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Seismotectonics of the northeast Indian region based on GPS velocities, stress and strain rate field characterization

Rajkumar[1], Sanjay Kumar Prajapati[2], Sanjit Kumar Pal[1], and Om Prakash Mishra[2]

[1]IIT ISM Dhanbad, Department of Applied Geophysics, India (rajkumar31894@gmail.com)
[2]National Center for Seismology, Ministry of Earth Sciences, India

Introduction

- The North-Eastern (NE) area of India is located on the confluence of three major tectonic plates, which makes it seismically the most active.
- The study focuses on a specific hyperactive zone in the NE region, which is confined to the grid 20°-30° N latitude and 88°-98° E longitude.
- The region is characterized by complex deformation patterns, with a combination of thrusting, strike-slip, and extensional tectonics. The major faults in the study region are Main Himalayan Thrust, Dauki Fault, Kopili Fault, Sagaing Fault, Kaladan Fault, Kabaw Fault, and the Eastern Himalayan Syntaxis.
- To understand the distribution of strain in the study region and tectonic processes along and across the major fault zone. We analysed the GPS data to determine that how much strain is being accumulated or released along various mapped faults as well as the orientation and magnitude of the strain.
- The study can help us better predict and prepare for the region's earthquakes and other tectonic hazards.
- We also computed the orientation and magnitude of the stresses derived from fault plane solutions and correlated them with crustal strain to identify whether the tectonic stresses are consistent with the observed orientation of crustal strain.

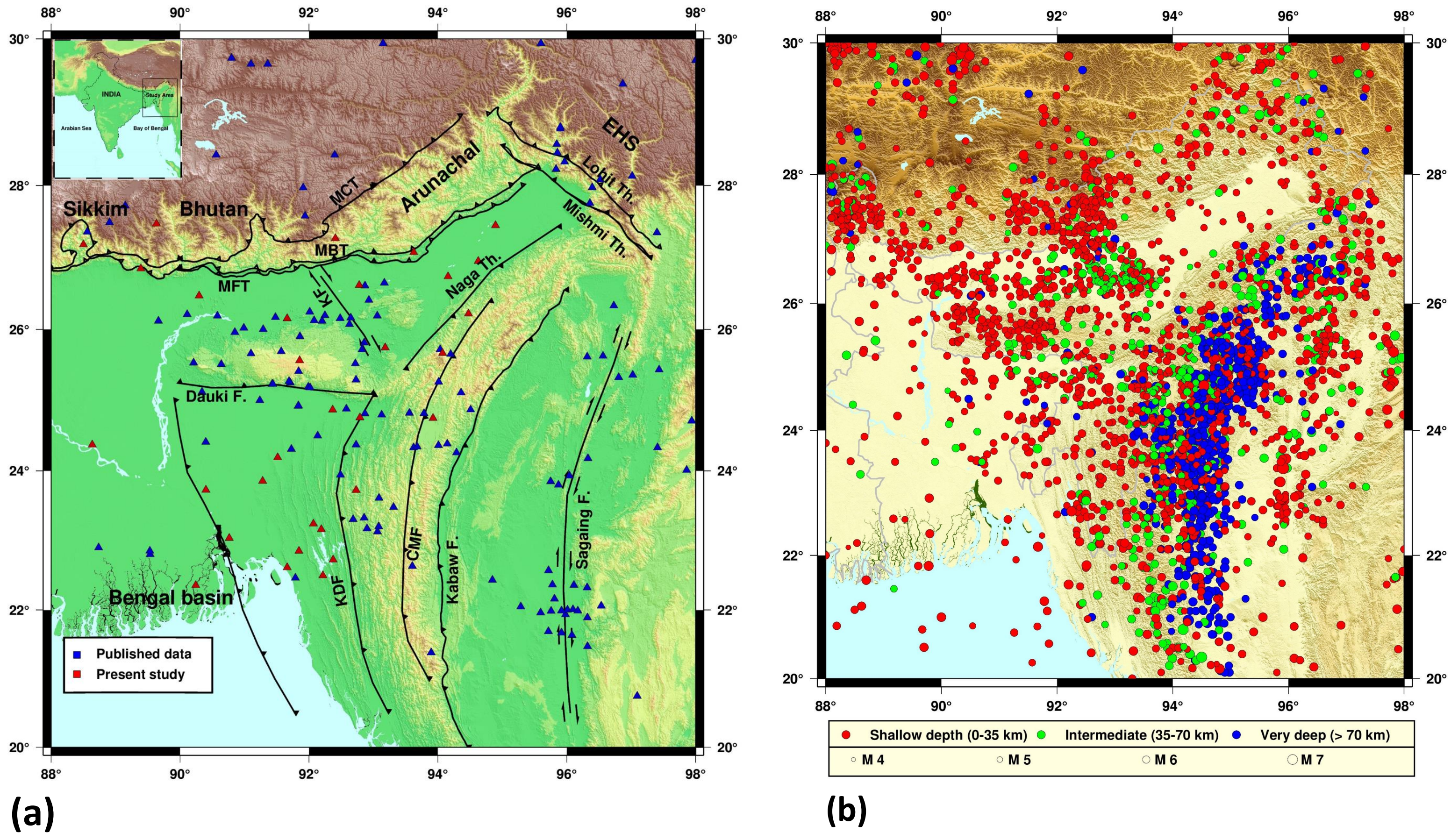


Figure 1.(a) Tectonic map of Northeast India showing faults and seismic stations. Blue triangles represent published station data, while red triangles represent the stations installed for the present study. The inset map shows the location of Northeast India within India. (b) shows the seismicity pattern in northeast India.

GPS data analysis

- We processed the data collected from 2002–2018 from the Permanent GNSS Network established under the MoES-sponsored project and UNAVCO GNSS sites of Bangladesh and combined them with previously published velocity solutions from the GPS survey measurements during 1997-2013 by various institutes.
- We combined all the aforementioned GPS studies in a unified reference frame velocity field for reduced uncertainties.
- We processed the GPS data using the GAMIT/GLOBK 10.6 (Herring *et al.* 2015) software. To tie the IGSN network to the latest version of the International Terrestrial Reference Frame, ITRF2014 (Altamimi *et al.* 2016), 15 nearby IGS stations (COCO, CHUM, DARW, DGAR, HYDE, IISC, KARR, KIT3, KUNM, LHAZ, NTUS, SELE, URUM, WUHN, YAR2) were included in the daily solution processing.
- Timeseries of a few cGPS sites are shown in Fig.2c and the horizontal velocity vector w.r.t. ITRF14 Fig. 2a and the Indian plate is shown in Fig.2b.
- The average velocity pattern is 46.5 ± 0.8 mm/yr in the Northeast direction.

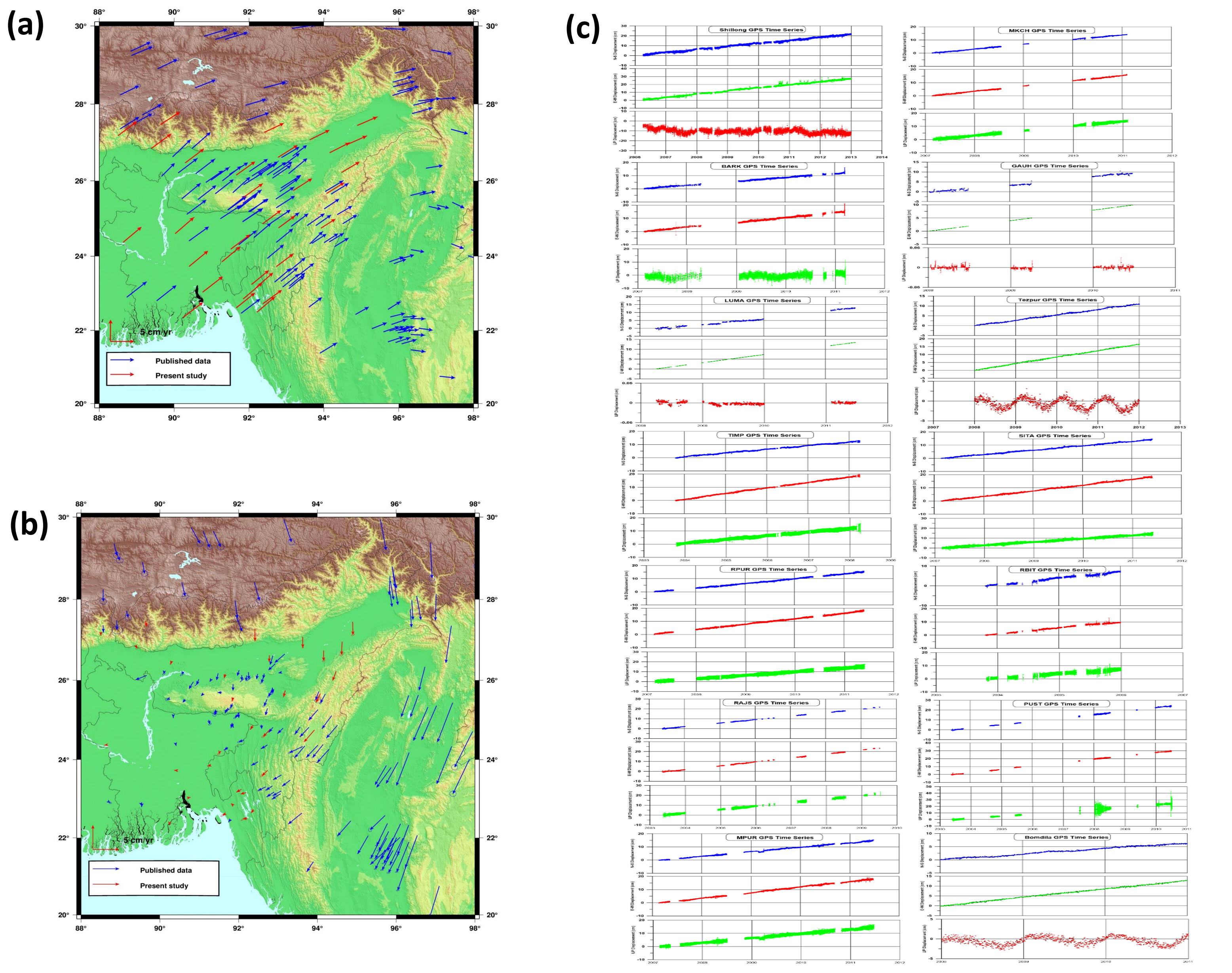


Figure 2. (a) represents the GPS velocity relative to the ITRF2014 (b) shows the GPS velocity in the Indian reference frame (c) displays a time series of processed GPS data

Strain Analysis

- Velocities obtained from GPS data processing can provide useful information on the tensional states of the terrestrial crust.
- Strain rates were calculated from the GPS velocity field by SSPX software developed by Cardozo & Allmendinger, 2009. The problem was considered two-dimensional because GPS data can only provide deformation rates on the earth's surface (x (EW) and y (NS) directions), and do not give any information on deformation rates in the radial direction (z).
- The strain field was computed on the nodes of the 25 × 25 km grid via the Least Square (LS) method which is based on the rescaling of the covariance matrix of velocity data by weighting function which takes into account the distances between the grid node and the GPS stations.
- The dilational strain distribution varies from -0.13 to 0.01 microstrain/year in the entire study region.
- The dilatational strain pattern suggests that crustal ESE-WNW extension dominates the active deformation along EHB, where the CMF and Sagaing strike-slip faulting is dominated. The Block shows a crustal extension with dilatational rates of 10–15 nstrain/yr.
- The continuous positive extension strain pattern reveals continuous crustal extension of the MHT fault around the central part of the Himalayas, with rates between -10 to 10 nstrain/yr.
- The extreme eastern part of the Himalayan region (Arunachal Himalaya) generates a horizontal shortening which is maximum over the Kopili fault.
- The strongest negative strain dilatation anomalies are found in the Mishmi thrust, where the 1950 Assam earthquake occurred.
- The high dilatational field corresponds to the Main Boundary and Central Himalayan Thrusts (MBT and MCT).
- Moderate to high range of dilatation strain present in some regions of IBA, near the intersection areas of Kopili, Dauki Faults, and IBA.
- Thrust faulting predominates on the eastern boundary, while normal faulting is prevalent in the upper Himalayas, and strike-slip in other areas.
- In the Burmese arc area, horizontal compression predominates in the NS direction with a minor component in the EW direction.

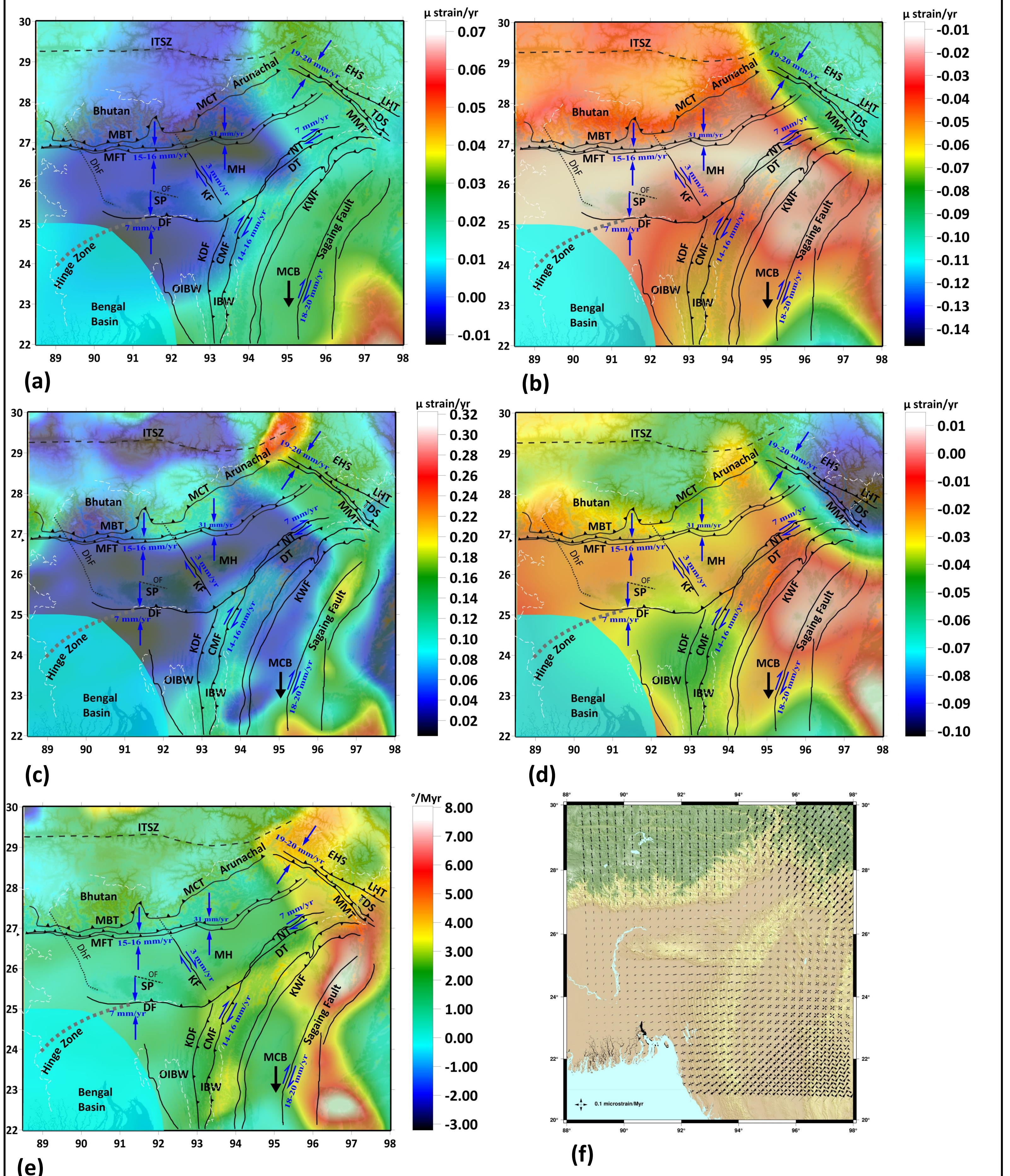
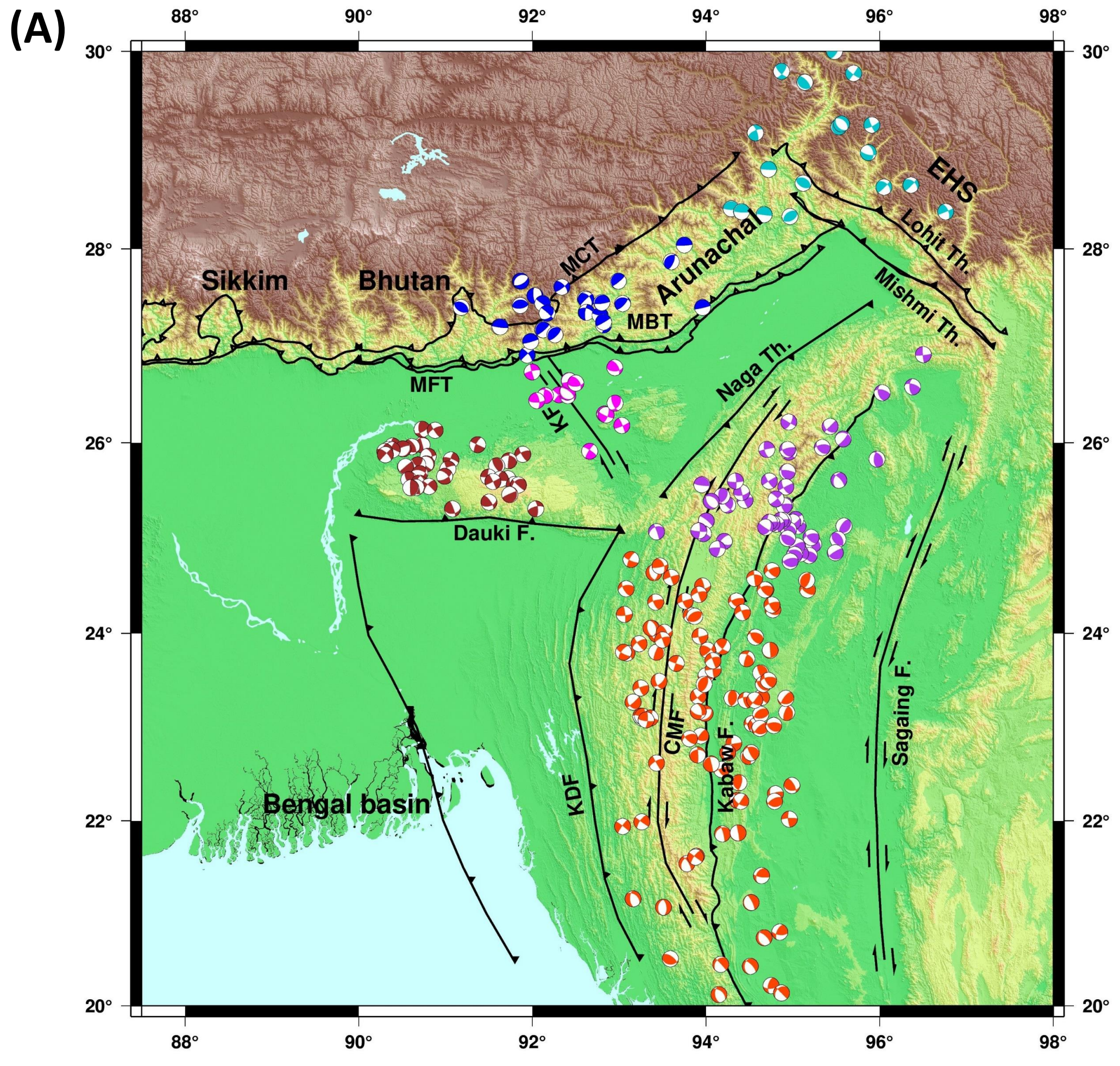


Figure 4. Strain components and strain map in Northeast India. (a) Emax represents the maximum principal strain, (b) Emin represents the minimum principal strain, (c) shear strain, (d) dilatation strain, (e) rotation value, and (f) vector diagram of strain map in Northeast India.

Stress Inversion of Focal Mechanism

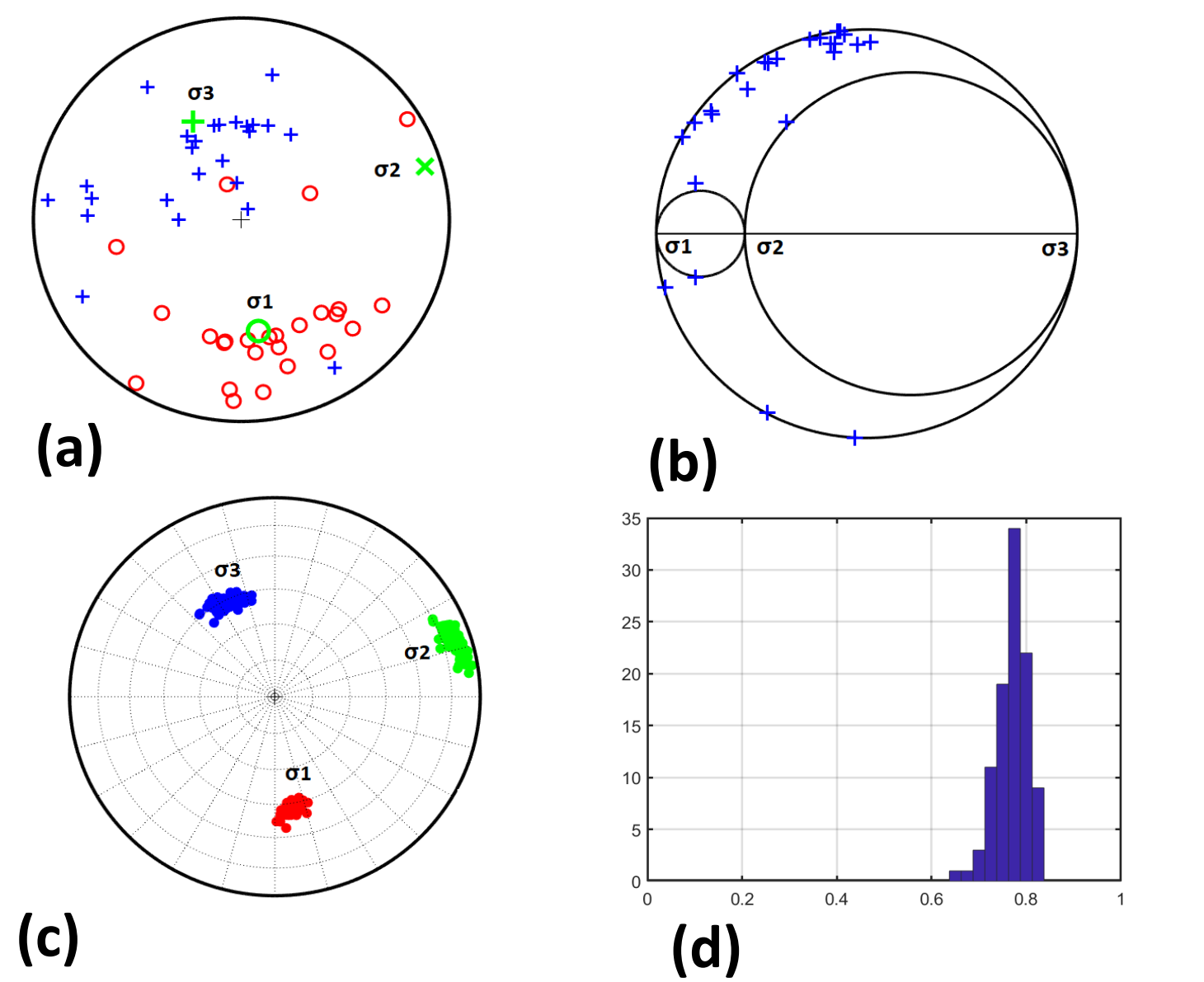
(A)



Tectonic Zone	P(σ1)		N(σ2)		T(σ3)		Shape ratio	R'	FT	S_H max	
	Azimuth	Plunge	Azimuth	Plunge	Azimuth	Plunge					
Himlayan Zone	171	43	73	9	334	46	0.79	2.79	odd	-	-
Shillong Plateau	170	11	261	4	12	79	0.77	2.77	TF	α_P	N170˚
Kopili Fault	264	18	107	71	356	7	0.70	1.30	SS	α_T+90˚	N86˚
Mishmi Thrust	162	17	65	22	286	61	0.80	2.80	TF	α_P	N162˚
Eastern Thrsut Belt (N)	25	2	293	30	118	60	0.50	2.50	TF	α_P	N25˚
Eastern Thrust Belt (S)	197	10	299	51	100	38	0.77	1.23	SS	α_P	N197˚

(B)

Himalayan Thrust Zone



Eastern Thrust Belt

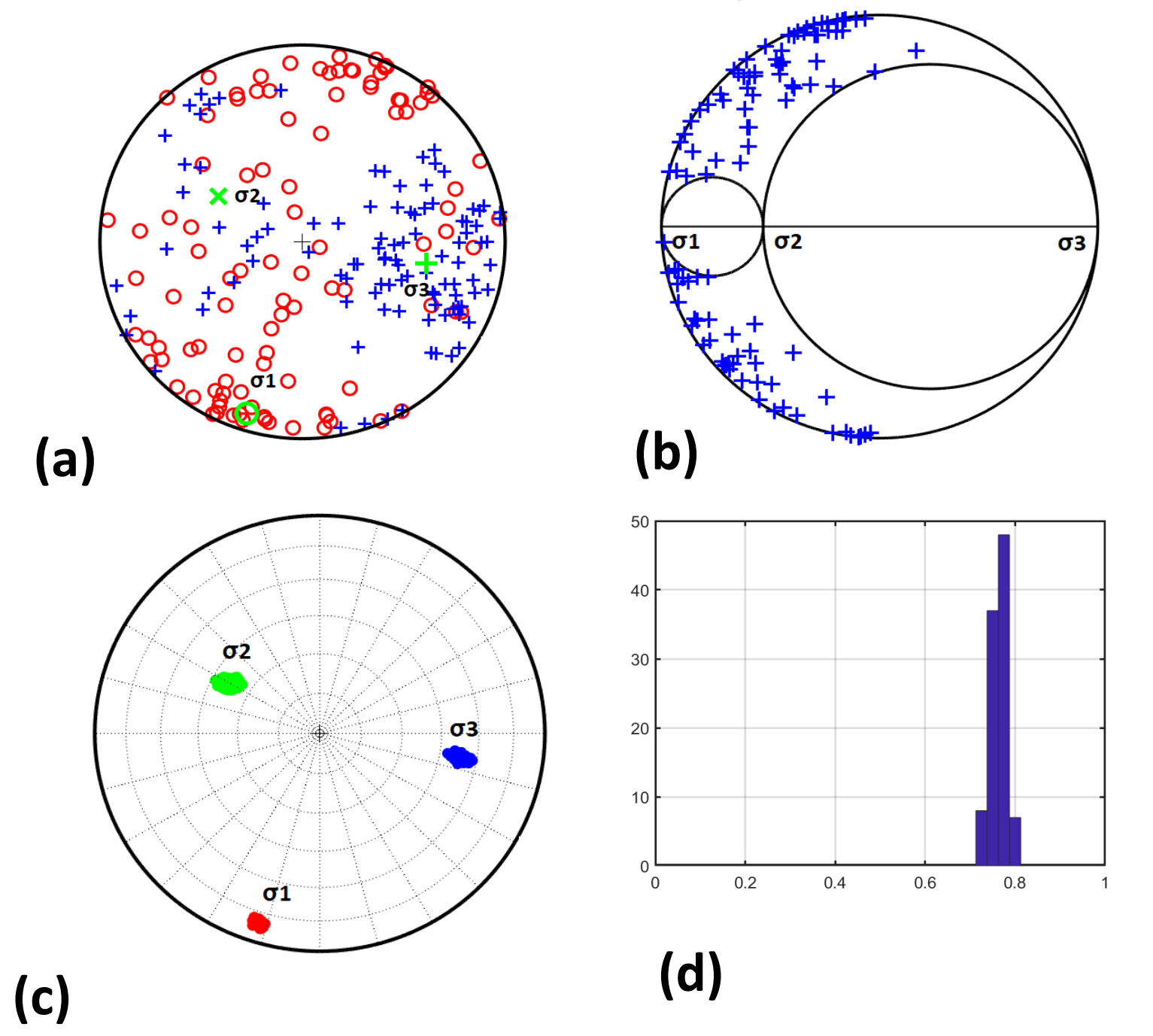


Figure 3(A) shows the focal mechanism solution in Northeast India. (B) Results of stress analysis for Himalayan Thrust Zone (top) and Eastern Thrust Belt (bottom) regions. (a) depicts the P and T axes with the optimum principal stress axes (azimuth and plunge). (b) shows Mohr's circles. (c) displays the confidence limits of the principal stress directions. (d) presents a histogram of the shape ratio R. The P axes are marked by red circles, and T axes are represented by blue crosses. Red denotes maximum compressive stress, green represents intermediate principal stress, and blue signifies minimum compressive stress. Table shows the azimuth and plunge along different blocks.

Stress pattern from focal mechanism solutions

- In 2014, Vavryčuk developed a technique using earthquake focal mechanisms to determine the regional stress tensor in a specific area.
- The technique determines the orientation of the three principal stresses (σ1, σ2, and σ3), with the condition that σ1 > σ2 > σ3.
- The assumption of homogeneous stress in the source region allows the estimation of the active stress state in the study region.
- The technique involves finding the optimal fit for the regional principal stress directions and the shape ratio R, which is the ratio of the intermediate stress relative to the maximum and minimum horizontal stresses.
- By finding the best fitting stress tensor, the technique can resolve fault slip in the direction of the maximum resolved shear stress during an earthquake.
- For each inversion, 100 realizations are produced, and the mean deviation is set to 5°.
- The inversion is done in iterative steps, with the principal stress directions and shape ratio calculated first without known fault planes.
- The real fault planes are determined using the Mohr-Coulomb method (Vavryčuk 2014).
- The iterations are repeated until the outcome converges to the best-fitting solution.
- The results include a stereogram of pressure (P) and tension (T) axes, a stereogram of principal stress axes with their accuracy, a bar graph of R values, and a figure of Mohr circles (Fig. 3B).
- The study aims to determine the dominant tectonic regime related to earthquakes in the region and the orientation of the stress field in the different blocks of the northeast Indian region where seismic activity is frequent.
- The Shmax azimuth for the Shillong plateau is determined to be N170°, and the direction of Shmax is almost south, indicating that this region commonly experiences thrust-type fault.
- In the Eastern thrust northern region, the Shmax azimuth is determined to be N25°, indicating that this area commonly experiences thrust-type faults. In contrast, the southern region has a Shmax azimuth of N197°, suggesting that this area is more prone to strike-slip faults.

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