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GLOBAL EARTHQUAKE MODEL

working together to assess risk

PSHA Model for Indian sub-continent:
tailored version of Nath and Thingbaijam (2012)

GEM Hazard Team

GEM-UNDRR Technical Panel Meeting

October 31, 2023

OPENQUAKE

Outline

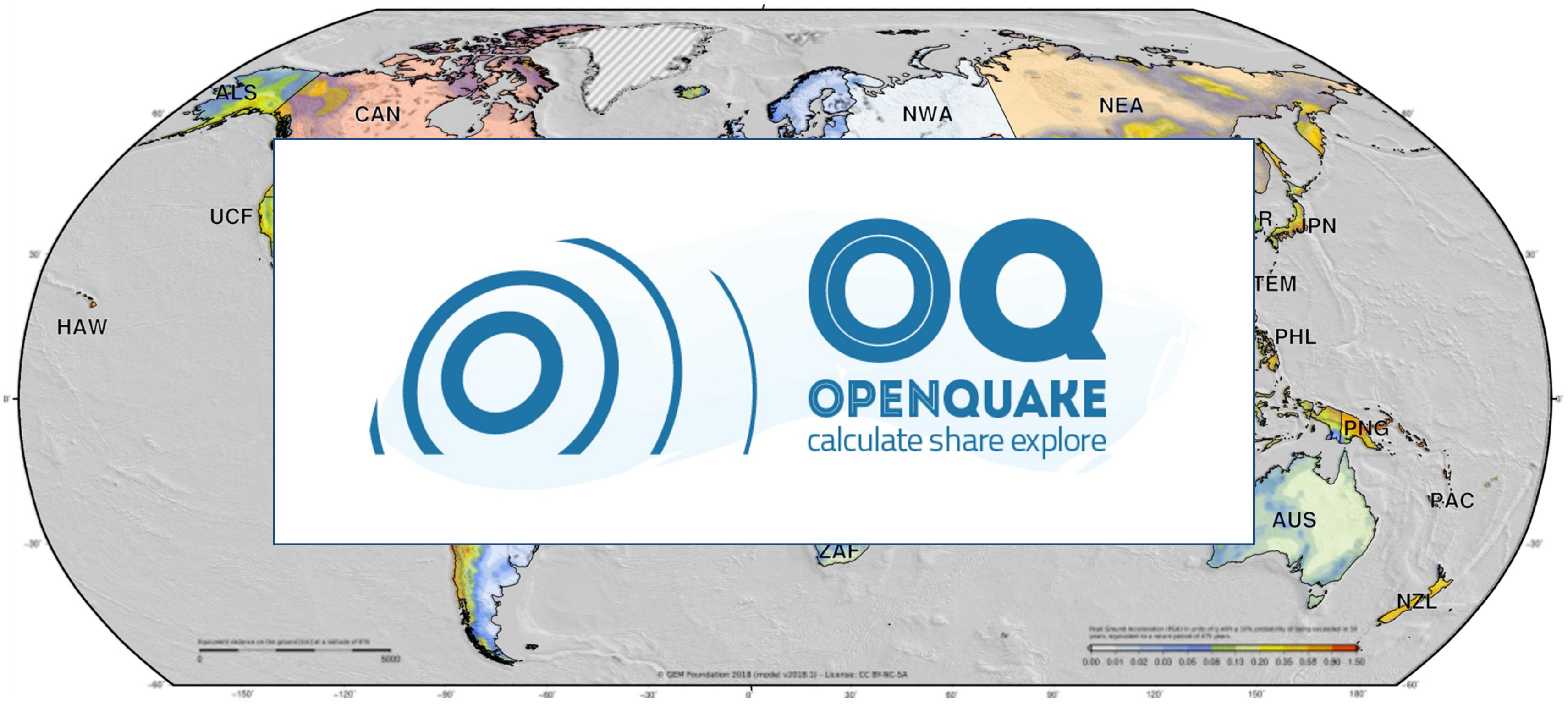
- Presentation of original model by Nath and Thingbaijam (2012)
- Main areas identified for improvement
- Changes introduced
  - Seismic source characterisation
  - Ground motion characterisation
- Impact on hazard results

PSHA model by Nath and Thingbaijam (2012)

- Developed by researchers at Indian Institute of Technology
- Covers India, Bangladesh, Bhutan and Nepal
- Seismic source characterization: three seismic source models
  1. Area sources
  2. Gridded seismicity with smoothed rates, calibrated with M_{min}=4.5
  3. Gridded seismicity with smoothed rates, calibrated with M_{min}=5.5
- Ground motion characterization
  - Multi-model approach to capture epistemic uncertainty
  - Several of the adopted models are meant to be used in India
- Used since 2018 in GEM's Global Hazard Mosaic; translated into the OQ engine format by Nick Ackerley, see https://github.com/nackerley/indian-subcontinent-psha

GEM's Global Seismic Hazard Mosaic and Map

From Pagani et al. (2020)



https://hazard.openquake.org/gem

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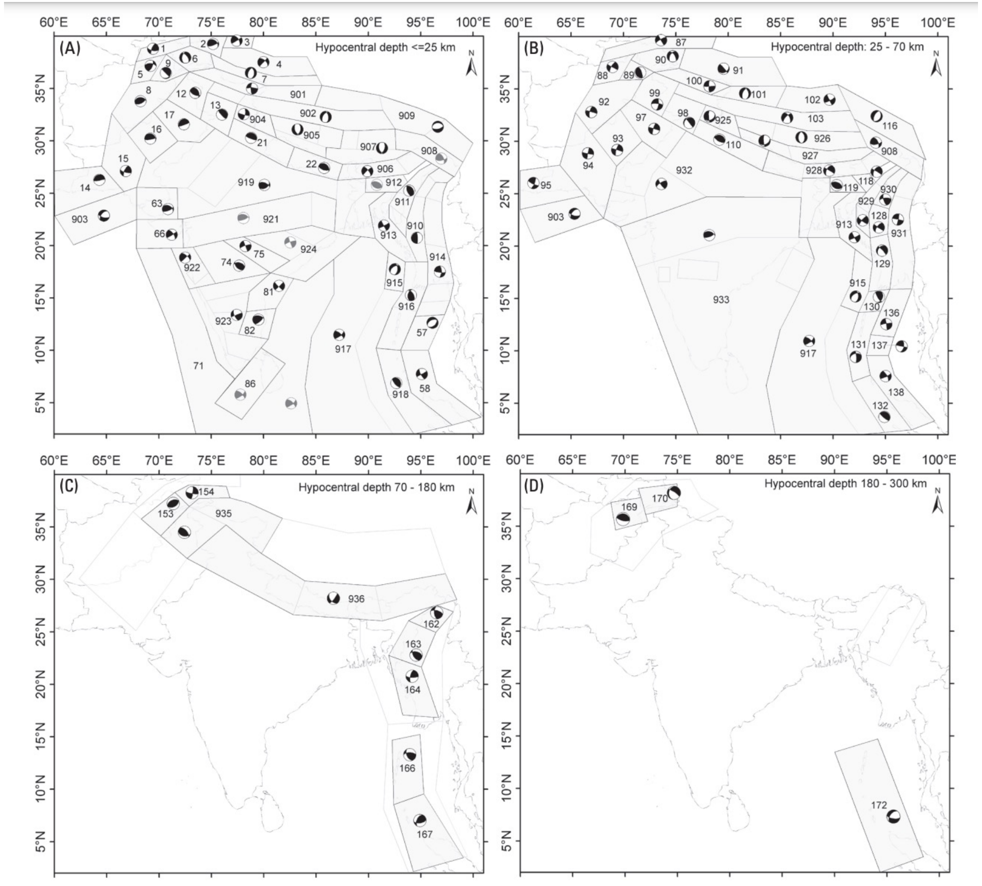
Seismic source characterization



- Based on Thingbaijam and Nath (2011)
- Four depth layers, each with a dominant focal mechanism
- Sources use MLE GR MFDs with M_{max} from catalogue, historical records to A.D. 819, and paleoseismicity

Nath and Thingbaijam (2012), Figure 2

Ground Motion Characterization

Nath and Thingbaijam (2012), Table 2

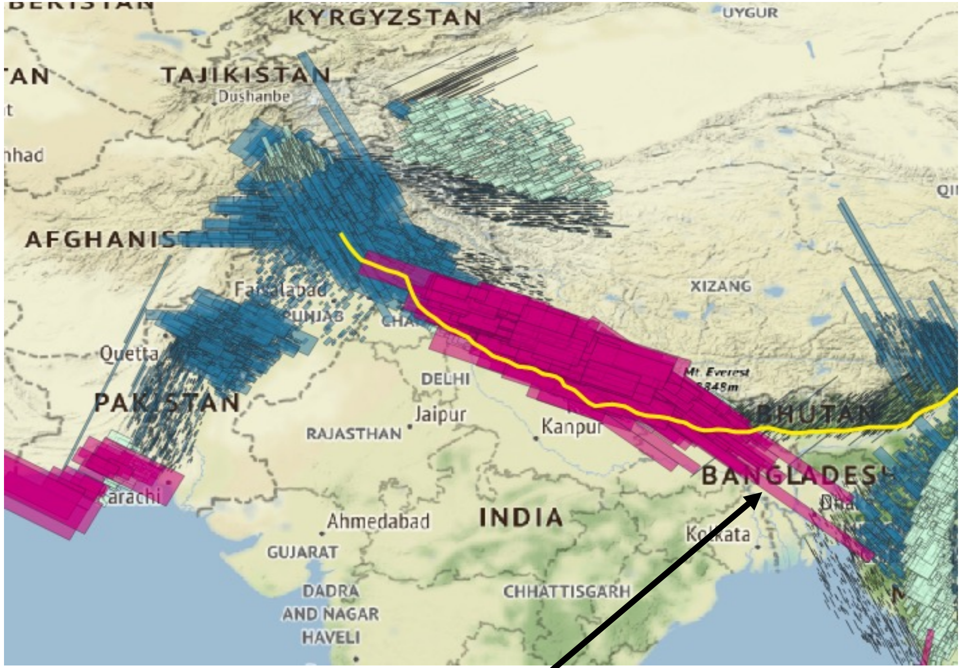
Tectonic Province	Reference and Code in Brackets
Tectonically active shallow crust	Akkar and Bommer 2010 (AKBO10), Boore and Atkinson 2008 (BOAT08), Campbell and Bozorgnia 2008 (CABO08), Sharma *et al.* 2009 (SHAR09)
Active shallow crust/ Subduction	Kanno *et al.* 2006 (KAN06), Zhao *et al.* 2006 (ZHAO06)
Subduction	Atkinson and Boore 2003 (ATBO03), Atkinson and Macias 2009 (ATMA09), Gupta 2010 (GUPT10) Lin and Lee 2008 (LILE08), Youngs *et al.* 1997 (YOU97)
Stable continental region	Toro 2002 (TOR02), Campbell 2003 (CAM03), Atkinson and Boore 2006 (ATBO06), Raghukanth and Iyengar 2007 (RAIY07)
Intraplate margin	Toro 2002 (TOR02), Atkinson and Boore 2006 (ATBO06), Sharma *et al.* 2009 (SHAR09), Nath *et al.* 2011 (NATH11)

- Subduction: ATMA09 only used for M>=7.5
- Active shallow crust: SHAR09 only used for source zones with normal faulting mechanisms
- Sharma et al. (2009), Gupta (2010), and Nath et al. (2011) developed for India

Main areas identified for improvement

Seismic source characterization

- focused on the rupture geometries generated by the model
- several sources produce ruptures M>9; the distributed seismicity sources produce unrealistic geometries
- Reviewed nodal plane orientations in northeast part of the model



M_W ~ 9 ruptures generated by sources representing the Main Himalayan Thrust

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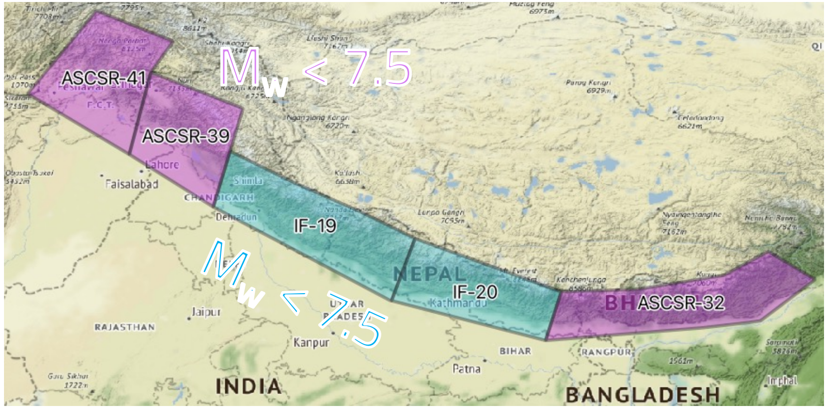
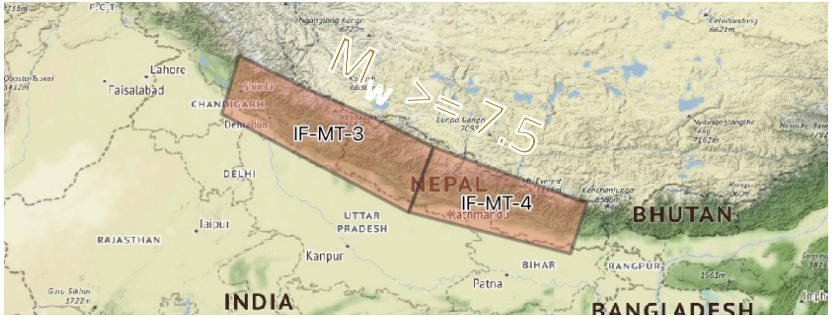
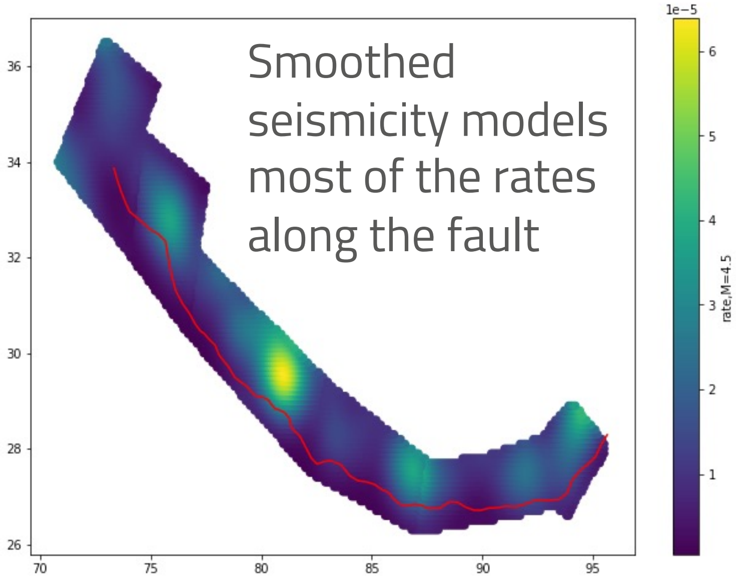
Main Himalayan Thrust





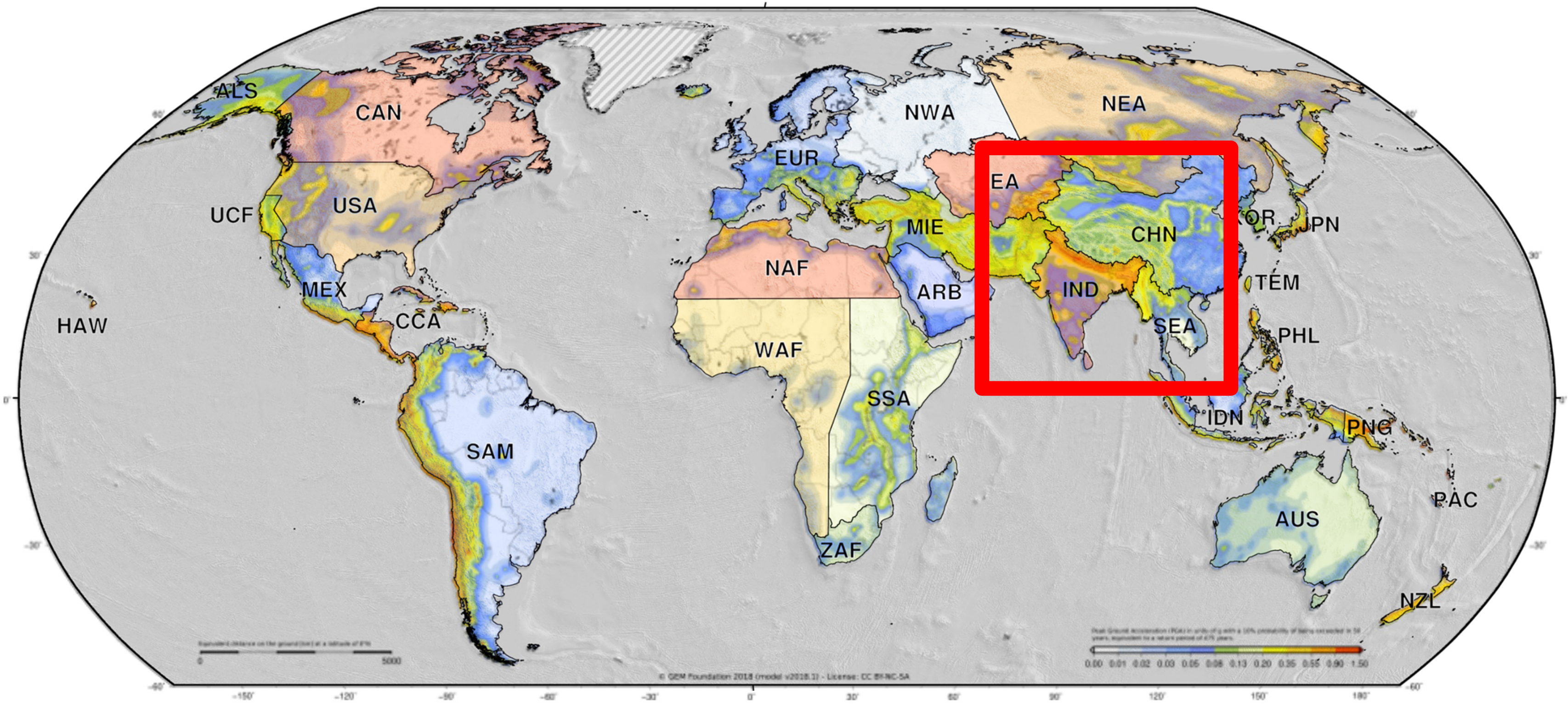


Smoothed seismicity models most of the rates along the fault

We propose moving the largest ruptures onto a fault source that produces reasonable geometries

GEM's Global Seismic Hazard Mosaic and Map

From Pagani et al. (2020)



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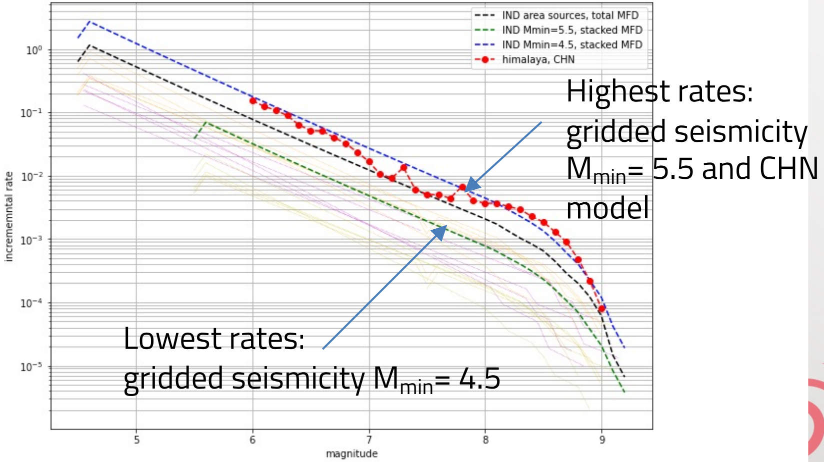
Main Himalayan Thrust

- GEM's model for China also covers the MHT using a simple fault source constrained by slip rates
- We the simple fault source from the China model to replace all ruptures with $M_w > 7.5$
- Fault source dips 15 degrees to 25 km depth

We used two equally weighted occurrence rates for each source model in the logic tree:

- The rates originally assigned in the China model
- The rates for $M_w > 7.5$ from the respective source model



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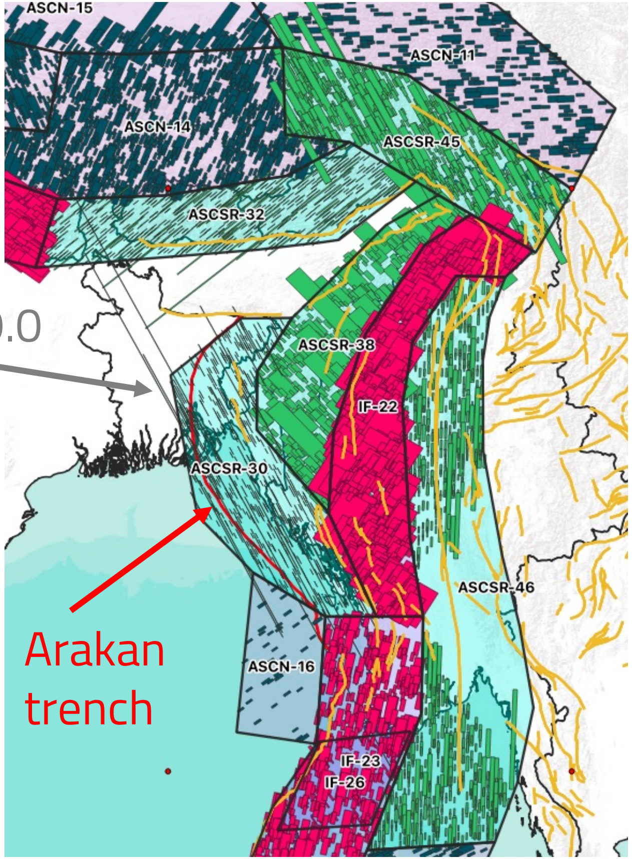
Northeast India/Eastern Bangladesh

The onshore-extent of the Arakan trench is covered by an Active Shallow Crustal source that produces ruptures bisecting Bangladesh

$M_W > 9.0$

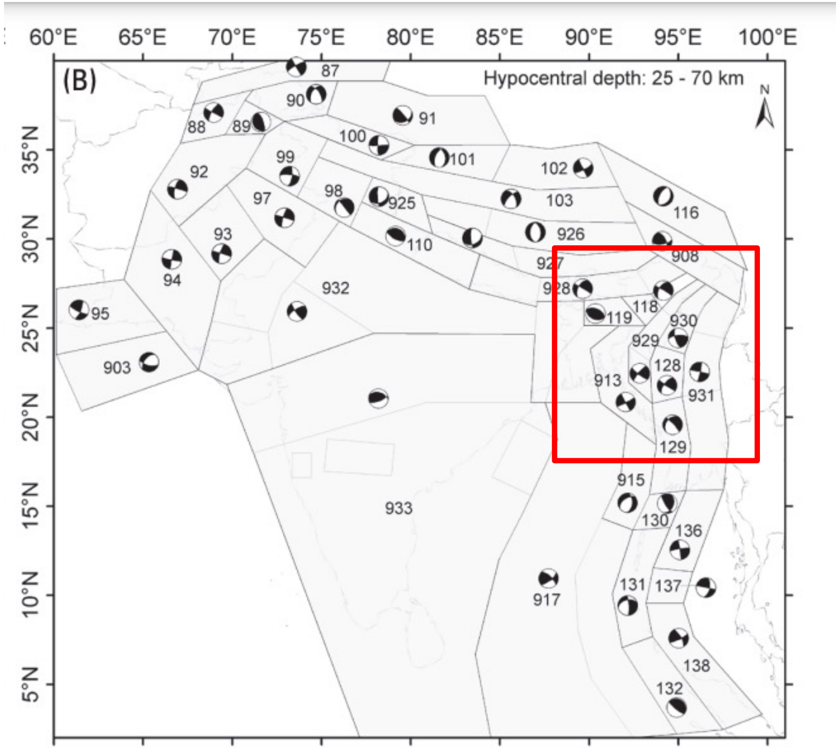


We moved the highest magnitudes onto a simple fault source taking the geometry from GEM's model for Southeast Asia

Focal mechanism adjustments

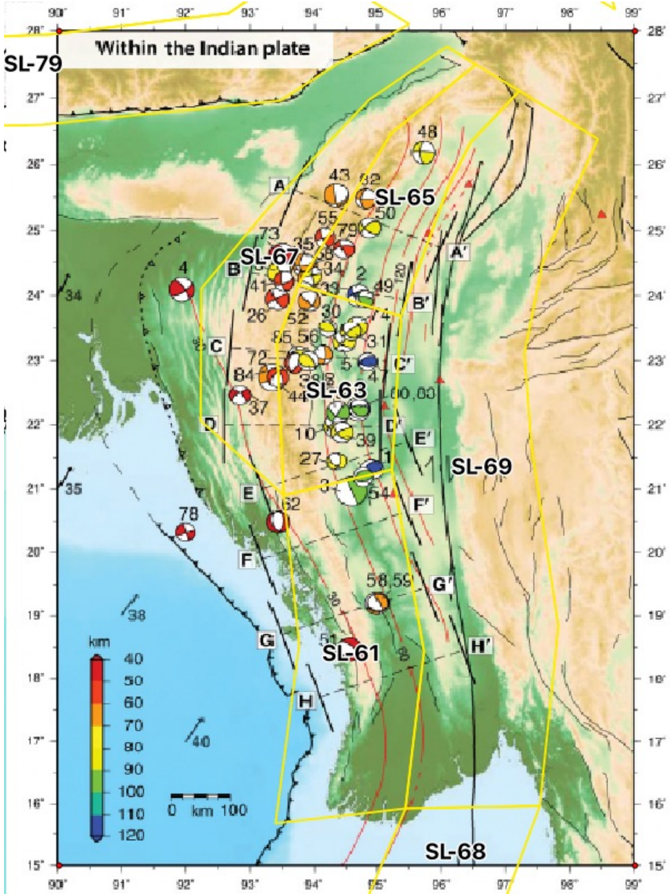
- Some source zones in the NE part of the model produce ruptures with surprising mechanisms relative to their expected ones, i.e. strike-slip earthquakes in the slab perpendicular to the trench axis

- We reviewed against a recent compilation of focal mechanisms and tectonic interpretation by Fadil et al (2023)



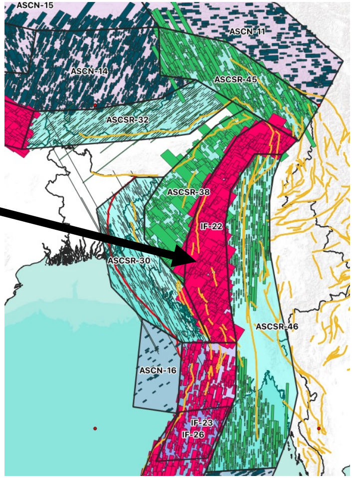
Focal mechanism adjustments

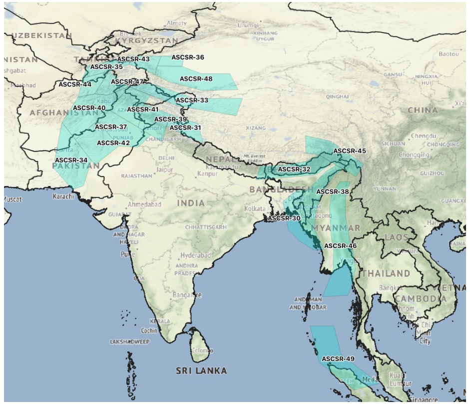
- Nath & Thingbaijam note that intraslab sources at 25–70 km may include crustal earthquakes; they characterized as such for consistency with events used to constrain some intraslab GMPEs
- Fadil et al. (2023) explains many of the surprising orientations; in some cases we add a second FM where we see ambiguity, e.g. we add a NS-oriented thrust mechanism along the IMB range front, SL-63 and SL-65

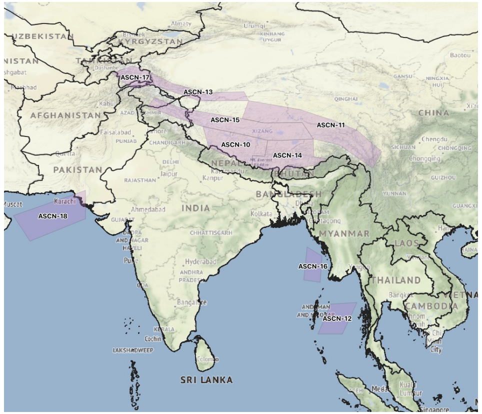


Changes to tectonic region type

- Moved all sources along the MHT into an independent TRT
- Reassigned IF-22 to ASC – this was formerly subduction since it predominantly includes thrust faults
- Merged the ASC-normal and ASC-reverse/strike-slip TRTs into a single one - the former approach artificially decorrelated epistemic uncertainties



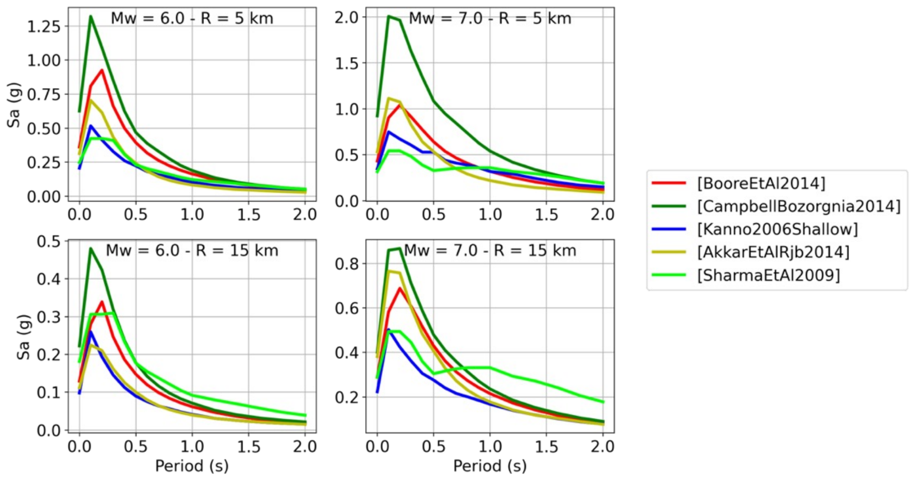




Ground motion characterization

- Where possible, we compared GMPEs to data, but this was insufficient for making a selection
- Used the criteria of Stewart et al. (2013), which suggested GMPEs for global seismic hazard maps, to evaluate the GMPEs selected by Nath and Thingbaijam (2012)

- Example: evaluated spectral shapes, and handling of magnitude and attenuation



Active shallow crust

- Kanno et al. (2006) lacks magnitude saturation which can cause unreasonable estimates for large earthquakes included in the SSC – we removed this model

GMPE	TRT
BooreEtAl2014	active shallow crust normal
CampbellBozorgnia2014	
Kanno2006Shallow	
AkkarEtAlRjb2014	
Kanno2006Shallow	active shallow crust strike-slip reverse
BooreEtAl2014	
CampbellBozorgnia2014	
SharmaEtAl2009	
AkkarEtAlRjb2014	

- Removed Sharma et al. (2009) because of linear scaling of M_w; unrealistic ground motions and spectral shapes outside the range of magnitudes used to constrain it (M_w 5.5 – 6.8)

Active shallow crust

- Without Sharma et al. (2009), we were able to combine the two TRTs for active shallow crust into a single one

- Since we lack strong motion data for selecting GMPEs, we chose to use the ones from GEM's China model in an effort toward consistency

TRT	GMPE
Active shallow crust	Abrahamson et al 2014
	Chiou and Youngs (2014)
	Cauzzi et al (2015)

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Intraplate margin

- Toro et al (2002) spectral acceleration at 3 and 4 s were added in the SHARE project using scaling factors; no site term -> replaced with Yenier and Atkinson (2015)
- Remove Sharma, as above

AtkinsonBoore2006	intraplate margin lower
ToroEtAl2002SHARE	
SharmaEtAl2009	
NathEtAl2012Lower	
AtkinsonBoore2006	intraplate margin upper
ToroEtAl2002SHARE	
NathEtAl2012Upper	
SharmaEtAl2009	

↓

intraplate margin lower	AtkinsonBoore2006
	YenierAtkinson2015
	NathEtAl2012Lower
intraplate margin upper	AtkinsonBoore2006
	YenierAtkinson2015
	NathEtAl2012Upper

Stable shallow crust

- Removed Raghu Kanth and Iyengar (2007) based on (Stewart et al., 2013) :

"nonlinear effects are very strong and the amplifications are not smooth but show large period-to-period variations, which we consider unrealistic. The standard deviations … are much lower than those from the other models because only the parametric component of the variability was included…"

- Replaced Toro (2002) with Yenier and Atkinson (2015) as above

AtkinsonBoore2006	stable shallow crust
ToroEtAl2002SHARE	
RaghukanthIyengar2007	

→

AtkinsonBoore2006
YenierAtkinson2015

Subduction intrslab

- Gupta (2010) constrained by only one earthquake of M_w 7., one of M_w 6.3 and one of M_w 6.4, all for R> 150 km; we discarded this GMPE
- No tectonic explanation for the GMPEs using region-specific terms; instead we proposed two recent global models

AtkinsonBoore2003SSlabJapan	subduction intraslab Himalayas
AbrahamsonEtAl2015SSlab	
ZhaoEtAl2006SSlab	
LinLee2008SSlab	
AtkinsonBoore2003SSlabCascadia	subduction intraslab
AbrahamsonEtAl2015SSlab	
ZhaoEtAl2006SSlab	
Gupta2010SSlab	

↓

Subduction Inslab	Abrahamson et al 2015 - Inslab
	Parker et al (2020) - Inslab

Subduction interface

- No GMPE is developed for a tectonic setting such as the MHT; it is neither active shallow crust nor a subduction zone
- We chose not to mix GMPEs from different TRTs because while this may lead to an improved mean hazard calculation, no single realization is realistic
- For the MHT, we use the same GMPEs as in GEM's China model in a move toward consistency; these are the same as for the Active Shallow Crust

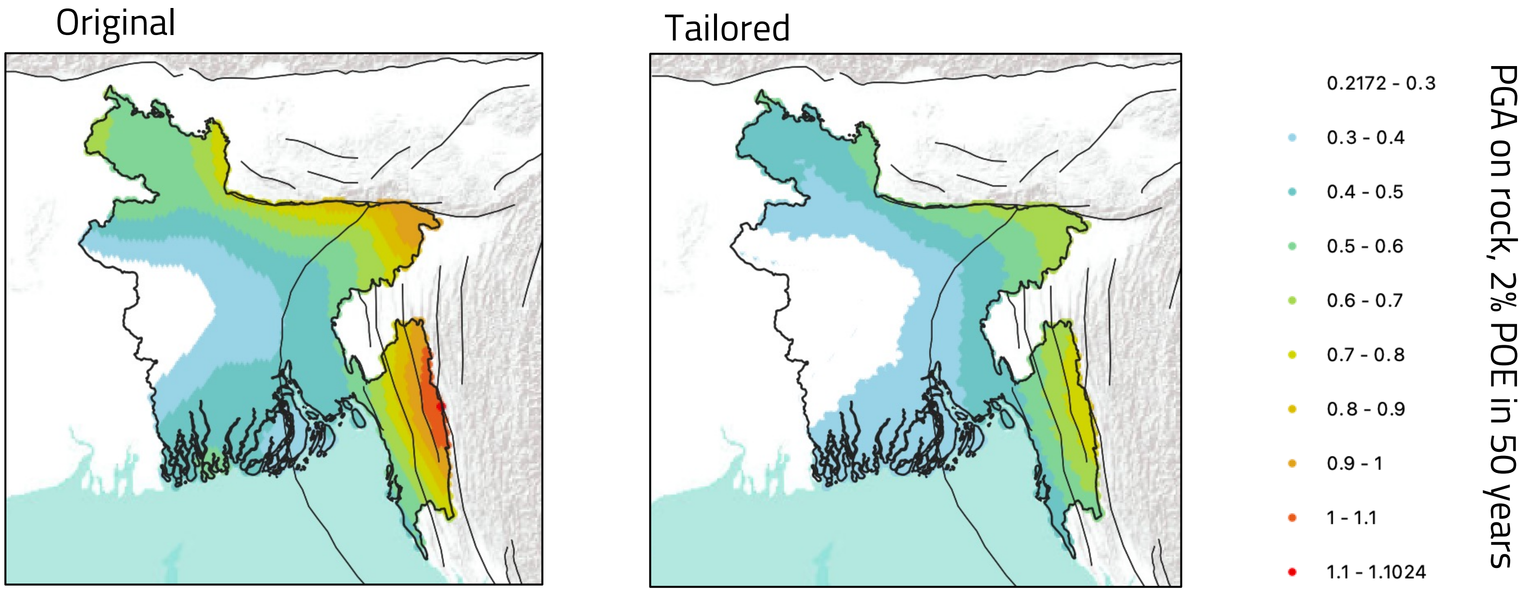
Active shallow crust	Abrahamson et al 2014
	Chiou and Youngs (2014)
	Cauzzi et al (2015)

- For other subduction interface sources, we used the interface versions of the GMPEs selected for the intraslab

Subduction Interface	Abrahamson et al 2015 - Interface
	Parker et al (2020) - Interface

Impact on hazard

- Hazard decreases relative to the original model
- the impact of relevant tectonic structures is evident in the hazard pattern



Conclusions

- Tailored model includes rupture geometries that better represent what known tectonic structures could produce, especially for the largest events

- GMPEs have been reviewed to exclude ones constrained with little data, that have limitations in their main parameters that are violated by the source model (i.e., magnitude saturation), or that are not sufficiently flexible for use in all the intended PSHA applications of this model

- The hazard is lower in the tailored model than the original one

Thank you!

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https://www.globalquakemodel.org