

DETERMINATION OF LOCAL MAGNITUDE SCALE FOR UGANDA

NYAGO Joseph*
MEE12609

Supervisor: Tatsuhiko HARA**

ABSTRACT

We have derived a local magnitude M_L scale for Uganda using waveform data recorded by a temporary broadband seismic network deployed in Uganda and a permanent broadband station. We used 54 earthquakes recorded between July 2007 and November 2008. First, we determined hypocenters of these earthquakes using P and S phase arrivals. Most of their locations are associated with the western rift of the East African Rift System. We compared the hypocenters of seven earthquakes determined by this study to those reported by NEIC's PDE catalog and IDC bulletins. They do not differ much, and they are roughly consistent with each other. To develop the M_L scale, we removed instrument responses in the waveforms and then applied the frequency response of the standard Wood-Anderson torsion seismograph for amplitude measurements. We obtained 529 amplitude data from horizontal components of 52 earthquakes whose focal depths are up to 34 km. We performed simultaneous linear inversion to determine the coefficients of distance correction function and local magnitudes to obtain the formula $M_L = \log A + 0.848 \log(r/100) + 0.00116(r - 100) + 3.0$, where A is the maximum peak amplitude (mm) observed on the horizontal component seismogram, and r is the hypocentral distance (km). The coefficients of the above formula are smaller than those obtained for Southern California, and closer to those obtained for Tanzania. Uganda, through the Department of Geological Survey and Mines (DGSM), is in the process of upgrading its seismological monitoring network with modern digital monitoring and data acquisition systems. Therefore, the result of this study and its application to data from the upcoming new seismic network will be useful for improving earthquake monitoring and seismicity study in Uganda.

Keywords: M_L , amplitude, hypocenter, distance correction.

1. INTRODUCTION

The use of earthquake magnitude scales to quantify seismic energy and moment released by earthquakes is a common practice in the field of seismological data analysis. One of the most widely used magnitude scales at local epicentral distances is the local magnitude (M_L) scale, originally defined by Richter (1935, 1958). M_L scale is typically based on amplitude measurements of high frequency S waves (Brazier *et al.*, 2008).

The main objective of this study is to determine a local magnitude, M_L scale for Uganda. There is need to develop a magnitude scale to be able to accurately quantify earthquakes occurring within the study area.

2. SEISMIC STATIONS AND DATA

2.1 Seismological data acquisition

*Department of Geological Survey and Mines, Seismology Unit (DGSM) Entebbe, Uganda.

**International Institute of Seismology and Earthquake Engineering, Building Research Institute (IISEE, BRI) Tsukuba, Japan.

In this study, seismic data from 12 seismic stations were used. The 11 stations were part of a seismological experiment, the AfricaArray-Uganda Broadband Seismic Study conducted between July 2007 and November 2008. We also used additional waveform data recorded by a Global Seismographic Network (GSN) station MBAR. Figure 1 shows the location of seismic stations used in this study.

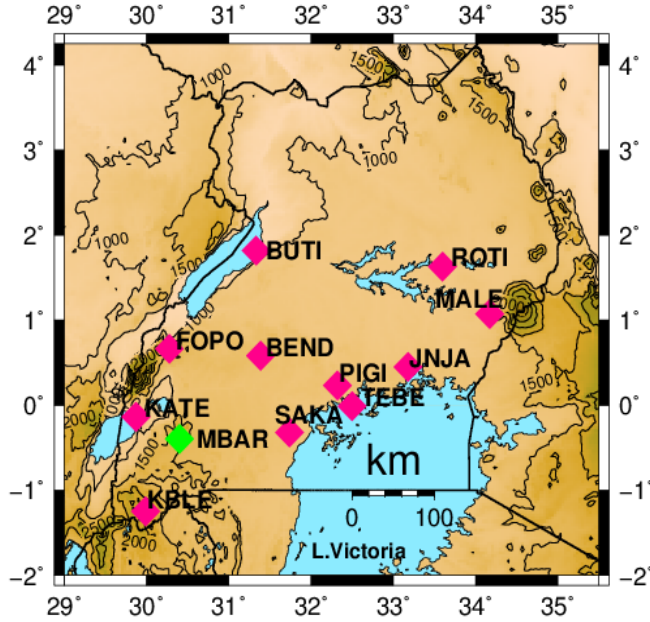


Figure 1. Locations of seismic stations used in this study are indicated with diamonds. The Pink diamonds denote AfricaArray temporary broadband stations, and the green diamond denotes the IRIS-GSN station.

3.2 Local magnitude, M_L scale

The basic concept of M_L scale was introduced by Richter (1935) and defined using the logarithm ($\log A$) of the maximum displacement, measured on the two horizontal components of a standard Wood-Anderson torsion seismometer (Anderson and Wood, 1925). The relationship between the relative size of an earthquake and its amplitude follows the original Richter (1935, 1958) local magnitude, defined such that an earthquake of $M_L = 3$ is recorded with a peak amplitude of 1mm at an epicentral distance of 100km.

In this study, we followed the procedure of Miao and Langston (2007), in which they followed Hutton and Boore (1987) approach. They used the following formula to derive the M_L formula:

$$-n \log(r_{ij}/100) - K(r_{ij} - 100) + M_{Li} = \log A_{ij} + 3.0 \quad (1)$$

where n and K are the parameters related to the geometrical spreading and anelastic attenuation, A_{ij} is the horizontal peak amplitude of the i^{th} event observed at the j^{th} station component, r_{ij} is the hypocentral distance (km) from the i^{th} event to the j^{th} station component, M_{Li} is the local magnitude of the i^{th} event. In the original definition of Richter (1935, 1958) and Miao and Langston (2007), the station correction factors are included. In this study, we did not consider them due to the limited size of the dataset.

2.2 Data retrieval

We retrieved broadband waveform data from the IRIS DMC in the SEED format. We obtained waveform data for 54 local seismic events. We used RDSEED program to convert the SEED format data to SAC format.

3. METHOD AND DATA ANALYSIS PROCEDURE

3.1 Hypocenter determination

We performed hypocenter determination for the 54 local earthquakes using the location program, HYPOCENTER 4.0 (Lienert and Havskov, 1995). We picked arrival times of P and S waves manually. We used iasp91 as a crustal model for hypocenter determination. For the depth range between 35 and 120 km, the velocity structures are linearly interpolated. The starting depth for hypocenter determination was set to 10 km.

Recently, Mungunsuren (2012) applied this method to obtain a M_L scale for Mongolia. We followed the inversion procedure for M_L of this previous study.

3.3 Amplitude measurement procedure

For peak amplitude measurements, first, we removed instrument responses from the SAC waveform data by deconvolution, and then the frequency response of the standard Wood-Anderson torsion seismometer for displacement, (a natural period of $T_0 = 0.8$ sec, a damping constant $h = 0.8$, and static magnification of 2800) was convolved. We obtained 531 amplitude measurements from 52 crustal local earthquakes whose focal depths fall in the range 0 – 34 km. For M_L inversion, we used 529 amplitude measurements excluding 2 outliers. The hypocentral distance range of the amplitude data used is from 14 to 700 km.

4. RESULTS AND DISCUSSION

4.1 Hypocenter solutions

Figure 2 shows the determined hypocenter solutions. Most of them are associated with the tectonic activity of the western rift of the EARS, whose foci lie between depths of 0 and 34 km, while events that are not associated with the western rift have depths up to 20 km. Shudofsky (1985) showed that earthquakes associated with the EARS have focal depths as great as 25 - 30 km. Nyblade and Langston (1995) reported source parameters of some East African shallow earthquakes. They observed that their foci were lying between depths of 24 and 34 km in the Archean and Proterozoic lithosphere, where the crust could have been thinned by rifting. Lindenfeld et al. (2012) analyzed seismicity of the Rwenzori Mountains within the western rift and reported that focal depth distribution extends from the surface down to a depth of 32 km with a single peak around 15 km. For determination of M_L formula, we used data from earthquake events with focal depths up to 34 km.

For seven events among of the 54 earthquakes used in this study, their hypocenters were determined by USGS and/or IDC (Table 1). Figure 3 shows the comparison of hypocenters determined by NEIC and IDC to those determined in this study. The hypocenters do not differ much, and they are roughly consistent with each other. For some of the events, the epicenters obtained in this study are closer to the western rift. The focal depths obtained in this study are deeper for most of the events.

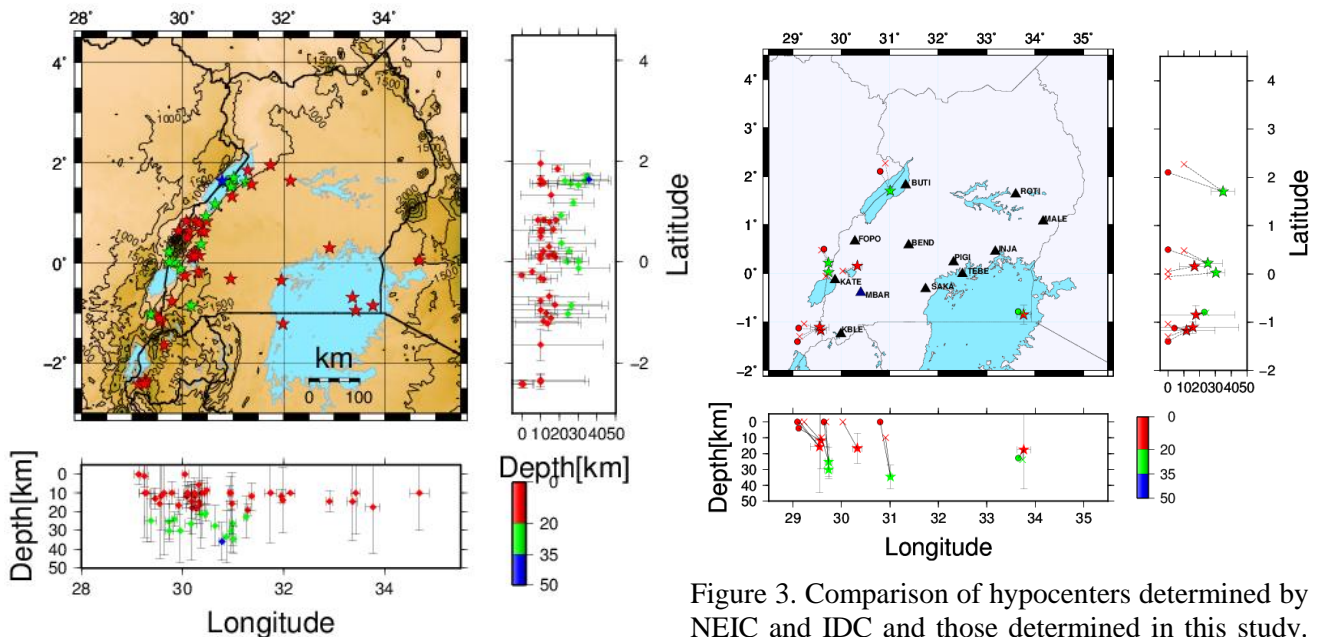


Figure 2. Hypocenters solutions determined in this study.

Figure 3. Comparison of hypocenters determined by NEIC and IDC and those determined in this study. The stars denote epicenters determined in this study. The red crosses denote epicenters by NEIC and solid circles denote those by IDC.

Table 1. List of events whose hypocenters were determined and reported by USGS and/or IDC.

Event No.	Date			Origin Time	Hypocenter			Reporting Agency
	Year	Month	Day	HH:MM:SS	Latitude (°)	Longitude (°)	Depth [km]	
1	2008	05	11	10:34:10.37	0.48 0.50	29.59 29.64	10 not reported	NEIC-PDE IDC-SEL3
2	2008	08	26	14:56:57.03	2.27 2.10	30.91 30.80	10 not reported	NEIC-PDE IDC-SEL3
3	2008	08	29	16:36 13.50	-0.06	29.68	0	IDC-SEL3
4	2008	10	01	14:15:53.51	-0.81	33.74	24.7	NEIC-PDE
5	2008	10	05	00:02:12.63	-1.13	29.12	4.0	IDC-SEL3
6	2008	10	05	00:32:25.41	-1.41	29.09	10	IDC-SEL3
7	2008	10	30	00:45:48.38	0.05	30.03	0	IDC-SEL3

4.2 Determination of Local magnitude, M_L scale

In this study, we determined a local magnitude formula for Uganda. A linear inversion under constraints (Jackson, 1979) was performed using Eq. (1). According to the preliminary calculations and previous studies on M_L scales, we set 3, 0.001, and 4 for the standard deviation of model parameters of n , K and M_L , respectively. The distance correction obtained from the inversion is as follows:

$$-\log A_0 = 0.848 \log(r/100) + 0.00116(r-100) + 3.0 \quad (2)$$

where r is the hypocentral distance in km. The coefficients for the $\log(r)$ and r terms, 0.848 and 0.00116, are smaller than those (1.11 and 0.00189) for Southern California (Hutton and Boore, 1987). The coefficients of this study are closer to those (0.776 and 0.000902) obtained for Tanzania (Langston *et al.*, 1998). The M_L formula for Uganda is given as follows using the distance correction expressed by Eq. (2):

$$M_L = \log A + 0.848 \log(r/100) + 0.00116(r-100) + 3.0 \quad (3)$$

where A is the maximum amplitude in mm observed on the horizontal component seismogram, and r is the hypocentral distance in km. Figure 4 shows the comparison between the observed amplitudes and calculated amplitudes for the obtained n , K , and M_L .

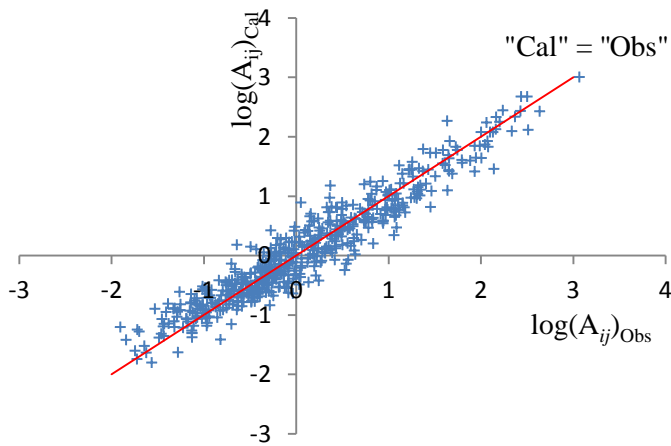


Figure 4. Comparison between calculated and observed amplitudes.

We compute M_L residual, δM_L by the following formula:

$$\delta M_L = M_L^{sta} - M_L^{ave} \quad (4)$$

where M_L^{sta} is a M_L calculated for a station for a particular event and M_L^{ave} is the mean M_L for that event. Figure 5 shows the M_L residuals as a function of hypocentral distance. We also calculate the mean M_L residuals per 100 km bin interval as shown in Figure 6. We observe no significant dependence of M_L

residuals on hypocentral distance considering the standard deviations shown in Figure 6. This therefore suggests that Eq. (3) is applicable to hypocentral distances up to about 700 km.

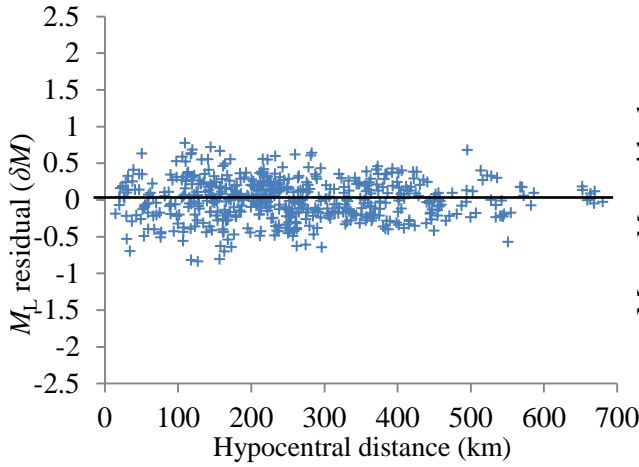


Figure 5. Distribution of M_L residuals as a function of hypocentral distance.

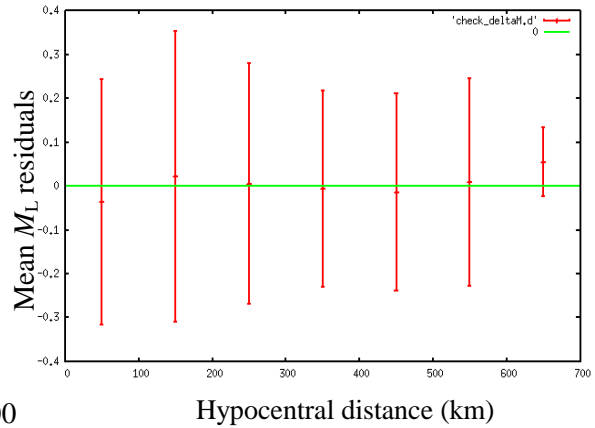


Figure 6. Mean M_L residuals calculated per 100 km bin intervals with the standard deviations.

We compared the M_L magnitudes of four earthquakes obtained from this study to the body wave magnitudes determined by USGS and reported in PDE catalogs. Figure 6 shows the comparison between these two magnitudes. They agree relatively well considering the errors of M_L .

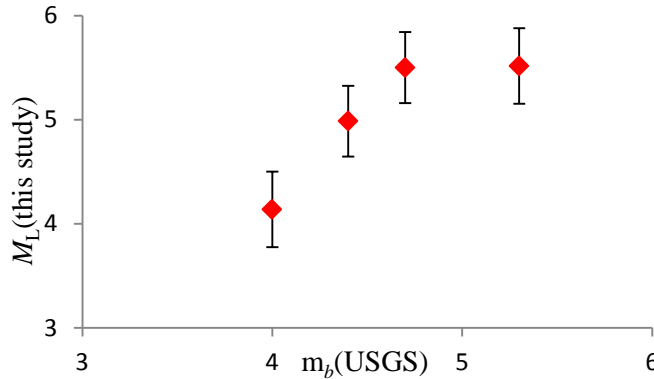


Figure 6. Comparison of magnitudes for the selected four events: M_L (from this study) and m_b (from USGS).

5. CONCLUSION

A local magnitude scale for Uganda has been derived following the original definition of M_L (Richter, 1935), using simulated Wood-Anderson seismograms from broadband waveform data for local earthquakes recorded by the AfricaArray-Uganda Broadband Seismic Experiment and the IRIS-IDA permanent station. We retrieved waveform data from the IRIS DMC and picked P and S wave arrivals. We determined hypocenters of 54 local earthquakes. Most of the hypocenters are associated with the western rift of EARS. We compared the hypocenters of seven events to those reported by the NEIC's PDE catalogs and IDC bulletins. They do not differ much, but are roughly consistent with each other, although the focal depths in this study are deeper, for which further studies such as effects of crustal structure will be necessary.

We obtained 529 amplitude data from horizontal components of 52 local earthquakes with focal depths up to 34 km. By following Miao and Langston (2007), we performed a simultaneous linear inversion to determine the coefficients of distance correction function and M_L . The obtained distance correction function is $-\log A_0 = 0.848 \log(r/100) + 0.00116(r-100) + 3.0$, where r is the hypocentral distance in km, and A_0 is the distance correction.

From this distance correction function, the following formula was proposed for Uganda $M_L = \log A + 0.848 \log(r/100) + 0.00116(r-100) + 3.0$, where A is the maximum amplitude in mm observed on the horizontal component, and r is the hypocentral distance in km. The coefficients for the $\log(r)$ and r terms, 0.848 and 0.00116, are smaller than those (1.11 and 0.00189) for Southern California. They are closer to those (0.776 and 0.000902) obtained for Tanzania. We observed that the residuals of M_L are not significantly dependent on hypocentral distance up to 700 km.

At present, four broadband seismic stations are installed and recording waveform data in Uganda. Site surveys and noise calibration exercises are being conducted to ascertain the suitability of proposed locations of the seismic vaults to deploy more stations. It is expected that in near future additional four stations will be installed to increase the number to eight stations including the IRIS global seismographic station, MBAR.

Using data from these seismic stations, I plan to determine hypocenters and M_L of local earthquakes in Uganda, fully utilizing the achievements of this study. This will be an impetus towards improving earthquake monitoring and study of seismicity rate in Uganda and the region.

ACKNOWLEDGEMENTS

I am grateful to Prof. Andrew Nyblade and IRIS DMC staff for their earlier support on data access and retrieval. I thank Dr. Toshiaki Yokoi and Dr. Bun'ichiro Shibasaki for their comments which improved this manuscript.

REFERENCES

- Anderson, J.A., and Wood, H.O., 1925, *Bull. Seismol. Soc. Am.*, 15, 1-72.
Brazier, R.A., Miao, Q., Nyblade, A., and Langston, C.A., 2008, *Bull. Seismol. Soc. Am.*, 98, 2341-2348.
Hutton, L.K., and Boore, D. M., 1987, *Bull. Seismol. Soc. Am.*, 77, 2074-2094.
Jackson, D.D., 1979, *Geophys. J. R. astr. Soc.*, 57, 137-157.
Kennett, B.L.N., and Engdahl, E.R., 1991, *Geophys. J. Int.*, 105, 429-465.
Langston, C.A., Brazier, R., Nyblade, A.A., and Owens, T.J., 1998, *Bull. Seismol. Soc. Am.*, 88, 712-721.
Lienert, B.R. and Havskov, J., 1995, *Seismol. Res. Lett.*, 66, 26-40.
Lindenfeld, M., Rumpker, G., Batte, A., and Schumann, A., 2012, *Solid Earth*, 3, 251-264.
Miao, Q., and Langston, C.A., 2007, *Bull. Seismol. Soc. Am.*, 97, 2137-2151.
Mungunsuren, D., 2013, *Bulletin of IISEE*, 47, 31-36.
Nyblade, A.A., and Langston, C.A., 1995, *Geophys. J. Int.*, 121, 49-62.
Richter, C.F., 1935, *Bull. Seismol. Soc. Am.*, 25, 1-32.
Richter, C.F., 1958, *Elementary Seismology*, Freeman, W. H. San Francisco., 578.
Shudofsky, G., 1985, *Geophys. J. R. astr. Soc.*, 83, 563-614.