PSHA; Model and Results for northeast India; An example

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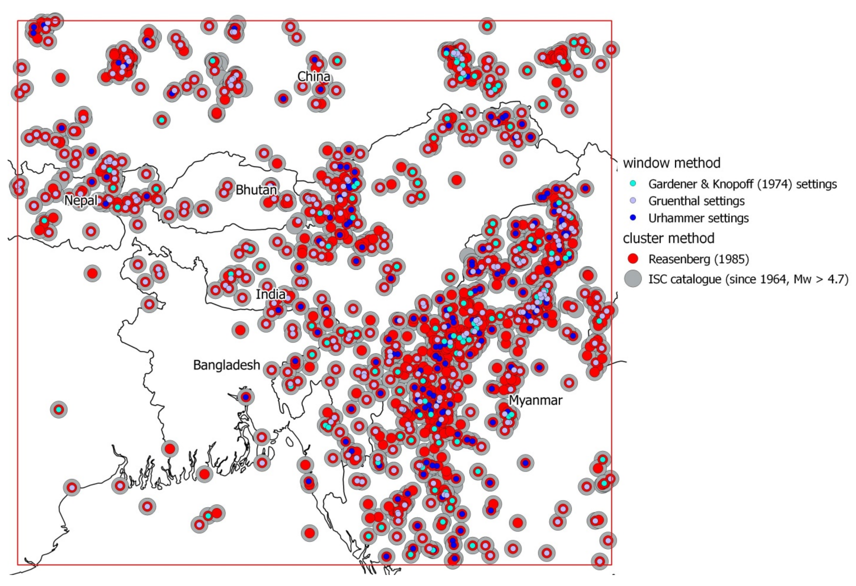
Abstract

We have calculated earthquake hazard for Northeast India and Bhutan applying a hybrid PSHA model in a logic tree framework implementing four independent branches: a) the classical area zonation, b) implementing a regional fault model, c) using the earthquake catalogue as a point source model and finally d) using the Kernel approach in a gridded regional model (Woo, 1996). Each of the models have their pros and cons, and naturally, may be applied differently in a local context rather than in a regional context as the present one. The logic tree is furthermore implemented with 16 GMPE branches. The results naturally depend on weighting and parametrization, but initially show significantly lower hazard levels for northeast India than earlier studies.

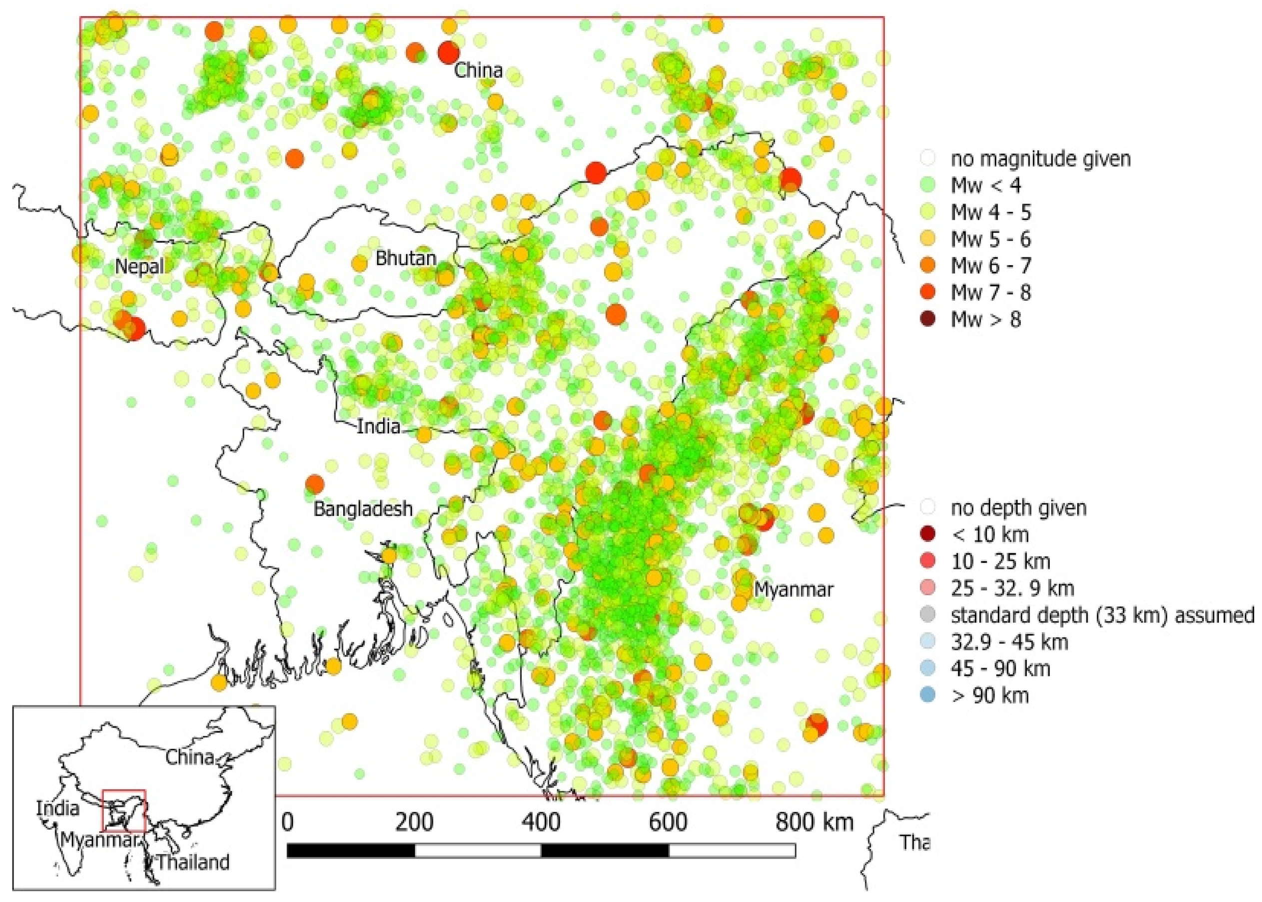
Declustering

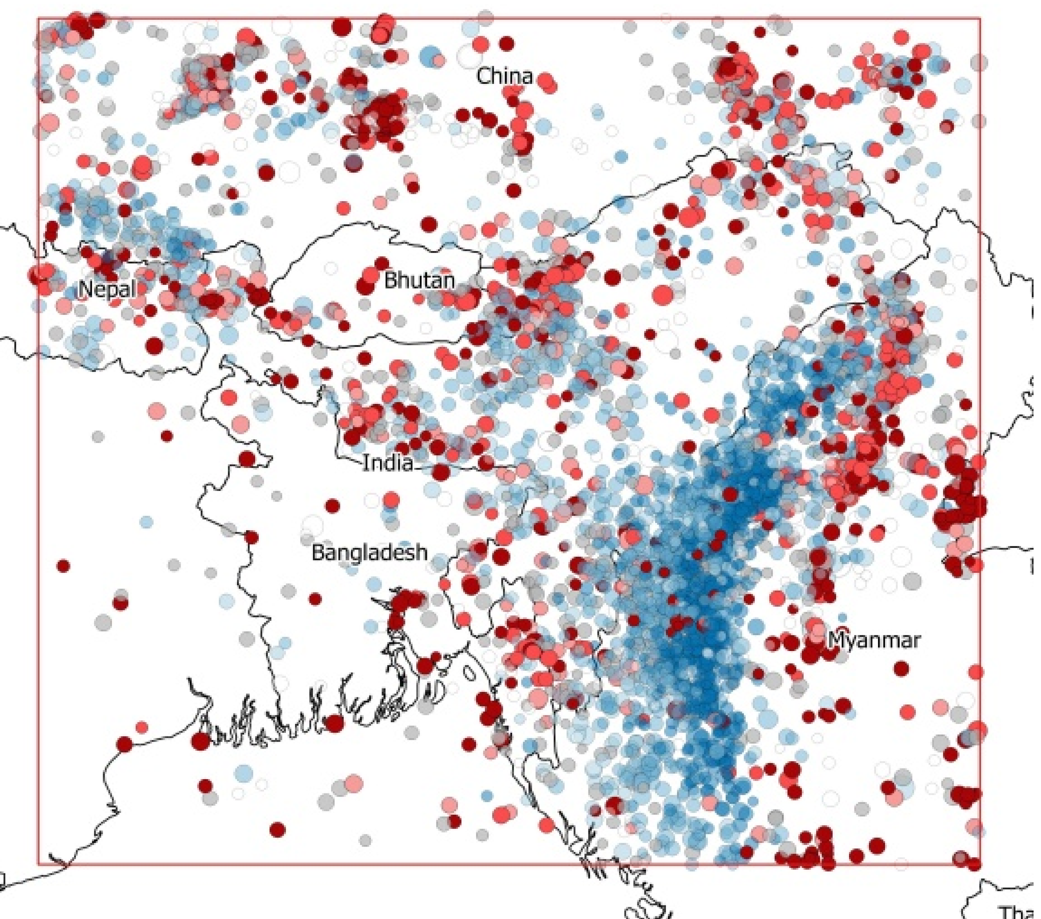
Several methods for declustering were applied. Since declustering methods are based on conceptual models of main shock definition, there is no a priori superior method (Van Stiphout et al., 2012). Thus, we test two different deterministic declustering methods: a window method by Gardener and Knopoff (1974) and a cluster method by Reasenberg (1985). In addition, we test two alternative window parameter settings by Gruenthal (Van Stiphout et al., 2012) and Uhrhammer (1986). We use the algorithms as provided by the online supplement to Van Stiphout et al. (2012) downloaded from the CORSSA website (www.corssa.org).



Declustering of the ISC catalogue: grey dots: earthquakes contained in the ISC catalogue since 1964; red dots: catalogue declustered using Reasenberg (1985) method; blue dots: catalogue declustered employing the Gardener and Knopoff (1974) method with Uhrhammer (1986) settings; light blue dots: catalogue declustered applying the Gardener and Knopoff (1974) method with Gruenthal (Van Stiphout et al., 2012) settings; cyan dots: catalogue declustered after the Gardener and Knopoff (1974) method with original settings.

Background: Data





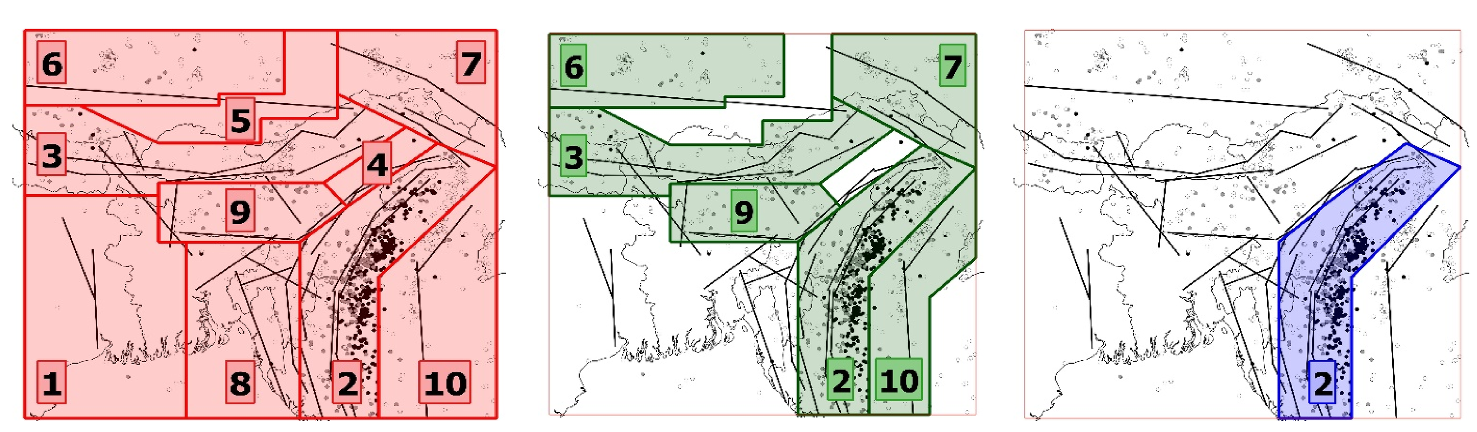
In order to cover both North-East India and Bhutan as well as the subduction zone beneath the Indo-Burman mountain ranges, we chose the region for our hazard assessment from 86°E to 98°E and 20° to 31°N. For this area, we compared several seismic catalogues, the ISC reviewed bulletin since 1960 (www.isc.ac.uk), the EHB bulletin since 1960 (www.isc.ac.uk/ehbbulletin), the PDE catalogue since 1973 (USGS National Earthquake Information Center, http://earthquake.usgs.gov/~regional/neic), the Rajendran/Raghukanth catalogue and the NEIST catalogue. The first four catalogues differ mainly in the number of reported events, the latter covers only the central part of the study area and therefore had to be omitted. The ISC bulletin was considered to be most trustworthy. Whereas both the EHB bulletin and the PDE catalogue report fewer events, we discovered discrepancies in reported magnitudes for events reported in the Rajendran/Raghukanth catalogue and therefore performed our study with the help of the ISC bulletin.

In order to homogenize magnitudes to a common magnitude scale (i.e. moment magnitude Mw), we employ an orthogonal regression method (Das et al., 2013) and calibrate it using data from the Harvard CMT catalogue (www.globalcmt.org/CMTsearch.html) recorded during the same time period and in the same region. We arrive at the following relationships between surface wave magnitude MS, body wave magnitude mb and moment magnitude Mw:

$$M_w = 0.69624\ M_s + 1.88476 \qquad M_w = 1.16213 m_b + 0.79782$$

The above figures show the earthquakes in the ISC catalogue for the available time period (1906 to 2010). On the left, symbol colours and diameters correspond to moment magnitude, on the right, symbol colours are chosen according to hypocentral depth. The inset depicts the location of the study area. Since the depth distribution is inhomogeneous, we subdivide the catalogue into three depth categories for the following analysis: shallow earthquakes (0 – 45 km hypocentral depth), intermediate depth earthquakes (45 - 90 km hypocentral depth) and deep earthquakes (hypocentral depth larger than 90 km).

Zonation model

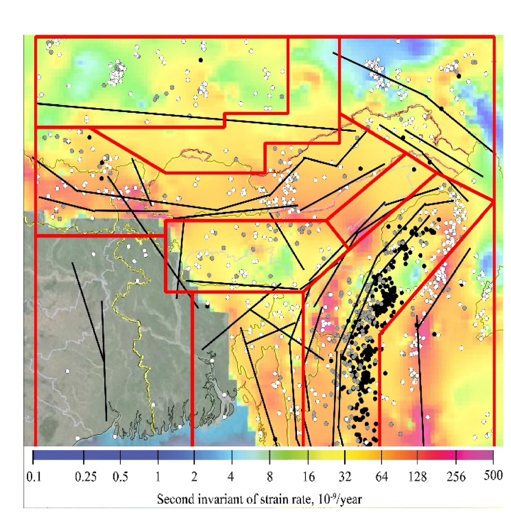


Seismotectonic provinces describe a geographic region being sufficiently homogeneous in its geological, geophysical and seismological properties to assume a uniform earthquake potential throughout. Although the earthquake record may indicate preferred earthquake locations, earthquakes are expected to occur randomly throughout the seismotectonic zone (Reiter, 1990).

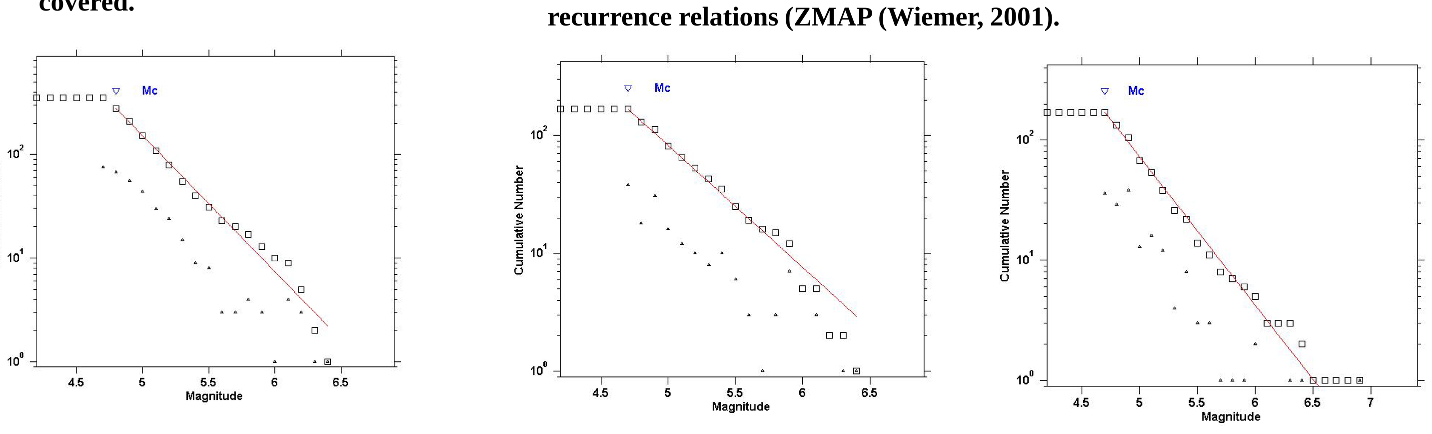
The disadvantage of defining seismotectonic zones is that they represent a potentially unphysical simplification of geological structures and the process of defining the zones is rather subjective, but it avoids the over-interpretation of an earthquake catalog covering only a short time span compared to the return periods of larger events.

Geophysical information (gravity, magnetic anomalies and strain) were also checked and included as basis for the zonation.

Maximum likelihood regression for Himalaya megazone, Indo-Burma subduction megazone and active crust and alluvial region megazone for earthquakes within the shallow depth range (0-45 km) established a basis for recurrence relations (ZMAP (Wiemer, 2001).



Above: Strain data for the region covered.



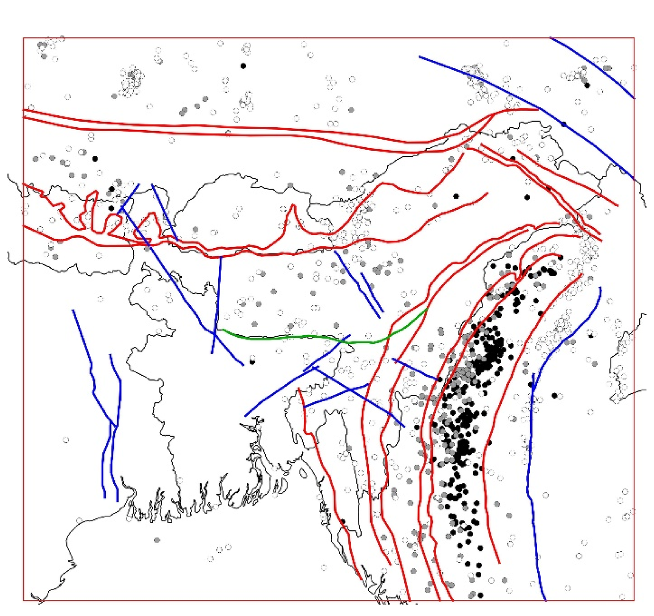
Recurrence regressions for 3 shallow megazones: Left: the Himalaya megazone: integrating zones 3, 5, 6 and 7. Middle: the Indo-Burma subduction zone: integrating zones 2 and 8. Right: the active crust and alluvial region: integrating zones 1, 4, 9 and 10. For both the Himalaya megazone and the Indo-Burma subduction zone the resulting b-values are high (1.3 and 1.2).

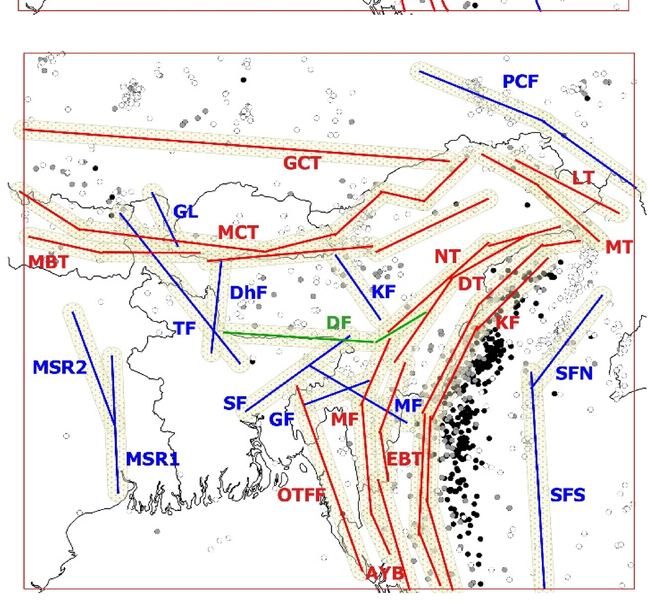
Fault model and potentials

The fault model is based on maps by the Indian Geological Survey and faults have been digitized by hand. To quantify faults by a rectangular fault model, all faults were divided into linear segments (below). In addition to this line fault model, we employ a buffer zone model with a range of 25 km around the surface expression of the fault lines to account for ruptures of splay faults and uncertainty in fault locations and dips.

The table describes the properties of the fault model. For both line fault model and buffer zone model, the same recurrence parameters are utilized. Since both models are applied simultaneously, 50% of the seismic activity of each fault (described by the λ-value) is assigned to either model. Maximum magnitudes are computed from the fault lengths using the Wells and Coppersmith (1994) relations, but never exceeding the regional Mmax. The b-value is fixed to 0.75 for all faults. Slip rates are derived from geodetic data.

Region	Abbreviation	Fault name	Segment no.	Length (km)	Maximum expected magnitude	Slip rates	λ
Indo-Burma range	AYB	Arakan-Yoma belt	1	250	7.9	2.5	0.0740
			2	116	7.7	2.5	0.0640
			3	170	7.9	2.5	0.0740
	DT	Disang thrust	1	250	7.9	2.5	0.0740
			2	190	7.9	2.5	0.0740
	EBT	Eastern Boundary thrust	1	140	7.8	2.5	0.0710
			2	280	7.9	2.5	0.0740
			3	280	7.9	2.5	0.0740
			4	190	7.9	2.5	0.0740
			5	90	7.5	2.5	0.0560
	KF	Kabaw fault	1	215	7.9	2.5	0.0740
			2	180	7.9	2.5	0.0740
			3	235	7.9	2.5	0.0740
			4	230	7.9	2.5	0.0740
	MF	Mizu folds	1	100	7.5	2.5	0.0600
			2	250	7.9	2.5	0.0740
			3	160	7.9	2.5	0.0740
	NT	Naga thrust	1	300	7.9	2.5	0.0740
			2	160	7.9	2.5	0.0740
Tibet	GT	Gangtok lineament	1	140	7.8	2.4	0.0700
	GCT	Great Counter thrust	1	930	7.9	4	0.1330
Assam plains	KF	Kopili fault	1	180	7.9	1.5	0.0440
Assam syntax	LT	Lohit thrust	1	260	7.9	2.5	0.0740
	MT	Mishmi Thrust	1	190	7.9	2.5	0.0740
			2	145	7.9	2.5	0.0740
	PCF	Po Chu fault	1	295	7.9	2.5	0.0740
			2	250	7.9	2.5	0.0740
Himalaya	MBT	Main Boundary thrust	1	160	7.9	2.5	0.0740
			2	230	7.9	2.5	0.0740
			3	370	7.9	2.5	0.0740
			4	280	7.9	2.5	0.0740
	MCT	Main Central thrust	1	150	7.9	2.5	0.0740
			2	417	7.9	2.5	0.0740
			3	160	7.9	2.5	0.0740
			4	140	7.9	2.5	0.0740
			5	90	7.5	2.5	0.0560
			6	135	7.8	2.5	0.0700
West Bangladesh	MSR	Munger Saharsa Ridge	1	320	7.9	2.8	0.1654
			2	270	7.9	2.8	0.1654
Sagaing	SFN	Sagaing fault north	1	260	7.9	4.5	0.1330
	SFS	Sagaing fault south	1	470	7.9	4.5	0.1330
Shillong	MF	Mat fault	1	260	7.9		0.0440
	OTFF	Open Tripura frontal fault	1	450	7.9	1.5	0.0440
	SF	Sylhet fault	1	290	7.9	1.5	0.0440
	GF	Gumti fault	1	150	7.9	1.5	0.0440
	DF	Dauki fault	1	330	7.9	1.5	0.0440
			2	130	7.8	1.5	0.0410
	DhF	Dhubri fault	1	212	7.9	1.5	0.0440
	TF	Tista fault	1	430	7.9	1.5	0.0440

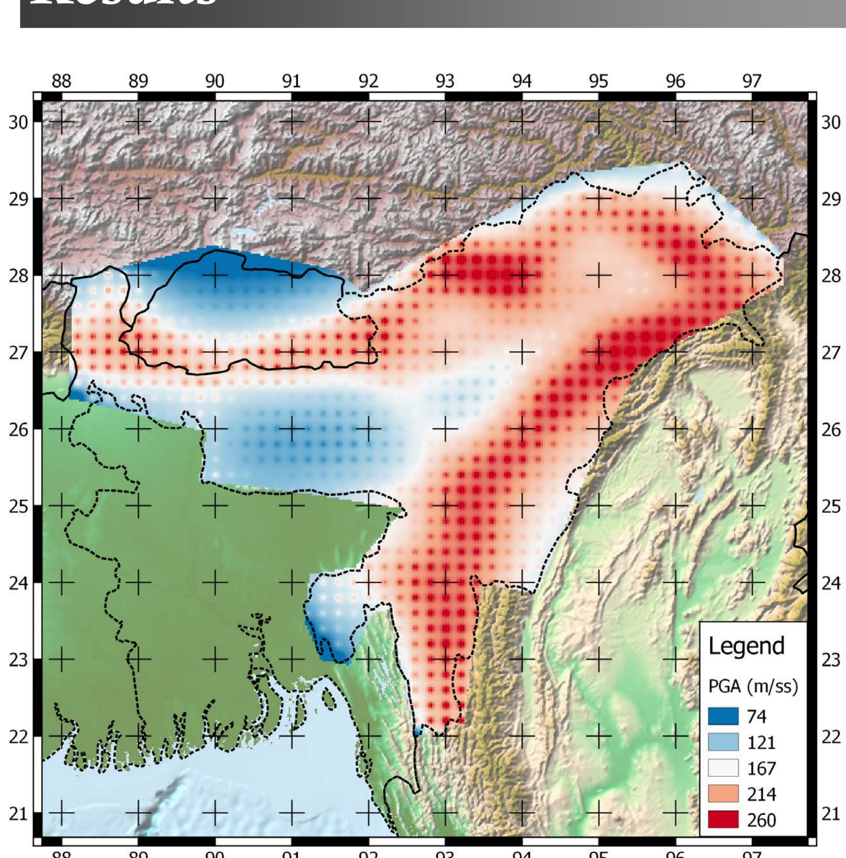


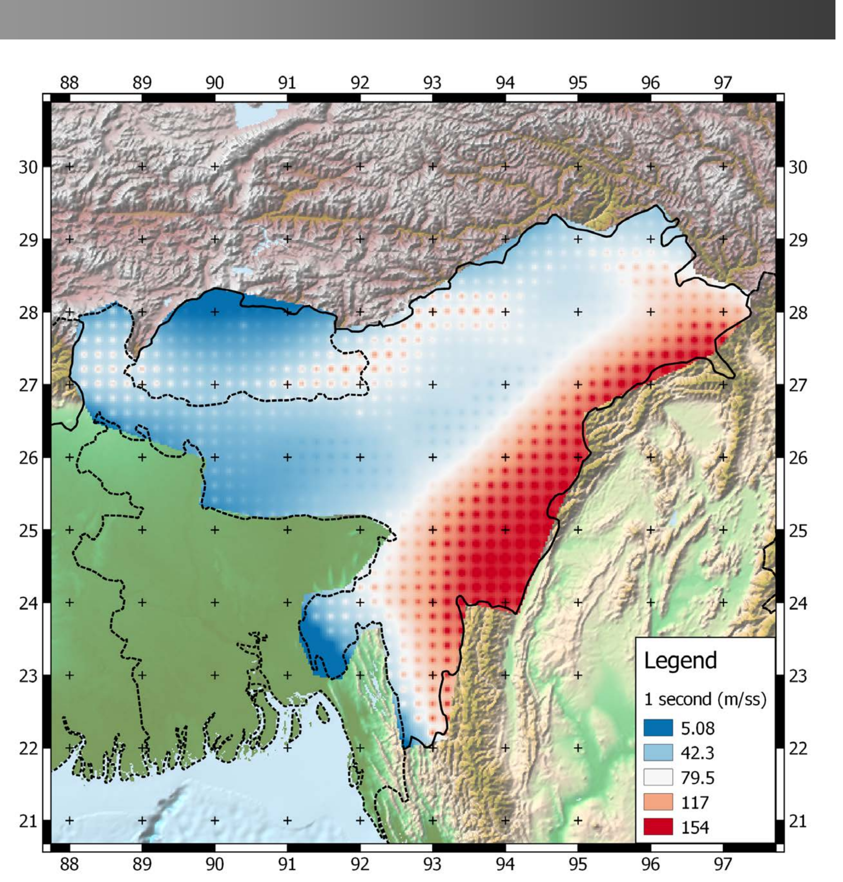


Upper: digitized faults;

Lower: fault model; red lines: thrust faults, blue lines: strike-slip faults, green lines: normal faults; yellow polka-dotted polygons: buffer zones. For explanation of abbreviations see Table 1. Catalogued earthquakes as described in section 3 plotted with white, grey and black circles for hypocentral depths of 0 – 45 km, 45 – 90 km and deeper than 90 km, respectively.

Results





Left: PGA distribution

Right: 1 second distribution

Conclusions

- All results are computed at VS30 corresponding to bedrock outcrop, and the results demonstrate Sa maximas with PGA around 4 m/ss along the subduction zone bordering Myanmar and India.
- The PGA results are significantly lower than the old GSHAP results both along collision and subduction zones as well as in Assam. The obtained results are also lower than indicated in the more recent India Earthquake Zone map (Zone 5) and the CSIR-SERC - IITM – NDMA published results (http://serc.res.in/portfolio-item/probabilistic-seismic-hazard-analysis-of-india).
- The northern Assam and Arunachal states along the Himalaya collision show low historical seismic activity. The high PGA values (around 3.8 m/ss) shown are mainly due to the quantification of active faults (geodesy and geology interpretations).
- The relatively low Sa@1Hz demonstrate the low historical seismicity rates along the eastern Himalayas.
- The four models implemented provide uncertainties and possibilities for differentiated weighting:
  - The recurrence models based on area-zones and point sources are based on regression analyses of historical seismicity.
  - The recurrence models for dipping faults (rectangles and buffer zones) are developed from geological and geodetic observations.
  - The Kernel approach is based on historical earthquake observations, but include also historical earthquakes beyond catalogue completeness.
- The main objective of the presented results is to demonstrate how different types of information can be used and combined to assess earthquake shaking probabilities within a probabilistic and statistically consistent approach.

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