SSHAC Level 1 Demonstration Project: Generic Western United States (GWUS) Ground Motion Model

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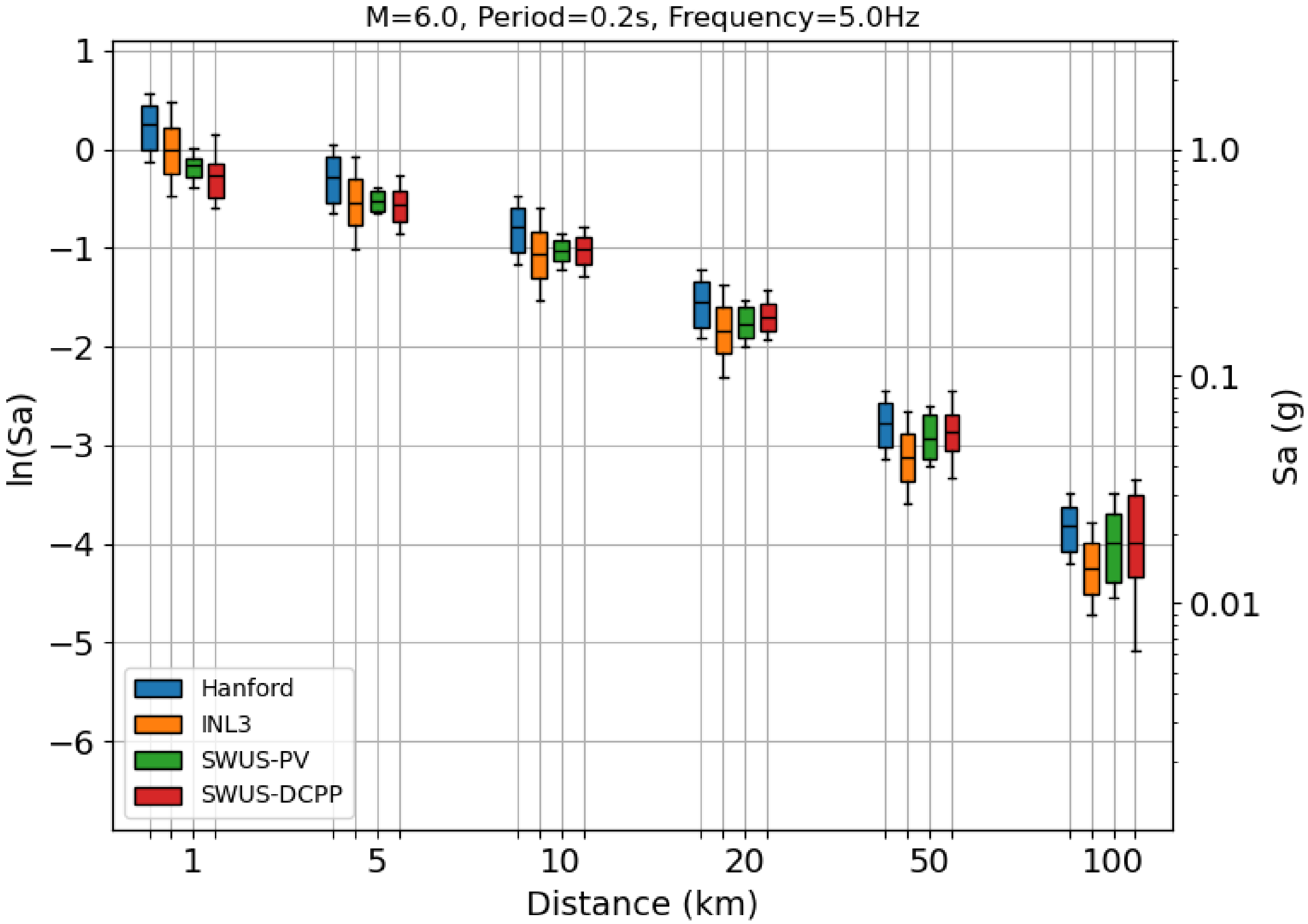
SSHAC Level 1 Demonstration Project

- Purpose
  - Illustrate how a Senior Seismic Hazard Analyses Committee (SSHAC) Level 1 study can be used to develop the seismic hazard for some advanced NPP designs to satisfy requirements in 10 CFR 100.23
  - Identify simplifications in source and ground motion models used in probabilistic seismic hazard analyses (PSHAs)
    - GWUS GMM for shallow crustal earthquakes
- Details on the SSHAC Level 1 Project will be presented later today by John Stamatakos from the Southwest Research Institute (SwRI)

Motivation

- Need for a GMM that captures the CBR of ground motions in the WUS
  - Simplify the SSHAC process for GMM characterization
  - Provide high level of regulatory assurance

Shaded box represents 16th and 84th Percentile
Whiskers represent 5th and 95th Percentile



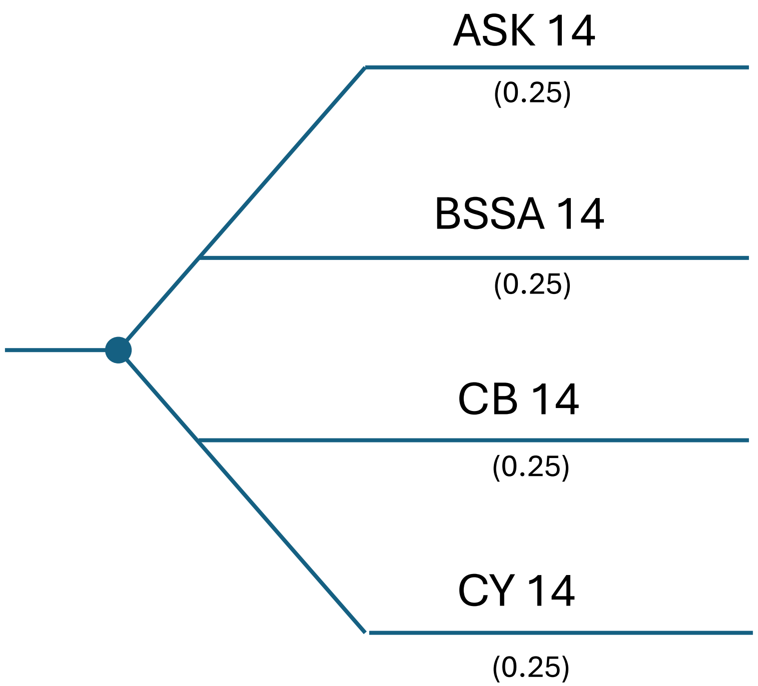
*NUREG-2213, U.S. NRC (2018)

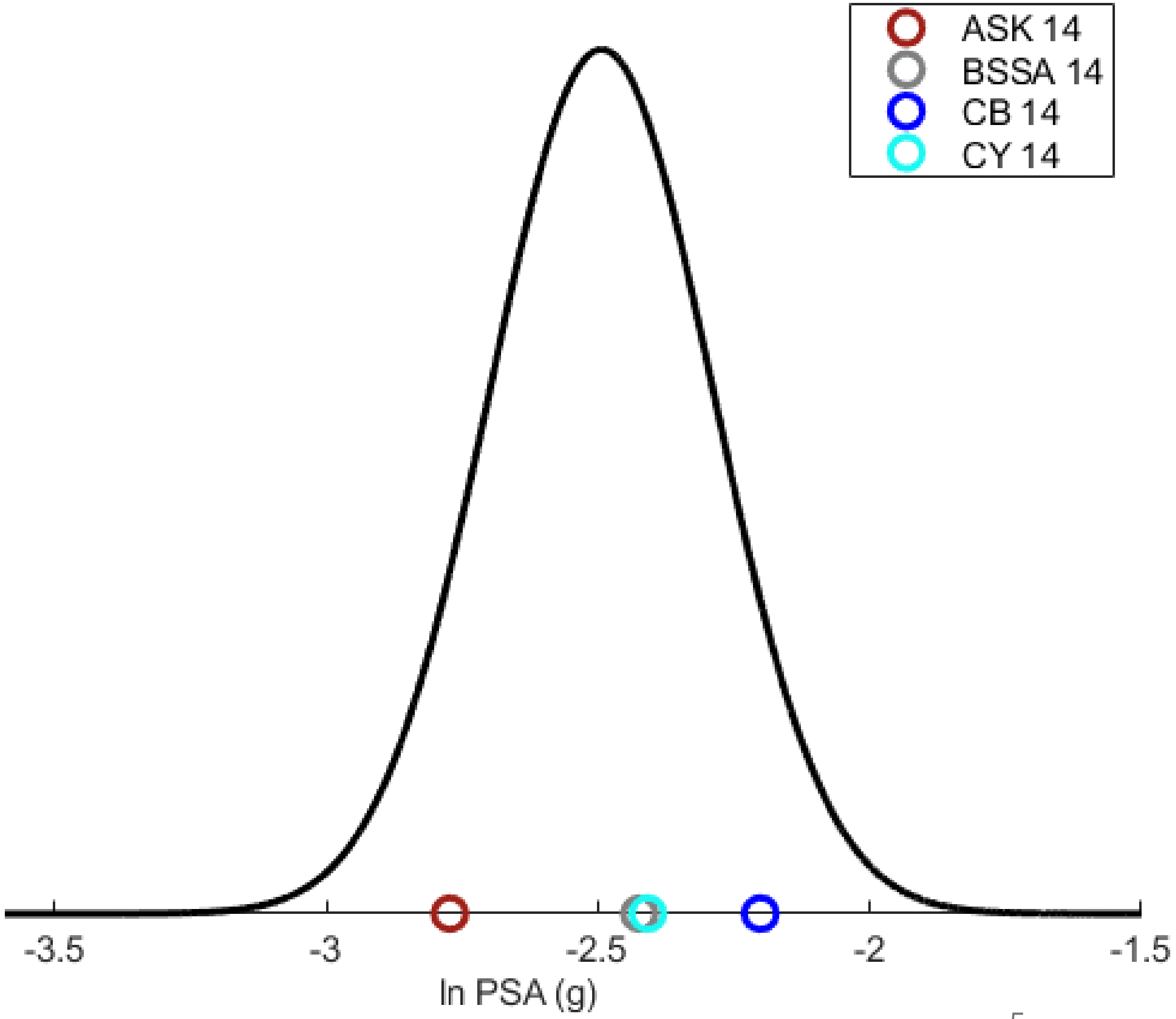
GWUS Development

- Model the ground motion as a continuous distribution
  - Construct a joint probability distribution informed by a set of ground motion models evaluated for 154 magnitude and distance scenarios
- Sample ground motion distribution
  - 10,000 samples from a multi-variate normal distribution
  - Check samples for physicality
- Identify ground motions models that capture the CBR
  - Sammon's approach for domain reduction
  - Discretization of ground motion space
- Final Model Development
  - 17 Median models
  - Adjustments for normal and reverse faulting and for sites on the hanging wall

*PEER 2018

Mutually Exclusive and Collectively Exhaustive (MECE)





*Bommer and Scherbaum (2008)

Joint Distribution

- NGA West 2 GMMs = {ASK 14, BSSA 14, CB 14, CY 14}
- Frequencies = { 0.1, 0.133, 0.2, 0.333, 0.5, 0.667, 1.0, 1.333, 2.0, 2.5, 3.333, 5.0, 6.667, 10, 13.333, 20, 33.333, 50,100 }
- $\boldsymbol{M}$ = {5, 5.5, 6, 6.5, 7, 7.5, 8}
- $\boldsymbol{R_{rup}}$ = {0.1, 1, 5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 175, 200}
- 154 $\boldsymbol{M}$ and $\boldsymbol{R_{rup}}$ Combinations

Sampling the Joint Distribution

Model	M=5,R_{rup} = 1km	M=5,R_{rup} = 5km	M=5,R_{rup} = 10km	---	---	---	M=8,R_{rup} =175km	M=8,R_{rup} =200km
ASK 14	-2.701	-2.733	-3.224	---	---	---	-3.097	-3.219
BSSA 14	-3.658	-3.658	-3.658	---	---	---	-3.782	-3.923
CB 14	-2.845	-2.865	-3.225	---	---	---	-3.553	-3.676
CY 14	-2.428	-2.637	-3.374	---	---	---	-3.552	-3.707
μ	-2.908	-2.974	-3.370	---	---	---	-3.496	-3.631

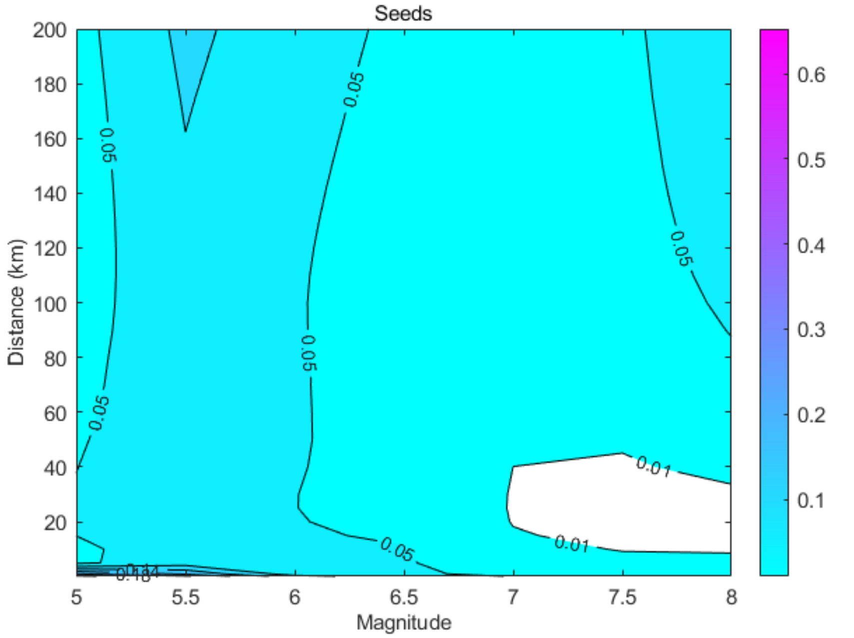
$$f(x,\mu,\Sigma) = \frac{1}{\sqrt{|\Sigma|(2\pi)^N}} e^{-\frac{1}{2}(x-\mu)^T\Sigma^{-1}(x-\mu)}$$

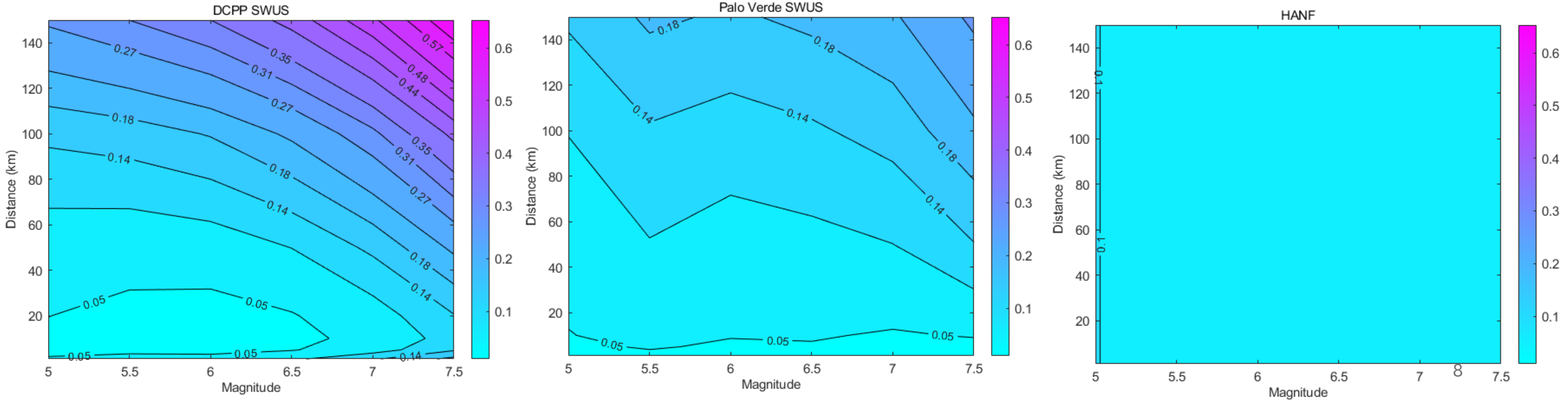
$$\Sigma_{i,j} = \rho_{ij}\sigma_i\sigma_j$$

- Each sample from the multi-variate normal distribution checked for physicality
  - Ground motions increase with magnitude
  - Ground motions decrease with distance

Seed Model Variance 1Hz

- Seed model variance much smaller than existing SSHAC models
- Variance not smooth across magnitude and distance scenarios
  - This can result in samples not behaving in a physically predictable way
  - This can also limit sampling of the tails

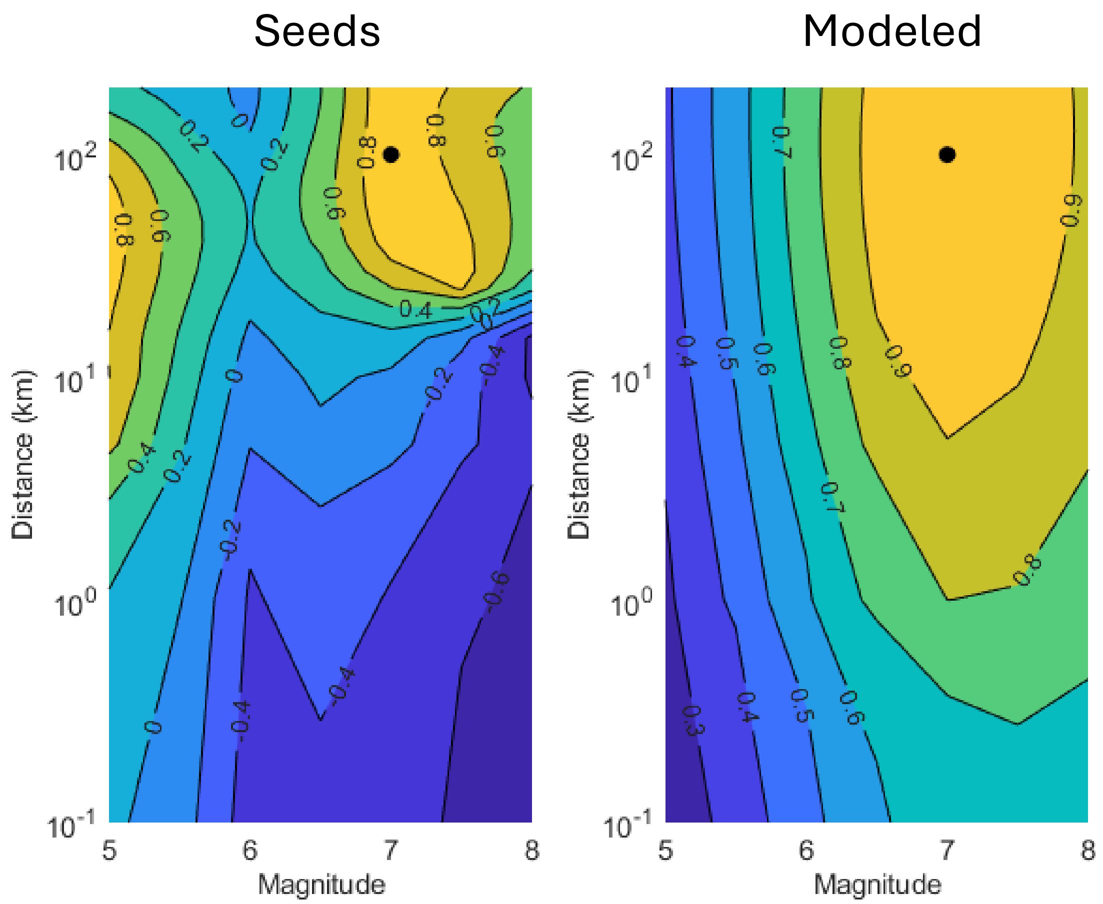




Correlation Model

- Correlation coefficients do not vary smoothly over the full magnitude and distance scenarios.
  - This result in samples not behaving in a physically predictable way
  - This can also limit sampling of the tails.

- Gaussian Process Regression used to model correlation



*Rasmussen and Williams. 2006

Sampled Distribution

An ideal path for capturing the full epistemic uncertainty in ground motions would be to simply perform PSHA calculations using all 10,000 sampled GMMs. However, this is computationally unrealistic, and therefore an alternative approach to capturing the epistemic uncertainty is needed.

Model	M=5,R_{rup} = 1km	M=5,R_{rup} = 5km	M=5,R_{rup} = 10km	---	---	---	M=8,R_{rup} =175km	M=8,R_{rup} =200km
1	-3.004	-2.923	-3.251	---	---	---	-3.105	-3.225
2	-3.240	-3.308	-3.753	---	---	---	-3.158	-3.280
3	-3.695	-3.787	-4.277	---	---	---		
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999	-4.486	-4.391	-4.302	---	---	---	-3.976	-4.106
10,000	-2.257	-2.323	-2.933	---	---	---	-2.772	-2.928

Visualize the ground-motion space

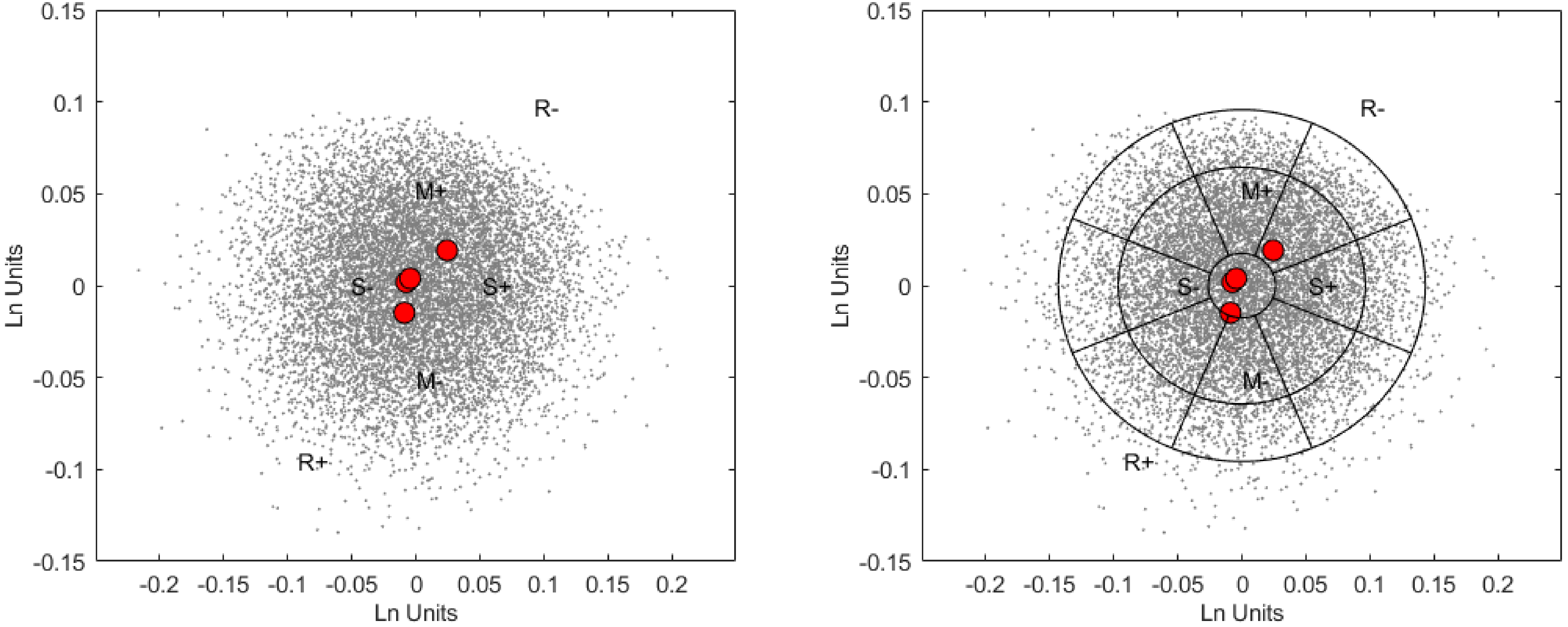
- Reduce the ground motion space from 154 dimensions down to 2 dimensions using Sammon mapping.

- Sammon's mapping projects a high-dimensional space to a space of lower dimensionality by trying to preserve the structure of inter-point distances in high-dimensional space in the lower-dimension projection by minimizing the error function:

$$E = \frac{1}{\sum_{i<j} \overline{\overline{\Delta_{GM_{i,j}}}}} \sum_{i<j} \frac{\left(\overline{\Delta_{GM_{i,j}}} - \overline{\Delta_{MAP_{i,j}}}\right)^2}{\overline{\Delta_{GM_{i,j}}}}$$

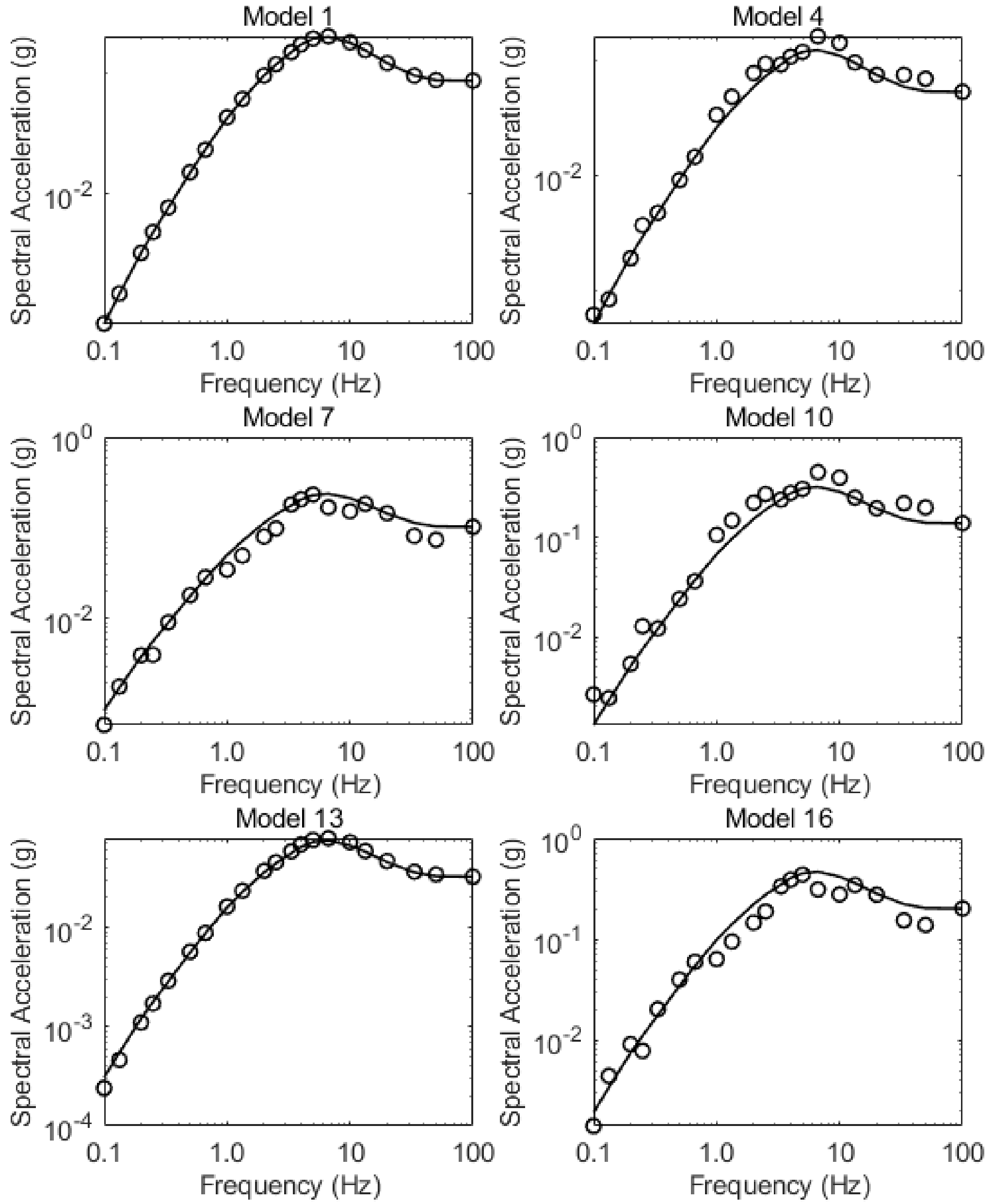
$$\overline{\Delta_{GM_{i,j}}} = \sqrt{\frac{1}{N_d} \sum_{k=1}^{N_D} (GMM_{i,k} - GMM_{j,k})^2}$$

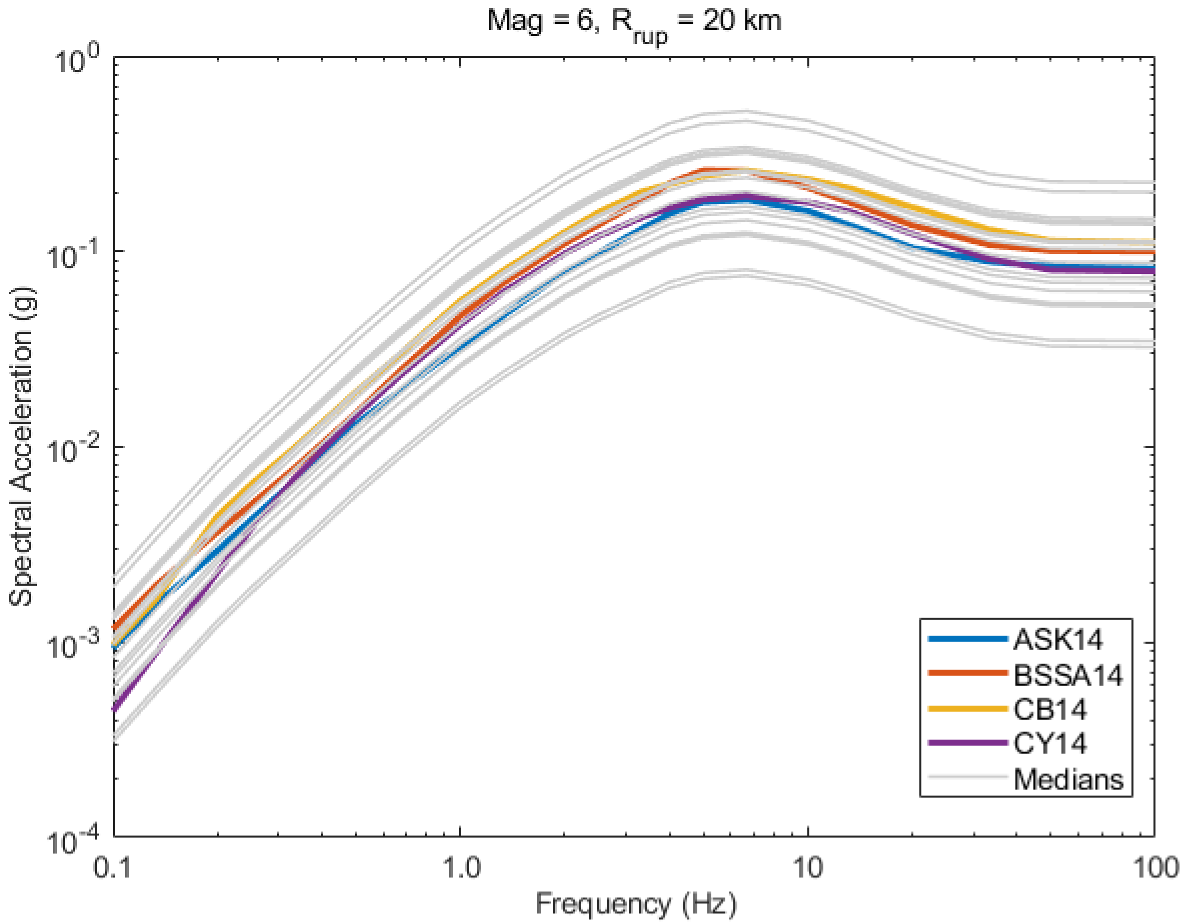
Sammons Mapping and Discretization



*PEER 2018

Median Models





Ground Motion Tables for PSHA Calculations

Mag	R_{rup}	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12	Model 13	Model 14	Model 15	Model 16	Model 17
5.0	0.1	-2.920	-3.439	-3.294	-2.931	-2.596	-2.434	-2.607	-2.949	-3.288	-3.883	-3.613	-2.904	-2.254	-2.054	-2.448	-3.009	-3.589
5.0	1.0	-2.985	-3.505	-3.360	-2.997	-2.662	-2.500	-2.673	-3.015	-3.353	-3.949	-3.679	-2.970	-2.320	-2.120	-2.514	-3.075	-3.655
5.0	5.0	-3.380	-3.900	-3.755	-3.391	-3.057	-2.895	-3.068	-3.409	-3.748	-4.343	-4.074	-3.365	-2.714	-2.514	-2.909	-3.470	-4.050
5.0	10	-3.976	-4.496	-4.351	-3.987	-3.652	-3.490	-3.664	-4.005	-4.344	-4.939	-4.669	-3.961	-3.310	-3.110	-3.505	-4.066	-4.646
5.0	15	-4.455	-4.975	-4.830	-4.467	-4.132	-3.970	-4.143	-4.485	-4.823	-5.419	-5.149	-4.440	-3.790	-3.590	-3.984	-4.545	-5.125
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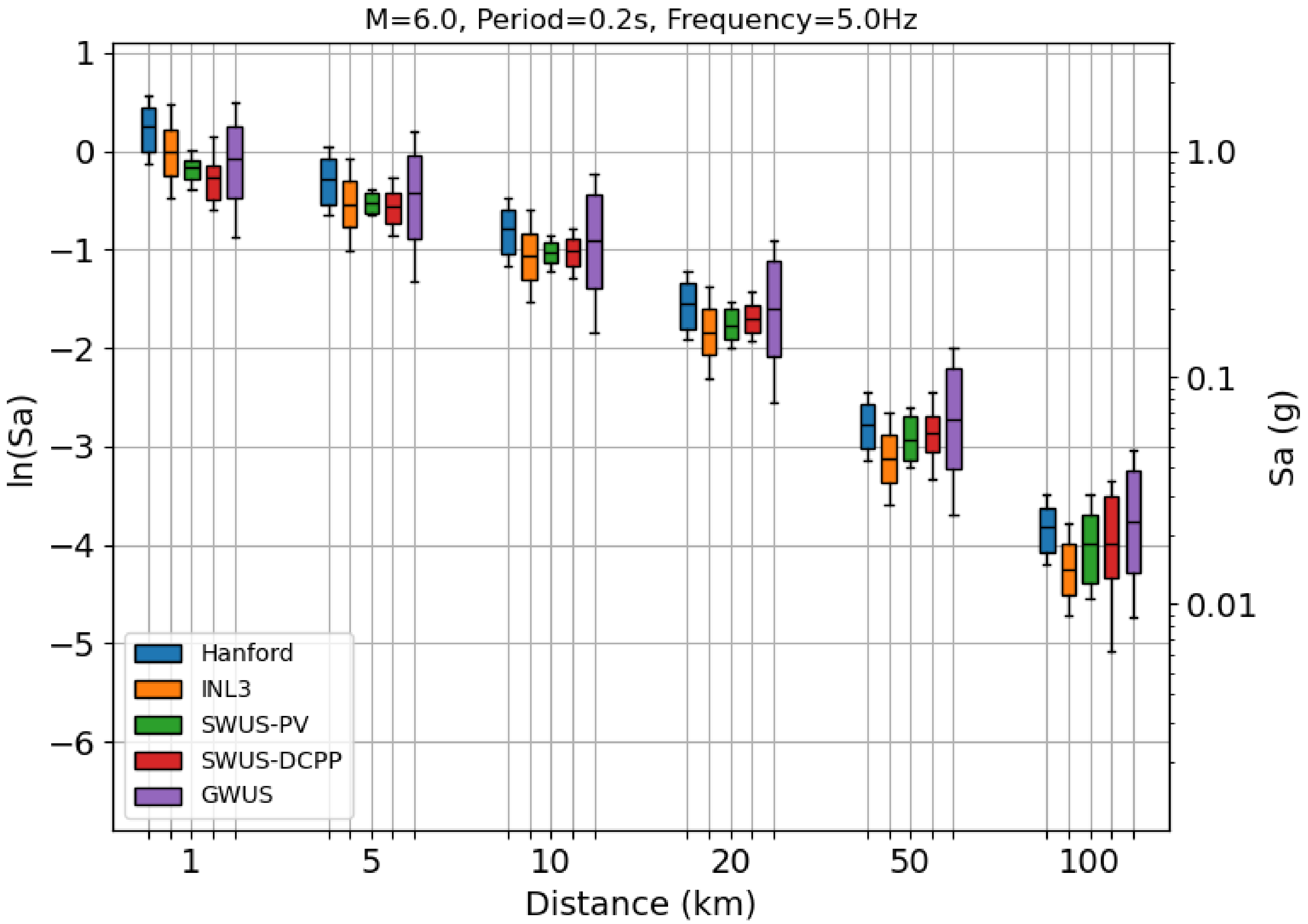
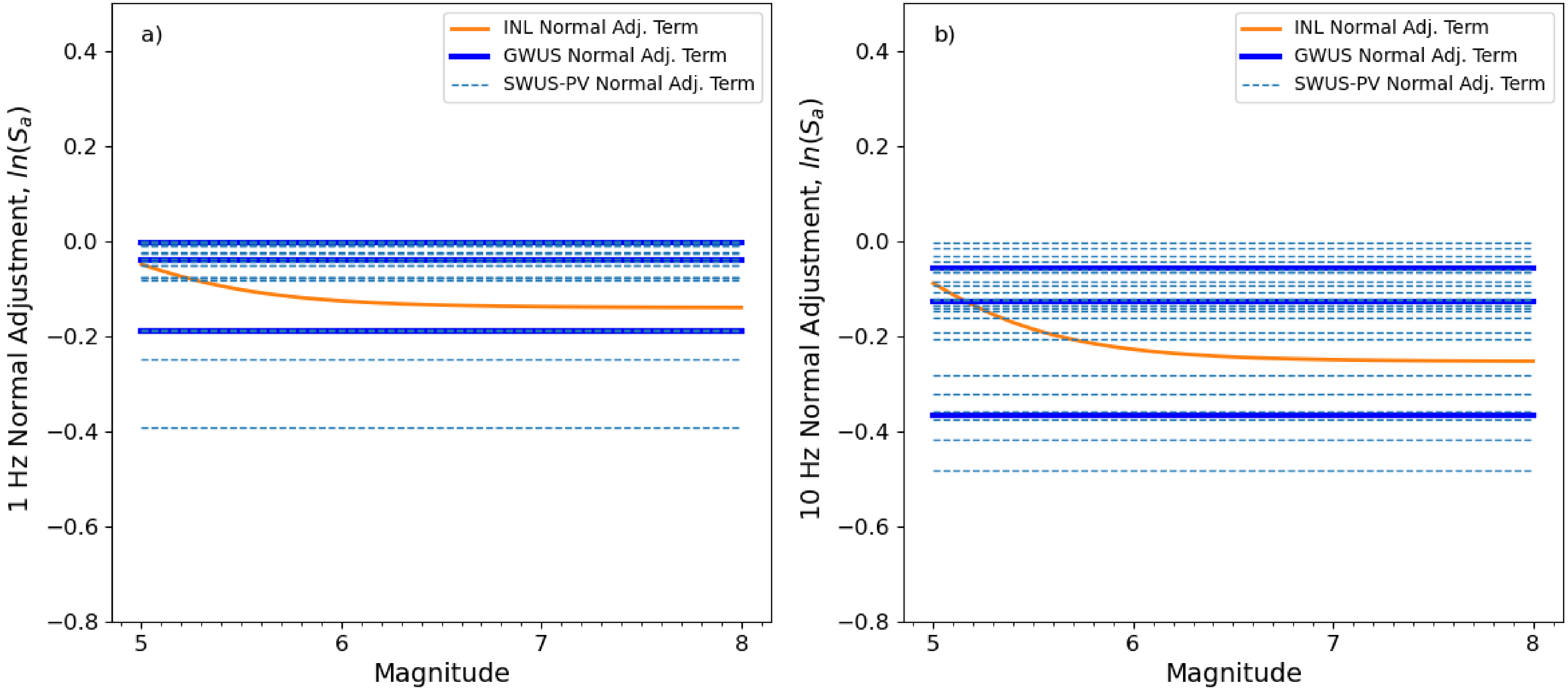
8.0	130	-3.181	-3.701	-3.556	-3.193	-2.858	-2.696	-2.869	-3.211	-3.549	-4.145	-3.875	-3.166	-2.516	-2.316	-2.710	-3.271	-3.851
8.0	140	-3.248	-3.768	-3.623	-3.259	-2.925	-2.763	-2.936	-3.278	-3.616	-4.211	-3.942	-3.233	-2.583	-2.382	-2.777	-3.338	-3.918
8.0	150	-3.312	-3.832	-3.687	-3.323	-2.988	-2.826	-3.000	-3.341	-3.680	-4.275	-4.005	-3.297	-2.646	-2.446	-2.840	-3.402	-3.982
8.0	175	-3.460	-3.980	-3.835	-3.471	-3.136	-2.974	-3.148	-3.489	-3.828	-4.423	-4.153	-3.444	-2.794	-2.594	-2.988	-3.550	-4.130
8.0	200	-3.595	-4.115	-3.970	-3.607	-3.272	-3.110	-3.283	-3.625	-3.963	-4.559	-4.289	-3.580	-2.930	-2.730	-3.124	-3.685	-4.265

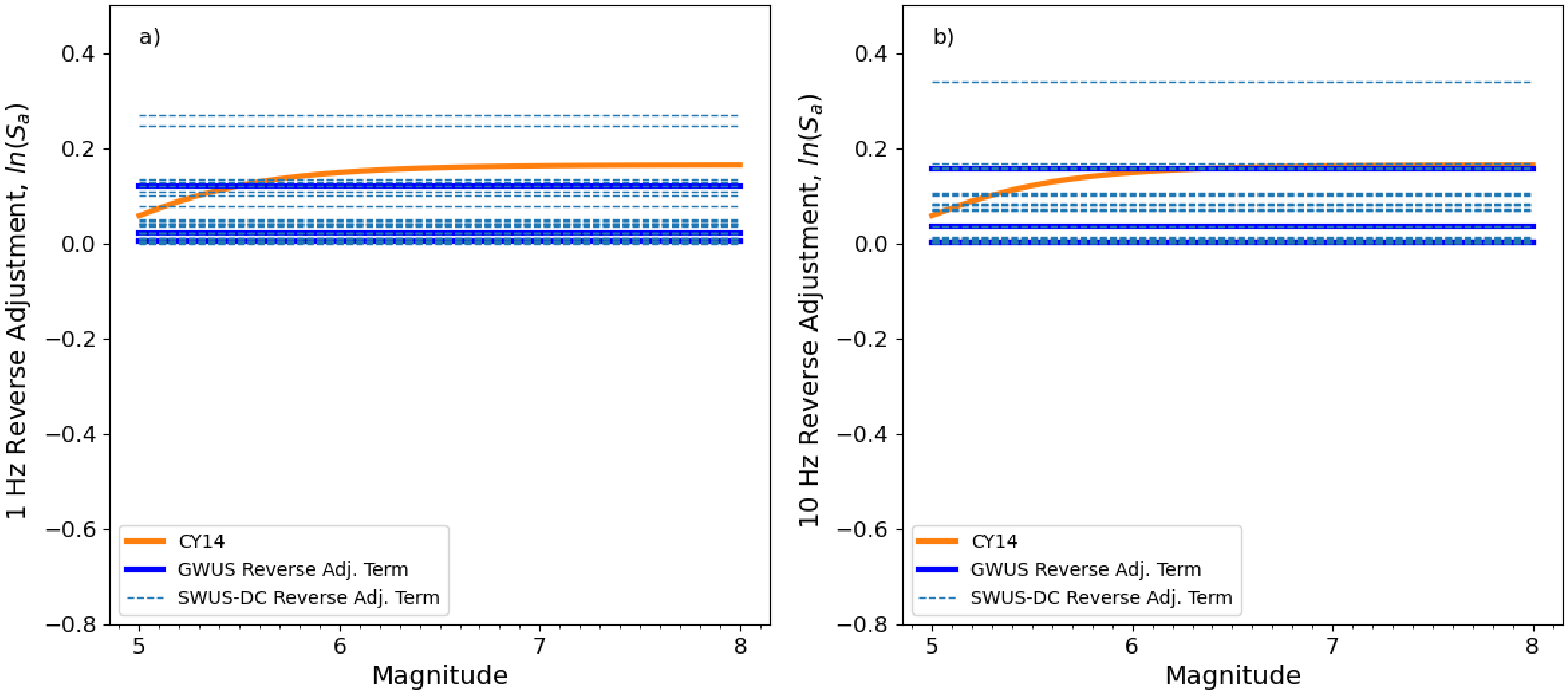
GMM Comparison



Normal Fault Adjustments (PV SWUS)

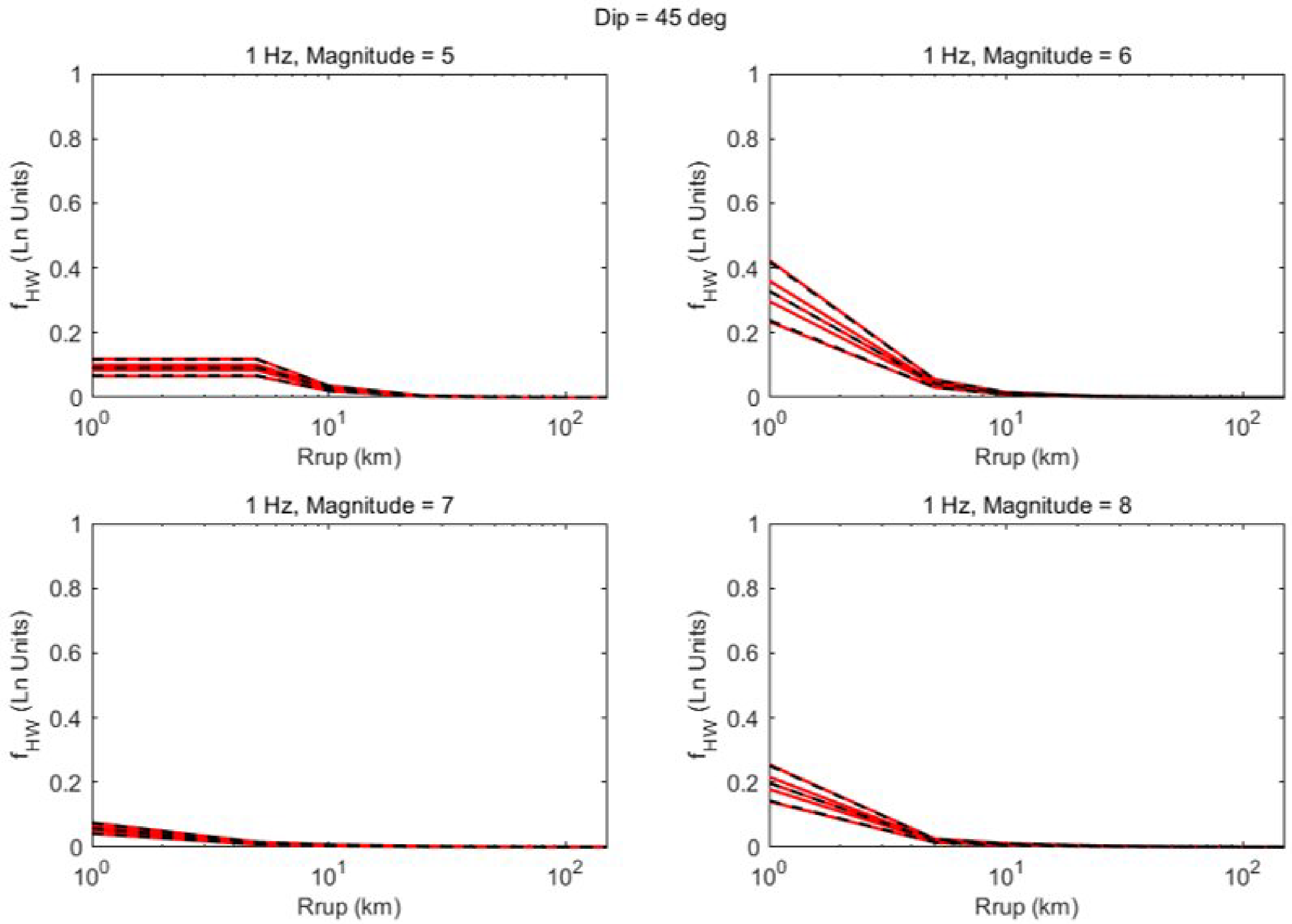


Reverse Fault Adjustments (DCPP SWUS)



Hanging Wall Adjustments (SWUS)

$$f_{HW}(M, Dip, W, R_x) = C_1 \cos(dip) \times \left[C_2 + (1 - C_2) \tanh\left(\frac{C_3 R_x}{W \cos(dip)} \right) \right] \times (1 + C_4(M - 7)) T_{HW\_R}(R_{RUP}, R_{JB}) T_{HW\_Z}(Z_{TOR})$$



Implementation

- 17 Median models with weights for 19 oscillator frequencies
- 3 sets of adjustments for normal, reverse, hanging wall
- INL SSHAC 3 single-station standard deviation to account for aleatory variability

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