Ground Motion Simulations Validation – process and summary of status

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PEER

SCEC
an NSF + USGS center

Many thanx to: N. Abrahamson, P. Somerville, F. Silva, P. Maechling, R. Archuleta, J. Anderson, K. Assatourians, G. Atkinson, J. Bayless, J. Crempien, C. Di Alessandro, R. Graves, T. Hyun, R. Kamai, K. Olsen, W. Silva, R. Takedatsu, F. Wang, K. Wooddell,, D. Dreger, G. Beroza, S. Day, T. Jordan, P. Spudich, J. Stewart and their collaborators…

Menu du jour

- Introduction
- Validation framework and schemes
- Overview of simulation methods
- Sample results and evaluation tools
- Path forward to forward simulations
- Next steps

Large collaborative validation of simulations using the SCEC BroadBand Platform

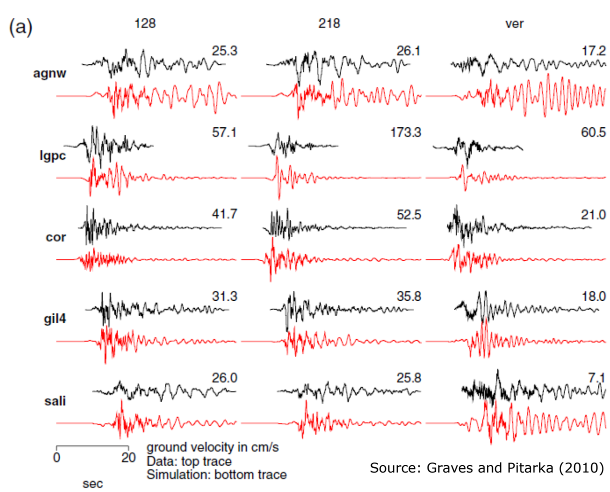
Driven by need of seismic hazard projects to supplement recorded datasets

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

- Southern California Earthquake Center (SCEC) BroadBand Platform
  - Set of computational tools for ground motion simulations, including post-processing

Collaboration of SWUS-SCEC-PEER critical to success!!!

Past validations…



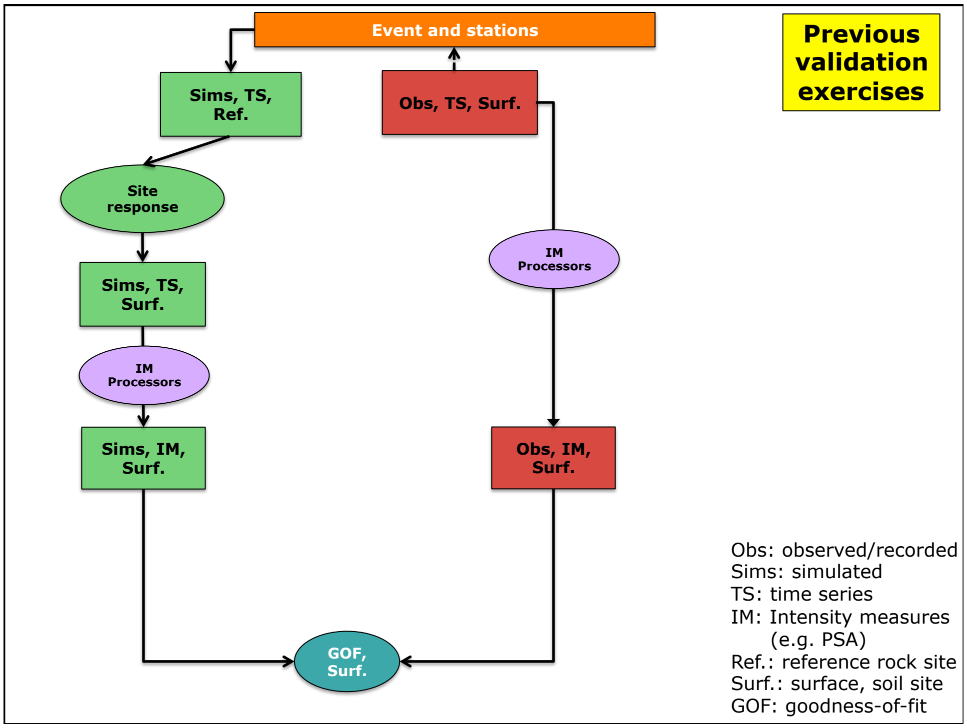
Source: Graves and Pitarka (2010)

Objectives

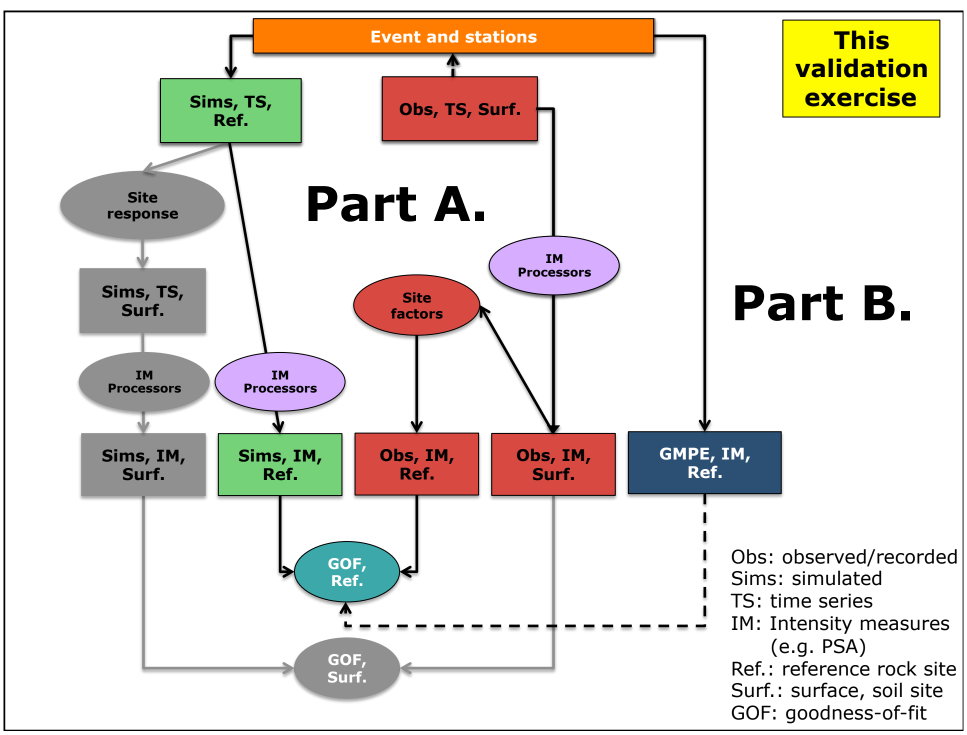
- Quantitative validation for forward simulations in engineering problems
  - Short term goal: supplement recorded data for development of GMPEs
  - Long term goal: develop acceptance of simulations for engineering design
- Key focus: 5% damped elastic "average" PSA (*f*=0.1-100 Hz/ T=0.01-10 s)
  - Correlates well with structural response – basis of design
  - Allows large number of validation evaluations

Key lessons learned – past validations

- Need more transparency...
- Need to validate against many events
- Need clear documentation of fixed and optimized parameters from modelers for each region
- Need source description that is *consistent* between methods
- Use unique crustal structure (V, Q) for all models
- Consider multiple source realizations
- Run simulations for reference site conditions – correct data with 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/BBP version



Event and stations
Previous validation exercises
Sims, TS, Ref.
Obs, TS, Surf.
Site response
IM Processors
Sims, TS, Surf.
IM Processors
Sims, IM, Surf.
Obs, IM, Surf.
GOF, Surf.
Obs: observed/recorded
Sims: simulated
TS: time series
IM: Intensity measures (e.g. PSA)
Ref.: reference rock site
Surf.: surface, soil site
GOF: goodness-of-fit



Event and stations
This validation exercise
Sims, TS, Ref.
Obs, TS, Surf.
Part A.
Site response
IM Processors
Site factors
Part B.
Sims, TS, Surf.
IM Processors
IM Processors
Sims, IM, Surf.
Sims, IM, Ref.
Obs, IM, Ref.
Obs, IM, Surf.
GMPE, IM, Ref.
GOF, Ref.
GOF, Surf.
Obs: observed/recorded
Sims: simulated
TS: time series
IM: Intensity measures (e.g. PSA)
Ref.: reference rock site
Surf.: surface, soil site
GOF: goodness-of-fit

Validation schemes

- A. Validation against recorded earthquake ground motions
- B. Validation against GMPE for generic scenarios

Validation allows for development of region-specific rules (source scaling, path)

Part A (comparison with recordings)

Selection of events and stations

EQ NAME	REGION	# RECORDS <200km (*<1000km)	Mag. (Mw)	Type	# SELECTED RECORDS
El Mayor Cucapah	WUS	134	7.20	SS	40
Northridge	WUS	124	6.69	REV	40
Hector Mine	WUS	103	7.13	SS	40
Landers	WUS	69	7.28	SS	40
Whittier Narrows	WUS	95	5.99	REV OBL	40
Big Bear	WUS	42	6.46	SS	28
Parkfield	WUS	78	6.00	SS	40
Loma Prieta	WUS	59	6.93	REV OBL	40
North Palm Springs	WUS	32	6.06	REV OBL	32
Coalinga	WUS	27	6.36	REV	27
San Simeon	WUS	21	6.50	REV	21
Saguenay	CENA	14*	5.90	REV OBL	14
Riviere-du-Loup	CENA	98*	4.64	REV	40
Mineral, VA	CENA	94*	5.70	REV	40
Tottori	JAPAN	171	6.61	SS	40
Chuetsu-Oki	JAPAN	286	6.80	REV	40
Niigata	JAPAN	246	6.63	REV	40
Iwate	JAPAN	186	6.90	REV	40
Kocaeli	TURKEY	14	7.51	SS	14
Chi-Chi	TAIWAN	257	7.62	REV OBL	40
L' Aquila	ITALY	40	6.30	NML	40
Christchurch	NEW ZEALAND	26	6.20	REV OBL	26
Darfield	NEW ZEALAND	24	7.00	SS	24

- Large dataset (>20 EQs)
- Many regions & tectonic environments
- Span wide magnitude range (Mw 4.64 to 7.62)
- Variety of mechanisms
- Well-recorded (17 EQs with> 40 records)
- Select a large subset of stations (~40) that are consistent with mean and standard deviation PSa of the full dataset.

Simulation Methodologies

Broadband using Green's functions

- U. Nevada Reno Composite Source Model (CSM)
- U. California Santa Barbara (UCSB)

Stochastic methods

- SMSIM (point source) – not formally evaluated
- EXSIM

Hybrid - Green's functions LF, Stochastic HF

- Graves and Pitarka (G&P) – sub-fault source spectra
- San Diego State University (SDSU) – scattering functions (kappa, Q, intrinsic attenuation)

Deterministic source – simplified stochastic wave propagation

- Irikura recipe – not ready for evaluation

Input – Source geometry (event-specific)

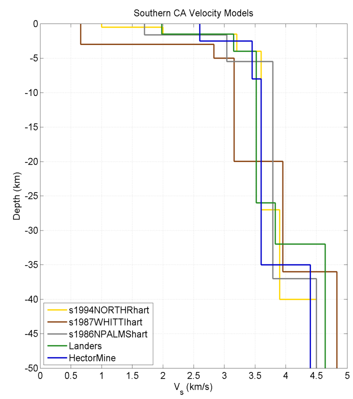
src file on SCEC BBP

- MAGNITUDE
- FAULT_LENGTH
- DLEN
- FAULT_WIDTH
- DWID
- DEPTH_TO_TOP
- STRIKE
- RAKE
- DIP
- LAT_TOP_CENTER
- LON_TOP_CENTER
- HYPO_ALONG_STK
- HYPO_DOWN_DIP
- DT
- SEED
- CORNER_FREQ
- SEISMIC MOMENT
- HYPO LAT
- HYPO LONG
- HYPO DEPTH

Methods and Input

Input – Path (region-specific)

- For Greens' functions
  - LF: 1D velocity structures: V_s, V_p, rho, Q_s, Q_p
  - UCSB & UNR: Modified "equivalent" profile to account for Q(f)
  - All use a standard shallow velocity profile with V_{s30} = 863 m/s
- Stochastic methods
  - Use region-specific empirical models for Q(f), geometrical spreading and duration



Part A (comparison with recordings)

Process and nomenclature

For each scenario, specification of:

Source (from src)

- Kinematic models: rules for slip, rise time, rake, etc.
- Stochastic models: sub-faults as point sources with time-dependent f_c

Path (consistent with 1D velocity model)

- Kinematic models: Green's functions computed with velocity models
- Stochastic models: Empirical geometrical spreading, Q(f) duration

For each scenario, seismograms generated for:

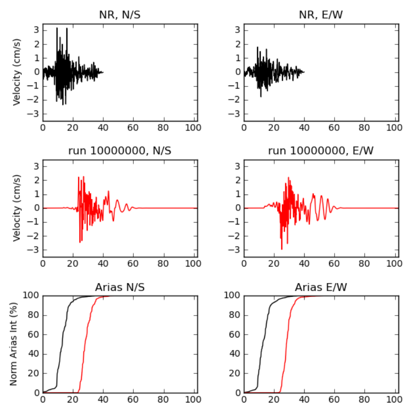
- 50 source realizations X ~ 40 stations X 2 horizontal dir.

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



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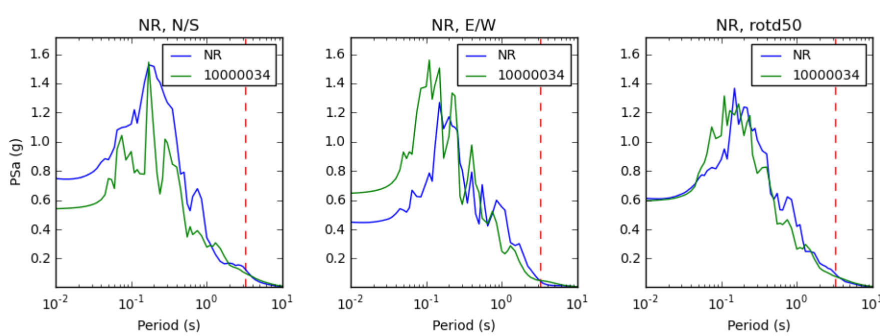
Part A (comparison with recordings)

Evaluation products

PSa for station 2001-SCE, NR vs 10000034



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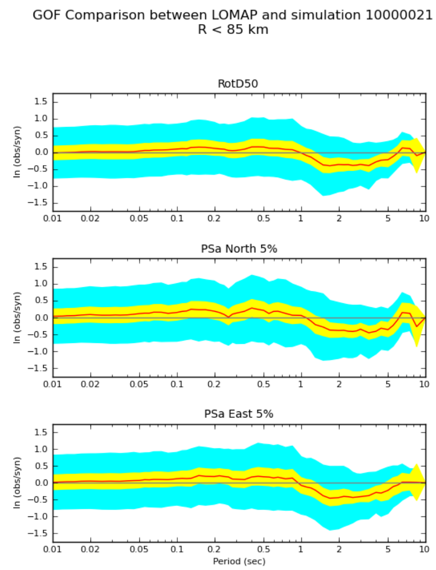
Part A (comparison with recordings)

Evaluation products

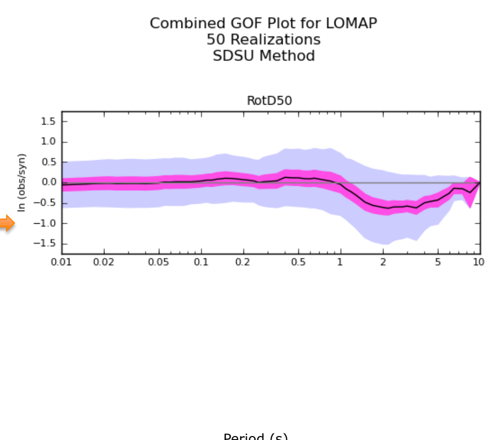
- Goodness-of-fit measures for PSA and PGA
  - *Average GOF with T for all stations within an event*



Part A (comparison with recordings)

Evaluation products

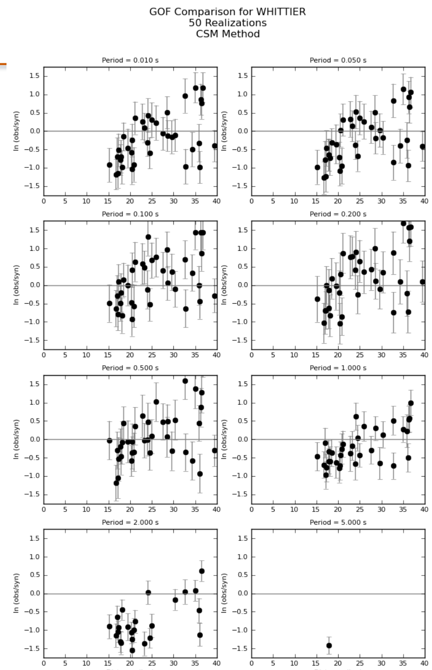
- Goodness-of-fit measures for PSa and PGA
  - *Average GOF with T for all stations within an event*
  - *Average GOF for all realizations (all stations)*



Part A (comparison with recordings)

Evaluation products

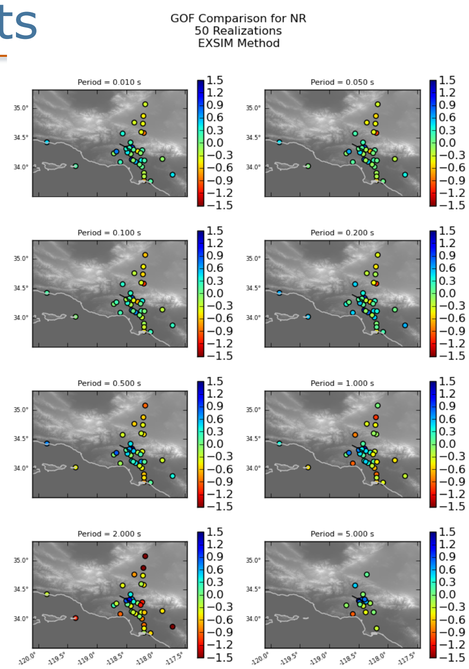
- Goodness-of-fit measures for PSa and PGA
  - *Average GOF with T for all stations within an event*
  - *Average GOF for all realizations (all stations)*
  - Average GOF with distance (all realizations)



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 relizations)

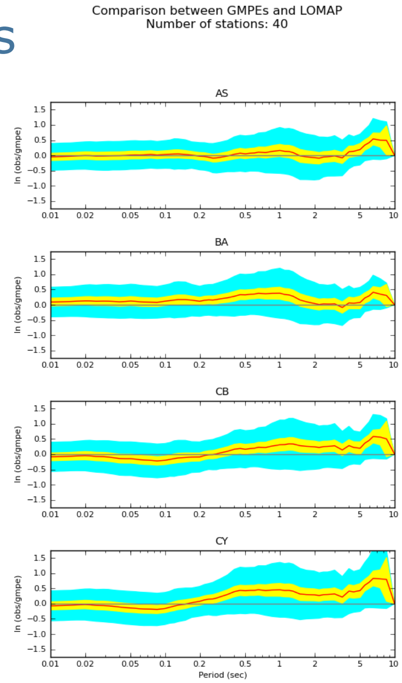


Evaluation products

Part A (comparison with recordings)

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

Allows to see trends/event terms

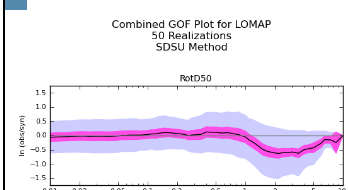


Evaluation products

Part A (comparison with recordings)

- Summary table for GOF
  - T bins
  - R bins
  - Events/M bins
  - Mechanism

		PSA period range							
	Event (Mw, Mech.)	[0.01-0.1] s		]0.1-1] s		]1-3] s		> 3s	
Rrup=[0-20] km	Whittier Narrows (5.89, ROBL)	-0.67	0.74	-0.36	0.60	-0.86	0.87	-1.25	1.25
	North Palm Springs (6.12, ROBL)	-0.32	0.77	-0.22	0.67	-0.24	0.58	-0.09	0.35
	Tottori (6.59, SS)	-0.55	0.69	-0.06	0.61	-0.24	0.59	-0.11	0.48
	Niigata (6.65, REV)	-0.15	0.73	0.08	0.66	-0.55	0.74	-0.62	0.79
	Northridge (6.73, REV)	-0.24	0.58	0.15	0.57	-0.13	0.51	-0.06	0.44
	Loma Prieta (6.94, ROBL)	-0.25	0.53	-0.09	0.55	-0.37	0.66	-0.28	0.44
	Landers (7.22, SS)	-0.45	0.84	-0.14	0.66	-0.19	0.51	-0.03	0.78
	Average CA	-0.36	0.65	-0.10	0.60	-0.34	0.62	-0.18	0.52
	Average ALL	-0.37	0.66	-0.08	0.60	-0.34	0.63	-0.23	0.55
Rrup=]20-70] km	Whittier Narrows (5.89, ROBL)	0.06	0.63	0.24	0.70	-0.45	0.71	-0.73	0.73
	North Palm Springs (6.12, ROBL)	0.77	0.98	0.54	0.82	0.02	0.48	-0.48	0.49
	Tottori (6.59, SS)	0.37	0.66	-0.14	0.82	-0.92	1.02	-0.66	0.75
	Niigata (6.65, REV)	0.59	0.86	0.31	0.97	-0.80	1.04	-1.11	1.18
	Northridge (6.73, REV)	0.11	0.48	0.35	0.60	-0.38	0.58	-0.57	0.67
	Loma Prieta (6.94, ROBL)	-0.39	0.54	-0.26	0.56	-0.41	0.63	-0.07	0.40
	Landers (7.22, SS)	-0.21	0.38	-0.17	0.41	-0.63	0.74	-0.67	0.81
	Average CA	0.08	0.61	0.15	0.63	-0.42	0.65	-0.47	0.65
	Average ALL	0.18	0.65	0.14	0.69	-0.55	0.76	-0.70	0.83
Rrup=]70-200] km	Whittier Narrows (5.89, ROBL)								
	North Palm Springs (6.12, ROBL)	-0.30	0.41	-0.48	0.56	-0.13	0.40		
	Tottori (6.59, SS)	0.05	0.66	-0.24	0.78	-0.83	1.06	-0.56	0.76
	Niigata (6.65, REV)	-0.51	0.77	-1.04	1.18	-1.47	1.52	-1.56	1.57
	Northridge (6.73, REV)	0.24	0.66	0.38	0.79	-0.52	0.71	-0.16	0.30
	Loma Prieta (6.94, ROBL)	0.41	0.54	0.46	0.63	0.37	0.87	0.05	0.64
	Landers (7.22, SS)	-0.40	0.56	-0.55	0.71	-0.38	0.54	0.00	0.52
	Average CA	-0.14	0.55	-0.22	0.69	-0.21	0.62	0.01	0.53
	Average ALL	-0.19	0.64	-0.46	0.85	-0.74	1.00	-0.85	1.04
Mechanism	Reverse (REV)	0.00	0.68	-0.02	0.82	-0.69	0.90	-1.03	1.13
	Reverse-Oblique (ROBL)	-0.01	0.68	0.07	0.66	-0.33	0.67	-0.21	0.46
	Strike-Slip (SS)	-0.13	0.58	-0.24	0.66	-0.62	0.80	-0.46	0.71
	Normal (NM)								
Total	Average CA	-0.08	0.61	0.03	0.63	-0.36	0.64	-0.30	0.59
	Average ALL	-0.04	0.65	-0.05	0.71	-0.55	0.79	-0.64	0.83

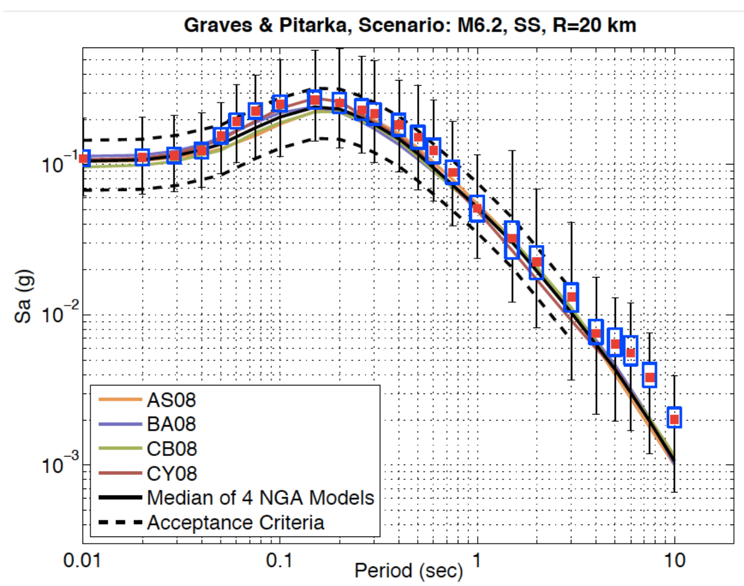


Scenario selection

- Selected 3 scenarios for which NGA-West1&2 GMPEs are well constrained by data:
  - M6.2 SS, 20 and 50 km
  - M6.6 SS, 20 and 50 km
  - M6.6 REV, 20 and 50 km
- 50 realizations of the source, WITH randomized hypocenter location for each
- Simulations for two velocity models: NorCal and SoCal

Part B (comparison with GMPEs)

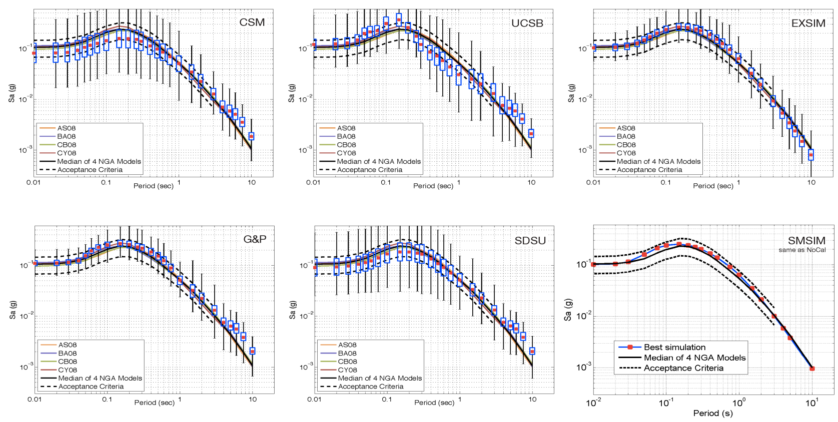
Evaluation criteria



Part B (comparison with GMPEs)

Sample results

Part B. Southern California (M6.2, SS, Z_{tor}=4 km, R_{jb}=20 km)



Validation and Forward simulations

From validation to forward simulations

- Modelers to select best fitting realization(s) and path forward:

PATH 1

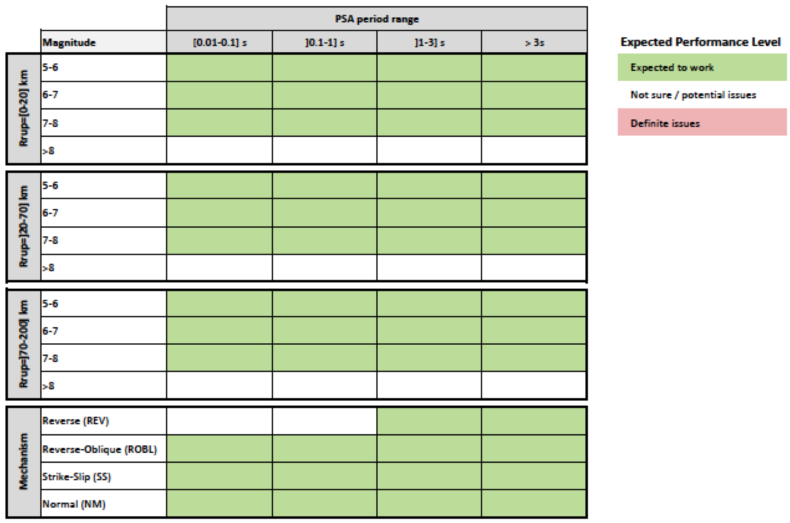
- Find the best fitting source (srf) realization
- Use its goodness of fit to represent modeling uncertainty
- Include uncertainty in srf specification when forward modeling future scenarios

PATH 2

- Use the average goodness of fit of 50 srf's to represent modeling uncertainty
- No need to include uncertainty in srf specification when forward modeling future scenarios

Evaluation

1. Self-assessment from Modelers – based on technical basis behind method



Evaluation

2. Evaluation committee

- Evaluate the method developer's self-assessments
- Evaluate the GOF for part A and B
  - PSA controlling factor in evaluation
  - Various numerical criteria for bins of M, R, T: (e.g. improvement relative to GMPEs, trends with distance)
  - "Verdict" for each methodology
    - Applicable NOW for a given region, distance, bandwidth?
    - Limitations (close R, large M, etc.)?
    - Method needs refinement?

Next steps

- Validation of methods for CENA scenarios (second round)
  - Requires appropriate regionalization
  - Requires site correction factors
- Forward simulations

Thank you!

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