Summary of Magnitude Working Group Recommendations on Standard Procedures for Determining Earthquake Magnitudes from Digital Data

[Procedures as adopted by the IASPEI Commission on Seismological Observation and Interpretation (CoSOI), Santiago, Chile, October, 2005. Subsequent to the October 2005 adoption of the procedures, this summary's nomenclature for mB(BB) (denoted mB in 2005) was adopted.]

The Working Group on Magnitudes (*Magnitude WG)* of the International Association of Seismology and Physics of the Earth's Interior (IASPEI) Commission on Seismological Observation and Interpretation (CoSOI) was established to recommend standard procedures for making measurements from digital data to be used in calculating several widely used types of earthquake magnitude. The recommended procedures from the *Magnitude WG* have been approved by the IASPEI Commission on Seismological Observations and Interpretations and are expected to be implemented by all seismological centres. We henceforth refer to the proposed procedures as the IASPEI standard procedures for magnitude determination. The *Magnitude WG* is planning to publish an article, in the open literature, that explains the reasons and arguments that lead to the IASPEI standard procedures.

The IASPEI standard procedures address the measurement of amplitudes and periods from digital data for use in calculating the generic magnitude types M_L, M_S, m_b, m_B, and $m_b(L_g)$. For M_S, standard procedures are proposed for two different traditions – M_S measured from waves with periods near 20*s* [here denoted $M_S(20)$] and M_S measured from waves in a much broader period-range [here denoted $M_S(BB)$]. For the generic intermediate-period/broadband body wave magnitude m_B, we propose a procedure based on the maximum amplitude of the P-wave measured on a velocity-proportional trace: we denote the resulting magnitude $m_B(BB)$. The IASPEI standard procedures also specify a standard equation for M_W from among several slightly different equations. Abbreviated provisional descriptions of the procedures are described below.

The *magnitude WG* is currently monitoring a test implementation of the IASPEI standard procedures, to be sure that descriptions of the procedures, such as described below, are consistent with the intent of the *WG*. When this test has been completed, we will provide at this site a more complete description of the IASPEI standard procedures, including filter parameters that will be necessary to replicate the responses of standard instruments that are specified in the standard procedures.

The amplitudes used in the magnitude formulas are generally to be measured as one-half the maximum peak-to-adjacent-trough deflection of the seismogram trace. None of the magnitude formulas presented in this article are intended to be used with the full peak-to-trough deflection as the amplitude.

M_L -- *local magnitude consistent with the magnitude of Richter (1935)*

For crustal earthquakes in regions with attenuative properties **similar** to those of Southern California, the standard equation is

$$(1)\ M_L = \log_{10}(A) + 1.11 \log_{10}R + 0.00189 * R - 2.09$$

where:

A = maximum **trace** amplitude in ***nm*** that is measured on output from a **horizontal-component** instrument that is filtered so that the response of the seismograph/filter system replicates that of a **Wood-Anderson standard seismograph** but with a **static magnification of 1**;

R = **hypocentral distance in *km***, typically less than 1000 km.

Equation (1) is an expansion of that of Hutton and Boore (1987). The constant term in equation (1), -*2.09*, is based on an experimentally determined static magnification of the Wood-Anderson of *2080*, rather than the theoretical magnification of *2800* that was specified by the seismograph's manufacturer. The formulation of equation (1) reflects the intent of the *Magnitude WG* that reported M_L amplitude data not be affected by uncertainty in the static magnification of the Wood-Anderson seismograph.

For crustal earthquakes in regions with attenuative properties that are **<u>different</u>** than those of coastal California, and for measuring magnitudes with vertical-component seismographs, the standard equation is of the form:

$$(2)\ M_L = \log_{10}(A) + C(R) + D$$

where A and R are as defined in equation (1), except that A may be measured from a **vertical-component** instrument, and where $C(R)$ and D have been **calibrated** to adjust for the different regional attenuation and to adjust for any systematic differences between amplitudes measured on horizontal seismographs and those measured on vertical seismographs.

$M_S(20)$, <u>*teleseismic surface-wave magnitudes at period of ~ 20 sec*</u>.

$$(3)\ M_S(20) = \log_{10}(A_{max}/T) + 1.66 \log_{10}\Delta + 3.3$$

where:

A_{max} = **vertical-component** ground displacement in ***μm*** measured from the maximum trace-amplitude of a **surface-wave** phase having a period between **18*s* and 22*s*** on a waveform that has been filtered so that the frequency response of the seismograph/filter system replicates that of a World-Wide Standardized Seismograph Network (WWSSN) **long-period seismograph** (seismometer period 15*s*, galvanometer period, 90*s*);

T = period in seconds ($18s \leq T \leq 22s$);

Δ = **<u>epicentral</u>** distance in degrees, $\mathbf{20^\circ} \leq \Delta \leq 160^\circ$;

and where the earthquake has a focal-depth of **less than 60 *km***.

$M_S(BB)$ *surface-wave magnitudes from Broad Band instruments*.

(4) $M_S(BB) = log_{10}(A/T)_{max} + 1.66\ log_{10}\Delta + 3.3$

where

$(A/T)_{max} = (V_{max}/2\pi)$, where V_{max} = ground **velocity in *μm/s*** associated with the maximum trace-amplitude in the surface-wave train as recorded on **vertical-component** seismogram that is **proportional to velocity**, and where the period T, $\mathbf{3s \le T < 60s}$, should be preserved together with A or V_{max} in bulletin data-bases;

Δ = **epicentral** distance in degrees, $\mathbf{2^\circ \le}\ \Delta \le 160^\circ$, focal depth **less than 60 *km***.

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m_b – *short-period body-wave magnitude*

(5) $m_b = log_{10}(A_{max}/T) + Q(\Delta, h)$

where,

A_{max} = P-wave ground displacement in ***μm*** calculated from the maximum trace-amplitude in the **entire P-phase train** (time spanned by P, pP, sP, and possibly PcP and their codas, and ending preferably **before PP**);

T = period in seconds, $\mathbf{T < 3s}$;

A and T are measured on output from a **vertical-component** instrument that is filtered so that the frequency response of the seismograph/filter system replicates that of a WWSSN **short-period** seismograph;

$Q(\Delta, h)$ = attenuation function for **PZ** (P-waves recorded on vertical component seismographs) established by **Gutenberg and Richter (1956**);

Δ = **epicentral** distance in degrees, $\mathbf{21^\circ \le \Delta \le 100^\circ}$;

h = focal depth.

$m_B(BB)$ –*broadband body-wave magnitude*

(6) $m_B = log_{10}(A/T)_{max} + Q(\Delta, h)$

where,

$(A/T)_{max} = (V_{max}/2\pi)$, where V_{max} = ground **velocity in *μm/s*** associated with the maximum trace-amplitude in **the entire P-phase train** (time spanned by P, pP, sP, and possibly PcP and their codas, but ending preferably before PP) as recorded on a **vertical-component** seismogram that is **proportional to velocity** in the period-range **0.2*s* < *T* < 30*s***, and where T should be preserved together with A or V_{max} in bulletin data-bases;

$Q(\Delta, h)$ = attenuation function for **PZ** established by **Gutenberg and Richter (1956)**, as discussed above with respect to m_b;

Δ = epicentral distance in degrees, $\mathbf{21^\circ \leq \Delta \leq 100^\circ}$;

h = focal depth.

M_W – <u>*moment magnitude*</u>

(7a) $M_W = (2/3)\cdot(\log_{10}M_0 - 9.1)$

where M_0 = scalar moment in ***N·m***, determined from waveform modelling or from the long-period asymptote of spectra.

or its CGS equivalent (M_0 in **dyne·cm**),

(7b) $M_W = (2/3)\cdot(\log_{10}M_0 - 16.1),$

$m_b(L_g)$ – <u>*regional Lg magnitude measured in a narrow period range around 1s*</u>.

(8) $m_b(L_g) = 5.0 + \log_{10}[A_i(10)/110]$

where,

$A_i(10)$ = ground displacement in ***μm*** of "hypothetical" Lg wave at a distance of **10 *km***, extrapolated from observation at station *i*.

The extrapolated amplitude $A_i(10)$ is calculated as:

$$(9)\ A_i(10) = A(r_i)\cdot(r_i/10)^{1/3}\cdot[\sin(r_i/111.1)/\sin(10/111.1)]^{1/2}\cdot\exp[\gamma(r_i - 10)]$$

where:

$A(\Delta_i)$ = "sustained ground-motion amplitude" in ***μm*** at *i*th station, defined as the third largest amplitude in the time window corresponding to group velocities of 3.6 to 3.2 *km/s*, in the period-range 0.7 to 1.3*s*.

r_i = **epicentral distan**ce of *i*th station, in *km*.

γ = coefficient of attenuation in km^{-1}. γ is related to the quality factor Q through the equation $\gamma = \pi/(Q\cdot U\cdot T)$, where U is group velocity and T is the wave period of the L_g wave. γ is a strong function of crustal structure and should be determined specifically for the region in which the $m_b(L_g)$ is to be used.

A and *T* are measured on output from a **vertical-component** instrument that is filtered so that the frequency response of the seismograph/filter system replicates that of a WWSSN **short-period** seismograph. Arrival times with respect to the origin of the seismic disturbance are used, along with epicentral distance, to compute group velocity *U.*

At the regional and near-teleseismic distances within which $m_b(L_g)$ is typically used, equations (8) and (9) may be simplified to:

$$(10)\ m_b(L_g) = 2.96 + 0.833\log_{10}[r_i/10] + .4343\gamma r_i + \log_{10}(A_i)$$

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