Summary Of A Large Scale Validation Project Using The SCEC Broadband Ground Motion Simulation Platform

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SCEC
an NSF + USGS center

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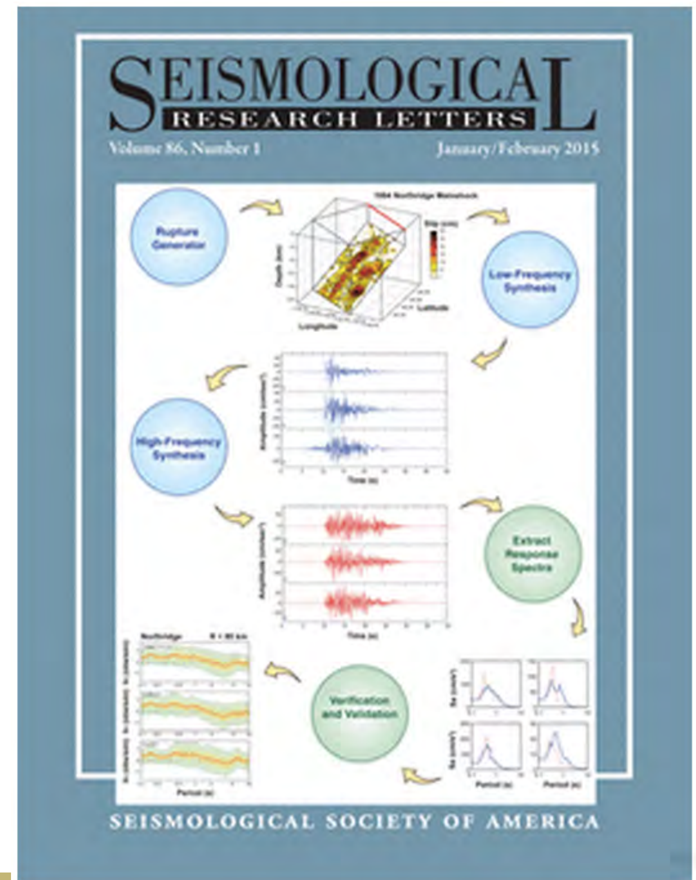
SRL Special Focus on BBP Validation

- Published Jan. 2015
  - Built on work from SWUS and NGA-East
  - Nine papers
    - Intro
    - BBP software and implementation
    - Validation exercise design
    - Evaluation of results
    - Updated methodologies:
      - EXSIM
      - Graves and Pitarka (GP)
      - SDSU
      - UCSB
      - Composite Source Model (CSM)



What is the validation objective?

- Proof that the method works!
  - Past work showed that some methods could reproduce past events very closely
  - Such validations may require a lot of “tuning” and sometimes used inverted sources (circularity)
  - These are useful, but not sufficient in building confidence in the models
- Proof that the method will work again in the future!
  - Could the model could be used for events that haven’t occurred yet?
  - We want to validate for “forward simulations”...

Users and objectives

Validation driven by need of seismic hazard projects to supplement recorded datasets

- South-Western U.S. utilities (SWUS)
- PEER NGA-East project (new CENA hazard model)
- PEER NGA-West projects

<u>Quantitative</u> validation for <u>forward simulations</u> in engineering problems

- Short term goal: supplement recorded data for development of ground motion models (GMMs=GMPEs) and hazard analyses
- Long term goal: develop acceptance of simulations for engineering design

Key focus: 5% damped elastic "average" PSA (*f*=0.1-100 Hz)

Other metrics being explored now... duration, frequency content, etc.

Key lessons learned – past validations

Need more transparency, repeatability, independence from the modeler.

- Need to validate against many events, aggregate results
- Need clear documentation of fixed and optimized parameters from modelers for each region
- Need source description that is *consistent* between methods, or that can be adapted with rules
- Use unique crustal structure (V, Q) for all models
- Consider multiple kinematic source realizations with fixed (Part A) and randomized (Part B) hypocenter location
- Handle site response outside of the simulations (correct data to reference Vs empirical site factors)
- Make all validation metrics computation and plots in uniform units/format – implement post-processing pipeline on BBP
- Need to tie-in to specific code version
- Have an independent operator run the code

Key elements for (empirical) ground-motion model (GMM) development

- Times series and frequency content (FAS) are "reasonable"
  - Visual inspection

PSA evaluation – using 50 source realizations

- PART A: validation against recorded events
  - Evaluation of bias [ln(data)/ln(model)] using various approaches
  - Check that attenuation rate is consistent with observations
  - 13 events completed, ~40 stations/event
- PART B: validation against existing GMMs in ranges where they are well constrained by data
  - PSA fits current state of knowledge in a broad sense, within a wide acceptance range

Simulation Methods and Modelers

Method Name(s)	Method type – Finite fault models	Contact(s) and Institution
Composite Source Model (CSM)	Broadband deterministic	J. Anderson (UNR)
UCSB		R. Archuleta, J. Crempien (UCSB)
EXSIM	Stochastic Brune spectrum	K. Assatourians, G. Atkinson (UWO)
Graves and Pitarka	Hybrid: deterministic LF and stochastic HF	R. Graves (USGS)
SDSU (BB Toolbox)		K. Olsen (SDSU)

Part A (comparison with recordings)

Selection of events and stations

Region	Event Name	Year	Mw	# Records < 200 km
WUS	**Loma Prieta**	1989	6.94	59
WUS	**Northridge**	1994	6.73	124
WUS	**Landers**	1992	7.22	69
WUS	**Whittier Narrows**	1987	5.89	95
WUS	**North Palm Springs**	1986	6.12	32
JAPAN	**Tottori**	2000	6.59	171
JAPAN	**Niigata**	2004	6.65	246
WUS	**Alum Rock**	2007	5.45	40
WUS	**Chino Hills**	2008	5.39	40
CENA	**Saguenay**	1988	5.81	11
CENA	**Riviere-du-Loup**	2005	4.60	21
CENA	**Mineral, VA**	2011	5.68	10
WUS	El Mayor Cucapah	2010	7.20	134
WUS	Hector Mine	1999	7.13	103
WUS	Big Bear	1992	6.46	42
WUS	Parkfield	2004	6.50	78
WUS	Coalinga	1983	6.36	27
WUS	San Simeon	2003	6.50	21
JAPAN	Chuetsu-Oki	2007	6.80	286
JAPAN	Iwate	2008	6.90	186
TURKEY	Kocaeli	1999	7.51	14
TAIWAN	Chi-Chi	1999	7.62	257
ITALY	L' Aquila	2009	6.30	40
NEW ZEALAND	Christchurch	2011	6.20	26
NEW ZEALAND	Darfield	2010	7.00	24

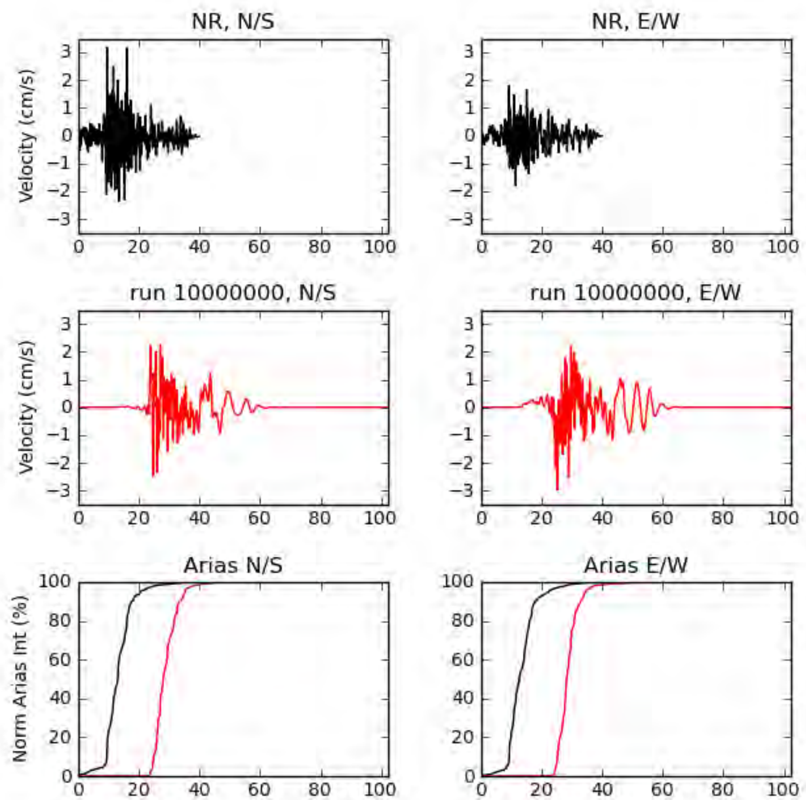
- Large dataset (25 EQs)
- Many regions & tectonic environments
- Span wide magnitude range (Mw 4.6 to 7.62)
- Variety of mechanisms
- Well-recorded (16 EQs with> 40 records within 200 km)
- Select large subset of stations (~40) that are consistent with mean and standard deviation PSa of the full dataset.

Evaluation products

- Qualitative evaluation of velocity time series and Husid plot based on Arias intensity

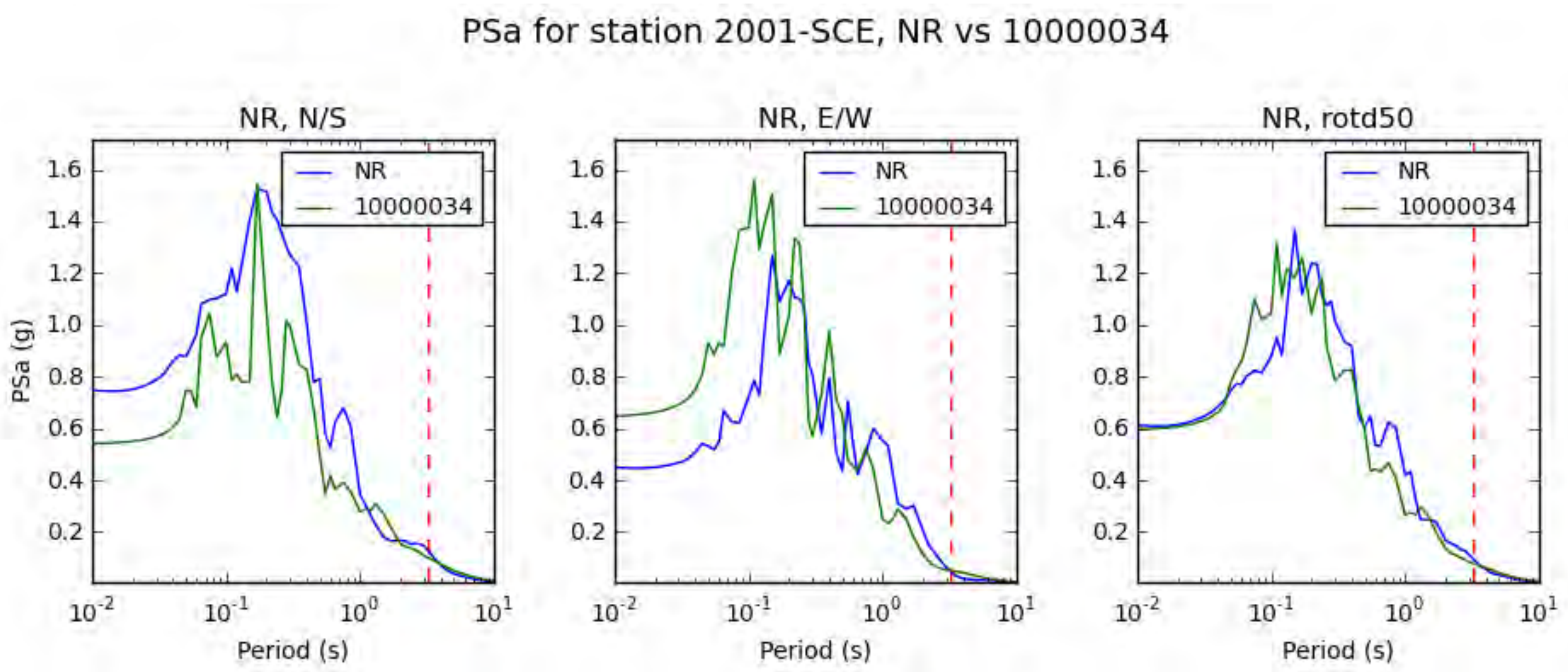
RECORDED
V_{s30} = 822 m/s

SIMULATED
V_{s30} = 863 m/s



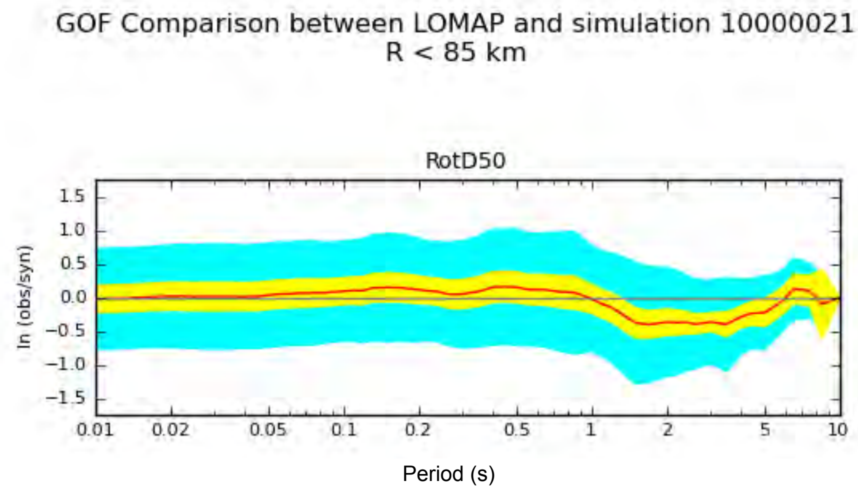
Part A (comparison with recordings)

Evaluation products



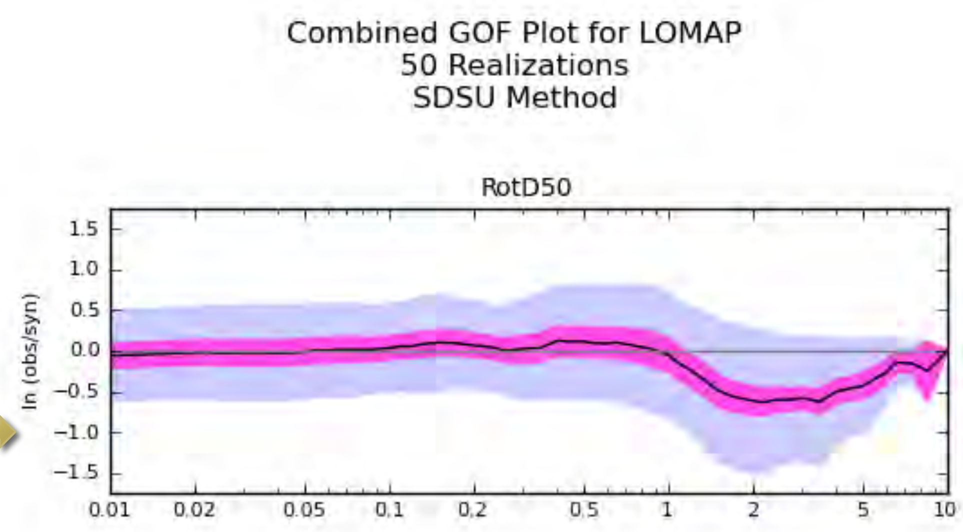
Evaluation products

- Bias as goodness-of-fit measure for PSA and PGA
  - *Average GOF with T for all stations within an event*



Evaluation products

- Goodness-of-fit measures for PSa and PGA
  - *Average GOF with T for all stations within an event*
  - *Average GOF for all realizations (all stations)*

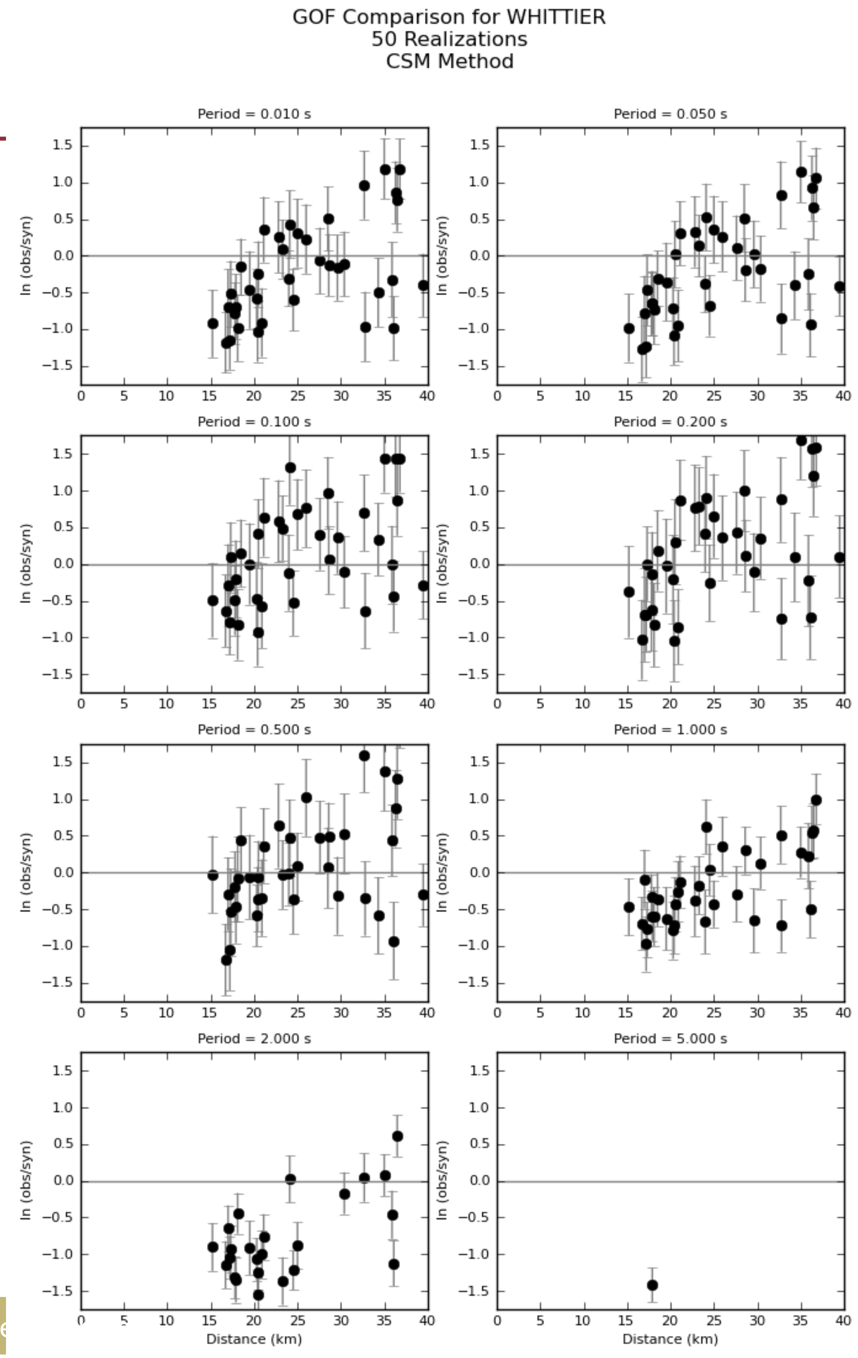


Period (s)

Evaluation products

- Goodness-of-fit measures for PSa and PGA
  - *Average GOF with T for all stations within an event*
  - *Average GOF for all realizations (all stations)*
  - Average GOF with distance (all realizations)

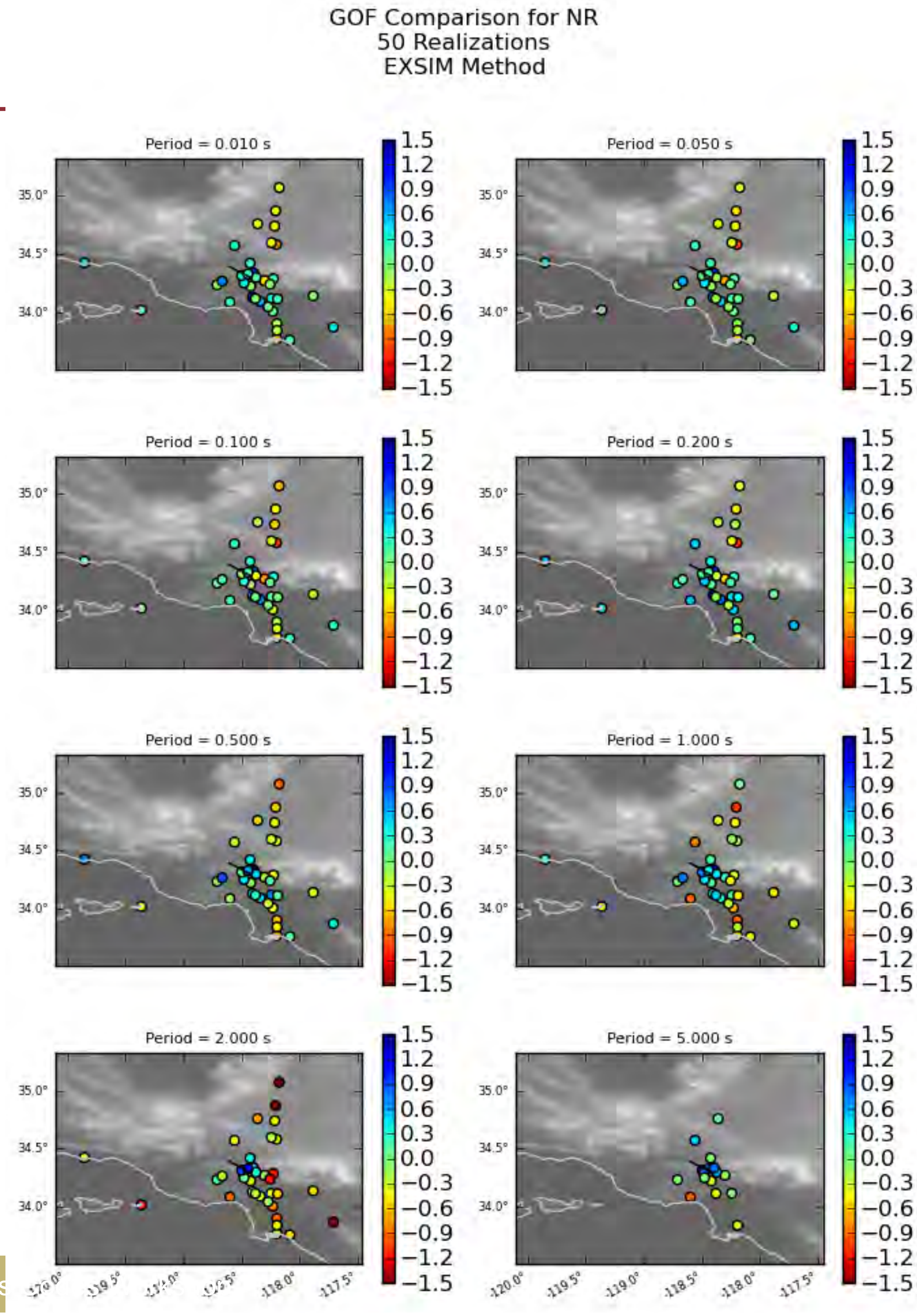
Part A (comparison with recordings)



Part A (comparison with recordings)

Evaluation products

- Goodness-of-fit measures for PSa and PGA
  - *Average GOF with T for all stations within an event*
  - *Average GOF for all realizations (all stations)*
  - Average GOF with distance (all realizations)
  - Map of GOF (all realizations)

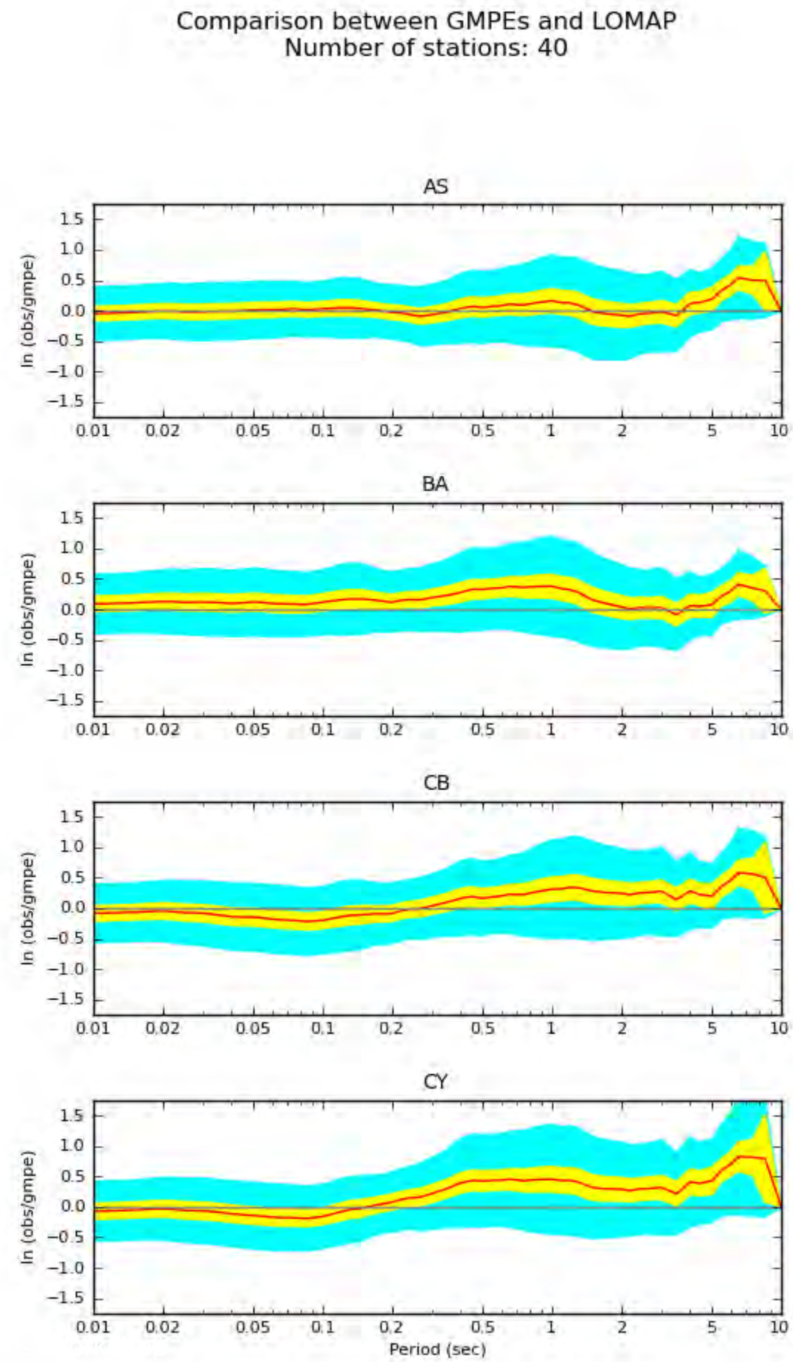


Evaluation products

- GOF plots also developed for
  - NGA-West1 (2008) GMPEs
  - SMSIM

Allows to see trends/event terms

Part A (comparison with recordings)



Evaluation – Part A

1. Comparison of PSA GOF for each event

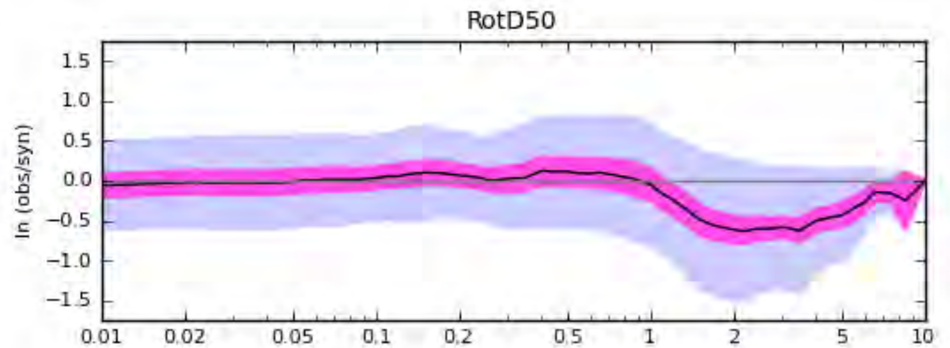
   Mean bias

   Mean absolute bias

- Failure threshold is ln(2)=0.69
- Thresholds of 0.5 and 0.35 were considered as passing criteria

Combined metric: mean and mean absolute bias

- Used alone
- Used with GMPEs



3. Evaluation of attenuation bias

- Distance dependence slope of zero within 95% confidence interval

Part A, GOF Validation Threshhold = 0.50 (-0.50 ≤ highlighted green values ≤ 0.50)

Unacceptable Threshhold = 0.70 (highlighted red values < -0.70 or > 0.70)

		PSA Period Range = [0.01-0.1] s									
	Event (Mw, Mech.)	**UCSB**		**EXSIM**		**G&P**		**SDSU**		**GMPE**	
Rrup=[0-5] km	Chino Hills (5.39, ROBL)										
	Alum Rock (5.45, SS)			-1.04	1.04	-0.94	0.94	-0.65	0.65	-1.33	1.33
	Whittier Narrows (5.89, REV)										
	North Palm Springs (6.12, ROBL)	0.19	0.30	0.38	0.38	0.11	0.14	0.36	0.36	0.16	0.16
	Tottori (6.59, SS)	-0.18	0.21	-1.18	1.18	0.10	0.16	-3.52	3.52	0.23	0.23
	Niigata (6.65, REV)										
	Northridge (6.73, REV)										
	Loma Prieta (6.94, ROBL)	0.16	0.38	0.19	0.38	0.05	0.31	0.19	0.33	-0.12	0.38
	Landers (7.22, SS)	1.16	1.16	0.73	0.73	0.91	0.91	0.92	0.92	1.05	1.05
	Riviere-du-Loup (4.6 REV)										
	Mineral (5.68 REV)										
	Saguenay (5.81 REV)										
	Average CA	0.37	0.52	0.11	0.55	0.04	0.49	0.20	0.48	-0.08	0.61
	Average CENA										
	Average ALL	0.28	0.47	-0.08	0.64	0.05	0.44	-0.33	0.92	-0.04	0.56

0.01 to 0.1 s

Distance	Event (Mw, Mech.)	UCSB		EXSIM		G&P		SDSU		GMPE	
		PSA Period Range = [0.01-0.1] s									
0-5 km	Chino Hills (5.39, ROBL)										
	Alum Rock (5.45, SS)			-1.04	1.04	-0.94	0.94	-0.65	0.65	-1.33	1.33
	Whittier Narrows (5.89, REV)										
	North Palm Springs (6.12, ROBL)	0.19	0.30	0.38	0.38	0.11	0.14	0.36	0.36	0.16	0.16
	Tottori (6.59, SS)	-0.18	0.21	-1.18	1.18	0.10	0.16	-3.52	3.52	0.23	0.23
	Niigata (6.65, REV)										
	Northridge (6.73, REV)										
	Loma Prieta (6.94, ROBL)	0.16	0.38	0.19	0.38	0.05	0.31	0.19	0.33	-0.12	0.38
	Landers (7.22, SS)	1.16	1.16	0.73	0.73	0.91	0.91	0.92	0.92	1.05	1.05
	Riviere-du-Loup (4.6 REV)										
	Mineral (5.68 REV)										
	Saguenay (5.81 REV)										
	Average CA	0.37	0.52	0.11	0.55	0.04	0.49	0.20	0.48	-0.08	0.61
	Average CENA										
	Average ALL	0.28	0.47	-0.08	0.64	0.05	0.44	-0.33	0.92	-0.04	0.56
5-20 km	Chino Hills (5.39, ROBL)			0.21	0.32	-0.01	0.33	0.17	0.28	-0.40	0.50
	Alum Rock (5.45, SS)			-0.28	0.35	-0.51	0.53	-0.13	0.25	-0.47	0.48
	Whittier Narrows (5.89, REV)	-0.17	0.63	0.23	0.32	-0.30	0.41	-0.28	0.43	-0.18	0.41
	North Palm Springs (6.12, ROBL)	-0.41	0.55	0.08	0.38	-0.20	0.42	-0.11	0.33	-0.15	0.34
	Tottori (6.59, SS)	-0.34	0.43	-0.46	0.47	0.32	0.39	-1.15	1.16	0.59	0.61
	Niigata (6.65, REV)	-0.27	0.59	0.16	0.52	0.28	0.44	-1.76	1.76	0.40	0.55
	Northridge (6.73, REV)	0.49	0.62	0.23	0.38	0.06	0.34	-0.06	0.37	-0.01	0.40
	Loma Prieta (6.94, ROBL)	0.11	0.28	0.33	0.40	0.07	0.33	0.18	0.35	0.10	0.38
	Landers (7.22, SS)	-0.48	0.98	-0.29	0.57	-0.38	0.52	-0.29	0.66	-0.16	0.49
	Riviere-du-Loup (4.6 REV)			-0.62	0.63	-0.09	0.39	0.20	0.42	0.54	0.63
	Mineral (5.68 REV)	-0.74	0.74	-0.46	0.46	-0.43	0.43	-0.55	0.55	0.71	0.71
	Saguenay (5.81 REV)										
	Average CA	0.06	0.55	0.15	0.37	-0.13	0.39	-0.06	0.37	-0.13	0.41
	Average CENA	-0.74	0.74	-0.57	0.57	-0.20	0.40	-0.05	0.47	0.60	0.65
	Average ALL	-0.02	0.54	0.06	0.40	-0.06	0.39	-0.27	0.53	0.00	0.45
20-70 km	Chino Hills (5.39, ROBL)			0.26	0.52	-0.04	0.47	0.01	0.47	-0.39	0.60
	Alum Rock (5.45, SS)			-0.73	0.80	-1.03	1.04	-0.72	0.80	-0.99	1.02
	Whittier Narrows (5.89, REV)	0.33	0.52	0.31	0.49	-0.12	0.39	-0.27	0.43	-0.18	0.43
	North Palm Springs (6.12, ROBL)	0.14	0.56	0.56	0.67	0.32	0.58	0.30	0.52	0.31	0.53
	Tottori (6.59, SS)	-0.01	0.40	0.21	0.41	0.76	0.79	0.11	0.46	1.07	1.08
	Niigata (6.65, REV)	-0.20	0.51	0.16	0.46	0.24	0.52	-0.02	0.43	0.36	0.59
	Northridge (6.73, REV)	-0.50	0.56	-0.10	0.30	-0.26	0.34	-0.54	0.55	-0.28	0.35
	Loma Prieta (6.94, ROBL)	-0.54	0.64	-0.13	0.39	-0.46	0.53	-0.33	0.43	-0.26	0.42
	Landers (7.22, SS)	-0.87	1.00	-0.17	0.27	-0.34	0.38	-0.27	0.35	-0.18	0.35
	Riviere-du-Loup (4.6 REV)			0.22	0.50	0.20	0.53	0.33	0.54	0.94	0.98
	Mineral (5.68 REV)	-0.20	0.29	0.70	0.70	0.34	0.40	-0.04	0.28	1.42	1.42
	Saguenay (5.81 REV)	1.73	1.73	0.57	0.58	1.03	1.04	0.74	0.74	1.61	1.61
	Average CA	-0.23	0.65	0.03	0.50	-0.26	0.53	-0.25	0.50	-0.27	0.52
	Average CENA	0.77	1.01	0.31	0.53	0.31	0.57	0.34	0.53	1.07	1.10
	Average ALL	-0.18	0.61	0.08	0.49	-0.08	0.55	-0.15	0.50	0.01	0.63
70-200 km	Chino Hills (5.39, ROBL)			0.46	0.61	0.44	0.58	0.31	0.55	-0.13	0.52
	Alum Rock (5.45, SS)			-0.72	0.86	-0.77	0.86	-0.54	0.80	-0.98	1.06
	Whittier Narrows (5.89, REV)										
	North Palm Springs (6.12, ROBL)	-0.24	0.27	0.08	0.22	-0.02	0.15	-0.23	0.26	-0.20	0.29
	Tottori (6.59, SS)	-0.44	0.54	0.48	0.60	0.69	0.74	0.29	0.48	0.58	0.68
	Niigata (6.65, REV)	0.08	0.61	0.05	0.56	-0.12	0.57	0.13	0.61	-0.28	0.70
	Northridge (6.73, REV)	-0.27	0.32	0.16	0.39	0.15	0.46	-0.05	0.28	0.04	0.31
	Loma Prieta (6.94, ROBL)	0.12	0.36	0.61	0.61	0.40	0.42	0.54	0.54	0.45	0.45
	Landers (7.22, SS)	0.03	0.32	-0.01	0.15	0.02	0.17	-0.08	0.21	0.14	0.23
	Riviere-du-Loup (4.6 REV)			0.42	0.48	0.41	0.47	-0.46	0.53	1.51	1.51
	Mineral (5.68 REV)	0.51	0.70	-0.07	0.59	-0.27	0.65	-0.27	0.38	1.23	1.38
	Saguenay (5.81 REV)	2.56	2.56	0.42	0.55	1.04	1.05	-0.08	0.39	1.68	1.68
	Average CA	0.00	0.32	0.04	0.50	0.00	0.48	-0.01	0.48	-0.17	0.53
	Average CENA	1.66	1.75	0.26	0.55	0.45	0.78	-0.23	0.42	1.49	1.54
	Average ALL	0.27	0.73	0.15	0.53	0.17	0.59	0.01	0.49	0.25	0.78
	Reverse (REV)	0.22	0.71	0.17	0.46	0.05	0.49	-0.18	0.51	0.27	0.69
	Reverse-Oblique (ROBL)	-0.11	0.49	0.29	0.50	0.05	0.47	0.10	0.45	-0.08	0.48
	Strike-Slip (SS)	-0.34	0.59	-0.19	0.51	-0.13	0.63	-0.29	0.57	-0.05	0.70
	Normal (NM)										
	Average CA	-0.11	0.57	0.06	0.47	-0.17	0.49	-0.15	0.47	-0.22	0.50
	Average CENA	1.38	1.56	0.22	0.54	0.34	0.66	0.02	0.47	1.25	[illegible]
	Average ALL	-0.02	0.63	0.09	0.49	-0.01	0.53	-0.13	0.51	0.07	0.63

0.1 to 1 s

Distance	Event (Mw, Mech.)	UCSB		EXSIM		G&P		SDSU		GMPE	
		PSA Period Range =]0.1-1] s									
0-5 km	Chino Hills (5.39, ROBL)										
	Alum Rock (5.45, SS)			-1.15	1.15	-1.11	1.11	-0.78	0.78	-1.33	1.33
	Whittier Narrows (5.89, REV)										
	North Palm Springs (6.12, ROBL)	0.96	0.96	0.15	0.31	0.02	0.20	0.22	0.32	0.07	0.24
	Tottori (6.59, SS)	1.08	1.08	-0.19	0.63	0.58	0.60	-2.13	2.13	0.62	0.62
	Niigata (6.65, REV)										
	Northridge (6.73, REV)										
	Loma Prieta (6.94, ROBL)	0.58	0.58	0.20	0.37	0.15	0.35	0.29	0.37	0.00	0.41
	Landers (7.22, SS)	1.58	1.58	0.28	0.28	0.55	0.55	0.45	0.45	0.69	0.69
	Riviere-du-Loup (4.6 REV)										
	Mineral (5.68 REV)										
	Saguenay (5.81 REV)										
	Average CA	0.86	0.86	-0.02	0.47	-0.01	0.49	0.13	0.44	-0.10	0.58
	Average CENA										
	Average ALL	0.89	0.90	-0.04	0.50	0.07	0.50	-0.20	0.68	0.01	0.58
5-20 km	Chino Hills (5.39, ROBL)			0.33	0.44	0.20	0.42	0.29	0.38	-0.14	0.38
	Alum Rock (5.45, SS)			-0.16	0.40	-0.36	0.49	-0.03	0.38	-0.22	0.43
	Whittier Narrows (5.89, REV)	0.72	0.80	0.23	0.40	-0.15	0.39	-0.16	0.40	0.01	0.40
	North Palm Springs (6.12, ROBL)	0.57	0.70	-0.13	0.40	-0.24	0.41	-0.17	0.41	-0.19	0.37
	Tottori (6.59, SS)	0.35	0.52	-0.03	0.38	0.31	0.48	-0.51	0.74	0.55	0.64
	Niigata (6.65, REV)	0.61	0.62	0.29	0.49	0.19	0.45	-1.03	1.17	0.33	0.51
	Northridge (6.73, REV)	0.77	0.82	0.30	0.45	0.21	0.43	0.16	0.42	0.18	0.46
	Loma Prieta (6.94, ROBL)	0.43	0.51	0.22	0.39	0.04	0.37	0.20	0.39	0.15	0.39
	Landers (7.22, SS)	0.53	0.77	-0.12	0.52	-0.06	0.47	-0.02	0.54	0.17	0.49
	Riviere-du-Loup (4.6 REV)			0.12	1.04	0.20	1.13	0.32	1.17	-0.10	1.06
	Mineral (5.68 REV)	0.60	0.72	-0.17	0.23	-0.04	0.49	-0.58	0.58	0.34	0.37
	Saguenay (5.81 REV)										
	Average CA	0.63	0.72	0.15	0.42	-0.02	0.42	0.05	0.41	0.03	0.42
	Average CENA	0.60	0.72	0.03	0.77	0.12	0.92	0.02	0.97	0.05	0.83
	Average ALL	0.60	0.69	0.14	0.43	0.03	0.44	-0.07	0.51	0.10	0.46
20-70 km	Chino Hills (5.39, ROBL)			0.15	0.50	-0.05	0.51	-0.02	0.50	-0.27	0.56
	Alum Rock (5.45, SS)			-0.77	0.83	-1.02	1.04	-0.70	0.79	-0.81	0.86
	Whittier Narrows (5.89, REV)	0.99	1.00	0.20	0.50	-0.09	0.46	-0.25	0.51	-0.06	0.48
	North Palm Springs (6.12, ROBL)	0.86	0.93	0.07	0.55	0.00	0.51	-0.01	0.50	0.06	0.52
	Tottori (6.59, SS)	-0.11	0.58	-0.13	0.54	-0.02	0.63	-0.14	0.68	0.33	0.72
	Niigata (6.65, REV)	0.18	0.60	-0.02	0.55	-0.20	0.66	-0.13	0.58	0.02	0.63
	Northridge (6.73, REV)	-0.16	0.36	-0.17	0.39	-0.27	0.41	-0.37	0.46	-0.14	0.34
	Loma Prieta (6.94, ROBL)	-0.04	0.46	-0.10	0.43	-0.35	0.50	-0.18	0.42	-0.04	0.43
	Landers (7.22, SS)	-0.09	0.67	-0.31	0.43	-0.32	0.44	-0.27	0.44	-0.11	0.42
	Riviere-du-Loup (4.6 REV)			0.40	0.66	0.02	0.55	0.14	0.60	-0.08	0.77
	Mineral (5.68 REV)	0.29	0.62	-0.02	0.61	-0.38	0.71	-1.06	1.07	0.07	0.68
	Saguenay (5.81 REV)	1.28	1.28	-0.58	0.60	-0.16	0.26	-0.77	0.78	-0.19	0.51
	Average CA	0.37	0.71	-0.11	0.52	-0.29	0.55	-0.26	0.52	-0.19	0.52
	Average CENA	0.78	0.95	0.25	0.65	-0.04	0.53	-0.10	0.67	-0.08	0.73
	Average ALL	0.31	0.69	-0.07	0.53	-0.24	0.56	-0.22	0.55	-0.12	0.56
70-200 km	Chino Hills (5.39, ROBL)			0.27	0.59	0.34	0.58	0.31	0.60	-0.03	0.59
	Alum Rock (5.45, SS)			-0.83	0.95	-0.83	0.93	-0.48	0.77	-0.82	0.96
	Whittier Narrows (5.89, REV)										
	North Palm Springs (6.12, ROBL)	0.52	0.52	-0.39	0.52	-0.30	0.41	-0.46	0.50	-0.37	0.48
	Tottori (6.59, SS)	-0.24	0.50	0.41	0.64	0.23	0.56	0.47	0.65	0.19	0.57
	Niigata (6.65, REV)	-0.07	0.67	-0.27	0.61	-0.71	0.87	0.01	0.63	-0.71	0.90
	Northridge (6.73, REV)	0.18	0.43	0.16	0.48	0.22	0.57	0.19	0.49	0.28	0.51
	Loma Prieta (6.94, ROBL)	0.60	0.65	0.62	0.65	0.55	0.60	0.74	0.77	0.72	0.74
	Landers (7.22, SS)	0.37	0.52	-0.28	0.37	-0.10	0.30	-0.14	0.35	0.08	0.36
	Riviere-du-Loup (4.6 REV)			0.54	0.83	0.30	0.71	-0.34	0.71	0.61	1.15
	Mineral (5.68 REV)	1.38	1.38	0.10	0.53	0.12	0.59	0.08	0.48	0.97	1.08
	Saguenay (5.81 REV)	3.57	3.57	0.73	0.80	1.43	1.43	0.04	0.46	1.47	1.47
	Average CA	0.41	0.54	-0.13	0.60	-0.06	0.57	0.01	0.57	-0.08	0.61
	Average CENA	2.61	2.62	0.47	0.72	0.72	0.98	-0.04	0.53	1.10	1.26
	Average ALL	0.63	1.00	0.05	0.63	0.03	0.70	0.07	0.58	0.09	0.78
	Reverse (REV)	0.70	0.94	0.13	0.54	-0.03	0.60	-0.14	0.56	0.07	0.66
	Reverse-Oblique (ROBL)	0.47	0.66	0.12	0.49	0.00	0.49	0.07	0.49	-0.02	0.50
	Strike-Slip (SS)	0.07	0.59	-0.28	0.58	-0.29	0.63	-0.24	0.61	-0.13	0.63
	Normal (NM)										
	Average CA	0.46	0.69	-0.05	0.51	-0.17	0.52	-0.13	0.50	-0.12	0.51
	Average CENA	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Average ALL	0.47	0.78	0.00	0.54	-0.10	0.58	-0.11	0.55	-0.02	0.60

1 to 3 s

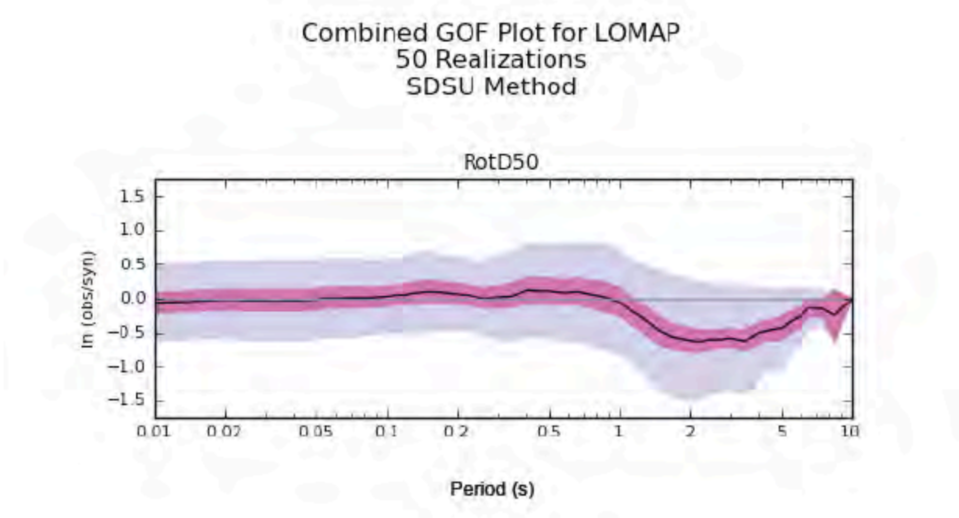
Distance	Event (Mw, Mech.)	UCSB		EXSIM		G&P		SDSU		GMPE	
		PSA Period Range =]1-3] s									
0-5 km	Chino Hills (5.39, ROBL)										
	Alum Rock (5.45, SS)			-1.15	1.15	-1.32	1.32	-1.32	1.32	-1.77	1.77
	Whittier Narrows (5.89, REV)										
	North Palm Springs (6.12, ROBL)	0.93	0.93	0.20	0.20	-0.45	0.48	-0.51	0.51	-0.08	0.22
	Tottori (6.59, SS)	1.25	1.25	-0.17	0.21	-0.07	0.21	-2.41	2.41	-0.03	0.18
	Niigata (6.65, REV)										
	Northridge (6.73, REV)										
	Loma Prieta (6.94, ROBL)	0.65	0.87	0.48	0.97	-0.08	0.52	-0.12	0.53	0.32	0.85
	Landers (7.22, SS)	2.04	2.04	0.61	0.61	0.58	0.58	0.53	0.53	0.94	0.94
	Riviere-du-Loup (4.6 REV)										
	Mineral (5.68 REV)										
	Saguenay (5.81 REV)										
	Average CA	0.98	1.12	0.18	0.81	-0.24	0.66	-0.28	0.66	0.01	0.91
	Average CENA										
	Average ALL	1.03	1.14	0.13	0.73	-0.22	0.59	-0.58	0.91	0.00	0.81
5-20 km	Chino Hills (5.39, ROBL)			0.64	0.64	0.73	0.73	0.65	0.65	0.03	0.27
	Alum Rock (5.45, SS)			0.25	0.51	-0.24	0.60	-0.27	0.60	-0.16	0.52
	Whittier Narrows (5.89, REV)	0.41	0.51	-0.14	0.28	-0.45	0.49	-0.54	0.55	-0.41	0.47
	North Palm Springs (6.12, ROBL)	0.59	0.70	-0.08	0.44	-0.23	0.60	-0.30	0.65	-0.21	0.57
	Tottori (6.59, SS)	0.37	0.57	0.02	0.39	0.06	0.48	-0.84	1.08	0.09	0.35
	Niigata (6.65, REV)	0.07	0.28	-0.16	0.52	-0.48	0.78	-1.69	1.69	-0.30	0.63
	Northridge (6.73, REV)	0.38	0.70	0.23	0.54	-0.09	0.35	-0.14	0.35	0.18	0.54
	Loma Prieta (6.94, ROBL)	0.25	0.57	-0.12	0.36	-0.29	0.40	-0.32	0.40	-0.10	0.29
	Landers (7.22, SS)	0.52	0.53	-0.40	0.45	-0.31	0.51	-0.36	0.51	-0.08	0.36
	Riviere-du-Loup (4.6 REV)			0.64	1.03	0.69	1.02	0.63	1.03	-0.02	0.85
	Mineral (5.68 REV)	0.92	0.92	0.20	0.20	0.04	0.06	-0.20	0.20	0.32	0.32
	Saguenay (5.81 REV)										
	Average CA	0.38	0.62	0.08	0.45	-0.16	0.48	-0.21	0.48	-0.07	0.44
	Average CENA	0.92	0.92	0.47	0.70	0.44	0.64	0.30	0.71	0.11	0.64
	Average ALL	0.36	0.59	0.07	0.46	-0.14	0.51	-0.37	0.64	-0.06	0.46
20-70 km	Chino Hills (5.39, ROBL)			0.36	0.55	0.19	0.50	0.10	0.47	-0.08	0.40
	Alum Rock (5.45, SS)			-0.58	0.67	-0.79	0.84	-0.81	0.86	-0.87	0.88
	Whittier Narrows (5.89, REV)	0.78	0.79	-0.22	0.37	-0.37	0.56	-0.51	0.61	-0.48	0.55
	North Palm Springs (6.12, ROBL)	0.84	0.86	-0.35	0.53	-0.05	0.42	-0.15	0.42	-0.32	0.49
	Tottori (6.59, SS)	-0.28	0.48	-0.41	0.58	-0.59	0.67	-0.80	0.84	-0.41	0.56
	Niigata (6.65, REV)	-0.41	0.62	-0.43	0.61	-0.93	1.05	-0.97	1.08	-0.60	0.73
	Northridge (6.73, REV)	-0.20	0.38	-0.55	0.58	-0.18	0.52	-0.22	0.53	-0.34	0.41
	Loma Prieta (6.94, ROBL)	0.03	0.43	-0.22	0.51	-0.43	0.56	-0.45	0.57	0.02	0.46
	Landers (7.22, SS)	-0.19	0.69	-0.64	0.70	-0.52	0.63	-0.55	0.64	-0.35	0.56
	Riviere-du-Loup (4.6 REV)			0.37	0.53	-0.04	0.60	0.01	0.61	-0.70	0.93
	Mineral (5.68 REV)	0.82	0.97	0.58	1.34	0.53	0.85	0.02	0.98	0.22	1.24
	Saguenay (5.81 REV)	0.29	0.29	-1.46	1.46	-1.06	1.06	-1.60	1.60	-1.46	1.46
	Average CA	0.15	0.60	-0.30	0.57	-0.32	0.58	-0.38	0.59	-0.33	0.54
	Average CENA	0.79	0.93	0.39	0.66	0.03	0.64	0.00	0.67	-0.57	0.98
	Average ALL	0.01	0.59	-0.28	0.58	-0.39	0.65	-0.46	0.68	-0.39	0.59
70-200 km	Chino Hills (5.39, ROBL)			0.20	0.67	0.24	0.75	0.19	0.73	-0.01	0.62
	Alum Rock (5.45, SS)			-0.17	0.37	-0.82	0.84	-0.85	0.86	-0.28	0.44
	Whittier Narrows (5.89, REV)										
	North Palm Springs (6.12, ROBL)	0.82	0.83	-0.45	0.46	0.32	0.42	0.23	0.36	-0.32	0.38
	Tottori (6.59, SS)	-0.05	0.57	0.34	0.70	-0.30	0.69	-0.33	0.70	-0.33	0.69
	Niigata (6.65, REV)	-0.61	0.79	-0.39	0.65	-1.32	1.34	-1.33	1.36	-1.03	1.07
	Northridge (6.73, REV)	-0.13	0.41	-0.83	0.88	-0.31	0.55	-0.32	0.56	-0.47	0.64
	Loma Prieta (6.94, ROBL)	0.82	1.05	0.76	0.99	0.54	0.94	0.51	0.92	1.14	1.24
	Landers (7.22, SS)	0.61	0.77	-0.28	0.45	0.06	0.40	0.03	0.39	0.31	0.59
	Riviere-du-Loup (4.6 REV)			0.56	1.12	0.36	1.03	0.01	0.99	-0.29	0.99
	Mineral (5.68 REV)	1.46	1.46	0.49	0.64	0.85	0.88	0.72	0.80	0.58	0.70
	Saguenay (5.81 REV)	2.91	2.91	0.44	0.60	1.63	1.63	0.15	0.43	0.65	0.69
	Average CA	0.60	0.80	-0.03	0.58	-0.02	0.66	-0.06	0.65	0.14	0.64
	Average CENA	2.13	2.13	0.48	0.71	1.05	1.19	0.38	0.69	0.45	0.75
	Average ALL	0.42	0.97	0.04	0.63	-0.13	0.86	-0.26	0.79	-0.10	0.74
	Reverse (REV)	0.24	0.78	-0.12	0.57	-0.31	0.79	-0.48	0.79	-0.35	0.69
	Reverse-Oblique (ROBL)	0.41	0.66	0.10	0.57	0.00	0.57	-0.05	0.56	0.01	0.51
	Strike-Slip (SS)	0.09	0.65	-0.26	0.58	-0.42	0.65	-0.55	0.74	-0.29	0.61
	Normal (NM)										
	Average CA	0.32	0.65	-0.14	0.55	-0.21	0.58	-0.26	0.58	-0.16	0.55
	Average CENA	[illegible]	[illegible]	[illegible]	[illegible]	0.60	0.92	0.22	0.69	0.02	0.83
	Average ALL	0.23	0.71	-0.11	0.57	-0.26	0.68	-0.38	0.71	-0.23	0.61

More than3 s

Distance	Event (Mw, Mech.)	UCSB		EXSIM		G&P		SDSU		GMPE	
		PSA Period Range > 3s									
0-5 km	Chino Hills (5.39, ROBL)										
	Alum Rock (5.45, SS)			-0.96	0.96	-1.11	1.11	-1.05	1.05	-1.66	1.66
	Whittier Narrows (5.89, REV)										
	North Palm Springs (6.12, ROBL)	0.41	0.41	-0.08	0.08	-0.94	0.94	-0.95	0.95	-0.50	0.50
	Tottori (6.59, SS)	1.11	1.11	-0.23	0.23	-0.30	0.30	-1.91	1.91	-0.41	0.41
	Niigata (6.65, REV)										
	Northridge (6.73, REV)										
	Loma Prieta (6.94, ROBL)	0.27	0.59	0.09	0.58	-0.39	0.39	-0.39	0.39	-0.18	0.43
	Landers (7.22, SS)	2.25	2.25	1.13	1.13	0.45	0.45	0.44	0.44	1.17	1.17
	Riviere-du-Loup (4.6 REV)										
	Mineral (5.68 REV)										
	Saguenay (5.81 REV)										
	Average CA	1.07	1.24	0.26	0.81	-0.25	0.55	-0.24	0.54	0.01	0.88
	Average CENA										
	Average ALL	1.08	1.21	0.16	0.70	-0.26	0.50	-0.56	0.80	-0.07	0.79
5-20 km	Chino Hills (5.39, ROBL)			0.80	0.80	0.80	0.80	0.84	0.84	0.22	0.32
	Alum Rock (5.45, SS)			0.63	0.78	-0.18	0.68	-0.17	0.68	0.12	0.74
	Whittier Narrows (5.89, REV)	-0.14	0.27	-0.35	0.38	-1.02	1.02	-1.01	1.01	-0.81	0.81
	North Palm Springs (6.12, ROBL)	0.25	0.37	0.02	0.56	-0.05	0.24	-0.05	0.24	-0.21	0.69
	Tottori (6.59, SS)	0.44	0.64	0.32	0.41	0.05	0.44	-0.30	0.65	0.09	0.34
	Niigata (6.65, REV)	-0.24	0.28	-0.22	0.46	-0.54	0.67	-1.27	1.27	-0.53	0.69
	Northridge (6.73, REV)	0.15	0.59	0.30	0.42	-0.10	0.32	-0.10	0.32	0.14	0.43
	Loma Prieta (6.94, ROBL)	0.38	0.54	0.19	0.47	-0.25	0.28	-0.25	0.28	0.05	0.40
	Landers (7.22, SS)	0.39	0.49	-0.29	0.53	-0.85	0.85	-0.85	0.85	-0.28	0.56
	Riviere-du-Loup (4.6 REV)			1.14	1.14	1.12	1.12	1.25	1.25	0.87	0.87
	Mineral (5.68 REV)	0.57	0.57	0.28	0.28	-0.03	0.03	-0.22	0.22	0.19	0.19
	Saguenay (5.81 REV)										
	Average CA	0.24	0.53	0.31	0.56	-0.08	0.51	-0.07	0.51	0.04	0.48
	Average CENA	0.57	0.57	0.93	0.93	0.83	0.85	0.88	0.99	0.70	0.70
	Average ALL	0.21	0.51	0.25	0.52	-0.10	0.52	-0.26	0.66	-0.01	0.49
20-70 km	Chino Hills (5.39, ROBL)			0.61	0.67	0.57	0.64	0.55	0.63	0.15	0.41
	Alum Rock (5.45, SS)			0.03	0.41	-0.54	0.58	-0.55	0.58	-0.38	0.46
	Whittier Narrows (5.89, REV)	0.37	0.37	0.06	0.22	-0.46	0.46	-0.49	0.49	-0.30	0.31
	North Palm Springs (6.12, ROBL)	-0.13	0.15	0.34	0.34	-0.43	0.43	-0.43	0.43	0.03	0.15
	Tottori (6.59, SS)	-0.24	0.45	-0.01	0.38	-0.44	0.57	-0.47	0.59	-0.27	0.45
	Niigata (6.65, REV)	-0.90	0.94	-0.31	0.49	-1.09	1.13	-1.09	1.13	-0.70	0.74
	Northridge (6.73, REV)	-0.36	0.49	-0.26	0.43	-0.33	0.80	-0.33	0.80	-0.18	0.35
	Loma Prieta (6.94, ROBL)	0.43	0.54	0.30	0.48	-0.18	0.36	-0.18	0.36	0.43	0.53
	Landers (7.22, SS)	0.08	0.56	-0.29	0.53	-0.73	0.75	-0.73	0.75	-0.19	0.57
	Riviere-du-Loup (4.6 REV)			0.24	0.32	-0.23	0.29	-0.13	0.23	-0.71	0.72
	Mineral (5.68 REV)	0.43	0.43	1.35	1.35	0.02	0.08	-0.05	0.10	0.68	0.68
	Saguenay (5.81 REV)										
	Average CA	0.12	0.53	0.02	0.51	-0.35	0.62	-0.35	0.62	-0.01	0.49
	Average CENA	0.43	0.43	0.37	0.44	-0.20	0.26	-0.13	0.21	-0.55	0.72
	Average ALL	-0.25	0.63	-0.05	0.47	-0.54	0.72	-0.54	0.72	-0.25	0.55
70-200 km	Chino Hills (5.39, ROBL)			0.47	0.83	0.59	0.91	0.58	0.91	0.23	0.72
	Alum Rock (5.45, SS)			0.09	0.22	-0.86	0.86	-0.86	0.86	-0.10	0.32
	Whittier Narrows (5.89, REV)										
	North Palm Springs (6.12, ROBL)										
	Tottori (6.59, SS)	-0.01	0.53	0.74	0.87	-0.31	0.58	-0.31	0.58	-0.04	0.59
	Niigata (6.65, REV)	-1.34	1.35	-0.14	0.52	-1.49	1.50	-1.49	1.50	-0.89	0.94
	Northridge (6.73, REV)	-0.03	0.03	-0.56	0.56	-0.31	0.31	-0.31	0.31	-0.15	0.20
	Loma Prieta (6.94, ROBL)	0.49	0.83	0.30	0.68	0.03	0.62	0.03	0.62	0.71	0.86
	Landers (7.22, SS)	0.94	0.98	0.13	0.53	0.03	0.47	0.03	0.47	0.72	0.83
	Riviere-du-Loup (4.6 REV)			0.97	0.97	0.69	0.69	0.32	0.32	0.13	0.18
	Mineral (5.68 REV)	0.46	0.46	1.08	1.08	0.22	0.28	0.18	0.29	0.74	0.78
	Saguenay (5.81 REV)	0.66	0.66	-0.12	0.12	0.37	0.37	-0.42	0.42	-0.25	0.27
	Average CA	0.89	0.96	0.22	0.56	0.00	0.69	0.00	0.69	0.39	0.69
	Average CENA	0.48	0.48	0.97	0.99	0.24	0.29	0.13	0.31	0.63	0.73
	Average ALL	-0.26	0.90	0.33	0.68	-0.51	0.87	-0.52	0.87	-0.09	0.74
	Reverse (REV)	-0.65	0.87	-0.02	0.53	-0.80	0.95	-0.86	1.00	-0.46	0.72
	Reverse-Oblique (ROBL)	0.37	0.53	0.40	0.61	0.16	0.54	0.16	0.54	0.22	0.51
	Strike-Slip (SS)	0.19	0.62	0.17	0.56	-0.39	0.61	-0.45	0.65	-0.04	0.56
	Normal (NM)										
	Average CA	0.32	0.63	0.15	0.54	-0.20	0.60	-0.20	0.60	0.10	0.55
	Average CENA	0.48	0.48	0.75	0.79	0.13	0.33	0.10	0.33	0.22	0.72
	Average ALL	-0.13	0.71	0.15	0.56	-0.43	0.72	-0.48	0.76	-0.14	0.61

Combined Metric Comparison with GMPEs

$$CGOF_{Normalized} = \frac{CGOF_{sims}}{CGOF_{GMPE}}$$



CGOF$_{Normalized}$

Change the values below

Part A, GOF Validation Threshhold = ##

Unacceptable Threshhold = ##

weight= ##

bined Metric Performance I

sected to W otential Issue efinite Issue

0-5 km

Group	Event (Mw, Mech.)	PSA Period Range = [0.01-0.1] s					PSA Period Range = [0.1-1] s					PSA Period Range = [1-3] s					PSA Period Range > 3s				
		UCSB	EXSIM	G&P	SDSU	GMPE	UCSB	EXSIM	G&P	SDSU	GMPE	UCSB	EXSIM	G&P	SDSU	GMPE	UCSB	EXSIM	G&P	SDSU	GMPE
Rrup=[0-5] km	Chino Hills (5.39, ROBL)																				
	Alum Rock (5.45, SS)		0.78	0.71	0.49	1.33		0.86	0.83	0.59	1.33		0.65	0.75	0.75	1.77		0.58	0.67	0.63	1.66
	Whittier Narrows (5.89, REV)																				
	North Palm Springs (6.12, ROBL)	1.53	2.38	0.78	2.25	0.16	6.19	1.48	0.71	1.74	0.16	6.20	1.33	3.10	3.40	0.15	0.82	0.16	1.88	1.90	0.50
	Tottori (6.59, SS)	0.85	5.13	0.57	15.3	0.23	1.74	0.66	0.95	3.44	0.62	11.9	1.81	1.33	23.0	0.11	2.71	0.56	0.73	4.66	0.41
	Nigata (6.65, REV)																				
	Northridge (6.73, REV)																				
	Loma Prieta (6.94, ROBL)	1.08	1.14	0.72	1.04	0.25	2.83	1.39	1.22	1.61	0.21	1.30	1.24	0.51	0.56	0.59	1.41	1.10	1.28	1.28	0.31
	Landers (7.22, SS)	1.10	0.70	0.87	0.88	1.05	2.29	0.41	0.80	0.65	0.69	2.17	0.65	0.62	0.56	0.94	1.92	0.97	0.38	0.38	1.17
	Riviere-du-Loup (4.6 REV)																				
	Mineral (5.68 REV)																				
	Saguenay (5.81 REV)																				
	Average CA	1.29	0.96	0.77	0.99	0.35	2.53	0.72	0.74	0.84	0.34	2.28	1.08	0.98	1.02	0.46	2.60	1.20	0.90	0.88	0.45
	Average CENA																				
	Average ALL	1.25	1.20	0.82	2.08	0.30	3.03	0.92	0.97	1.49	0.30	2.68	1.06	1.00	1.84	0.41	2.66	1.00	0.88	1.58	0.43

5-20 km

Group	Event (Mw, Mech.)	UCSB	EXSIM	G&P	SDSU	GMPE	UCSB	EXSIM	G&P	SDSU	GMPE	UCSB	EXSIM	G&P	SDSU	GMPE	UCSB	EXSIM	G&P	SDSU	GMPE
Rrup=[5-20] km	Chino Hills (5.39, ROBL)		0.59	0.38	0.50	0.45		1.48	1.19	1.29	0.26		4.27	4.87	4.33	0.15		2.96	2.96	3.11	0.27
	Alum Rock (5.45, SS)		0.66	1.09	0.40	0.48		0.86	1.31	0.63	0.33		1.12	1.24	1.28	0.34		1.64	1.00	0.99	0.43
	Whittier Narrows (5.89, REV)	1.36	0.93	1.20	1.20	0.30	3.71	1.54	1.32	1.37	0.21	1.05	0.48	1.07	1.24	0.44	0.25	0.45	1.26	1.25	0.81
	North Palm Springs (6.12, ROBL)	1.96	0.94	1.27	0.90	0.25	2.27	0.95	1.16	1.04	0.28	1.65	0.67	1.06	1.22	0.39	0.69	0.64	0.32	0.32	0.45
	Tottori (6.59, SS)	0.64	0.78	0.59	1.93	0.60	0.73	0.34	0.66	1.05	0.60	2.14	0.93	1.23	4.36	0.22	2.51	1.70	1.14	2.21	0.22
	Nigata (6.65, REV)	0.91	0.72	0.76	3.71	0.48	1.46	0.93	0.76	2.62	0.42	0.38	0.73	1.35	3.63	0.47	0.43	0.56	0.99	2.08	0.61
	Northridge (6.73, REV)	2.71	1.49	0.98	1.05	0.21	2.48	1.17	1.00	0.91	0.32	1.50	1.07	0.61	0.68	0.36	1.30	1.26	0.74	0.74	0.29
	Loma Prieta (6.94, ROBL)	0.81	1.52	0.83	1.10	0.24	1.74	1.13	0.76	1.09	0.27	2.10	1.23	1.77	1.85	0.20	2.04	1.47	1.18	1.18	0.23
	Landers (7.22, SS)	2.25	1.32	1.38	1.46	0.33	1.97	0.97	0.80	0.85	0.33	2.39	1.93	1.86	1.98	0.22	1.05	0.98	2.02	2.02	0.42
	Riviere-du-Loup (4.6 REV)		1.07	0.41	0.53	0.59		1.00	1.15	1.28	0.58		1.92	1.97	1.91	0.44		1.31	1.29	1.44	0.87
	Mineral (5.68 REV)	1.04	0.65	0.61	0.77	0.71	1.86	0.56	0.75	1.63	0.36	2.88	0.63	0.16	0.63	0.32	3.00	1.47	0.16	1.16	0.19
	Saguenay (5.81 REV)																				
	Average CA	1.13	0.96	0.96	0.80	0.27	3.00	1.27	0.98	1.02	0.23	0.50	0.27	0.32	0.35	0.26	1.48	1.67	1.13	1.12	0.26
	Average CENA	1.18	0.91	0.48	0.42	0.63	1.50	0.91	1.18	1.13	0.44	0.92	0.59	0.54	0.51	0.38	0.81	1.33	1.20	1.34	0.70
	Average ALL	1.24	1.02	1.00	1.78	0.23	2.30	1.02	0.84	1.04	0.28	0.48	0.27	0.33	0.51	0.26	1.44	1.54	1.24	1.84	0.25

20-70 km

Group	Event (Mw, Mech.)	UCSB	EXSIM	G&P	SDSU	GMPE	UCSB	EXSIM	G&P	SDSU	GMPE	UCSB	EXSIM	G&P	SDSU	GMPE	UCSB	EXSIM	G&P	SDSU	GMPE
Rrup=[20-70] km	Chino Hills (5.39, ROBL)		0.79	0.52	0.48	0.50		0.78	0.67	0.63	0.42		1.90	1.44	1.19	0.24		2.29	2.16	2.11	0.28
	Alum Rock (5.45, SS)		0.76	1.03	0.76	1.01		0.96	1.23	0.89	0.84		0.71	0.93	0.95	0.88		0.52	1.33	1.35	0.42
	Whittier Narrows (5.89, REV)	1.39	1.31	0.84	1.15	0.31	3.69	1.30	1.02	1.41	0.27	1.52	0.57	0.90	1.09	0.52	1.21	0.46	1.51	1.61	0.31
	North Palm Springs (6.12, ROBL)	0.83	1.46	1.07	0.98	0.42	3.09	1.07	0.88	0.88	0.29	2.10	1.09	0.58	0.70	0.41	1.56	3.78	4.78	4.78	0.09
	Tottori (6.59, SS)	0.19	0.29	0.72	0.27	1.08	0.66	0.64	0.62	0.78	0.53	0.78	1.02	1.30	1.69	0.49	0.96	0.54	1.40	1.47	0.36
	Nigata (6.65, REV)	0.75	0.65	0.80	0.47	0.48	1.20	0.88	1.32	1.09	0.33	0.77	0.78	1.49	1.54	0.67	1.28	0.56	1.54	1.54	0.72
	Northridge (6.73, REV)	1.68	0.63	0.95	1.73	0.32	1.08	1.17	1.42	1.73	0.24	0.77	1.51	0.93	1.00	0.38	1.60	1.30	2.13	2.13	0.27
	Loma Prieta (6.94, ROBL)	1.74	0.74	1.46	1.12	0.34	1.06	1.13	1.81	1.28	0.24	0.96	1.52	2.06	2.13	0.24	1.01	0.81	0.56	0.56	0.48
	Landers (7.22, SS)	3.53	0.83	1.36	1.17	0.27	1.43	1.40	1.43	1.34	0.27	0.97	1.47	1.26	1.31	0.46	0.84	1.08	1.95	1.95	0.38
	Riviere-du-Loup (4.6 REV)		0.38	0.38	0.45	0.96		1.25	0.67	0.87	0.43		0.55	0.39	0.38	0.82		0.39	0.36	0.25	0.72
	Mineral (5.68 REV)	0.17	0.49	0.26	0.11	1.42	1.21	0.84	1.45	2.84	0.38	1.23	1.32	0.95	0.68	0.73	0.63	1.99	0.07	0.11	0.68
	Saguenay (5.81 REV)	1.07	0.36	0.64	0.46	1.61	3.66	1.69	0.60	2.21	0.35	0.20	1.00	0.73	1.10	1.46					
	Average CA	1.11	0.67	1.00	0.95	0.40	1.52	0.89	1.18	1.10	0.36	0.86	1.00	1.03	1.11	0.44	1.30	1.06	1.94	1.94	0.25
	Average CENA	0.82	0.39	0.41	0.40	1.09	2.14	1.11	0.70	0.95	0.41	1.11	0.68	0.43	0.43	0.78	0.68	0.64	0.36	0.27	0.64
	Average ALL	1.23	0.89	0.98	1.02	0.32	1.47	0.88	1.18	1.13	0.34	0.61	0.88	1.06	1.16	0.49	1.10	0.65	1.58	1.58	0.40

70-200 km

Group	Event (Mw, Mech.)	UCSB	EXSIM	G&P	SDSU	GMPE	UCSB	EXSIM	G&P	SDSU	GMPE	UCSB	EXSIM	G&P	SDSU	GMPE	UCSB	EXSIM	G&P	SDSU	GMPE
Rrup=[70-200 or 300] km	Chino Hills (5.39, ROBL)		1.65	1.57	1.32	0.33		1.39	1.48	1.47	0.31		1.38	1.57	1.46	0.32		1.37	1.58	1.57	0.48
	Alum Rock (5.45, SS)		0.77	0.80	0.66	1.02		1.00	0.99	0.70	0.89		0.75	2.31	2.38	0.36		0.74	4.10	4.10	0.21
	Whittier Narrows (5.89, REV)																				
	North Palm Springs (6.12, ROBL)	1.04	0.61	0.35	1.00	0.25	1.22	1.07	0.84	1.13	0.43	2.36	1.30	1.06	0.84	0.35					
	Tottori (6.59, SS)	0.78	0.86	1.13	0.61	0.63	0.97	1.38	1.04	1.47	0.38	0.61	1.02	0.97	1.01	0.51	0.86	2.56	1.41	1.41	0.32
	Nigata (6.65, REV)	0.70	0.62	0.70	0.76	0.49	0.46	0.55	0.98	0.40	0.81	0.67	0.50	1.27	1.28	1.05	1.47	0.36	1.63	1.63	0.92
	Northridge (6.73, REV)	1.69	1.57	1.74	0.94	0.18	0.77	0.81	1.00	0.86	0.40	0.49	1.54	0.77	0.79	0.56	0.17	3.20	1.77	1.77	0.18
	Loma Prieta (6.94, ROBL)	0.53	1.36	0.91	1.20	0.45	0.86	0.87	0.79	1.03	0.73	0.79	0.74	0.62	0.60	1.19	0.84	0.62	0.41	0.41	0.79
	Landers (7.22, SS)	0.95	0.43	0.51	0.78	0.19	2.02	1.48	0.91	1.11	0.22	1.53	0.81	0.51	0.47	0.45	1.24	0.43	0.32	0.32	0.78
	Riviere-du-Loup (4.6 REV)		0.30	0.29	0.33	1.51		0.78	0.57	0.60	0.88		1.31	1.09	0.78	0.64		6.26	4.45	2.06	0.16
	Mineral (5.68 REV)	0.46	0.25	0.35	0.25	1.31	1.35	0.31	0.35	0.27	1.03	2.28	0.88	1.35	1.19	0.64	0.61	1.42	0.33	0.31	0.76
	Saguenay (5.81 REV)	1.52	0.29	0.62	0.14	1.68	2.43	0.52	0.97	0.17	1.47	4.34	0.78	2.43	0.43	0.67	2.54	0.46	1.42	1.62	0.26
	Average CA	0.46	0.77	0.69	0.70	0.35	1.38	1.06	0.91	0.84	0.35	1.79	0.78	0.87	0.91	0.39	1.71	0.72	0.64	0.64	0.54
	Average CENA	1.13	0.27	0.41	0.21	1.52	2.22	0.50	0.72	0.24	1.18	3.55	0.99	1.87	0.89	0.60	0.71	1.44	0.39	0.32	0.68
	Average ALL	0.97	0.66	0.74	0.49	0.52	1.87	0.78	0.84	0.75	0.44	1.65	0.80	1.18	1.25	0.42	1.40	1.22	1.66	1.67	0.42

Group	Event (Mw, Mech.)	UCSB	EXSIM	G&P	SDSU	GMPE	UCSB	EXSIM	G&P	SDSU	GMPE	UCSB	EXSIM	G&P	SDSU	GMPE	UCSB	EXSIM	G&P	SDSU	GMPE
Mechanism	Reverse (REV)	0.97	0.66	0.56	0.72	0.48	2.25	0.92	0.86	0.96	0.37	0.98	0.66	1.06	1.22	0.52	1.29	0.47	1.48	1.58	0.59
	Reverse-Oblique (ROBL)	1.07	1.41	0.93	0.98	0.28	2.17	1.17	0.94	1.08	0.26	2.06	1.29	1.10	1.17	0.26	1.23	1.38	0.96	0.96	0.37
	Strike-Slip (SS)	1.24	0.93	1.01	1.15	0.38	0.87	1.13	1.21	1.12	0.38	0.82	0.93	1.19	1.43	0.45	1.35	1.22	1.67	1.83	0.30
	Normal (NM)																				
Total	**Average CA**	0.94	0.74	0.92	0.86	0.36	1.83	0.89	1.10	1.00	0.32	1.37	0.97	1.11	1.18	0.36	1.46	1.06	1.23	1.23	0.33
	Average CENA	1.16	0.30	0.39	0.19	1.27	2.88	0.68	0.74	0.45	0.76	4.47	1.33	1.79	1.07	0.43	1.02	1.64	0.49	0.46	0.47
	Average ALL	0.93	0.83	0.77	0.91	0.35	2.02	0.87	1.10	1.06	0.31	1.12	0.81	1.12	1.30	0.42	1.12	0.95	1.53	1.65	0.38

Attenuation Bias

Fit a line through distance binned GOF values

$$\ln\left(\frac{Sa_{obs}}{Sa_{syn}}\right) = a + b \cdot \ln(R)$$

Determine whether slope *b*=0 lies within 95% confidence interval

Distance Metric - All CA+JP+CENA (March 2014 v14.3)

Period	UCSB	EXSIM	G&P	SDSU	GMPE
0.01 to 0.1 s	0.38	0.36	0.67	0.61	0.53
0.1 to 1.0 s	0.08	0.23	0.01	0.48	0.03
1 to 3 s	0.16	0.10	0.05	0.33	0.11
> 3 s	1.19	0.34	0.83	0.41	0.13

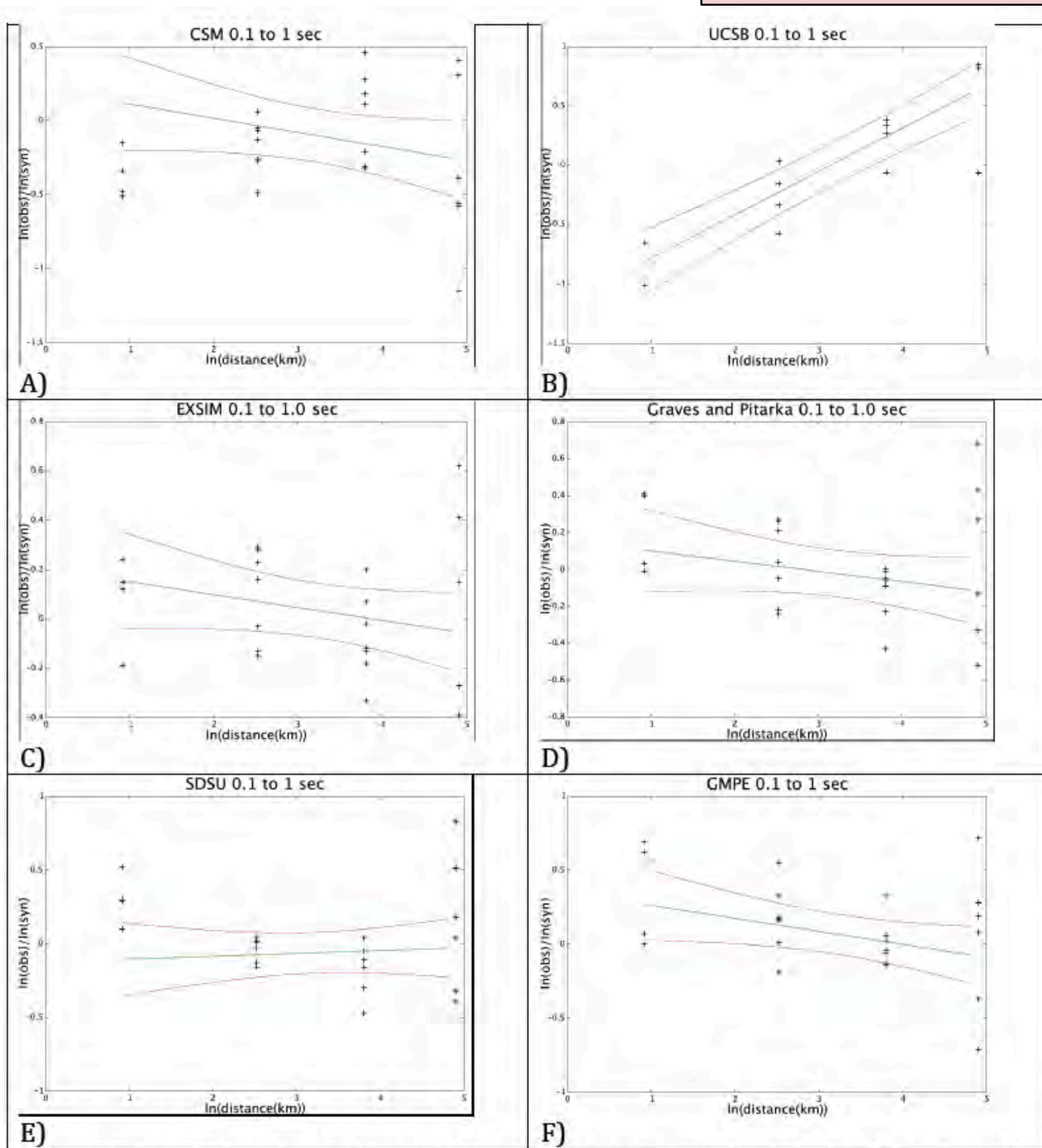
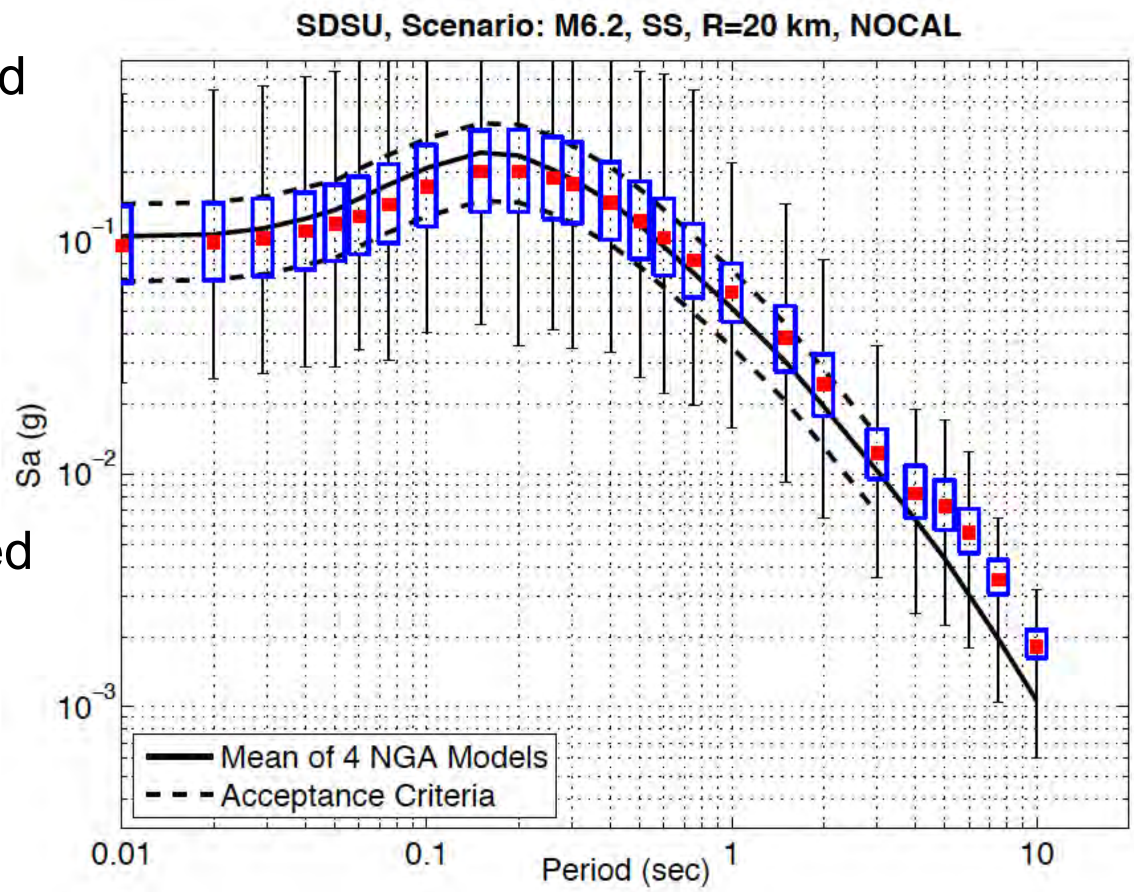


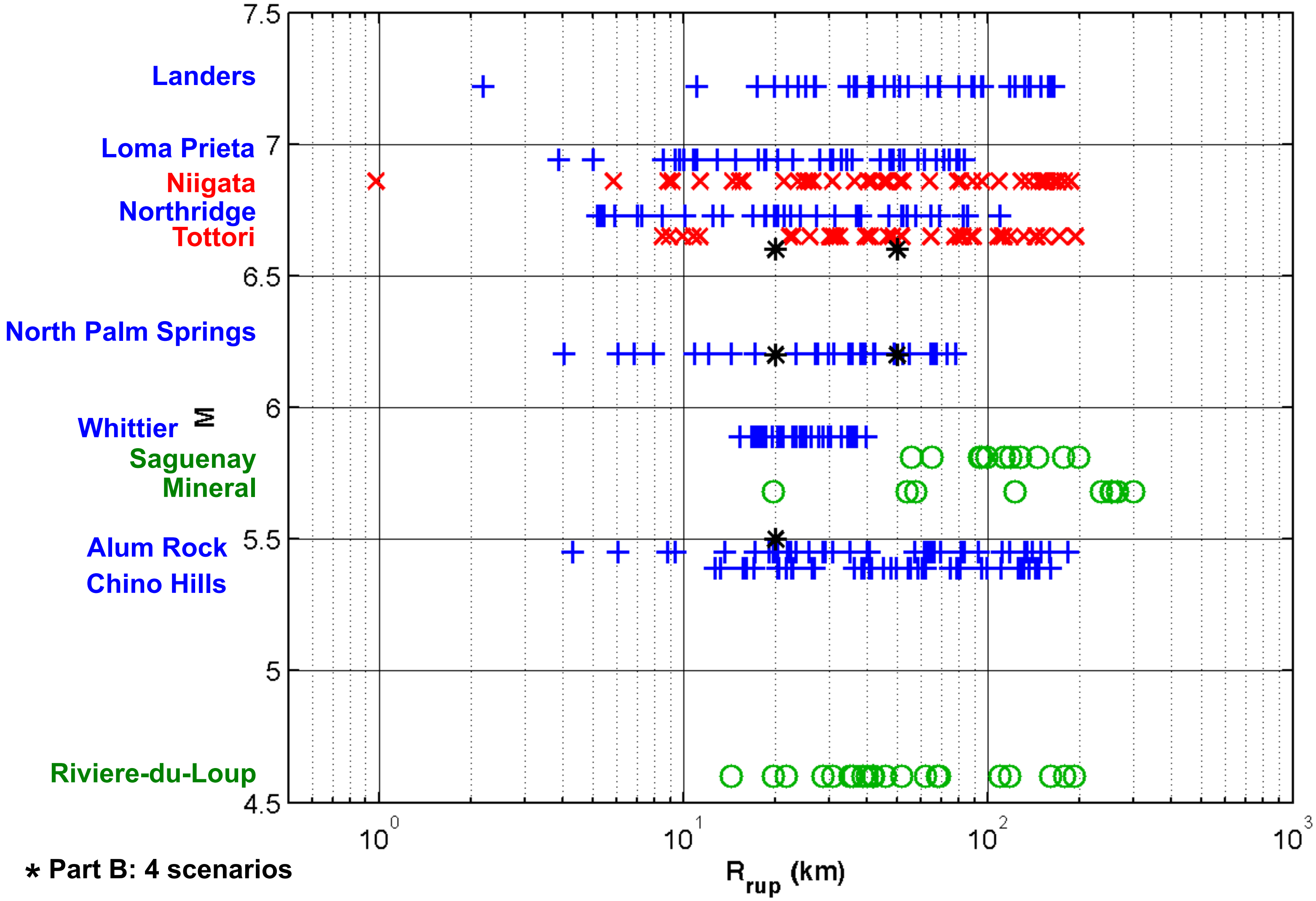
Figure 1. Best fit line (green), and 95% confidence regions (red-dashed) for the 0.1 to 1 s period bin. GOF values from Table 3.1.2 are shown for event and distance bin. A) CSM; B) UCSB; C) EXSIM, D) G&P, E) SDSU, and F) GMPE. Y-axis is mean bias in natural log units. Values are for each distance bin plotted with respect to the natural log of the central distance of each bin. Data are weighted by the number of stations and discrete periods in each distance bin.

Part B – Design and Evaluation criteria

- Scenarios from NGA-West1&2 well constrained by data at 20 and 50 km Rrup
  - M5.5 REV
  - M6.2 SS
  - M6.6 SS & REV
- 50 realizations of the source, WITH randomized hypocenter location for each
- Simulations for two velocity models: NorCal and SoCal

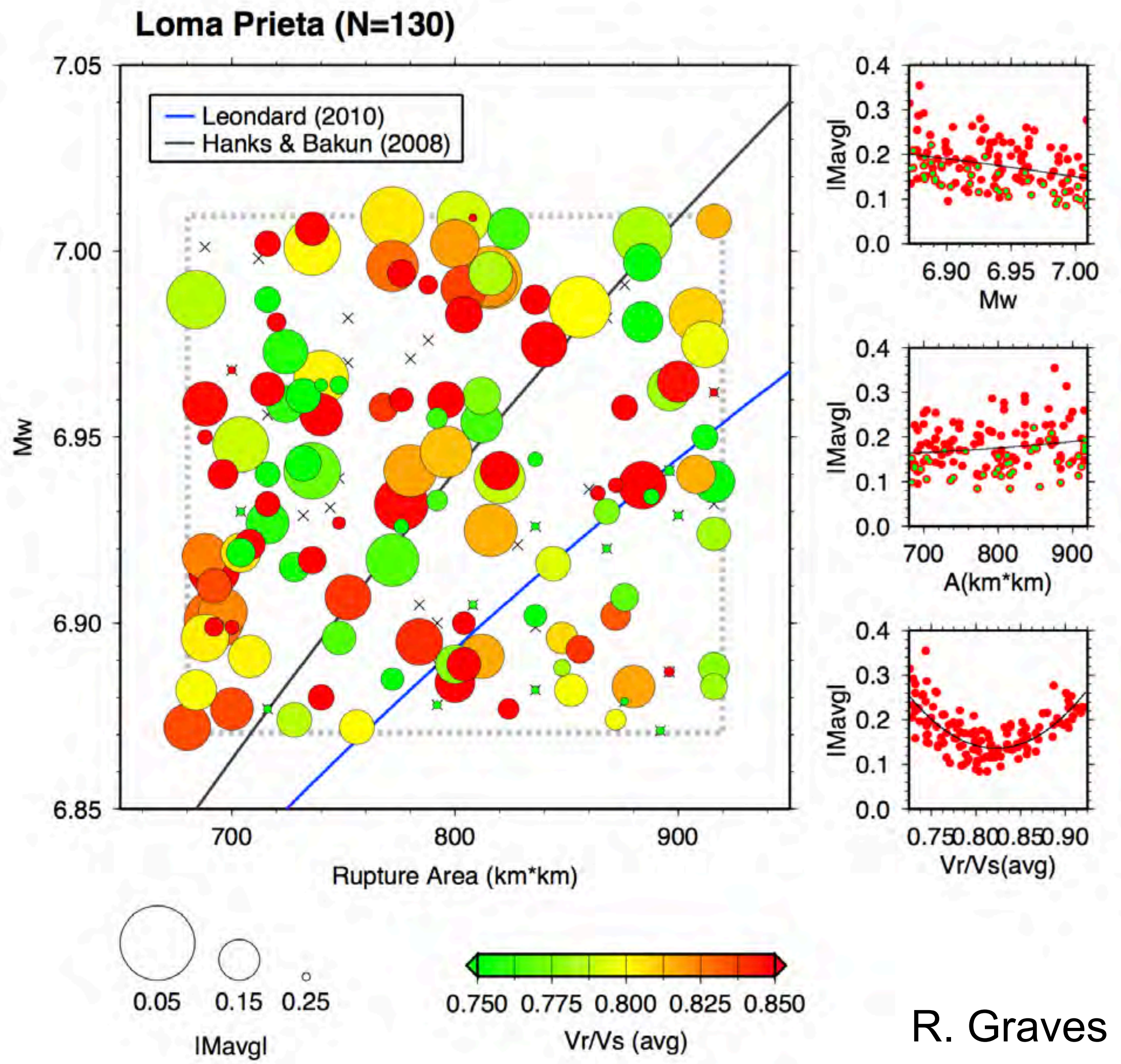


Summary of Simulated Events



Capturing the uncertainty

- In scenario definitions
  - M and geometry



R. Graves

Capturing the uncertainty

- In input parameters
  - Perform sensitivities due to assumptions and parameter values
  - Develop appropriate parameter space to sample in forward simulations

Application to dynamic codes simulations - considerations

- Define a few initial scenarios and define what bounds a problem:
  - What is "fixed" in the validation: M or moment? fault length? Initial stress level? How?
  - What velocity structure, upper Vs? Path properties to be specified?
  - How many realizations? Start with initial set of validation for *tuned* (optimized) simulations?
- Start *thinking* in terms of "rules"
  - Define input parameters, default values and ranges
  - Think how parameters can be set in a general sense from basic scenario definition
  - Rules will most likely be regional in nature
- Think about what uncertainties can be explored
  - Trade-off with computing resources?
- Define initial set of evaluation metrics; borrow what already exists and expand as needed

Thank you!

Validation Gauntlet Development

- 1. Define application and key ground-motion parameters
- 2. Implement validation parameters on appropriate platform, generate plots and ASCII output
- 3. Form an evaluation panel; evaluate the ground-motion parameters
- 4. Develop the gauntlet (evaluation panel activity, performed outside the platform)
- 5. Implement the gauntlet on the platform so it provides fast feedback to model developers

Evaluation

- Review panel
  - Douglas Dreger (Chair), UC Berkeley
  - Gregory Beroza, Stanford
  - Steven Day, SDSU
  - Christine Goulet, UC Berkeley
  - Thomas Jordan, USC
  - Paul Spudich, USGS
  - Jonathan Stewart, UCLA
- Input for review
  - Modeler's documentation and self-assessment
  - BBP results (parts A and B)
    - Part A: criteria based on binned GOF according to M (event), R, T
    - Part B: simple pass-fail