New Manual of Seismological Observatory Practice (NMSOP-2), 19 p. (available at http://bib.telegrafenberg.de/publizieren/vertrieb/nmsop/, last accessed December 2013).

Dewey, J. (2012). Program Description 3.1, in Bormann, P. (Ed.) New Manual of Seismological Observatory Practice (NMSOP-2), 5 p. (available at http://bib.telegrafenberg.de/publizieren/vertrieb/nmsop/, last accessed December 2013).

Bormann, P. (2012). Proposal for unique magnitude and amplitude nomenclature, Information Sheet 3.2, in Bormann, P. (Ed.) New Manual of Seismological Observatory Practice (NMSOP-2), 26 p. (available at http://bib.telegrafenberg.de/publizieren/vertrieb/nmsop/, last accessed December 2013).

Bormann, P., Fujita, K, Machey, K, and Gusev, A. (2012). The Russian K-class system, its relationships to magnitudes and its potential for future development and application, Information Sheet 3.7, in Bormann, P. (Ed.) New Manual of Seismological Observatory Practice (NMSOP-2), 27 p. (available at http://bib.telegrafenberg.de/publizieren/vertrieb/nmsop/, last accessed August 2014).

Bormann, P., Wendt, S., and Di Giacomo, D. (2013). Seismic Sources and Source Parameters, Chapter 3, in Bormann, P. (Ed.) New Manual of Seismological Observatory Practice (NMSOP-2), 259 p. (available at http://bib.telegrafenberg.de/publizieren/vertrieb/nmsop/, last accessed December 2013).

Bormann, P., and D. Di Giacomo (2014). Earthquake: magnitudes, energy, and moment, in Encyclopedia of Complexity and Systems Science, A. Meyers (Editor), Springer, Heidelberg-New York, second electronic edition (submitted, under revision)

Bormann, P. (2014). Are new data suggesting a revision of the Mw and Me formulas? Submitted to J. Seismology.