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Evolution of *b-values* before large earthquakes of $m_b \geq 6.0$ in the Andaman region

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ABSTRACT

We have considered six earthquakes of $m_b \geq 6.0$ in the Andaman region (2000-2012), with focal depths within 45km, to examine the spatial variations of *b-value* at epicentre within a one-year period prior to the occurrence of the earthquakes. We have found a correlation between the low *b* for the one year time interval and the occurrence of large events. The epicentral *b-values* of six earthquakes are lower than 1.0 and five out of six earthquakes show very low *b-value* at the epicentre. Our study indicate that *b-value* may be employed to forecast a major earthquake.

KEYWORDS Gutenberg–Richter relation. *b-value*. Resolution. Andaman earthquake.

INTRODUCTION

One of the basic seismological parameters used to describe an ensemble of earthquakes is the *b-value* in the Gutenberg-Richter frequency-magnitude relation. It characterizes the distribution of earthquakes over the observed range of magnitudes. The *b-value* is normally 1.0 but for shorter time windows it varies significantly depending on the tectonic setting of the seismically active region (Pacheco *et al.*, 1992; Wiemer and Wyss, 1997; Singh *et al.*, 2008; Singh and Chadha, 2010; Singh, 2014). There are many factors causing the deviation of *b* from normal value 1.0. Increased material heterogeneity or crack density results in high *b-values* (Mogi, 1962) and an increase in applied shear stress (Scholz, 1968) or an increase in effective stress (Wyss, 1973) decreases the *b-value*. Many evidences suggest that *b* can act as a stress meter in the crust which came from the fact of asperity (Wiemer and Wyss, 1997; Singh, 2014). A lower value of *b* implies that the region is under higher applied shear stress, and a higher value of *b* indicates that the area is already gone through the tectonic events. Spatial variations of *b-value* have also been studied by several researchers in a number of seismically active areas (Wiemer and Katsumata, 1999; Singh *et al.*, 2008; Singh *et al.*, 2009; Singh, 2014). Observations of *b-values* in space reflect locally the effective stress (Scholz, 1968). As *b-value* is directly related to the distribution of differential stresses in the Earth's crust, it can be used for seismic hazard assessment studies in a region. Hence the inverse relationship between the concentration of stress at epicentral region prior to the occurrence of the earthquakes and the *b-value* is evidently of particular interest in the prediction of major earthquakes. Globally it is observed that *b-value* varies with duration of months and years prior to the occurrence of a large shock (*e.g.* Imoto, 1991; Jaumé and Sykes, 1999). Changes in *b-value* preceding major shocks are also evident from laboratory studies (Scholz, 1968). In the present study our aim is to investigate the evolution of *b-value* as a function of space associated with the six large events of $m_b \geq 6.0$ from 2000 to 2012 in the Andaman region which is tectonically very complex and seismically very active.

DATA AND METHODOLOGY

The study area includes the Andaman region of latitude 8º–15ºN and longitude 91º–95ºE (Fig 1). We have used the data reported by the International Seismological Centre catalogue from January 2000 to December 2012. It provides around 4885 local events of m_b 2.7–6.7. Most of the earthquakes are located in the concave side of the Andaman arc (Fig 1). The magnitude of completeness M_c is crucial for mapping the spatial *b-value*. We have analysed events only with magnitudes equal to or greater than the magnitude of completeness (M_c). M_c is determined from the Gutenberg-Richter diagram using the maximum curvature method (Wiemer and Wyss, 2000). The method gives a good first hand estimate of M_c that can be successfully used in spatial frequency magnitude distribution (FMD) study. We have calculated the M_c separately for the earthquakes that occurred one year prior to each of the selected main event for the present analysis (Fig. 2). For mapping of the *b-value*, we have considered the events with magnitude $m_b \geq M_c$.

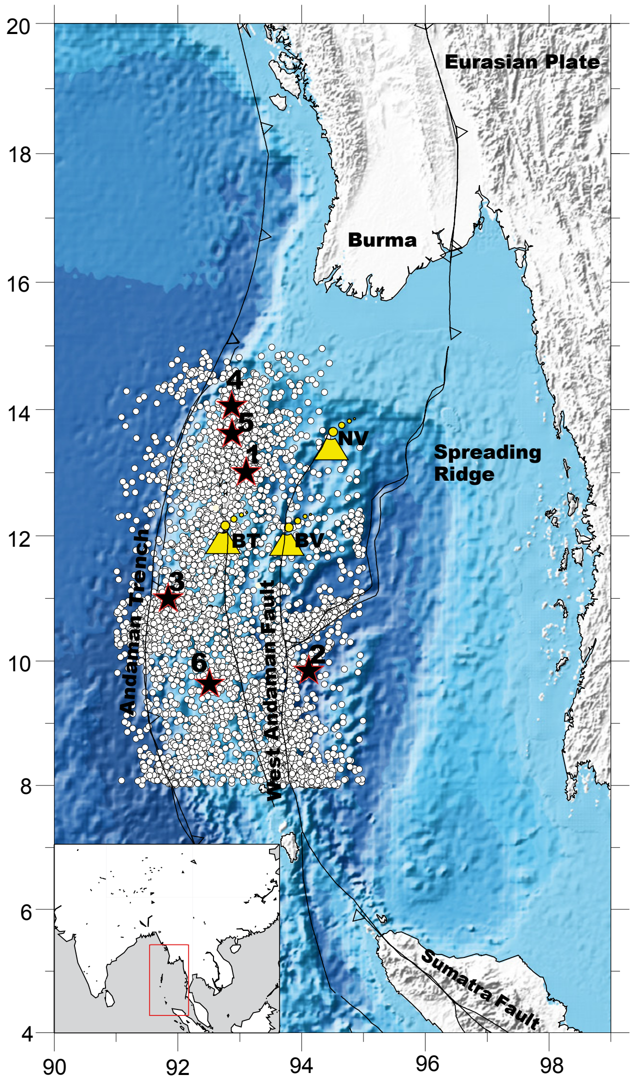

FIGURE 1. Distribution of the earthquakes in the study area from 2000-2012. Stars represent the earthquakes of $m_b \geq 6$ with focal depths less than 45km used in the present analysis. Numbers indicate the serial numbers as specified in Table 1. BT: Baratang (mud volcano); BV: Barren volcano and NV: Narcondum volcanic zones. The inset in the figure shows the location of the study area.

The statistical distribution of sizes, for a group of earthquakes, can be expressed in terms of Gutenberg-Richter relation (Gutenberg and Richter, 1944) where the number of earthquakes N with magnitude equal or greater than M is related to the magnitude by

$$\log N = a - b \cdot M \qquad \text{[eq. 1]}$$

where a and b are constants. The parameter a describes the productivity of a volume, and b, the slope of the FMD, describes the relative size distribution of events. The *b-value* can be obtained using two methods: least-square fit method and maximum likelihood method. In the present study the maximum likelihood method is used for the estimation of *b-value* which is often claimed to be a better estimation than the least-square method (Hirata, 1989). By this method the *b-value* is defined as

$$b = \frac{\log_{10} e}{[M - (M_c - \Delta M_{bin}/2)]} \qquad \text{[eq. 2]}$$

where M is the mean magnitude of the sample, M_c is the magnitude of completeness, ΔM_{bin} is the binning width of the catalogue (Aki, 1965; Utsu, 1999) and $\log_{10} e = 0.4343$.

In this study, we have examined the *b-value* distribution before large events of $m_b \geq 6.0$, in the Andaman region from 2000–2012. The focal depth of the events is within 45km (Table 1). We have examined the spatial *b-value* distribution one year prior to each of the 6 investigated earthquakes. To map the variation of *b-value* as a function of space, the entire region consisting of 4885 local events has been set into 0.1°×0.1° grid cells. The grid cells were created interactively, and for each node a minimum number of events (N_{min}) were assigned. In the present study N_{min}=30 and the grid cell with less than 30 events was removed. The *b-values* were estimated for circular areas at grid nodes where radii of the circles differed from grid cell to grid cell in order to accommodate the constant number of 30 earthquakes. We mapped the radii of each circle, which was used to measure the resolution, and is presented in the next section. All the calculations were made by applying the ZMAP software package (Wiemer, 2001).

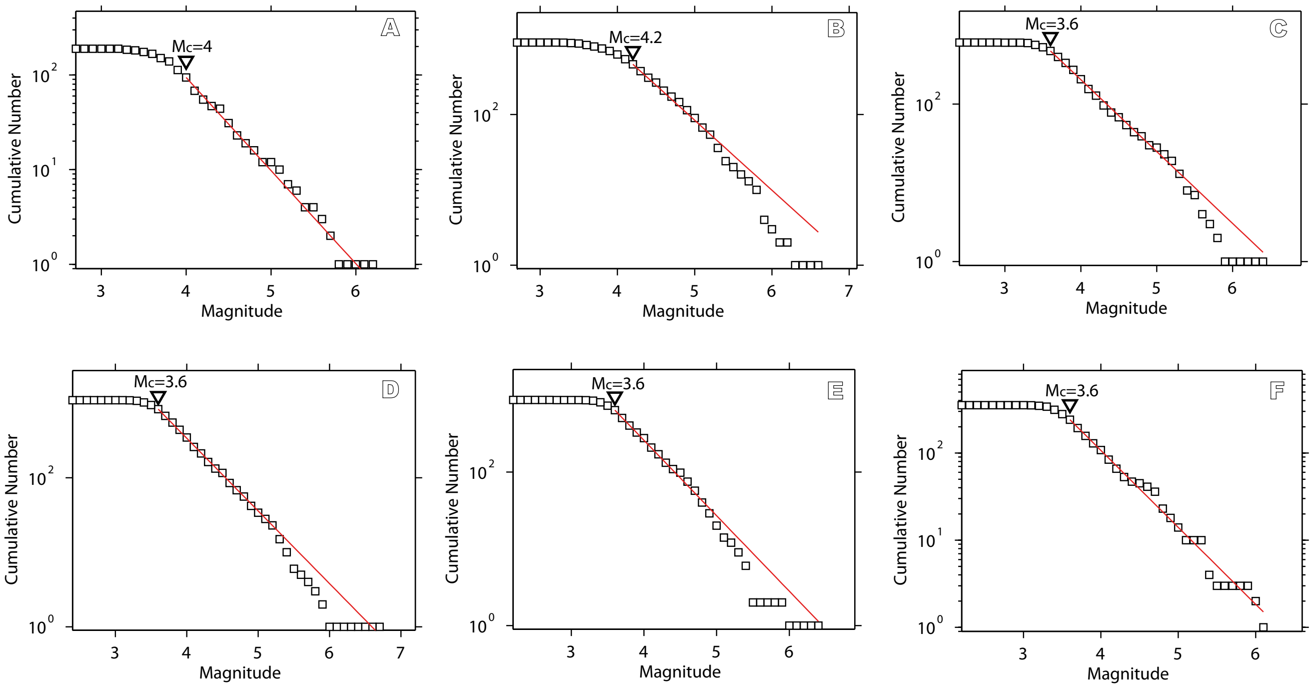

FIGURE 2. Frequency-magnitude distribution of the events for the year A) 2002, B) 2004, C) 2008, D) 2009, E) 2010, F) 2011.

RESULTS AND DISCUSSION

Spatial *b-value* map

We have examined the spatial distribution of *b-values* one year prior to the occurrence of large earthquakes with m_b≥6.0 in the Andaman region from 2000 to 2012. The regions with *b-values* lower than 1.0 are regarded as low and *b-values* above 1.0 are considered as high. The spatial variation is mapped by projecting the epicentres of earthquakes onto a plane. The average *b-value* of the study area is found to be low for all the earthquakes we have considered, this reflecting that the area is under critical stress (Fig 3). Complex tectonic process at this region activates different fault segments and possesses different state of stress and heterogeneities. The epicentral *b-values* of six earthquakes are lower than 1.0 and five out of six earthquakes exhibit very low *b-values* at the epicentre (Fig 3) that suggests a correlation between low *b* and the occurrence of large events. According to Scholtz (1968) and Wyss (1973), an area with low *b-value* is considered to have increased stress, *i.e* the area is considered as high potential of future large shock. The *b-value* shows systematic variations in the time interval preceding a major event (Kayal, 2008). Nuannin *et al*. (2012) have observed that the epicentral areas of their 15 studied events of Andaman-Sumatra subduction zone are characterized by low *b-value* zones and all occurred within the time intervals of low *b-value*. For the earthquakes of M_L≥6.0 in the Taiwan region, Chan *et al*. (2012) have reported that the epicenters are located predominately in the regions with low *b-values* relative to the entire study area, and Nuannin *et al*. (2005) have observed that the area around the epicentres of the mega Sumatra earthquakes of 2004, M_w9.0 and M_w8.7 of 2005 occurred within the zones of low *b-values*. Main *et al*. (1989) have shown that during the earthquake cycle *b-value* varies between 0.5 and 1.5, and regions with *b*=0.5 are in a state of critical failure, in risk of experiencing a large earthquake. Recently, Roy *et al*. (2013) have observed that the lower *b-value* structures in the subduction zone are the source zones for the great earthquakes of M_w>7.5 in the Andaman-Sumatra Subduction Zone.

TABLE 1. The epicentral location of the events of m_b≥6 from January 2000 to December 2012 used in the present analysis

SL.Nº	Date	Longitude	Latitude	Magnitude (M_b)	Depth
1	13-09-2002	93.1050	13.0050	6.2	21.0
2	26-12-2004	94.1139	9.8410	6.6	30.0
3	27-06-2008	91.8410	10.9960	6.4	27.6
4	10-08-2009	92.8685	14.0522	6.7	30.7
5	30-03-2010	92.8746	13.6128	6.4	38.5
6	03-06-2011	92.5110	9.6290	6.1	44.0

It is worth mentioning that in the present study the epicentre of 26th December 2004 earthquake has occurred in a region which has a relatively higher *b-value* than the average *b-value* of the study area in the preceding year (Fig 3B). Chan *et al*. (2012) have suggested that in this scenario stress might have increased in the entire rupture fault zones of large earthquakes rather than at the rupture initiations. Our study supports the hypothesis that the seismicity preceding a large event can be correlated to low *b-value* which may imply that the *b-value* can be used to forcast major events.

Map resolution

The density of earthquakes associated with each grid node is an important parameter for the geographical resolution of *b-value*. In our study, as we have taken N_{min} equal to 30 events, the resolution is inversely proportional to the radius of circle that contain the N_{min} events. We have observed that the map resolution in the area under investigationis of 50-100km for the epicentral region, except for the regions of the two events occurred in 2002 and 2011, which have resolutions around 100–150km and 150–200km, respectively, due to the paucity of the earthquakes (Fig 4). The map resolution decreases away from the epicenter region because of low seismicity.

CONCLUSION

The study includes 4885 local earthquakes in the Andman region from 2000 to 2012. In this period we have considered six major earthquakes of m_b≥6.0 with focal depths within 45km, to study the spatial variation of *b-value* prior to their occurrence. It shows that all the events have occurred at the region where high stress was concentrated (low *b-value*) one year preceding the event. The observed correlation between low *b* and the occurrence of a large earthquake in the present study may indicate that *b-value* can be employed to forcast major events.

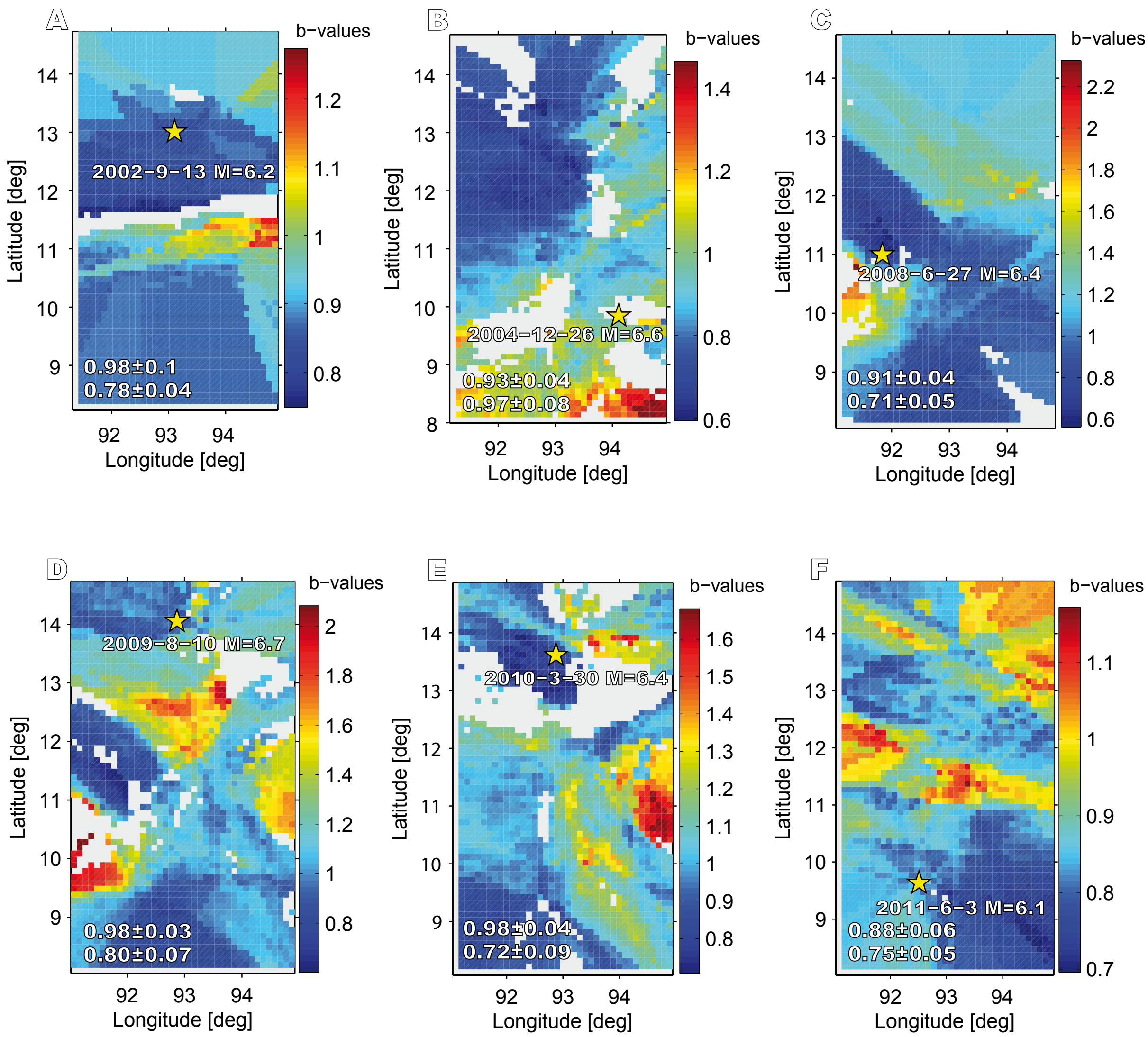

FIGURE 3. Spatial *b-value* distribution analysed in one-year prior to the occurrence of the earthquakes in A) 2002, B) 2004, C) 2008, D) 2009, E) 2010, and F) 2011. Stars represent the epicentre location of the earthquakes. The lower-left corners of each panel represent the *b-value* with associated standard deviations at the epicentre preceding the main event (lower line) as well as for the whole region (upper line).

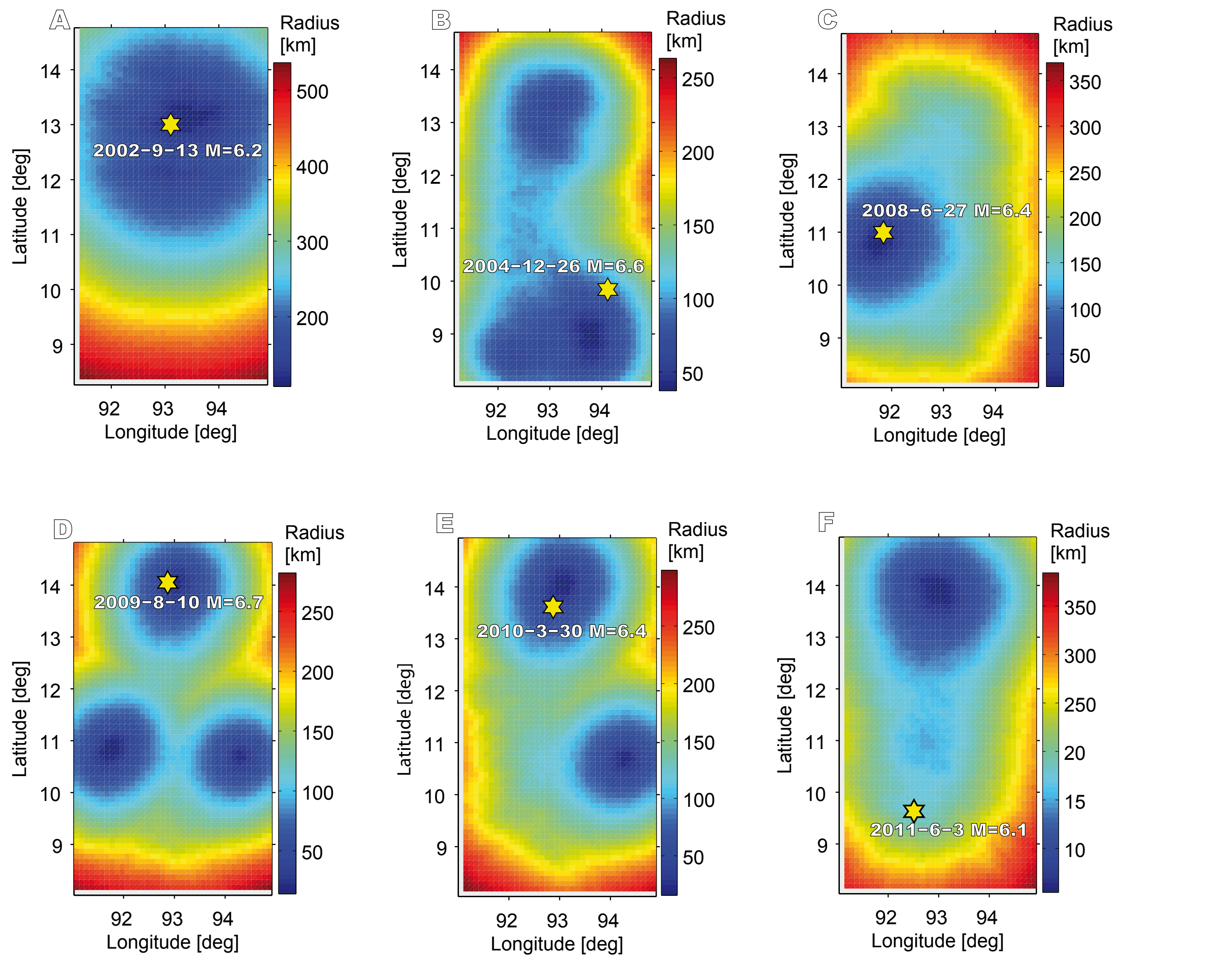

FIGURE 4. *b-value* resolution map for the different events occurred in A) 2002, B) 2004, C) 2008, D) 2009, E) 2010, and F) 2011. Blue indicates the area with high resolution whereas red shows the low resolution area. Stars indicate the epicentral locations of the studied earthquakes.

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REFERENCES

Aki, K., 1965. Maximum likelihood estimate of *b-value* in the formula log N= a-bM and its confidence limits. Bulletin of the Earthquake Research Institute, University of Tokyo, 43, 237-239.

Chan, C.H., Wu, Y.M., Tseng, T.L., Lin, T.L., Chen, C.C., 2012. Spatial and temporal evolution of *b-values* before large earthquakes in Taiwan. Tectonophysics, 532-535, 215-222.

Gutenberg, B., Richter, C.F., 1944. Frequency of earthquake in California. Bulletin of Seismological Society of the America, 34, 185-188.

Hirata, T., 1989. A correlation between the *b-value* and the fractal dimension of earthquakes. Journal of Geophysical Research, 94, 7507-7514.

Imoto, M., 1991. Changes in the magnitude-frequency *b-value* prior to large (M=6.0) earthquakes in Japan. Tectonophysics, 193, 311-325.

Jaumé, S.C., Sykes, L.R., 1999. Evolving towards a Critical Point: A Review of Accelerating Moment/energy Release prior to Large and Great Earthquakes. Pure and Applied Geophysics, 155, 279-306.

Kayal, J.R., 2008. Microearthquake seismology and seismotectonics of South Asia. Springer, Berlin, 282pp.

Main, I.G., Meredith, P. G., Jones, C., 1989. A reinterpretation of the precursory seismic *b-value* anomaly from fracture mechanics. Geophysical Journal International, 96, 131-138.

Mogi, K., 1962. Magnitude-frequency relation for elastic shocks accompanying fractures of various materials and some related problems in earthquakes. Bulletin of Earthquake Research Institute, University of Tokyo, 40, 831-853.

Nuannin, P., Kulhanek, O., Persson, L., 2005. Spatial and temporal *b* value anomalies preceding the devastating off coast of NW Sumatra earthquake of December 26, 2004. Geophysical Research Letter, 32, L11307.

Nuannin, P., Kulhanek, O., Persson, L., 2012. Variations of *b-values* preceding large earthquakes in the Andaman–Sumatra subduction zone. Journal of Asian Earth Sciences, 61, 237-242.

Pacheco, J.R., Scholz, C.H., Sykes, L.R., 1992. Changes in frequency-size relationship from small to large earthquakes. Nature, 335, 71-73.

Roy, S., Ghosh, U., Hazra, S., Kayal, J.R., 2012. Fractal Dimension and *b* Value Mapping Before and After the 2004 Megathrust Earthquake in the Andaman-Sumatra Subduction Zone. In: Baken, D.N., Bunde, A., Dimri, V.P., Sharma, A.S. (eds.). Extreme Events and Natural Hazards: The Complexity Perspective. Washington, D.C., American Geophysical Union, 196, 55-62.

Scholz, C.H., 1968. The frequency-magnitude relation of microfracturing in rock and its relation to earthquakes. Bulletin of the Seismological Society of America, 58, 399-415.

Singh, C. 2014. Spatial variation of seismic *b-value* across NW Himalaya. Geomatics, Natural Hazards and Risk, 1-9. DOI: 10.1080/19475705.2014.941951

Singh, C., Chadha, R.K., 2010. Variation in the frequency-magnitude distribution with depth in the Koyna, Reservoir site, India. Journal of Asian Earth Science, 39, 331-334.

Singh, C., Bhattacharya, P.M., Chadha, R.K., 2008. Seismicity in Koyna-Warna Reservoir Site in Western India: Fractal and *b-value* Mapping. Bulletin of the Seismological Society of America, 98(1), 476-482.

Singh, C., Singh, A., Chadha, R.K., 2009. Fractal and *b-value* mapping in eastern Himalaya and southern Tibet. Bulletin of the Seismological Society of America, 99, 3529-3533.

Utsu, T., 1999. Representation and analysis of the earthquake size distribution: a historical review and some new approaches. Pure and Applied Geophysics, 155, 509-535.

Wiemer, S. 2001. A software package to analyse seismicity: ZMAP. Seismological Research Letters, 72, 373-382.

Wiemer, S., Wyss, M., 1997. Mapping the frequency-magnitude distribution in asperities: An improved technique to calculate recurrence times. Journal of Geophysical Research, 102(B7), 15115-15128.

Wiemer, S., Katsumata, K., 1999. Spatial variability of seismicity parameters in aftershock zones. Journal of Geophysical Research, 104, 13135-13151.

Wiemer, S., Wyss, M., 2000. Minimum magnitude of completeness in earthquake catalogs: Examples from Alaska, the western U.S. and Japan. Bulletin of the Seismological Society of America, 90, 859-869.

Wyss, M. 1973. Towards a physical understanding of the earthquake frequency distribution. Geophysical Journal of the Royal Astronomical Society, 31, 341-359.

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