Preliminary 2021 National Seismic Hazard Model for Hawaii

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USGS Update of the Hawaii Seismic Hazard Model Workshop #2

Virtual Workshop (Microsoft Teams) – November 18, 2020

U.S. Department of the Interior
U.S. Geological Survey
Geologic Hazard Science Center (Golden, CO)
https://earthquake.usgs.gov/hazards/

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- When not speaking, please turn off your camera. This also helps save bandwidth, which can help with picture and audio quality issues.
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Agenda

Session #1 (12:00 pm – 2:00 pm MST; 9:00 am – 11:00 am HST)

Overview of Proposed Model and Discussion (120 min)

2:00 pm – 3:00 pm Break (60 min)

Session #2 (3:00 pm – 5:00 pm MST; 12:00 pm – 2:00 pm HST)

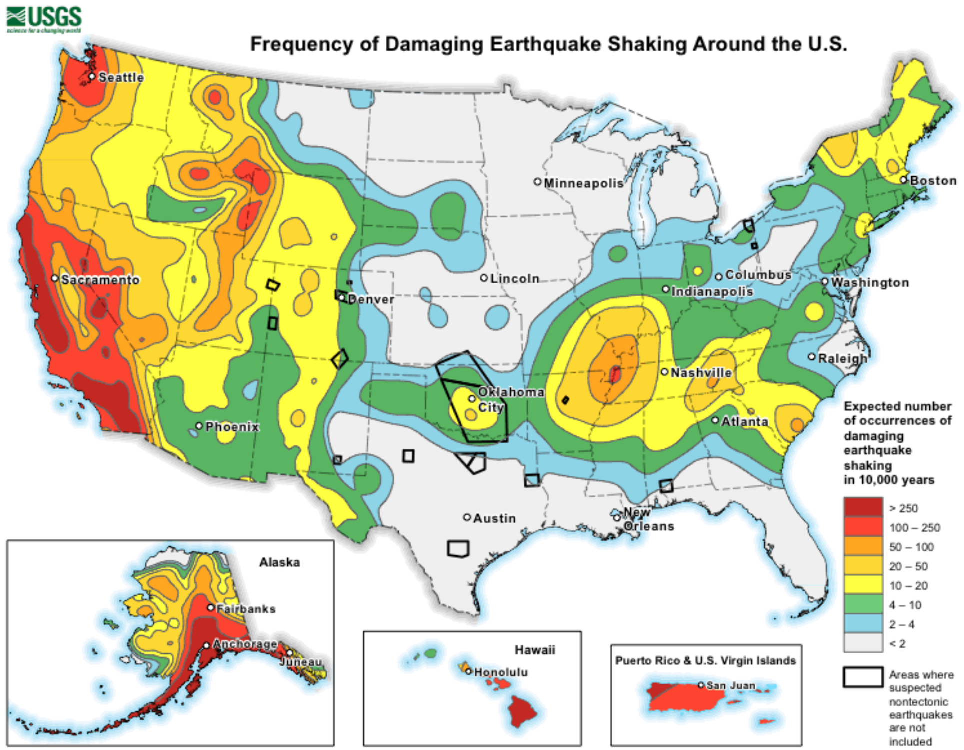
Preliminary Hazard Results, Planned Products, and Discussion (120 min)

USGS Hawaii Hazard Model Timeline

- Hawaii Workshop #1 - University of Hawaii at Manoa (September 18, 2019)
- HETAC Briefing (September 11, 2020)
- Hawaii Workshop #2 – Virtual (November 18, 2020)
- Review – HETAC, USGS Steering Committee, USGS internal review, scientific meeting presentations, public comment (Nov 13 -Dec 13 2020)
- Submit paper to *Earthquake Spectra* and peer review (December 2020 - June 2021)
- Present reviewed model to HETAC, Seismological Society of America, public release of product (Summer or Fall, 2021)

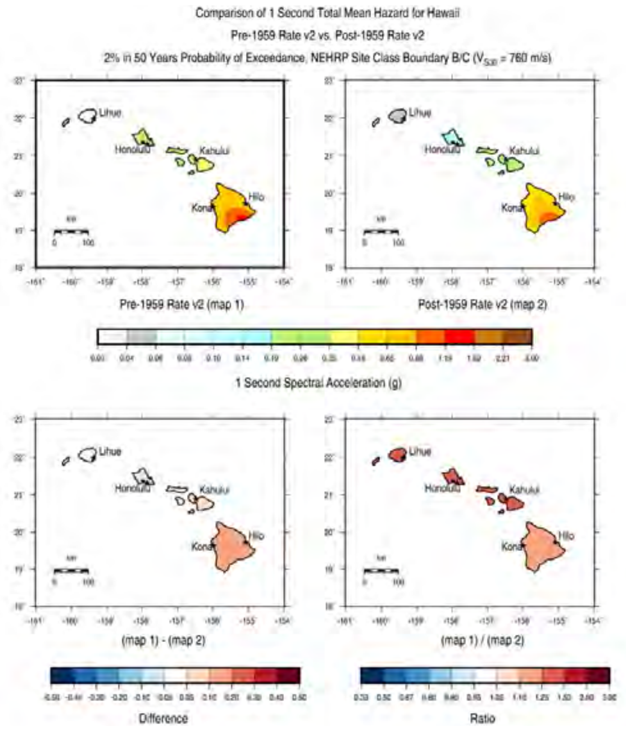
2021 National Seismic Hazard Model for Hawaii: Why Update?

- Hawaii hazard is significant, comparable with California and Alaska
- Last updated 1998-2001 (Klein et al., 2001)
- Many new Hawaiian earthquakes (23 years, large earthquakes in 2006 M6.7 - Kiholo Bay, 2018 M6.9- Kalapana)
- New geodetic data and models
- New Quaternary-fault database for Hawaii
- New methodologies: (declustering methods, adaptive smoothing, residual analysis)
- New strong motion data and new generations of ground motion models (NGAW2, Hawaii specific)
- New site effects data for Island of Hawaiʻi (V_{S30})



Input Models

1. Catalog (*C. Mueller*)
2. Declustering (*A. Llenos*)
3. Earthquake Rates (*M. Petersen*)
4. Mmax (*M. Petersen*)
5. Smoothing (*M. Moschetti*)
6. Caldera Collapse and Volcanic-Earthquake Correlation (*A. Michael*)
7. Faults/décollements (*M. Petersen*)
8. Ground Motion (*M. Moschetti*)
9. Site Effects (*S. Ahdi*)
10. Risk (*K. Jaiswal*)

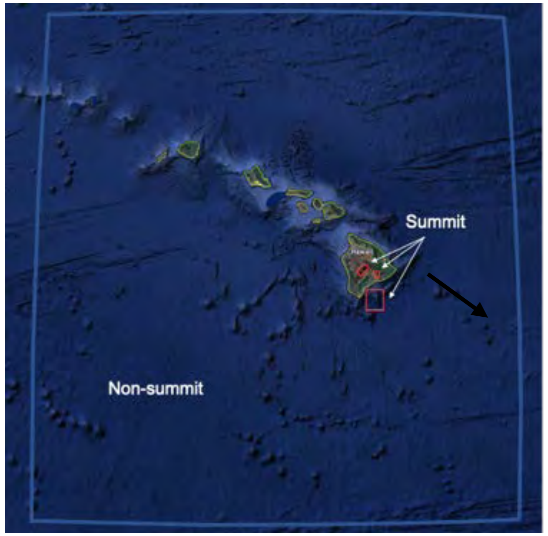


Sensitivity study figures: top two are maps for models being compared, lower left is difference between upper left and upper right map, lower right is ratio of upper left divided by upper right maps.

We will describe models and show sensitivity studies for most models so you can determine the importance and uncertainty of each model. In the second session we will show some uncertainty estimates.

1. Earthquake Catalog

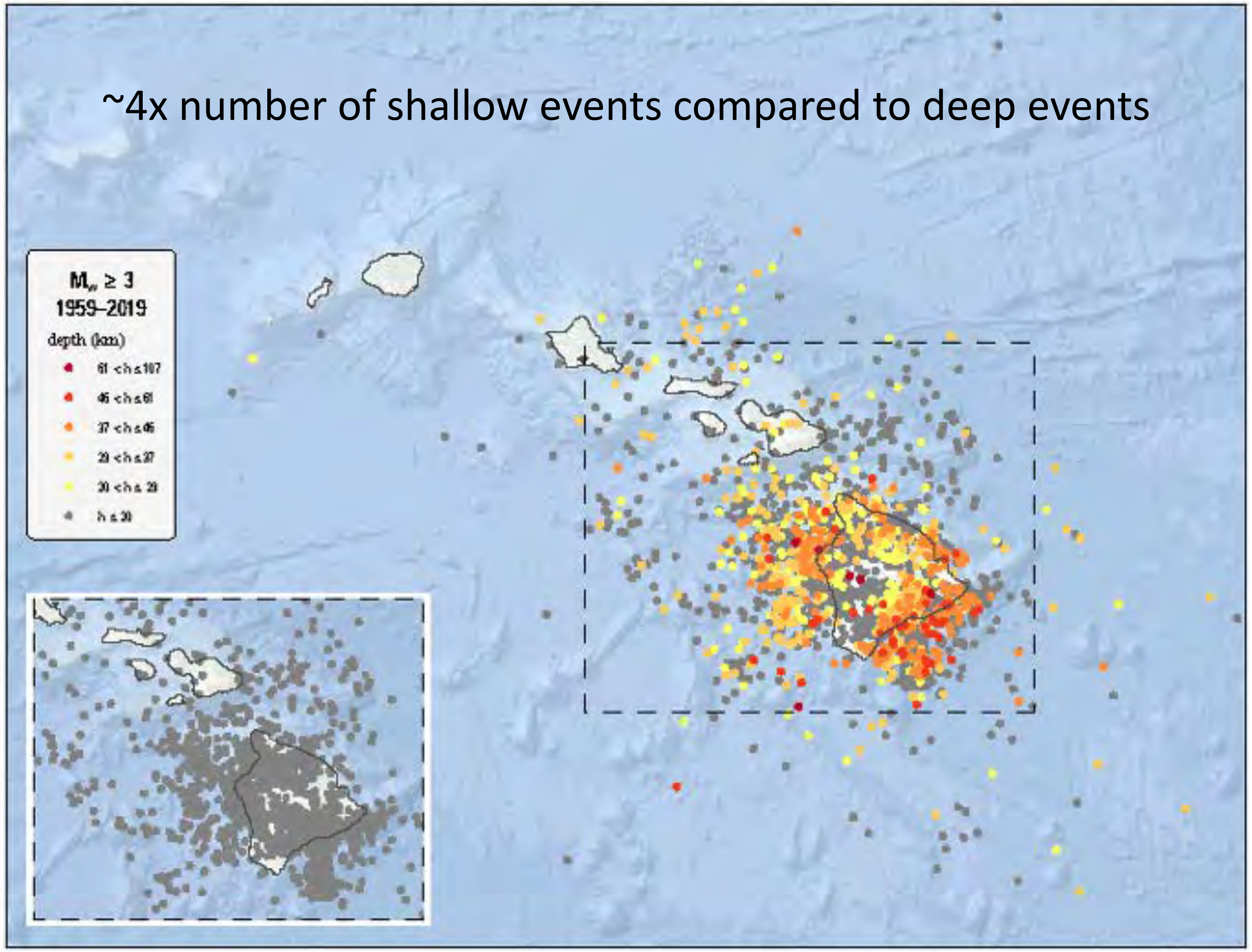
- Input Catalogs
  - Hawaiian Volcano Observatory (HVO) - Oct 1959 to Mar 2009
  - USHIS (Stover & Coffman) - M≥4.5/MMI≥VI - 1959 to 1989
  - ComCat – 1959 to present
  - Note: HVO and USHIS were incorporated into ComCat after April 2019 (finalized in August 2020)
- Catalog Compilation
  - Reformat and merge input catalogs
  - Get uniform moment magnitudes (conversion rules)
  - Get parameters for computing unbiased seismicity rates
  - Get UTC, flag "volcanic eruptions"
  - Delete duplicates
- Final Catalog (Oct 1959 – Dec 2019)
  - 28,300 events
  - M2.5+
  - M_c2.9+ since ~1959
  - Divide catalog into shallow (≤20km), deep (>20km), summit, non-summit, and caldera collapse

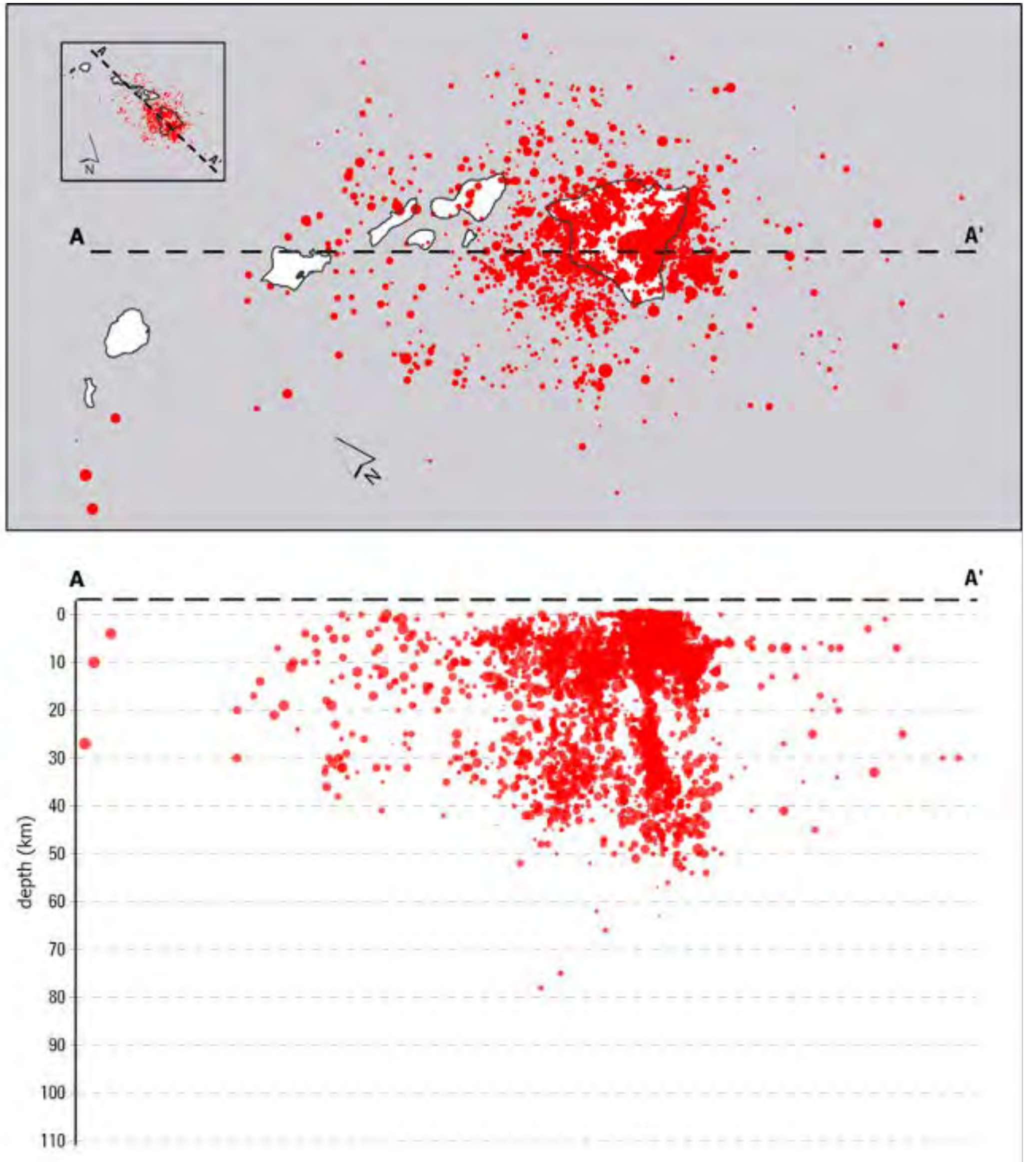


Summit: Kīlauea, Mauna Loa, and Lō'ihi volcanos

Earthquake Catalog

~4x number of shallow events compared to deep events

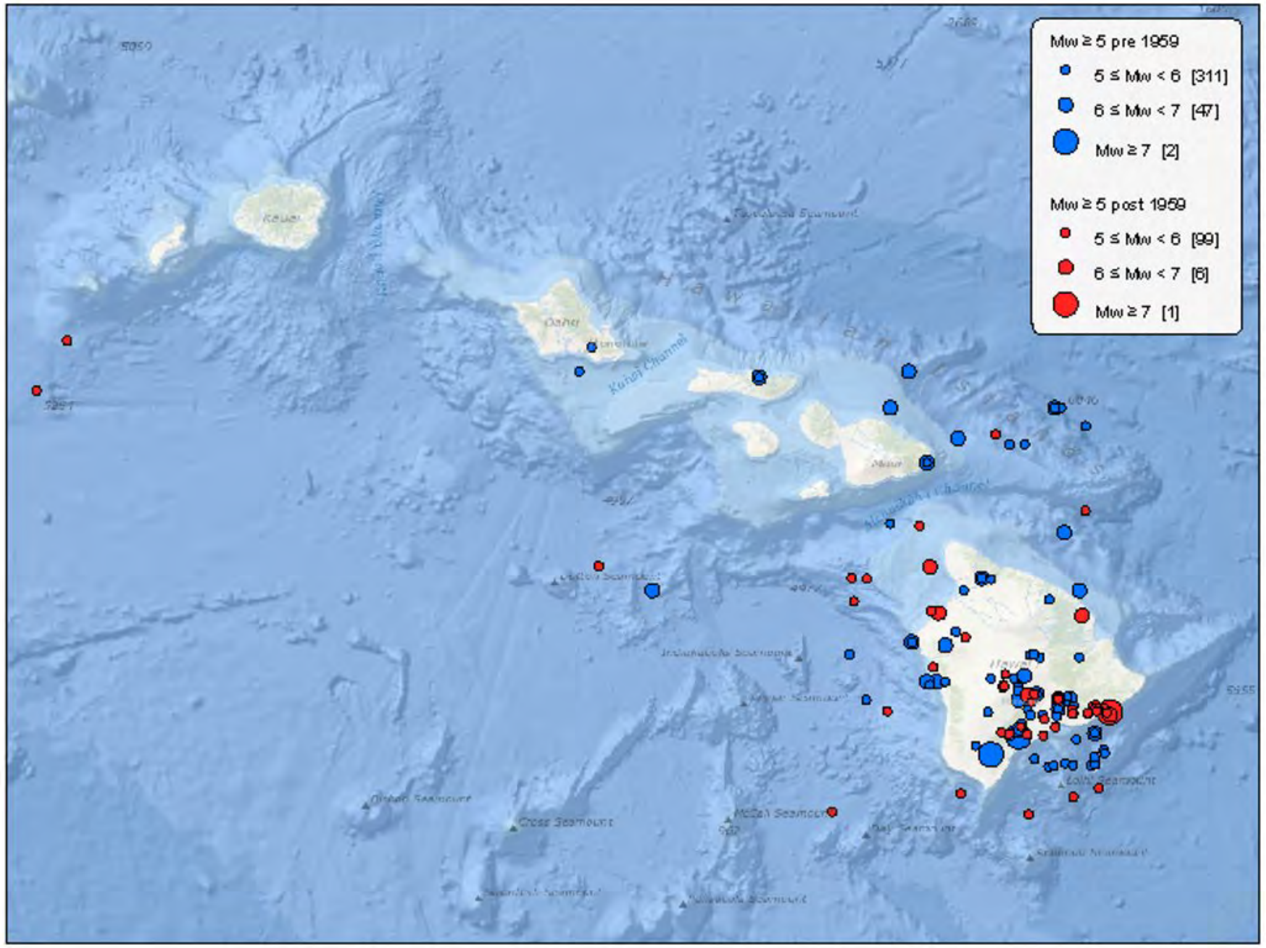




X-section (A to A') of seismicity across the island chain.

Earthquake Catalog

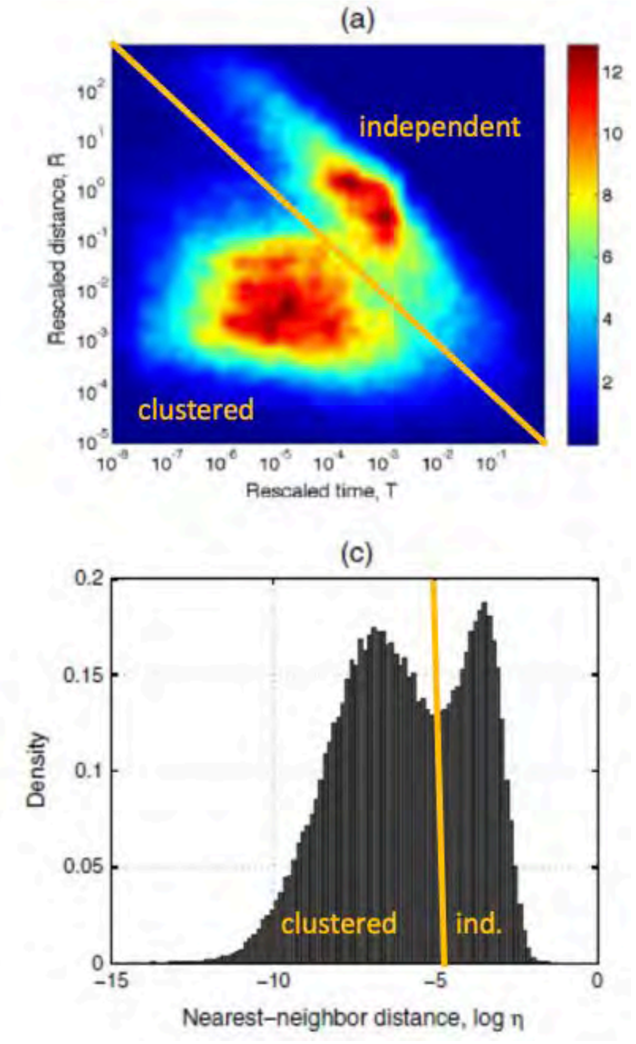
- Historic Catalog (pre-1959)
  - Based on Klein & Wright (2000) - USGS Professional Paper 1623
  - ~3,700 events
  - M≥3
  - Not used for PSHA calculations, but used to inform rate model



pre-1959 seismicity (blue) and post-1959 seismicity (red)

2. Declustering Models

- Reasenberg (1985) (R85)
  - Clusters identified by linking events through spatial and temporal interaction zones
  - Default (California-tuned) R85 parameters used, except for Hawaii-specific minimum look-ahead time and probability of detection
  - Maximum distance threshold imposed (30 km)
  - Used in 2001 Hawaii model
- Zaliapin et al. (2008) (NN)
  - Seismicity separated into clustered and independent events based on the bimodal distribution of nearest neighbor space-time distances
- Other methods investigated
  - Gardner and Knopoff (1974)
  - ROBERE (Llenos and Michael, 2020)



Modified from Zaliapin and Ben-Zion (2013)

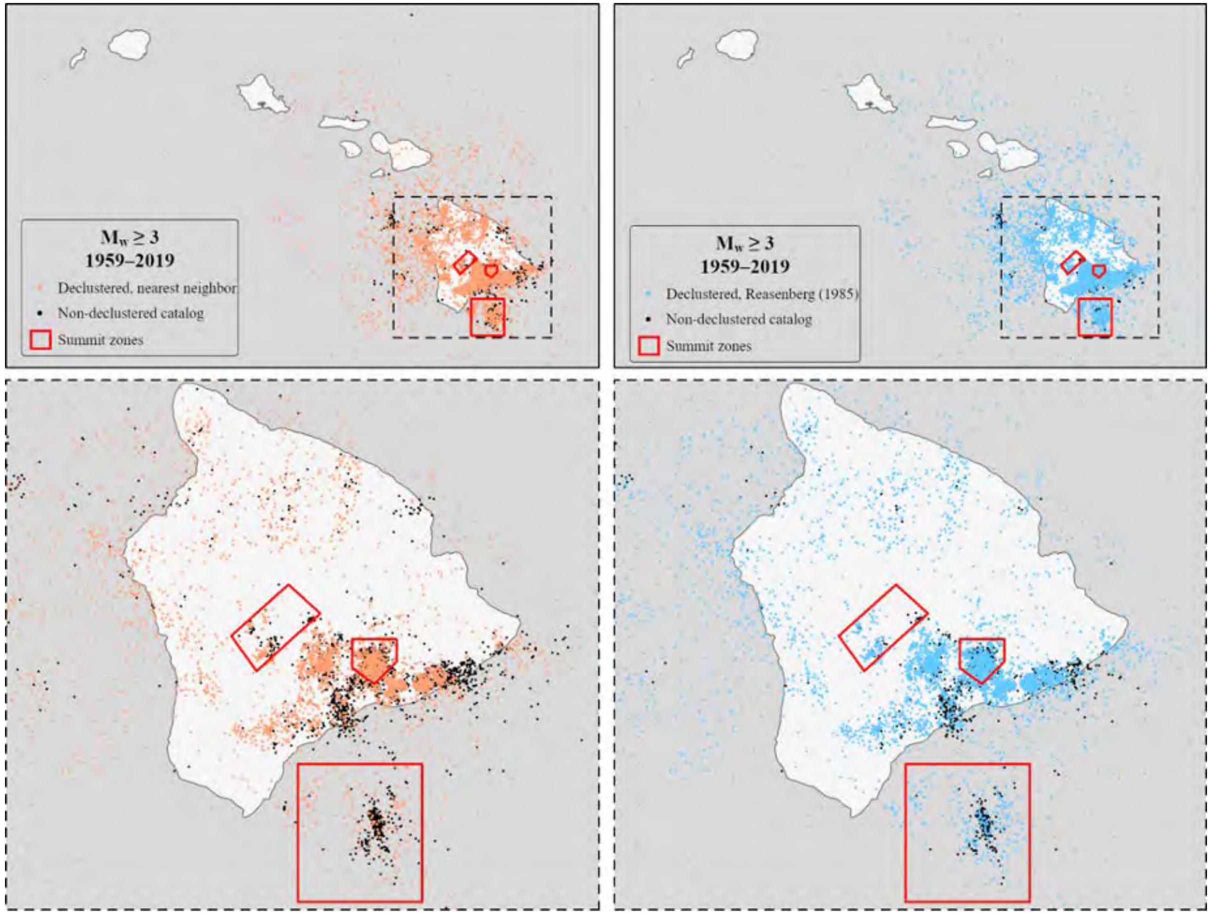
Declustering Results

- NN tends to remove more events from the catalog than R85
- Spatial distributions, *b*-values are relatively similar

Catalog	Depth	Zone Type	N(M>=3.5)	B-value
Full	Shallow	Summit	633	1.2
		Non-summit	1391	1
	Deep	Summit	109	0.95
		Non-summit	326	0.95
Declustered (R85)	Shallow	Summit	200 (32%)	1.15
		Non-summit	1099 (79%)	1
	Deep	Summit	105 (96%)	0.95
		Non-summit	310 (95%)	0.95
Declustered (NN)	Shallow	Summit	140 (22%)	1.3
		Non-summit	879 (63%)	1
	Deep	Summit	96 (88%)	0.9
		Non-summit	237 (73%)	0.95

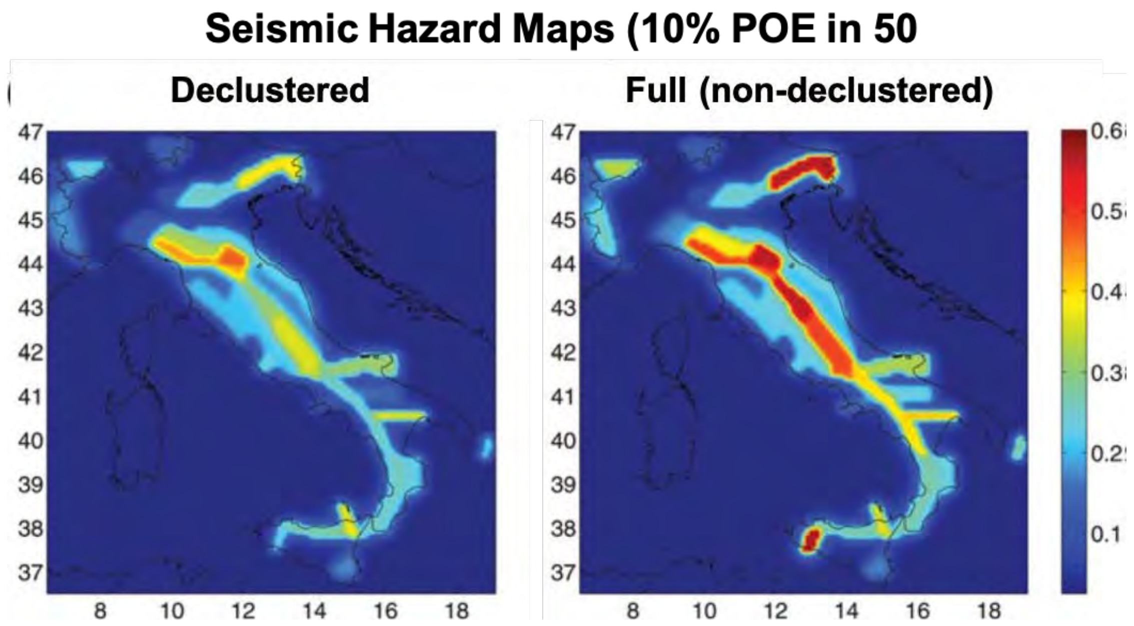
NN: 1,352 events (1,107 removed)

R85: 1,714 events (745 removed)



Using Full Catalogs in PSHA (Marzocchi and Taroni, 2014)

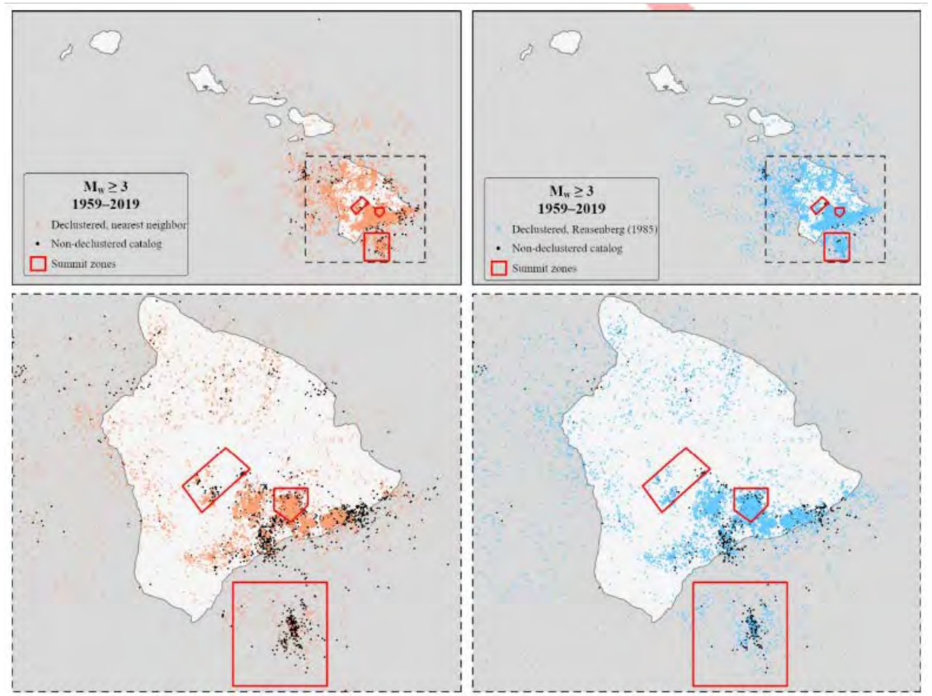
- Declustering is useful to prevent aftershocks from biasing the expected long-term spatial distribution of mainshocks but may underestimate the true seismic hazard.
- First decluster to remove spatial bias, then rescale *a*-grids so that rate of earthquakes and *b*-value matches those in full catalog.



Using Full Catalogs in PSHA (Marzocchi and Taroni, 2014)

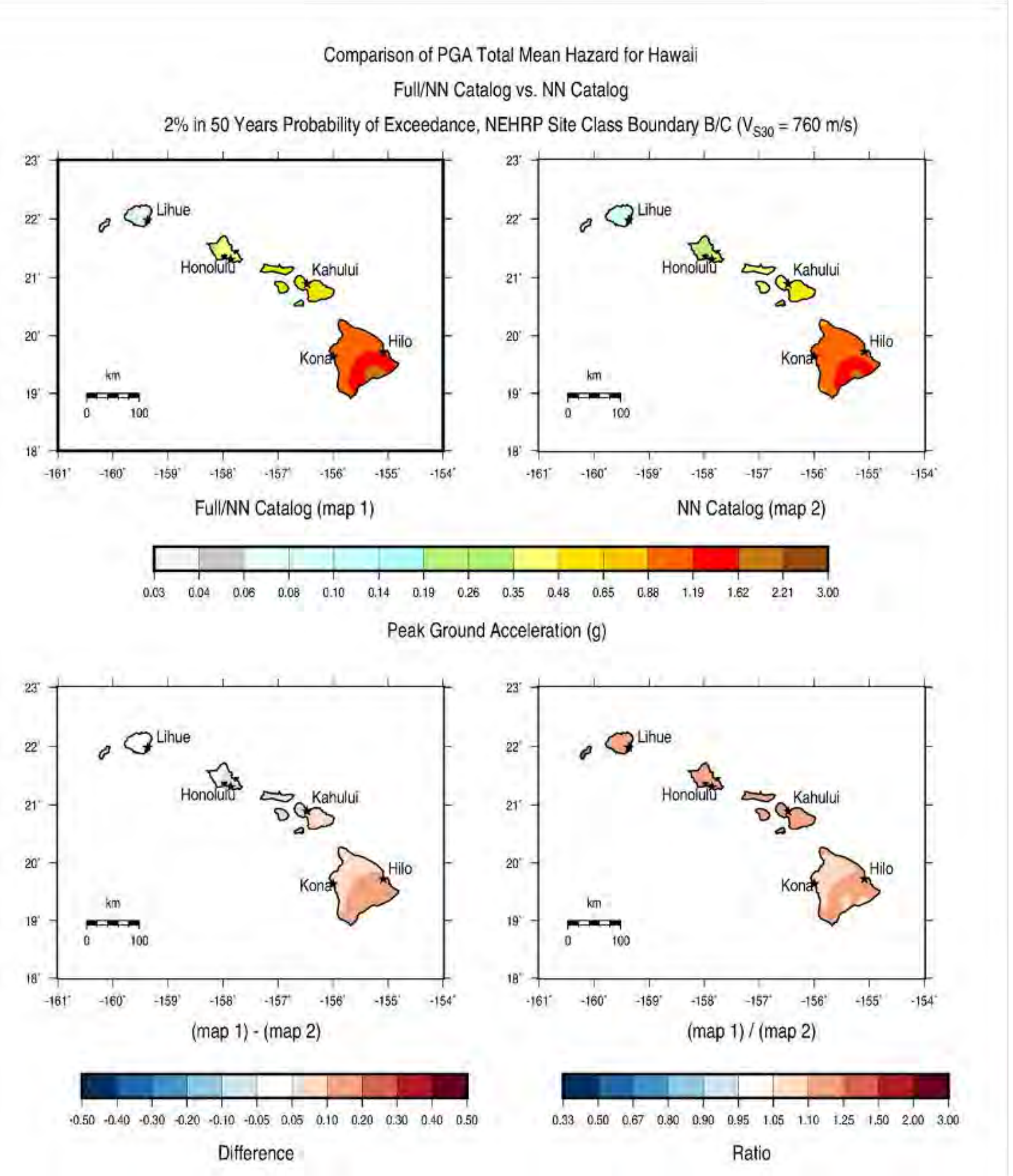
- Declustering is useful to prevent aftershocks from biasing the expected long-term spatial distribution of mainshocks but may underestimate the true seismic hazard.
- First decluster to remove spatial bias, then rescale *a*-grids (agrid scaling factor in table below) so that rate of earthquakes and *b*-value matches those in full catalog.

Catalog	Depth	Zone Type	Nfull/ Ndeclus	Agrid scaling factor
Declustered (R85)	Shallow	Summit	3.17	4.95
		Non-summit	1.27	1.27
	Deep	Summit	1.04	1.04
		Non-summit	1.05	1.05
Declustered (NN)	Shallow	Summit	4.52	1.86
		Non-summit	1.58	1.58
	Deep	Summit	1.14	1.8
		Non-summit	1.38	1.38



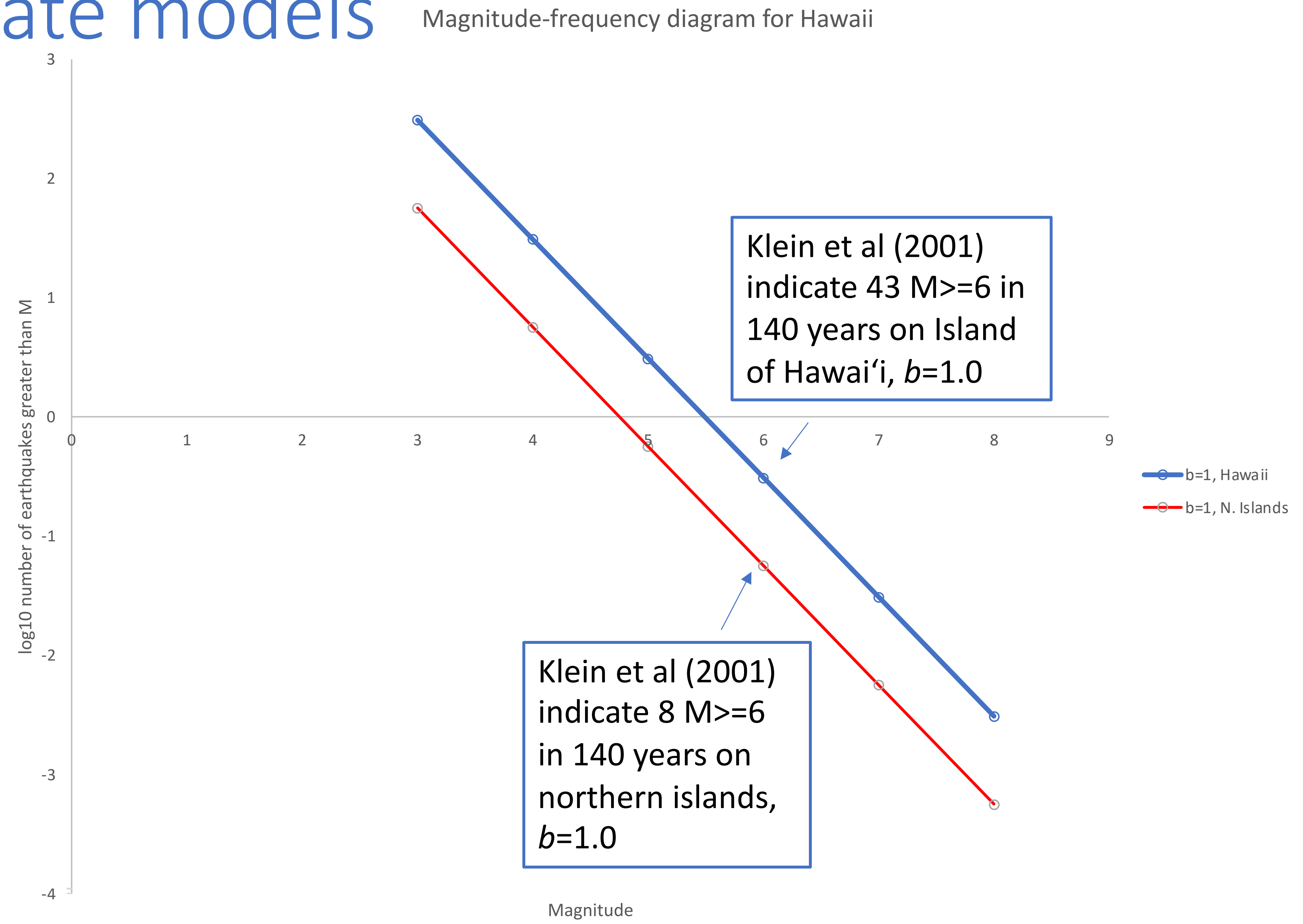
Declustering Sensitivities

- NN and R85 catalogs show similar hazard results
- Comparisons of NN and Full/NN show 5-25% increases for rescaled models (see figure on right)
- We give equal weight (0.25) to each declustered catalog: NN, R85, NN with scaling to full catalog weight, and R85 with scaling to full catalog weight



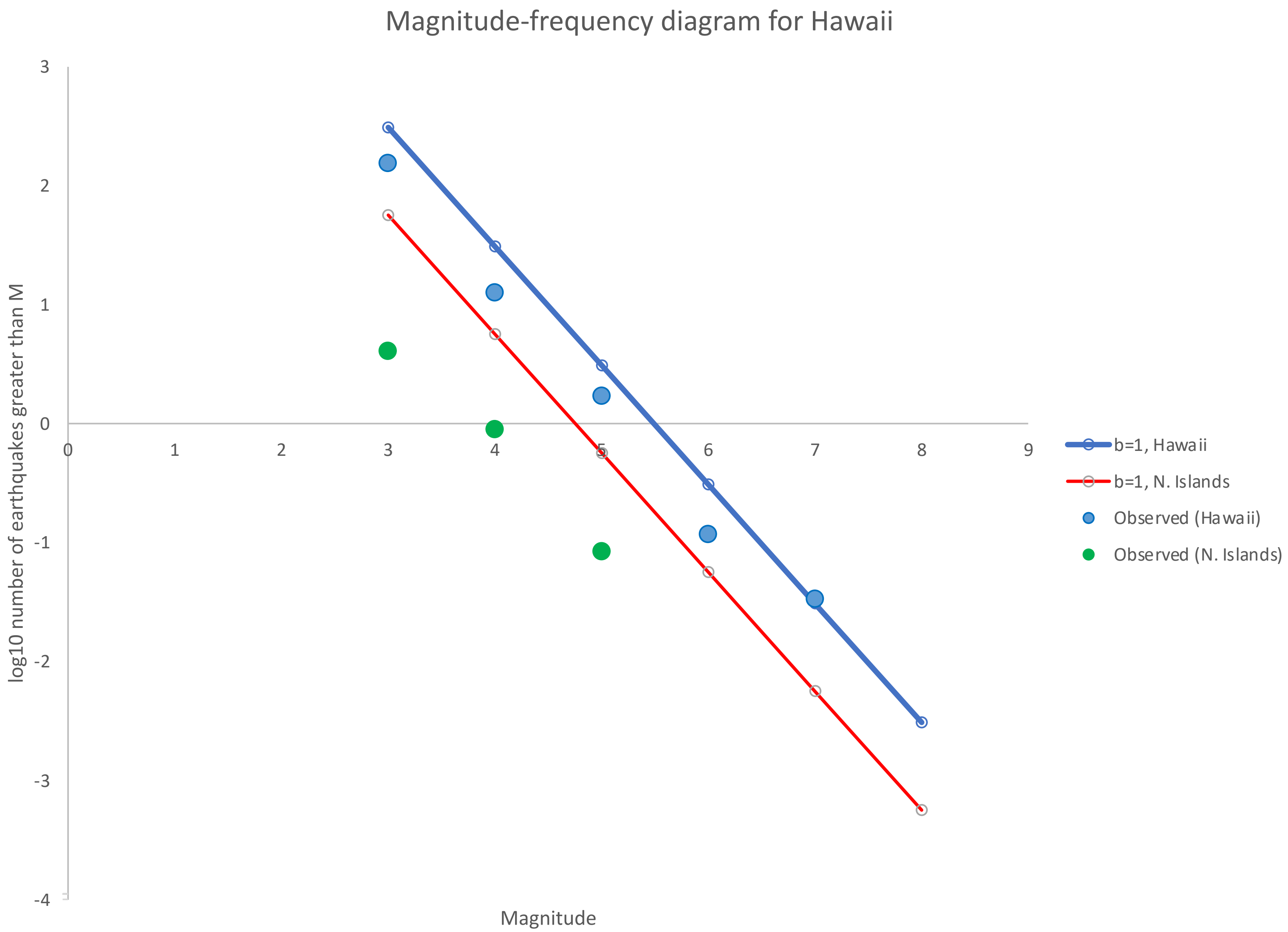
3. Earthquake Rate models

Rate model proposed by Klein et al. (2001) based on their observations.



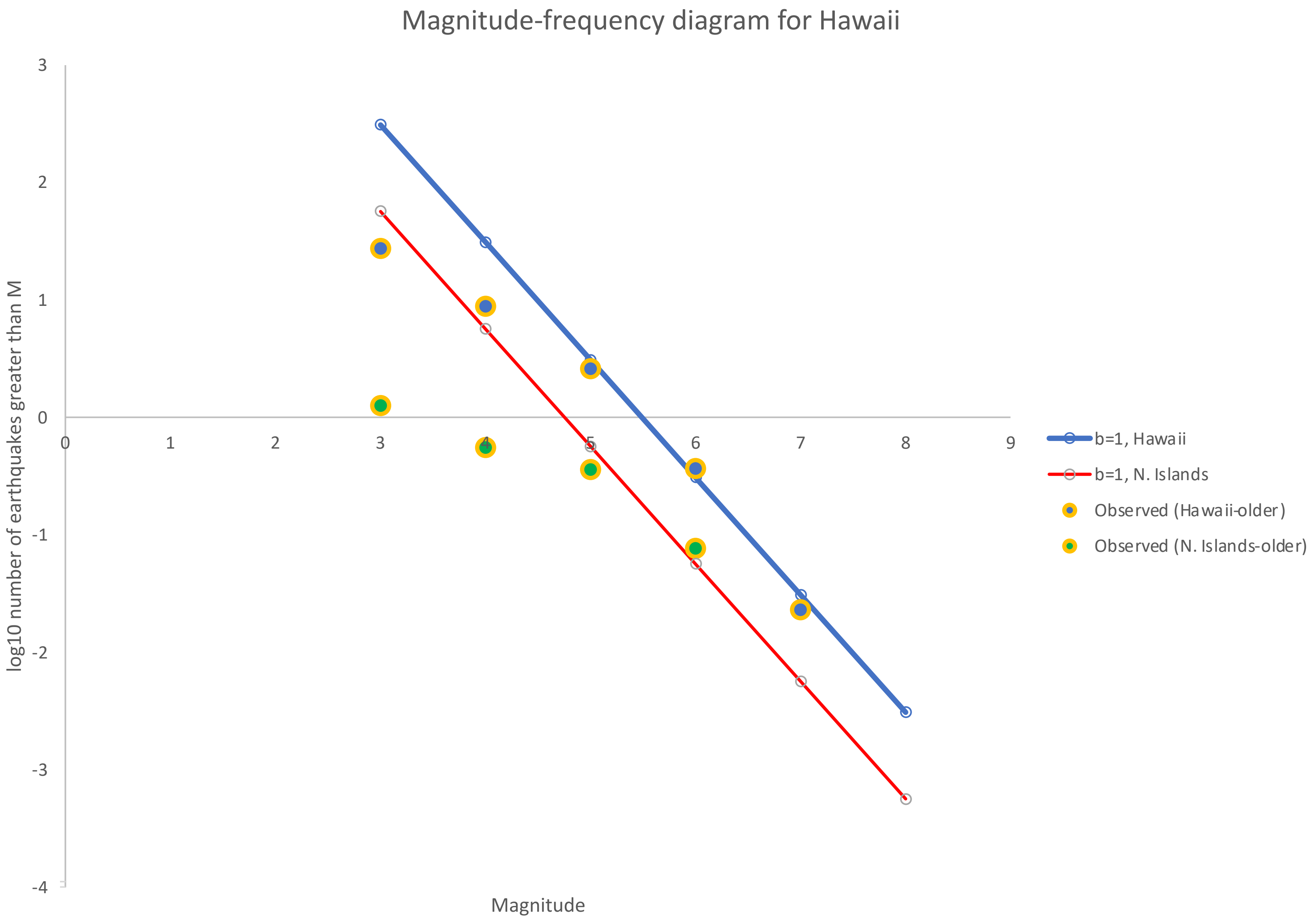
Earthquake Rate models: Post-1959

When we plot the observed data, we get similar rates to what Klein et al. (2001) proposed for the post-1959 data.



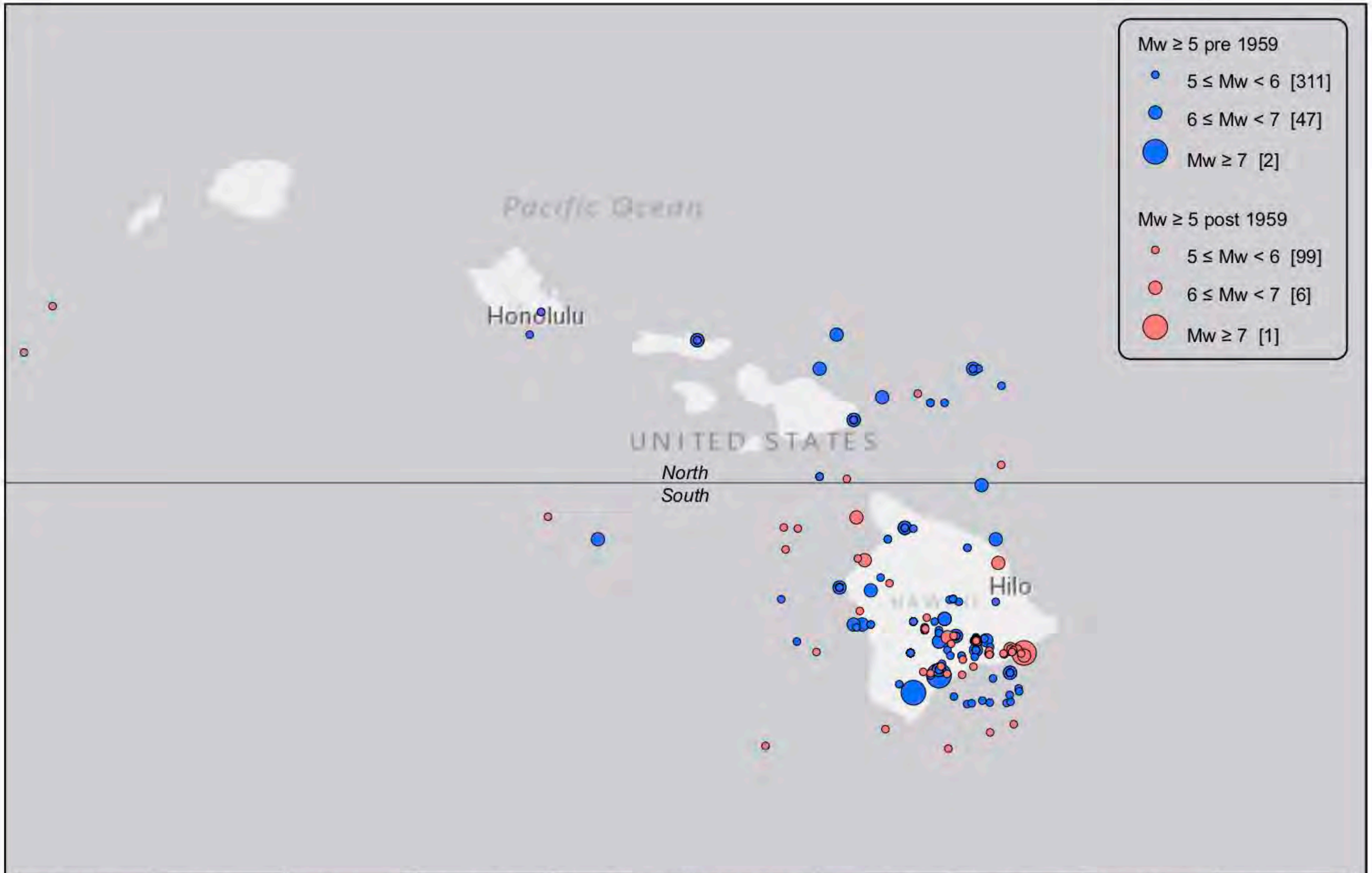
Earthquake Rate models: Pre-1959

When we plot the observed data, we get lower rates than Klein et al. (2001) proposed for the pre-1959 data.



Rate Model

- M7 earthquakes only on Island of Hawai'i
- M6 earthquakes only in pre-1959 catalog for northern islands, none since 1959 in northern islands
- M5 earthquakes 3 to 4 times higher in the pre-1959 catalog
- M3-7 earthquakes 2+ times higher in the pre-1959 catalog
- We will add a branch to the logic tree to represent this factor of at least 2 for the pre-1959 rates compared to the post-1959 rates

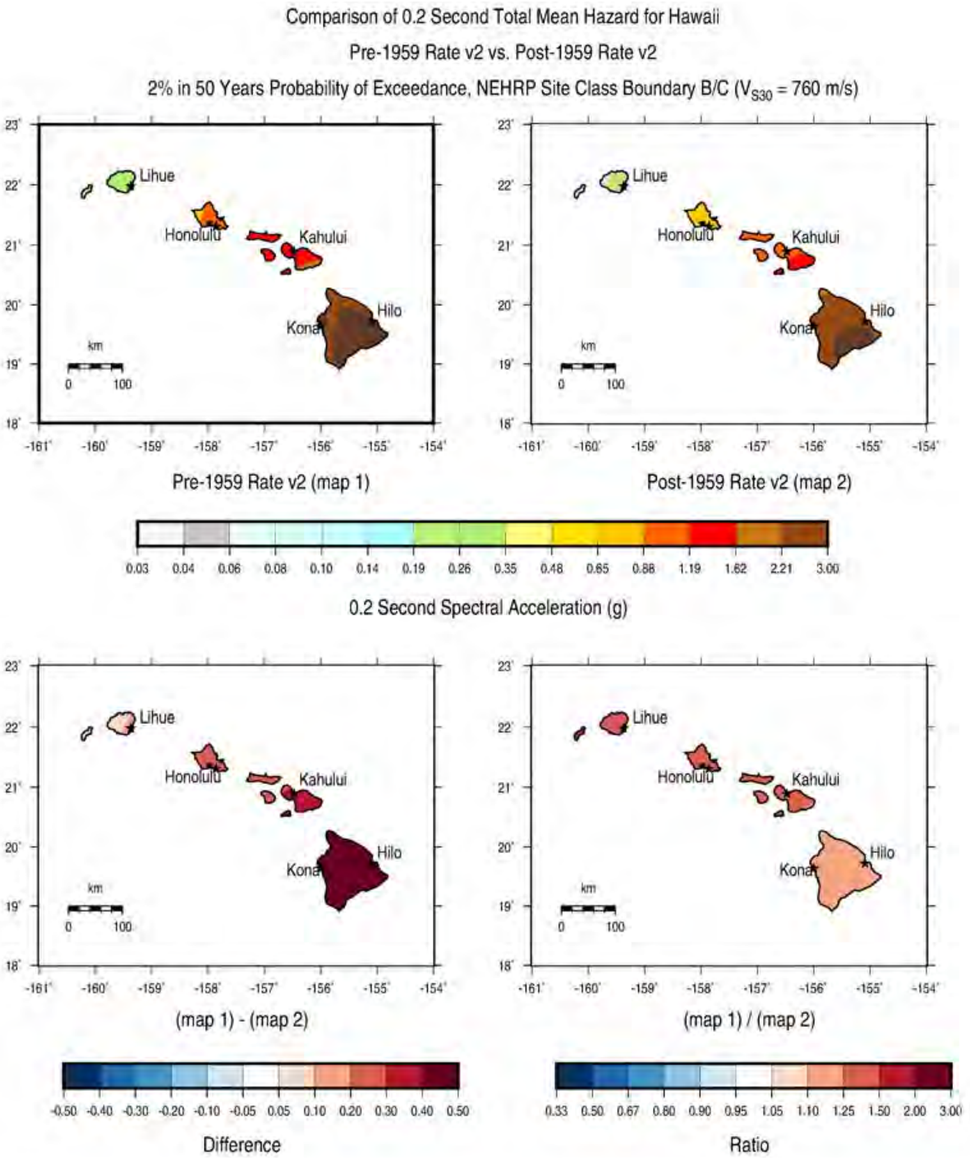


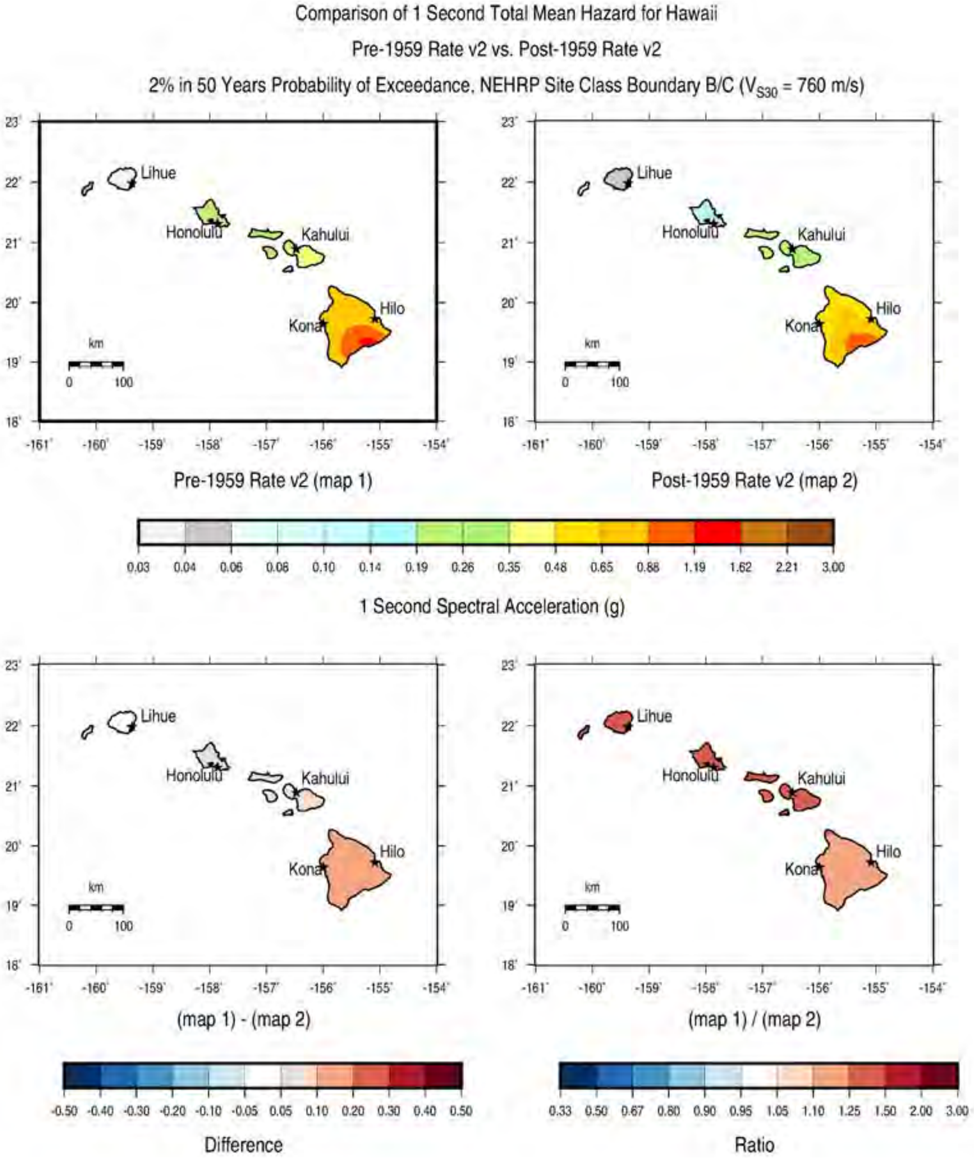
Catalog	Mw ≥ 7 pre 1959	Mw ≥ 7 post 1959	Mw ≥ 7 1868-1959	Mw ≥ 6 pre 1959	Mw ≥ 6 post 1959	Mw ≥ 6 1868-1959	Mw ≥ 5 pre 1959	Mw ≥ 5 post 1959	Mw ≥ 5 1868-1959
North	0	0	0	9	0	9	39	5	44
South	2	1	3	40	7	47	321	101	422
North + South	2	1	3	49	7	56	360	106	466

Earthquake Rate models

- Post-1959 earthquake catalog used for smoothed and gridded sources (discussed later)
- Post-1959 rates applied in model 1
- Post-1959 rates doubled in model 2 to account for higher rates represented in pre-1959 catalog
- Pre-1959 weighted 0.33, post-1959 weighted 0.67 because we trust the post-1959 catalog more than pre-1959 catalog, when few seismic stations were available and locations and magnitudes were more uncertain.

Earthquake Rate models: Sensitivity (weight of 1.0 for each model)

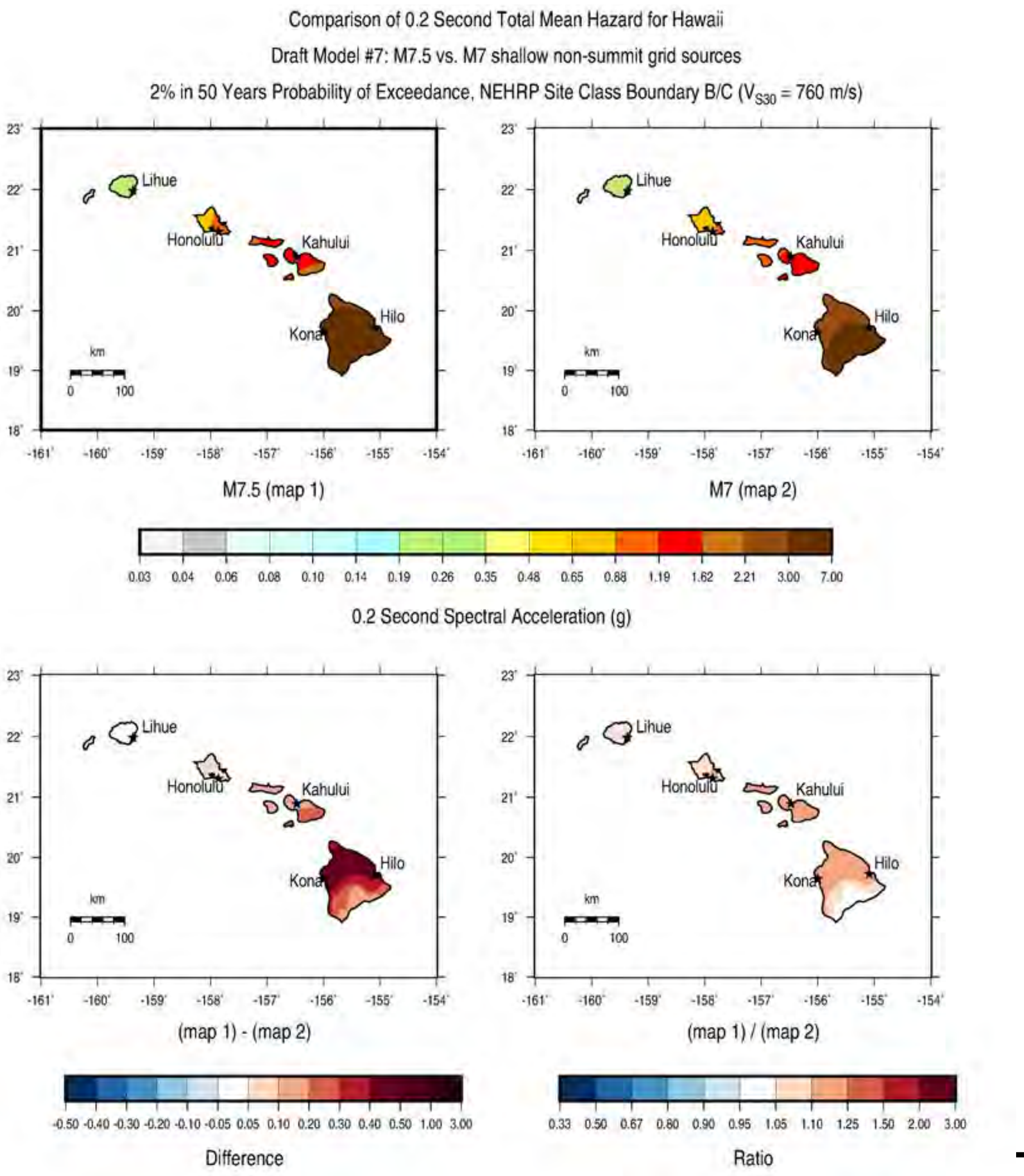


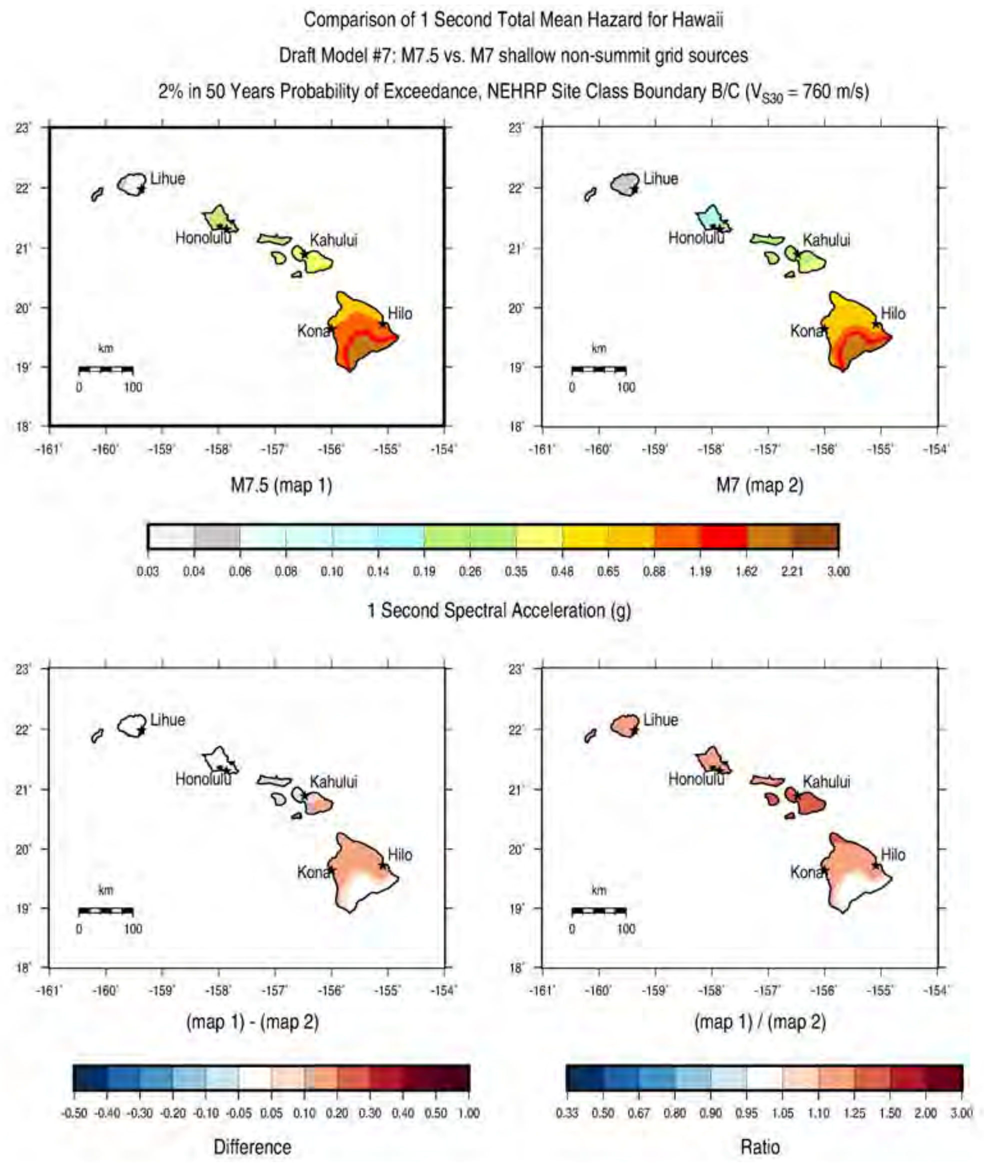


4. Mmax Models

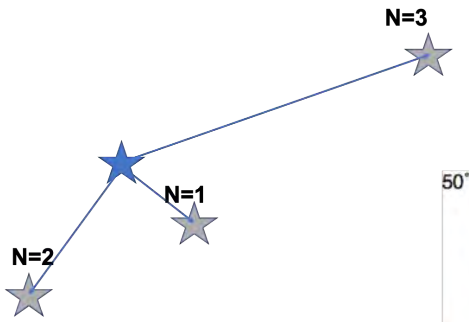
- We allow for M7, M7.5, and M8 earthquakes in the gridded seismicity sources.
- In recent NSHMs we allow for earthquakes up to M8 in gridded seismicity sources.
- We cannot rule out events like the Lanai earthquake (Butler, 2020) or décollements under the island (e.g., Wyss and Koyanagi, 1992).
- We assign weights of M7 (0.7), M7.5 (0.2), and M 8.0 (0.1).

Mmax Models: Sensitivity (weight of 1.0 for each model)

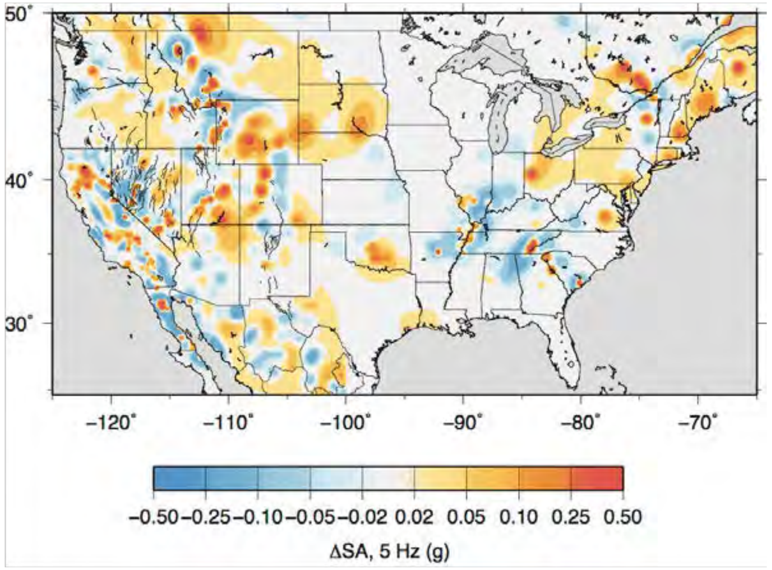


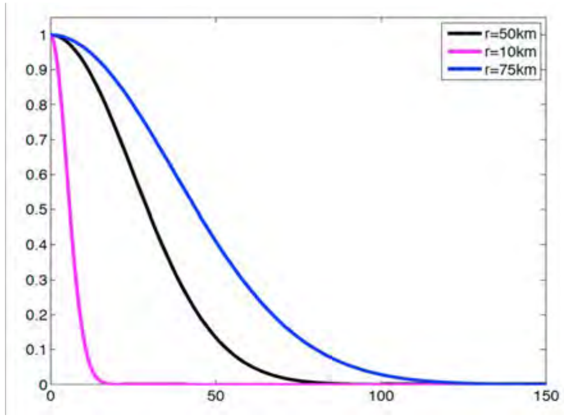


5. Smoothing Models



- Implementing Adaptive Smoothed Seismicity
  - Method applied in multiple regions and applications (e.g., 2014 and 2018 NSHMs)
  - Smoothed seismicity (earthquake-catalog derived) largely controls hazard where faults and fault sources are absent
  - Shares many of the assumptions of fixed-smoothing methods (e.g., large-magnitude earthquakes occur where small earthquakes have occurred in the past, M-F relationships follow G-R distributions between Mmin and Mmax at all grid cells, etc.)
  - Smoothing kernels differ for different earthquakes
  - Based on method of Helmstetter et al. (2010)





Example (radial) smoothing kernels for different smoothing distances

Smoothing Models

Proposed Zones for Update of the Hawaii Seismic Hazard Model

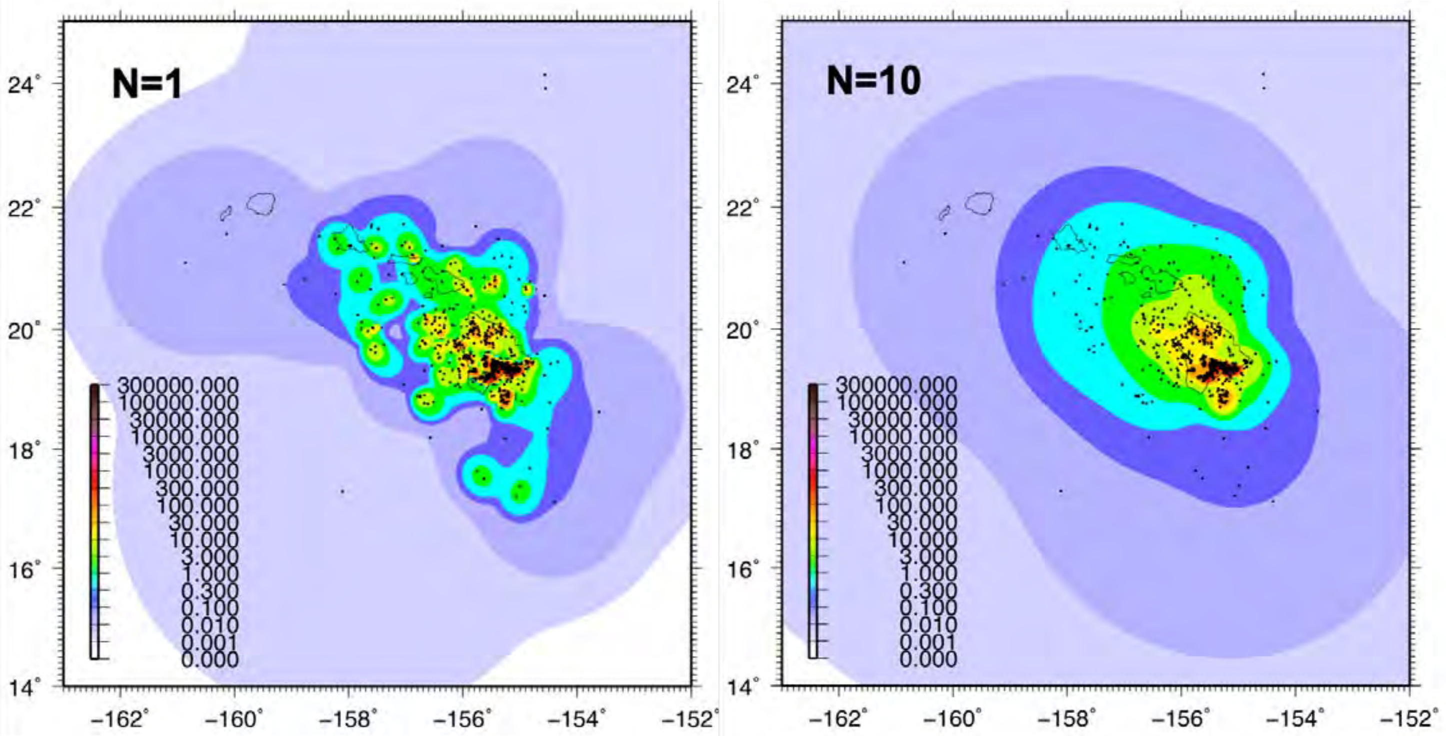
Shallow

ZKON	Kona
ZHIL	Hilea
MSUM	Mauna Loa Summit and uppermost rift zones
ZKAO	Kaoiki
KCAL	Kilauea Caldera
KSWR	Kilauea SW rift zone
KSEF	Kilauea SE flank and E rift zone
ZLOH	Loihi submarine volcano

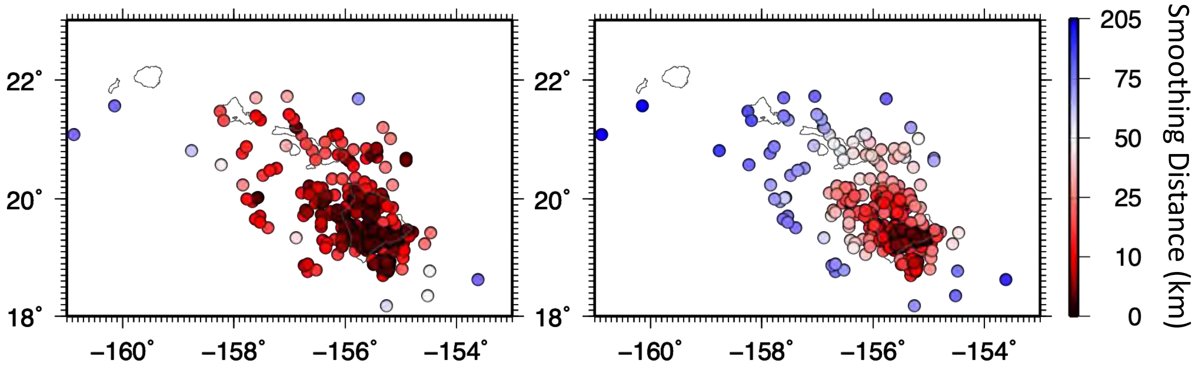
Deep

Deep	Deep

We originally came up with some spatial zones, based on seismicity patterns, but further analysis of *b*-values showed that there really was only a distinction between shallow, deep, non-summit, and summit zones.



The larger the nearest-neighbor number, the more hazard increases to the outer islands.

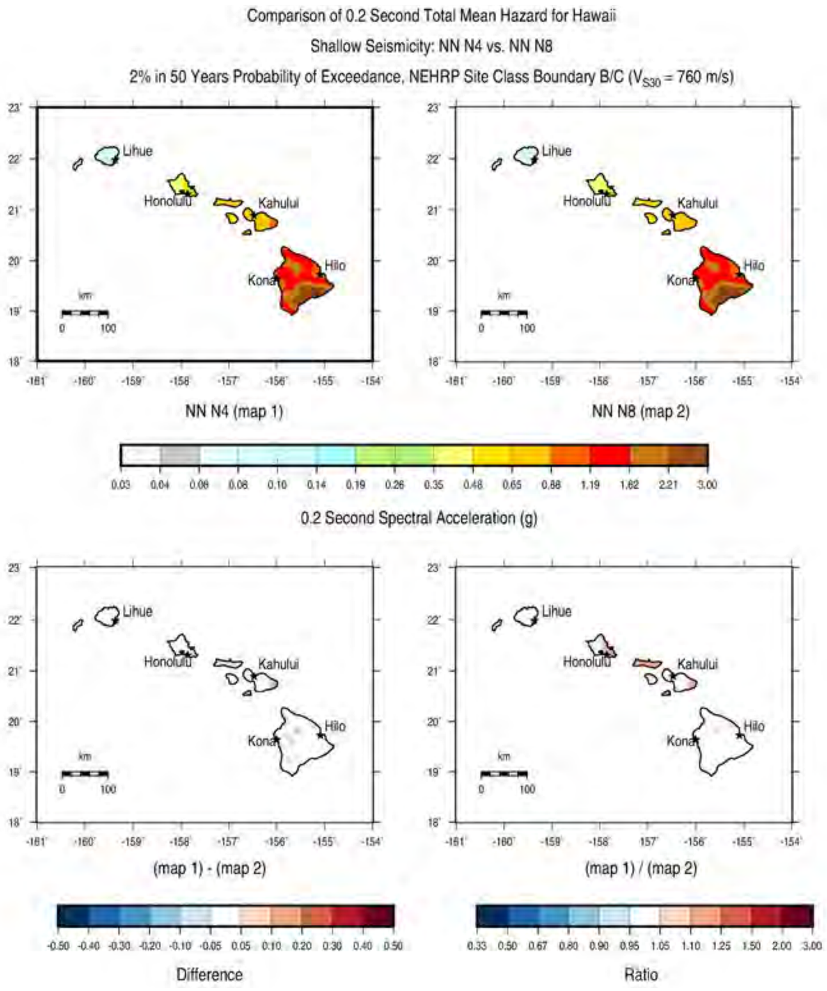


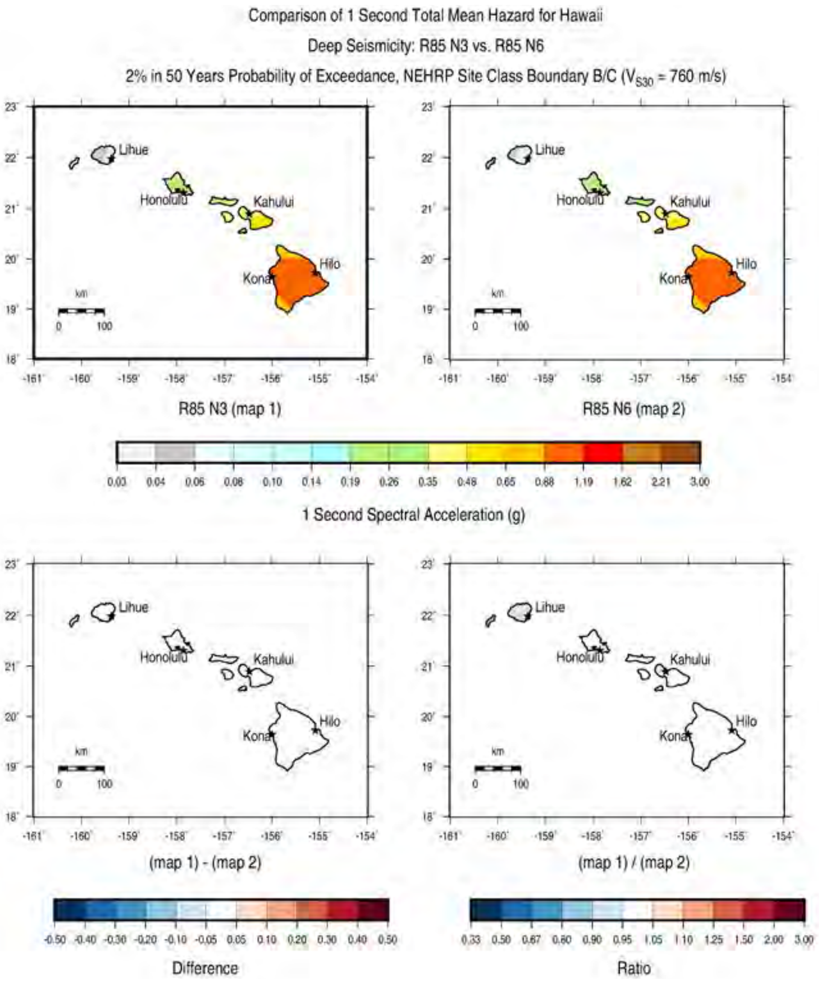
Significant differences in smoothing distances (km) across the islands.

- Minimum smoothing distance: 5 km
- Maximum smoothing distance: 100 km
- M_c>3.5, since 1960
- Separate earthquake catalog into shallow/deep and then Summit/Non-Summit zones

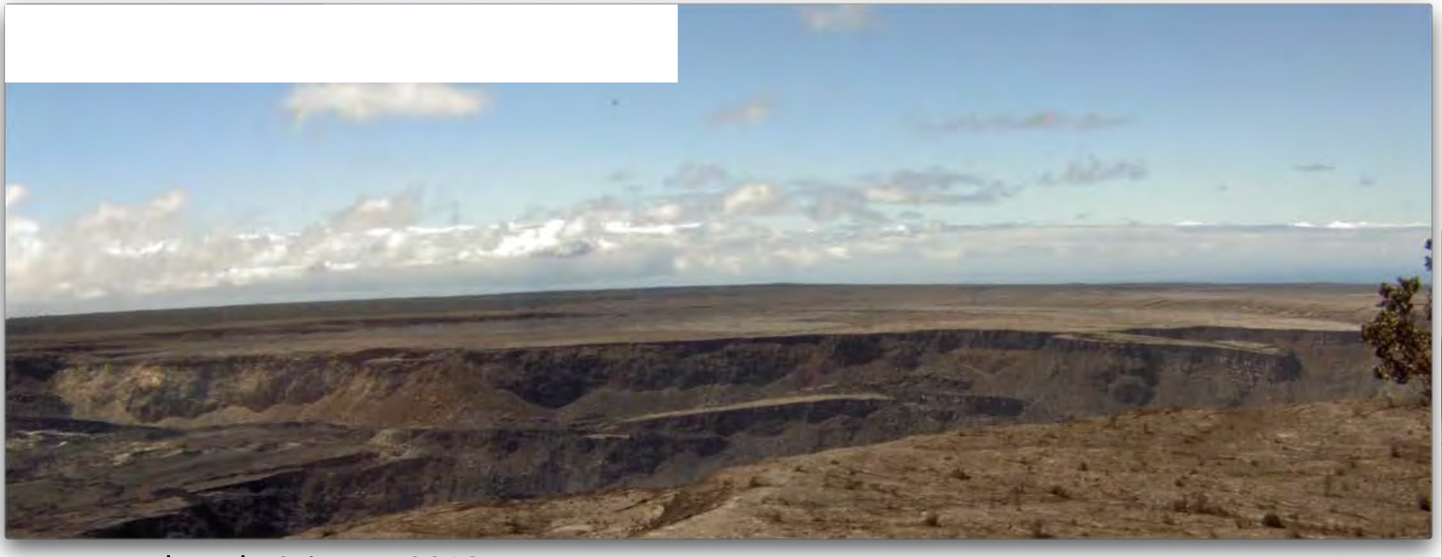
Smoothing Models: Sensitivity (weight of 1.0 for each model)

- Sensitivity comparing lowest and highest N-numbers
- Differences and ratios are low, in localized areas



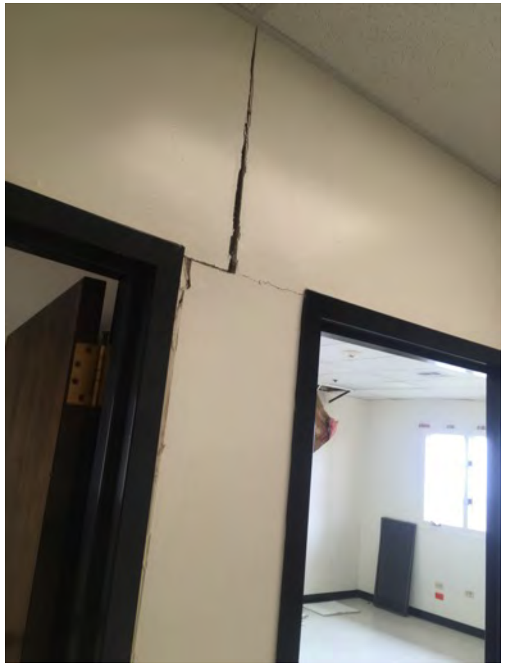


6. Caldera Collapse Earthquakes



From Neal et al., Science, 2019

2018	Number
M ≥ 4.0	85
M ≥ 4.5	63
M ≥ 5.0	54
M ≥ 5.5	0



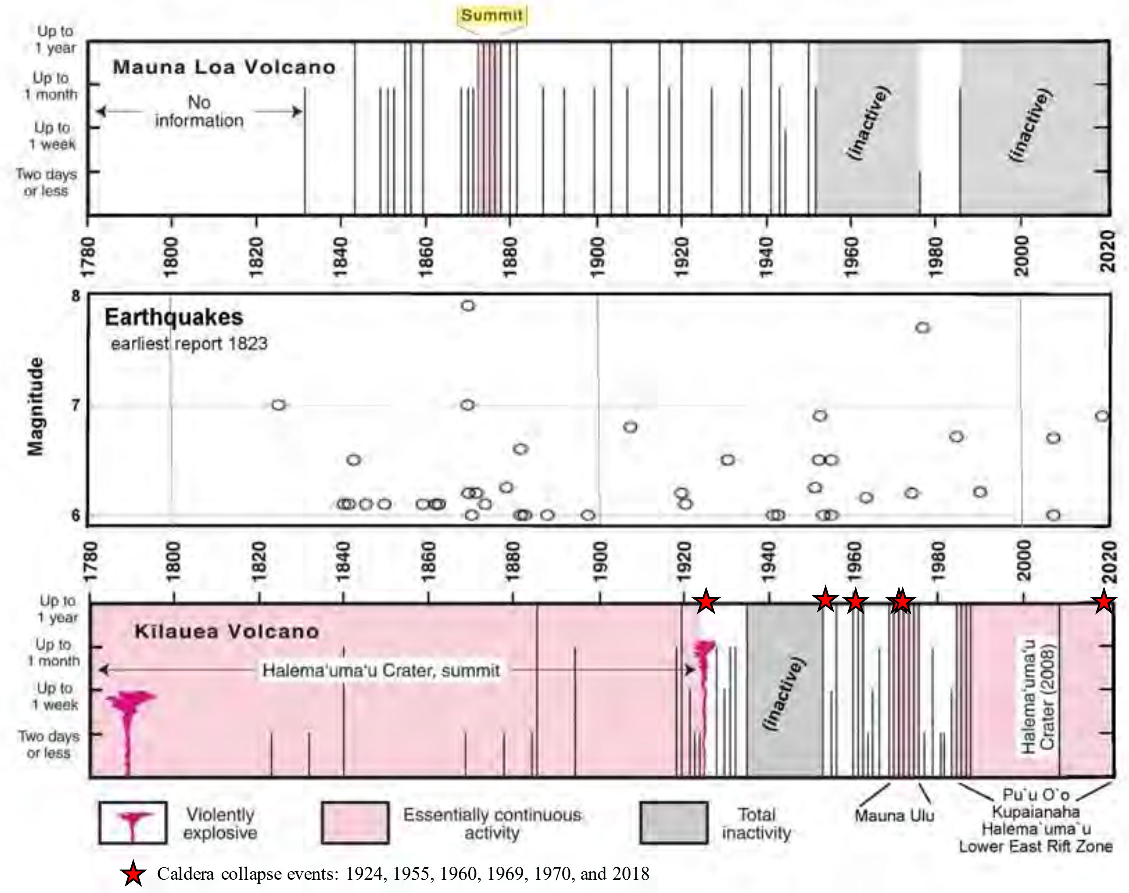
photos from USGS HVO

6. Caldera Collapse Earthquakes

- Since 1906, there have been 6 summit subsidence events at Kilauea that included earthquakes within the caldera.
- We term these Caldera Collapses.

Year	M≥4 earthquakes	M≥5 earthquakes
1924	24	0
1955	0	0
1960	0	0
1969	0	0
1970	0	0
2018	85	54

Island of Hawai`i Eruption and Large Earthquake (M 6 or larger) Timelines
adapted from Tilling and others [2010], USGS GIP 117, and USGS ComCat



6. Caldera Collapse Earthquakes

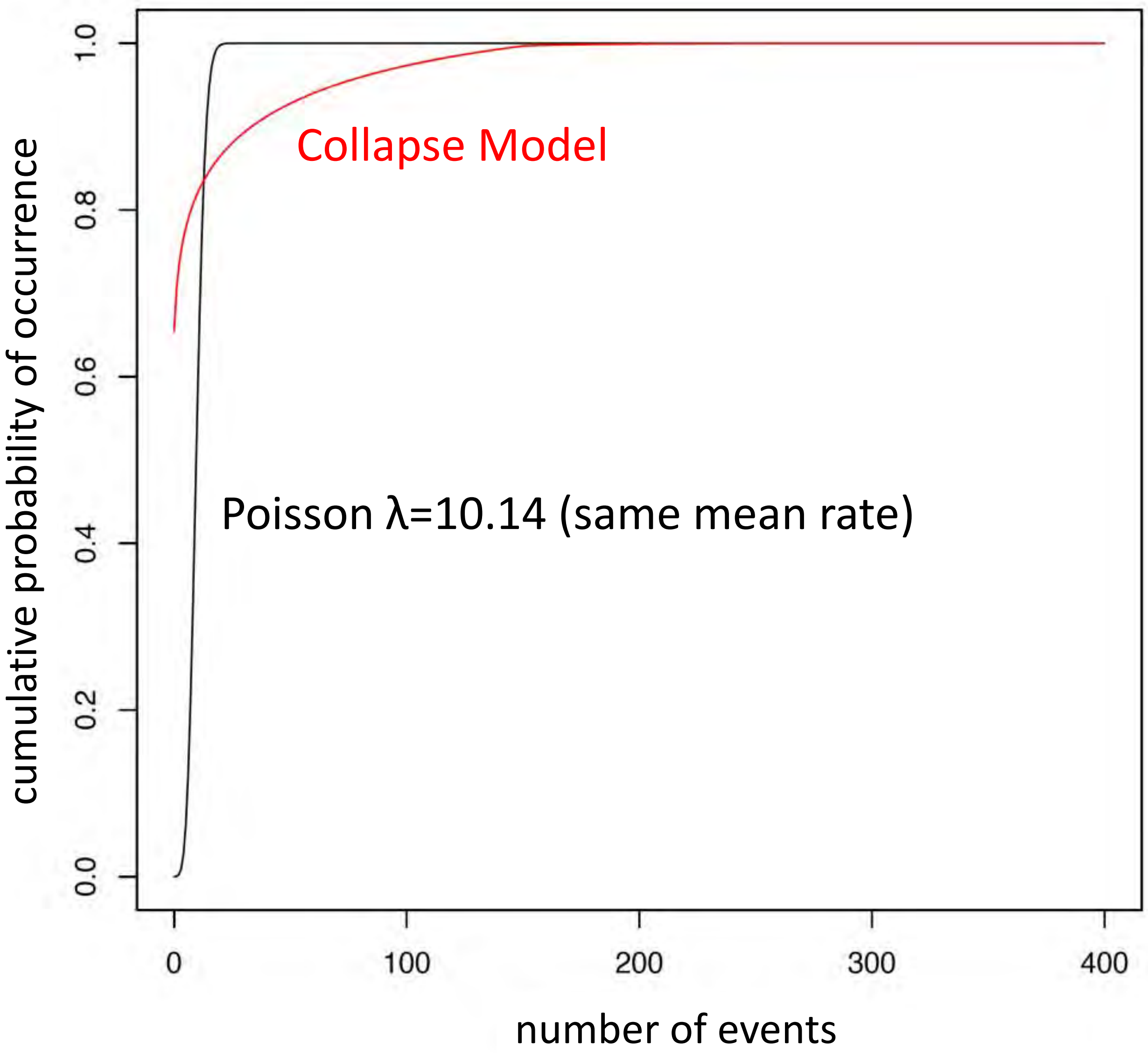
- Clustered Earthquake Probability Model:
  - Random, independent Caldera Collapses
  - Poisson rate of 2.6 collapses/50 years

Combined with

  - Rate of earthquakes in a collapse
  - Fit data to negative binomial distribution
  - Maximum number based on total volume above the magma chamber as compared to the volume of the 2018 collapse.

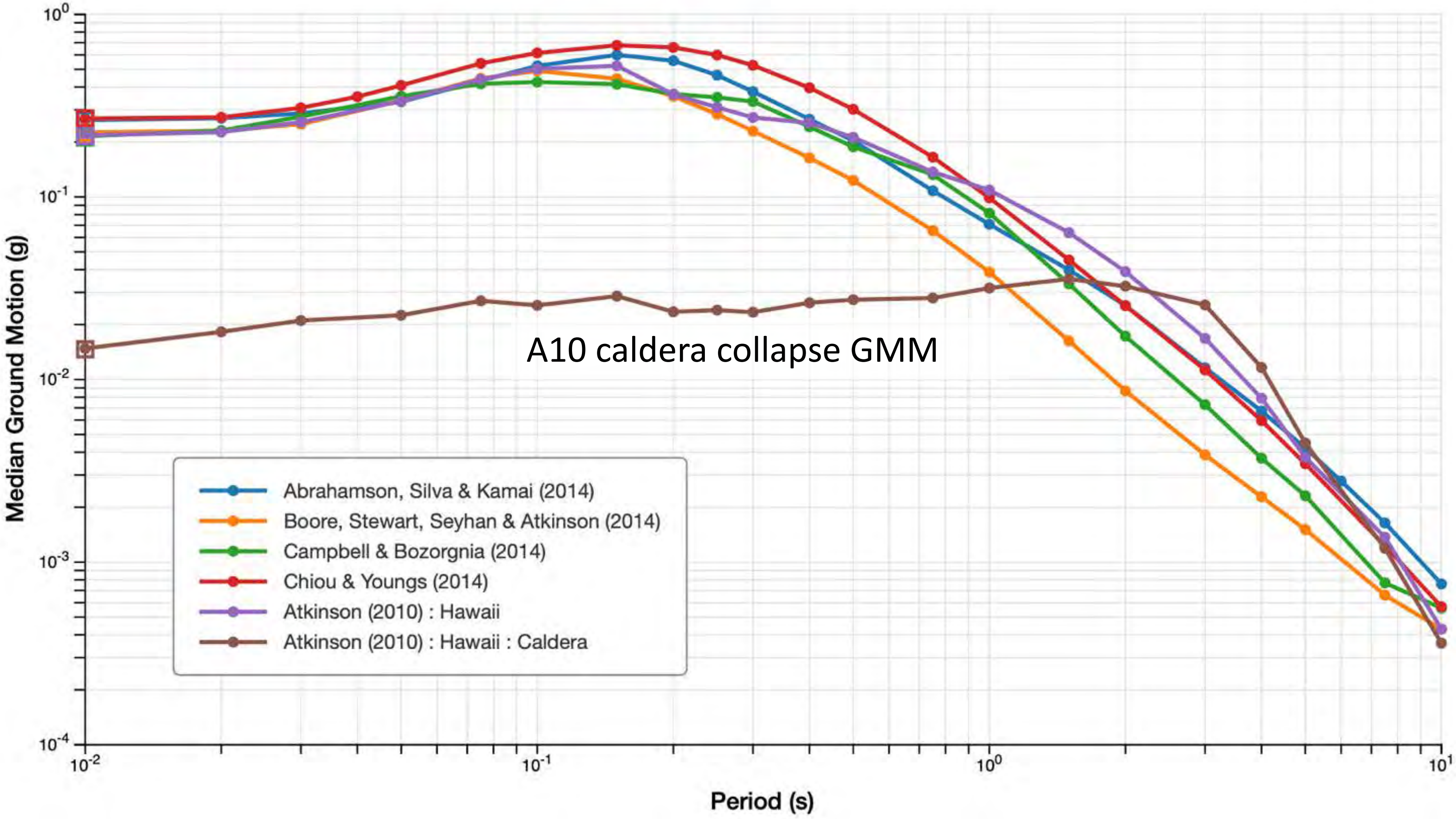
Collapse model will be published as Llenos and Michael.

Cumulative Probability of $M \geq 5$ earthquakes in 50 years



6. Caldera Collapse Earthquakes

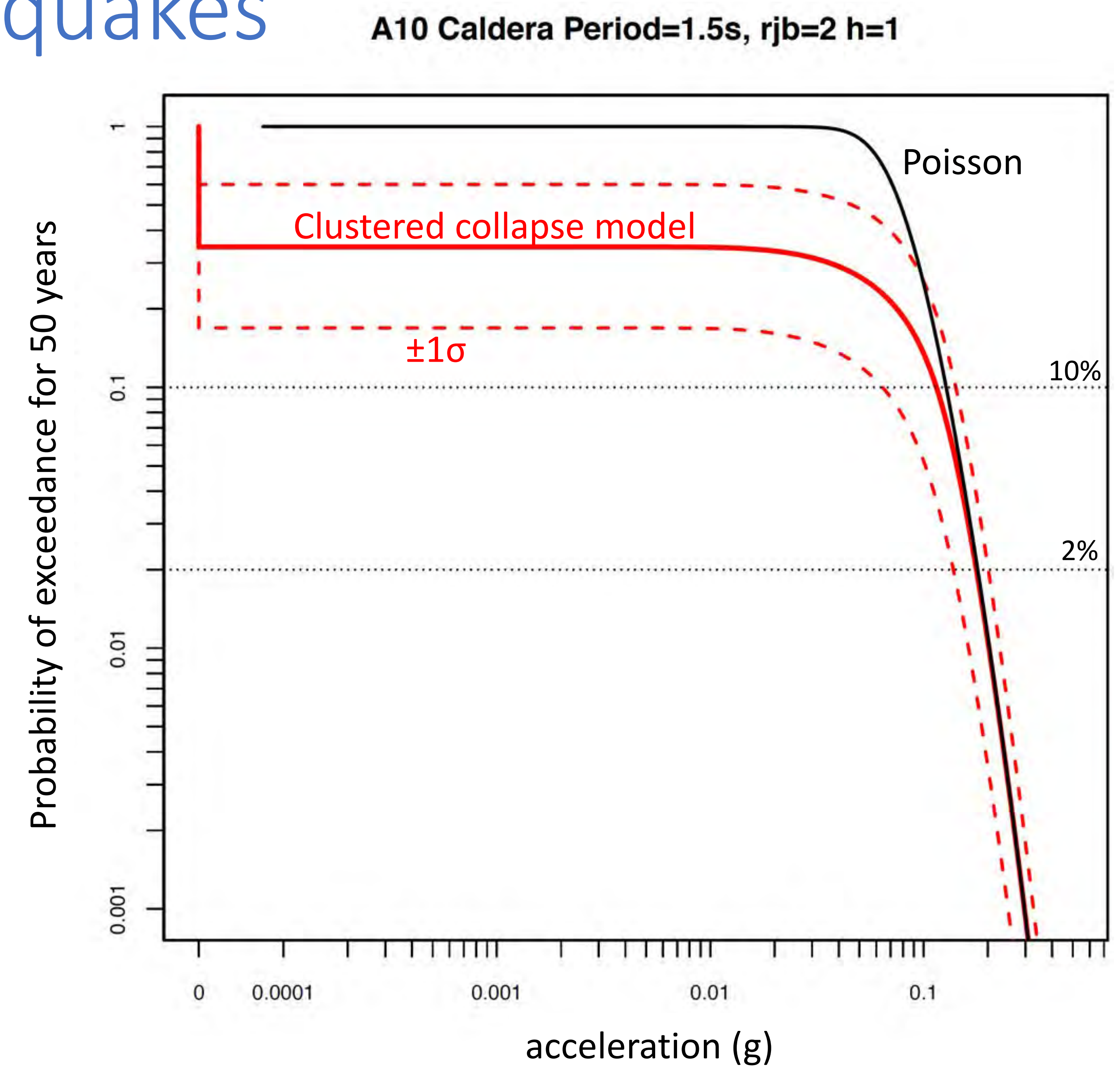
Collapse earthquakes have reduced ground motion at short periods.



A10 modified for caldera collapse events by Dan McNamara, Morgan Moschetti, and Peter Powers.

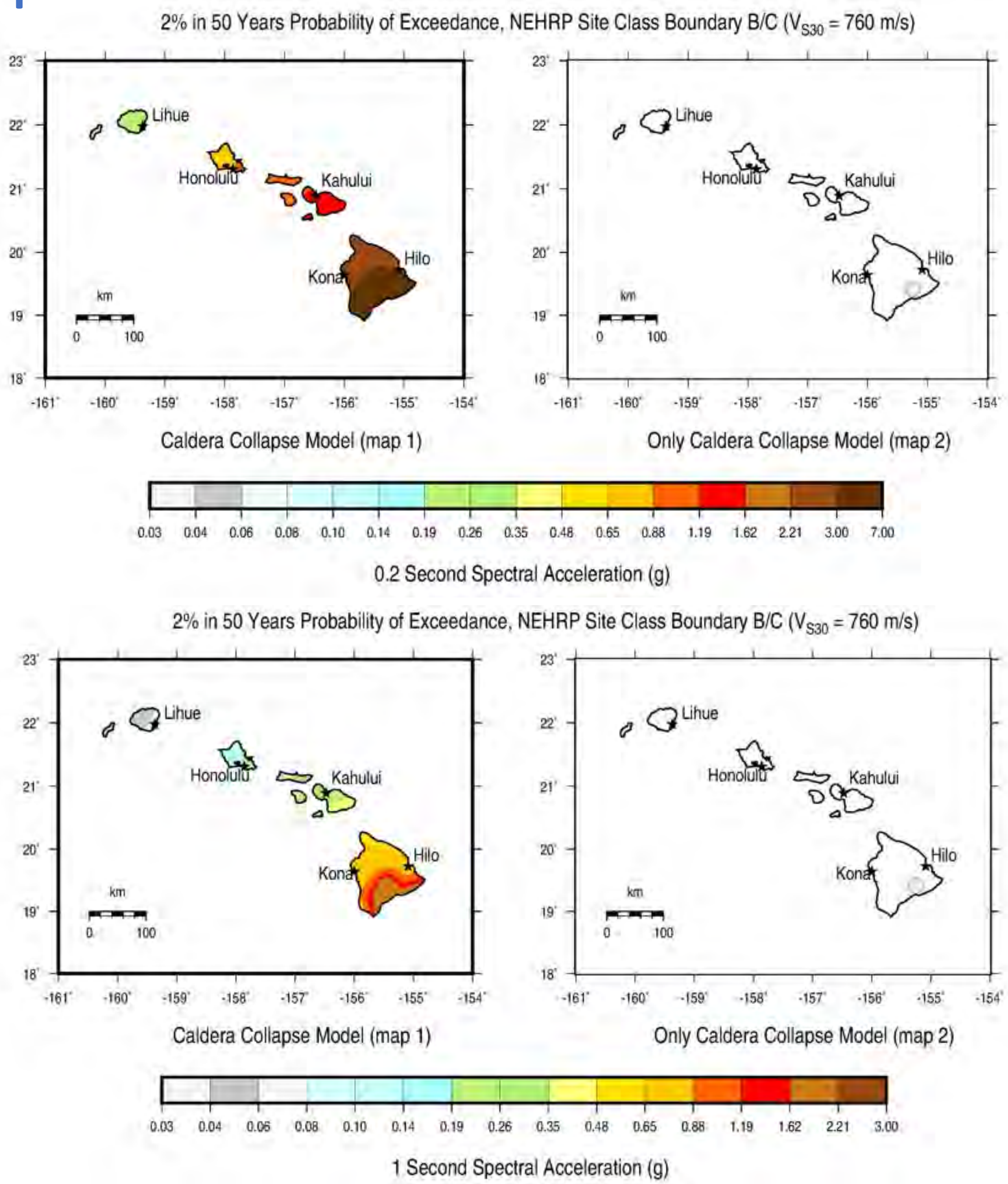
6. Caldera Collapse Earthquakes

- Clustered behavior requires using probability and not rate of exceedance.
- Poisson model is adequate at probabilities 10% in 50 years or less.
- Poisson model overestimates ground motions at higher probabilities.



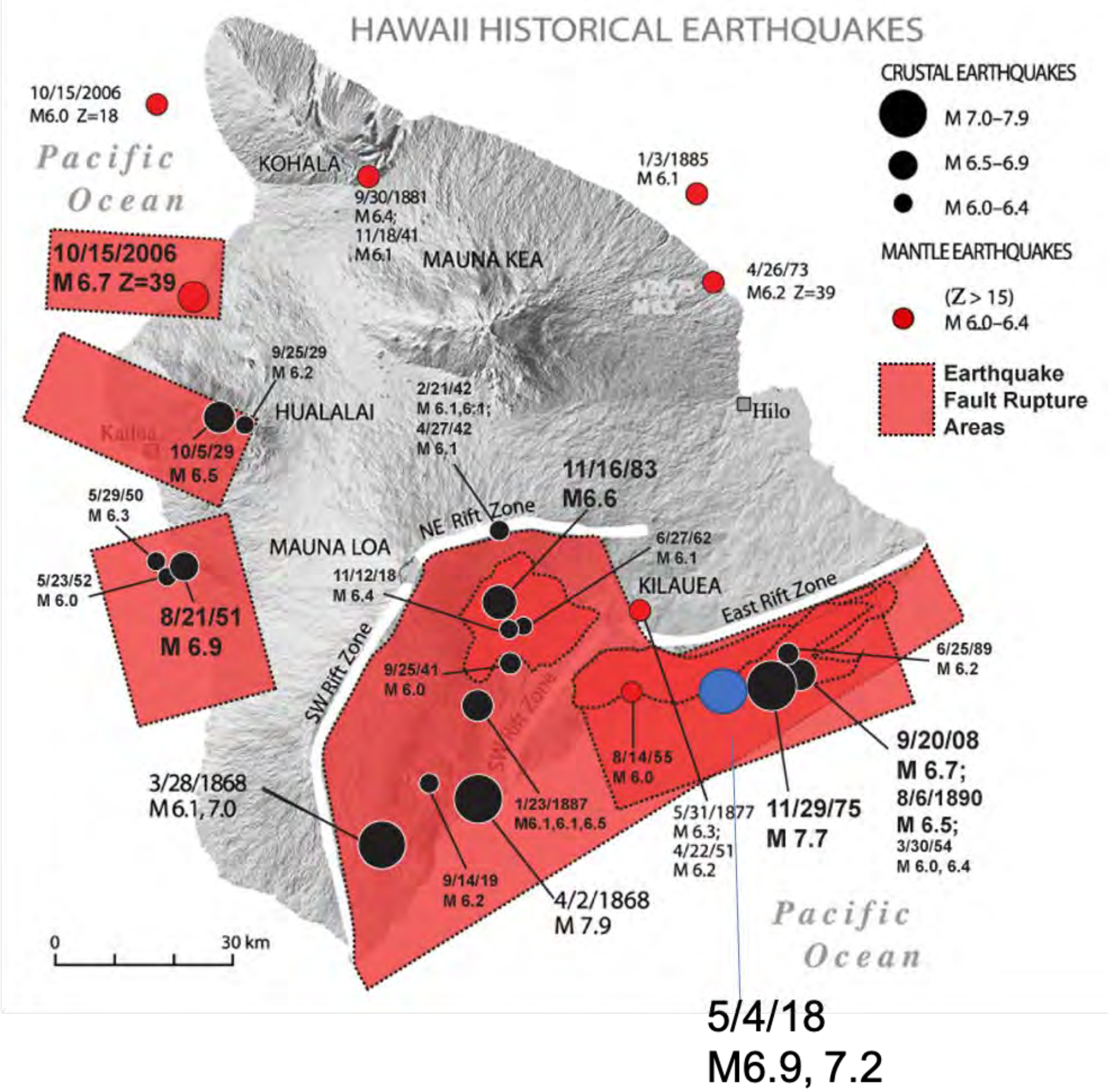
6. Caldera Collapse Earthquakes

- Mean hazard at 2% in 50 years for 0.2 s (top) and 1.0 s (bottom).
- Total hazard (left) vs. only caldera collapse hazard (right).
- Uses Poisson model.
- Caldera collapse hazard is only an issue close to Kilauea caldera.
- Can't ignore these events due to damage to HVO and potentially other caldera area structures.



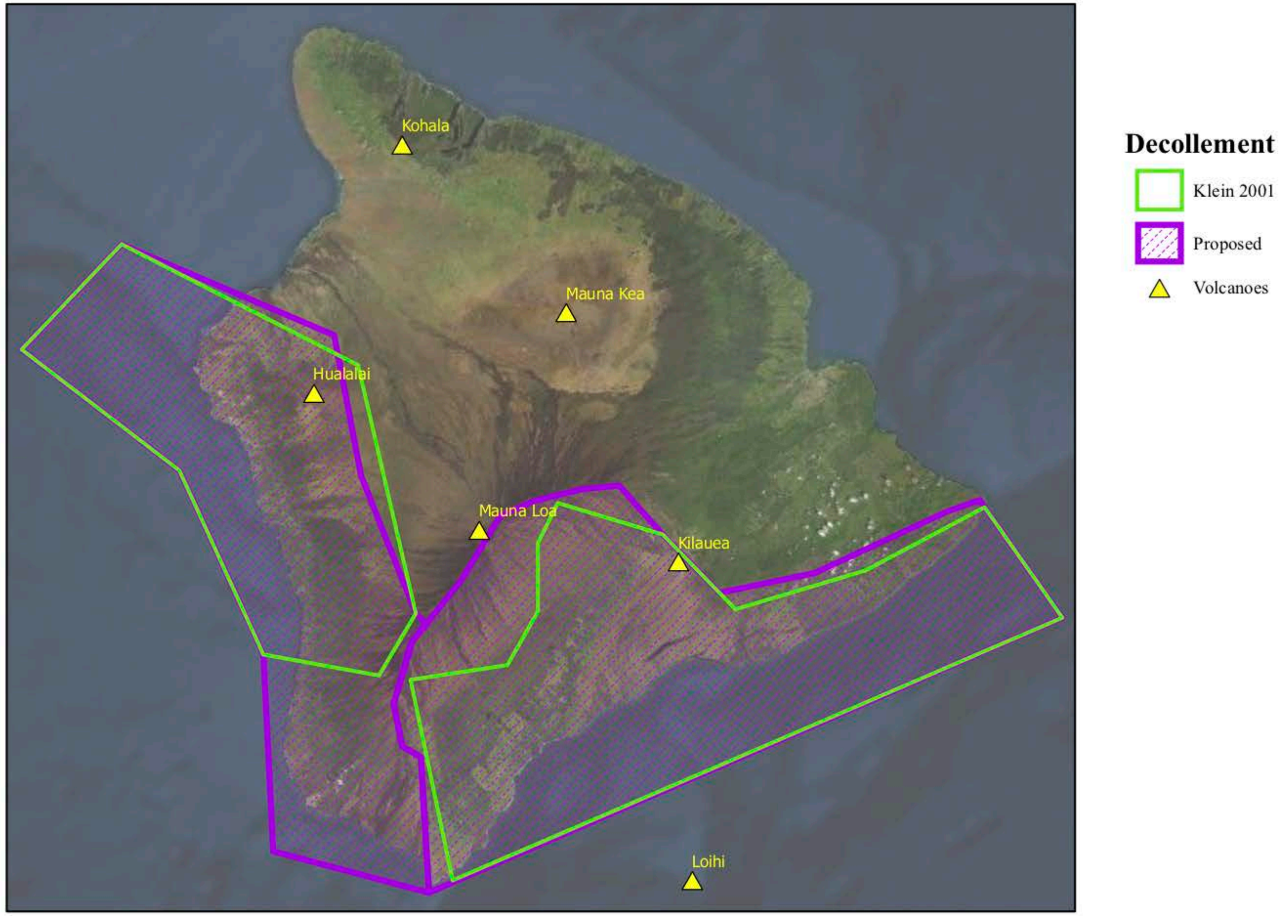
7. Fault Model

Figure from Klein et al. (2001); updated by Brian Shiro and Mark Petersen

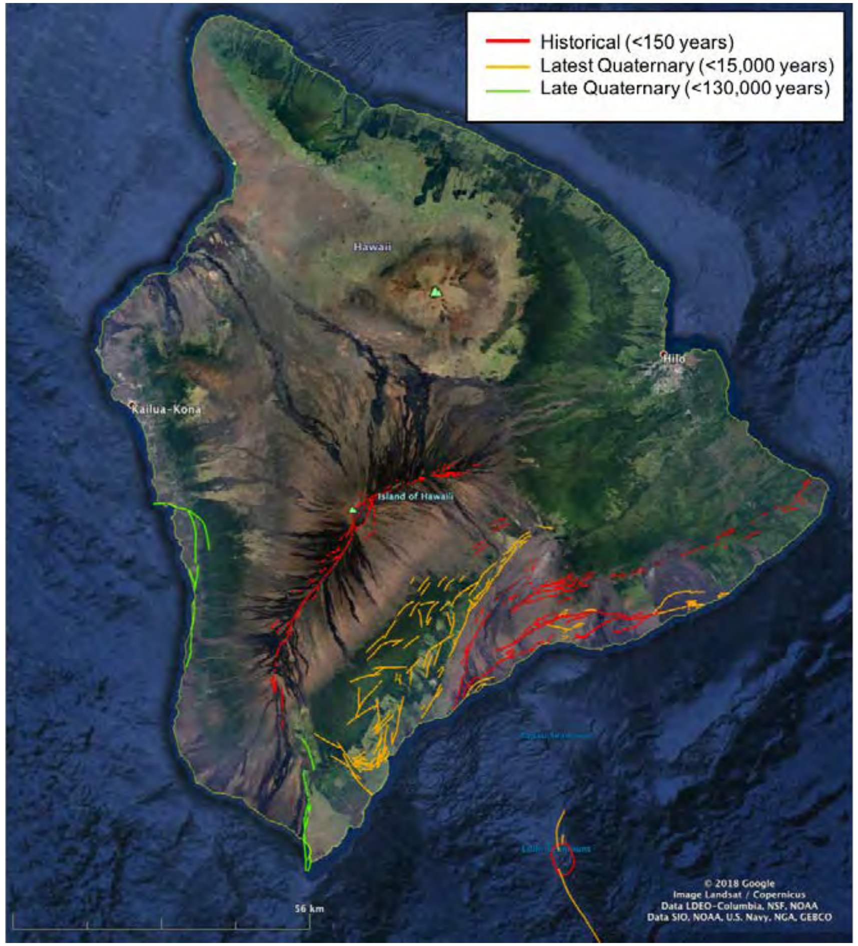


Fault Model: Geometry

(a) Flank Source Geometries

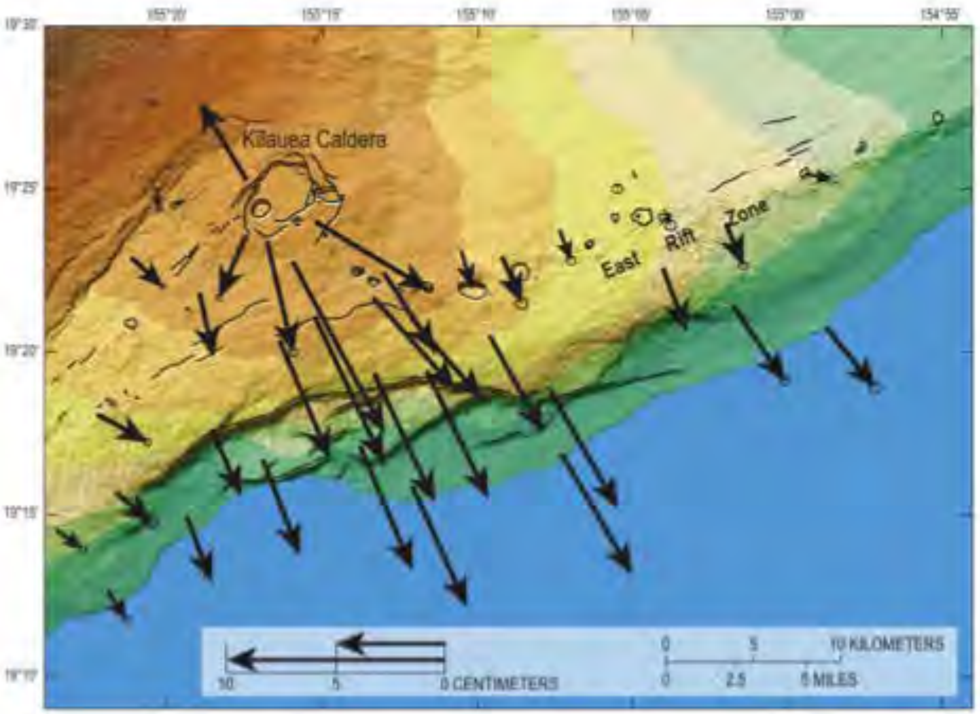


(b) Quaternary Faults



We have updated the décollement geometries from Klein et al. (2001), based on evidence in the Q-Fault database

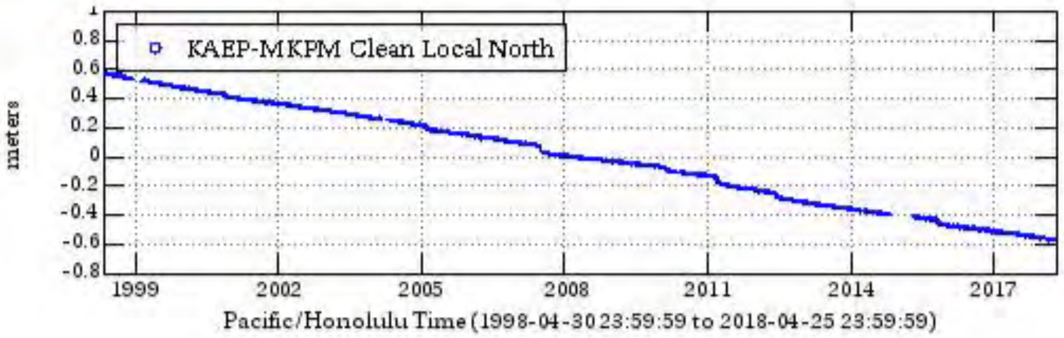
Fault Model: Slip rates



Geodetic data

Figure from Emily Montgomery-Brown (USGS)

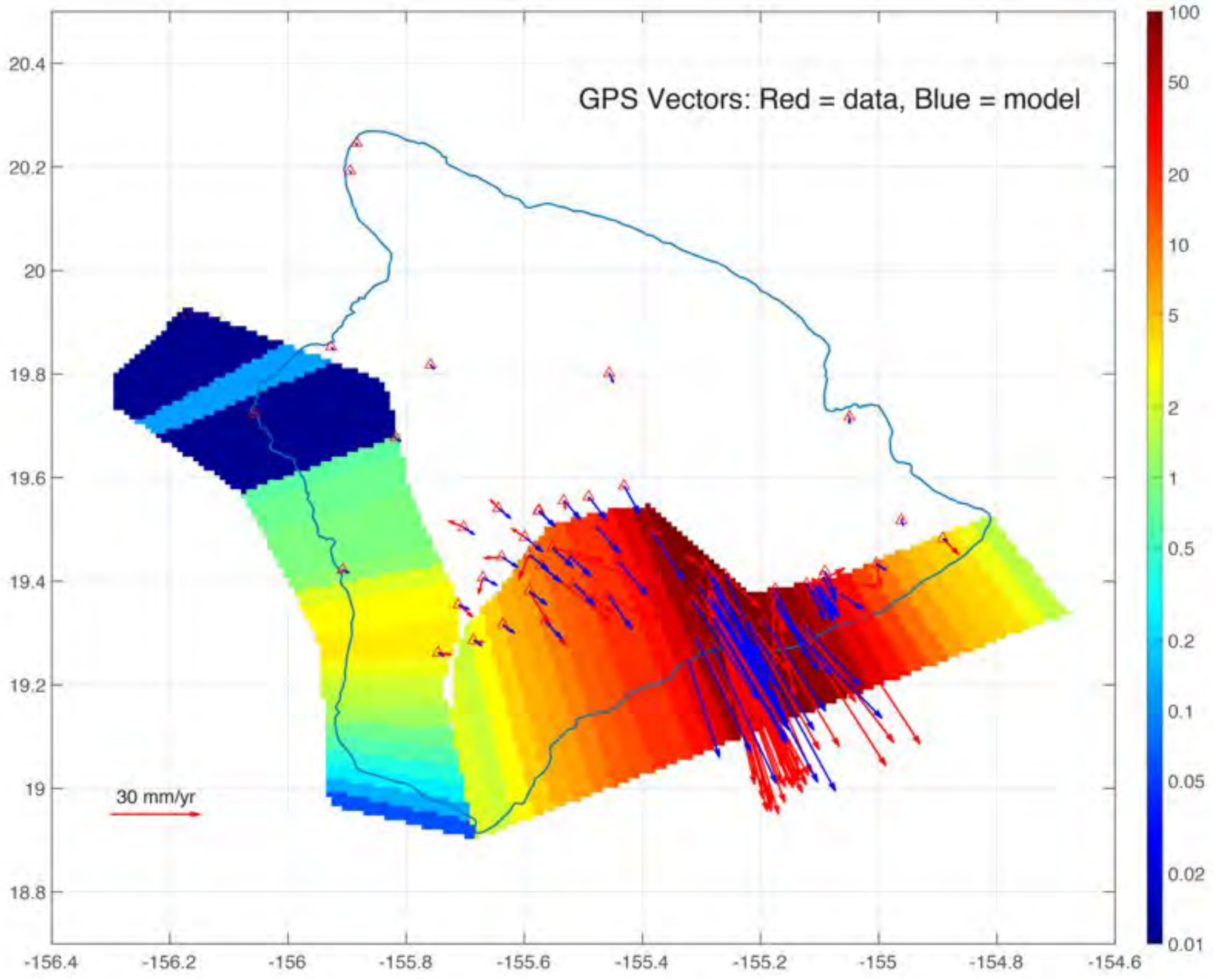
Slip about 7 cm/yr which is faster than the San Andreas Fault in California



Fault Model: Slip rates

Geodetic model

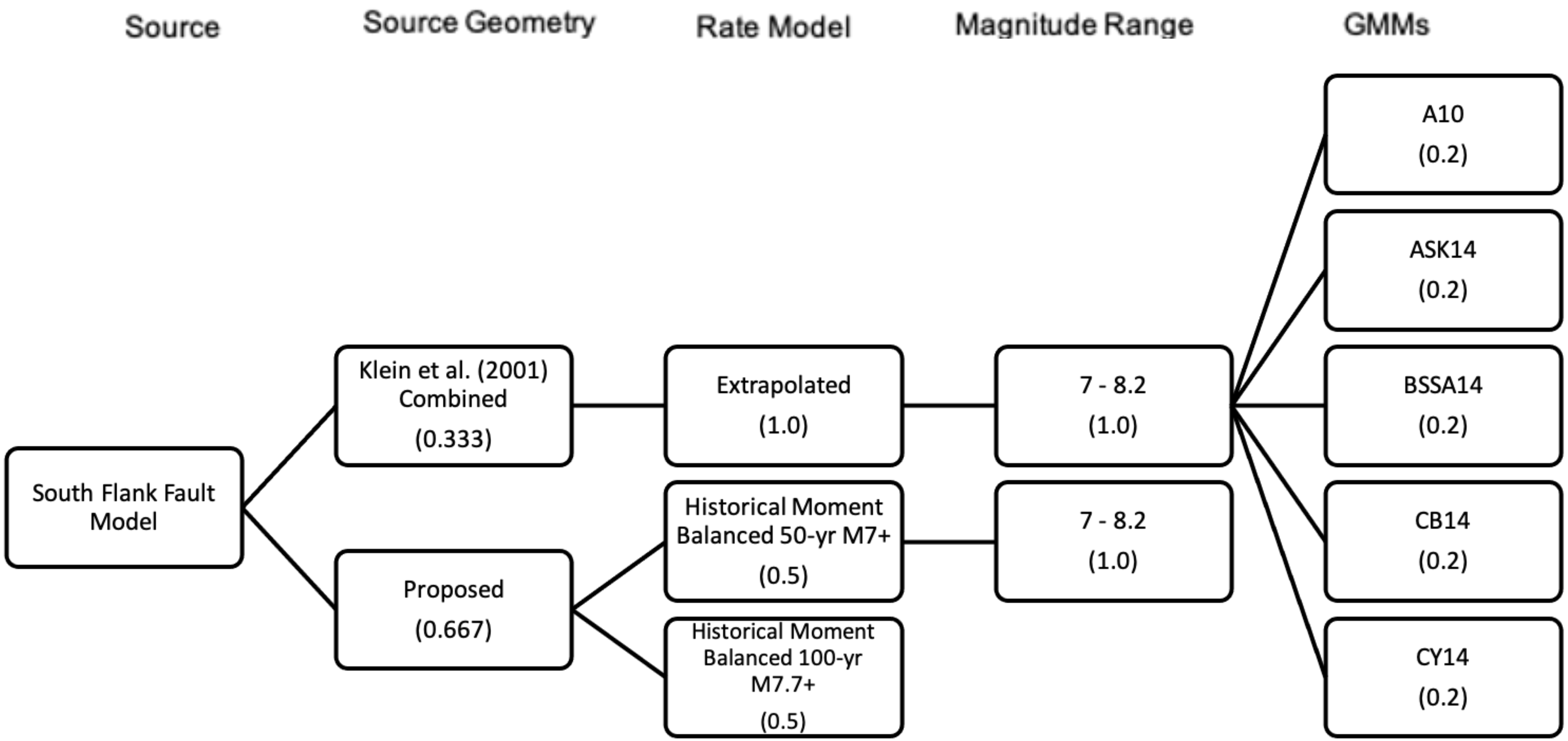
- GPS data (J. Foster and G. Apuzen-Ito).
- South flank geodetic models for décollement motion significantly higher than for west flank.
- Western flank M7 rate is modeled as about 1000-1500 years (similar to Klein et al. [2001] rate and the strain rate data).



Fault Model: Southern Décollement

- Klein et al. (2001) and applies an *a*-value of 1.552 and a *b*-value of 0.5713 for larger earthquakes. We apply their model for consistency and because it is a viable model that we cannot rule out using recent data.
- The second and third models are based on the inter-event timing of historical earthquakes with M > 7 and with comparisons with moment rate analysis (Chen et al., 2019).
- For model 2 we consider a 50-year recurrence of M 7+ (370 years for M 7.7+) earthquakes for earthquakes between M 7 and M 8.2. This is similar to interevent time between 1975 and 2018 events or 3 events in 150 years.
- For model 3 we consider a 100-year recurrence of M 7.7+ (20 years for M 7+) earthquakes for earthquakes between M 7 and M 8.2. This is similar to interevent time between 1868 and 1975 events.
- Each model is weighted 1/3, equal weights.

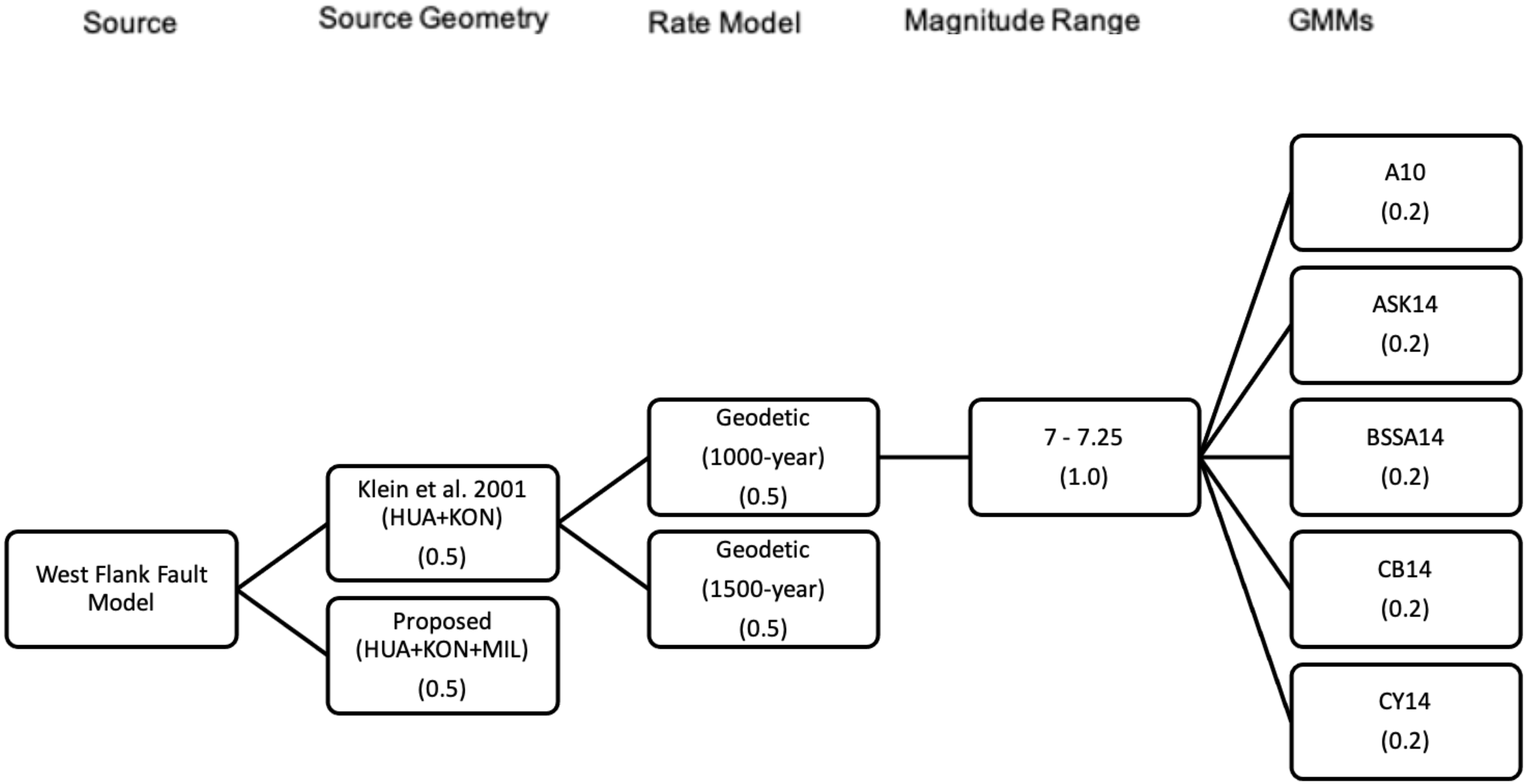
Fault Model: Southern Décollement



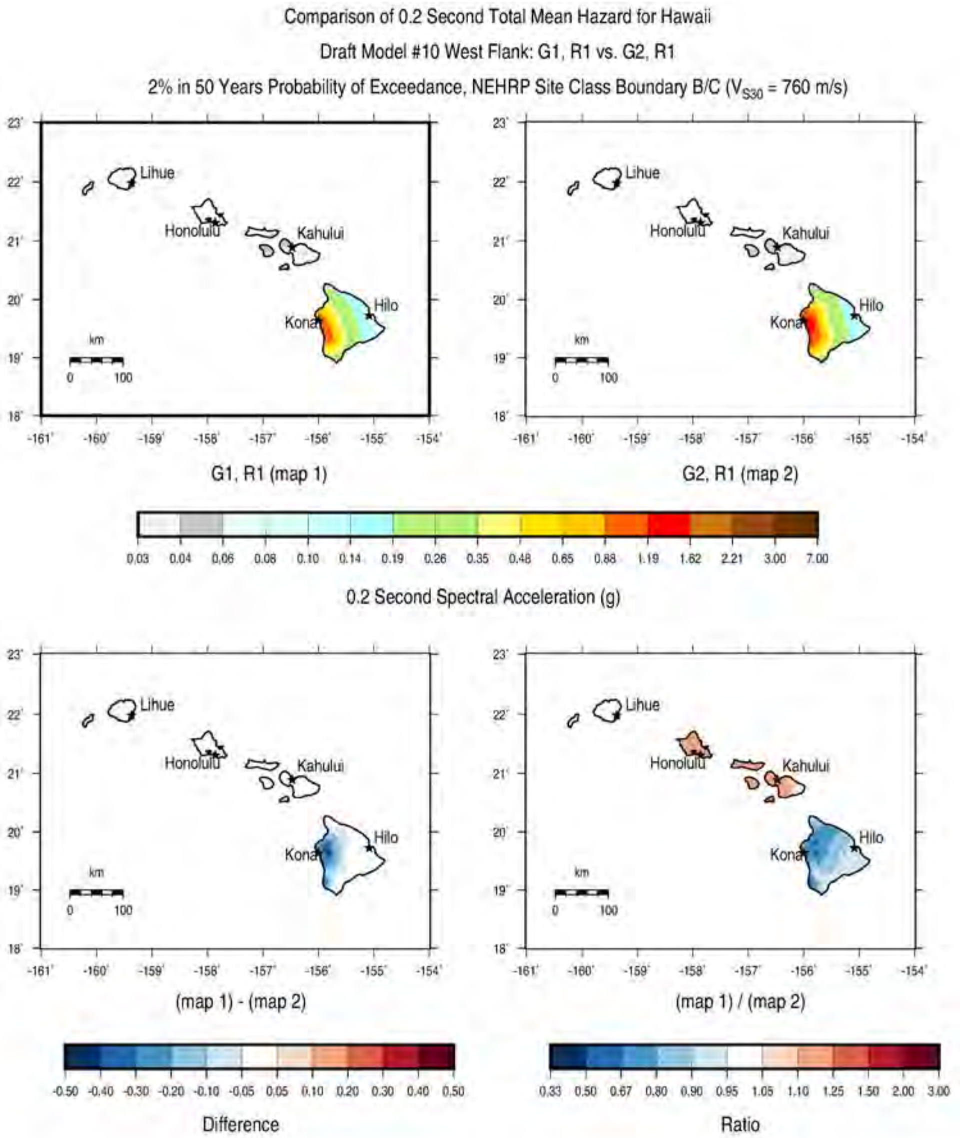
Fault Model: Western Décollement

- Geodetic models suggest much lower expected earthquake rates on the western flank décollements
- Our calculation of M7+ earthquakes using Klein et al. (2001) a- and b-values is generally consistent with a 300-year recurrence for M 7 earthquakes for western décollement sources.
- To estimate recurrence rates of M7 earthquakes for the west flank, we need an estimate of average fault displacement in a M 7 earthquake and a slip rate which we determined to be about 1.1 mm/yr.
- Zeng et al. (1986) indicate that the Loma Prieta earthquake (M 6.9) had an average displacement of about 1 m strike-slip motion.
- If we consider that a M 7 may rupture with 1 m displacement and the fault slips with 1.1 mm/yr, it would take about 1000 years for the appropriate displacement to build up.
- We consider two models to explain the earthquakes on the west décollement. The first model considers a 1000-year recurrence for M 7 earthquakes and the second model considers a 1500-year recurrence for M 7 earthquakes, based on estimates from GPS and slip rates described above. This second model could assume aseismic slip strain release.

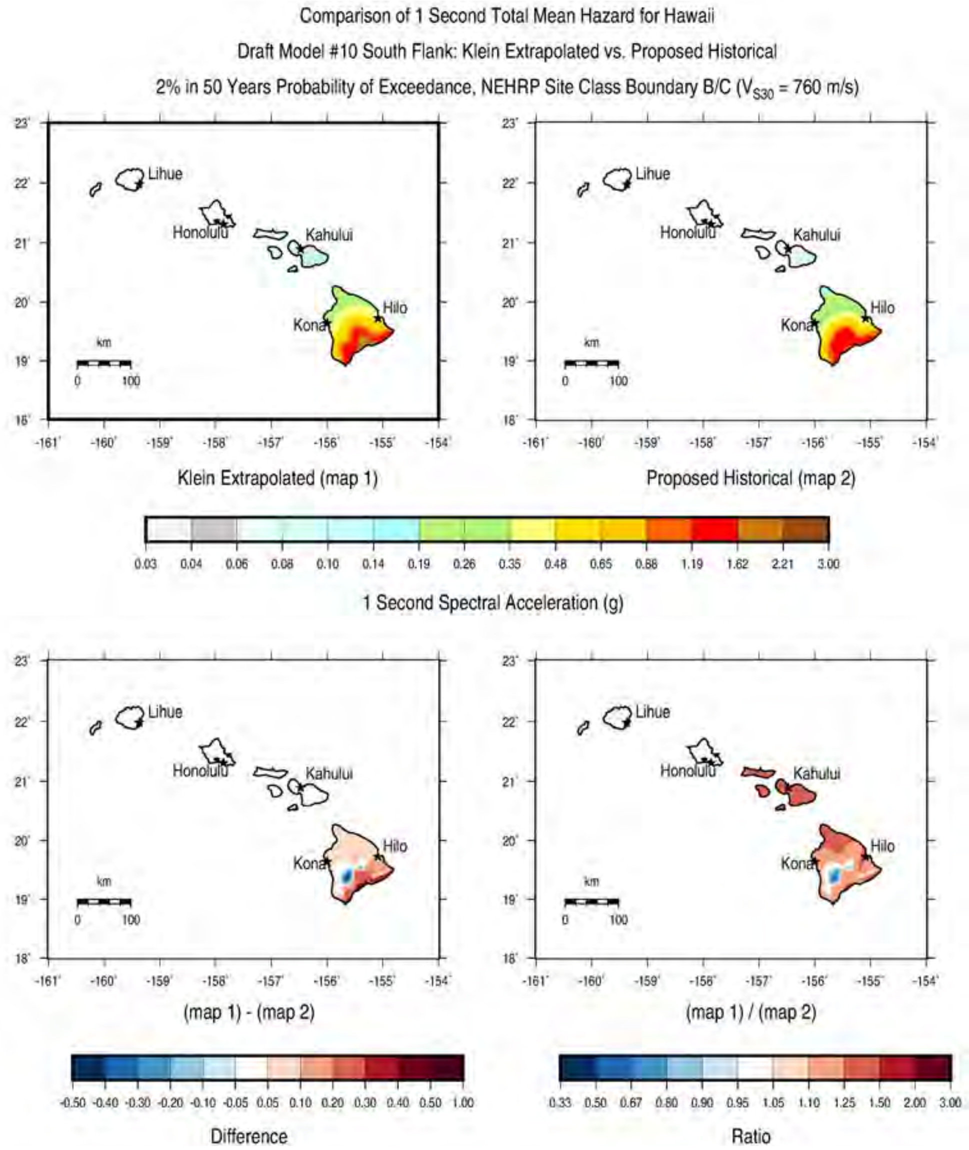
Fault Model: Western Décollement



Fault Model Sensitivities (weight of 1.0 for each model)



West Flank Geometry Comparison



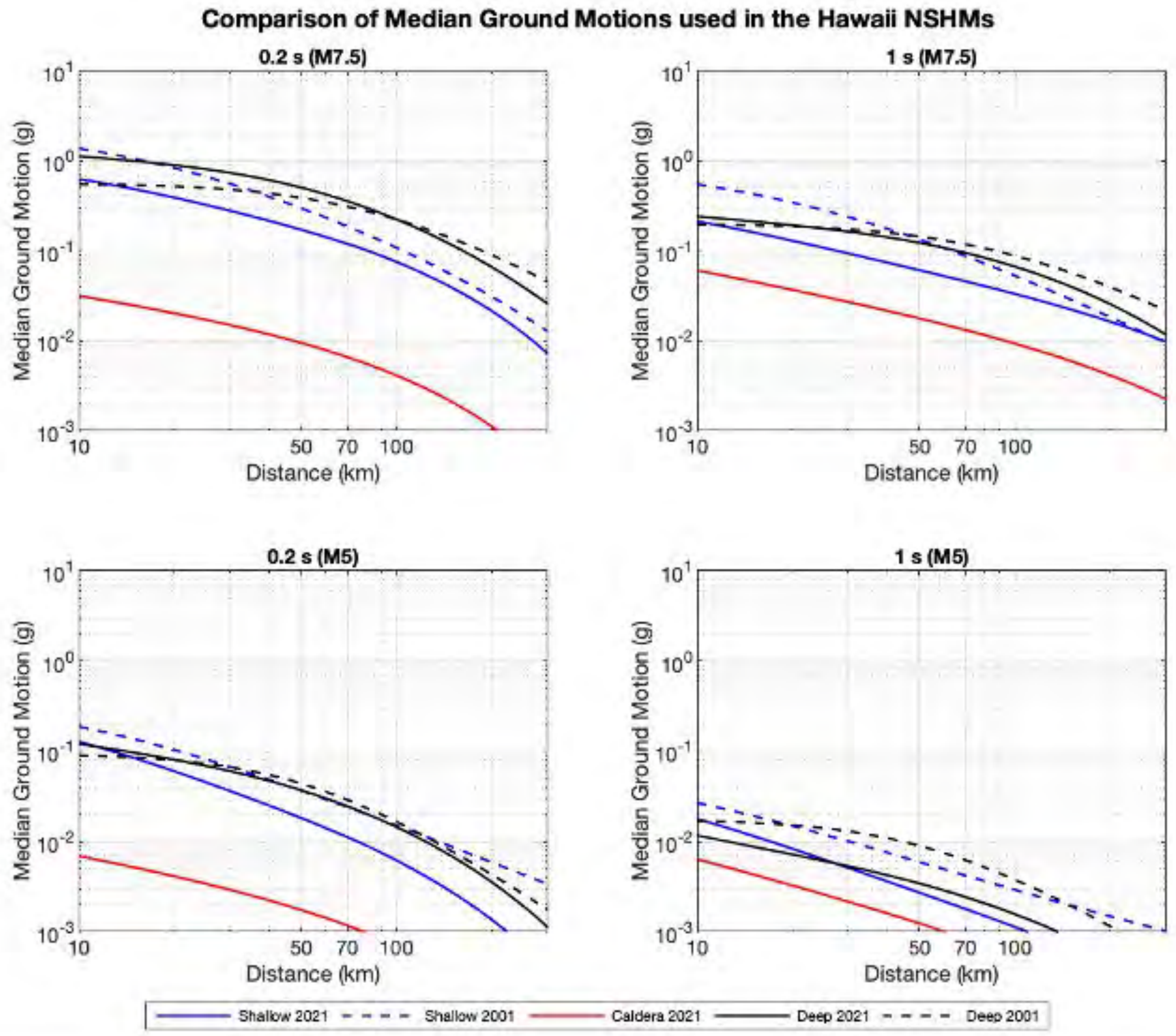
South Flank Rate Model Comparison

8. Ground Motion Models

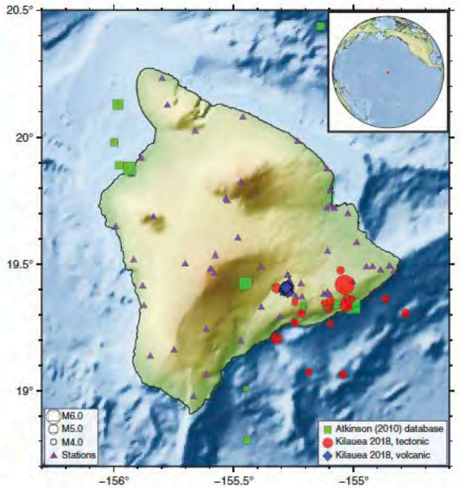
2001 GMMs (Klein et al., 2001)				2021 GMMs (This study)		
GMM	**Abbreviation**	**Weight**		**GMM**	**Abbreviation**	**Weight**
		M 5-7	**M 7-8.2**			
Active Crustal GMMs						
Boore et al. (1997)	B97	0.25 (PGA) 0.33 (0.2 s) 0.5 (1 s)	N/A	Atkinson (2010)	A10	0.2
Campbell (1997)	C97	0.25 (PGA)	N/A	Abrahamson et al. (2014)	ASK14	0.2
Munson and Thurber (1997)	MT97	0.25 (PGA) 0.33 (0.2 s)	0.5 (PGA) 0.5 (0.2 s)	Boore et al. (2014)	BSSA14	0.2
Sadigh et al. (1997)	S97	0.25 (PGA) 0.34 (0.2 s) 0.5 (1 s)	0.5 (PGA) 0.5 (0.2 s) 1.0 (1 s)	Campbell and Bozorgnia (2014)	CB14	0.2
				Chiou and Youngs (2014)	CY14	0.2
Caldera Collapse GMM						
N/A				Atkinson (2010)	A10 Caldera	1.0
Subduction Intraslab GMMs						
Youngs et al. (1997)	Y97	1.0 (PGA, 0.2 s, 1 s)	1.0 (PGA, 0.2 s, 1 s)	Atkinson (2010)	A10	0.4
				Wong et al. (2015)	W15	0.2
				Abrahamson et al. (2016)	BCHydro12 Slab	0.4

Ground Motion Models

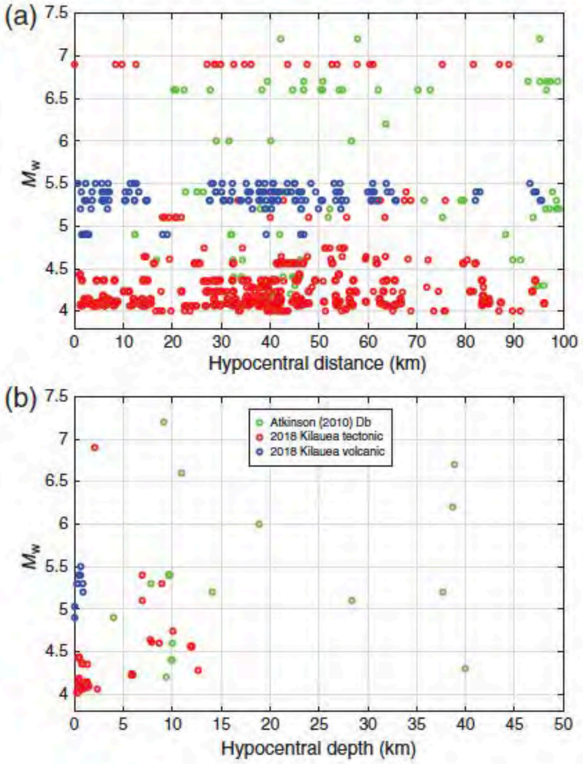
- Comparison of average GMMs for shallow (blue), deep (black), and caldera collapse events (red) in 2001 (dashed) and 2021 (solid) at 0.2s and 1s SA. Note: A caldera collapse GMM was not used in the 2001 NSHM for Hawaii.



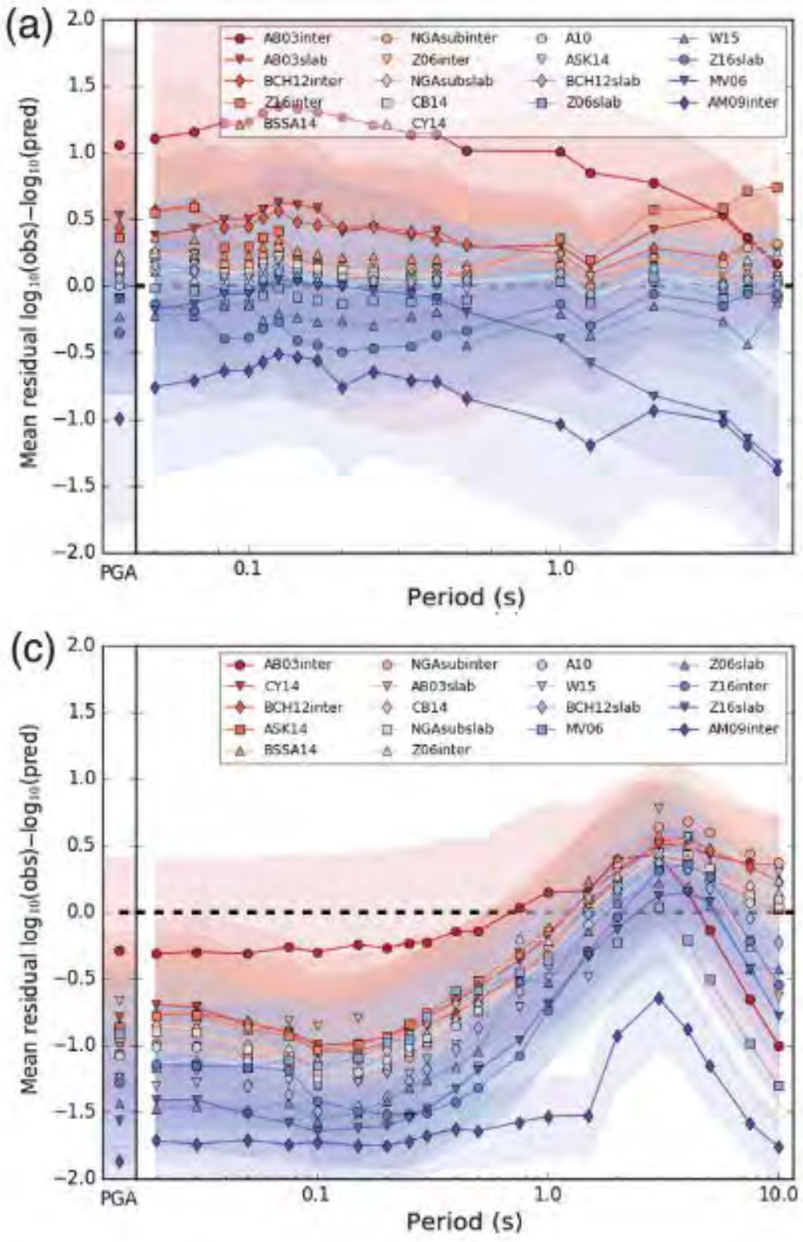
From McNamara et a. (2020, BSSA)



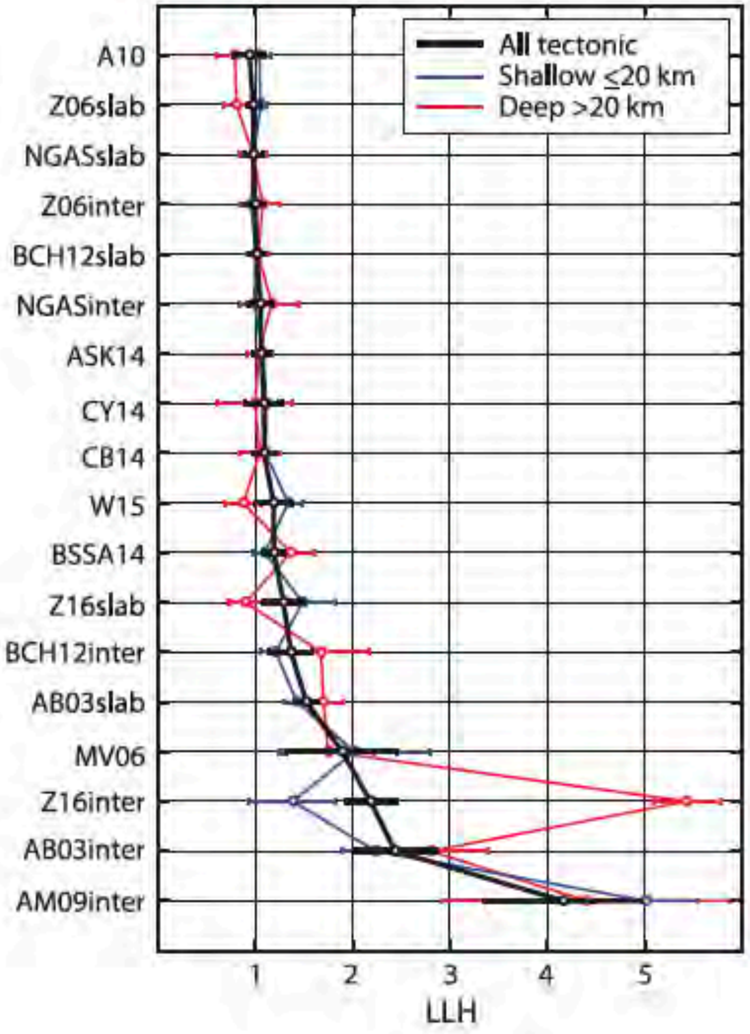
Location and size of events in the ground motion database for Hawaii



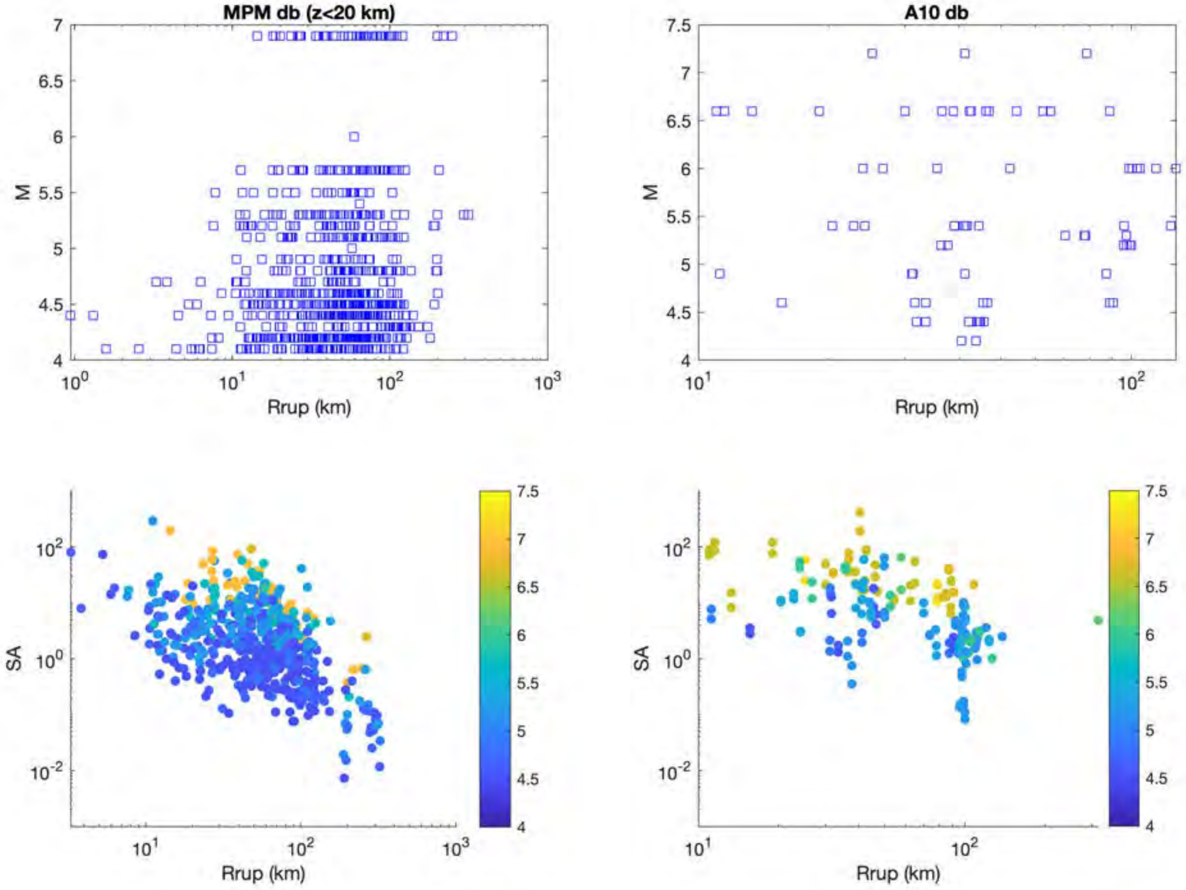
M vs. depth of events in the ground motion database for Hawaii



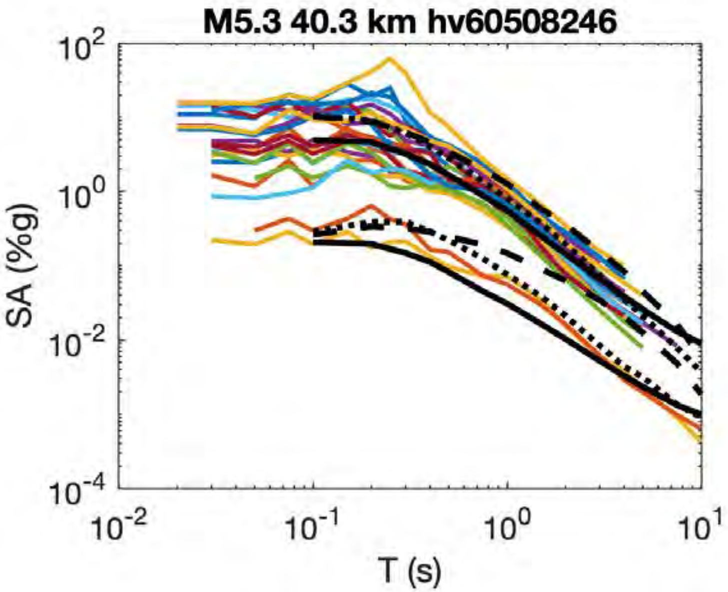
Mean residuals of GMMs vs. data in the ground motion database for Hawaii

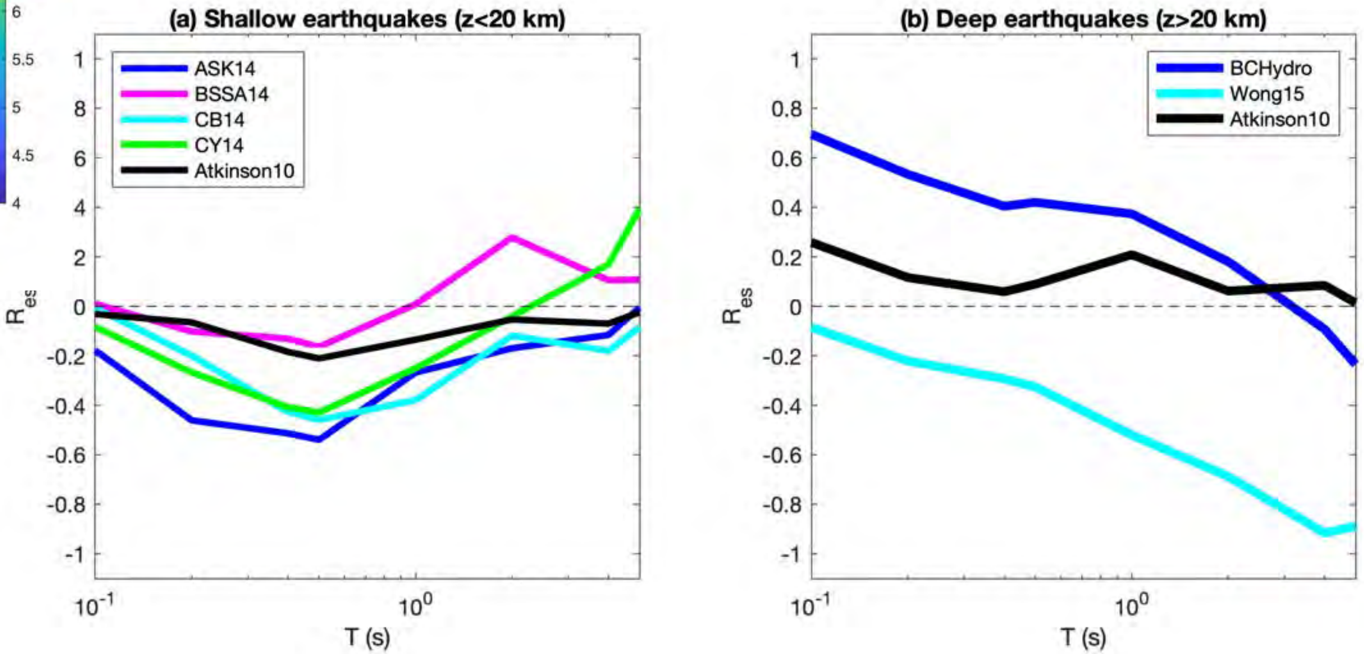


How well ground motion data in the database for Hawaii fit each GMM. This helped us select which GMMs to use in the model.



M vs. distance (Rrup) of events in our ground motion database for Hawaii vs. the A10 database.



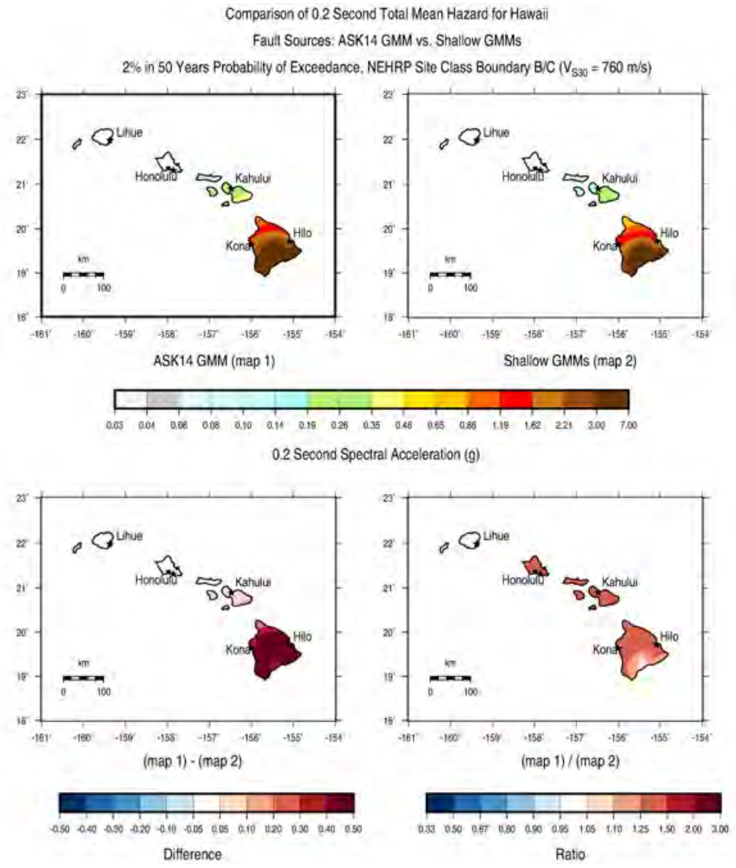


Residuals vs. period (T) for the shallow and deep GMMs we use in the 2021 model.

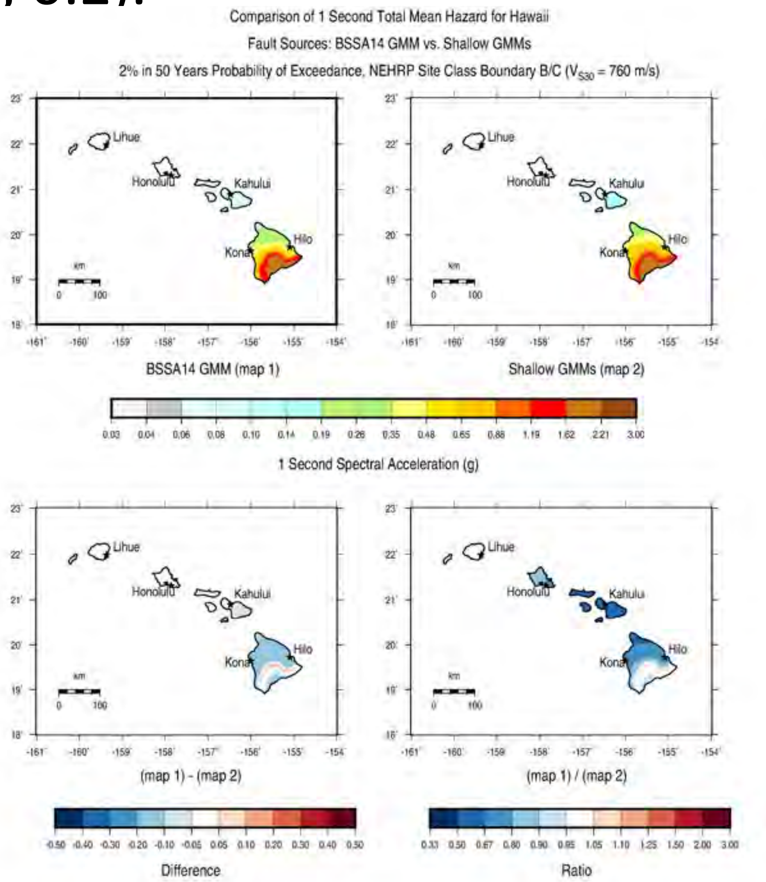
Ground Motion Model Sensitivities (weight of 1.0 for each model)

- Shallow GMMs (A10 and NGA-West2) look similar, but sensitivities show high (e.g., ASK14) and low (e.g., BSSA14) contributors to hazard.
- 0.2s comparisons of each shallow GMM (weight of 1.0) compared to weighted combination of shallow GMMs (all equally weighted: 0.2).

ASK14



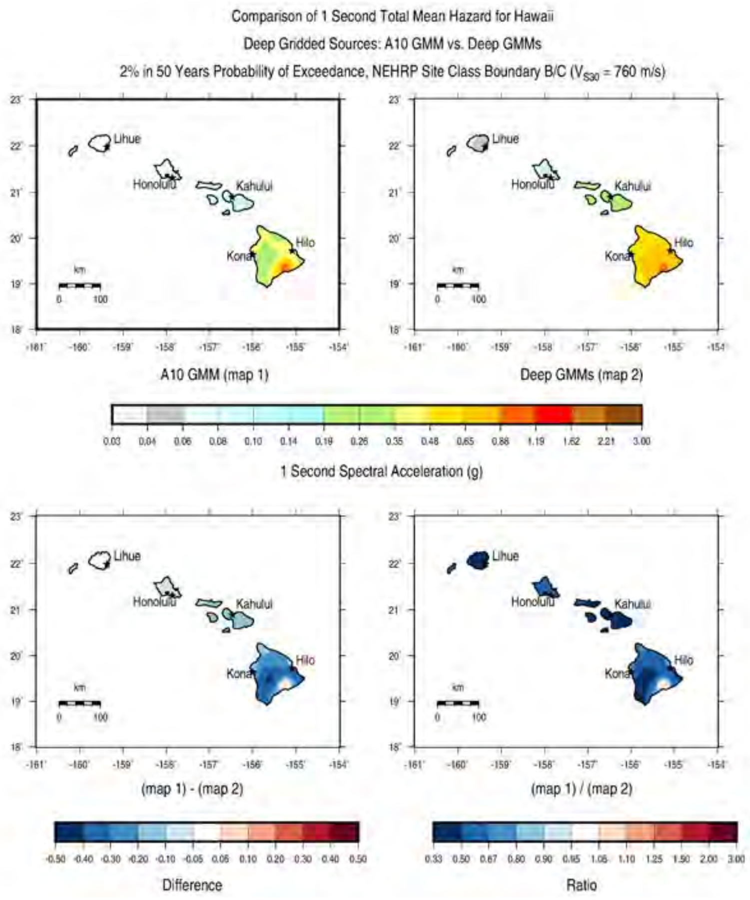
BSSA14



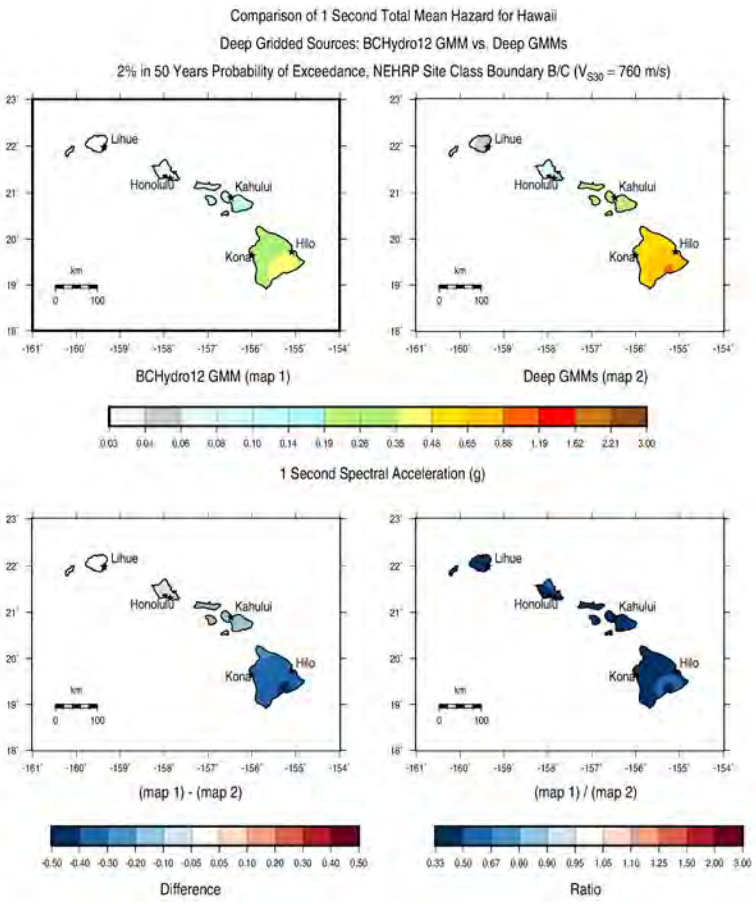
Ground Motion Model Sensitivities (weight of 1.0 for each model)

- 1s SA comparisons of each deep GMM (weight of 1.0) compared to weighted combination of deep GMMs (all equally weighted; 0.33)
- Wong et al. 2015 (W15) is higher than the other two

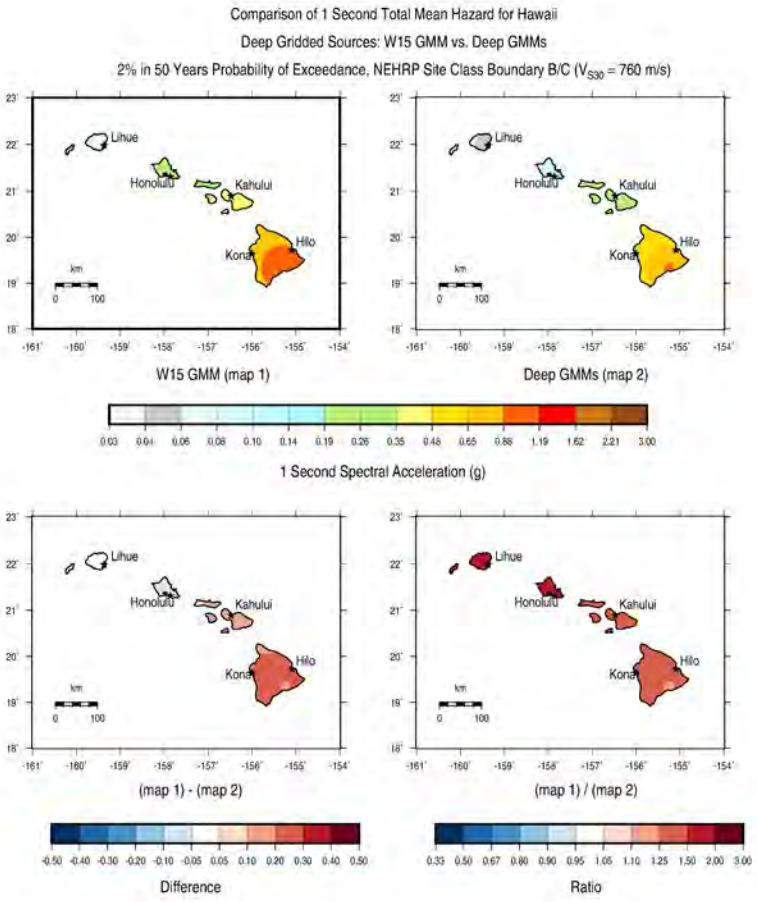
A10



BCHydro



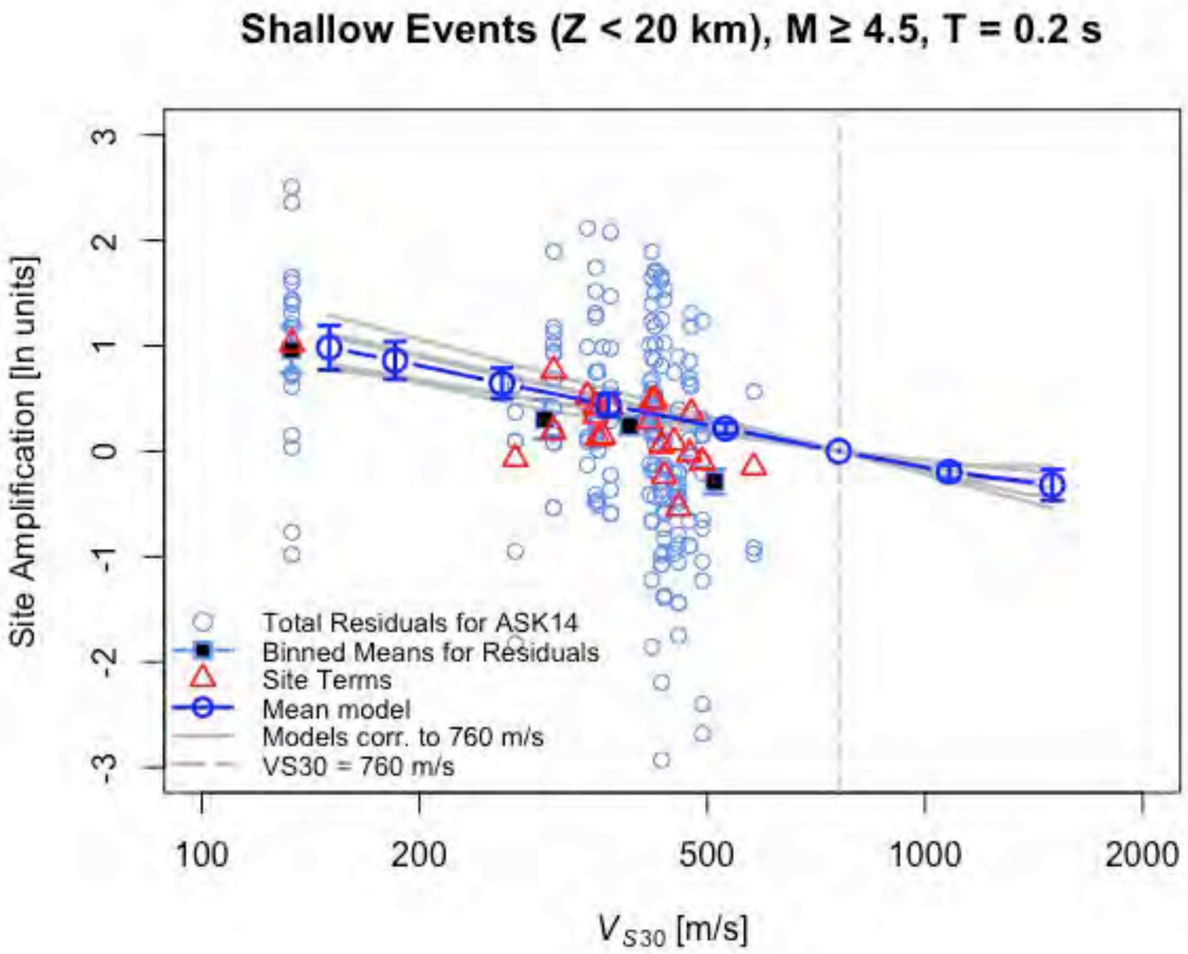
W15

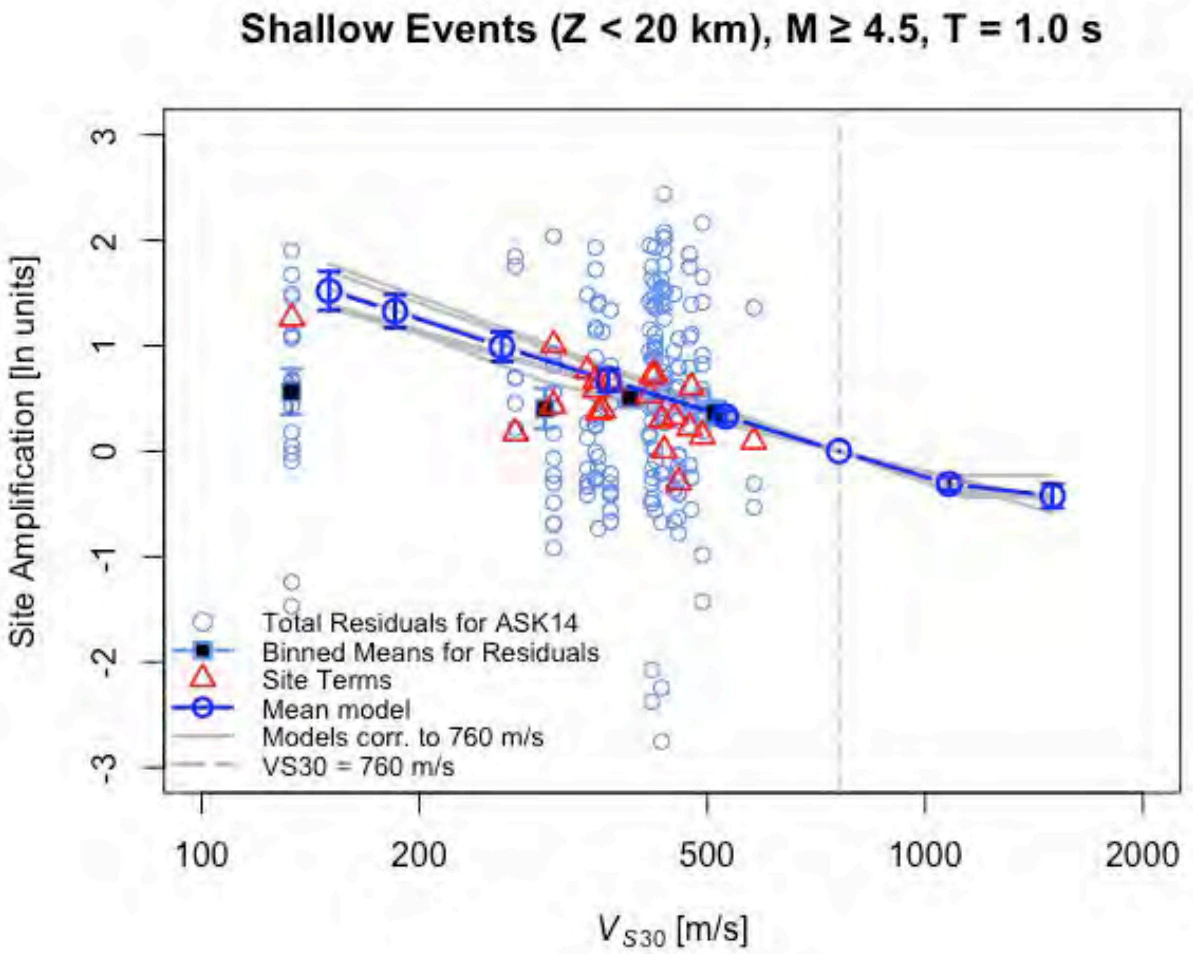


9. Site Effects Models

- Compared linear site response models (V_{S30} scaling) for six western North America GMMs (except Wong et al. 2015)
- Wong et al. (2011) measured V_{S30} at 22 stations using spectral analysis of surface waves (SASW) on the Big Island; other stations assigned from USGS Global V_{S30} Map
  - V_{S30} range: 133–580 m/s
- Did not explicitly consider effects of dominant site period
  - Many locations in Hawaii described as thin (0–18 m) residual soil overlying weathered to intact basalt ($V_S > 2$ km/s)
  - strong impedance contrasts
- Future work

9. Site Effects Models





10. Risk Models (see Session #2)

Break (60 min)

Please return at 3:00 pm MST (12:00 pm HST) for Session #2

It is OK to stay on the MS Teams call – just please turn off your camera and mute your microphone!

Preliminary Results (*A. Shumway, 30 min*)

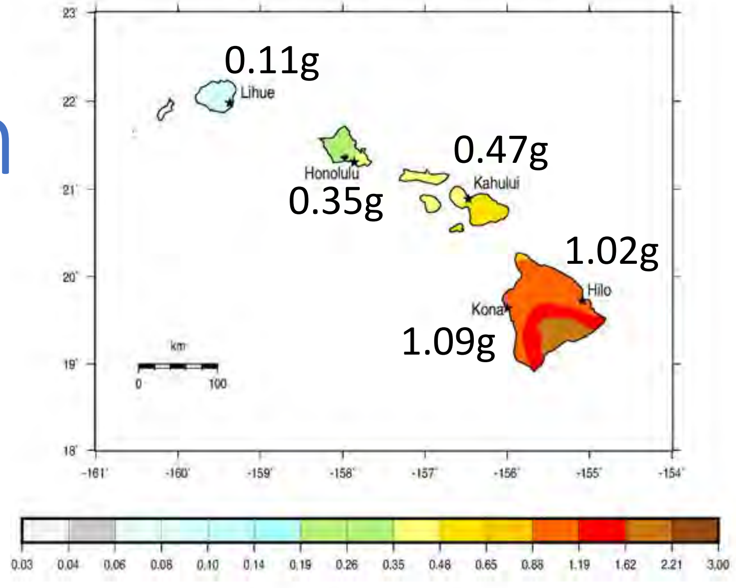
- Hazard Calculations
- Ground Motion Maps
- Hazard Curves
- Uniform Hazard Response Spectra (UHRS)
- Uncertainty Analysis
- Disaggregations
- Comparisons of Intensity Data for Honolulu (*M. Petersen*)

Hazard Calculations

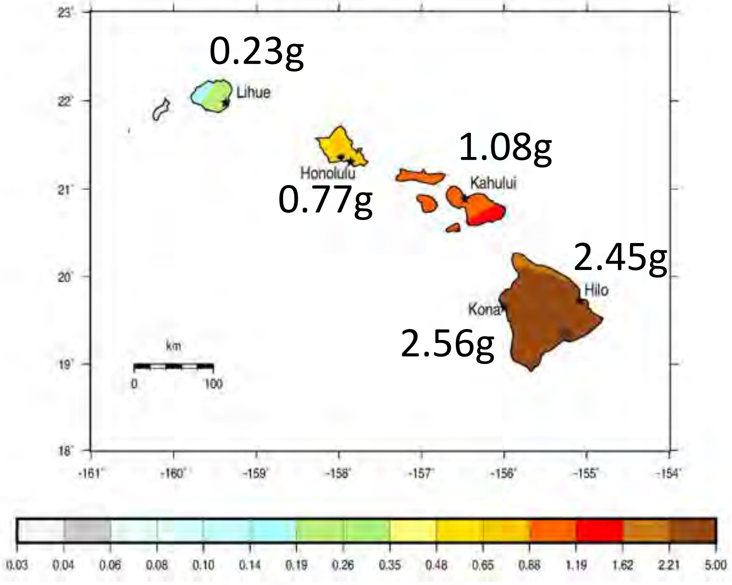
- Probabilistic seismic hazard calculations performed using the USGS computer code *nshmp-haz* (publicly available for download from GitHub; https://github.com/usgs/nshmp-haz).
- Version of code and source model used for calculations will be publicly available for download at time of publication.
- Results will be released for 22 periods, including PGA (0.01 to 10 s) and 8 NEHRP site classes (corresponding to V_{S30} values from 150 to 1500 m/s).
- Results include hazard curves and uniform-hazard ground motion data interpolated from the hazard curves for 2, 5, and 10% probability of exceedance in 50 years (corresponding to 4.04 x 10^{-4}, 1.03 x 10^{-3}, and 2.1 x 10^{-3} annual rates of exceedance, respectively).
- Results calculated on a 0.02^{o}-latitude-by-0.02^{o}-longitude grid (11,657 total sites).
- Results will be available in the USGS ScienceBase Catalog.
- A small subset of the results are presented here.

Rock Ground Motion Maps

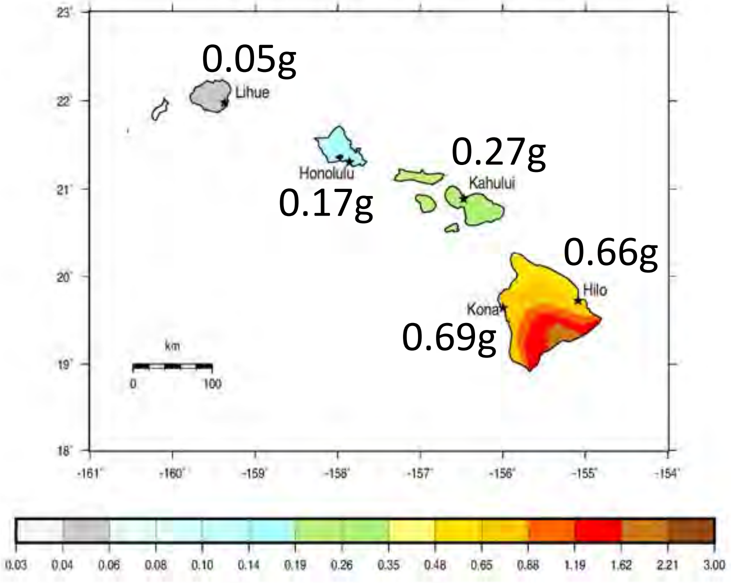
- Uniform-hazard ground motion maps for a soft rock site condition (V_{S30} = 760 m/s)
- PGA, 0.2, 1.0, and 5.0 s
- 2% in 50 years PE
- Hazard is highest on the Island of Hawai‘i and decreases to the northwest



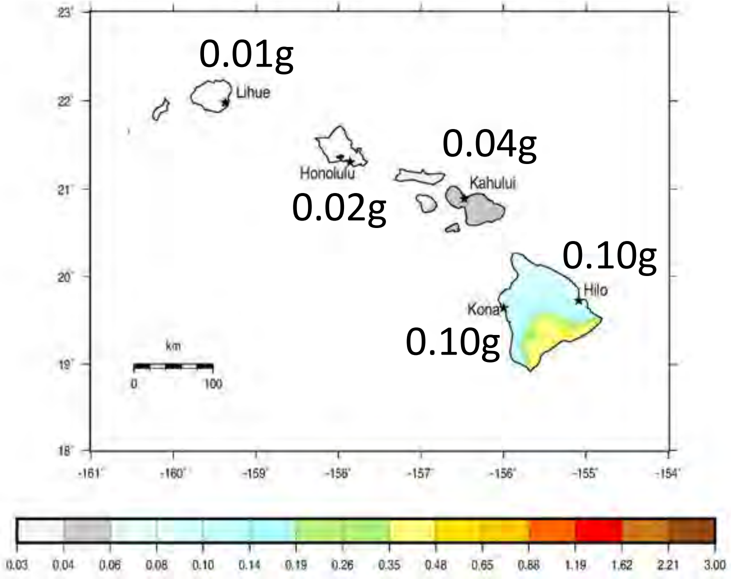
Peak Ground Acceleration (g)



0.2 Second Spectral Acceleration (g)



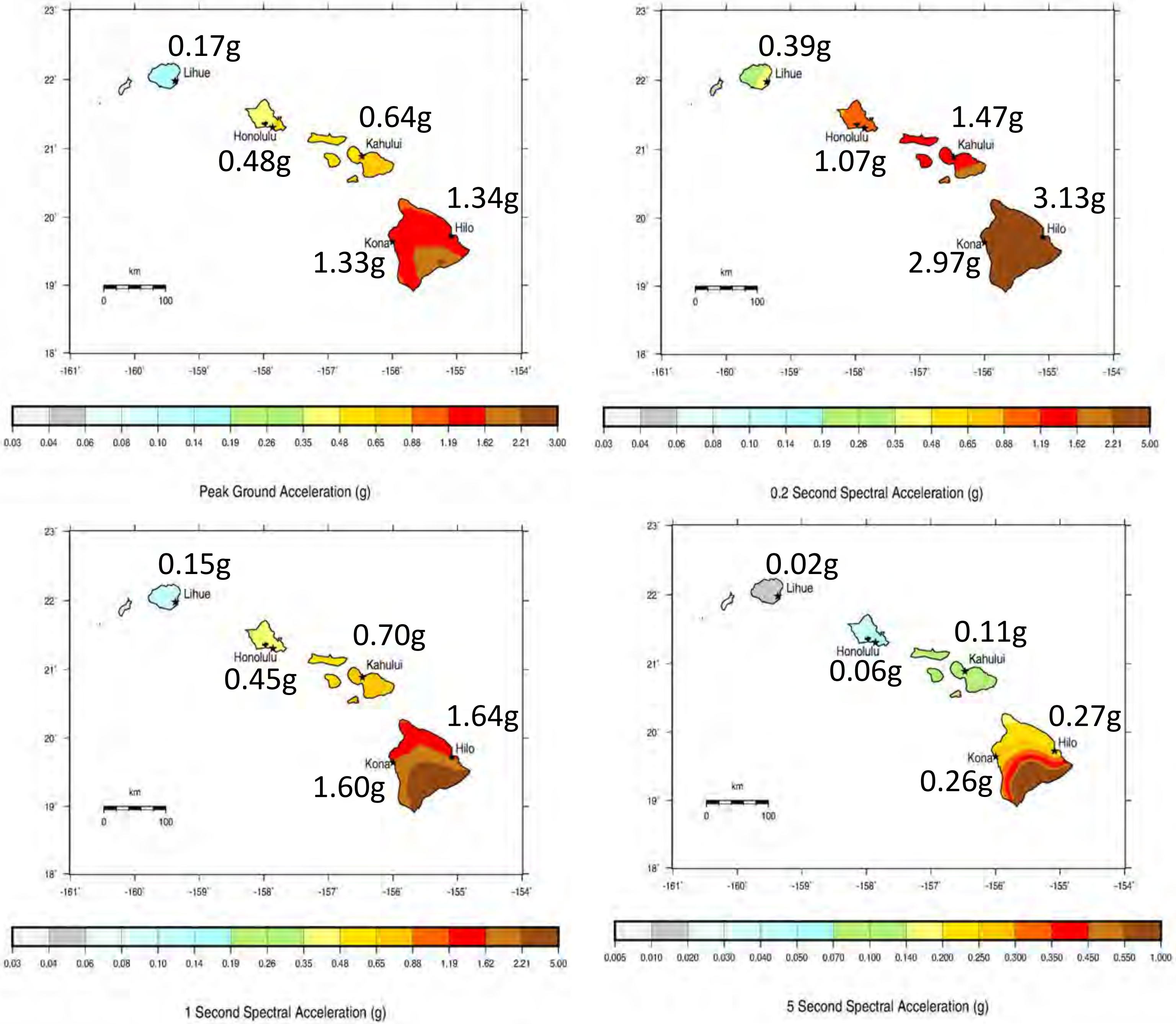
1 Second Spectral Acceleration (g)



5 Second Spectral Acceleration (g)

Soil Ground Motion Maps

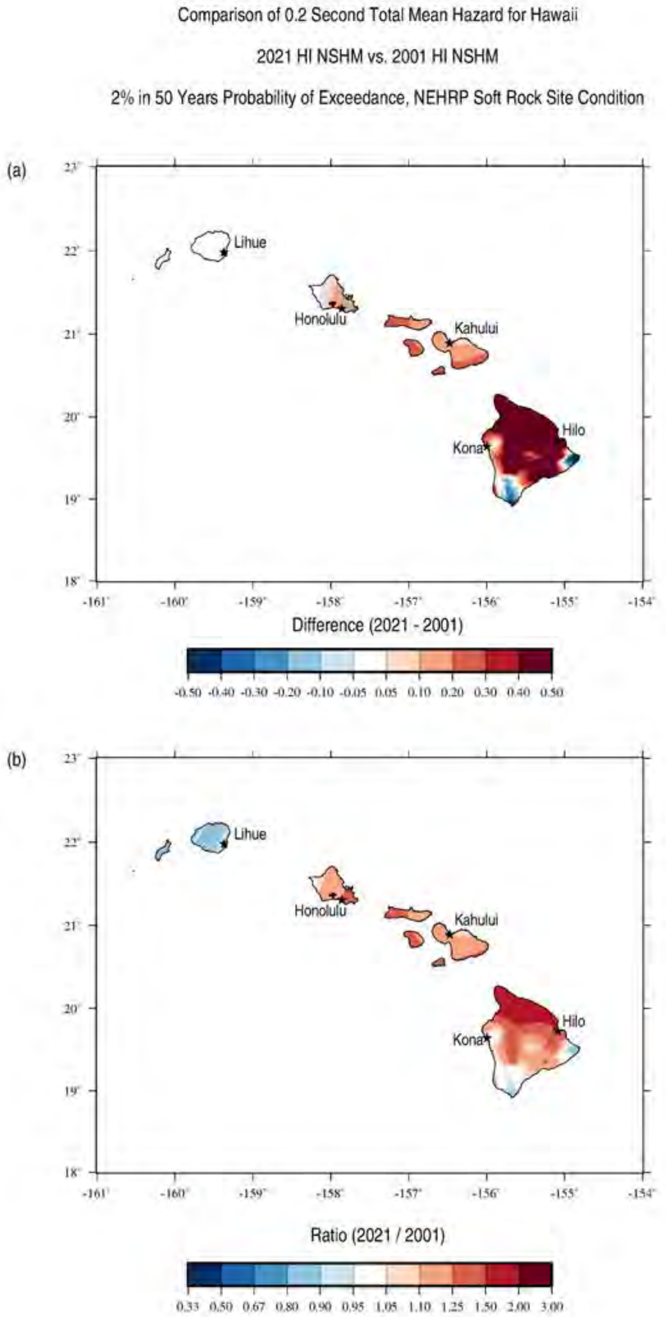
- Uniform-hazard ground motion maps for a medium-dense sand or stiff clay site condition (V_{S30} = 260 m/s)
- PGA, 0.2, 1.0, and 5.0 s
- 2% in 50 years PE
- Softer sites amplify ground motions (up to a factor of 3 at periods ≥ 1 s) compared to soft rock sites

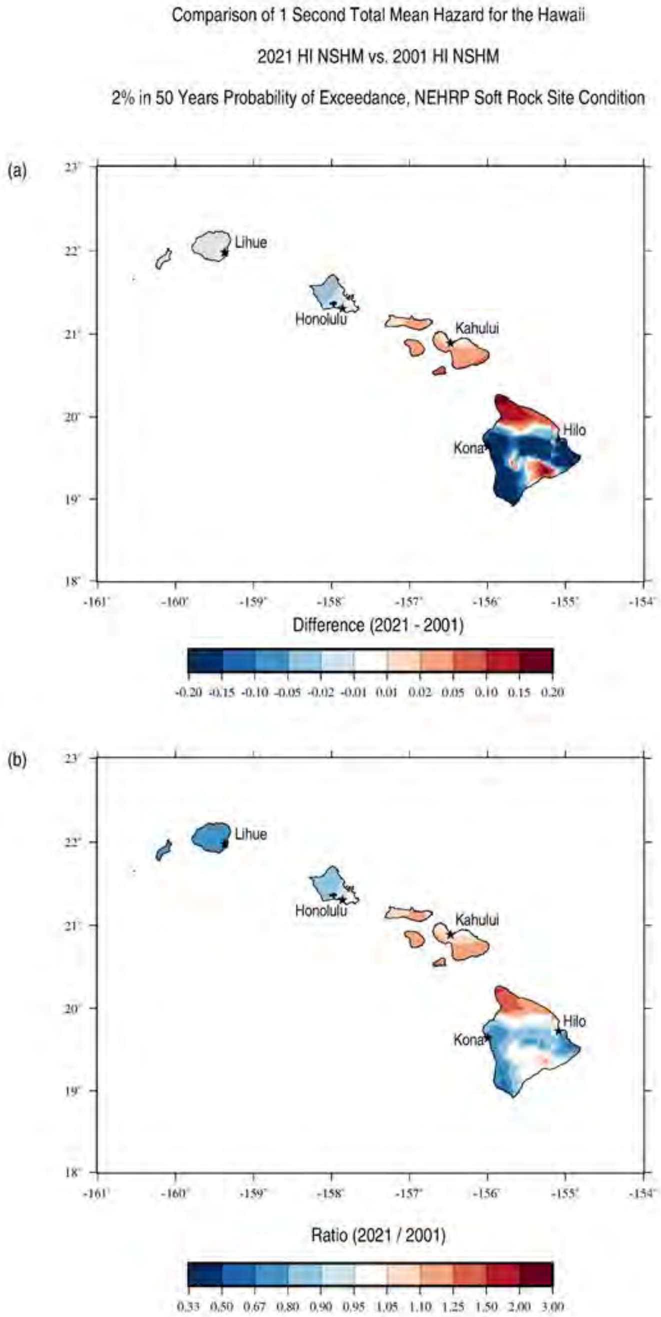


Comparison Maps

- Difference (2021 – 2001) and ratio (2021 ÷ 2001) comparison of the 2021 NSHM and the 2001 NSHM
- Uniform-hazard ground motion maps for a soft rock site condition (V_{S30} = 760 m/s)
- 0.2 and 1.0 s
- 2% in 50 years PE
- 0.2 s ground motions have mostly increased, while 1.0 s ground motions have mostly decreased

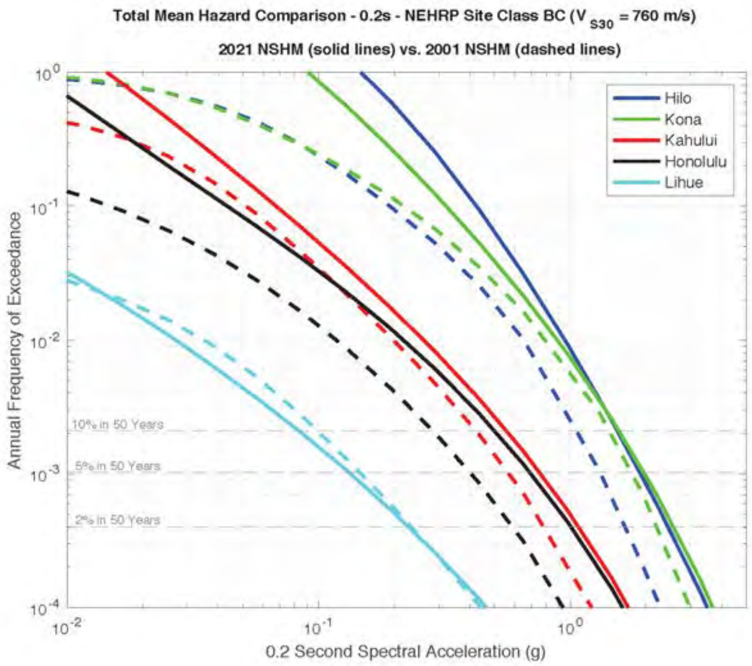
Comparison of 2% in 50 Years Probability of Exceedance for 0.2s Ground Motions							
Site	latitude	longitude	2001	2021	Difference	Ratio	Ratio (%)
Hilo	19.7	-155.06	1.8	2.45	0.65	1.36	36%
Kona	19.66	-156	2.43	2.56	0.13	1.05	5%
Kahului	20.9	-156.5	0.97	1.08	0.11	1.11	11%
Honolulu	21.3	-157.86	0.61	0.77	0.16	1.27	27%
Lihue	21.96	-159.36	0.25	0.23	-0.02	0.92	-8%
Comparison of 2% in 50 Years Probability of Exceedance for 1s Ground Motions							
Site	latitude	longitude	2001	2021	Difference	Ratio	Ratio (%)
Hilo	19.7	-155.06	0.77	0.66	-0.11	0.86	-14%
Kona	19.66	-156	0.92	0.69	-0.23	0.75	-25%
Kahului	20.9	-156.5	0.25	0.27	0.02	1.08	8%
Honolulu	21.3	-157.86	0.18	0.17	-0.01	0.96	-4%
Lihue	21.96	-159.36	0.07	0.05	-0.02	0.76	-24%

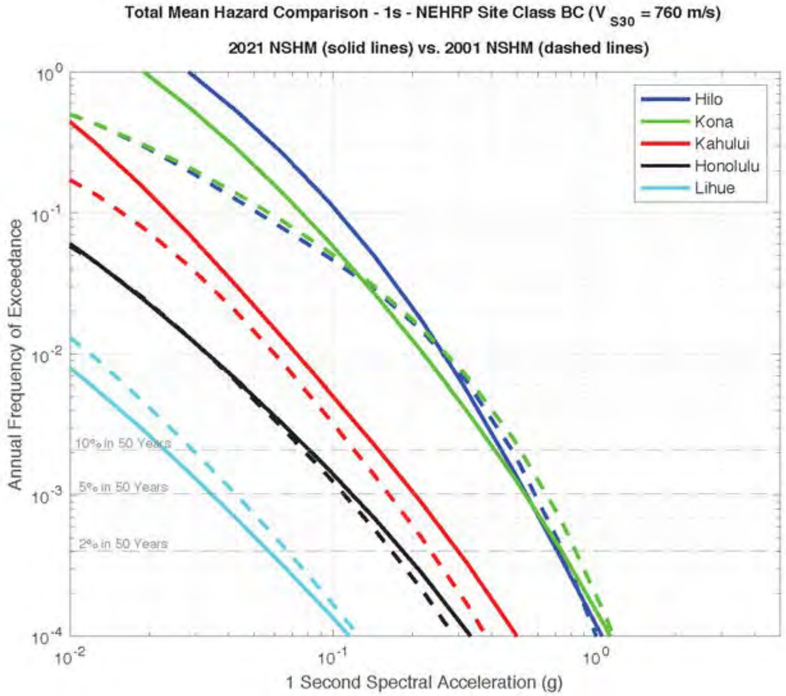




Hazard Curves

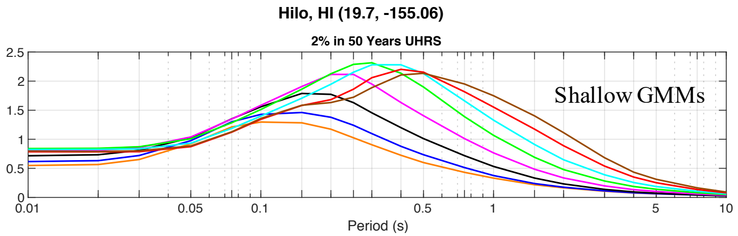
- Comparison of the 2021 NSHM (solid lines) and the 2001 NSHM (dashed lines)
- Uniform-hazard ground motion maps for a soft rock site condition (V_{S30} = 760 m/s)
- 0.2 and 1.0 s
- 2% in 50 years PE
- At 0.2 s, hazard at all sites, except Līhu'e, increase
- At 1.0 s, hazard at all sites, except Kahului, decrease

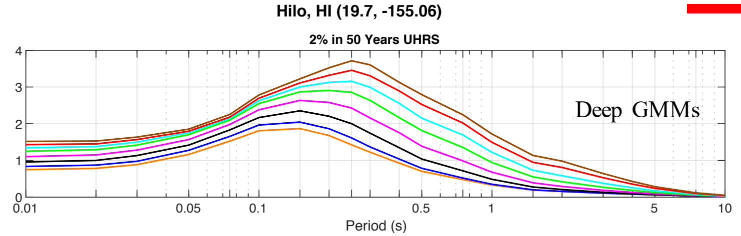


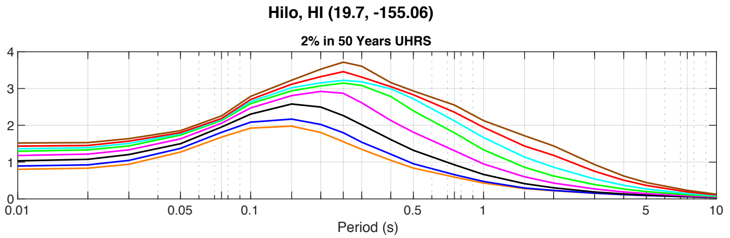


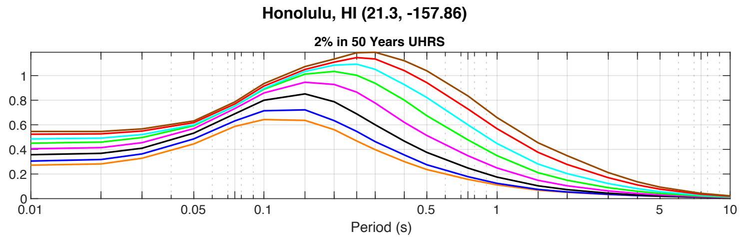
Uniform Hazard Response Spectra (UHRS)

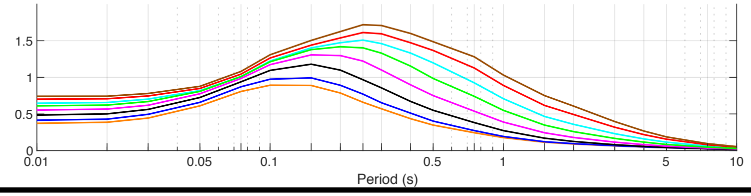
- Deep GMMs appear to be controlling the shape of the spectra at many sites

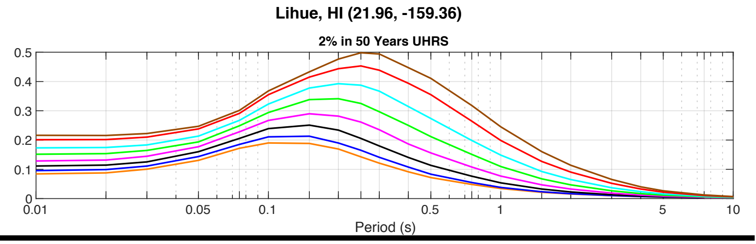






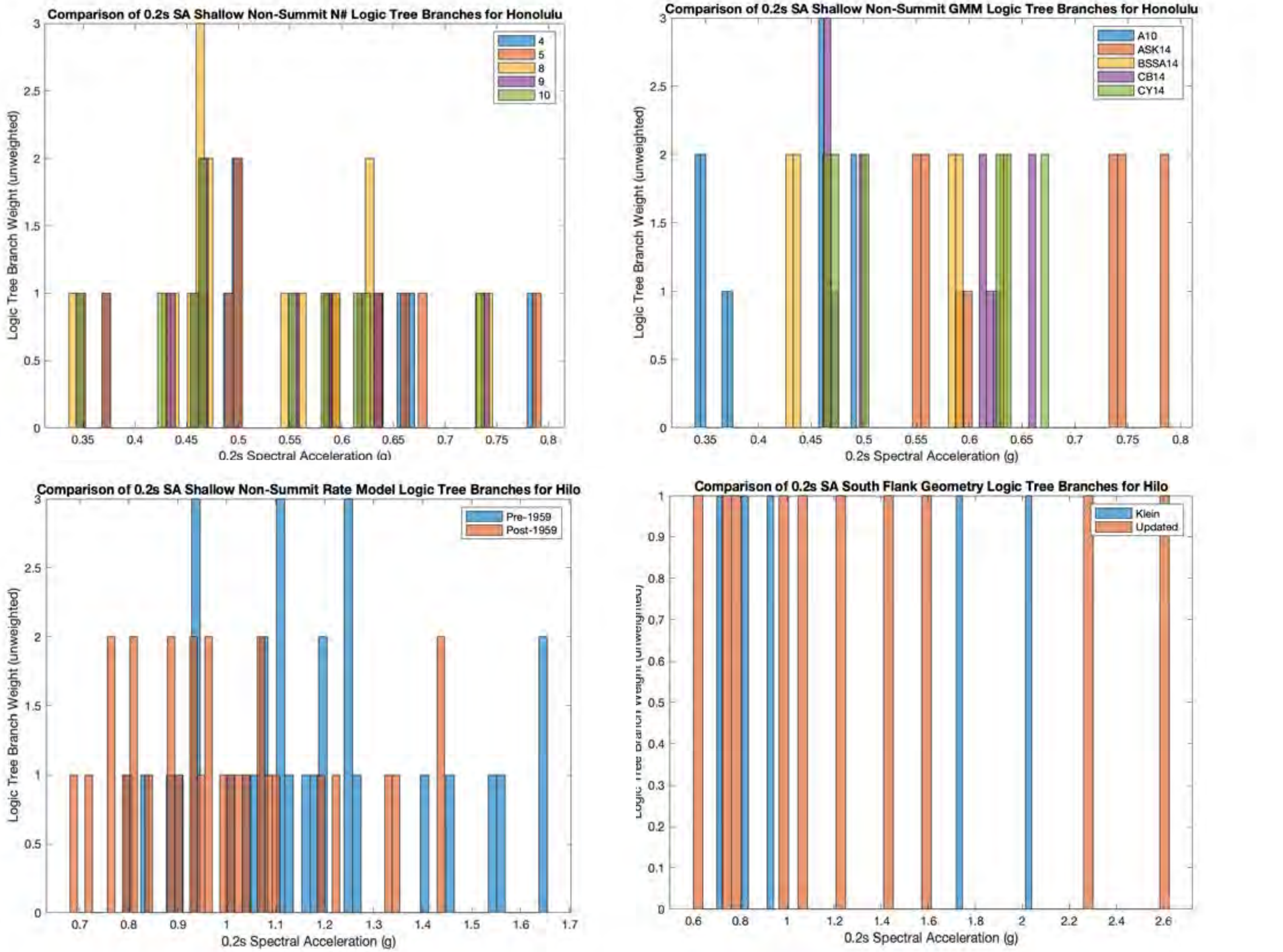




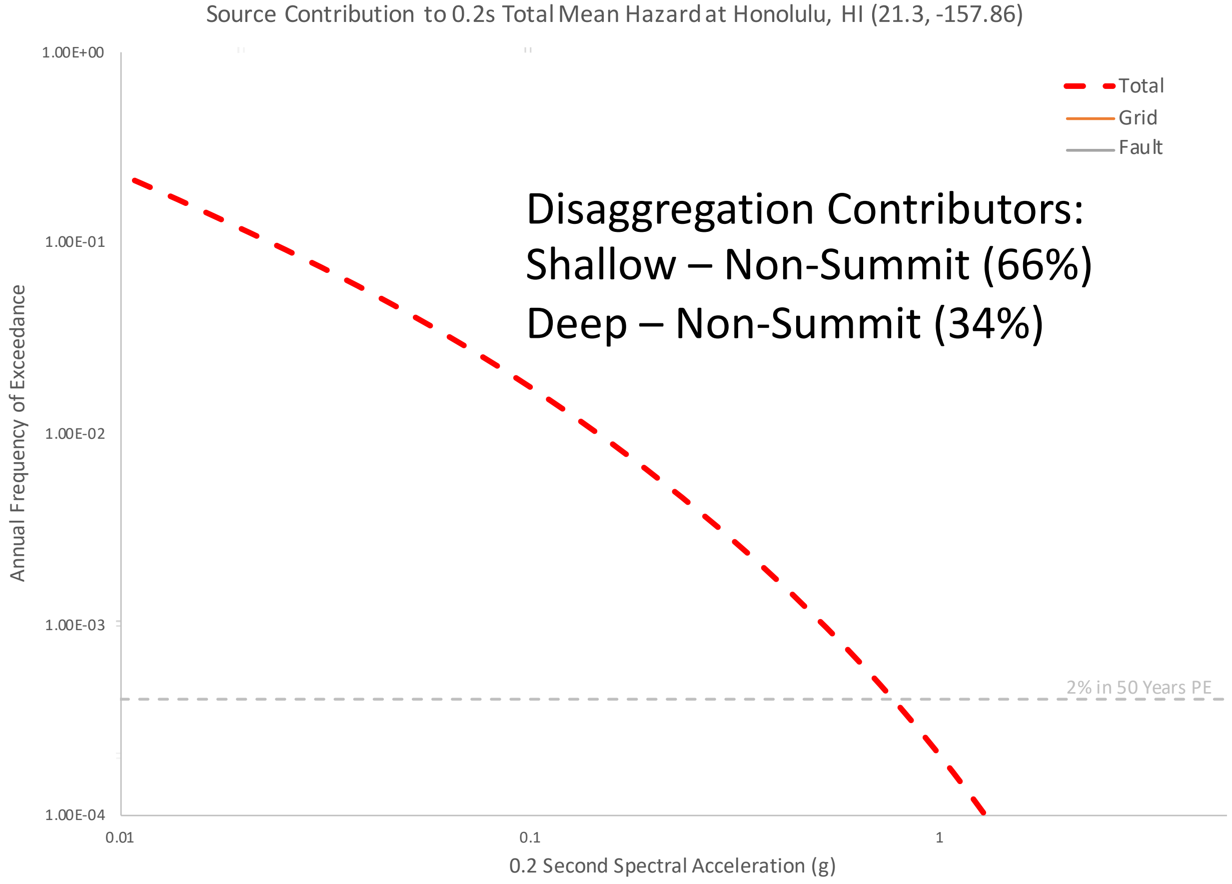


Uncertainty Analysis

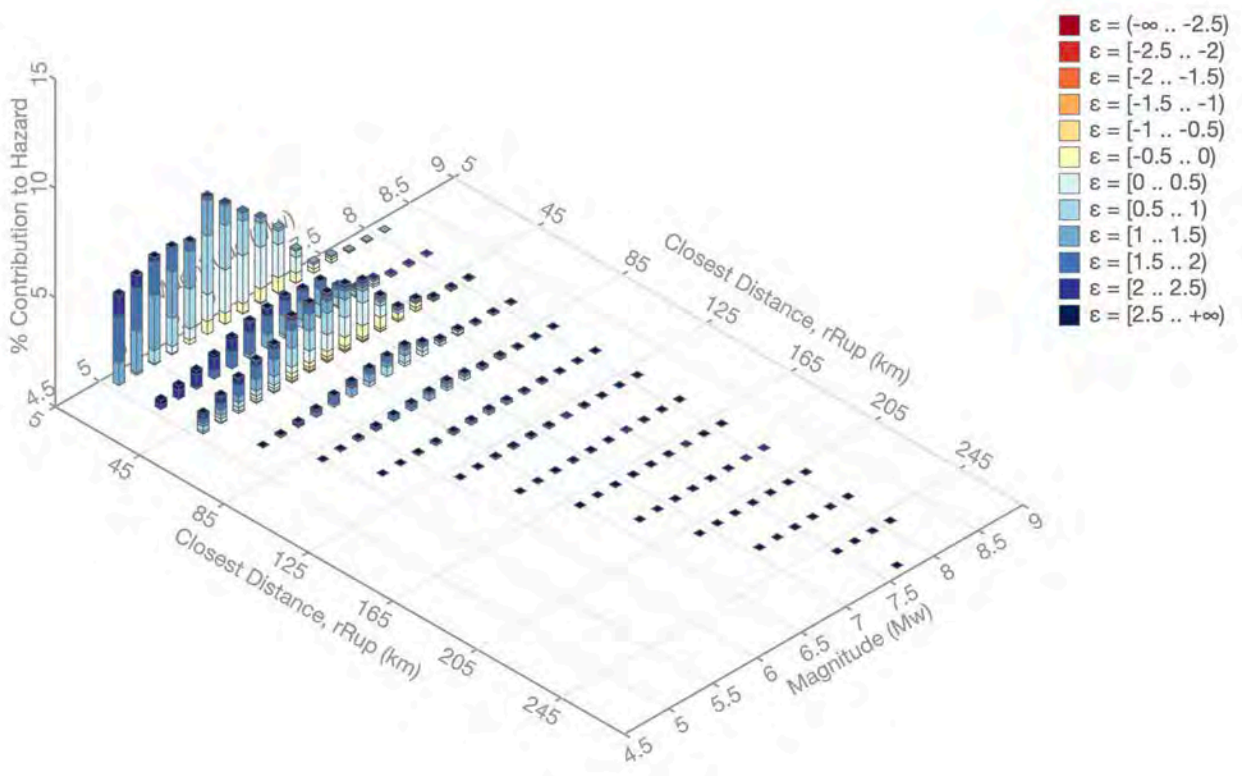
- When reporting results, it is important to report (and understand) the uncertainties associated with the model
- We have performed an uncertainty analysis to show the contribution to total mean hazard from each of the logic tree branches



0.2 Second Disaggregation (Honolulu)

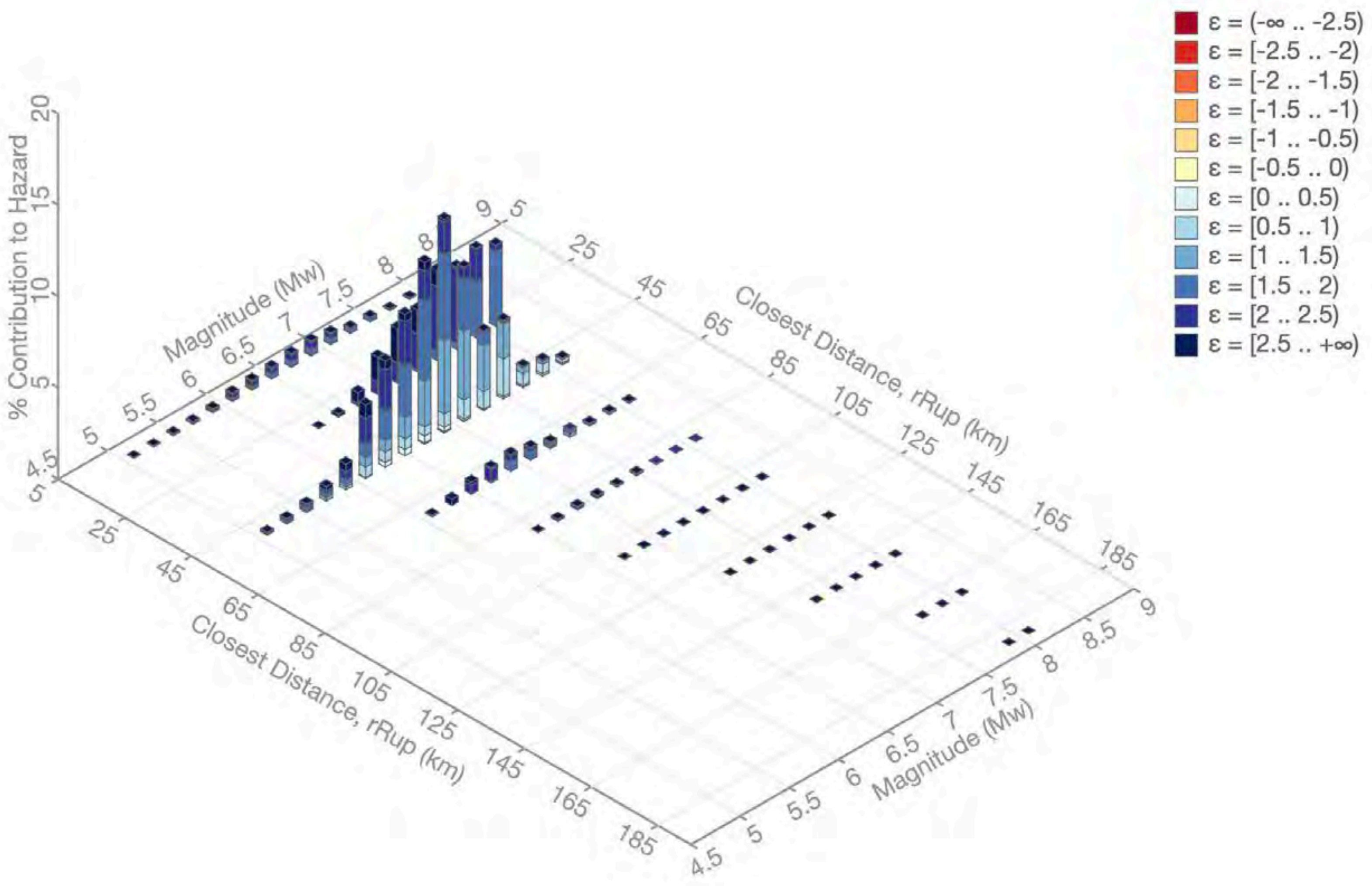


Disaggregation Contributors:
Shallow – Non-Summit (66%)
Deep – Non-Summit (34%)



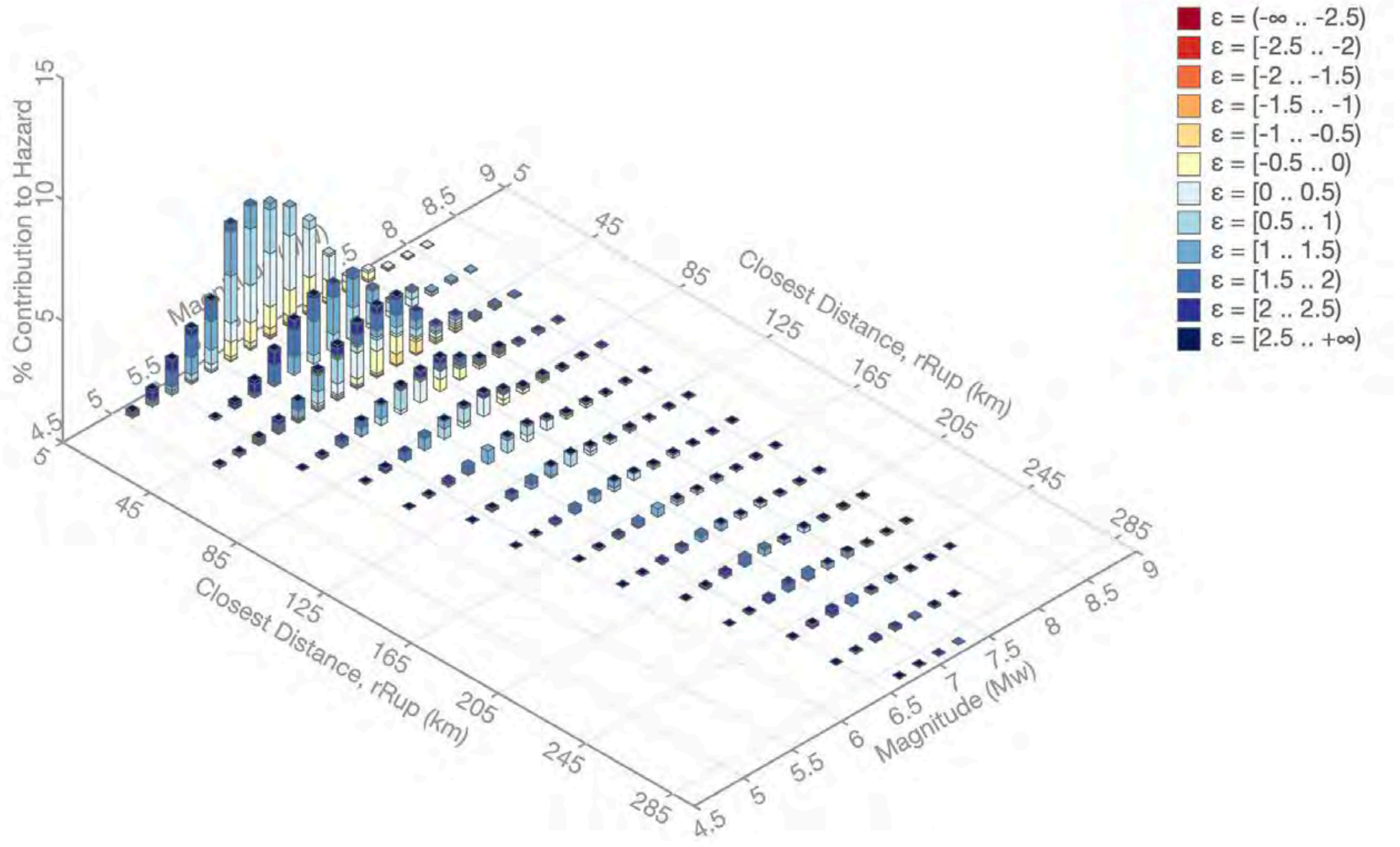
0.2 Second Disaggregations (Hilo)

Disaggregation Contributors:
South Flank (16%)
Deep – Non-Summit (52%)
Deep – Summit (~15%)
Shallow – Summit (~10%)



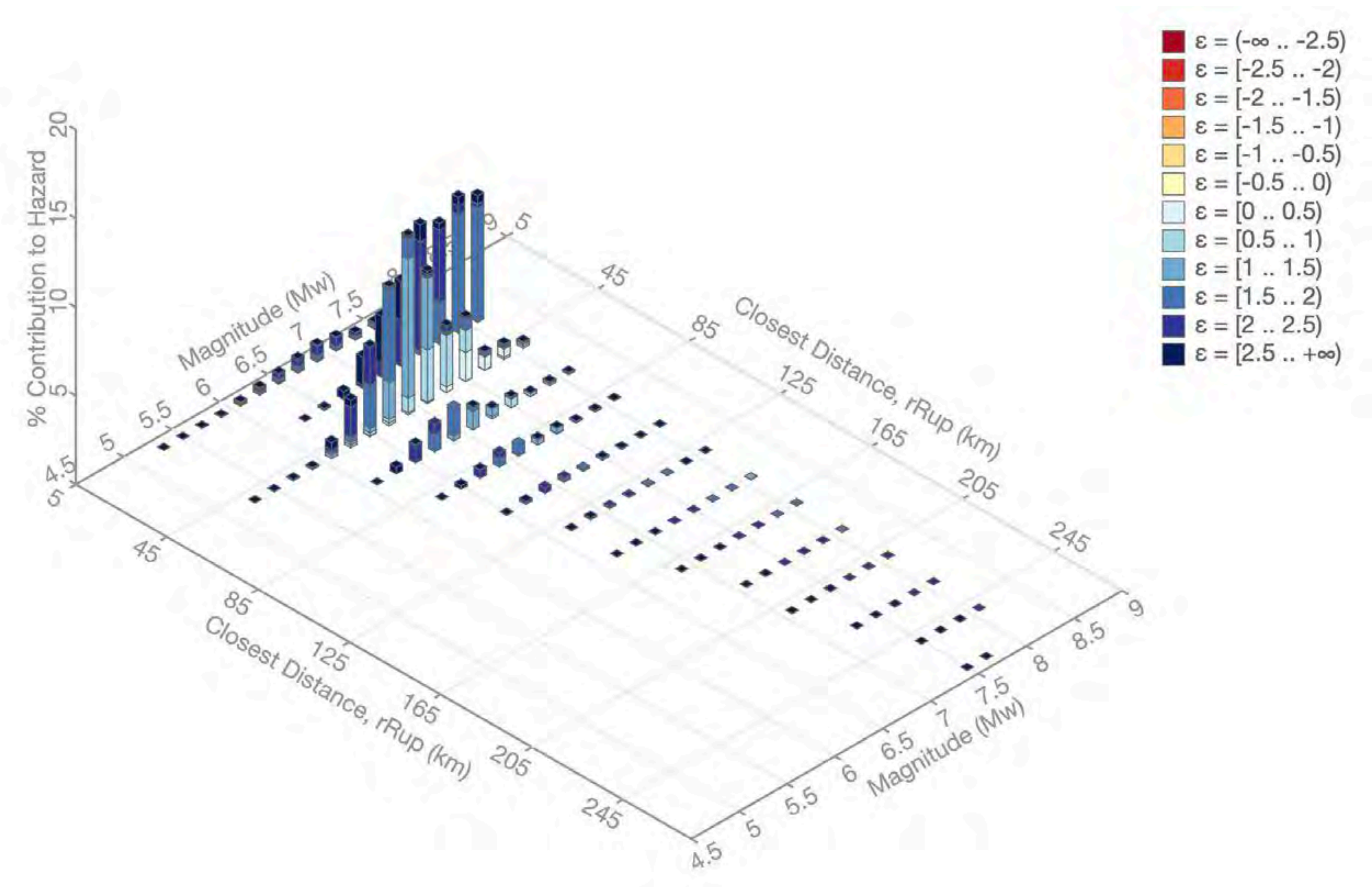
1 Second Disaggregations (Honolulu)

Disaggregation Contributors:
Shallow – Non-Summit (61%)
Deep – Non-Summit (39%)



1 Second Disaggregations (Hilo)

Disaggregation Contributors:
South Flank (24%)
Deep – Non-Summit (40%)
Shallow – Summit (~13%)
Deep – Summit (~15%)
Shallow – Non-Summit (~2%)



Comparison of Intensity Data for Honolulu

- Cox (1986) indicates that 113 earthquakes were felt between 1859 and 1986 (127 years) in Honolulu and that the highest intensities during this time were from the 1871 Lāna'i earthquake with intensity between VI and VII (MMI 6.5 ± 0.7) and the 1948 O'ahu earthquake which generally had intensity of VI but probably intensities of VII in a couple areas near Honolulu that may have been modified by site effects (MMI 6.0 ± 0.7; Cox, 1986, 1987). We are not aware of any larger intensities since 1986.
- We convert MMI to PGA using equations by Worden et al. (2012) and Wyss and Koyanagi (1992a) for comparison with our PGA map.
- The PGA hazard curve for a 100-year return period indicates ground shaking of about 20% g and the values for a 500-year return period indicates ground shaking of about 30% g for a firm rock site condition (V_{S30} = 760 m/s).
- The ground motion hazard values could double for soft soils making these observations generally consistent with the 50%, 10%, and 2% probability of exceedance in 50-year hazard values.

MMI	V	VI	VII	VIII
Exceedances in 120 years	13	3	1	0
PGA: Worden et al. (2012) (% g)	6.2% g	12% g	22% g	40% g
PGA: Wyss and Koyanagi, 1992a (% g)	13–20% g	20–32% g	32–51% g	51–80% g

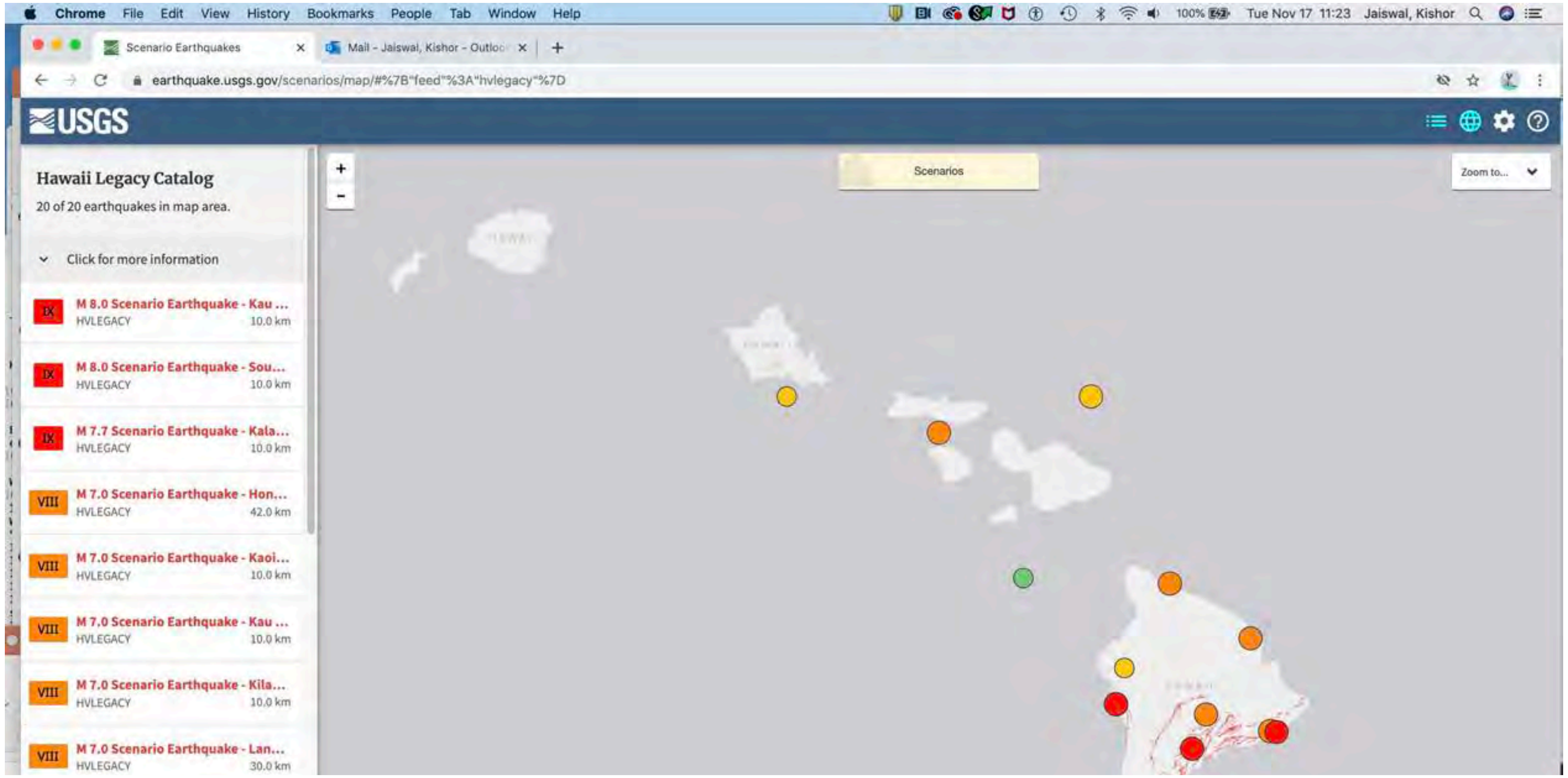
Products and Discussion (90 min)

- Scenarios and Risk Assessment (*K. Jaiswal*)
- Building Code (*S. Rezaeian*)
- Web Tools (*P. Powers*)

Hawaii Earthquake Scenarios, Potential Losses and Risk

By Kishor Jaiswal, Doug Bausch, and Mark D. Petersen

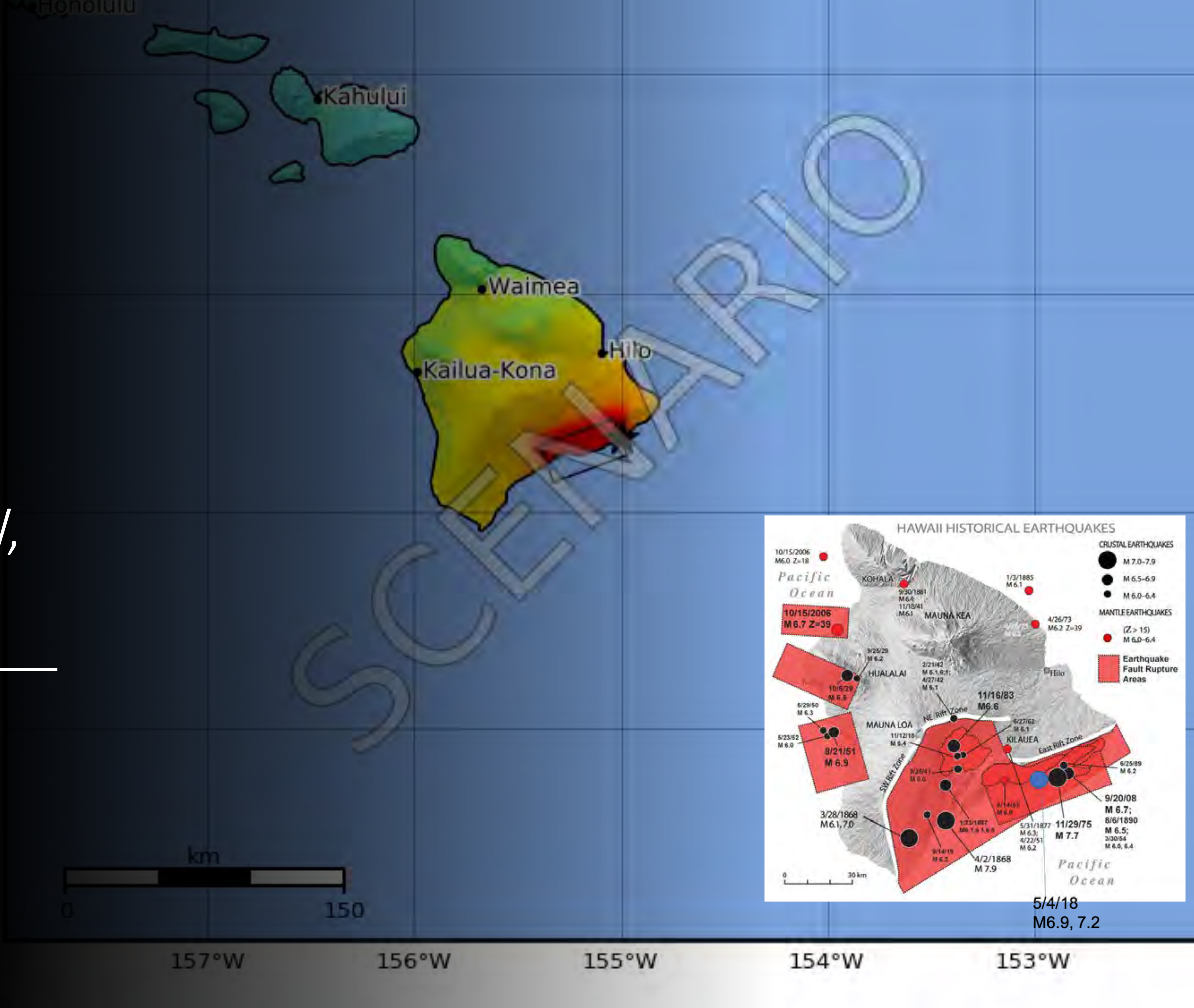
Hawaii Legacy ShakeMap Scenario Catalog

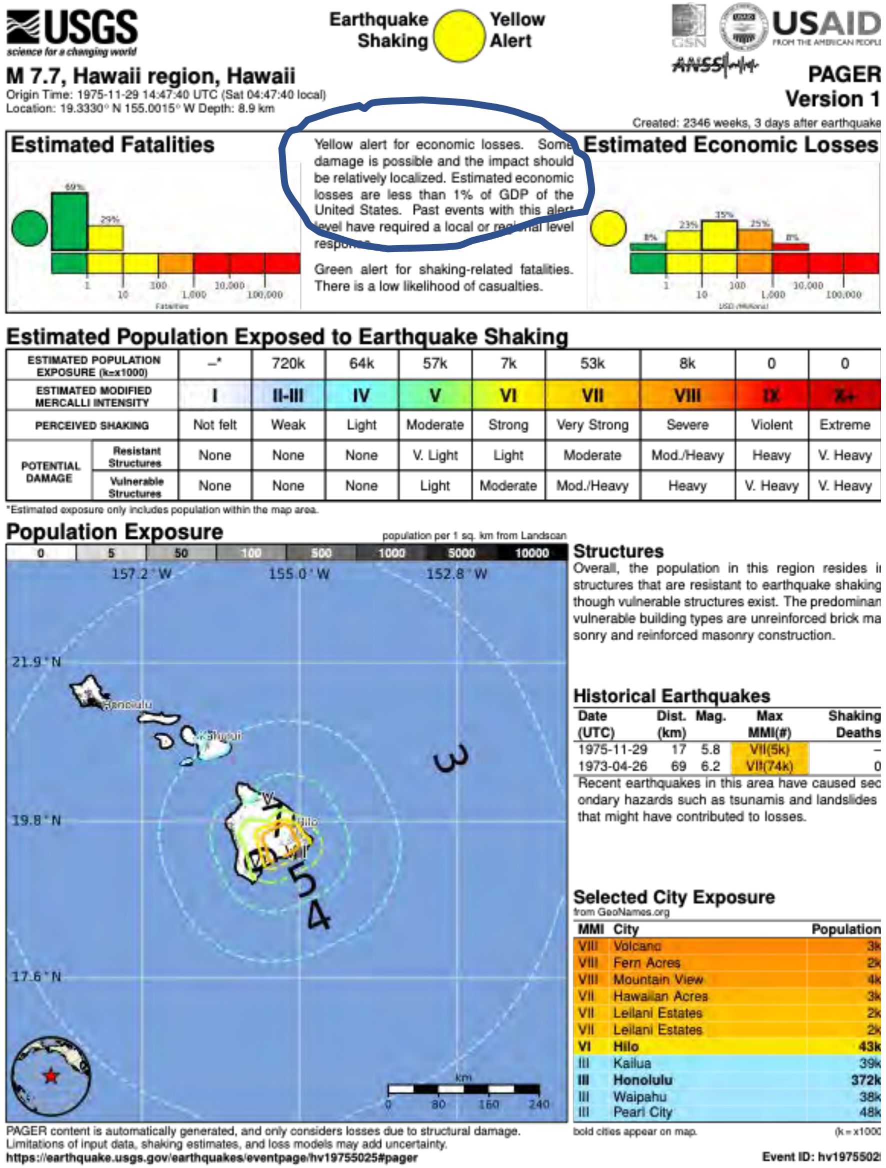


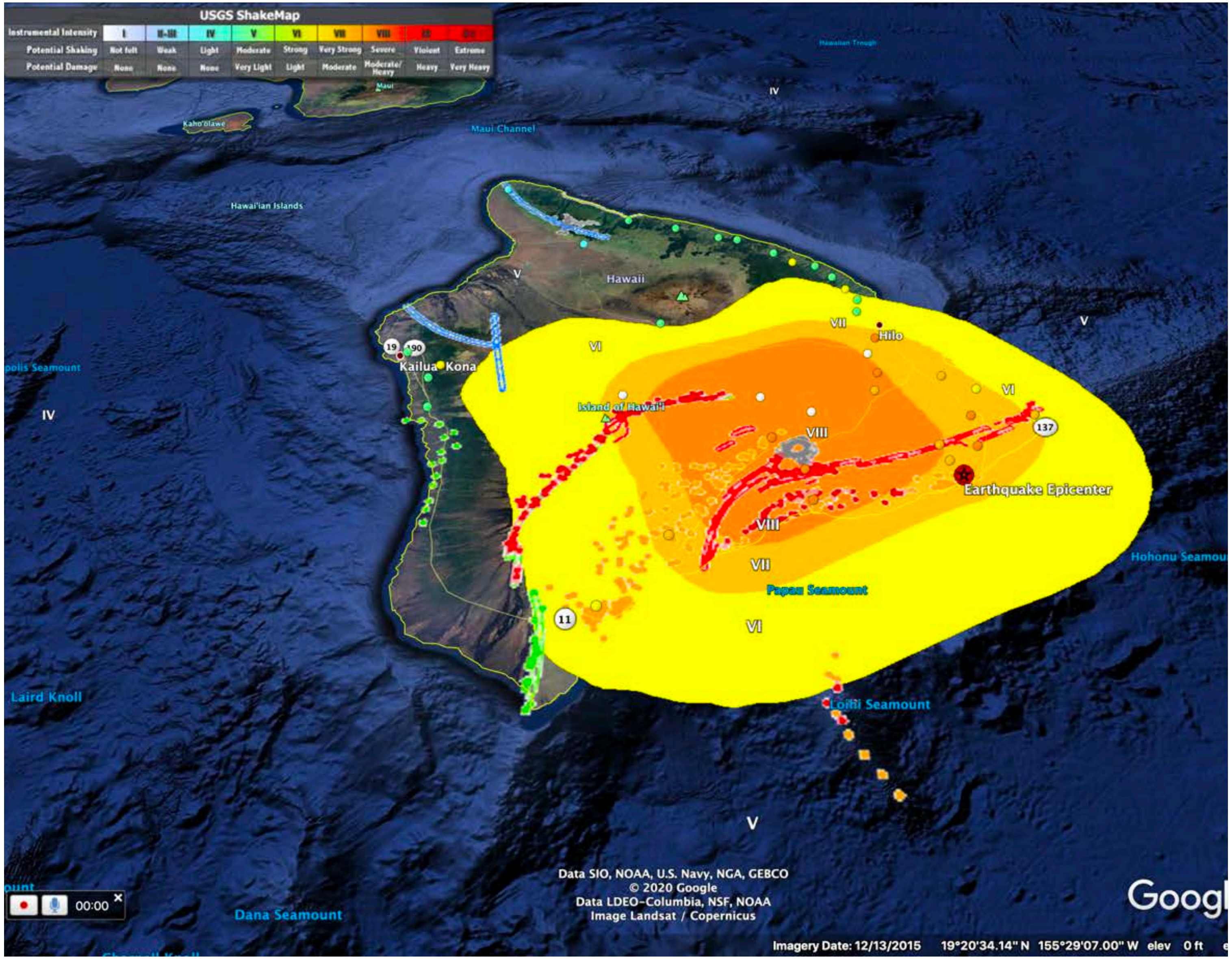
- HI Legacy Scenario Catalog: By Paul Okubo, D. Wald, and HETAC
- 20 Eqs (M6-M8)
- Potential for improvement in fault delineation or depth constraints
- Archaic GMPEs (not consistent with 2021 HI Model)

M7.7 Kalapana
Nov 29, 1975
(19.340°N 155.000°W, 10 km deep)

Total damage	$4–4.1 million
Max. intensity	VIII (Severe)
Tsunami	14.3 m (47 ft)
Fatalities	2 dead
Injuries	28 injured

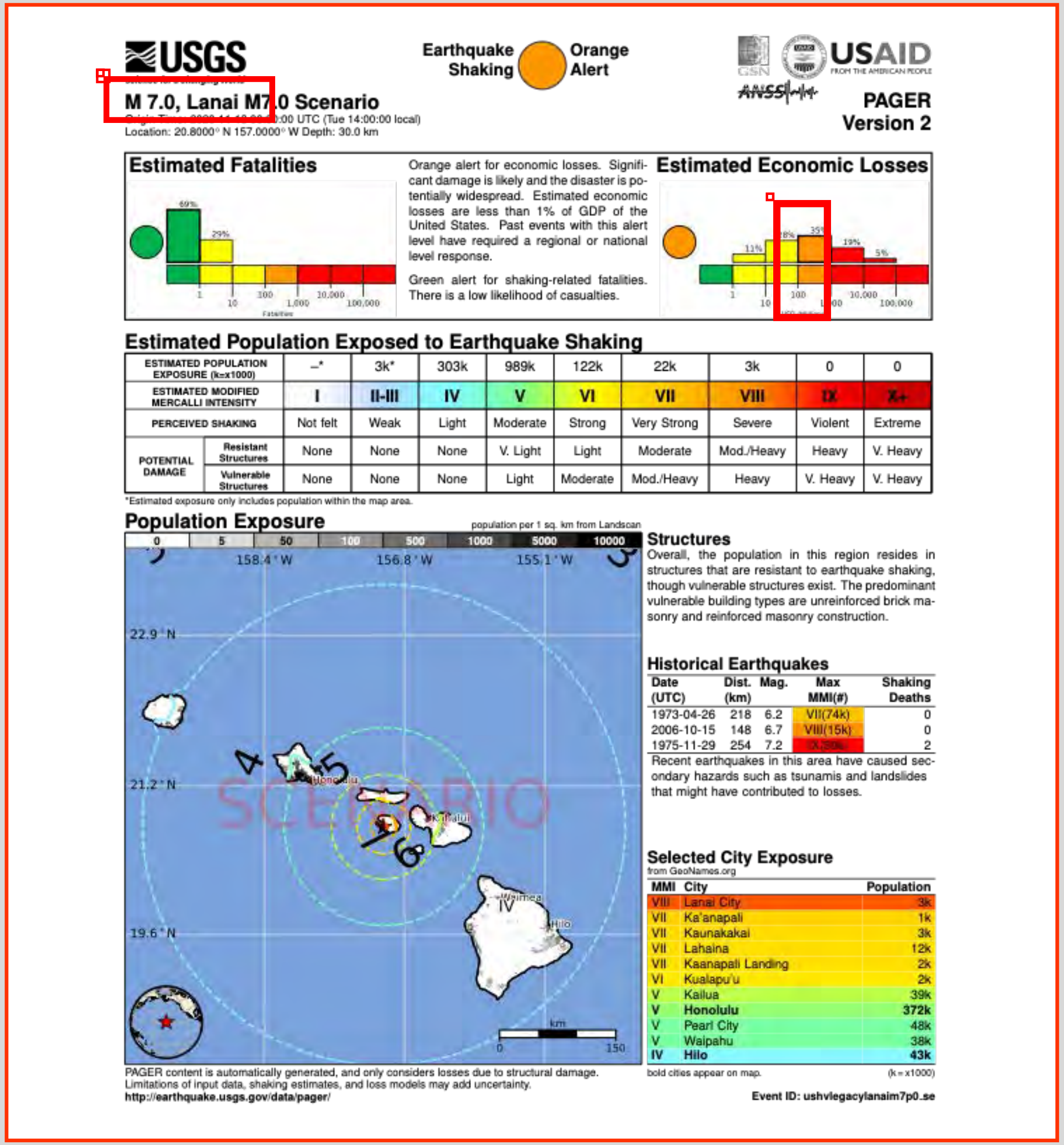






~10-100 Mil USD of economic damage/loss is possible, but the impact should be relatively localized.

Although there is a low likelihood of widespread fatalities, some casualties are still likely.



USGS — Earthquake Shaking Orange Alert

M 7.0, Lanai M7.0 Scenario

Origin Time: [illegible] UTC (Tue 14:00:00 local)
Location: 20.8000° N 157.0000° W Depth: 30.0 km

PAGER Version 2

Estimated Fatalities / **Estimated Economic Losses**

Orange alert for economic losses. Significant damage is likely and the disaster is potentially widespread. Estimated economic losses are less than 1% of GDP of the United States. Past events with this alert level have required a regional or national level response.

Green alert for shaking-related fatalities. There is a low likelihood of casualties.

Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k=x1000)	–*	3k*	303k	989k	122k	22k	3k	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE – Resistant Structures	None	None	None	V. Light	Light	Moderate	Mod./Heavy	Heavy	V. Heavy
POTENTIAL DAMAGE – Vulnerable Structures	None	None	None	Light	Moderate	Mod./Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure — population per 1 sq. km from Landscan

Structures
Overall, the population in this region resides in structures that are resistant to earthquake shaking, though vulnerable building types exist. The predominant vulnerable building types are unreinforced brick masonry and reinforced masonry construction.

Historical Earthquakes

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1973-04-26	218	6.2	VII(74k)	0
2006-10-15	148	6.7	VIII(15k)	0
1975-11-29	254	7.2	IX(30k)	2

Recent earthquakes in this area have caused secondary hazards such as tsunamis and landslides that might have contributed to losses.

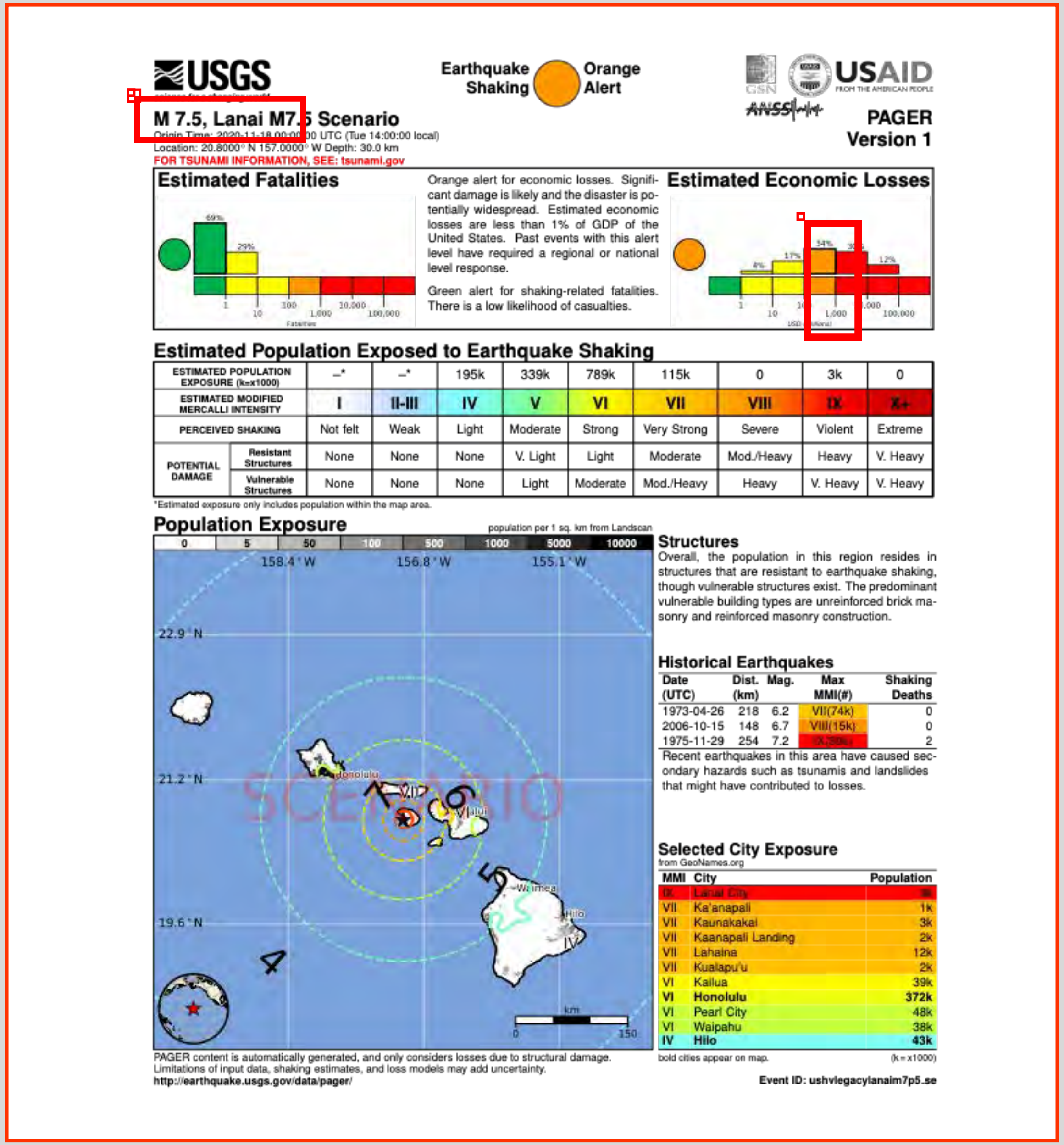
Selected City Exposure — from GeoNames.org

MMI	City	Population
VIII	Lanai City	3k
VII	Ka'anapali	1k
VII	Kaunakakai	3k
VII	Lahaina	12k
VII	Kaanapali Landing	2k
VI	Kualapu'u	2k
V	Kailua	39k
V	**Honolulu**	**372k**
V	Pearl City	48k
V	Waipahu	38k
IV	**Hilo**	**43k**

bold cities appear on map. (k = x1000)

PAGER content is automatically generated, and only considers losses due to structural damage. Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/data/pager/

Event ID: ushvlegacylanaim7p0_se



USGS — Earthquake Shaking Orange Alert

M 7.5, Lanai M7.[illegible] Scenario

Origin Time: [illegible] UTC (Tue 14:00:00 local)
Location: 20.8000° N 157.0000° W Depth: 30.0 km
FOR TSUNAMI INFORMATION, SEE: tsunami.gov

PAGER Version 1

Estimated Fatalities / **Estimated Economic Losses**

Orange alert for economic losses. Significant damage is likely and the disaster is potentially widespread. Estimated economic losses are less than 1% of GDP of the United States. Past events with this alert level have required a regional or national level response.

Green alert for shaking-related fatalities. There is a low likelihood of casualties.

Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k=x1000)	–*	–*	195k	339k	789k	115k	0	3k	0
ESTIMATED MODIFIED MERCALLI INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE – Resistant Structures	None	None	None	V. Light	Light	Moderate	Mod./Heavy	Heavy	V. Heavy
POTENTIAL DAMAGE – Vulnerable Structures	None	None	None	Light	Moderate	Mod./Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure — population per 1 sq. km from Landscan

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Overall, the population in this region resides in structures that are resistant to earthquake shaking, though vulnerable building types exist. The predominant vulnerable building types are unreinforced brick masonry and reinforced masonry construction.

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Recent earthquakes in this area have caused secondary hazards such as tsunamis and landslides that might have contributed to losses.

Selected City Exposure — from GeoNames.org

MMI	City	Population
IX	Lanai City	3k
VII	Ka'anapali	1k
VII	Kaunakakai	3k
VII	Kaanapali Landing	2k
VII	Lahaina	12k
VII	Kualapu'u	2k
VI	Kailua	39k
VI	**Honolulu**	**372k**
VI	Pearl City	48k
VI	Waipahu	38k
IV	**Hilo**	**43k**

bold cities appear on map. (k = x1000)

PAGER content is automatically generated, and only considers losses due to structural damage. Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/data/pager/

Event ID: ushvlegacylanaim7p5_se

FEMA P366 Annualized Loss Estimates

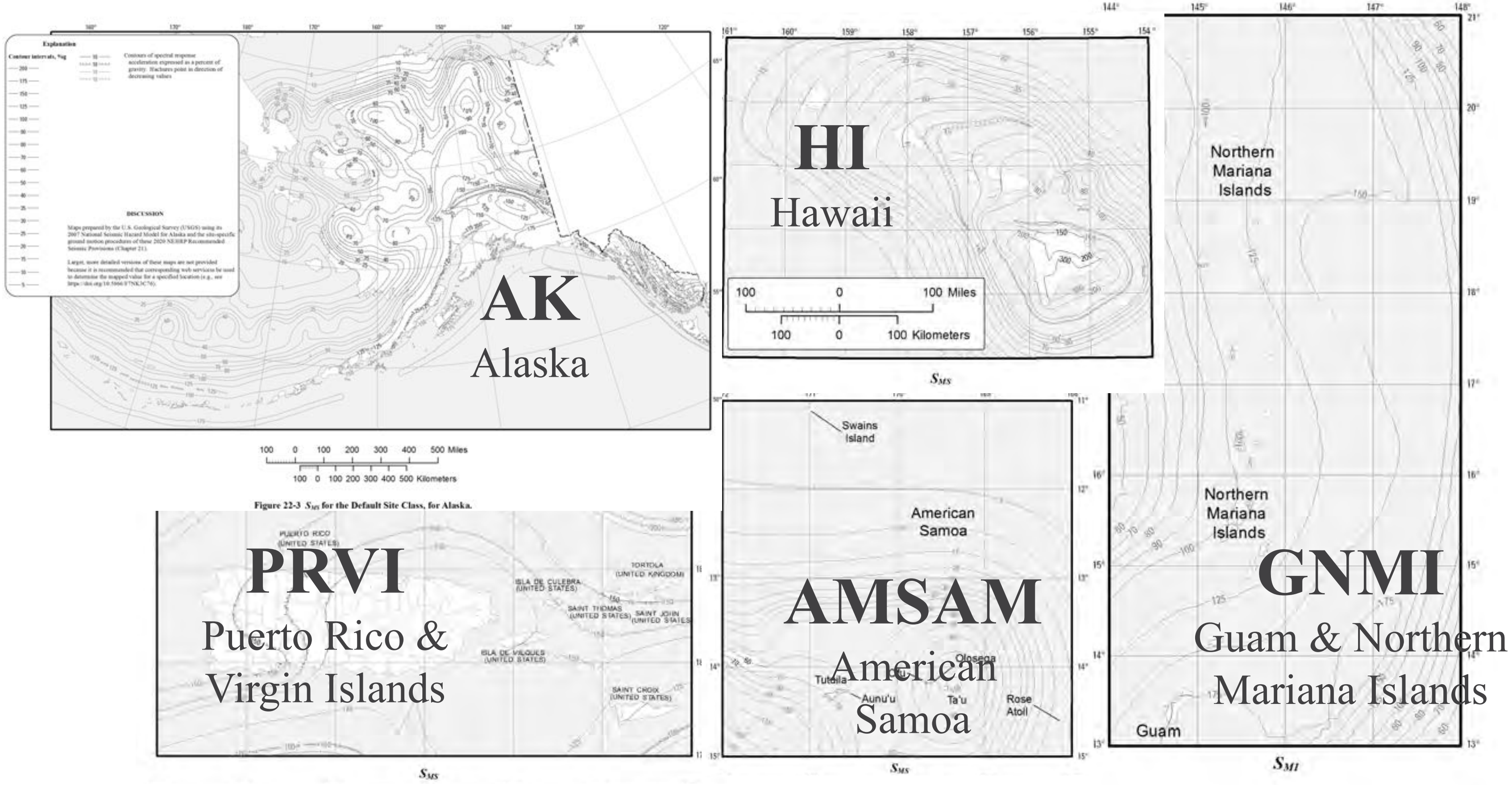
All values are in thousands of dollars

Using Hawaii 2021 (v11)	Capital Stock (Str, Nonstr, Content, Inventory etc.)	Income Loss (Reloc, wages etc.)	Total
Kalawao	8	1	9(16)
Maui	13,822	2,013	15,835(12,480)
Honolulu	37,645	5,214	42,859(39,780)
Hawaii	68,877	9,643	78,520(54,124)
Kauai			
Total			**137,432(106,824)**

New results show an increase (~28%) from $107M (FEMA P366, 2017: # shown in parenthesis) to $137M statewide to average annualized loss (AAL).

Updates to 2020 NEHRP Design Ground Motions Outside of Conterminous US (OCONUS):

- No updates were available for USGS hazard models (or deterministic calculations)
- We updated BC Ss & S1 using the “Site-Specific Procedures, Ch21” of 2020 NEHR: RTGM, maxdir
- We estimated MPRS (no site amplifications in 2020 NEHRP), using FEMA P-2078



Updates to S_S & S_1 for BC Site Class:

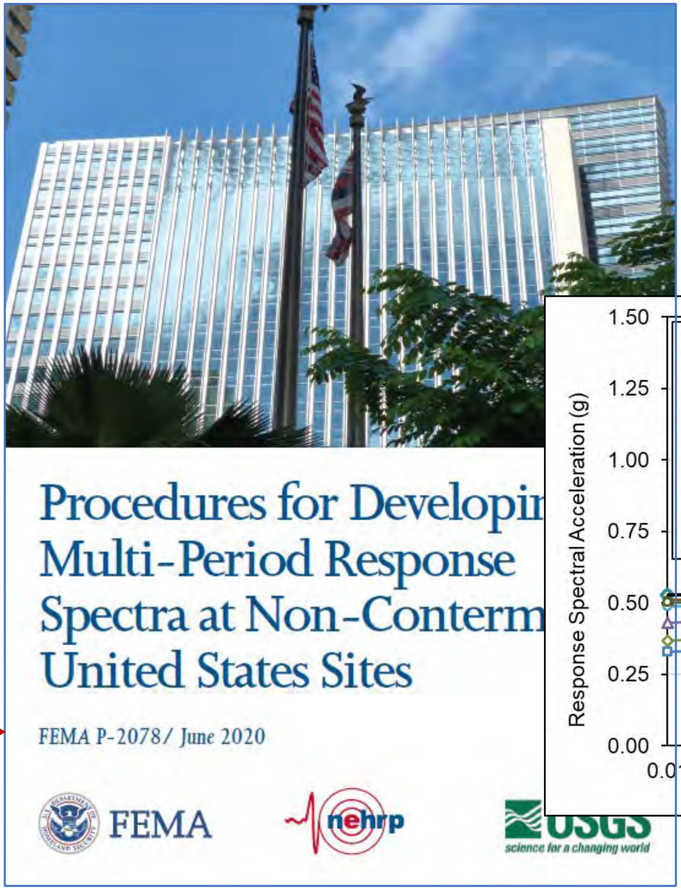
- No updates were available for USGS hazard models (or deterministic calculations)
- We updated BC Ss & S1 using the "Site-Specific Procedures, Ch21" of 2020 NEHR: RTGM, maxdir
- We estimated MPRS (no site amplifications in 2020 NEHRP), using FEMA P-2078

- No **max-direction** update for HI
- Updates to **risk-targeted calculations:**
  - β updated from 0.8 to 0.6 (HI AK PRVI)
  - minor prob. updates: interp HI, trunc, etc.
- Correction of **det. caps**: 84th% factor from 1.5 to 1.8

Regions:	Maxdir **Δ*Ss***	Maxdir **Δ*S1***	Total **Δ*Ss***	Total **Δ*S1***
HI (1998)	0%	0%	~ -15%	-15 to 0%
AK (2007)	10%	-5%	0 to +25%	0 to +25%
PRVI (2003)	10%	-5%	-5 to +10%	~ -15%
GNMI (2012)	10%	-5%	~ +10%	~ -5%
AMSAM (2012)	10%	-5%	> +10%	varies

Estimating MPRS, S_{MS} & S_{M1}:

- No updates were available for USGS hazard models (or deterministic calculations)
- We updated BC Ss & S1 using the "Site-Specific Procedures, Ch21" of 2020 NEHR: RTGM, maxdir
- We estimated MPRS (no site amplifications in 2020 NEHRP), using FEMA P-2078



Developed Generic Spectral Shapes:

functions of (S_S, S_1, T_L)

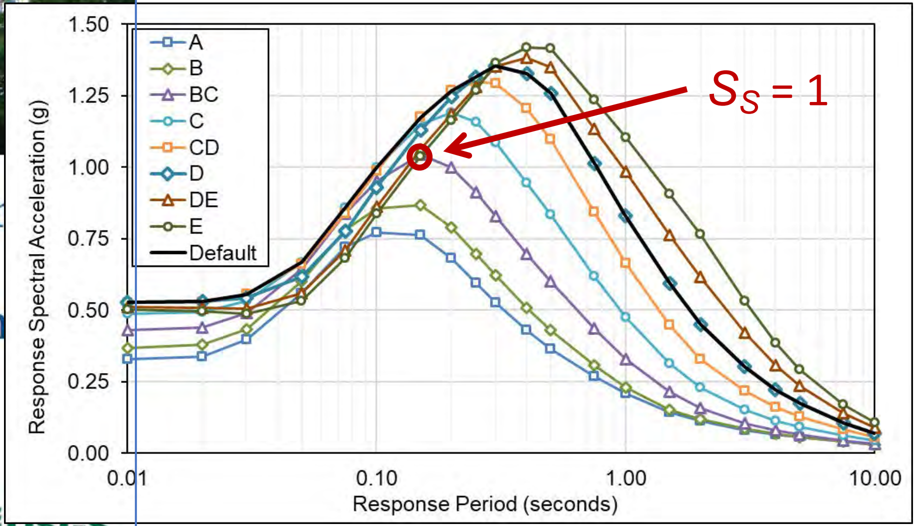
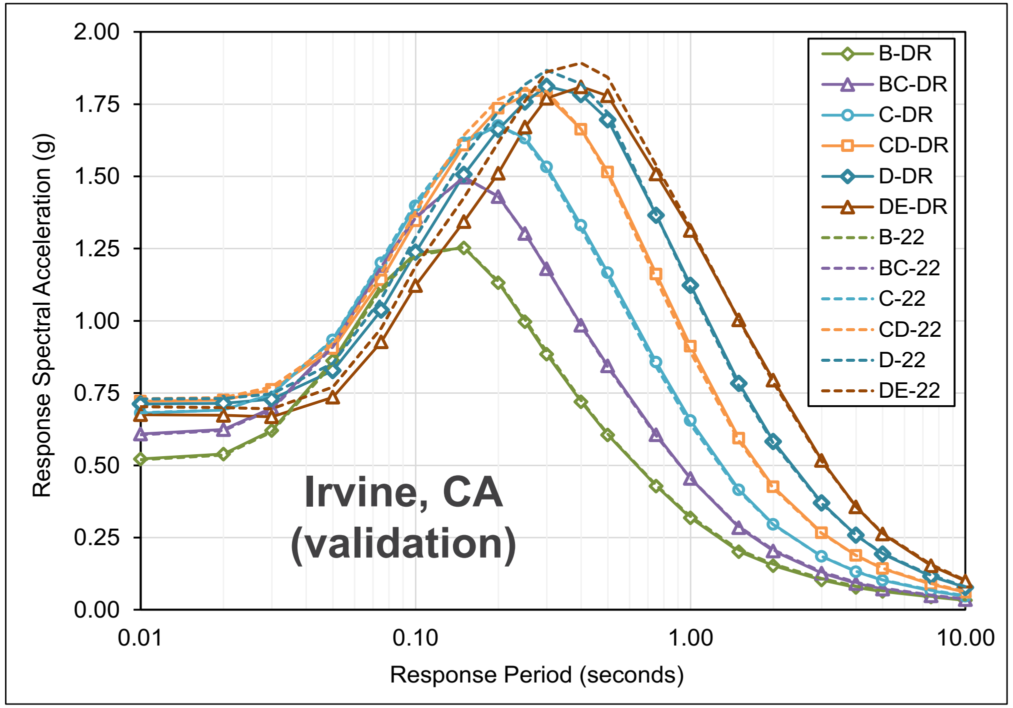
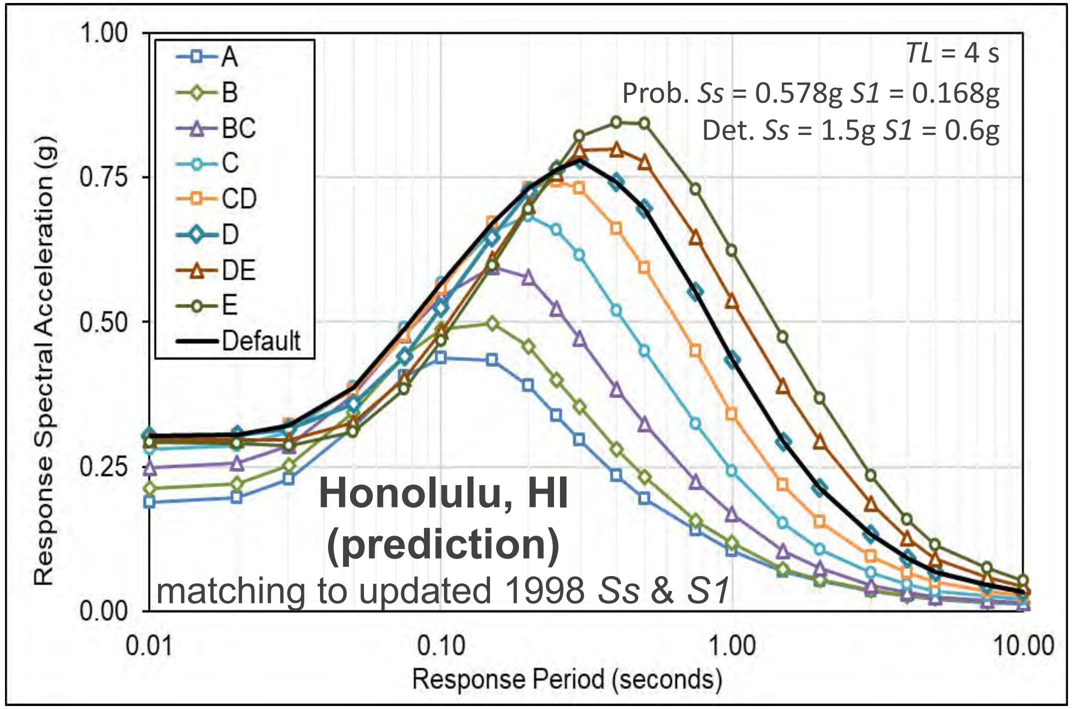


Figure B-17. Plots of probabilistic response spectrum shape parameters (RSSPs) by site class for Table B-17. GTL12S3R2.

Estimating MPRS, S_{MS} & S_{M1}:

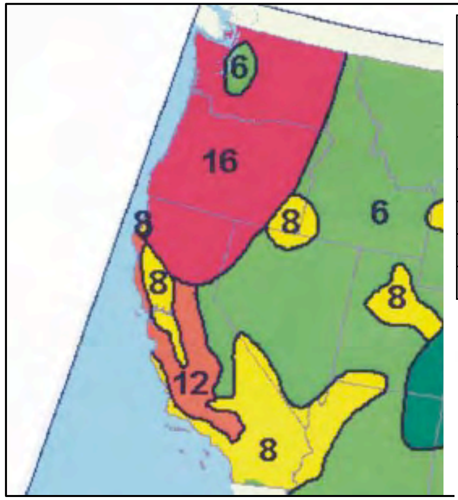


Solid Lines: Predicted values from *Ss* & *S1*
Dashed Lines: Exact values calculated from 2018 NSHM



Spectral Shape = f(T_L , S_S , S_S/S_1):

Figure 3.2-1 from Crouse et al. (2006)



Magnitude (M) Range	Corner Period, T_c (seconds)
6.0 - 6.5	4
6.5 - 7.0	6
7.0 - 7.5	8
7.5 - 8.0	12
8.0 - 8.5	16
8.5 - 9.0+	20

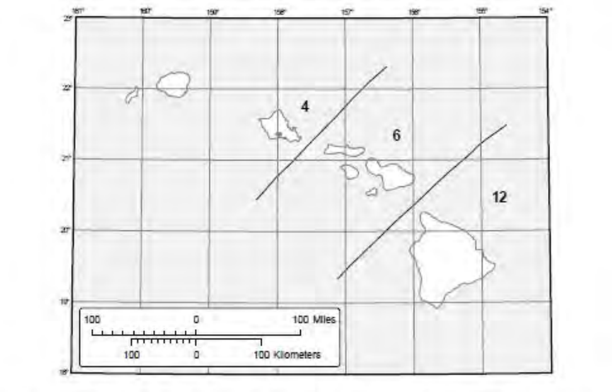
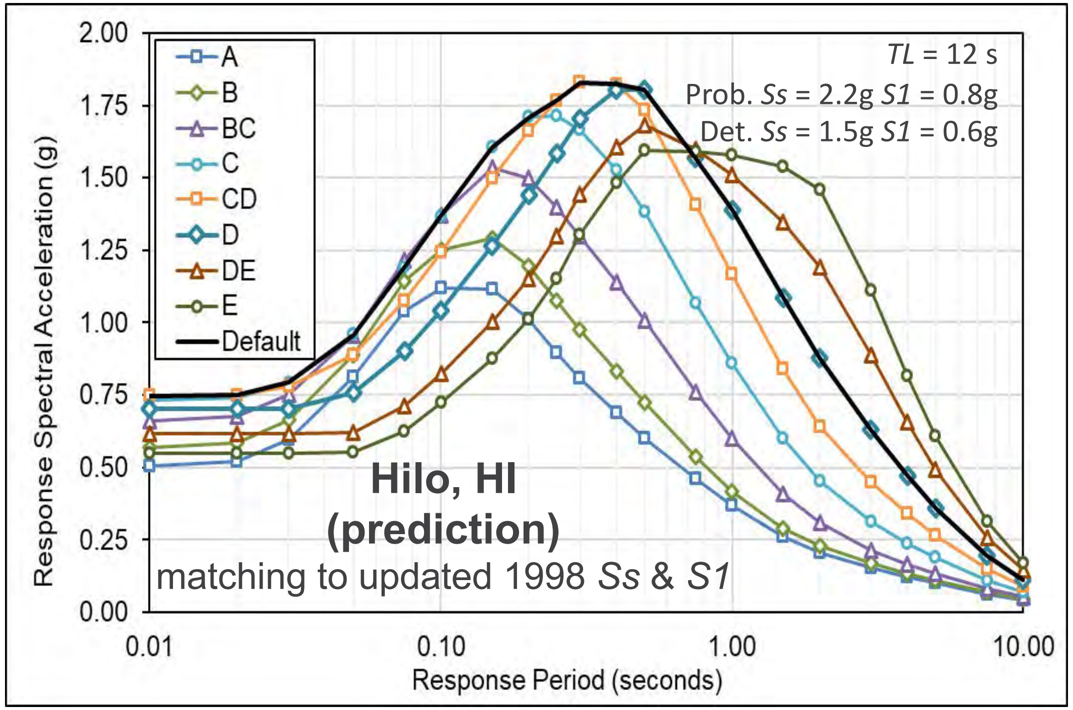
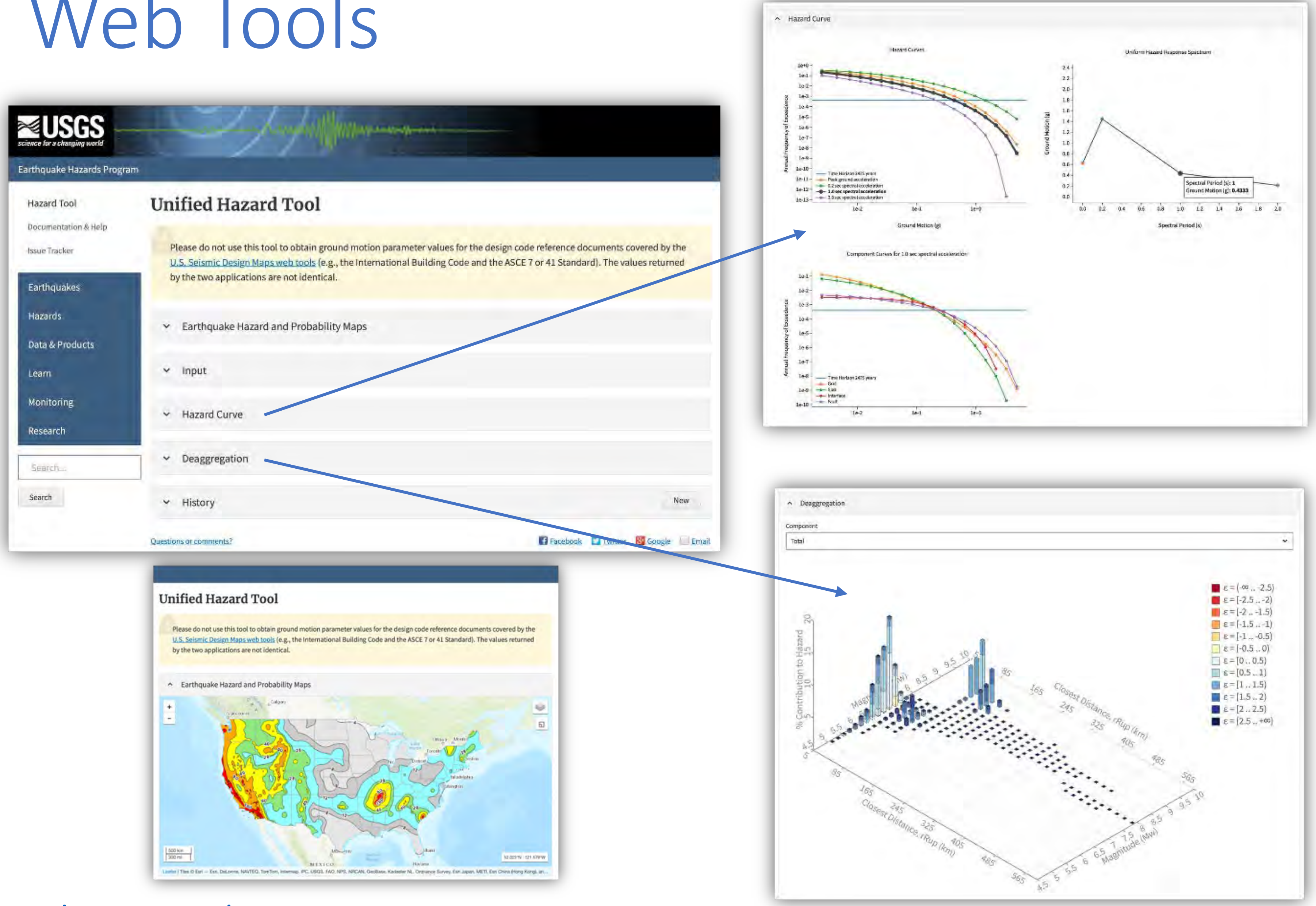


FIGURE 22-16 Mapped Long-Period Transition Period, T_L (s), for Hawaii



Software and Web Tools

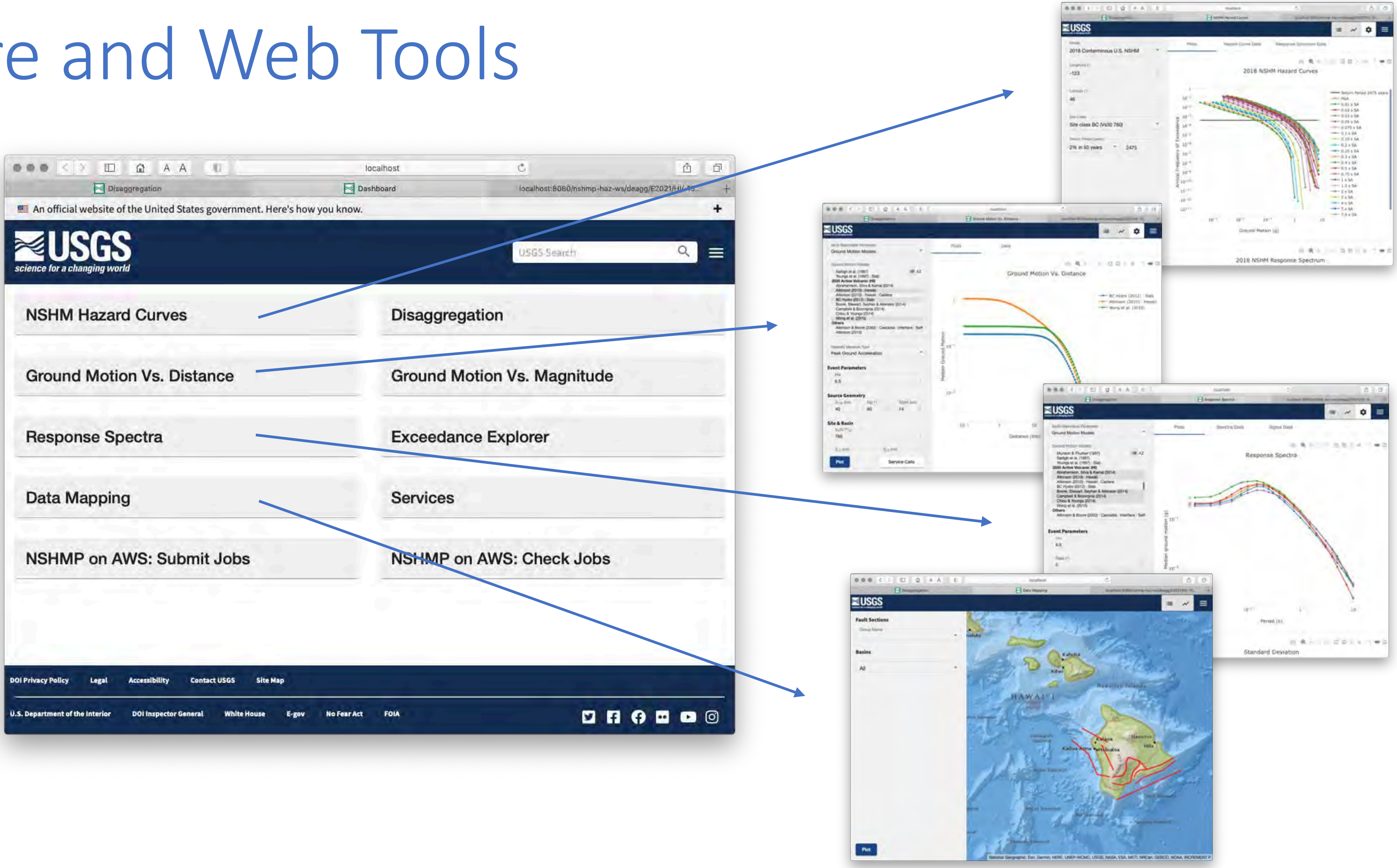
- *UHT*
- *nshmp-haz*
- *nshmp-haz-ws*



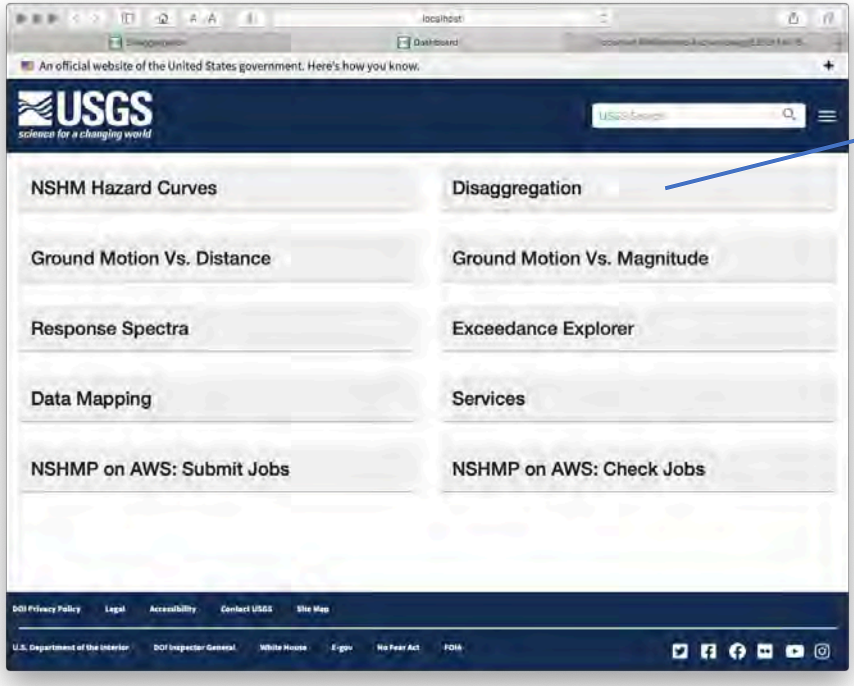
https://earthquake.usgs.gov/hazards/interactive/

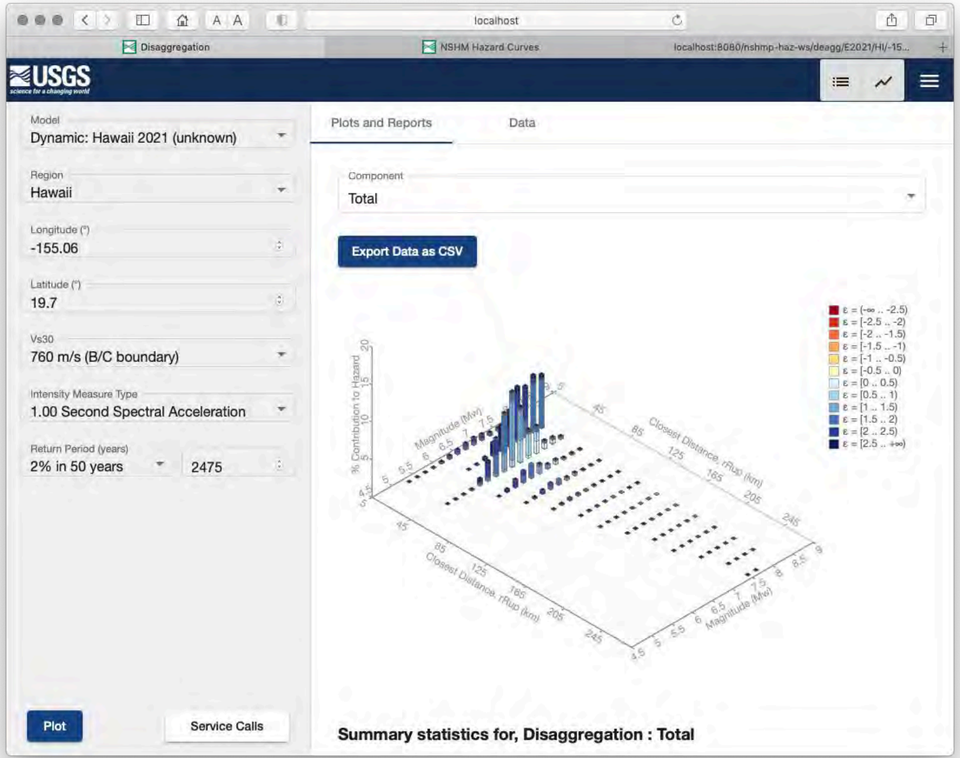
Software and Web Tools

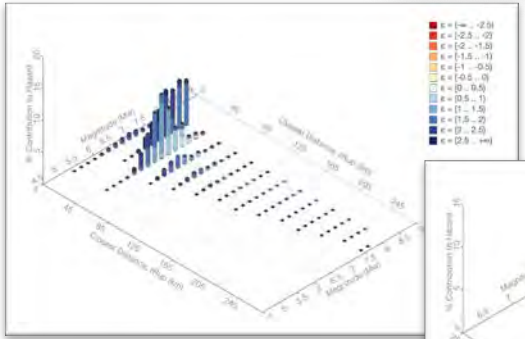
- *UHT v2*
- aws



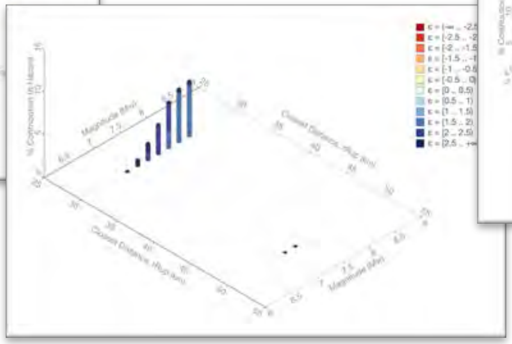
Software and Web Tools



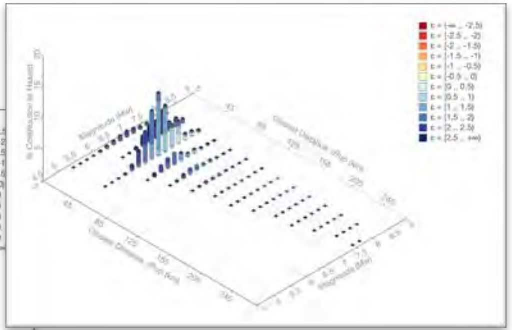




Total



SouthFlank



Grid

Discussion Topics

1. Catalog
2. Declustering Models
3. Earthquake Rates Models
4. Mmax Models
5. Smoothing Models
6. Caldera Collapse and Volcanic - Earthquake Correlation Model
7. Faults/décollements Model
8. Ground Motion Models
9. Site Effects Models
10. Results
11. Risk and Scenarios
12. Building Code
13. Software and Web Tools

USGS Hawaii Hazard Model Timeline

- Hawaii Workshop #1 - University of Hawaii at Manoa (September 18, 2019)
- HETAC Briefing (September 11, 2020)
- Hawaii Workshop #2 – Virtual (November 18, 2020)
- Review – HETAC, USGS Steering Committee, USGS internal review, scientific meeting presentations, Public comment (November, December 2020)
- Submit paper to *Earthquake Spectra* and peer review (December 2020 - June 2021)
- Present reviewed model to HETAC, Seismological Society of America, public release of product (Summer or Fall, 2021)

Adjourn