

Temporal variation of b-value and seismicity in the Indo-Burma Region: A precursor to large earthquake

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Abstract

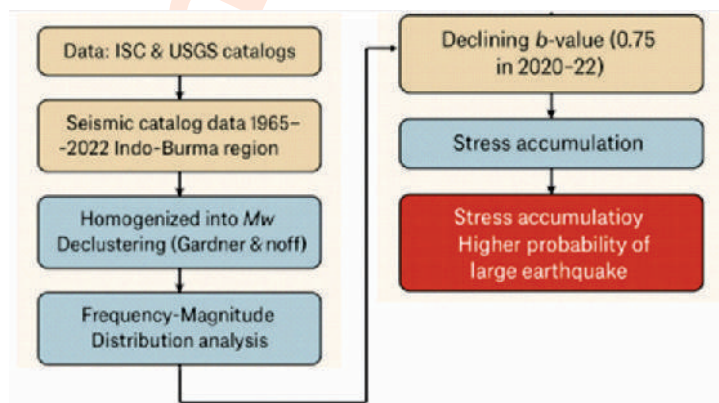
Aim: To determine seismicity parameters such as a-value, b-value, and M_c (magnitude of completeness) for different time periods from 1965 to 2022 in the Indo-Burmese region. This study also aims to analyze temporal variations and their implications for seismic hazard assessment.

Methodology: Seismic catalog data were obtained from the International Seismological Centre (ISC) and the United States Geological Survey (USGS) for the period 1965-2022. The data were homogenized into moment magnitude (M_w) and segmented into intervals of at least five years with a minimum of 50 seismic events per interval. Declustering was performed with Gardner and Knopoff algorithm. Seismic parameters were determined by the Gutenberg-Richter relation and maximum curvature method.

Results: The b-values varied approximately 0.75 to 1.64 over different time periods, with an average range of 0.9 to 1.2. M_c exhibited a decreasing trend over time, stabilizing at 4.1. These results indicate improved data quality and suggest changes in the stress regime and tectonic activity in the Indo-Burmese region over time. The lowest b value was observed between 2020 to 2022.

Interpretation: Temporal variations in seismicity parameters reflect the evolving tectonic processes and stress accumulation in the region. The observed decrease in M_c over time suggests improvements in seismic data recording. Variations in b-value indicate periods of stress accumulation and release, highlighting the importance of continued seismic monitoring for hazard assessment. This study suggests low b value from 2005 to 2022 in the region due to the buildup of stress and a potential large earthquake in the future.

Key words: Earthquakes, Hazard assessment, Indo-Burmese region, Seismicity



Introduction

The Indo-Burmese subduction region is characterized by complex tectonic structures and ongoing debates regarding the activity of subduction. The subducting Indian lithospheric plate below the Burmese plate leads to significant geological and seismological implications. The Indo-Burmese wedge and the Sagaing fault have been identified as key features formed during the subduction process (Chingtham *et al.*, 2025). Subduction in this region has been a subject of ongoing geological and seismotectonic studies, with debates on whether the subduction is still active or static (Satyabala, 1998). Some researchers argue that active subduction continues in the Burma region, supported by evidence such as deeper seismicity, high-velocity lithospheric structure, and a curved S-shaped boundary of the Sagaing fault between the Indian and Burmese plates (Raof *et al.*, 2017). Additionally, the Indo-Burmese Wedge has been analysed to provide a structural and kinematic analysis based on seismic reflection, geodetic, and geological field data (Maurin and Rangin, 2009). Furthermore, the region is associated with a locked and loading megathrust linked to active subduction beneath the Indo-Burmese Ranges, indicating ongoing tectonic activity (Steckler *et al.*, 2016).

The main objective of this study is to determine the seismicity parameters: a-value, b-value, and M_c (magnitude of Completeness) for the Indo-Burmese subduction region. The seismicity parameters, particularly the b-value and magnitude of completeness (M_c), play a crucial role in understanding seismic activity and hazard assessment. The b-value, derived from the Gutenberg-Richter relationship, represents the frequency of earthquakes of different magnitudes, providing information into the seismic energy release and fault characteristics (Woessner and Wiemer, 2005). On the other hand, M_c signifies the lowest magnitude at which all seismic events in a specific space-time volume are detected, affecting the accuracy of seismicity-based studies and hazard assessments (Das *et al.*, 2012).

The assessment of M_c is fundamental for various seismicity analyses, as it determines the threshold magnitude above which all seismic events are reported, affecting the reliability of seismic hazard assessments. Furthermore, the variation of seismic parameters, including M_c , across the study area highlights the need for a comprehensive understanding of spatial mapping and estimation of these parameters for accurate seismic hazard analysis. The accurate determination of M_c is essential for seismicity and seismic hazard assessment studies, as it influences the detection and reporting of seismic events, thereby impacting the reliability of derived seismic parameters and hazard assessments. In the context of the Indo-Burmese subduction region, the evaluation of seismicity parameters such as the b-value and M_c is crucial for understanding seismic activity, fault characteristics, and seismic hazard assessment. Analyses of these parameters require a comprehensive assessment of seismic catalog quality, spatial mapping, and estimation methods to ensure accurate and reliable seismicity-based studies in the

region. In 1941, Beno Gutenberg and Charles F. Richter established a relationship between earthquake frequency and magnitude. Seismic activity is measured by the parameter 'a', which is dependent on a variety of factors, including the size of the area, time since the last earthquake, the total number of earthquakes, and the magnitude of each earthquake (Gutenberg and Richter, 1944). The b-value, displays the relative number of smaller versus larger earthquakes, is widely used to measure seismicity. An increase in b-value implies a greater proportion of earthquakes with small magnitudes relative to larger ones, while a low b-value indicates a higher proportion of larger earthquakes. Additionally, a low b-value suggests strong asperity and homogeneity in the component rock mass, whereas high b-values are associated with numerous smaller earthquakes in areas of low strength and high heterogeneity. As a result, it is commonly used to predict the size of future earthquakes and conduct probabilistic hazard assessments (Kayal *et al.*, 2012; Bora *et al.*, 2022; Sharma *et al.*, 2022).

The seismicity parameters for the Indo-Burmese region, as derived from earthquake catalogue data, reveal dynamic patterns of seismic activity over time. Magnitude of Completeness (M_c) values fluctuate between 4.1 and 5.8 across different periods, indicating variations in the completeness of earthquake magnitude recording. Meanwhile, the b values, ranging approximately 0.75 to 1.64, suggest changes in the distribution of earthquake magnitudes, with higher values indicating a larger number of smaller earthquakes relative to larger ones. Periods of increased seismic activity, such as during the mid-20th century, coincide with higher b values, suggesting active tectonic or changes in stress regimes. Conversely, periods with lower b values, such as during the early 21st century, indicate reduced seismic activity. These fluctuations in seismicity parameters reflect the complex interplay of tectonic processes and stress accumulation and release within the Indo-Burmese region, highlighting the importance of continued monitoring and analysis to better understand seismic hazard and risk in the area.

Materials and Methods

Study region: The active tectonic processes in Asia are largely driven by the continued collision between the Indian and the Eurasian plate. This collision has been documented by various researchers, including Satyabala (1998) and Steckler *et al.*, (2016). Between the Indian and South-east Asian plates lie the wedge-shaped Burma platelet, which has been separating them since the early Miocene. During the late Miocene and onwards, the convergence of these plates led to the accretionary prism being thrust onto the Indian continental margin, resulting in the formation of the Indo-Burmese ranges.

The eastern part of North-east India is characterized by the Naga-Lushai Hills. South of the Shillong Plateau lies the Bengal Basin, separated by the east-west trending Dauki Fault. Vertical movements have played a significant role in deposition of thick sedimentary layers belonging to the Irrawaddy system of

Burma and the Bengal Basin in India (Evans, 1964; Kayal, 2008; Sakawat et al., 2020). Towards the south, the Bengal Basin opens up to the Bay of Bengal.

Mikir Massif is considered a fragmented portion of the Shillong Plateau and is separated by a series of faults known as the Kopli Fault. The upper Assam Valley is bounded on the southwest by the Mikir Hills and the Shillong Plateau (Fig. 1 b). (Bilham and England, 2001) in their study indicated that the Shillong Plateau is not being formed through a system of thin-skinned thrusting, but rather, it is bordered by a high-angle reverse fault to its north and potentially to its south as well. Therefore, the Shillong Plateau exhibit characteristics similar to pop-up structures found in other thrust belts (Bilham and England, 2001; Kayal, 2008). The Indo-Burmese ranges span from the Arakan-Yoma region to the Mishmi thrust belts. These ranges predominantly consist of Cretaceous to upper Eocene shales and sandstones, which have experienced significant folding during the Oligocene and Miocene periods. The Burmese Basin is divided by the magmatic arc into back-arc and forearc troughs, with the oldest dated plutons dating back to the mid-Cretaceous and the youngest volcanic rocks recorded (Satyabala, 2003).

The geological setting of the Indo-Burmese subduction region is further characterized by the Paleogene evolution of the Burmese forearc basin, providing insights into the history of India-Asia convergence (Licht et al., 2016). Additionally, the region's upper mantle deformation has been studied, revealing fast axes of anisotropy aligning parallel to the arc, enhancing the understanding of mantle dynamics in the subduction and continent-continent collision zones. The tectonic framework of the Bengal Basin and its surroundings, which includes the active Indo-Burmese hyper-oblique subduction margin, has been investigated, providing a comprehensive geodynamic model of the region (Hossain et al., 2020). Moreover, the Indo-Burmese Ranges have been identified as under compression due to oblique convergence between the Sunda and Indian plates, further highlighting the active tectonic processes in the region (Angelier and Baruah, 2009).

Data and Methodology: For this work, seismic data has been obtained from ISC and USGS within a time period 01-01-1965 to 31-12-2022 for a 500 km radius with a central point as Churachandpur (24.3425N, 93.6980E), since CMF is one of the major fault systems in Indo-Burmese Region and most of the seismic activities originate in this fault system. In the obtained data, some events were incomplete as they could not be used them to deduce seismicity parameters, hence, they were omitted and 6713 raw data were obtained.

Homogenisation of data: The raw data obtained were in different magnitude scales (MW, mb, ML, MD and MS); hence, to create uniformity, first, they had to be homogenized into the same magnitude scale. To achieve consistency magnitude scaling, it was essential to convert different magnitude types into a single standardized scale. Moment magnitude (Mw) was preferred as it

avoids the saturation issues on other scales (Kanamori, 1983). For this purpose, region-specific empirical relationships developed by Sitharam and Sil (2014) was used. These relationships were derived using local seismic data covering North-east India (including Mizoram and Tripura) for the period 1731–2011, making them particularly suitable for our study area within the Indo-Burma subduction zone. These equations were originally formulated based on a statistical regression of co-reported magnitudes and validated for seismic hazard studies in this region (Sitharam and Sil, 2014), which are as follows:

$$M_w = 0.862 M_b + 1.034$$

$$M_w = 0.673 M_L + 1.730$$

$$M_w = 0.625 M_S + 2.350$$

$$M_w = (0.93 \pm 0.004) M_d + (0.35 \pm 0.14)$$

where, M_b = Body wave magnitude; M_L = Local Magnitude; M_S = Surface magnitude; M_d = Duration Magnitude.

After all, the magnitude was homogenised into the same magnitude. The next task was to subdivide these homogenized data into a period of minimum 5 years. Here, attention was paid on two things: firstly, event data for a particular period at a minimum had to be 50. Periods were segmented as follows: 1965-1969, 1970-1974, 1975-1979, 1980-1984, 1985-1989, 1990-1994, 1995-1999, 2000-2004, 2005-2009, 2010-2014, 2015-2019, 2020-2022.

Declustering of data: The homogenized data alone were not useful to obtain seismicity parameters, because these data not only contained the mainshocks but aftershocks as well as foreshocks too, hence it was important to declutter these data, and the process of decluttering was performed in which mainshocks were separated from aftershocks and foreshocks using the algorithm developed by Gardner and Knopoff (1974) because of its simplicity, stability, and clarity as well as it was widely in used, the process of decluttering was carried out by ZMAP software which functions on MATLAB.

Determination of b-value: The most studied seismicity parameter in seismology was b-value as its correlate with frequency magnitude relation's plot. It is used in analysis of seismic hazard assessment. To determine b-value there are different methods like least square methods, maximum curvature method, etc. The maximum curvature method developed by Wiemer and Wyss (2000) was used. The first step is to determine M_c (magnitude of completeness). M_c was obtained at the point where the maximum curve occurred in the frequency-magnitude distribution curve. It was based on the relationship of Gutenberg-Richter power law:

$$\log N(M) = a - bM$$

where, $N(M)$ is the frequency of earthquakes with magnitudes larger than or equal to M , and M is different for the corresponding time period, and b value was obtained using the relation given by Aki (1965).

$$b = \frac{\log_{10} e}{|<M> - (M_c \frac{\Delta M}{2})|}$$

where, $\langle M \rangle$ is the mean magnitude of the sample, ΔM is the binning width, here considered as 0.1, M_c is the lower limit of the earthquake magnitude. The a-value is dependent on the observation period and seismicity of the area, a- value varies as it depends on the length of the observation period as well as on the average size of the earthquake area reviewed.

Results and Discussion

After performing declustering using Gardner and Knopoff's (1974) algorithm, the a-value, b-value, and magnitude of completeness (M_c) were obtained for different periods from 1965 to 2022. The comprehensive analysis of seismicity parameters revealed significant temporal variations that provide crucial insights into the evolving seismic characteristics of the Indo-Burmese subduction zone. The M_c values demonstrated a systematic decreasing trend, ranging from 5.8 in the earliest period (1965-1969) to 4.1 in the recent intervals (Fig. 2). This temporal reduction reflects significant improvements in the seismic network infrastructure and detection capabilities over the study period, consistent with the global trend observed by Mignan and Woessner (2012) and Rydelek *et al.* (2004).

The most pronounced decrease occurred after 1990, where values stabilized around 4.1-4.3, indicating that the regional seismic network had reached a mature operational state

with consistent detection thresholds. Similar trends have been documented by Das *et al.* (2012) in North-east India and Woessner and Wiemer (2005) globally. The stabilization of M_c values at approximately 4.1 since 2005 has important implications for seismic hazard assessment. Lower M_c values enable the inclusion of smaller magnitude events in statistical analyses, thereby improving the robustness of frequency-magnitude relationships and enhancing the reliability of probabilistic seismic hazard calculations (Mignan and Woessner, 2012). This improvement was particularly significant for regions like the Indo-Burma subduction zone, where accurate characterization of seismic activity is essential for understanding tectonic processes.

The b-value exhibits substantial temporal variability, ranging from 0.75 to 1.64 (Table 1), with a mean value of approximately 1.1. The most striking feature was the systematic decline in b-value from 2005 onwards, culminating in the lowest recorded value of 0.75 during 2020-2022 interval. The temporal pattern revealed three distinct phases: (1) relatively high b-values (1.2-1.6) during 1965-1989, (2) moderate values (0.9-1.2) from 1990-2004 and (3) consistently low values (0.75-0.95) from 2005-2022. The physical interpretation of b-value variations is rooted in the fundamental relationship between stress conditions and material heterogeneity. Laboratory studies by Scholz (1968) and Mogi (1962) established that b-values are inversely correlated with applied stress levels, with lower values indicating higher

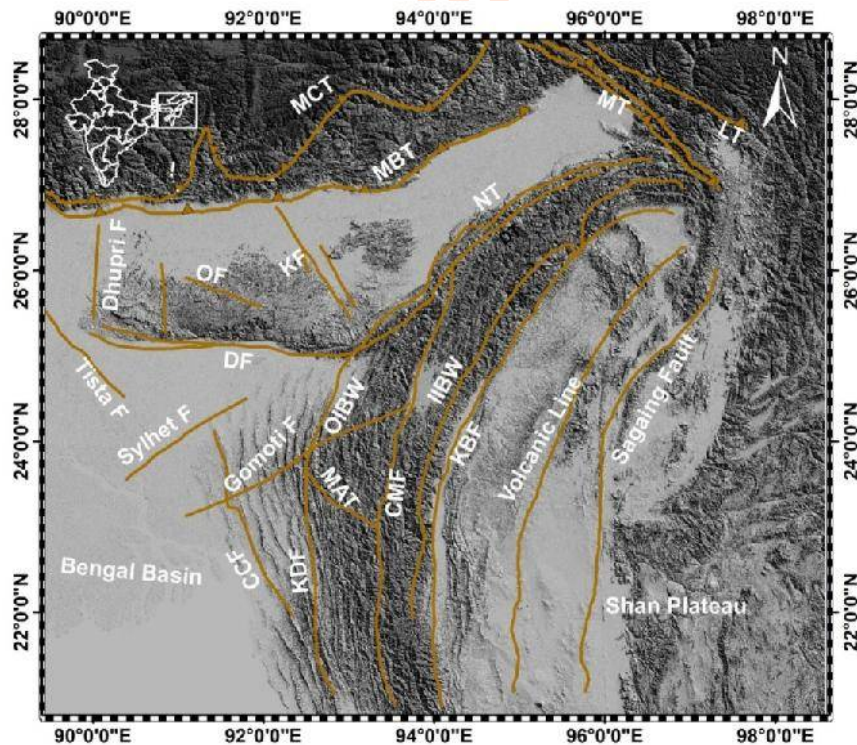


Fig. 1: Major tectonic features; MCT: Main Central Thrust; MBT, Main Boundary Thrust; Sagaing Fault; KBF, Kabawault; CMF, Churachandpur Mao Fault; MAT, Mat Fault; KDF, Kaladan Fault; CCF, Chittagong Coastal Fault; LT, Lohit Thrust; MT, Mishmi Thrust; NT, Naga Thrust; DT, Disang Thrust; KF, Kopili Fault; DF, Dauki Fault; OF, Oldham Fault; OIBW, Outer Indo Burma Wedge; IIBW, Inner Indo-Burma Wedge.

Table 1: Seismicity parameters in different time intervals

Time interval	a-value	b-value	Mc (Magnitude of completeness)
1965 - 1969	8.444	1.29+/-0.14	5.2
1970 - 1974	10.158	1.62+/-0.27	5.3
1975 - 1979	9.441	1.50+/-0.25	5.3
1980 - 1984	10.317	1.64+/-0.19	5.3
1985 - 1989	7.696	1.13+/-0.08	4.9
1990 - 1994	6.553	0.93+/-0.06	4.7
1995 - 1999	8.304	1.29+/-0.09	4.7
2000 - 2004	9.179	1.5+/-0.12	4.7
2005 - 2009	6.363	0.9+/-0.03	4.1
2010 - 2014	6.530	0.94+/-0.03	4.1
2015 - 2019	6.489	0.92+/-0.04	4.1
2020 - 2022	5.603	0.75+/-0.03	4.1

differential stress conditions and increased material homogeneity. The declining b-value trend observed in our study aligns with theoretical predictions for regions experiencing progressive stress accumulation. Wiemer *et al.* (2009) reported values dropping from 1.0 to 0.6-0.7 before 2004 Sumatra-Andaman earthquake (Mw 9.1), while Nanjo *et al.* (2012) observed comparable patterns before 2011 Tohoku earthquake (Mw 9.0). In the regional context, Bhattacharya and Kayal (2003) reported anomalously low b-values (0.6-0.8) preceding 1950 Assam earthquake (Mw 8.6) and 1897 Shillong earthquake (Mw 8.1), suggesting that similar patterns in our study area may indicate elevated seismic hazard potential. The current b-value of 0.75 is comparable to values observed before several major earthquakes worldwide, including 2009 L'Aquila earthquake (Console *et al.*, 2003), 1999 Chi-Chi earthquake in Taiwan (Chan *et al.*, 2012), and 2014 South Napa earthquake (Tormann *et al.*, 2015).

These correlations suggest that the Indo-Burma region may be experiencing conditions similar to those preceding significant seismic events. The a-values ranged from 5.603 to 10.317, with generally higher values observed in more recent periods. The a-value represents the logarithm of earthquake occurrence rates and is strongly dependent on catalog completeness, observation period duration, and regional seismic activity levels (Gutenberg and Richter, 1944). The temporal increase in a-values primarily reflects improved earthquake detection and reporting capabilities rather than a genuine increase in seismic activity rates, as demonstrated by Kagan (2002) in global seismicity studies. When normalized for catalog completeness effects, the higher a-values observed during 1995-2014 (8.5-10.3) coincided with periods of enhanced regional seismic activity, including several moderate to large earthquakes in the broader North-eastern region of India, such as 2009 Bhutan earthquake (Mw 6.1) and 2011 Sikkim earthquake (Mw 6.9).

The observed temporal variations in seismicity parameters, particularly the declining b-values between 2005 and 2022, suggest increased tectonic stress accumulation along the

Indo-Burmese subduction zone. This interpretation is supported by the complex tectonic setting of the region, where the continued northward motion of the Indian plate at approximately 50 mm yr⁻¹ (Demets *et al.*, 2010) generates ongoing convergent stress that accumulates along the Indo-Burma megathrust and associated fault systems. The role of oblique convergence in the Indo-Burma system creates complex three-dimensional stress fields that differ from predominantly orthogonal subduction zones (Satyabala, 2003). The interaction between thrust faulting on the megathrust and strike-slip motion on the Sagaing fault system, which accommodates a significant portion of plate motion through lateral displacement (Socquet *et al.*, 2006), contributes to the complex stress evolution reflected in the seismicity parameters. Geodetic studies by Gahalaut *et al.* (2013) indicate significant strain accumulation across the Indo-Burma ranges, consistent with locked fault segments and progressive stress concentration. This geodetic evidence supports the seismological interpretation of increasing stress conditions reflected in the declining b-values.

The lowest b-value (0.75) recorded during 2020-2022 corresponds with heightened seismic clustering and stress concentration, as documented by Sharma and Biswas (2022) and Bora *et al.* (2022). These studies identified spatial clustering of low b-values along the Indo-Burma ranges, interpreting them as zones of high stress concentration and potential earthquake nucleation sites. Kayal *et al.* (2012) emphasized that such low b-values indicate regions of strong asperities where stress heterogeneity is reduced and rupture potential is elevated. The seismicity parameters derived for the Indo-Burma region can be contextualized through comparison with other active subduction zones worldwide. The mean b-value of 1.1 falls within the typical range reported for subduction zones (0.8-1.4), however, the recent decline to 0.75 places the region at the lower end of this spectrum (Frohlich and Davis, 1993). However, important differences exist between the Indo-Burma and other well-studied subduction zones, particularly regarding the oblique convergence geometry that creates more complex stress fields compared to orthogonal convergence systems. The debate

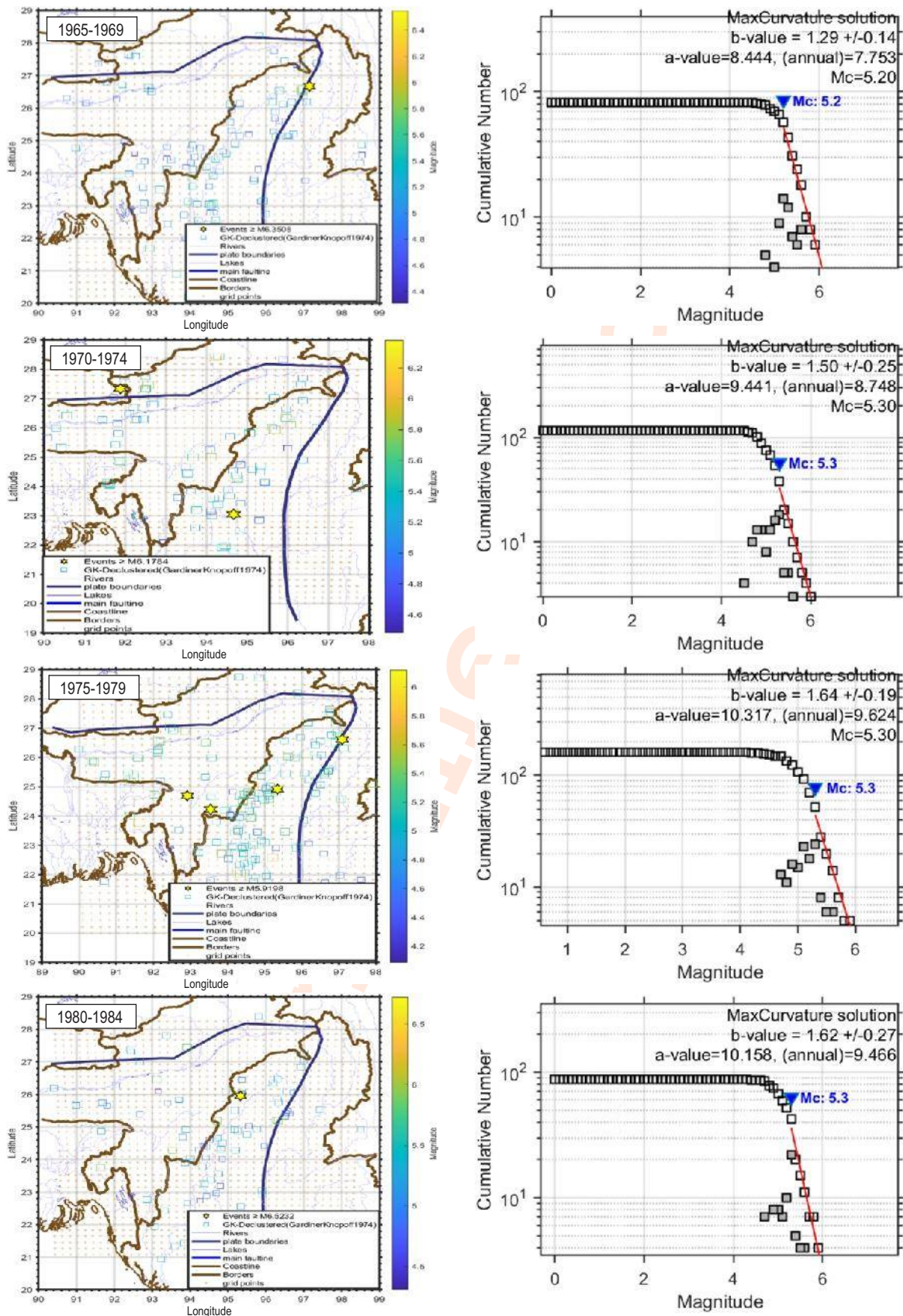


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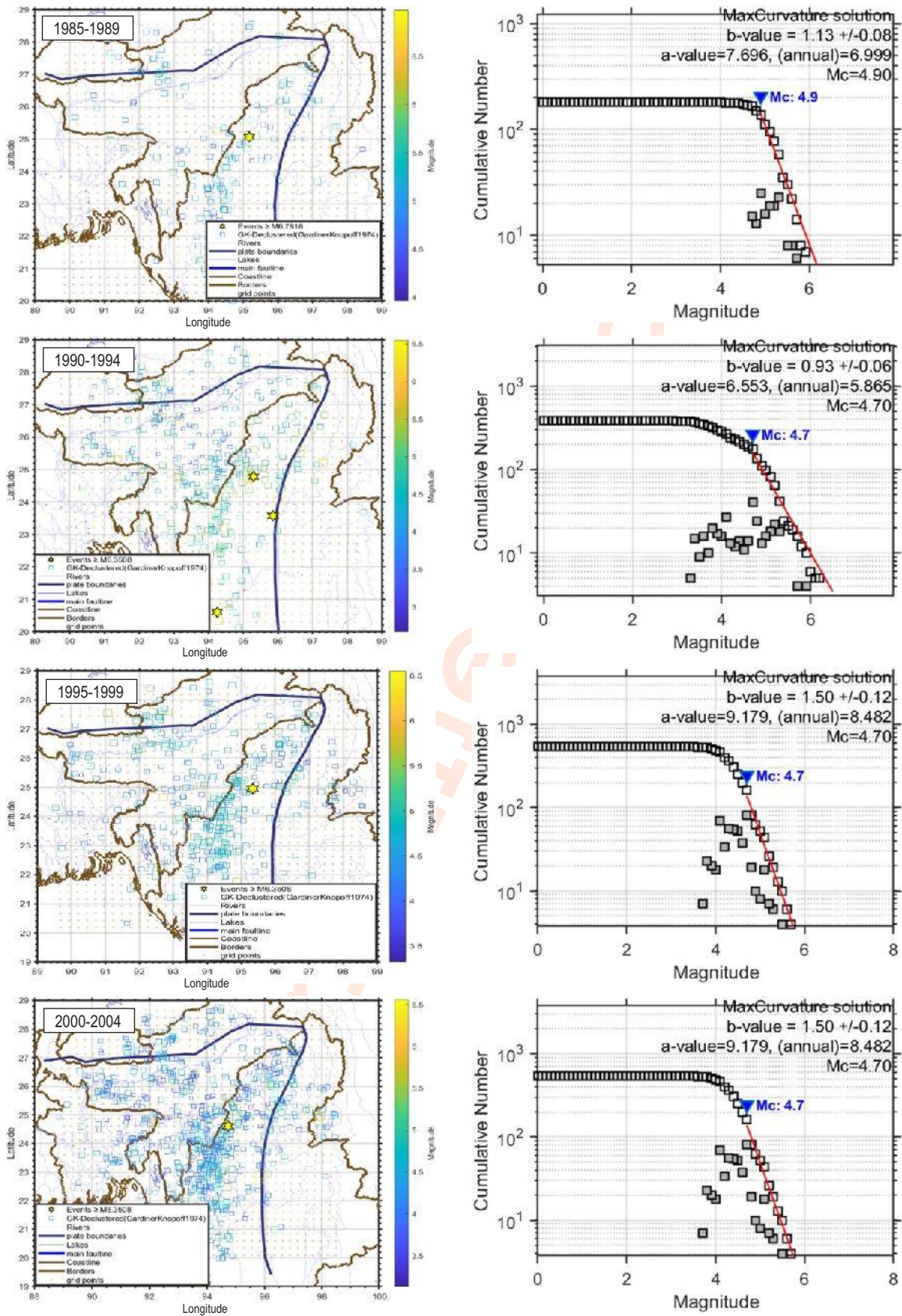


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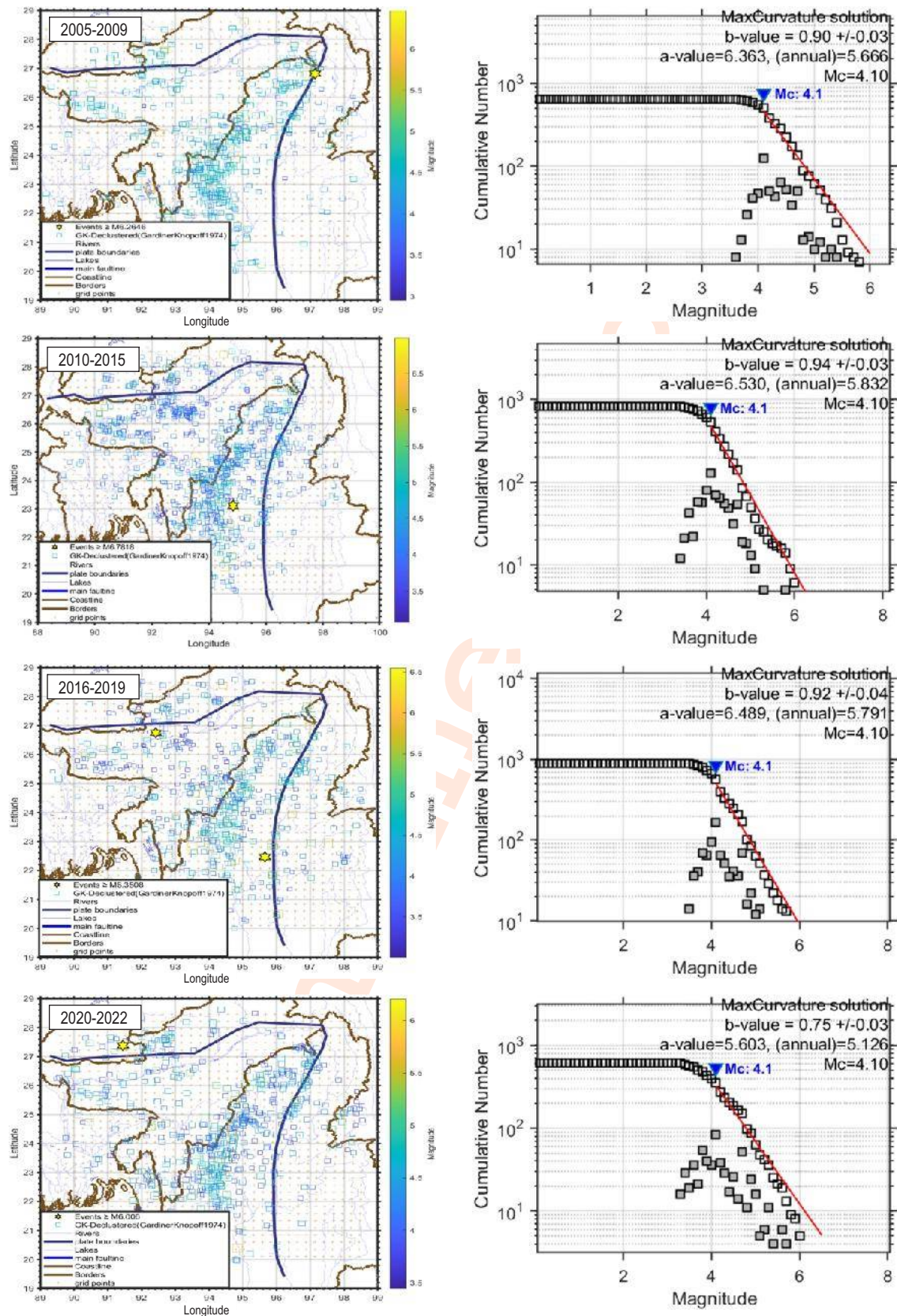


Fig. 2: Observed seismicity and parameters estimated for different time intervals.

regarding the current activity status of the Indo-Burma subduction zones (Satyabala, 1998; Steckler et al., 2016) adds complexity to the interpretation. The systematic decline in b-values has significant implications for seismic hazard assessment in the Indo-Burma region. Low b-values indicate an increased probability of larger magnitude events relative to smaller ones, effectively shifting the magnitude-frequency distribution toward more hazardous earthquakes. Probabilistic seismic hazard analysis (PSHA) calculations are particularly sensitive to b-value variations, as this parameter directly controls the relative likelihood of different earthquake magnitudes (Cornell, 1968).

A reduction in b-value from 1 to 0.75 can increase the calculated probability of large earthquakes ($M_w > 7$) by a factor of 2-3, depending on the specific magnitude range and return period considered (Kijko and Smit, 2012). This has direct implications for building codes and infrastructure planning in the region, particularly for critical facilities and densely populated urban areas.

The combination of systematically declining b-values, complex tectonic setting, and historical precedent of major earthquakes in the region suggests that the Indo-Burma subduction zone warrants continued careful monitoring. While b-value variations alone cannot predict the timing or exact location of future earthquakes, they provide valuable constraints on relative hazard levels and probable magnitude distribution of future seismic events. The current stress accumulation patterns, as reflected in the low b-values, indicate that the region may be approaching a phase of significant seismic activity, emphasizing hazard preparedness in this tectonically active and densely populated region.

This study reveals significant temporal variations in seismicity parameters across the Indo-Burmese subduction zone from 1965 to 2022. The declining trend in b-values, especially 2005 onwards, indicate increasing tectonic stress and the potential for a future large earthquake. The decreasing M_c values reflect improved seismic network performance and data quality. These findings underscore the importance of continuous seismic monitoring in this tectonically complex region. Overall, the results provide valuable insights for seismic hazard assessment and disaster preparedness in North-east India.

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