LOCAL MAGNITUDE CALCULATIONS FOR EARTHQUAKES IN AND AROUND BANGLADESH AND THEIR INFERENCE FOR DISTANCE CORRECTION FUNCTION

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ABSTRACT

We calculated local magnitudes for events that occurred in and around Bangladesh from January 2007 to December 2010. We retrieved waveform data from the Incorporated Research Institutions for Seismology (IRIS) Data Management Centre (DMC) and calculated synthetic Wood-Anderson seismograms. We selected 30 events for which there are at least 5 waveform data with the high signal to noise ratio. First we used the distance correction function obtained for southern California to calculate local magnitudes. We calculated a magnitude residual which is a difference between a magnitude estimate of each station and the median magnitude of that event. The hypocentral distance dependence of magnitude residuals is small, which suggests that the distance correction function for this area is similar to that of southern California. Then, we conducted a grid search for the coefficients of the distance correction function. The set of the coefficients with the minimum root mean square of the magnitude residuals is similar to that for southern California. We also compared local magnitude estimates to body wave magnitudes in the ISC catalog to find their correlation.

Keywords: Local magnitude, Distance correction function, Grid search.

1. INTRODUCTION

The Seismic Observatory and Research Centre, Bangladesh Meteorological Department (BMD) is responsible for providing earthquake information, tsunami advisory and warnings to the government and public and determines earthquake parameters (epicenters, magnitudes, etc.) of local earthquakes. The objective of this study is to calculate local magnitude of earthquakes in and around Bangladesh to infer an appropriate distance correction function of local magnitude for the study area. We also compare local magnitudes to body wave magnitudes to investigate their correlation.

2. METHODOLOGY

2.1. Local magnitude and recommendations of IASPEI

Magnitude is one of important earthquake source parameters. Magnitude scale for earthquakes was first introduced by Richter (1935, 1958). The equation of the local magnitude (M_L) based on the maximum trace amplitude (A) on horizontal components of the Wood-Anderson seismogram in millimeters is given as:

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$$M_L = \log A - \log A_0 + S, \tag{1}$$

where $-\log A_0$ is a distance correction function and S is a station correction. The local magnitude saturates at around 7 (e.g., Hanks and Boore, 1984).

In 2013, the International Association of Seismology and Physics of the Earth's Interior (IASPEI) Commission on Seismological Observations and Interpretations approved "Summary of Magnitude Working Group Recommendations on Standard Procedures for Determining Earthquake Magnitude from Digital Data" which was proposed by the Working Group on Magnitudes. Hereafter we refer to this procedure as IASPEI (2013). According to IASPEI (2013), the formula of the local magnitude of the crustal earthquakes for regions where the attenuative properties of seismic waves are similar to that of southern California is as follows

$$M_L = \log A + 1.11 \log r + 0.00189r - 2.09 \tag{2}$$

where A is the maximum trace amplitude in nanometer measured from a horizontal component seismogram for which the instrumental response of the Wood-Anderson seismograph is convolved (after removing the instrument response by deconvolution) and r is hypocentral distance. The applicable distance range of M_L is up to 1000 km. The coefficients are obtained for southern California by Hutton and Boore (1987). The constant term is based on the static magnification of the Wood-Anderson torsion seismometer (Uhrhammer and Collins,1990).

The formula proposed by IASPEI (2013) for regions where the attenuative properties are different from that of southern California is of the form:

$$M_L = \log A + C(r) + D \tag{3}$$

where A is the maximum amplitude in nanometer on the vertical component of the Wood-Anderson seismogram, and $C(r) + D$ is a distance correction function.

2.2. Local magnitude calculations using distance correction function for southern California

We first calculate M_L using the distance correction function given in Eq. (2). We did not include station corrections in the calculation. We use the median of the magnitude estimates for an event as the estimate for that event. Then we calculate local magnitude residual which is defined as the difference between each estimated M_L for a seismic station and the estimate for the same event. We calculate the root mean square (RMS) of the magnitude residuals.

2.3. Grid search method for determination of the distance correction function

The equation of M_L distance correction used by Hutton and Boore (1987) has the following form:

$$-\log A_0 = n\log(r/100) + K(r - 100) + 3.0 \tag{5}$$

where n and K are the coefficients for geometrical spreading and attenuation of seismic waves, respectively.

We set up an appropriate range for these unknown parameters to conduct grid search, which is shown in Table 1. For each set of the coefficients we calculated M_L, their medians for each event, and M_L residuals by the same process described in Section 2.2.

Table 1. The range of *n* and *K* with increments used in the grid search.

Coefficients	Lower bounds	Upper bounds	Increments
n	0.7	2	0.25
K	0.001	0.004	0.00005

We fit a straight line to obtain distance dependence of magnitude residuals. Finally, we calculated the RMS of the magnitude residuals, slope, a, and the intercept, b, for each set of the coefficients.

3. DATA

3.1. Data acquisition

The range of latitude and longitude of the study area is 19 degrees to 28 degrees and 87 degrees to 95 degrees respectively. Waveform data of seventy one events that occurred between January 1, 2009 and December 31, 2010 were available at the Wilber 3 of the Data Management Centre (DMC) of Incorporated Research Institutions for Seismology (IRIS). The range of the focal depth is set to that between 0 and 40 km. The magnitude range is that between 4.0 and 6.9. At that time, one project was operational by the name of network code XI "Collision of the Burma Arc accretionary prism and foldbelt with the Ganges-Brahmaputra Delta in Bangladesh" (Seeber et al., 2007). For that project, in Bangladesh 16 seismic stations with three components broadband seismometers were deployed and operated by the Lamont Doherty Earth Observatory (LDEO), Columbia University. In addition, the data was taken from the other stations of all available networks.

3.2. Data retrieval

We retrieved SAC waveform data from the IRIS DMC. There were 1136 vertical component waveform data from 148 stations of 10 networks in the hypocentral distance range up to 1000 km. In this study, we used the data from short period channels and broadband channels. We used Seismic Analysis Code (SAC, Goldstein and Snoke, 2005) to calculate synthetic Wood-Anderson seismograms. We downloaded the event information from the catalog of International Seismological Centre (ISC) for the comparison of magnitudes.

3.3. Data processing and amplitude measurement procedure.

The instrument response was first removed from the observed waveform data by deconvolution. Then the frequency response of the Wood-Anderson seismogram obtained by Uhrhammer and Collins (1990) was used to calculate synthetic Wood-Anderson seismograms. An example of the waveform data from station JAFL of network XI for the event that occurred at 18:51:51 UTC on 26th August, 2008 (M_w 4.8; depth 18 km) in Bangladesh is shown in Figure 1.

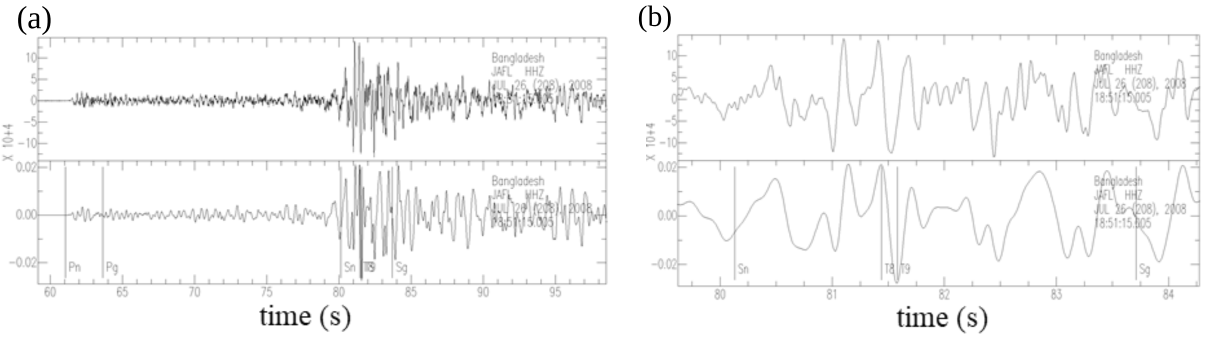

Figure 1. (a) The upper trace and the lower trace show an example of observed waveform data and synthetic Wood-Anderson seismograms, respectively. (b) The same waveform data shown in (a) are presented in the different time range. The maximum trace amplitude is measured on the simulated Wood-Anderson seismogram by the peak and trough, which are marked by T8 and T9 in the lower trace, respectively.

Then we evaluated the noise level (*N*) by the RMS of the time series in between 10sec and 5sec before the theoretical P wave arrival time. We evaluated the signal level (*S*) by the RMS of the time series in between 5sec and 10sec after the theoretical P wave arrival time. Then we obtained the signal to noise ratio (*S/N*).

We used only data with $S/N \geq 3.0$. Finally, we selected the events under the condition that the minimum number of stations for a particular event is five. In total 424 vertical component waveform data (378 broadband and 46 short period) of 30 events are used. The epicenters are shown in Figure 2. The data were recorded by the 95 stations of the 8 networks (Figure 3).

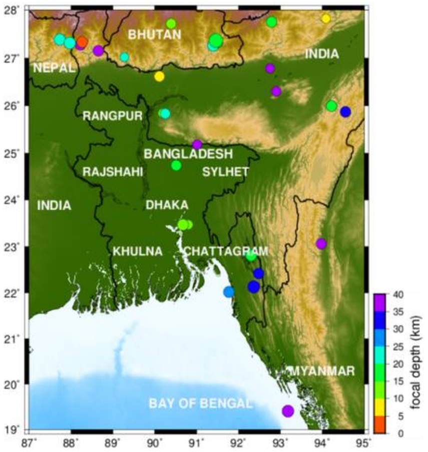

Figure 2: The epicenters of 30 events selected in this study.

Figure 3: The locations of the 95 stations of the 8 networks in this study.

4. RESULTS AND DISCUSSION

4.1. Forward calculations

The procedure to calculate local magnitudes was described in Section 2.2. Figure 4 represents local magnitude residuals as a function of hypocentral distance.

The hypocentral distance dependence of the magnitude residuals is very small. It suggests that the distance correction function appropriate for the study area is similar to that for southern California. Figure 5 shows the frequency distribution of the M_L residuals. The RMS of the magnitude residuals is 0.3021.

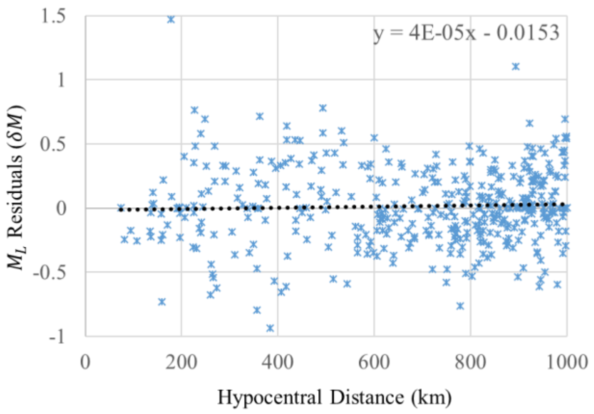

Figure 4. Local magnitude residuals with respect to hypocentral distance.

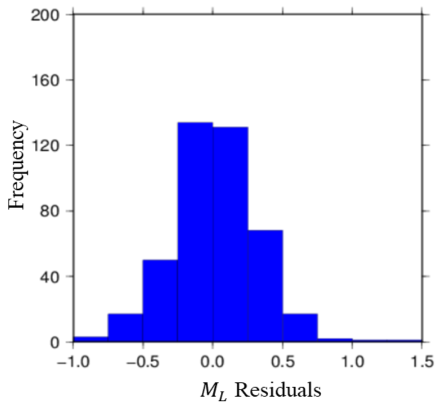

Figure 5: Frequency distribution of the magnitude residuals.

4.2. Grid search for coefficients *n* and *K*

A grid search was conducted to find the appropriate value of the coefficients *n* and *K*. The procedure of grid search was described in Section 2.3. Table 2 represents the five set of the coefficients *n* and *K* with the smallest RMSs of M_L residuals .

Table 2. The value of coefficients of *n* and *K* obtained from the grid search method.

n	*K*	RMS	|a*1000|	b
1.1	0.00180	0.30097	0.030	0.044
1.15	0.00175	0.30100	0.034	0.047
1.025	0.00185	0.30104	0.044	0.053
1.05	0.00185	0.30104	0.027	0.040
1.2	0.00170	0.30104	0.039	0.050

These coefficients are similar to those for southern California obtained by Hutton and Boore (1987), which is consistent with the inference suggested in Section 4.1, although the coefficients are not tightly constrained as is shown in Table 2. In neighboring countries, different distance correction functions are used for local magnitude calculations (e.g., Baruah et al., 2012; Baillard et al., 2017). The difference between this study and their formula is likely to partly reflect that the area in this study is rather wide including different tectonic regions.

Figure 6 shows that the distribution of M_L residuals with hypocentral distance for the coefficients n = 1.1 and K = 0.0018, which provides the minimum RMS of the M_L residual. Figure 7 shows the frequency distribution of M_L residuals.

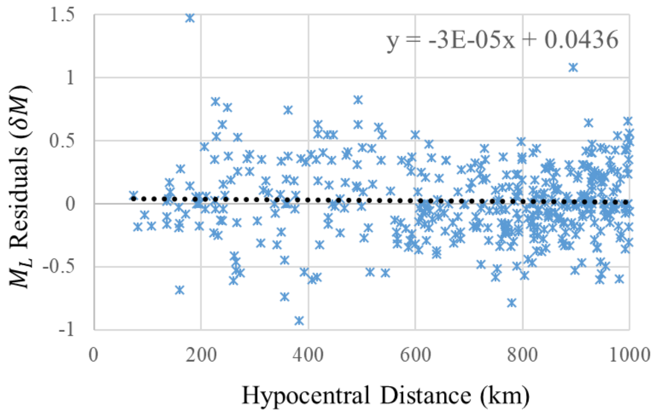

Figure 6. Local magnitude residuals with respect to hypocentral distance using the coefficients providing the minimum RMS of the magnitude residuals in this study.

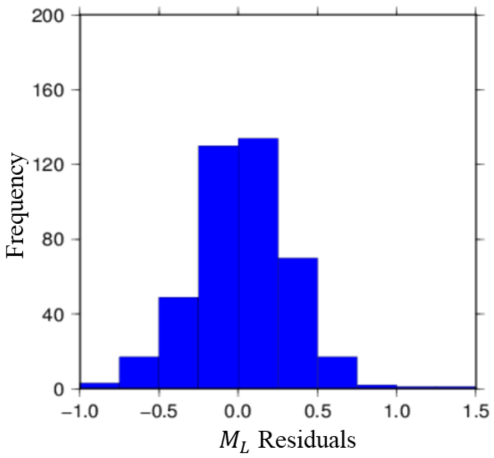

Figure 7. Frequency distribution of the magnitude residuals.

4.3. Comparison between M_L calculated and body wave magnitude from ISC

We compared the M_L calculated for n = 1.1 and K = 0.0018 with the body wave magnitudes in the catalog of the International Seismological Centre to find that they are correlated and comparable (Figure 8).

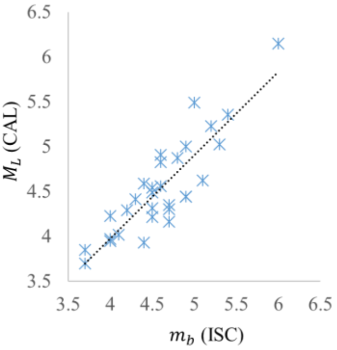

Figure 8. Comparison between local magnitudes (this study) and body wave magnitudes in the ISC catalog.

5. CONCLUSIONS

In this study we conducted local magnitude calculations and a grid search for the coefficients of a distance correction function in and around Bangladesh. We selected data based on the signal to noise ratios. We used only events for which there are at least five amplitude data. We used 424 vertical component waveform data for 30 earthquakes. The observed waveform data were used to compute synthetic Wood-Anderson seismogram for measuring maximum amplitudes.

We first calculated local magnitudes using the distance correction for southern California. We computed a median using the magnitudes of all stations for an event and calculated their magnitude residuals. The weak distance dependence of the magnitude residuals suggests that the distance corrections is similar to that of southern California. We used the grid search to confirm this inference. We calculated RMSs of the magnitude residuals for each set of the coefficients. The set of coefficients which provides the minimum RMS residuals is similar to that for southern California. We also compared the calculated local magnitudes to body wave magnitudes in the ISC catalog. The local magnitudes and the body wave magnitudes were correlated.

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