GLOBAL EARTHQUAKE MODEL
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PSHA input model documentation for Northeastern Asia (NEA)

GEM Hazard Team

Version history

Table 1 summarises version history for the NEA input model, named according to the versioning system described here, and indicating which version was used in each of the global maps produced since 2018. Refer to the GEM Products Page for information on which model versions are available for various use cases. The changelog describes the changes between consecutive versions and are additive for all versions with the same model year.

***Table 1** – Version history for the NEA input model.*

Version	2018.1	2019.1	2022.1	2023.1	Changelog
v2018.0.0	X	X			First version of the model.
v2018.1.0			X		A portion of source zone 11 was reassigned from "Cratonic Crust" to "Stable Continental Crust" following Chen et al. (2018). With this change, there is no longer a strong discontinuity in the hazard where the cratonic and active shallow crustal regions meet.
v2018.1.1				X	Mmin extended to M4 for crustal distributed seismicity. Source ids were revised to work with disaggregation by source. Inslab source files were consolidated into a single one.

The following text describes v2018.1.1.

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1 Summary

The Northeast Asia (NEA) model was developed internally by GEM. The active shallow part of the model is based on the combination of distributed sources and active faults, the latter obtained from the Global Active Fault Database of GEM. As for the case of Northern Africa, we have applied rate redistribution to better represent the spatial variability of seismicity. The deeper portion of the Kamchatka subduction zone was modelled as a combination of complex faults (the subduction interface) and finite ruptures (the slab zone) using the Subduction Toolkit developed by GEM. Border harmonisation of the present model with neighbouring hazard models, particularly with China and EMCA, posed a challenge in developing this model.

2 Tectonic overview

Northeastern Asia contains a broad zone of plate deformation that extends northeast from the Indo-Asian collision zone (Tibet, the Pamir, and the Tian Shan mountain belts) through Mongolia, northern China, and eastern Russia, to the Arctic Ocean and Okhotsk Sea between Japan and Kamchatka. The styles and kinematics of deformation are quite variable and may be influenced by mantle processes; western Mongolia is primarily deformed through reverse and sinistral faults in the Altai region, while the eastern Mongolia-Russia borderlands contain major rift zones, most notably the Baikal Rift. Deformation to the east of Baikal is split between several belts that bound the Eurasian, Amurian, Okhotsk, Bering, and North American plates; most of these are transpressive. Relative plate velocities are much lower in this region than between many adjacent plates, leading to subdued fault slip rates. Nonetheless, earthquakes may be extremely large in this region, such as the sequence of M_w 7.8-8.3 earthquakes that occurred in the Mongolia-China border region in the early 20th century; these are perhaps the largest continental intraplate earthquakes in recorded history. More rapid faulting is related to the subduction of the Pacific plate underneath the eastern margin of the collective Asian and North American plate groups in the western Aleutians, Kamchatka, and Sakhalin.

3 Basic Datasets

3.1 Earthquake Catalogue

For the purpose of having a unique catalogue valid for the whole Northeast Asia, GEM has created a new Mw-homogenised earthquake catalogue by assembling globally available sources (ISC review bulleting, GCMT, ISG-GEM, GHEC catalogues). The GEM implementation of the Northeast Asia Earthquake Catalogue, presently consists of 43187 events with

$4 \geq M_w \geq 9.1$, covering a period from 1038 to 2015 (Figure 1). The events of the catalogue have been subsequently categorized as shallow crustal, interface or slab events, and the corresponding sub-catalogues created.

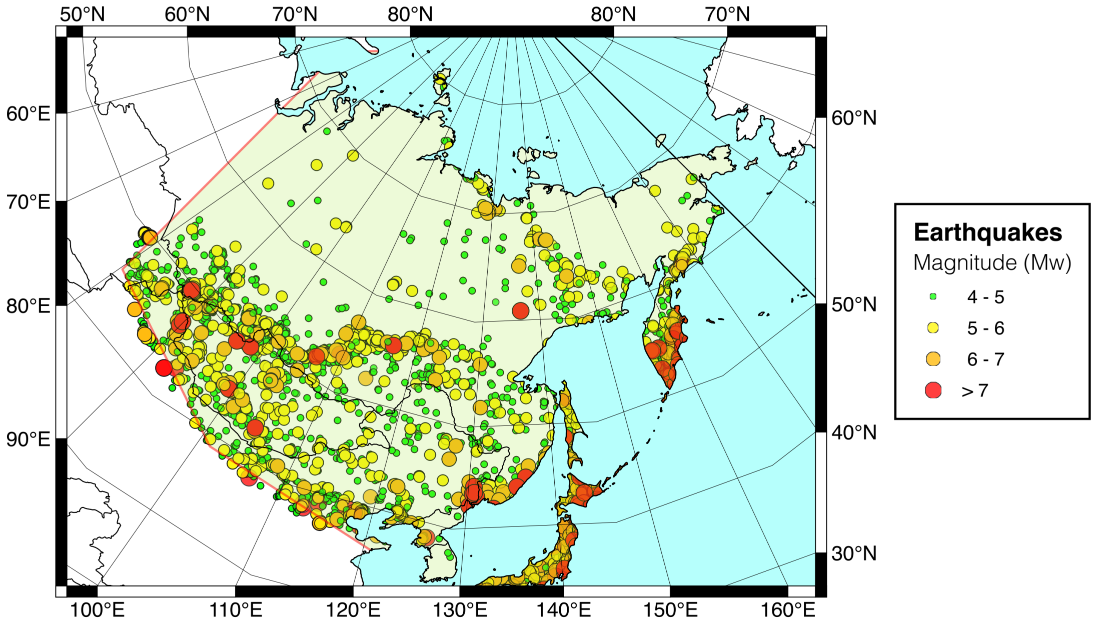

Figure 1 – *The Mw-homogenized earthquake catalogue prepared by GEM for Northeast Asia.*

3.2 Fault Database

In order to provide sources for fault-based PSHA, a new dataset of shallow active faults in Northeast Asia was created, containing ~291 active fault traces (Figure 2). Faults were mapped on topographic data (typically 30m SRTM) based on mapping in the literature as well as interpretation of topographic, seismic and geodetic data. The faults are publicly available at https://github.com/GEMScienceTools/n_africa_active_faults in a variety of GIS formats. Fault sources for hazard modeling were made from this data, with a few small or geometrically uncertain faults removed, and slip rates estimated for all structures even if no published rates were available. Slip rate estimates were made through expert judgment of the geodetic and seismic data, as well as consideration of geomorphic expression and similar, better studied faults in the region.

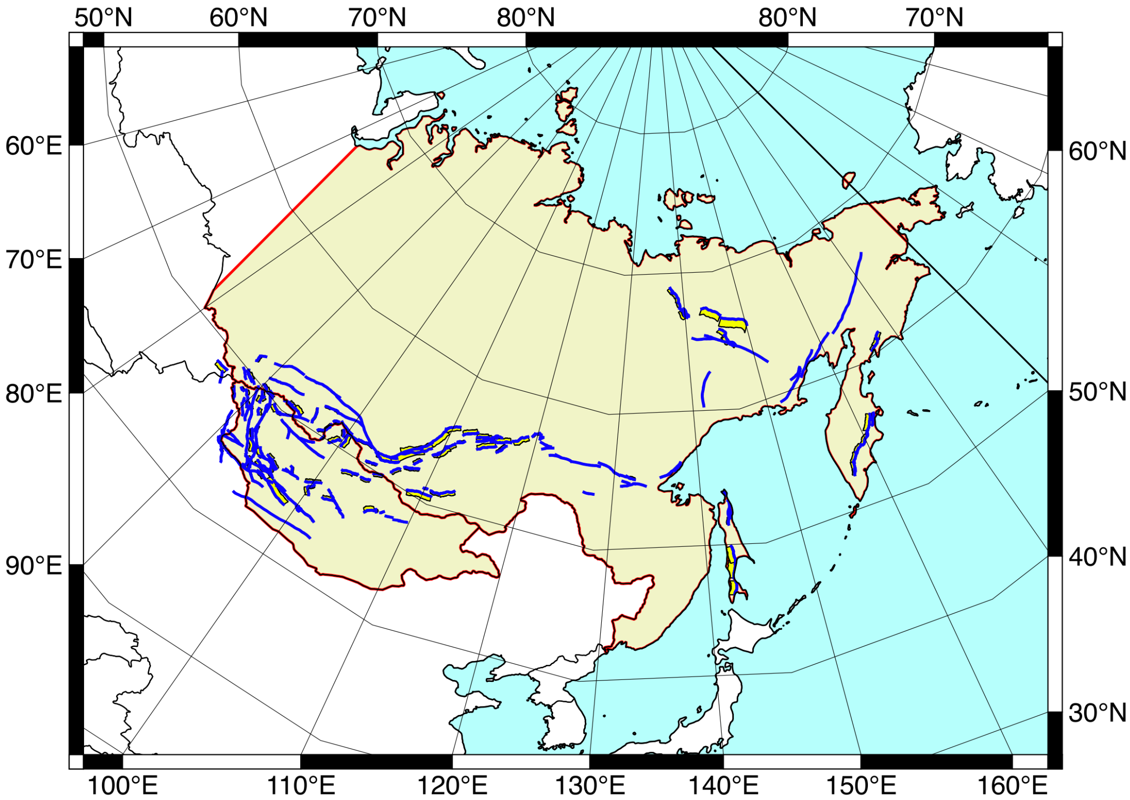

Figure 2 *– The GEM active fault database for Northeast Asia (fault traces in blue.*

4 Hazard Model

4.1 Seismic Source Characterisation

Area Source Zonation The Northeast Asia earthquake source model consists of a combination of distributed seismicity and finite faults. The shallow crust part of the source model consists of 23 independent source zones (Figure 3). The main constrain for the development of the source model came from the analysis of the earthquake catalogue (stationarity of the completeness periods, evaluation of the mean activity rate, distribution of seismogenic depths) and from a set of geological and seismotectonics considerations, such as style, geometry and distribution of existing faulting systems and their relation to the local stress and deformation regimes. Local and regional source models from previous hazard studies have also been taken into great consideration as starting point for the proposed zonation and to assure compatibility across the borders, particularly with the China model.

Seismicity analysis Seismicity in each area source is assumed to follow a double truncated Gutenberg-Richter magnitude occurrence relation (or magnitude-frequency distribution, MFD). Lower truncation is arbitrarily assigned to Mw 4.5. Gutenberg-Richter b-values

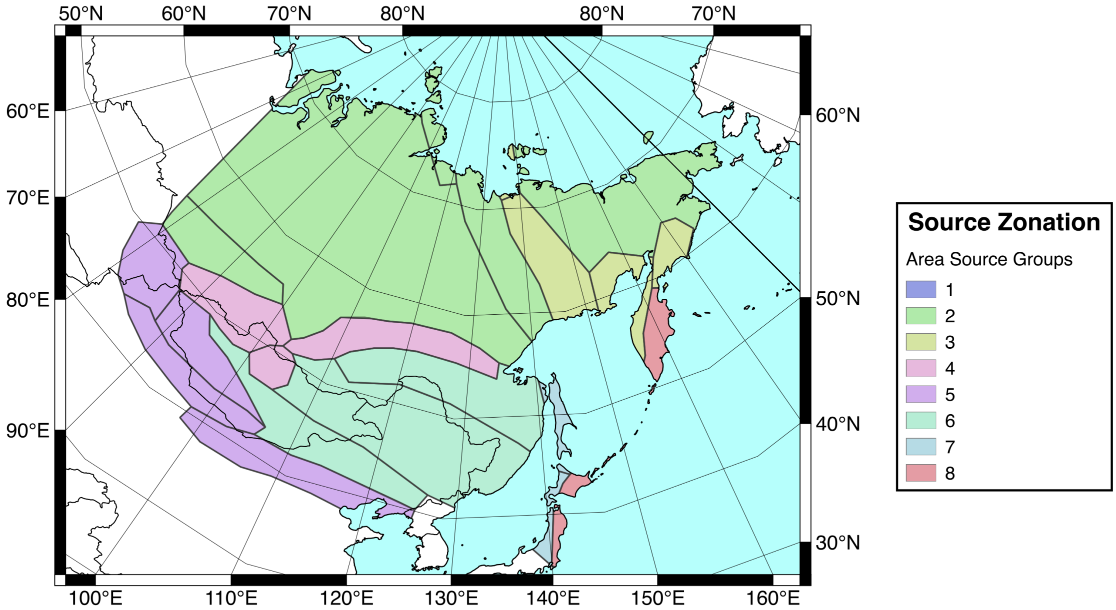

Figure 3 – *The proposed source zonation for Northeast Asia. Different colors are used to represent the 8 main seismicity groups of the region.*

have been calibrated for the whole catalogue and independently for each source group. Conversely, occurrence rates (a-values) have been calculated separately for each source zone by imposing the previously calibrated b-values. A different maximum magnitude (Mw-Max) estimate is derived independently for each source group as the largest observed event plus an arbitrary - although quite conservative - increment of 0.5 magnitude units.

Smoothed Seismicity To better represent the spatial variability of seismicity across the study area, the annual occurrence rates previously obtained for the homogenous source zones have been redistributed within each polygon using a procedure that accounts for the irregular spatial pattern of the observed events (Figure 4). The procedure shares some similarity with the popular smoothed seismicity approach (e.g. Frankel, 1995), but is more convenient in that a unique fit of the magnitude-frequency distribution is here required for each zone, while the corresponding total earthquake occurrence is only a-posteriori spatially reorganised as a function of the epicentral distance to all neighbouring events. Moreover, the combined use of zones gives the possibility to account for different modelling parameters (b-value, depth distribution, rupture mechanism) in separate regions.

Subduction The interface and intraslab geometries are built using the GEM Subduction Toolkit, by creating vertical sections perpendicular to the subduction trench (Figure 5) where the distribution of earthquake hypocenters can be represented and analyzed (Figure 6). Surfaces are cut at 50 km depth to separate the shallower interface from the deeper slab top. For both interface and intraslab component, occurrence rates have been

Source Id	Group	a-value	b-value	Mmax
1	3	5.6	1.07	8.05
2	3	5.44	1.07	8.8
3	3	4.78	1.07	7.5
4	4	5.05	1.03	8.6
5	4	4.92	1.03	7.13
6	1	4.03	0.93	6
7	4	4.79	1.03	8
8	5	4.88	1.09	6.76
9	5	5.12	1.09	6.82
10	5	4.95	1.09	7.36
11	1	3.78	0.93	6.56
12	4	5.11	1.03	8.09
13	1	3.4	0.93	6.32
14	1	3.99	0.93	7.57
15	6	4.08	0.84	7.56
16	6	4.14	0.84	8.24
17	2	4.5	1.03	7.36
18	2	4.72	1.03	7.49
19	1	4	0.93	8.45
20	2	4.74	1.03	7.31
21	2	4.59	1.03	8.12
22	7	4.65	0.8	9
23	7	3.99	0.8	8.05
10	5	4.95	1.09	7.36
11	1	3.78	0.93	6.56
12	4	5.11	1.03	8.09
13	1	3.4	0.93	6.32
Slab	5.43	0.87	8.4	

Table 2

determined from the declustered subcatalogues classified for the respective tectonic settings. The subduction has not been segmented, although a hard limit in the maximum extension of the rupture is imposed by the maximum magnitude and the adopted scaling relation.

Component	a-value	b-value	M_{max}
Interface	4.81	0.71	9.3
Slab	5.43	0.87	8.4

Table 3

4.2 Ground Motion Characterisation

To represent differences in the attenuation behavior across the region, we rely on the global tectonic zonation proposed by Chen et al. (2017). Using this approach, fours tectonic region types have been identified (Figure 7). Subduction was further classified as interface and Intraslab, according to the performed seismicity analysis. For each tectonic region, a combination of ground motion prediction equations has been selected and used in a logic-tree approach (see table)

Subduction Interface	Weight
AbrahamsonEtAl2015SInter	0.334
ZhaoEtAl2016SInter	0.333

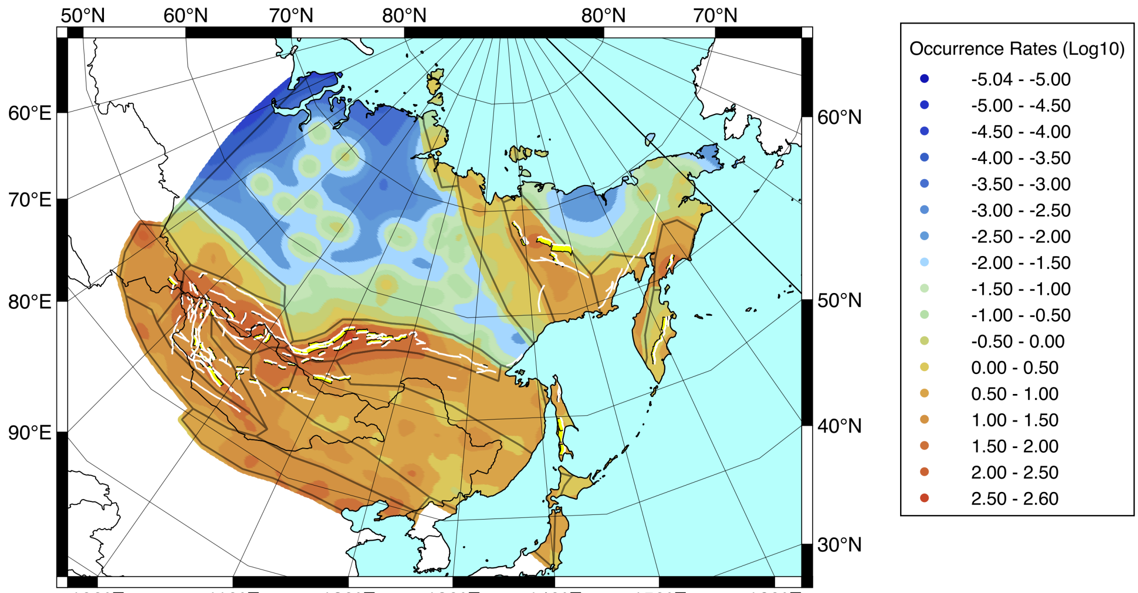

Figure 4 *– Example of spatial redistribution of the cumulative annual rates (M>0) using a decay parameter (λ) of 100. Only shallow crust seismicity is here considered. Rates are intended by unit area of 0.1° (about 11 km^2)*

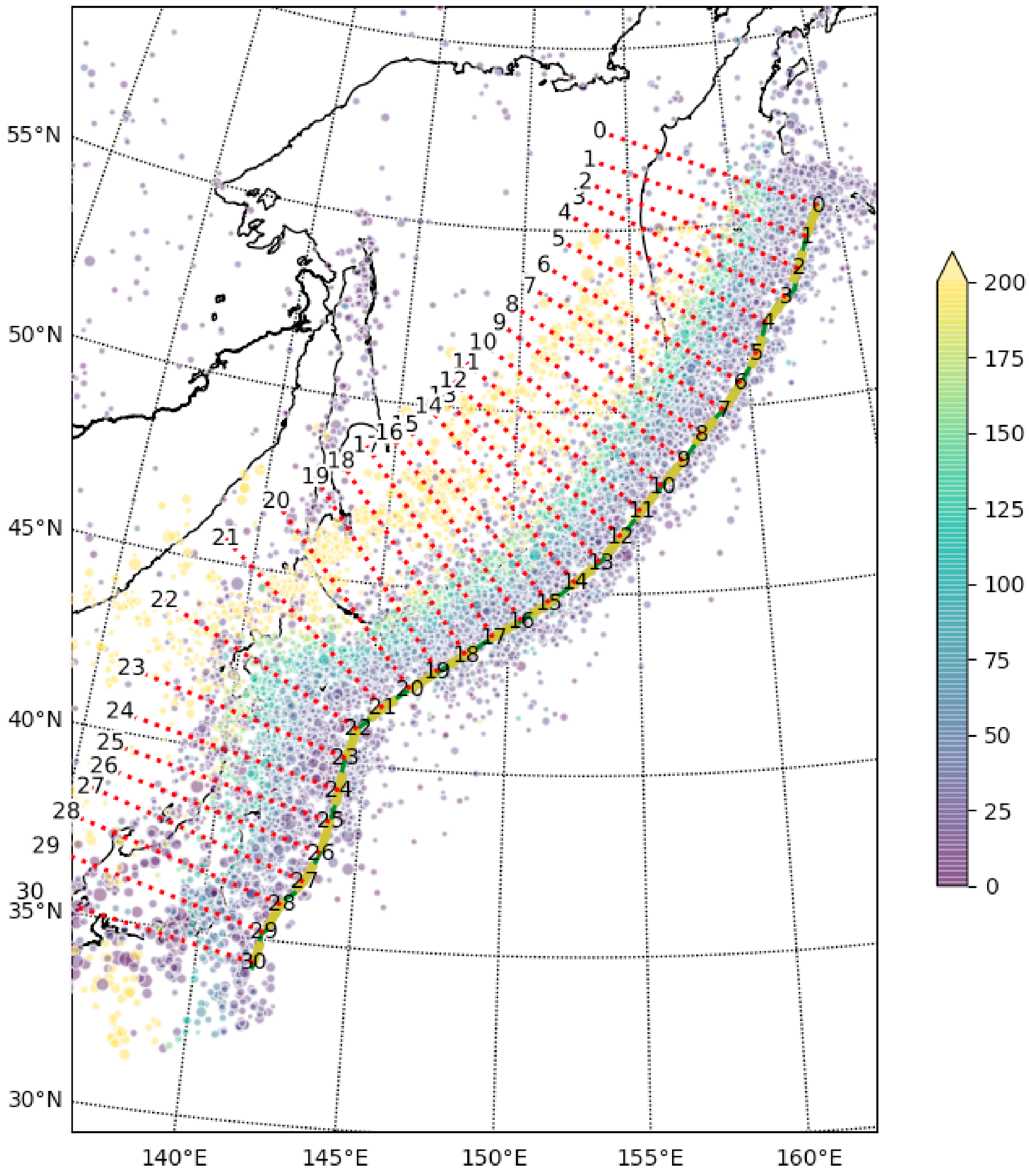

Figure 5 *– Location of the 30 sections used to build the subduction geometry (interface and intraslab) using the GEM Subduction Toolkit.*

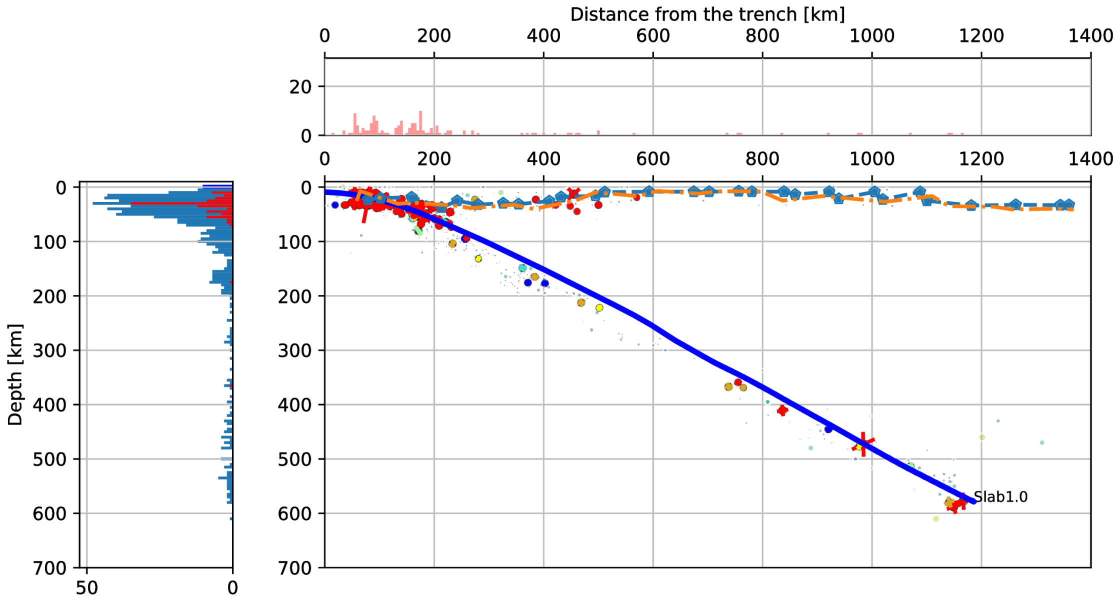

Figure 6 *– Example of vertical section (n. 23) showing the hypocentral distribution of events occurring along the subduction slab and interface.*

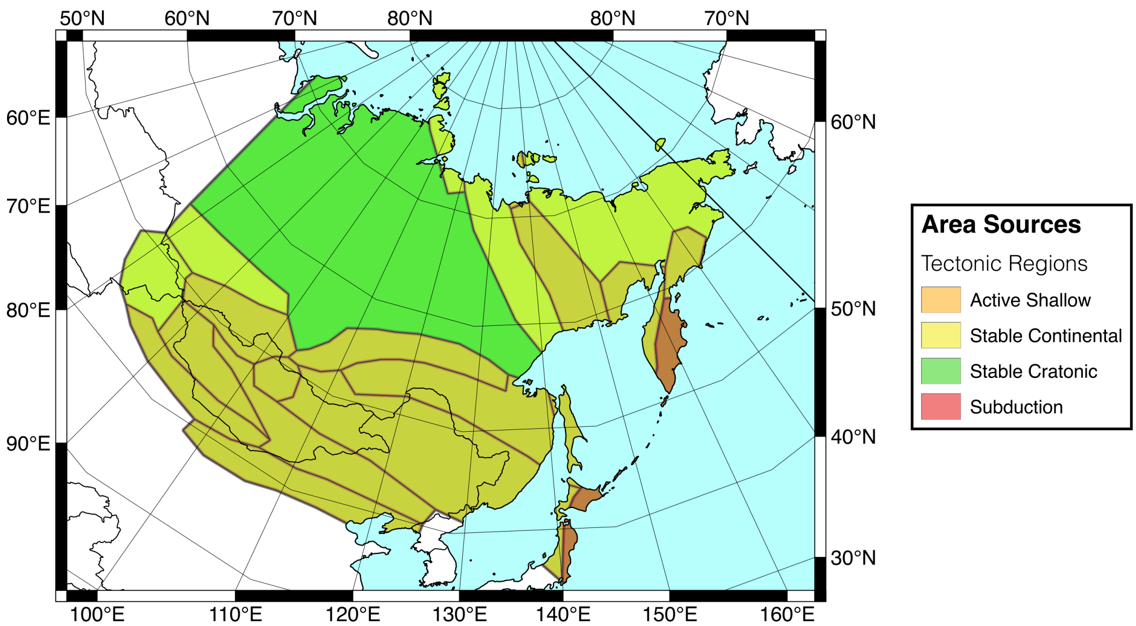

Figure 7 *– Tectonic region classification for the Northeast Asia model.*

5 Results

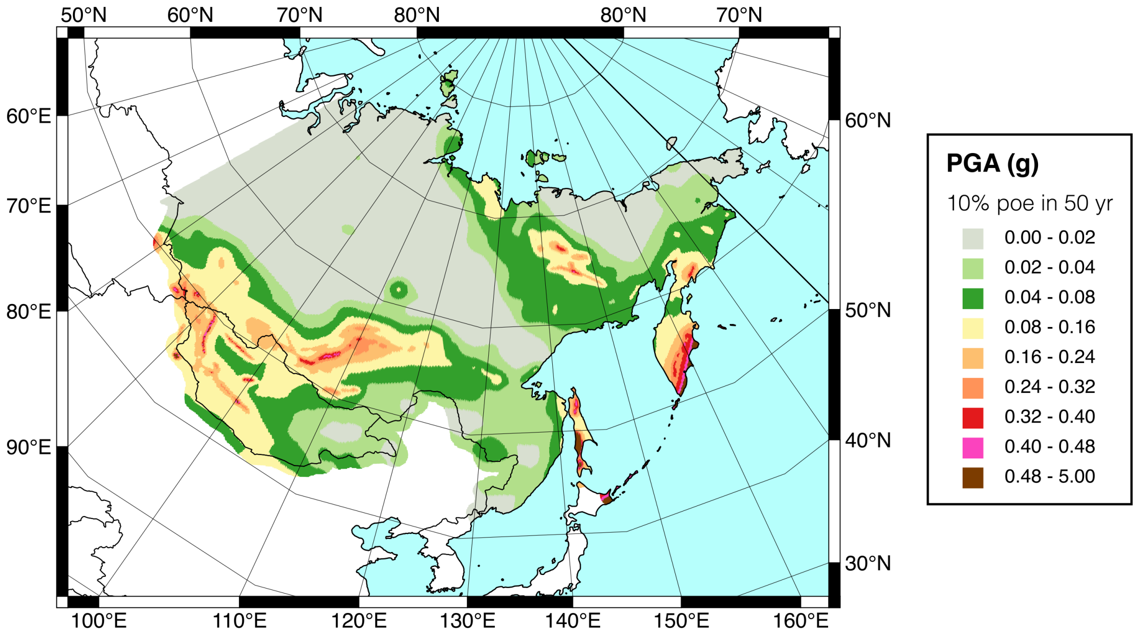

Figure 8 *– Hazard map computed at PGA for 10% PoE in 50 years.*

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