EVALUATION OF GROUND MOTION MODELS FOR USGS SEISMIC HAZARD MODELS: HAWAII TECTONIC EARTHQUAKES AND VOLCANIC EXPLOSIONS

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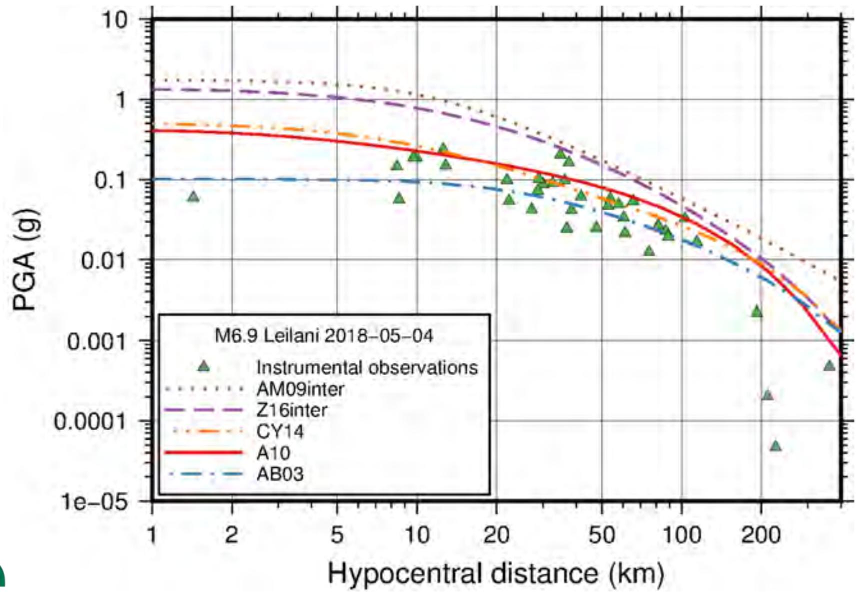
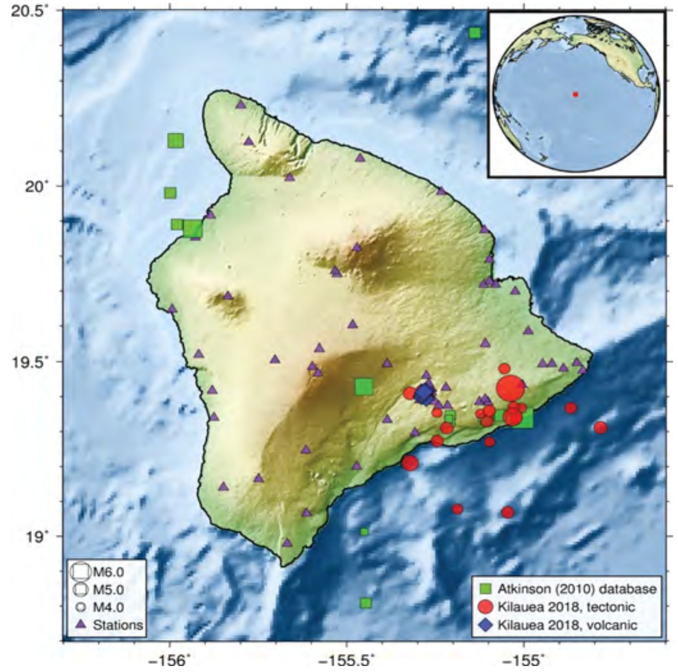
J. Rekoske, E. Thompson, C.S. Mueller, M.D. Petersen





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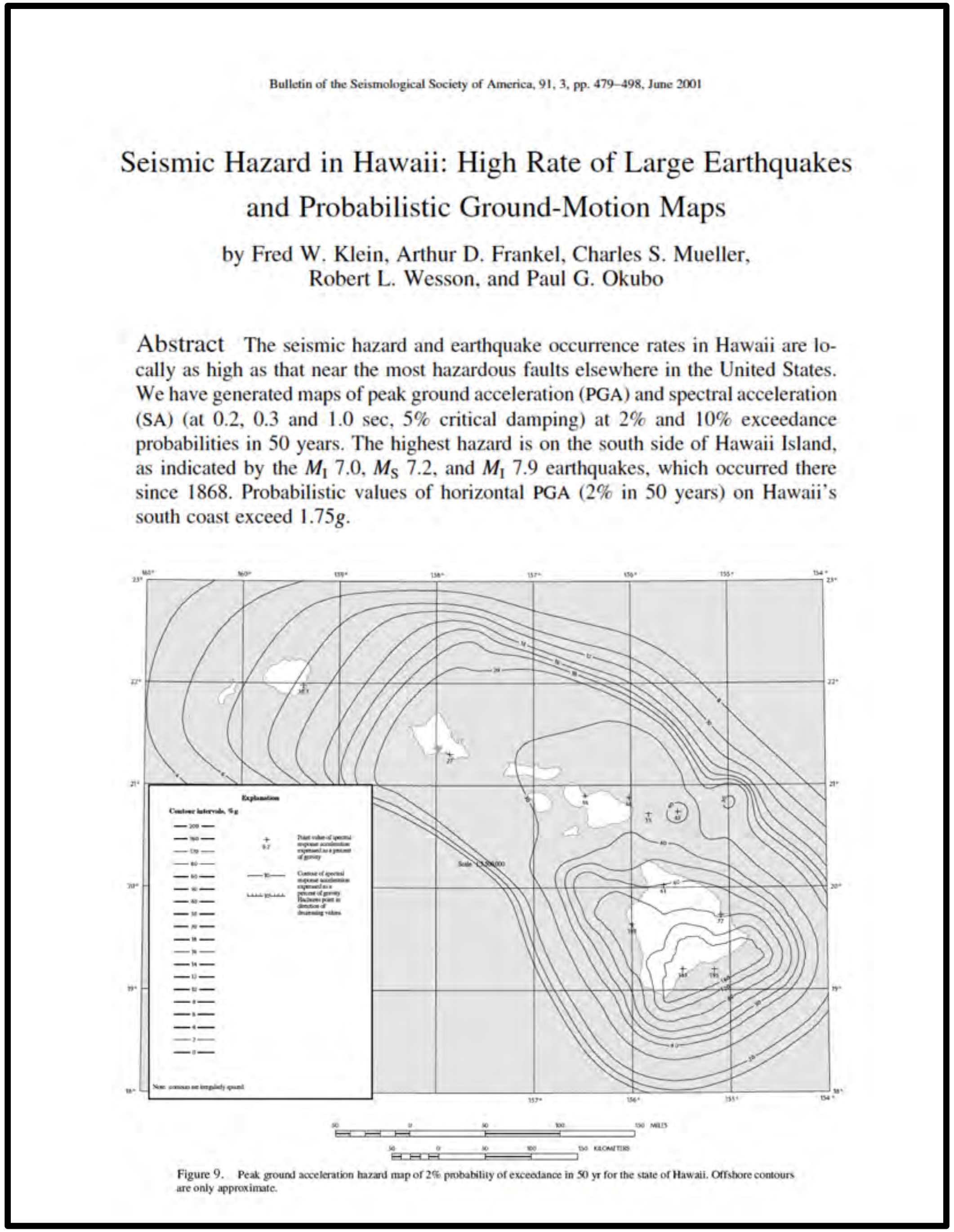
Objectives and Motivation

- Evaluate GMMs for the update of the USGS seismic hazard model for Hawaii (Klein et al., 2001)
  - GMMs are a significant source of uncertainty in seismic hazard models
  - Select and weight GMMs
  - Recent Kilauea sequence provides new and independent ground motion data



Bulletin of the Seismological Society of America, 91, 3, pp. 479–498, June 2001

Seismic Hazard in Hawaii: High Rate of Large Earthquakes and Probabilistic Ground-Motion Maps

by Fred W. Klein, Arthur D. Frankel, Charles S. Mueller, Robert L. Wesson, and Paul G. Okubo

Abstract The seismic hazard and earthquake occurrence rates in Hawaii are locally as high as that near the most hazardous faults elsewhere in the United States. We have generated maps of peak ground acceleration (PGA) and spectral acceleration (SA) (at 0.2, 0.3 and 1.0 sec, 5% critical damping) at 2% and 10% exceedance probabilities in 50 years. The highest hazard is on the south side of Hawaii Island, as indicated by the M_I 7.0, M_S 7.2, and M_I 7.9 earthquakes, which occurred there since 1868. Probabilistic values of horizontal PGA (2% in 50 years) on Hawaii's south coast exceed 1.75*g*.

Figure 9. Peak ground acceleration hazard map of 2% probability of exceedance in 50 yr for the state of Hawaii. Offshore contours are only approximate.

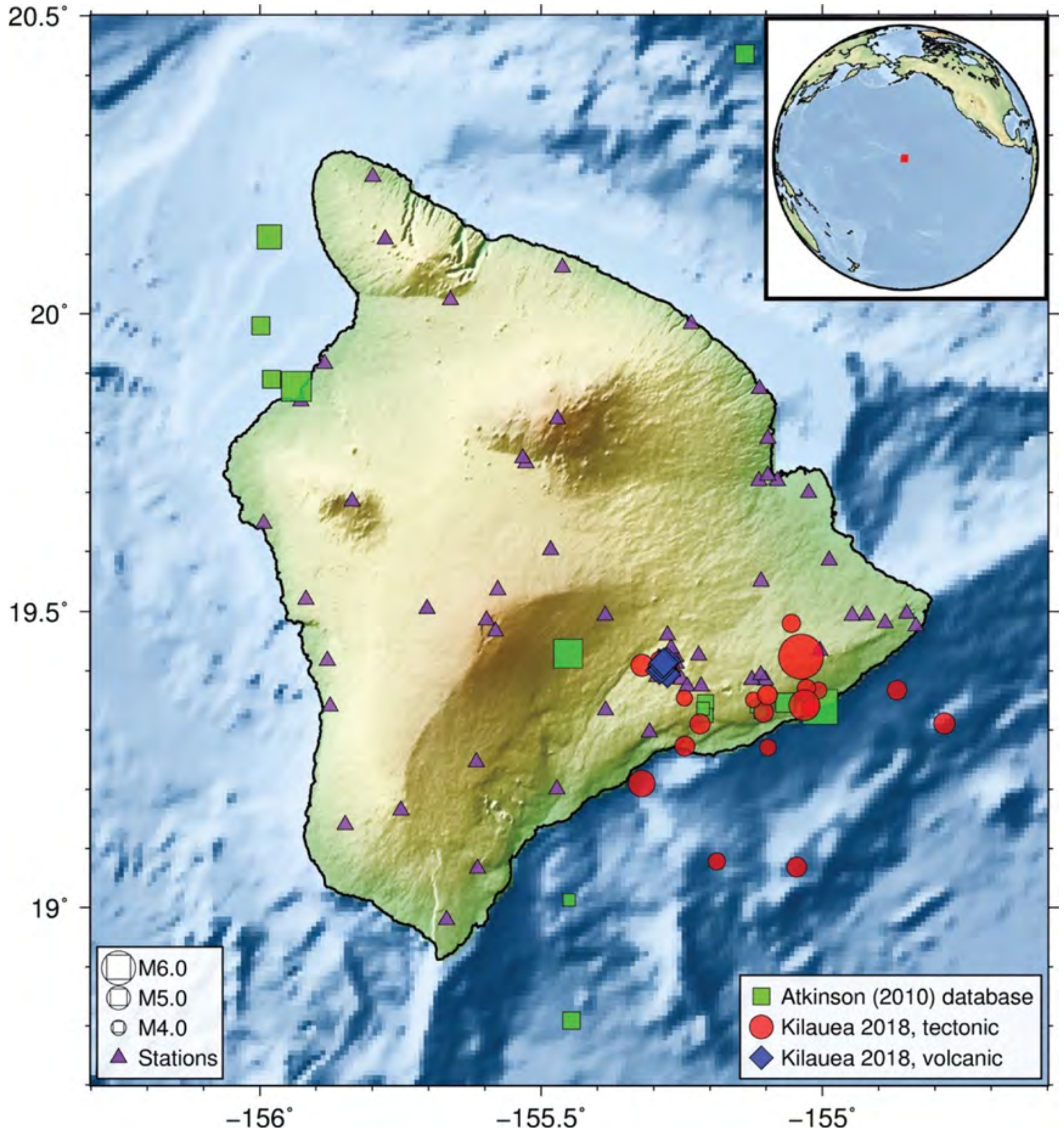
Ground Motion Data

2018 Kilauea volcanic sequence

- tectonic earthquakes and volcanic explosions
- PGA PGV PSA 0.02 – 10 s
- Mw 4-6.9

Atkinson (2010) - database of strong ground motion

- historical earthquakes (1973-2006)
- PGA, PSA 0.04 – 6.0 s
- Mw 4-7.3



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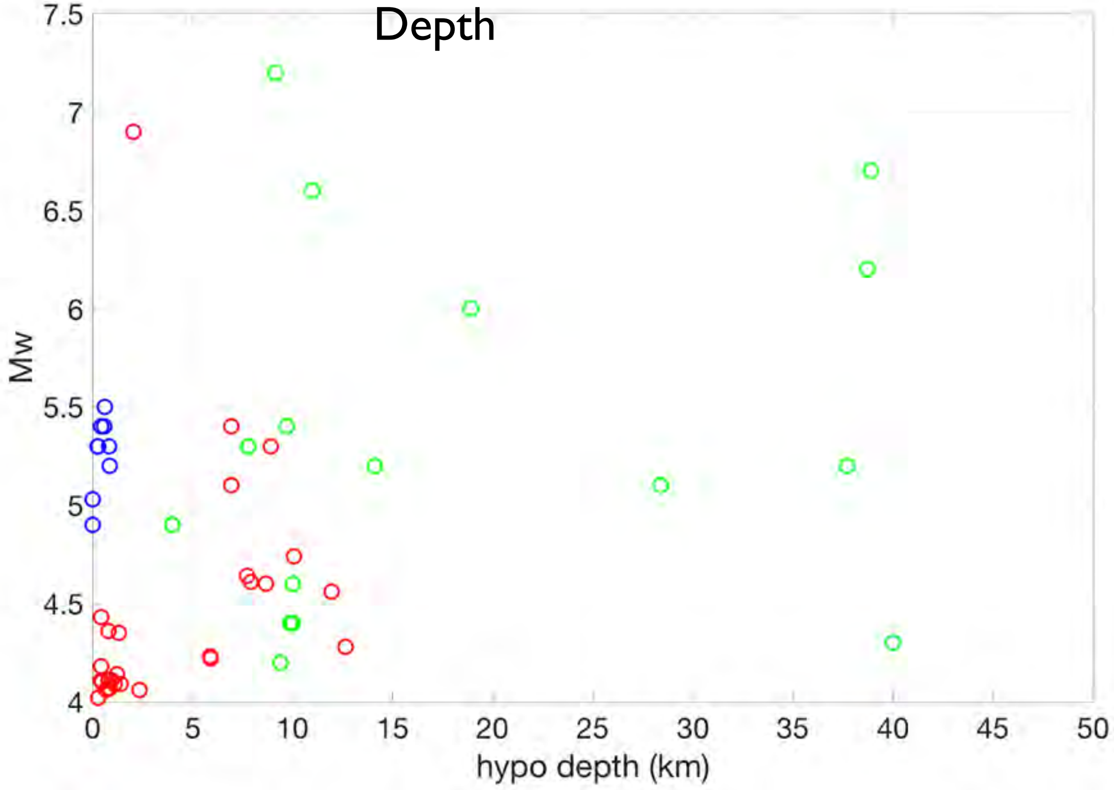
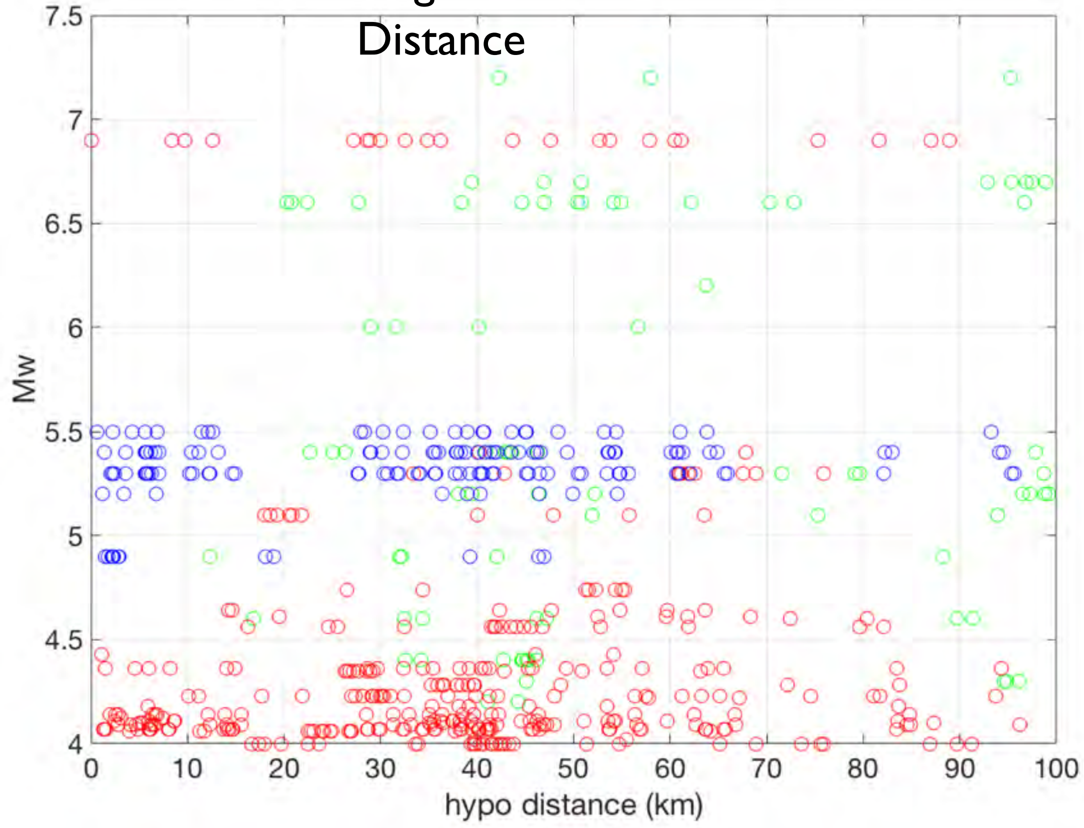
Ground Motion Data

Magnitude vs. Depth



Magnitude vs. Distance



Atkinson (2010) (green circles)
2018 Kilauea Volcanic Sequence
tectonic (red circles)
volcanic (blue circles)

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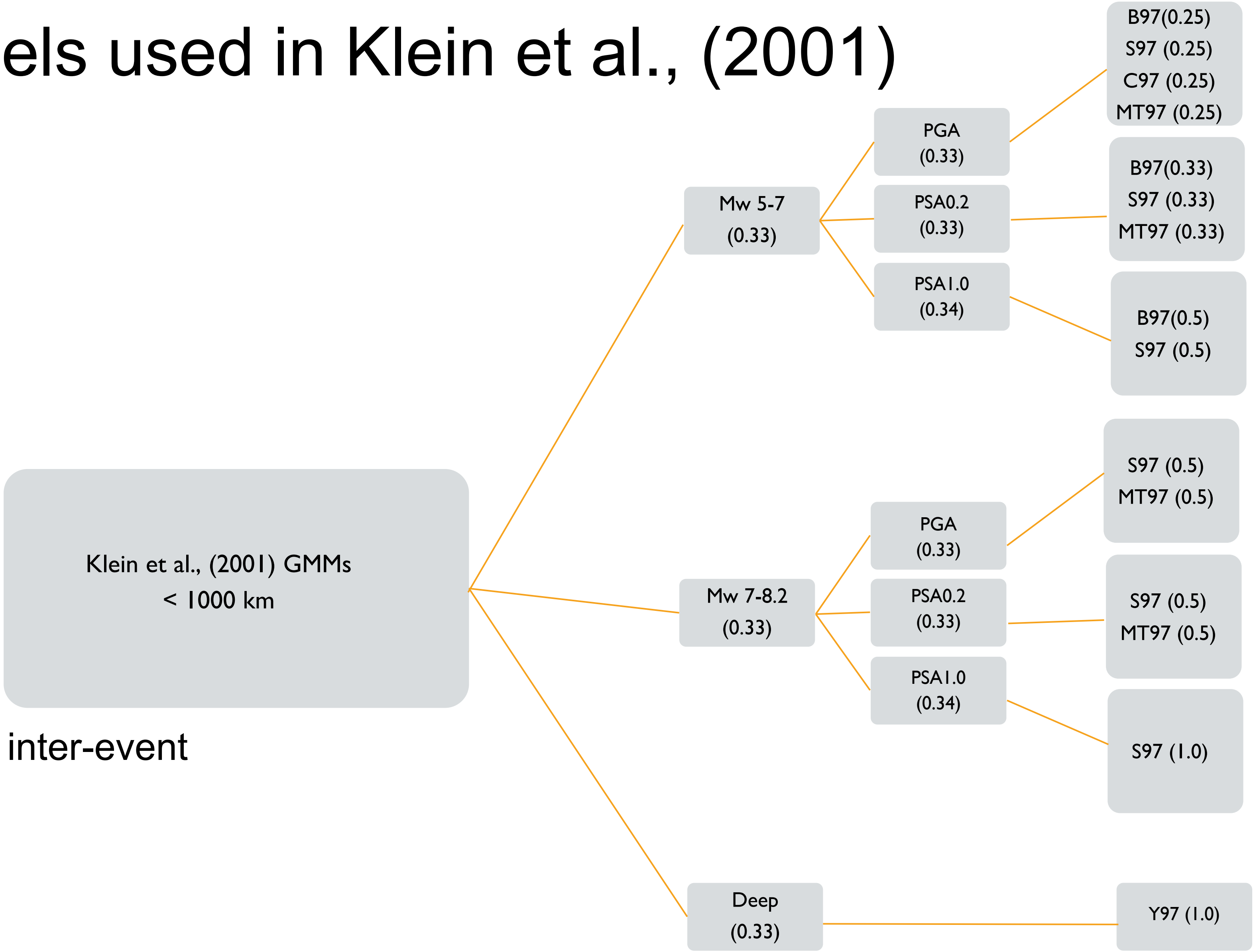
Ground Motion Models used in Klein et al., (2001)

GMMs in Klein et al., (2001)

Boore et al., (1997)
Campbell (1997)
Munson and Thurber (1997)
Sadigh et al., (1997)
Youngs et al., (1997) Slab

- Limited PSAs
- No depth terms
- No site amplification
- Uncertainty not well defined
- Only total sigma (No intra- and inter-event variability)



Logic tree used to weight GMMs based on Mw and hypo depth

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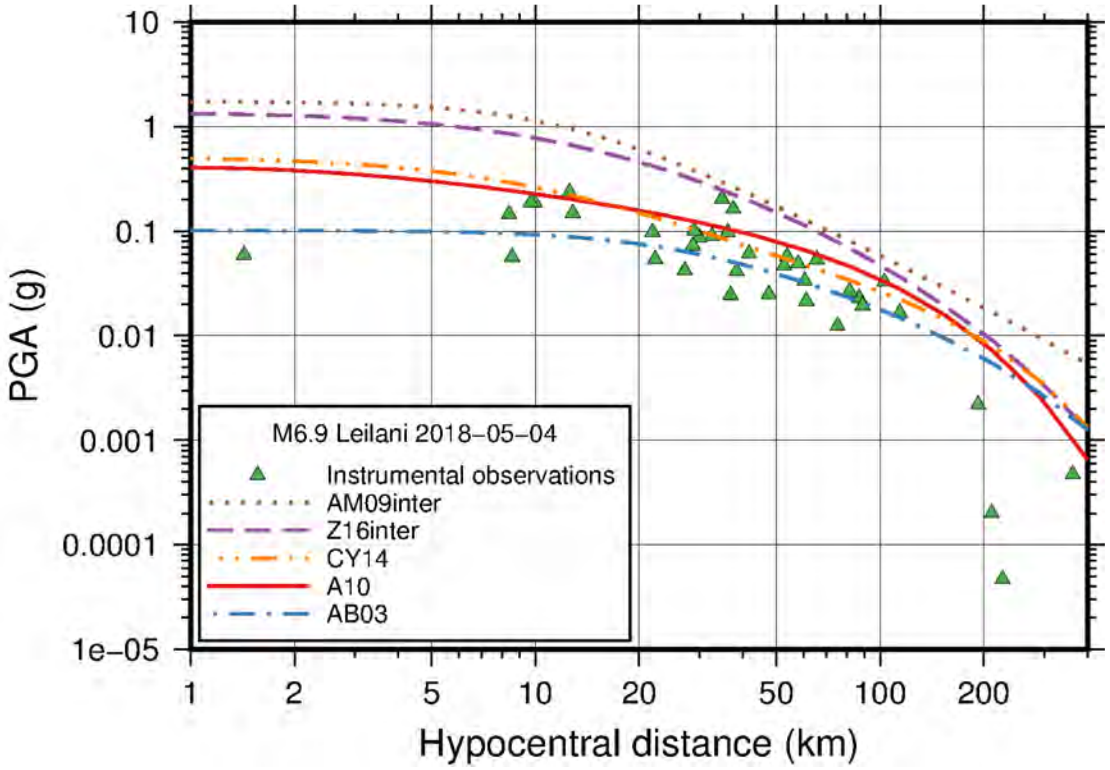
Ground Motion Models Evaluated for Update



18 candidate GMMs for active tectonic regions volcanic and subduction

Model Group	Geographic Region	Label	Parameters	Reference
Hawaii-specific	Hawaii	A10	Mw 5-8 Rjb 0-200 km Vs30 180-1300 m/s	Atkinson (2010)
	Hawaii	W15	Mw 5-8 Rrup 0-300 km Ztop 20-60 km Vs30 760 m/s	Wong et al. (2015)
NGA-West2	Western US active tectonic	ASK14	Mw 3-8.5 Rrup 0-300 km Vs30 180-1000 m/s Z1.0 0-3 km	Abrahamson et al. (2014)
	Western US active tectonic	CY14	Mw 3-8.5 Rrup 0-300 km Vs30 180-1000 m/s Z1.0 0-3 km	Chiou and Youngs (2014)
	Western US active tectonic	CB14	Mw 3-8.5 Rrup 0-300 km Vs30 180-1000 m/s Z1.0 0-3 km	Campbell and Bozorgnia (2014)
	Western US active tectonic	BSSA14	Mw 3-8.5 Rrup 0-300 km Vs30 180-1000 m/s Z1.0 0-3 km	Boore et al. (2014)
Subduction zone: slab and/or interface	Cascadia	AM09inter	Mw 5-9.5 Rrup 0-1000 km Vs30 150-1500 m/s	Atkinson and Macias (2009)
	Cascadia	BCH12[inter,slab]	Mw 5-9.5 Rrup 0-1000 km Vs30 150-1000 m/s	Abrahamson et al. (2016)
	Cascadia	NGAsub[inter,slab]	Mw 5-9.5 Rrup 0-1000 km Vs30 150-1000 m/s	Abrahamson et al., (2018)
	Japan	AB03[inter,slab]	Mw 4-8 Rrup 0-1000 km Vs30 760-2000 m/s	Atkinson and Boore (2003)
	Japan	Z16[inter,slab]	Mw 5-9.5 Rrup 0-1000 km Vs30 150-1000 m/s	Zhao et al. (2016a,b)
	Japan	Z06[inter,slab]	Mw 5-9.5 Rrup 0-1000 km Vs30 150-1000 m/s	Zhao et al. (2006)
Volcanic	New Zealand	M06	Mw 4-8 Rrup 0-200 km	McVerry et al. (2006)

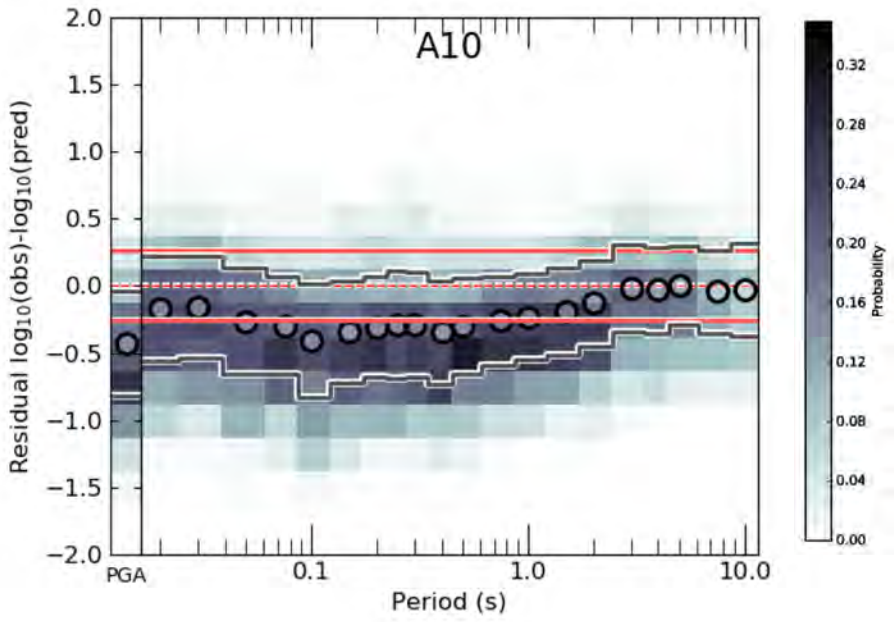
GMM Evaluation Methods

Residual Distribution

Looking for small mean residual across all periods

Preserves GMM over and under-prediction

Compares standard deviations



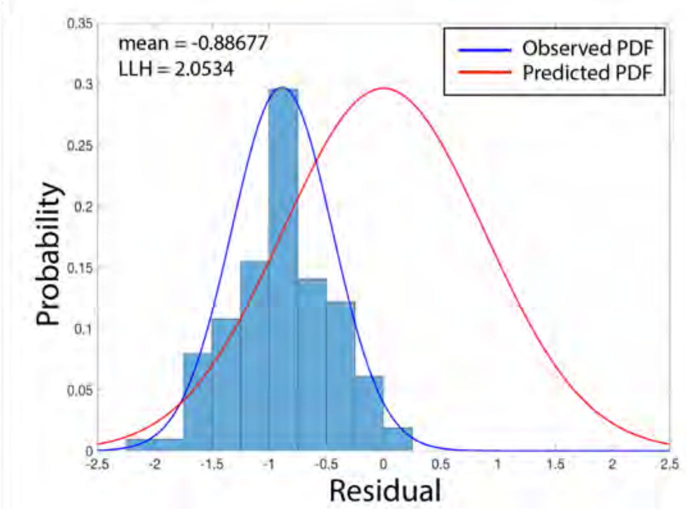
LLH probabilistic scoring method

(Scherbaum et al. 2009)

compares the distribution of the observed

and predicted ground motions

provides single score useful for weights



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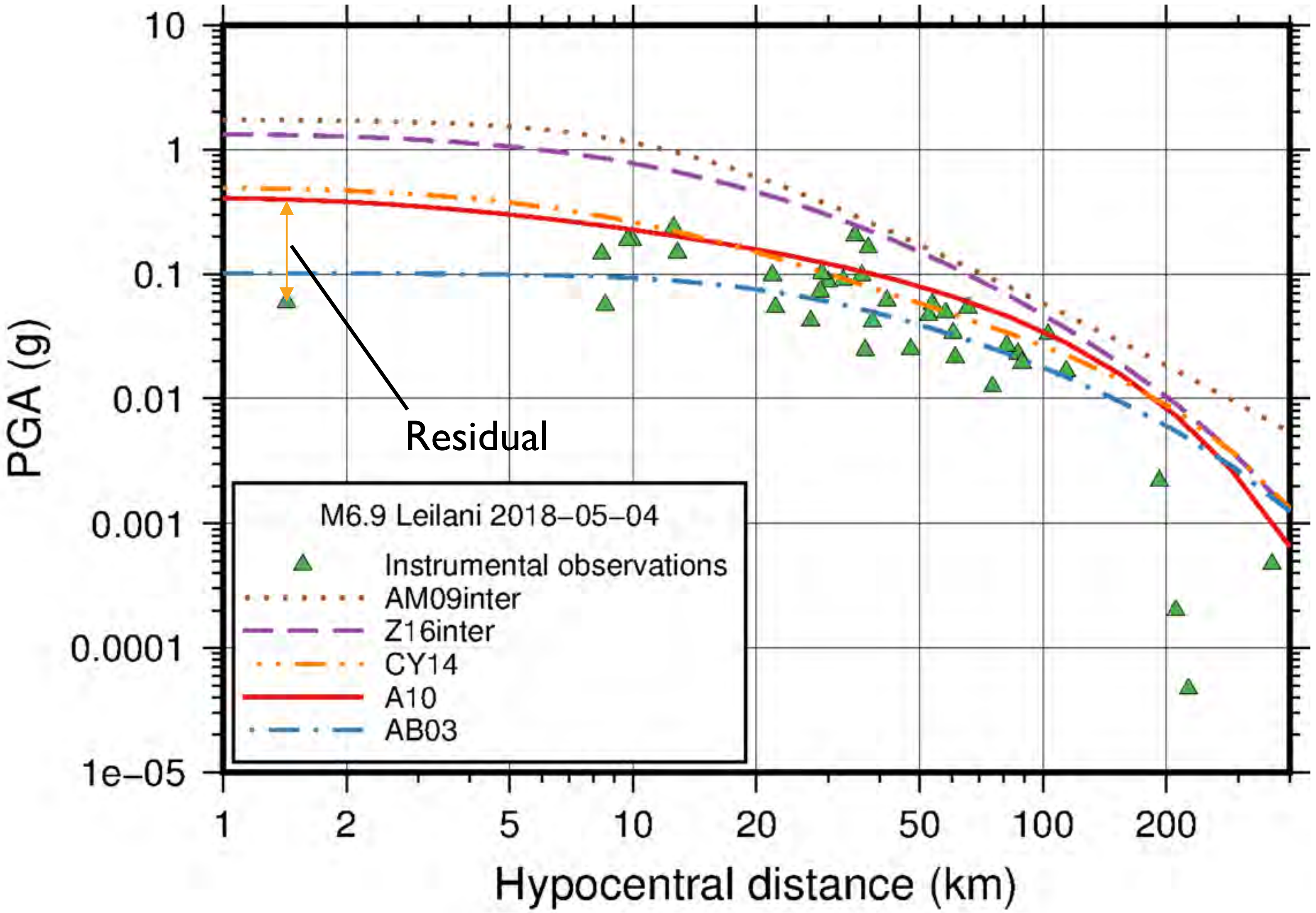
Residuals



GMM Parameter assumptions:

- measured Vs30, Wong 2011
  - Topo. Slope proxy
- Distance
  - Rrup = Hypocenter distance
  - Rjb = Epicentral distance

Residual = log(observed) – log(predicted)

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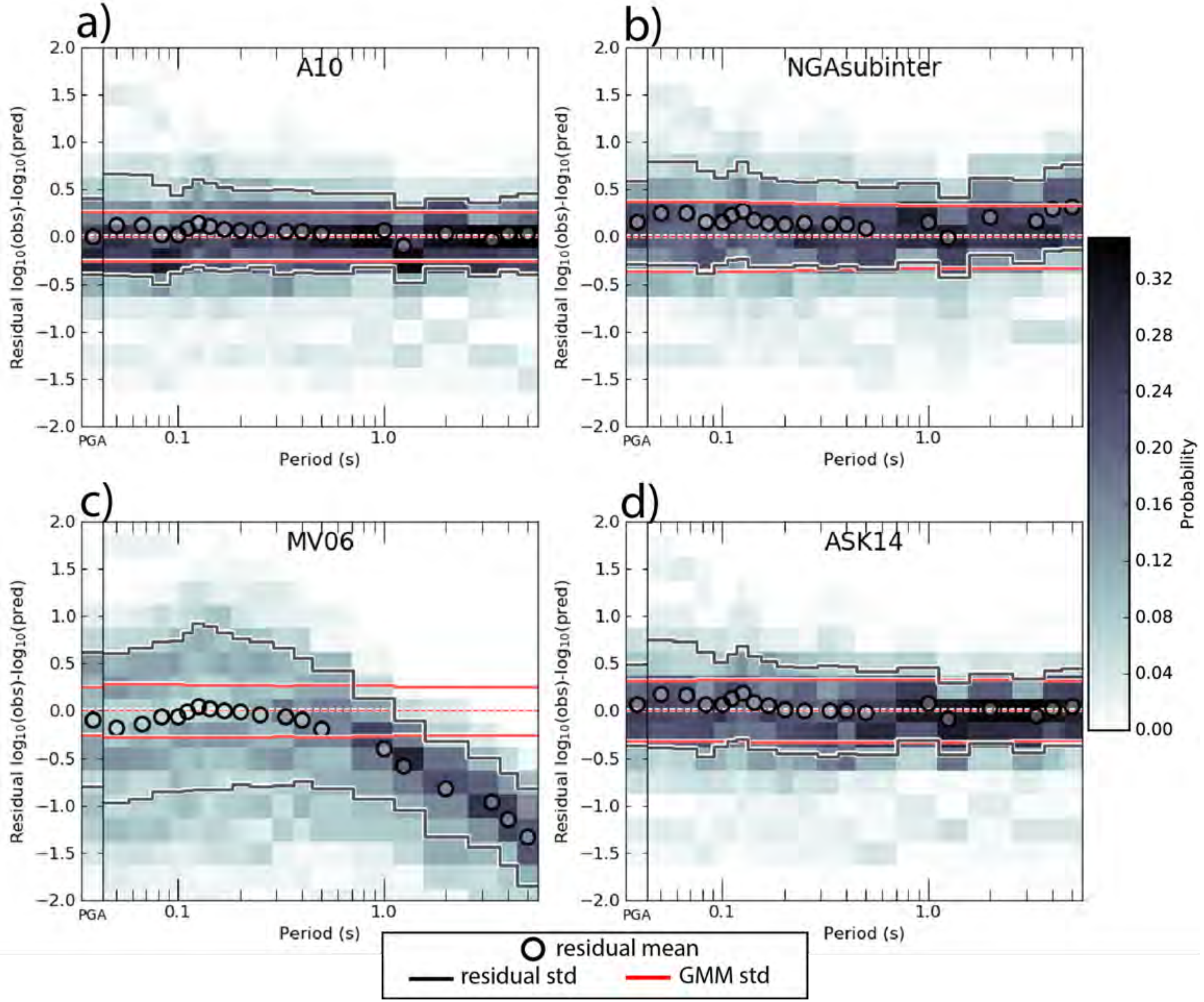
Residuals: Atkinson (2010) database

Shading shows residual distribution

Mean residual and standard dev. varies by period

GMM performance varies by period



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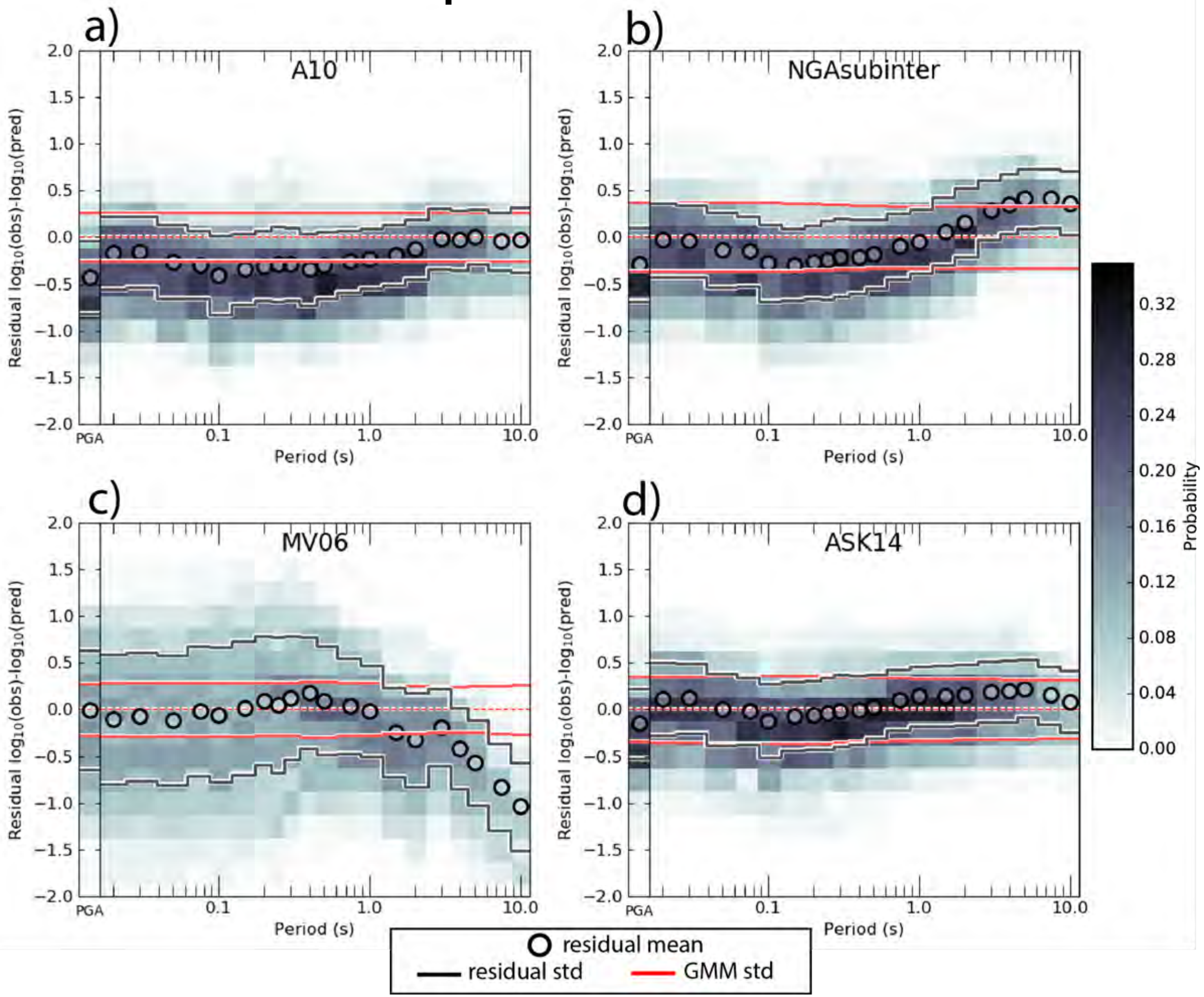
Residuals: 2018 Kilauea Tectonic Earthquakes

Shading shows residual distribution

Mean residual and standard dev. varies by period

GMM performance varies by period



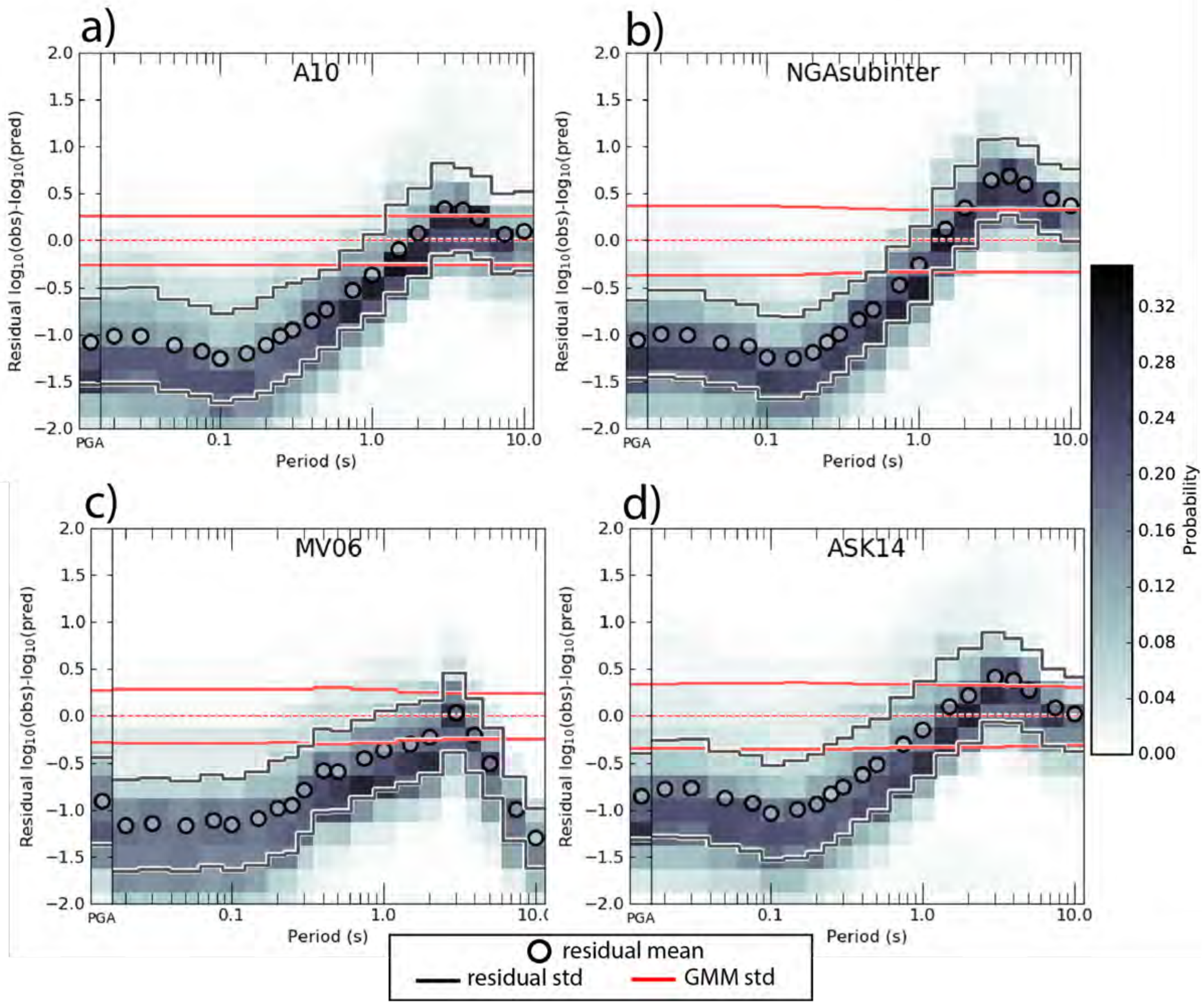
Residuals: 2018 Kilauea Volcanic Explosions

Shading shows residual distribution

Mean residual and standard dev. varies by period

GMM performance varies by period

Do we need a volcanic GMM?



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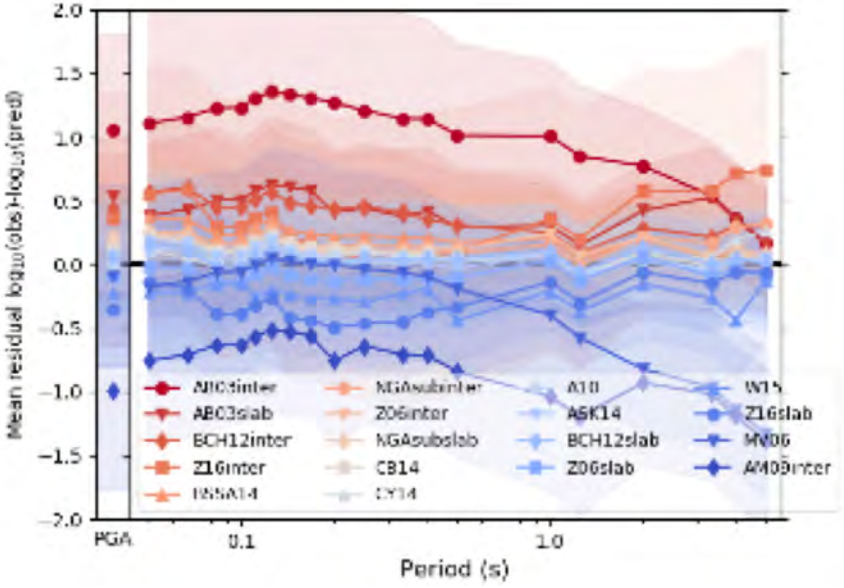
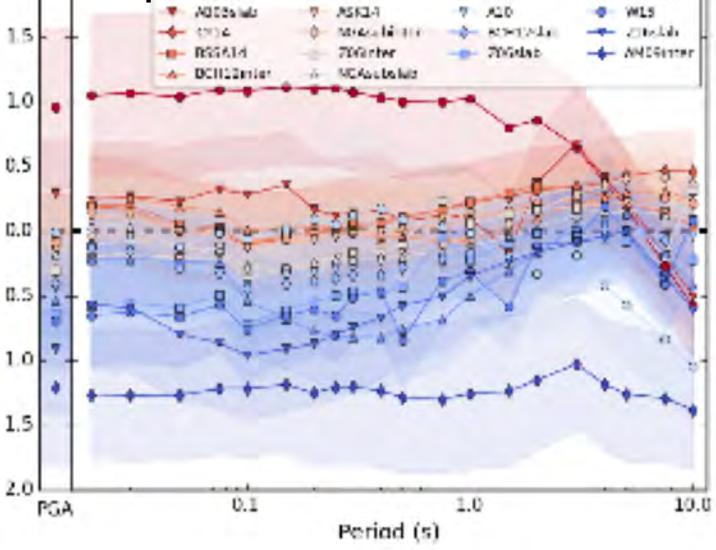
Mean Residuals

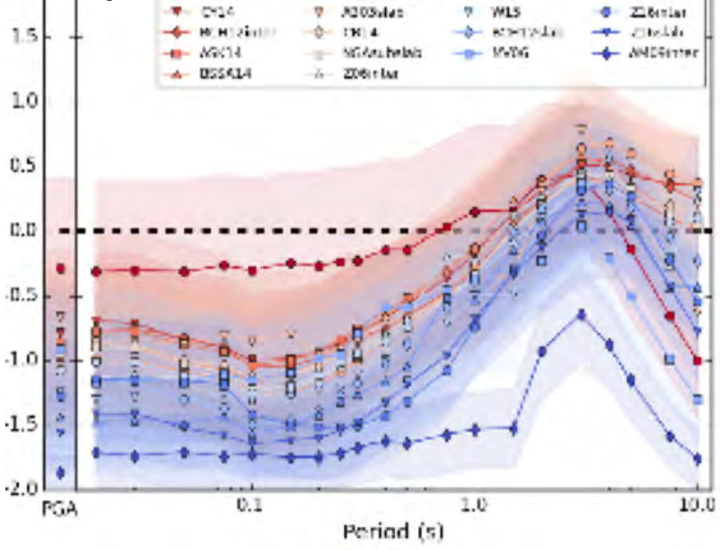
Atkinson (2010) database



2018 Kilauea Tectonic Earthquakes

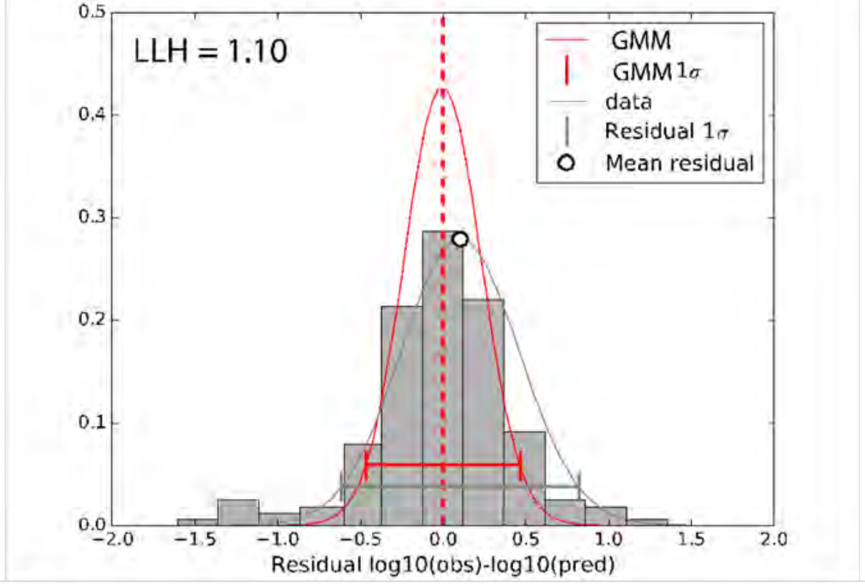


2018 Kilauea Volcanic Explosions



Volcanic explosions depleted in short-period energy

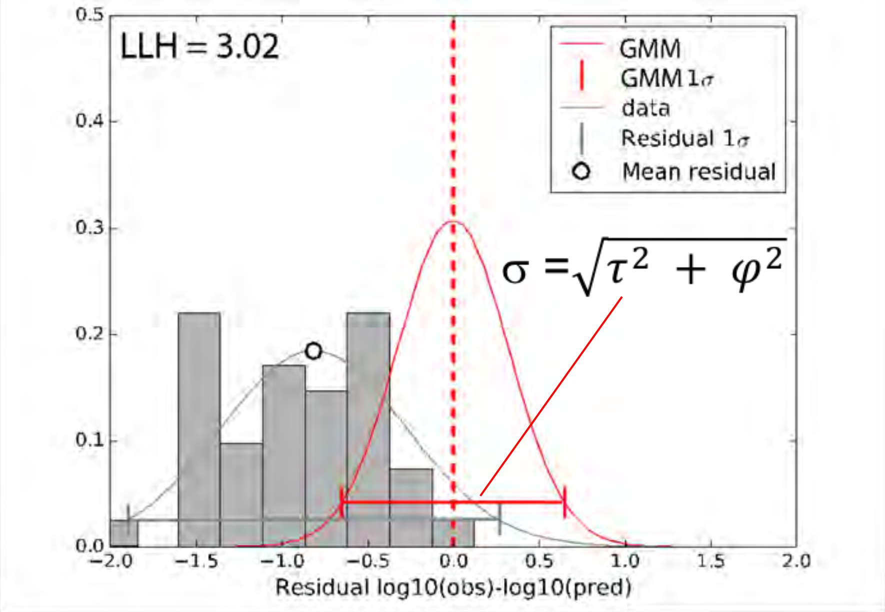
GMM scoring and weighting using residuals



The negative average log-likelihood (LLH) reflects the fit between the data and model:

Compare PDF distribution of predicted and observed ground motion

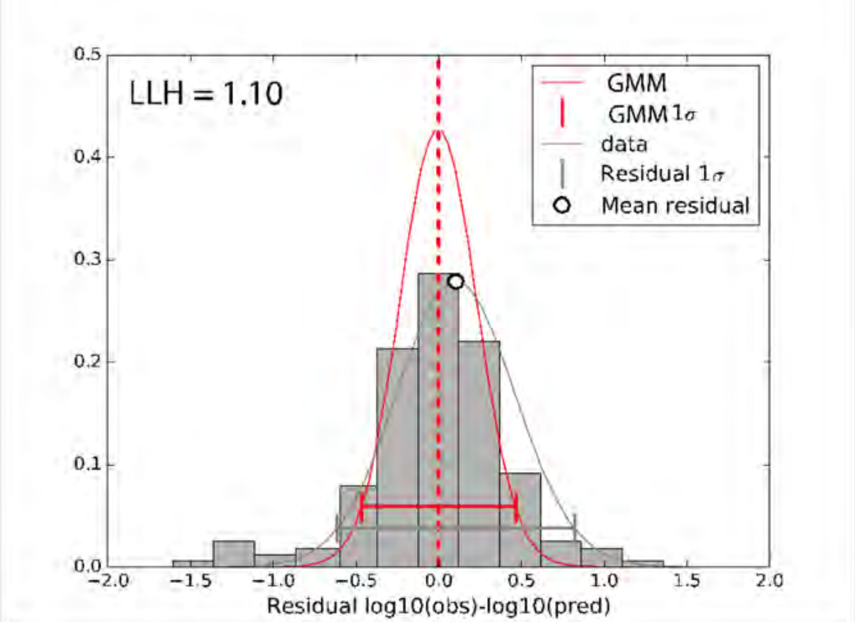
$$\mathrm{LLH} = -\frac{1}{N}\sum_{i=1}^{N}\log_2(g(x_i)),$$

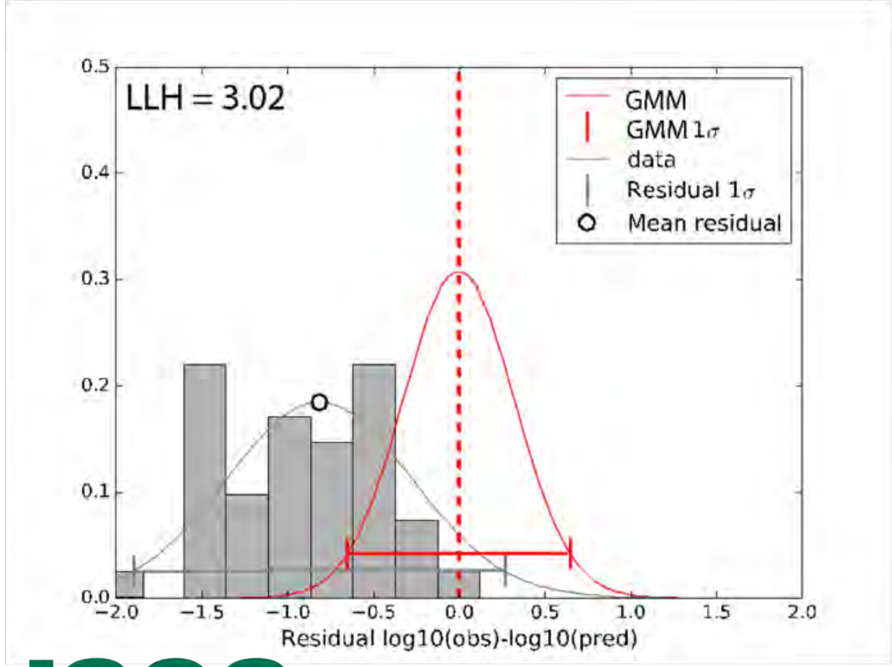


N = the number of observations xi , and g the probability density function (PDF) predicted by the GMPE (normal distribution)

Modern GMMs (NGA-sub) decompose total σ into the uncertainty of multiple correlated variables, the intra-(within) (φ) and inter-(between) event (τ) residuals (**Atik et al., 2010**).

Scherbaum et al., (2009); Ogweno and Cramer (2014); Beauval et al., (2010)





LLH interpretation examples

Lower LLH score indicates better GMM fit to data

Low LLH scores when means are similar (~1)

best LLH scores when GMM sigma similar to data sigma (<1)

LLH penalizes large GMM sigma (>2)

Limitations

limited to observed moderate magnitude earthquakes

Lose information on GMM over or under-prediction with a single score

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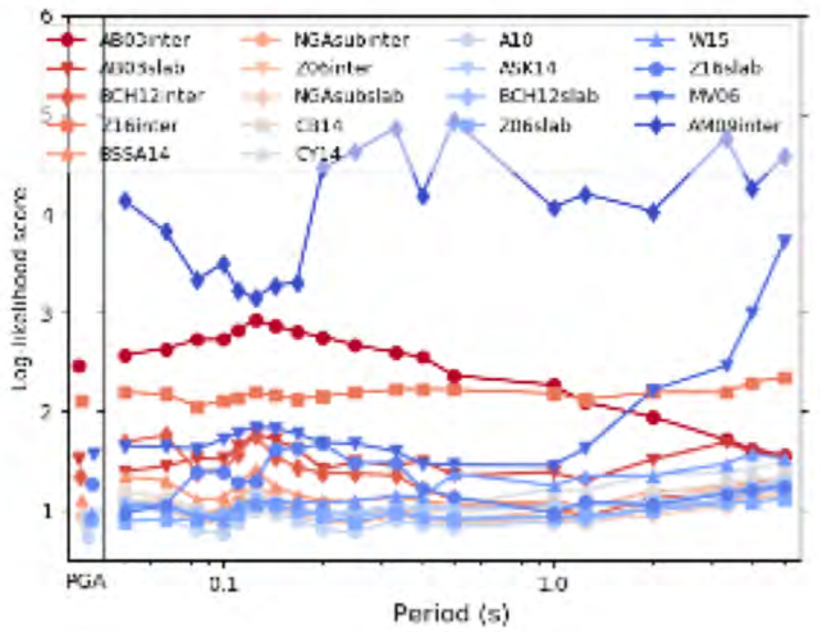
GMM weighting using LLH

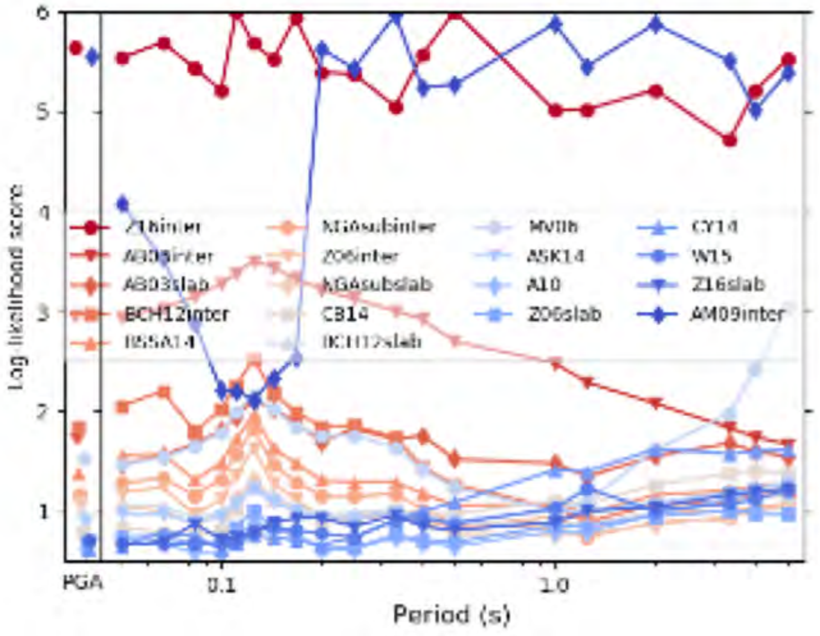
Lower LLH score indicates better fit

LLH scores vary by period

Weight each period?



Atkinson (2010) database



Atkinson (2010) Database

Deep Earthquakes

>20 km

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GMM Evaluation using LLH

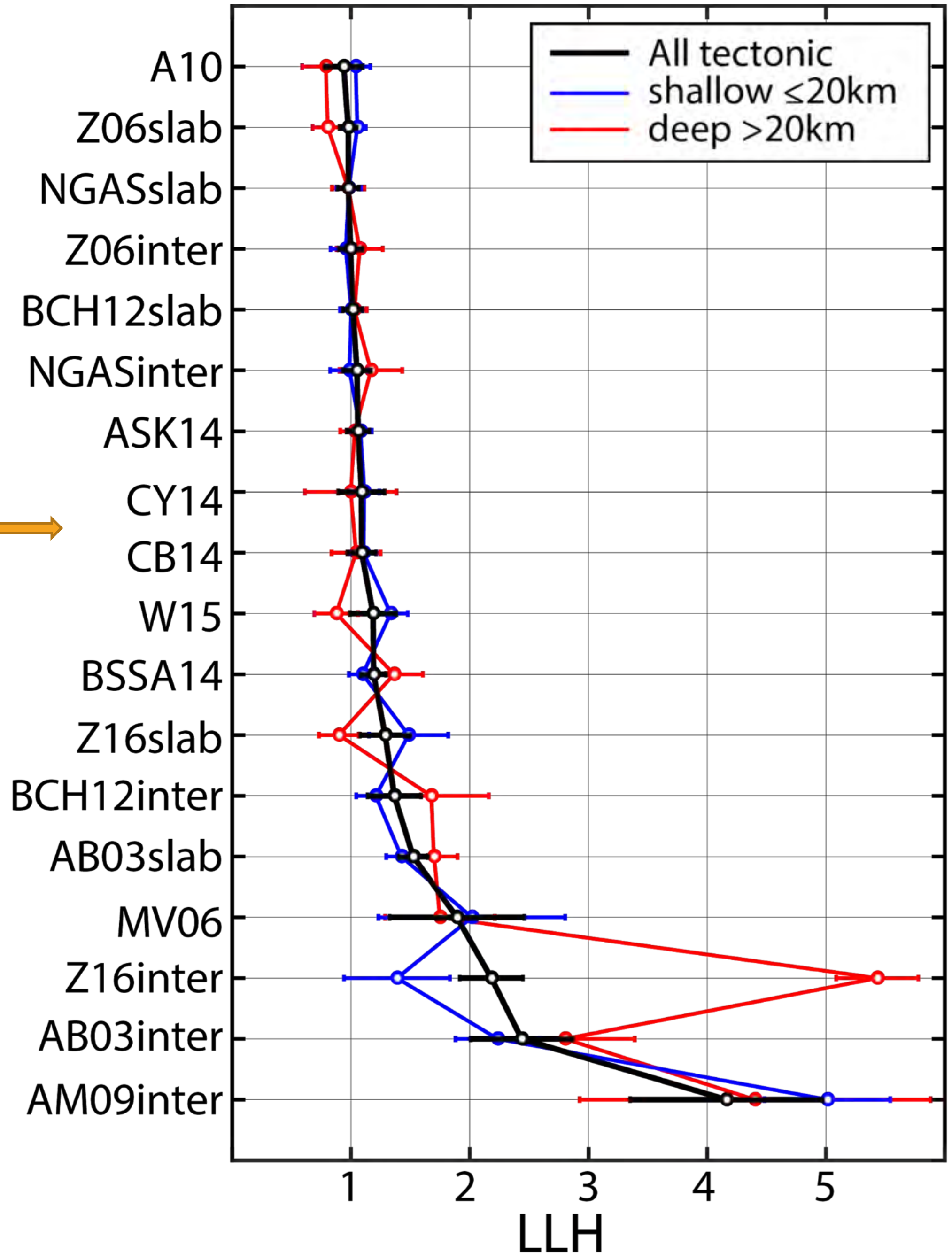
Combined Atkinson (2010) and Kilauea Tectonic EQs

Mean LLH computed for all periods

Sorted by black line

Lower LLH score indicates better fit

Use mean LLH for single GMM weight?



SUMMARY

1. Several GMMs preform well for tectonic earthquake ground motions (A10, W15, BCH12slab, NGAsubslab, NGAsubinter, ASK14, BSSA14, CY14, CB14).

2. GMMs A10, W15, Z06slab and Z16slab perform better for deep (>20 km) tectonic earthquakes.

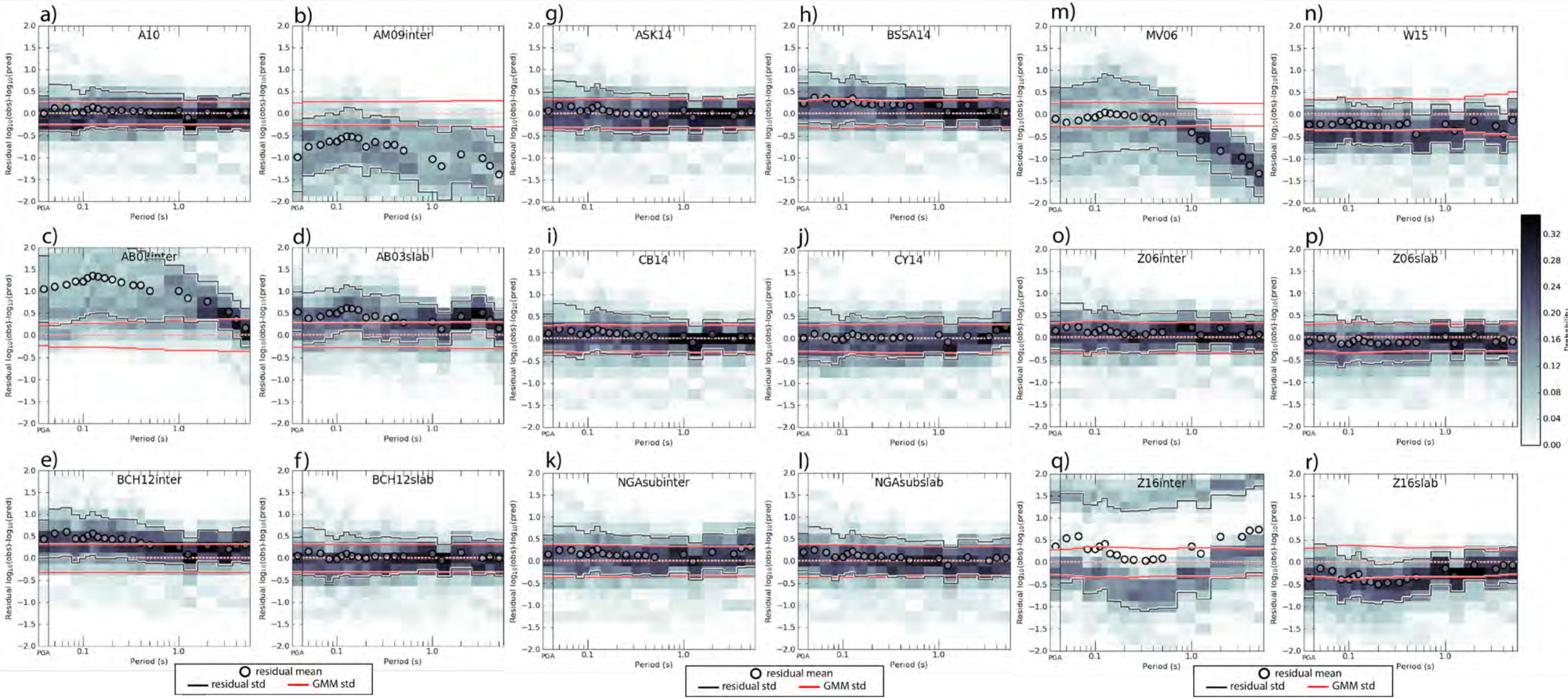
3. Volcanic eruption ground motions are significantly over-estimated by all GMMs at short-periods (PSAs < 3 s).

Remaining questions?

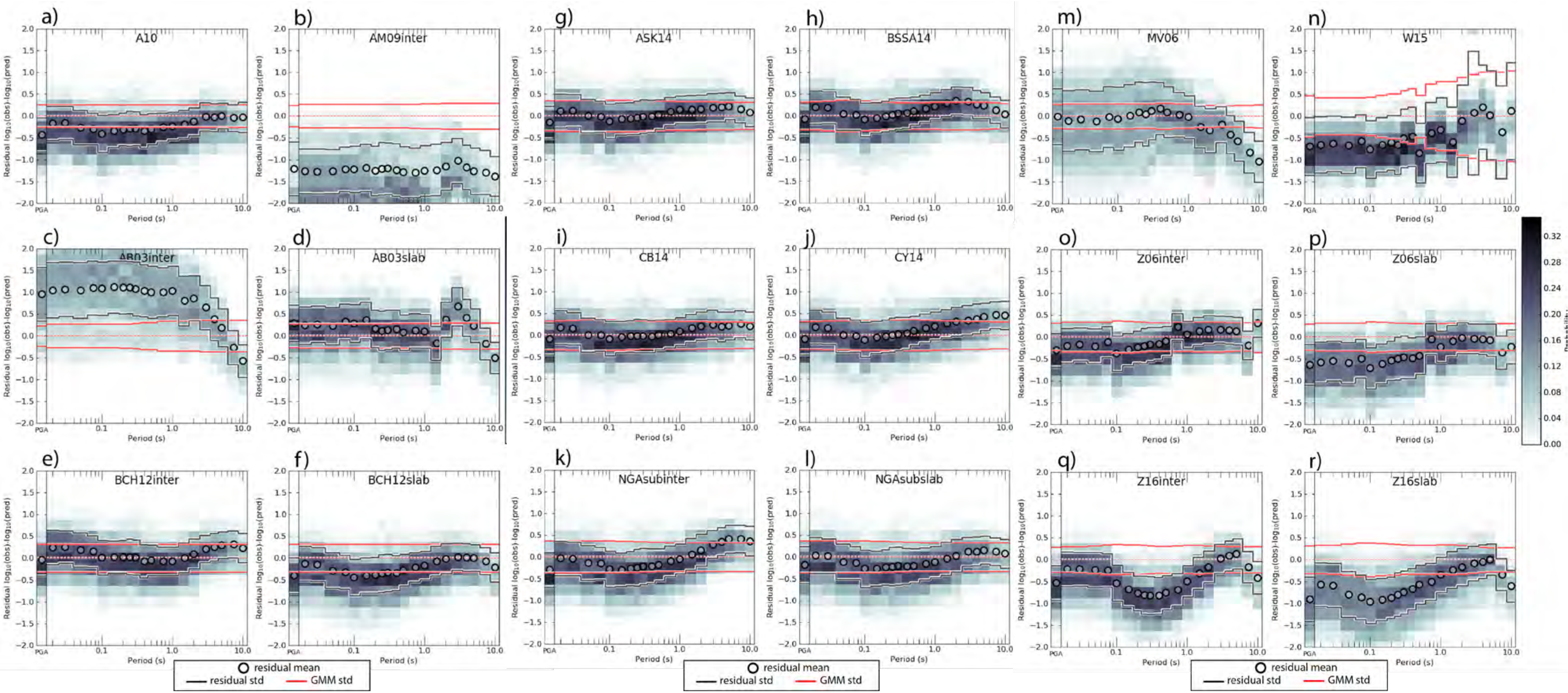
Do we need a GMM for volcanic earthquakes?

Do we need Hawaii specific site amplifications?

Residuals: Atkinson (2010) database



Residuals: 2018 Kilauea Tectonic Earthquakes



Residuals: 2018 Kilauea Volcanic Explosions