LOCAL MAGNITUDE SCALE FOR MONGOLIA AND DETERMINATION OF M_{WP} AND M_S *(BB)*

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ABSTRACT

We determined a new local magnitude (M_L) scale for the regional network of Research Center of Astronomy and Geophysics of Mongolian Academy of Sciences (RCAG, MAS). We used amplitude data from the Mongolian seismic network recorded by short-period seismographs from 143 local and regional earthquakes that occurred during 2005–2012. The magnitude range is between 3.5 and 6.7. We derived $-\log A_0$ distance correction function for M_L based on its original definition. We obtained the following formula for determining M_L in Mongolia:

$$M_L = \log A - 1.11\log(r/100) + 0.00061(r-100) + 3$$

where *A* is the maximum amplitude (mm) observed on the horizontal component, *r* is the hypocentral distance (km). We found that the residuals of magnitudes determined using the above formula do not have a significant epicentral dependence. The magnitudes determined by the above formula are slightly larger (by about 0.15) than those determined by the current formula.

Since RCAG has started deployment of its broadband seismic network recently, in order to enhance its seismic monitoring capability, we determined M_{wp} and M_s*(BB)* for five local earthquakes using waveform data from a single broadband station in Mongolia. The estimated magnitudes are relatively consistent with the moment magnitudes of the Global CMT solutions, which implies that these magnitude determination methods will work well for monitoring larger earthquakes, for which M_L will saturate. The routine determination of M_L, M_{wp} and M_s*(BB)* is important and effective for earthquake monitoring in and around Mongolia.

Keywords: M_L, Distance correction, M_{wp}, M_s*(BB)*, broadband station,

1. INTRODUCTION

The Research Center of Astronomy and Geophysics (RCAG) has been deploying its digital seismic network and conducting earthquake monitoring in and around Mongolia since 1994. Digital seismic stations have been calibrated so that digital records can be converted to ground velocities from one station to the other. This step is important in the constitution of the seismic catalogue with a magnitude determination. At present, the following formula is used at RCAG to determine local magnitude:

$$M_L = \log\left(\frac{A}{T}\right) + 0.816\log\Delta + 0.00045\Delta - 1.22 \quad (1)$$

where *A* is the maximum amplitude in nm, measured for period *T* on horizontal components, Δ is the epicentral distance in km. Ulziibat (2001) obtained this formula using data from digital stations operational since 1994. We found that the magnitudes determined by the above formula have

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significant epicentral distance dependence. In order to reduce this dependency, we developed a new local magnitude scale for Mongolia.

In addition, we determined broadband moment magnitude M_{wp} and surface-wave magnitude $M_s(BB)$ from a broadband station in Mongolia. M_{wp} gives quick and accurate size estimates for earthquakes both in regional (Tsuboi *et al*., 1995) and teleseismic (Tsuboi *et al*., 1999) distance ranges.

2. DATA

In this study, we used two kinds of dataset. First, we selected 143 local and regional earthquakes that occurred in 2005 – 2012. The magnitude range is between 3.5 and 6.7. We used 699 amplitude data from 23 short-period stations of the Mongolian seismic network.

We also used five earthquakes that occurred in and around Mongolia during 2004-2012. The magnitude range is 5.5 and 6.7. We retrieved waveform data recorded at a broadband seismic station, ULN from the Incorporated Research Institutions for Seismology (IRIS) Data Management Center (DMC).

3. METHODS

In this study, we determined the three different magnitudes.

1. We followed the procedure of Miao and Langston (2007) to determine a formula of M_L. Richter (1935, 1958) used the local-magnitude M_L defined by:

$$M_L = \log A - \log A_0 + S \tag{2}$$

where A is the maximum amplitude observed in mm, $\log A_0$ is an empirically determined distance correction function and S is an empirical station correction.

There are several different techniques to determine an empirical distance correction function for M_L (e.g., Kanamori and Jennings, 1978; Hutton and Boore, 1987). In this study, following Miao and Langston (2007), we used the approach suggested by Hutton and Boore (1987); the above equation can be expressed with an explicit distance correction function as:

$$-\log A_{ij} = n \log(r_{ij}/100) + K(r_{ij} - 100) + 3.0 - M_{Li} \tag{3}$$

where n and K are parameters related to the geometrical spreading and anelastic attenuation, A_{ij} is the horizontal maximum amplitude of the i th event observed at the j th station, r_{ij} is the epicentral distance from the i th event to the j th station component. M_{Li} is the local magnitude of the i th event.

They conducted a one-step linear inversion without iteration to determine the coefficients for a distance correction function under the condition that a local magnitude is 3 when maximum amplitude is 1 mm at a distance of 100 km. We did not include station corrections in the unknown model parameters to be determined due to limitation of the available data.

2. We followed Tsuboi *et al*. (1995) to calculate the broadband moment magnitude. The broadband moment magnitude, M_{wp}, gives quick and accurate size estimates for both regional (Tsuboi *et al*., 1995) and teleseismic (Tsuboi *et al*., 1999) earthquakes. It determines the seismic moment from P-wave of broadband seismograms and calculates the moment magnitude estimate. The seismic moment is read as peak amplitude of the integrated P-wave of displacement seismograms. We used the following equation to calculate approximate seismic moment M_0 :

$$M_0' = |\max(\int u_z(x_r, t)dt| \cdot 4\pi\rho\alpha^3 r \quad (4)$$

where u_z is the vertical component record, x_r is the receiver location, ρ is the density, α is the *P*-wave velocity, and *r* is the epicentral distance. We adopted $\rho = 2.6kg/cm^3$ and $\alpha = 6.0km/\sec$, respectively, considering that earthquakes in and around Mongolia usually occur in the upper crust. This equation means that we can have an estimate of seismic moment from the first peak of the *P*-wave portion of the velocity seismogram integrated twice. Using an estimate from this equation we can obtain an estimate of moment magnitude by using the standard moment-magnitude formula (Kanamori, 1977):

$$M_w' = \frac{2}{3}\log M_0' - 10.73 \quad (5)$$

where the unit of M_0' is dyne centimeters. To compensate for the correction of the radiation pattern, we followed Tsuboi *et al*. (1995); they suggested the correction for radiation pattern is adding 0.2 to M_w':

$$M_{wp} = M_w' + 0.2 \quad (6)$$

3. We followed the recommendation of the Working Group on Magnitudes, International Association of Seismology and Physics of the Earth's Interior (IASPEI) to calculate the surface-wave magnitude, $M_s(BB)$, using digital broadband velocity seismograms. The standard equation for $M_s(BB)$ is as follows:

$$M_s(BB) = \log(A/T)_{\max} + 1.66\log\Delta + 3.3 \quad (7)$$

where $(A/T)_{\max} = (V_{\max}/2\pi)$, where V_{max} = ground velocity in $\mu m/s$ 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*, $3s < T < 60s$, should be preserved together with *A* or V_{max} in bulletin data-bases. The applicable epicentral distance range Δ is larger than or equal to 2 degrees and smaller than or equal to 160 degrees. The focal depth should be less than 80 km.

4. RESULT & DISCUSSION

In this study, we derived a local magnitude scale for Mongolia based on the original definition of local magnitude (M_L), and we also determined M_{wp} for earthquakes in and around Mongolia analyzing waveform data from IRIS station. Also we determined surface-wave magnitude $M_s(BB)$ from broadband seismograms.

4.1 Determination of Local magnitude (M_L)

In this study, we derived a local magnitude scale for Mongolia. We performed linear inversion under constraints. Based on preliminary calculations and previous studies we set 3, 0.001, and 5 to the standard deviations of *n*, *K*, and magnitude before inversion, respectively. We obtained the following distance correction term:

$$-\log A_0 = 1.11\log(r/100) + 0.00061(r - 100) + 3 \quad (8)$$

where r is the hypocentral distance in km. The coefficient 1.11(±0.79) for the log(r) term is almost the same as that for Southern California (Hutton and Boore, 1987). The second coefficient 0.00061(±0.00071) is much smaller than that of Hutton and Boore (1987). Although it is difficult to have a tight constraint for this coefficient, we obtained a larger variance reduction for the observed amplitude measurements using the above formula than the formula of Hutton and Boore (1987). Thus, this smaller coefficient is likely to reflect the lower dissipation of seismic wave energy in the study area.

Figure 1 shows the distance-correction functions for southern California (Boore and Hutton, 1987), Central California (Bakun and Joyner, 1984), Central United States (Miao and Langston, 2007), Japan (Y. Fujino and R. Inoue, 1985, given as "written communication" which Boore and Hutton, 1987) and Mongolia (from our study). The attenuation curve computed for Japan by Fujino and Inoue (1985) is similar to that of our study.

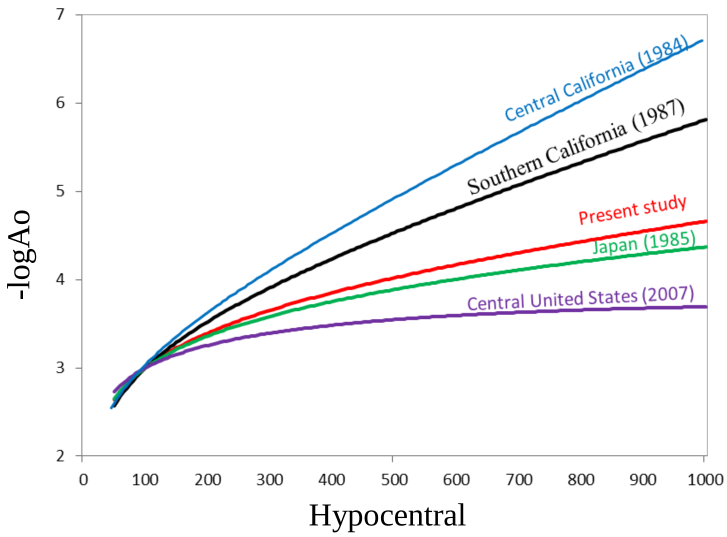

Figure1. Comparison of logA_0 of this study to those from pevious studies.

Using the above distance correction, we propose the following formula for determining a local magnitude in Mongolia.

$$M_L = \log A - 1.11\log(r/100) + 0.00061(r-100) + 3 \quad (9)$$

where A is the maximum amplitude in mm on the horizontal component records, r is the hypocentral distance in km. We calculated the M_L residuals using Eq. (9). Magnitude residuals were computed as the difference between magnitude assigned by a single station for a given earthquake and the average magnitude of the same earthquake. Figure 2 shows the hypocentral distance dependence of the residuals. The magnitude residuals do not have any significant hypocentral distance dependence, i.e., the residuals are close to zero for each hypocentral distance except for the distance range between 0 and 100 km. In this range, there are only three measurements. Therefore, it is difficult to judge whether the deviation of the residuals from zero is significant or not. Further accumulation of data will be necessary.

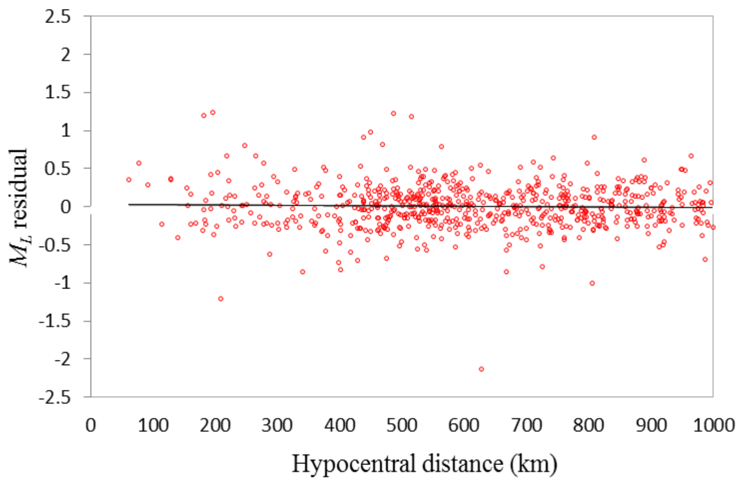

Figure 2. Local magnitude residuals as a function of hypocentral distance.

Then we compared our results of local magnitude to local magnitudes computed using the current formula, body-wave magnitude m_b by USGS, respectively (Figures 3 and 4).

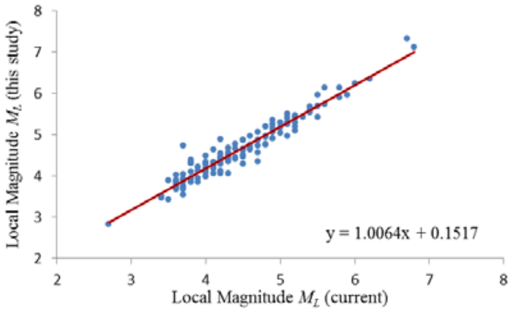

Figure 3. Comparison between M_L (this study) and M_L calculated using Eq. (1)

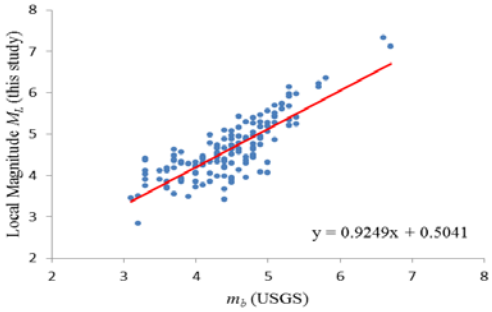

Figure 4. Comparision between our results of local magnitude M_L (this study) and m_b by USGS.

4.2 Determination of M_{wp} from broadband *P*-waveform

We used five local earthquakes which occurred in and around Mongolia in between 2006 to 2012.

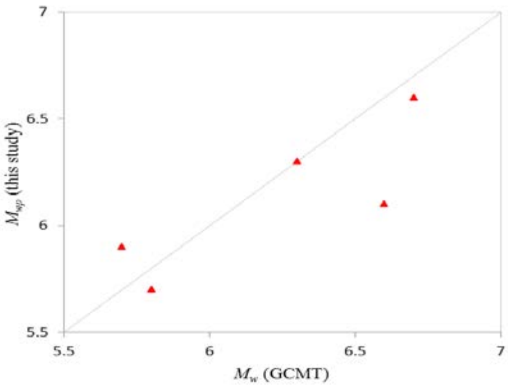

Figure 5. Comparison between M_{wp} (this study) and M_w (GCMT) from the Global CMT solutions.

Figure 5 shows that there is a relatively good correlation between them. The RMS of their differences is 0.38. These results indicate that M_{wp} gives a relatively good estimate of moment magnitude for these five earthquakes. Although it is preliminary since the number of earthquakes is few, this result suggest that the procedure to determine M_{wp} is also applicable to the study area.

4.3 Determination of $M_s(BB)$ from broadband seismograms

We determined surface-wave magnitude, $M_s(BB)$, using broadband seismograms. By picking the largest peak from the surface-wave train, we measured V_{max} ($\mu m/sec$), and then calculated $M_s(BB)$. We compared our results (Figures 6 and 7). They are in relatively good agreement.

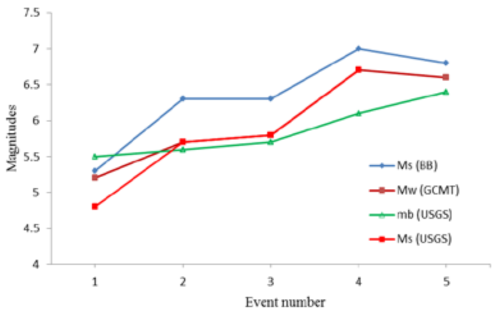

Figure 6. Comparison between $M_s(BB)$ and others magnitude scales.

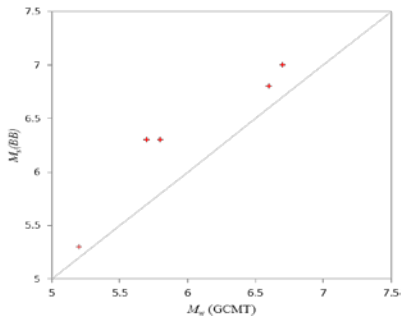

Figure 7. Comparison between $M_s(BB)$ and M_w(GCMT) from the Global CMT solution.

5. CONCLUSION

In the present study, we determined $-\log A_0$, distance correction function for M_L using 699 amplitude measurements for 143 local and regional earthquakes from the Mongolian seismic network. The magnitude range is between 3.5 and 6.7. Referring to the Richter's original condition that a magnitude 3 event would produce 1 mm of motion at 100 km, we obtained the following distance correction:

$$-\log A_0 = 1.11\log(r/100) + 0.00061(r-100) + 3$$

where r is hypocentral distance in km. Then, the following formula is proposed for the local magnitude in Mongolia.

$$M_L = \log A - 1.11\log(r/100) + 0.00061(r-100) + 3$$

where A is the maximum amplitude (mm) observed on the horizontal component, r is the hypocentral distance in km. We found that the residuals of magnitudes determined using the above formula do not have a significant epicentral dependence. On the other hand, the residuals of magnitudes determined using the current M_L formula adopted by RCAG have a significant epicentral dependence. The magnitudes determined by the above formula are slightly larger (by about 0.15) than those determined by the current formula.

Since RCAG has started deployment of its broadband seismic network, in order to enhance its seismic monitoring capability, we determined M_{wp} and $M_s(BB)$ for five local earthquakes using waveform data from a single broadband station in Mongolia. The estimated magnitudes are relatively consistent with the moment magnitudes of the Global CMT solutions, which implies that these magnitude determination methods will work for monitoring larger earthquakes, for which M_L will saturate.

The routine determination of M_L, M_{wp} and $M_s(BB)$ by RCAG is important and effective for earthquake monitoring in and around Mongolia, which will provide fundamental information for seismic hazard evaluation in Mongolia.

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