PSHA input model documentation for Hawaii (HAW)

GEM Hazard Team

Version history

Table 1 summarises version history for the HAW 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 HAW input model.*

Version	2018.1	2019.1	2022.1	2023.1	Changelog
v1998.0.0	X				First version of the model implemented in OpenQuake.
v1998.1.0				X	The gmmLT.xml has been revised by incorporating the GMPE logic tree used for the USGS model version 2021 (Petersen et al., 2021).

The following text describes v1998.1.0.

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1 Summary

The Global Hazard Mosaic coverage of Hawaii is based on the 1998 United States Geological Survey (USGS) model of *Klein et al., (2001)*. The GEM implementation relies on the best judgement of the Secretariat in converting the documented model into the OpenQuake (OQ) engine format from the NSHMP input files provided by the USGS.

2 Regional Tectonics

Most of the seismicity in Hawaii is associated with active rifting and volcanism. The largest earthquakes occur as the result of compressive stresses along sub-horizontal flank faults (basal decollments) along the volcanoes Mauna Loa, Kilauea, and Hualalai, posing the highest hazard to the southernmost Big Island of Hawaii. The most active flanks are those that are seaward and unbuttressed. Seismicity also occurs within the rift zones bounding the flanks, and in the Kilauea Caldera. Throughout the entire island chain, seismicity occurs due to flexural loading of the crust, and rates diminish with volcanic activity to the northwest. Deeper seismicity also occurs within the magma chambers.

3 Basic Datasets

Please refer to *Klein et al., 2001* for an explanation of the datasets and methodology used to build the model.

4 Seismic Source Characterisation

The source model utilizes five groups, which include sub-models based on magnitude (Table 1 of *Klein et al., (2001)*). We summarize these here.

- Flank zones (**complex faults and point sources**) that can presumably rupture in a single earthquake
- Uniform seismicity (**area sources**) in the rift zones and Kilauea Caldera
- Smoothed shallow seismicity (**point sources**) in other areas of Hawaii Island
- Smoothed deep seismicity (**point sources**) beneath Hawaii Island
- Smoothed shallow seismicity (**point sources**) that ramps downward away from the active volcanism (to the northwest)

All source groups model earthquakes with *Mmin* 5.0 and a variable *Mmax*, using different source types for different magnitude ranges. For each group and magnitude range, occurrence rates are derived using the truncated Gutenberg-Richter approach. This methodology extends to the flank zones in Group 1, despite the authors' recognition that the driving stresses are not spatially or temporally constant.

All sources are given full weighting in a single logic tree branch.

4.1 Flank zones

The flank zone group includes five perimeters (HLE, HUA, KAO, KON, SFL) that bound the supposed rupture areas of historic earthquakes (see *Klein et al., (2001)*, Figures 1, 2). The rupture areas are subhorizontal at a depth of ~10 km. The source model uses the perimeters as area sources for M<6.5, and complex faults for M6.5-7.0. Additionally, the three nearly continuous flanks in the southeastern Hawaii Island are linked together to form a single complex fault capable of earthquakes M7.0-8.2. For area sources, hypocenters were fixed at 10 km depth. All sources use a purely reverse mechanism. The occurrence rate properties are listed in Table 2, which is a summary of source properties from Table 3 in *Klein et al., (2001)*. Flank zones modelled individually are assigned the tectonic region of "Volcanic", while the combined source is called "Volcanic Large".

Flank zone	***a*-Value**	***b*-Value**	***M* range**
HLE	1.7255	0.5713	5.0-7.0
HUA	2.6318	0.7306	5.0-7.0
KAO	1.8810	0.5713	5.0-7.0
KON	0.3413	0.3100	5.0-7.0
SFL	2.1720	0.5700	5.0-7.0
HLE-KAO-SFL	2.4329	0.5713	7.0-8.2

Table 2 – *Flank zone recurrence parameters.*

4.2 Kilauea Caldera and rift zones

The three area sources of the Kilauea Caldera and rift zones (CAL, SWR, ERZ) are modeled as grids of point sources with 0.02°-spacing and magnitudes up to M6.5. Table 3 lists the occurrence rate properties, and is based on Table 3 in *Klein et al. (2001)*. *a*-Values are for the entire area source, and thus in the source model, the available moment is divided among the point sources. The tectonic region type is volcanic.

Area source	***a*-Value (zonal)**	***b*-Value**
CAL	4.1307	1.13
SWR	6.0750	1.58
ERZ	4.4646	1.48

Table 3 – *Area source recurrence parameters.*

4.3 Smoothed shallow seismicity

These point sources account for distributed seismicity not attributable to a specific feature. Occurrence rates for earthquakes *M*5.0-7.0 were derived for seven source zones (S1-7) with earthquakes <20 km depth (see Figure 2, *Klein et al., 2001*) across a 0.02° grid. Nodal planes are reverse focal mecahnisms with rotating strike and hypocentral depth fixed at 10 km. *b*-values are held constant across the grids, while *a*-values are adjusted according to the locally observed moment rates. Table 4 reports the GR-parameters, listing the *a*-value for the source zone (based on Table 3 in *Klein et al., 2001*). The tectonic region type is volcanic.

Source zone	*a*-Value (zonal)	*b*-Value
S1	5.2389	1.21
S2	3.1918	0.97
S3	4.1301	1.23
S4	2.7498	0.81
S5	4.2144	1.13
S6	3.7492	1.23
S7	4.8209	1.36

Table 4 *– Smoothed shallow seismicity recurrence parameters.*

4.4 Deep smoothed seismicity

These point sources are modelled the same as the shallow smoothed seismicity, varying only in their fixed hypocentral depth of 30 km. The six source groups (D1-6) are listed in Table 5 (based on Table 3 in *Klein et al., 2001*). The tectonic region type is deep seismicity.

Source zone	*a*-Value (zonal)	*b*-Value
D1	7.2195	1.71
D2	7.0389	2.03
D3	3.0028	0.93
D4	2.9083	0.90
D5	4.0666	1.07
D6	3.2977	0.91

Table 5 *– Smoothed deep seismicity recurrence parameters.*

4.5 Smoothed shallow seismicity, ramped

These point sources are modelled with the same focal mechanism and hypocentral depth as the smoothed shallow seismicity sources, but use only one source zone to resolve the GR *b*-value of 0.67. *a*-values are scaled not only by moment rate, but according to a ramping function that diminishes the modelled occurrence rates to the northwest; see the Appendix of *Klein et al. (2001)*. The tectonic region type is volcanic.

5 Ground Motion Characterisation

The ground motion characterisation is based on the most recent PSHA model for Hawaii developed by the USGS (Petersen et al., 2021. NB: the source model is not yet in use.)

DeepSeismicity	**Weight**
Atkinson2010Hawaii	0.4
AbrahamsonEtAl2015SSlab	0.4
WongEtAl2022Deep	0.2
Volcanic	**Weight**
AbrahamsonEtAl2014	0.2
BooreEtAl2014	0.2
CampbellBozorgnia2014	0.2
ChiouYoungs2014	0.2
Atkinson2010Hawaii	0.2

Table 6 *– GMPEs used in the HAW model.*

6 Results

Hazard curves were computed with the OQ engine for the following:

- Intensity measure types (IMTs): peak ground acceleration (PGA) and spectral acceleration (SA) at 0.2s, 0.3s, 0.6s, 1.0s, and 2s
- reference site conditions with shear wave velocity in the upper 30 meters (Vs30) of 760-800 m/s, as well as for Vs30 derived from a topography proxy (Allen and Wald, 2009)

Hazard maps were generated for each reference site condition-IMT pair for 10% and 2% probabilities of exceedance (POEs) in 50 yrs. Additionally, disaggregation by magnitude, distance, and epsilon was computed for the following cities: Honolulu. The results were produced as csv files and bar plots for each of the following combinations:

- hazard levels for 10% and 2% POE in 50 yrs
- PGA and SA at 0.2s, 0.3s, 0.6s, and 1.0s
- Vs30=800 m/s

All calculations used a ground motion sigma truncation of 5. Results were computed for sites with 6 km spacing

Visit the GEM Interactive Viewer to explore the Global Seismic Hazard Map values (PGA for Vs30=800 m/s, 10% poe in 50 years). For a comprehensive set of hazard and risk results, see the GEM Products Page.

7 References

Allen, T. I., and Wald, D. J., 2009, On the use of high-resolution topographic data as a proxy for seismic site conditions $Vs30$, Bulletin of the Seismological Society of America, 99, no. 2A, 935-943

Klein, F. W., Frankel, A. D., Mueller, C. S., Wesson, R. L., & Okubo, P. G. (2001). Seismic hazard in Hawaii: High rate of large earthquakes and probabilistic ground-motion maps. Bulletin of the Seismological Society of America, 91(3), 479-498.

Petersen, Mark D., et al. "2021 US National seismic hazard model for the State of Hawaii." Earthquake Spectra 38.2 (2022): 865-916.

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