Magnitude relations between the teleseismic *mb*, the regional m_R and *Mw* for intraplate earthquakes in Brazil.

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Abstract

Empirical relations between the regional (m_R), the teleseismic (*mb*) and the moment (*Mw*) magnitudes were determined for Brazilian intraplate earthquakes. The regional m_R is equivalent to the teleseismic *mb* in the range 3.5-5.5. *Mw* can be estimated from *m* (i.e., $mb|m_R$) by $Mw = 1.10\ m - 0.69$. The difference between *mb* and m_R depends on the type of faulting mechanism: $mb > m_R$ for dip-slip earthquakes (reverse and normal faulting), and $mb < m_R$ for strike-slip events.

1. Introduction

The Richter magnitude can be calculated in different ways, depending on the station distance, instrument frequency range, and chosen seismic phase. The most common magnitude scales for regional and global catalogs are (e.g., Bormann & Dewey, 2012; Di Giacomo et al., 2015).

a) short-period teleseismic *mb*: measured at the P-wave signal (P, pP, sP or PcP phases), with periods around 1 s (short-period measurement) and station distances between 20º and 100º. The original magnitude (Gutenberg, 1945; Gutenberg & Richter, 1956) used intermediate period instruments (3-30 s) and is better identified now as m_B.

b) teleseismic *Ms*: measured with the vertical component Rayleigh wave with period near 20s (also known more precisely as "*Ms-20*").

c) regional magnitudes: extrapolation of the teleseismic *mb* scale to regional distances to account for the specific attenuation properties of each region. In Brazil the regional magnitude m_R (Assumpção, 1983) is adopted in most catalogs.

d) local magnitude *ML*: measured with the maximum displacement of the seismogram at stations closer than 600 km (as originally defined by Richter, 1935).

e) Moment magnitude *Mw*: calculated by estimating the low-frequency level of the displacement spectrum, or by modeling the observed seismogram with numerical simulations.

Mw is the only magnitude directly related to physical properties of the source, as its definition was based on the seismic moment *Mo*: $Mw = (\log Mo - 9.1)/1.5$ (SI units). For this reason, it is regarded as the best measure of earthquake size and has been adopted as the standard magnitude in catalogs used for seismic hazard analysis, for example. However, calculating *Mw* (or *Mo*) is not always implemented in network practices due to its more complex numerical procedures. In addition, small earthquakes recorded at hundreds of km away may not have enough signal to noise ratio for a reliable estimate of *Mw*. For this reason, the other scales, especially *mb* and *ML*, continue to be widely used in the catalogs of NEIC-USGS and ISC.

The measurement of the other magnitudes (*mb*, *ML*, *Ms*) may be biased if the regional attenuation characteristics of the seismic waves are different from the average attenuation used in the original definition of the scales. For example, the original *mb* scale (Gutenberg 1945; Gutenberg & Richter, 1956) defined attenuation coefficients for distances as short as 5º. For these short distances, the majority of the earthquakes used to define the scale were from tectonically active region such as California and subduction zones. Thus, the original *mb* scale should not be used at short distances for earthquakes in stable continental regions (like mid-plate South America, where seismic amplitudes decay much slower with epicentral distance) because magnitude values are overestimated (by up to 1 magnitude unit). The regional scale used in Brazil, m_R, takes into account the lower attenuation of the P waves in the cold and thick lithosphere of the South America SCR, and was tied to the teleseismic *mb* (Assumpção, 1983). Fig. 1 shows a compilation of *mb* and m_R magnitudes for Brazilian earthquakes indicating that the two magnitudes are roughly equivalent. However, even the teleseismic *mb* (measured at stations beyond 20º) may be somewhat biased for events in Brazil because of the weaker asthenosphere compared to the average global asthenosphere.

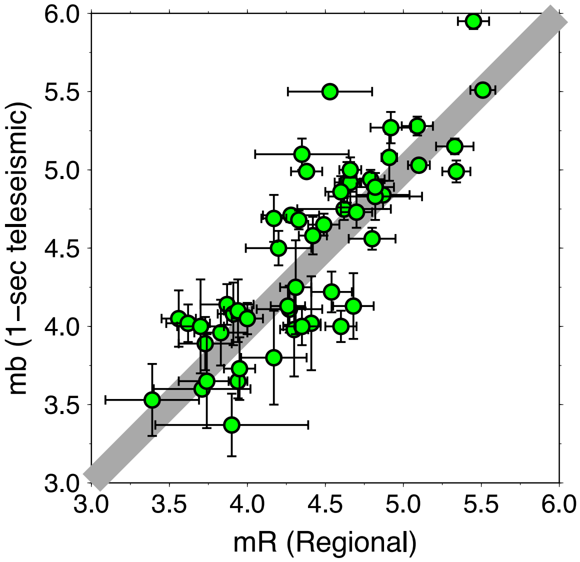


Fig. 1. *Magnitudes mb and m_R for Brazilian earthquakes. The gray line is the 1:1 relation.*

Due to the reasons above, empirical correlations between any magnitude and *Mw* are necessary to standardize the magnitude in earthquake catalogs (e.g., Di Giacomo et al., 2015). Also, most ground motion prediction equations used in seismic hazard analysis, are now derived for the *Mw* scale, which makes conversion from any other scale to *Mw* a necessary step in PSHA.

Here we compiled measurements of *Mw* for SCR in South America and compared with the *mb* and m_R values to obtain an empirical conversion from *mb*|m_R to *Mw*.

2. Data Compilation

The regional m_R scale for shallow (crustal) earthquakes, measured with the maximum amplitude in the whole P wavetrain, in the distance range 200-1500km, is equivalent to the 1-sec *mb* measured at teleseismic stations in the range 20°-100° (Assumpção, 1983; Assumpção et al., 2014). For earthquakes with both m_R and *mb* measurements, we simply use the average of the two values.

We compiled moment magnitude *Mw* from different sources and methods:

a) determination of the focal mechanism by fitting/inverting teleseismic *P* and *S* waves, for some intraplate sub-Andean earthquakes with *mb* ~5.5 (Assumpção & Araujo, 1993), or spectral amplitude of surface waves for some Brazilian *mb* ~5 earthquakes (Assumpção & Suárez, 1988).

b) moment tensor inversions by fitting waveforms at frequencies lower than the corner frequency, usually carried out with the ISOLA code (Sokos & Zahradník, 2013, Dias et al., 2016a). *Mw* for moderate size earthquakes were determined by Barros et al.(2015) and Dias et al.(2016a,b; 2018). Small earthquakes in the range m_R 2.5-4.0 were studied by Dias (2016), Agurto-Detzel et al.(2015, 2017) and Carvalho et al.(2020).

c) Moment tensor inversions by international agencies (USGS, and GCMT) were also used for moderate size events with *mb* ~5.

d) For small earthquakes in the range m_R 2 to 4, when the focal mechanism could not be determined, *Mw* was estimated by a joint inversion of the S-wave spectral amplitude to obtain *Mo* and corner frequency for each event, as well as an average inelastic attenuation coefficient for the Brazilian lithosphere (Drouet & Assumpção, 2015).

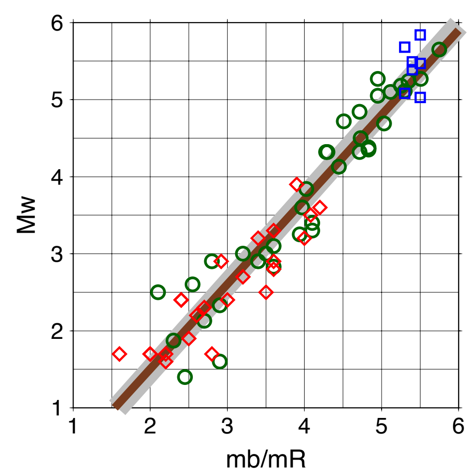
3. Empirical *Mw*:*mb* relation

We compiled data for 66 events with *mb* or m_R (called "*mb*|m_R"), and *Mw* magnitudes. For this analysis, "*mb*" is the average of the reported values from all agencies (USGS, ISC, and USP). The magnitude m_R is the average between USP and UnB values, if both are available. We take the "*mb*|M_R" as the average of the two values (average *mb* and average *mR*), or any of them when the other is not available. If more than one determination of *Mw* is available (from an international agency or a specific publication), we take the average value.

The empirical regression between the magnitudes of these 66 events is (Fig. 2):

Mw = 1.10 ***m*** - 0.69 (std.dev. = 0.36) (Eq.1)

which is very similar to the previous estimate of Drouet & Assumpção (2015) made with 48 events.



Mw = 1.098 m – 0.689

Fig. 2*. Empirical Mw:m relation. "m" stands for mb, m_R or the average of the two. Green circles are data with Mw obtained by moment tensor inversion. Blue squares are sub-Andean events with focal mechanism obtained by P and S waveform fitting (Assumpção & Araujo, 1993). Red diamonds are Mw estimated from low frequency spectral level (Drouet & Assumpção, 2015). The gray wide line is the previous regression (Mw = 1.121 m - 0.76) of Drouet & Assumpção (2015). The brown line is the updated regression, Eq. 1: Mw = 1.098 m - 0.689 (st.dev. = 0.36).*

4. Empirical relation *Mw* and felt area.

Magnitudes of historical earthquakes are often estimated by the intensity distribution (e.g., Quadros et al., 2019) or total felt area. For this reason, an empirical relation between Mw and felt area can be useful to help homogenize earthquake catalogs. The few available data for Brazilian events (Fig. 3) indicates an approximate relation of

Mw = 0.78 log (***Af***) + 0.50   (st.dev.=0.42)   (Eq. 2)

where Af is the total area (km^2) where the event was felt. The few Brazilian data is compatible with the relation of Johnston (1996) for worldwide intraplate earthquakes. The st. deviation of the Brazilian data in relation to Johnston's (1996) equation is 0.44 magnitude units, not much different from the fitted Eq. 2.

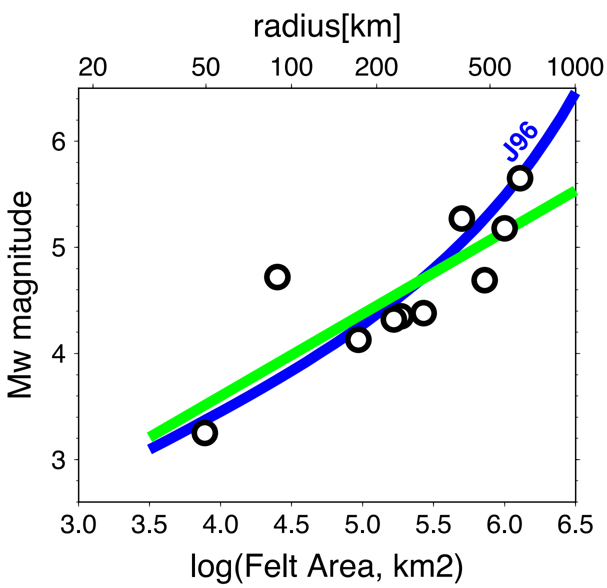


***Fig. 3**. Mw x total felt area (km^2) for intraplate Brazilian earthquakes. The green line is eq. 1, with st. deviation = 0.42; the blue line is the empirical relation for worldwide intraplate earthquakes (Johnston, 1996) with st.dev.= 0.44.*

5. Dependence on the focal mechanism

Although the regional magnitude m_R is roughly equivalent to the teleseismic *mb*, it has been observed that the difference between them correlates with the type of focal mechanism. Strike-slip events tend to have m_R > *mb*, whereas dip-slip events (reverse or normal faulting) tend to have *mb* > m_R. Fig. 4 shows a list of focal mechanisms ordered by the difference (m_R - *mb*). The same trend can be seen plotting the magnitude difference (m_R - *mb*) with the plunge of the B axis (Fig. 5).

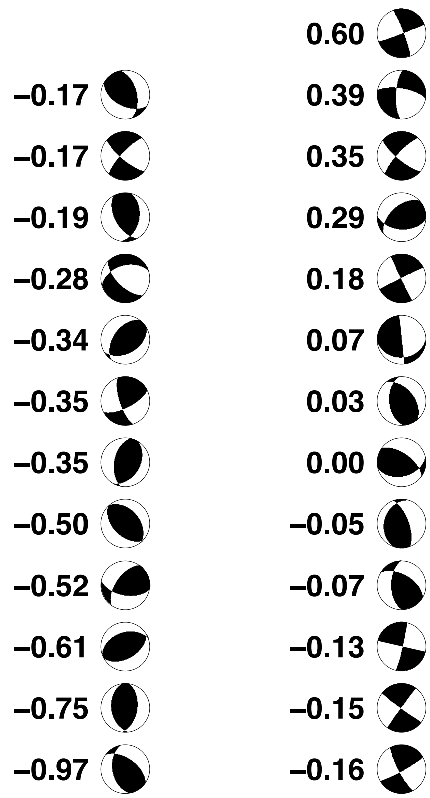


***Fig. 4**. Focal mechanisms ordered by the difference (m_R-mb) shown beside the beachball. Magnitudes m_R<mb (first column) tend to have dip-slip mechanisms; events with m_R>mb (2nd column) tend to have strike-slip mechanisms. Dip-slip mechanisms (reverse or normal faulting) tend to have mb>m_R.*

This can be explained by the different take-off angles of the P waves measured in the two magnitudes. For the teleseismic mb, measured in the distance range 20° to 95°, the take-off angles varies from 36° to 14° for an event in the upper crust. The regional magnitude m_R is measured mainly in the 200 - 1500km range where the predominant P waves are crustal reverberations (Moho and mid-crustal wide-angle reflections) and Pn, with take-off angles mostly within 49° and 90° degrees. That is, for strike-slip events, the teleseismic P waves take off with steep angles close to the B (null) axis and the regional waves take-off closer to the high amplitude lobes of the radiation pattern (on average) causing *mb* to be lower than m_R. For dip-slip mechanisms, the opposite occurs: the teleseismic P wave leaves the hypocenter close to the peak amplitude of the radiation lobe, which makes *mb* > m_R.

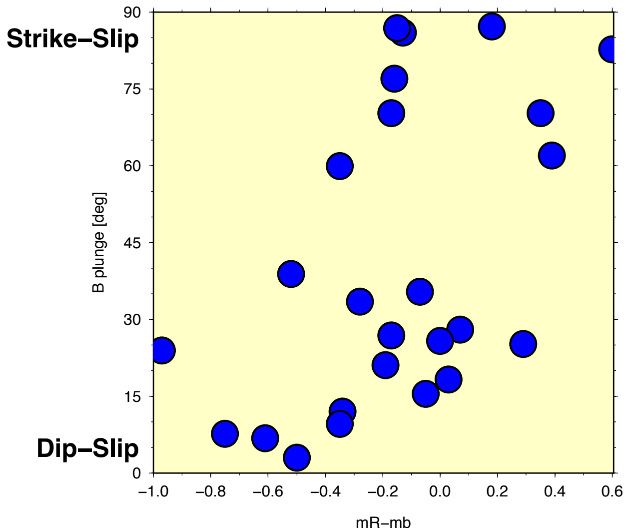


***Fig. 5**. Plunge of the B axis of the focal mechanism solution with the difference (m_R-mb). Shallow dipping B axis (< 45^O) indicate dip-slip mechanisms, and steeply dipping mechanisms (>45^O) indicate strike-slip mechanisms.*

5. Discussion and Conclusions

We updated the mb:Mw relation for Brazilian intraplate earthquakes, which can be used to estimate moment magnitudes for events for which a moment tensor inversion was not possible. This relation will be useful to get homogenized catalogs for seismic hazard studies, for example.

Although the Brazilian regional magnitude, m_R, is equivalent to the teleseismic *mb*, on average, there is a significant dependence of the mb:mR relation on the type of faulting mechanisms. Strike-slip events tend to have $mb < m_R$ and dip slip events (reverse or normal faulting) tend to have $mb > m_R$. This characteristic can be used as a preliminary estimate of the type of faulting mechanism for moderate magnitude events, before the fault plane solution can be determined.

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