SSHAC WS1　24 Sep 2016

WS1-2G-7-1

SCEC広帯域地震動プラットフォームにおける地震動評価（前半）
Ground Motion Validation on the SCEC Broadband Platform

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依頼内容
Request

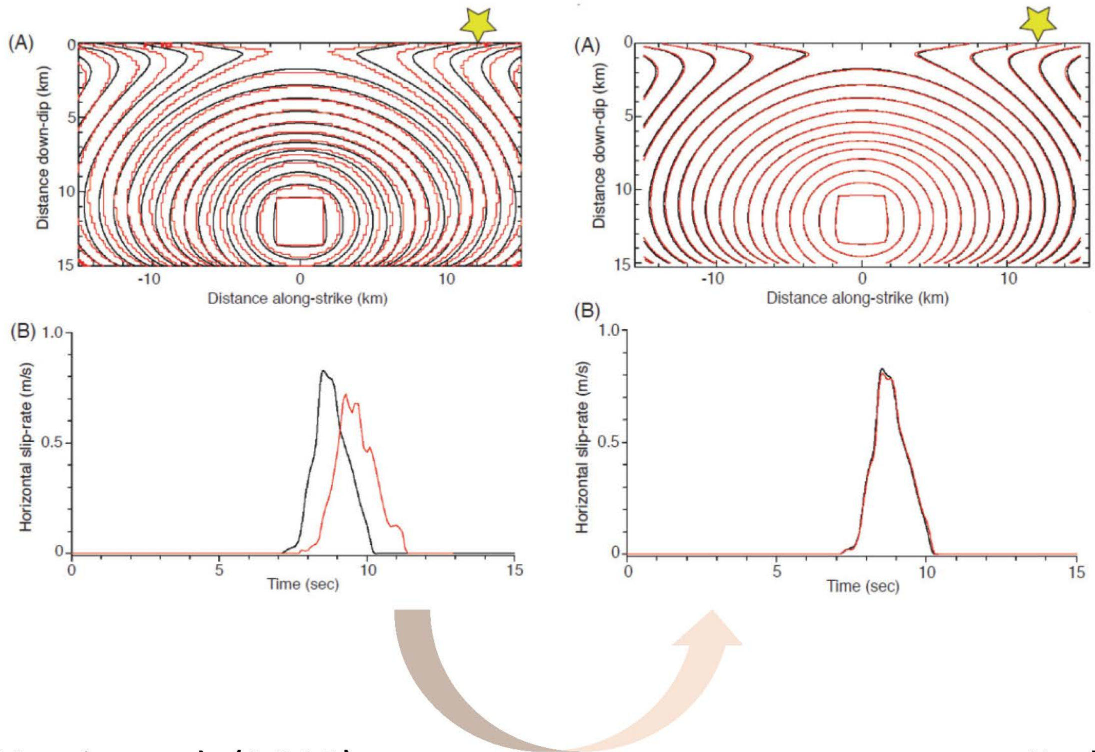
断層モデルの採用にあたり、海外で採用実績のあるSCEC BBPとの比較検証を行う予定である。ここでは、それに先立ち、SCEC BBPの概要・評価手法等について確認したい。

GMC plans to compare and validate ground motions between current methods and methods on the SCEC Broadband Platform. GMC would like to confirm summary and validation methods on the SCEC Broadband Platform.

Verification & Validation
V&V (検証と妥当性確認)

Verification

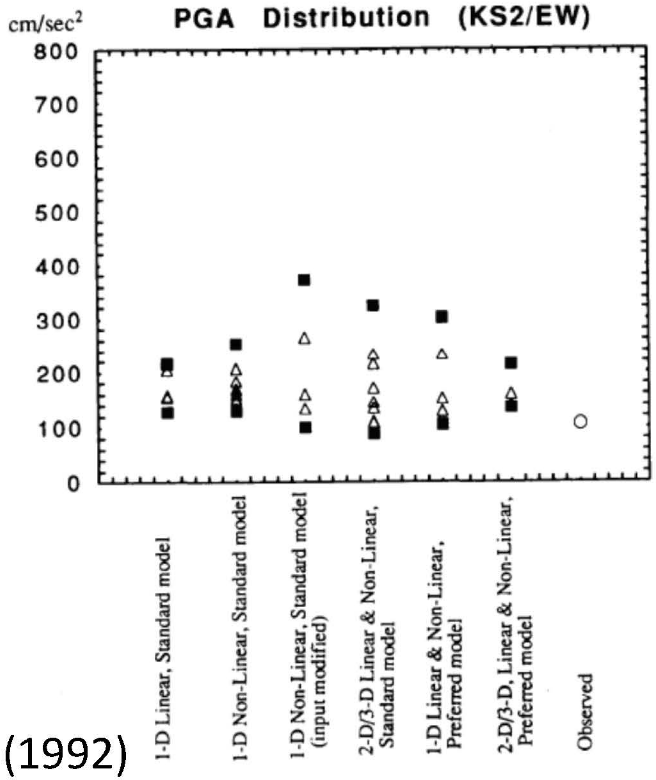
SCEC/USGS Spontaneous Rupture Code Verification Project



Harris et al. (2009)

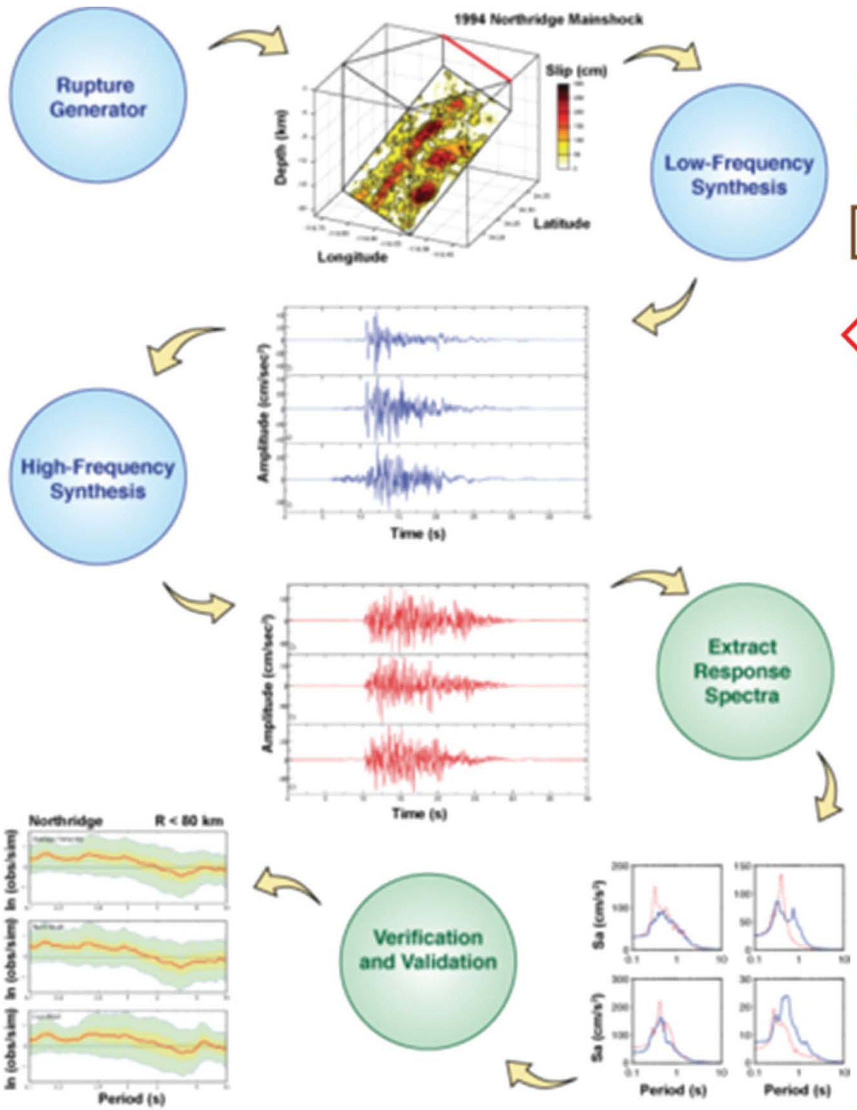
Validation

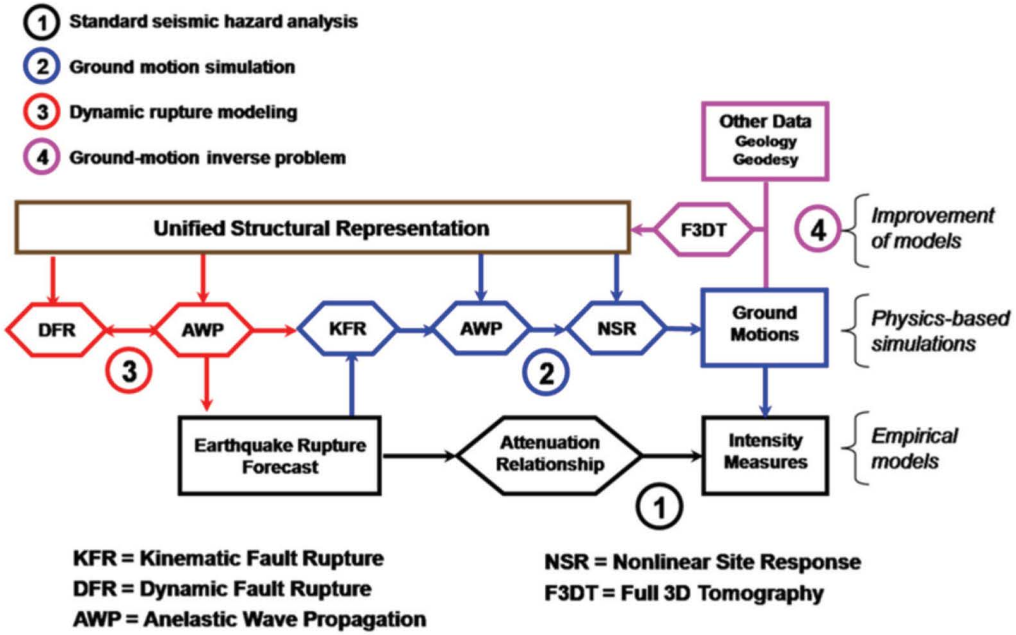
ESG Blind Prediction
in the Ashigara Valley (Odawara)



Kudo (1992)

SCEC Broadband Platform





Meachling et al. (2015)
Open Source: Latest version v16.5.0
https://scec.usc.edu/scecpedia/Broadband_Platform
https://scec.usc.edu/scecpedia/Main_Page

Part A: Event Validation

50 realizations for each event

Table 1
Selected Events for Part A Validation

Region*	Event Name	Year	M	Mechanism†	Number of Records <200 km	Number of Selected Records	Note on Selection
WUS	Chino Hills	2008	5.39	REV-OBL	40	40	NA
WUS	Alum Rock	2007	5.45	SS	40	40	NA
WUS	Whittier Narrows	1987	5.89	REV-OBL	95	40	Only stations within 40 km
WUS	North Palm Springs	1986	6.12	REV-OBL	32	32	NA
WUS	Northridge	1994	6.73	REV	124	40	All stations within 10 km selected
WUS	Loma Prieta	1989	6.94	REV-OBL	59	40	NA
WUS	Landers	1992	7.22	SS	69	40	Only stations within 100 km selected
Japan	Tottori	2000	6.59	SS	171	40	NA
Japan	Niigata	2004	6.65	REV	246	40	NA
CENA	Rivière-du-Loup	2005	4.60	REV	21	21	NA
CENA	Mineral	2011	5.68	REV	10‡	10	NA
CENA	Saguenay	1988	5.81	REV-OBL	11	11	NA

*WUS, western United States; CENA, central and eastern United States.
†Mechanisms: REV-OBL, reverse oblique; SS, strike slip; REV, reverse; NA, Not applicable.
‡Number of records less than 300 km.

Goulet et al. (2015)

Part B: GMPE Comparisons

50 realizations for each event

Part B: Validation against Relevant Ground-Motion Prediction Equations

The intent of the validation against GMPEs is to verify whether the different simulation models are relatively centered for cases in which a lot of recorded data are available. For this part of the exercise, four of the original PEER NGA-West1 GMPEs were used:

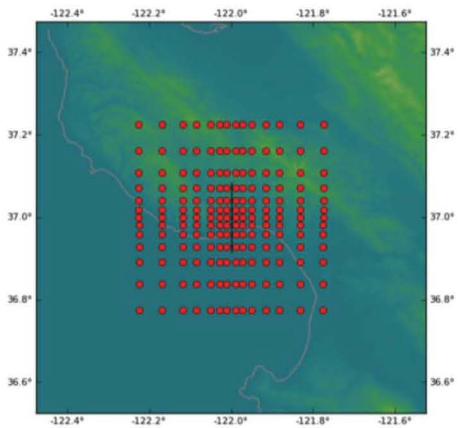
- Abrahamson and Silva (2008)
- Boore and Atkinson (2008)
- Campbell and Bozorgnia (2008)
- Chiou and Youngs (2008)

Data mining of the NGA-West1 database allowed the identification of the mechanism, magnitude, and distance ranges for which most data were available. These were grouped into scenarios for which the GMPEs are considered to be well constrained:

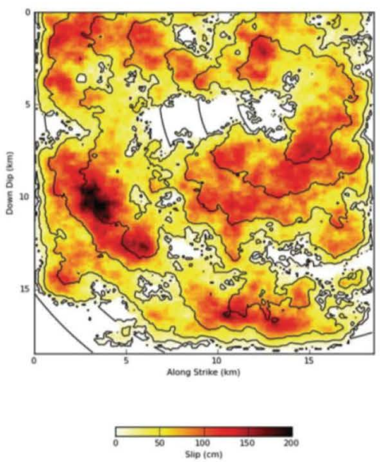
- **M** 5.5, 45°-dipping reverse, $Z_{tor} = 6$ km
- **M** 6.2, vertical strike slip, $Z_{tor} = 4$ km
- **M** 6.6, vertical strike slip with a surface rupture
- **M** 6.6, 45°-dipping reverse, $Z_{tor} = 3$ km

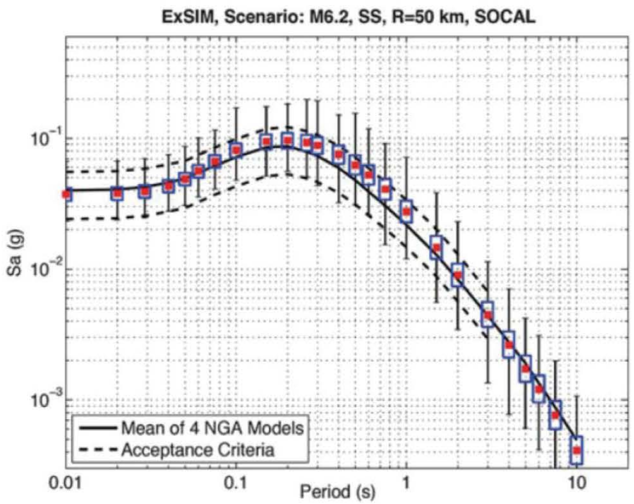
in which **M** is the moment magnitude and Z_{tor} is the depth to the top of rupture. For each of the scenarios, most of the available data were centered at rupture distances of 20 and 50 km. For each of these two distances, 40 stations were randomly located at different azimuths on the footwall side of the fault.

Fault trace and stations used in scenario simulation of an M6.5 event



Slip distribution and slip-time contours for one source realization of an M6.5 event

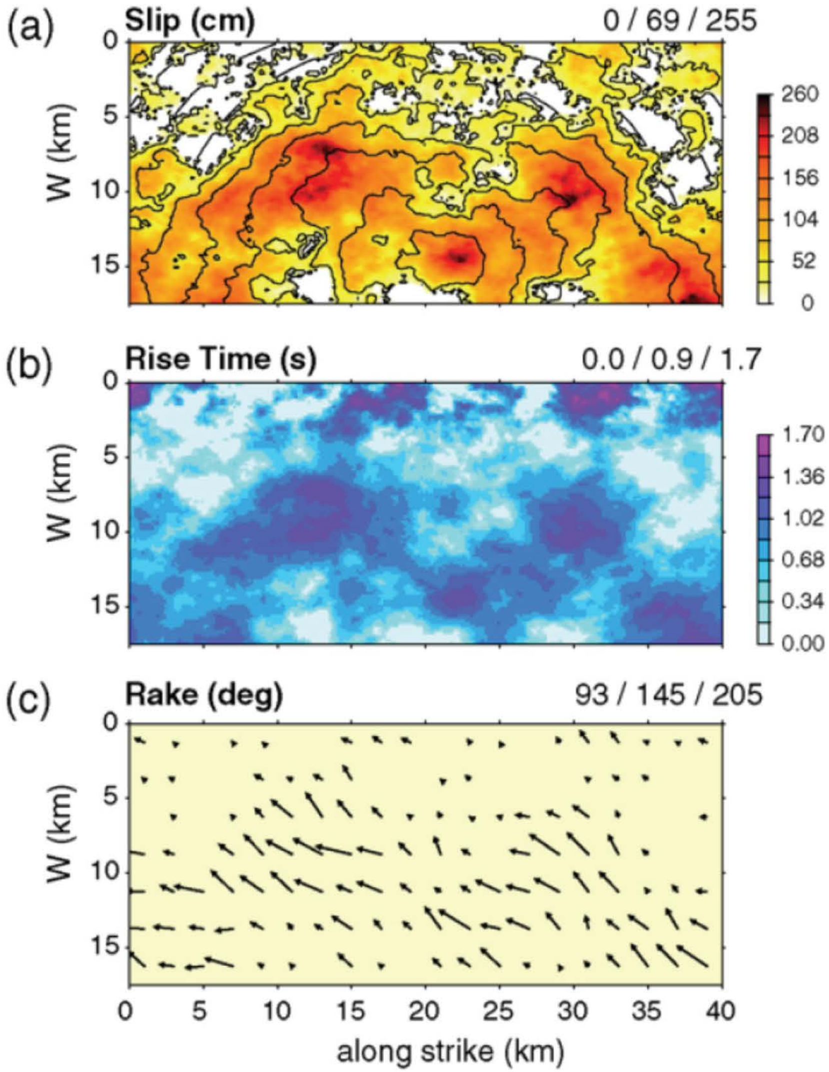




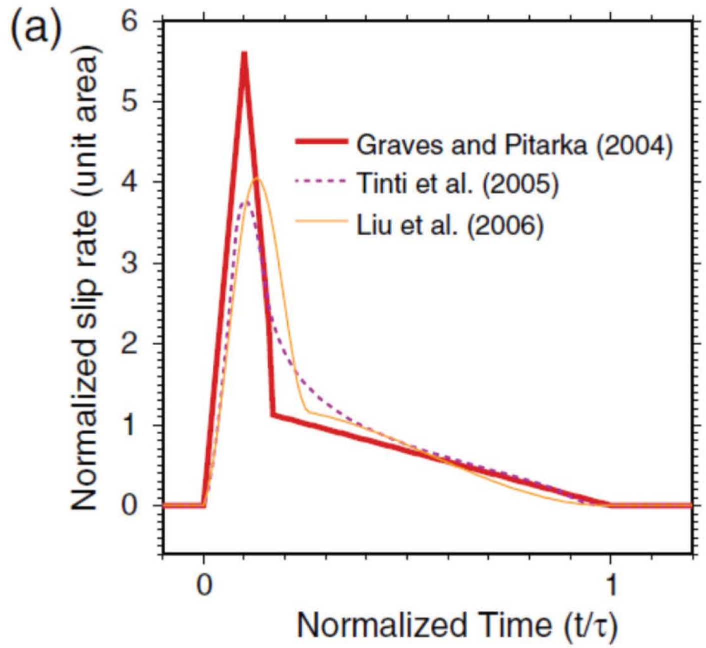
Goulet et al. (2015), Meachling et al. (2015)

Method 1: GP

Graves and **P**itarka



Fluctuation for slip, rise time, rake angle, and rupture velocity

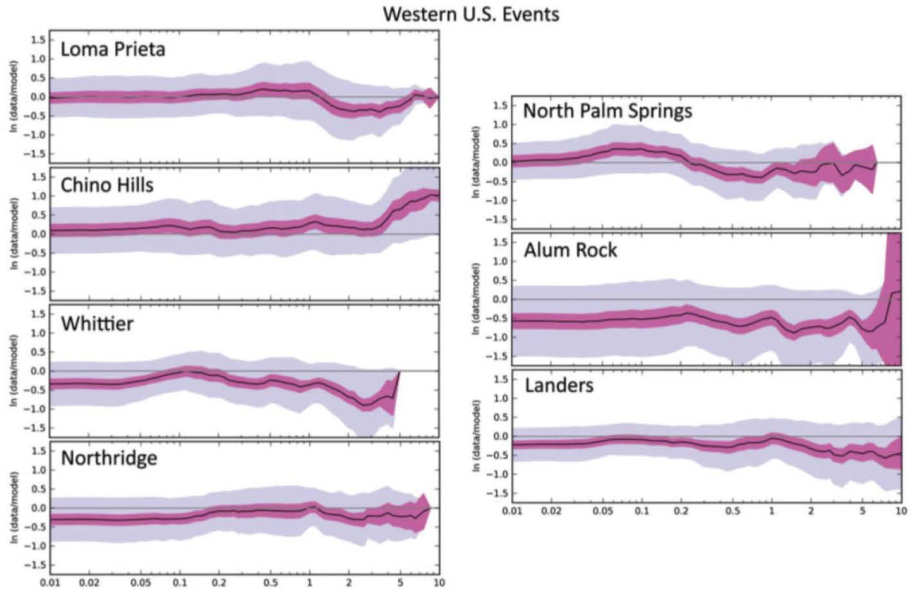


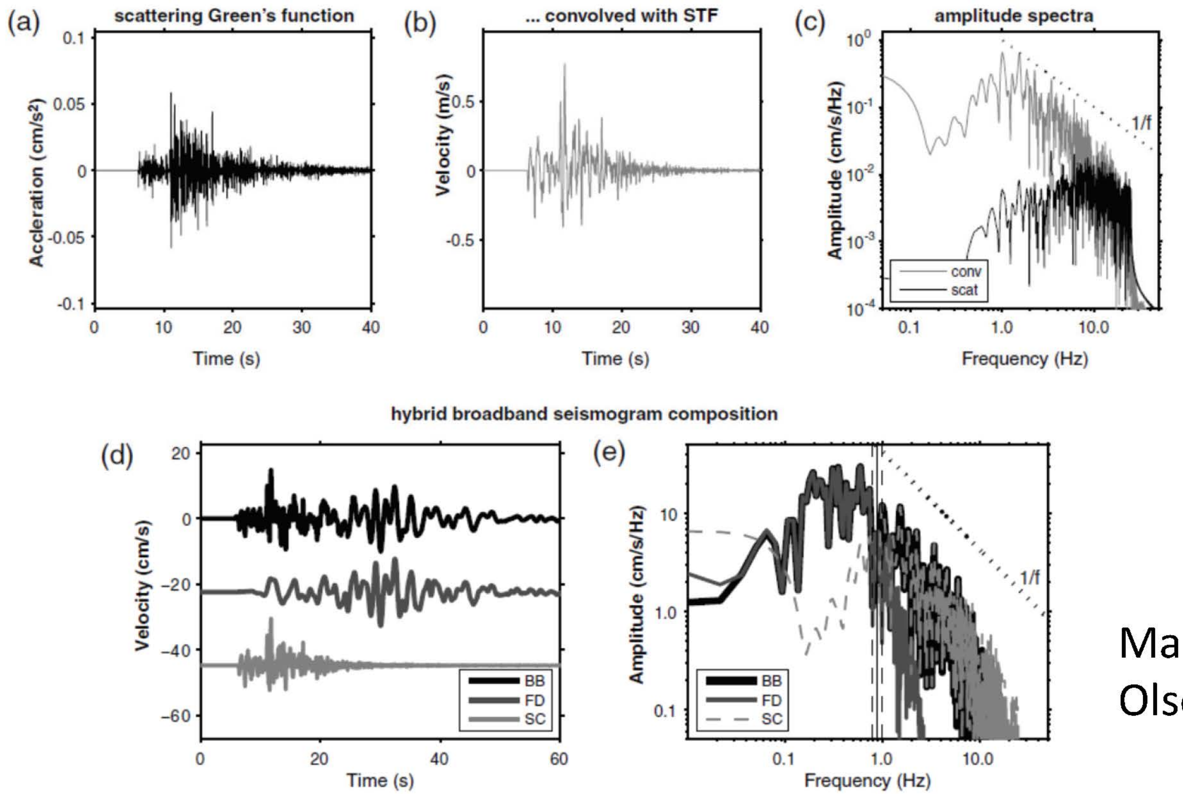
Graves and Pitarka (2010, 2015)

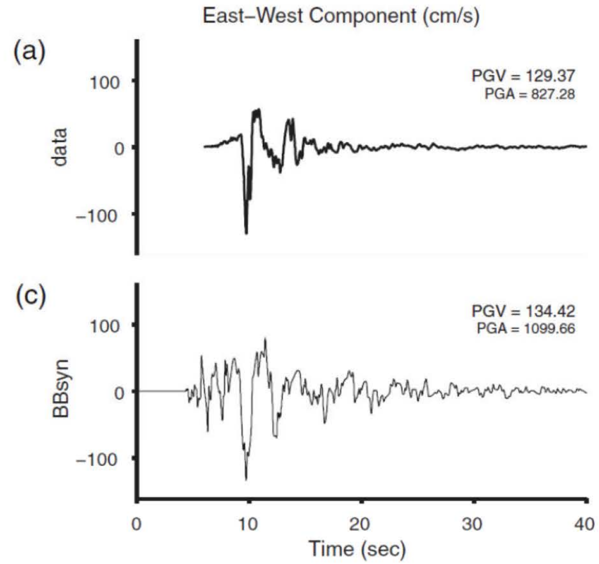
Method 2: SDSU

San **D**iego **S**tate **U**niversity

$$E(\vec{r},t)=\frac{\delta(t-\frac{r}{v})e^{-\eta v t}}{4\pi v r^2}+\sum_{n=1}^{2}E_n(\vec{r},t)+\left(\int_{-\infty}^{+\infty}\frac{e^{i\Omega}}{2\pi}d\Omega \times \int_0^\infty \frac{(\frac{\eta_s}{k})^3\times[\tan^{-1}(\frac{k}{\eta+i\Omega/v})]^4\times\sin(kr)}{2\pi^2 v r[1-\frac{\eta_s}{k}\tan^{-1}(\frac{k}{\eta+i\Omega/v})]}dk\right), \quad (1)$$



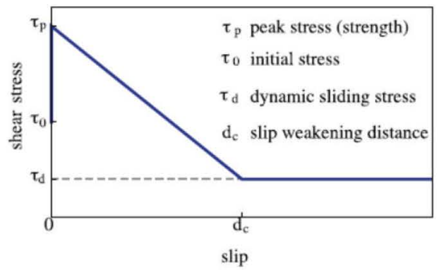


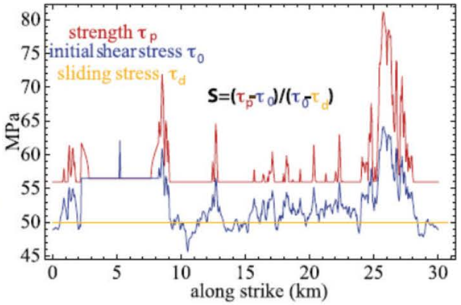


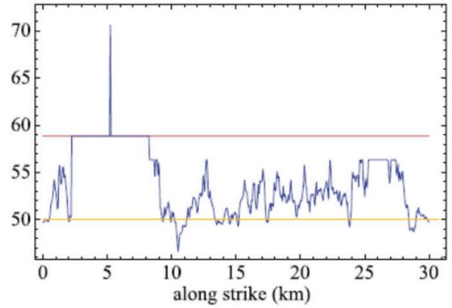
Mai et al. (2010)
Olsen and Takedatsu (2015)

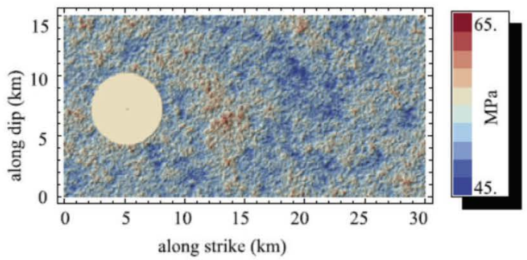
Method 3: UCSB

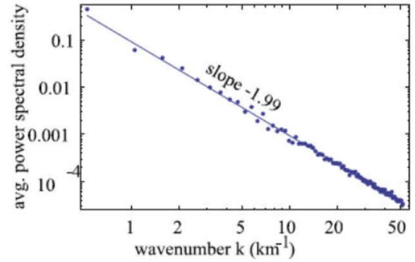
University of **C**alifornia, **S**anta **B**arbara

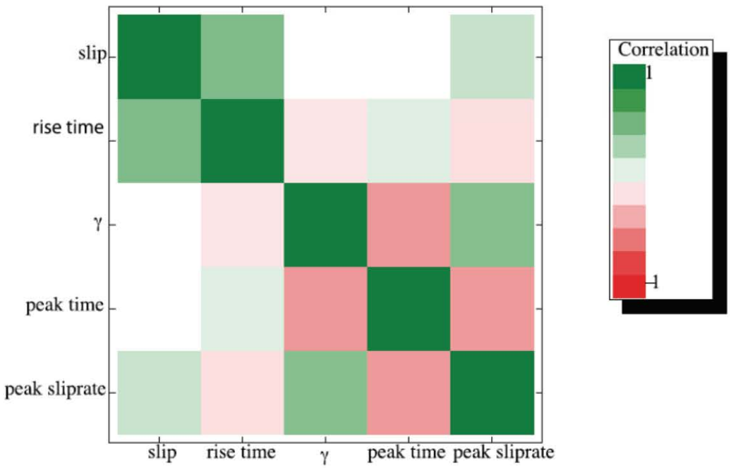




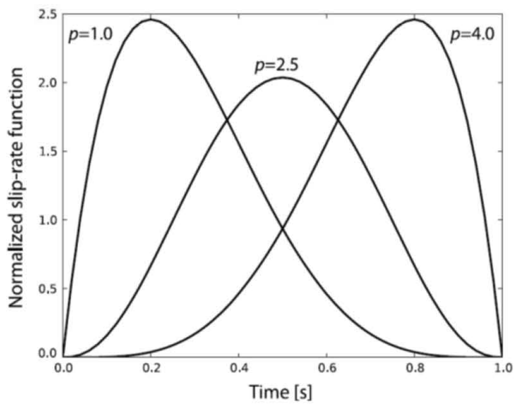








$$\dot{s}_i(x, \tau) = C\left(\frac{t}{T_r}\right)^p\left(1 - \frac{t}{T_r}\right)^{5-p},$$



Schmedes et al. (2010)

Crempien and Archuleta (2015)

Method 4: CSM

Composite **S**ource **M**odel

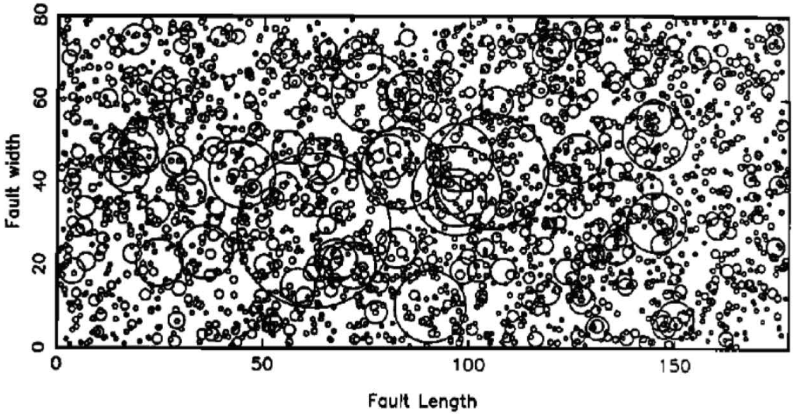
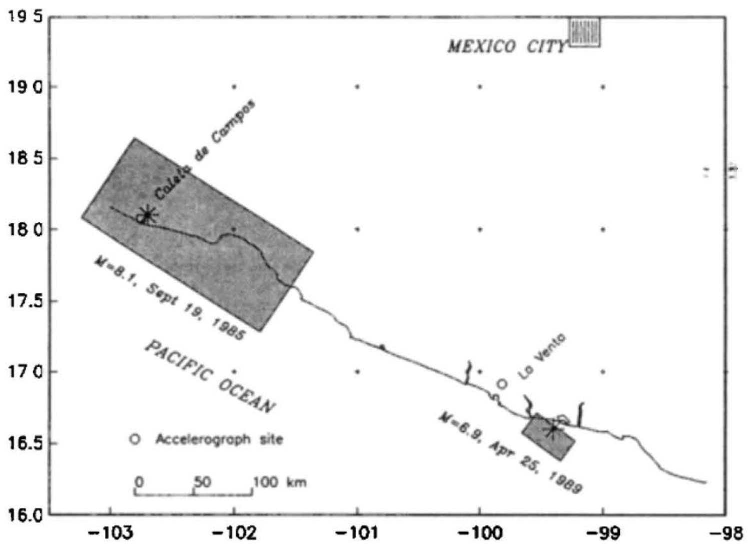


Figure 1. Spatial distribution of 10% of the subevents on the fault for one simulation.



Zeng et al. (1994), Anderson (2015)

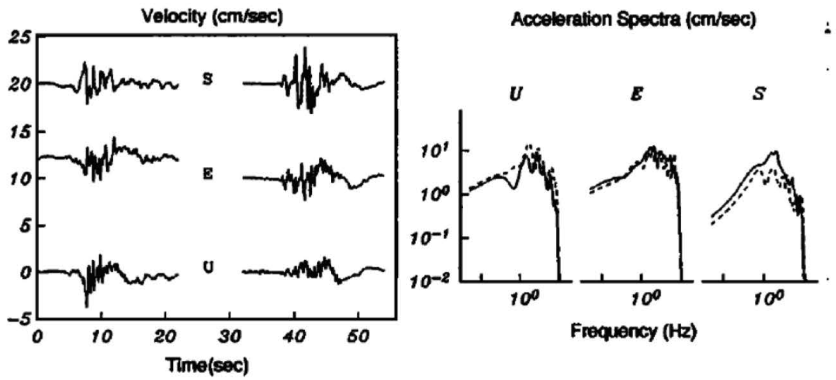
Composite source time function

We hypothesize that the source slip function can be simulated, in a kinematic sense, by randomly distributed subevents on the fault plane. The size distribution of subevents is based on a self-similar model proposed by Frankel (1991). In this model, an earthquake is made up of a hierarchical set of smaller earthquakes. The number of circular subevents with radius R is specified by

$$\frac{dN}{d(\ln R)} = pR^{-D} \qquad (1)$$

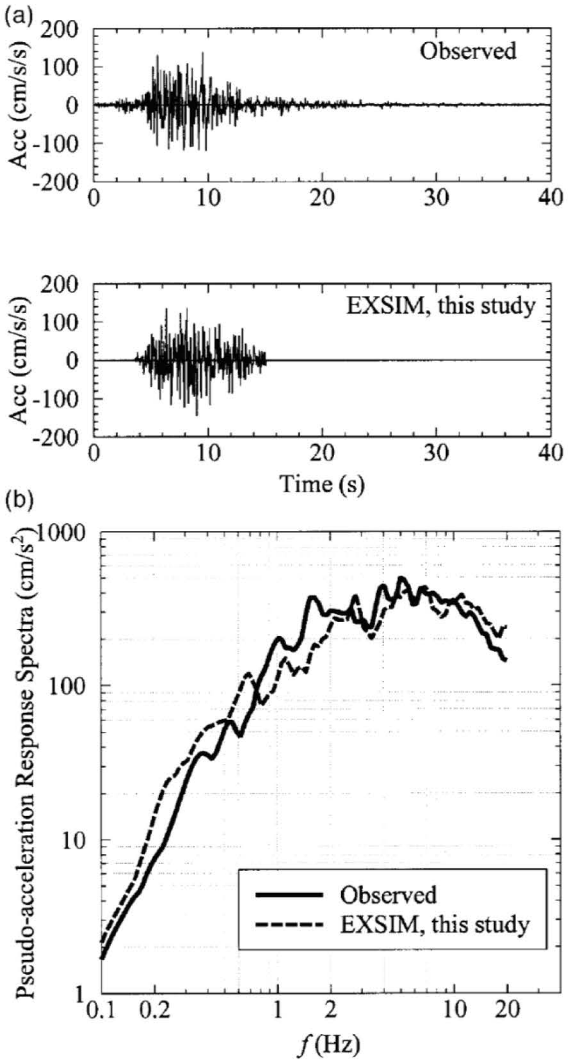
where D is the fractal dimension, N is the number of subevents, and p is a constant of proportionality. Frankel predicted that if the static stress drop of the sub-events is independent of their size, and if the sum of the areas of all the sub-events equals the area of the main shock, the high frequency roll-off of the displacement spectrum will be proportional to $\omega^{-(3-D/2)}$. The condition on the area is removed in our procedure, so this prediction may not strictly hold. Integrating Equation (1), the number of subevents with radii larger than R is

$$N(R) = \frac{p}{D}(R^{-D} - R_{\max}^{-D}) \qquad (2)$$



Method 5: EXSIM

EXtended earthquake fault **SIM**ulation program



$$A_{ij}(f) = \{CM_{0ij}(2\pi f)^2/[1 + (f_{0ij})^2]\}\{\exp(-\pi f\kappa)\exp(-\pi f R_{ij}/Q\beta)/R_{ij}\}, \quad (2)$$

Table 5

EXSIM Modeling Parameters for the Calibration of EXSIM, for California Earthquakes on NEHRP C Sites

$Q(f)$	$187f^{0.56}$
Distance-dependent duration	$T_0 + 0.1R$ (km)
Kappa	0.03
Crustal shear-wave velocity (km/sec)	3.7
Crustal density (g/cm³)	2.8
Crustal amplification model	Boore and Joyner, 1997 (for California NEHRP C site conditions)
Geometric spreading	$1/R$ ($R \leq 40$ km) $1/R^{0.5}$ ($R > 40$ km)
Stress drop (bars)	60
Pulsing area percentage	25%

SMSIM (Boore, 1983)
→ **FINSIM** (Bresenev and Atkinson, 1998)
→ **EXSIM** (Motazedian and Atkinson, 2005; Atkinson and Assatourians, 2015) (**FINSIM** with dynamic corner frequency)

Method 6: SONG

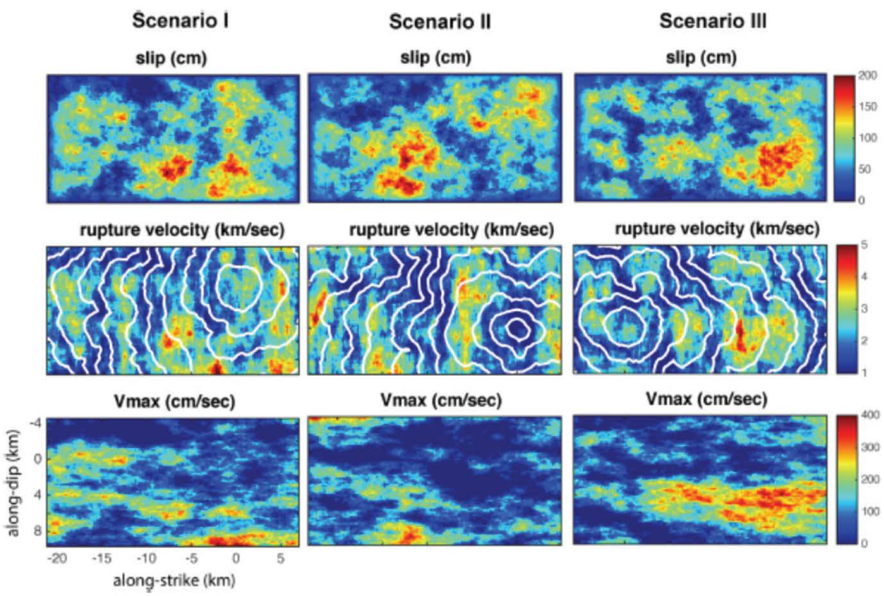
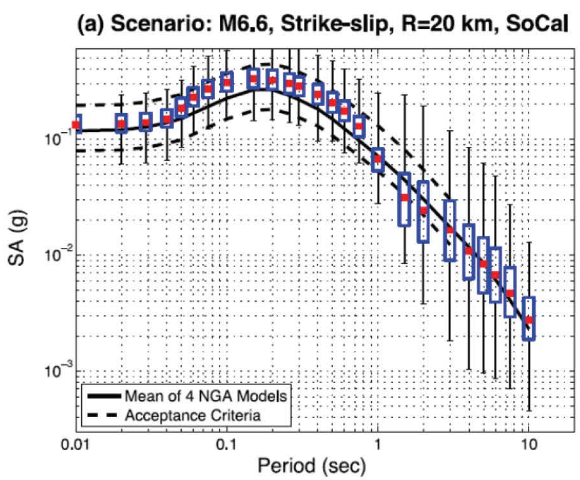


Table 1. A set of model parameters for pseudo-dynamic source modelling.

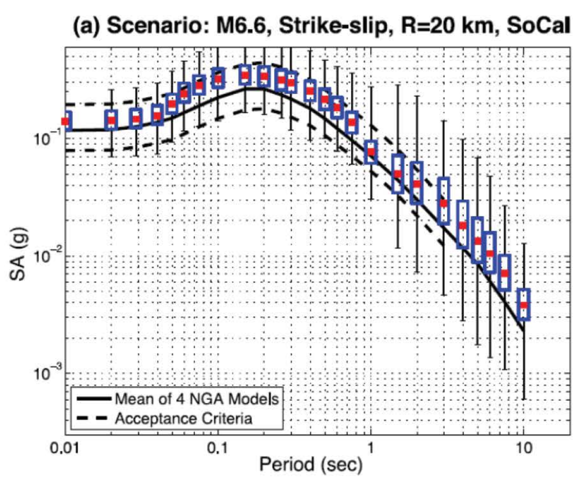
	Model parameter	Description
1-Point Statistics	μ_{slip}	Mean slip
	μ_{V_r}	Mean rupture velocity
	$\mu_{V_{\max}}$	Mean peak slip velocity
	σ_{slip}	Standard deviation of slip
	σ_{V_r}	Standard deviation of rupture velocity
	$\sigma_{V_{\max}}$	Standard deviation of peak slip velocity
2-Point Statistics	a_x	Correlation length in the along-strike direction (six parameters: slip versus slip, slip versus V_r, slip versus $V_{\max}$, V_r versus V_r, V_r versus $V_{\max}$ and $V_{\max}$ versus $V_{\max}$)
	a_z	Correlation length in the along-dip direction (six parameters: slip versus slip, slip versus V_r, slip versus $V_{\max}$, V_r versus V_r, V_r versus $V_{\max}$ and $V_{\max}$ versus $V_{\max}$)
	$\rho_{\max}$	Maximum correlation coefficient (three parameters: slip versus V_r, slip versus $V_{\max}$ and V_r versus $V_{\max}$)
	RD_x	Response distance in the along-strike direction (three parameters: *slip* versus V_r, *slip* versus $V_{\max}$ and V_r versus $V_{\max}$)
	rD_z	Response distance in the along-dip direction (three parameters: slip versus V_r, slip versus $V_{\max}$ and V_r versus $V_{\max}$)

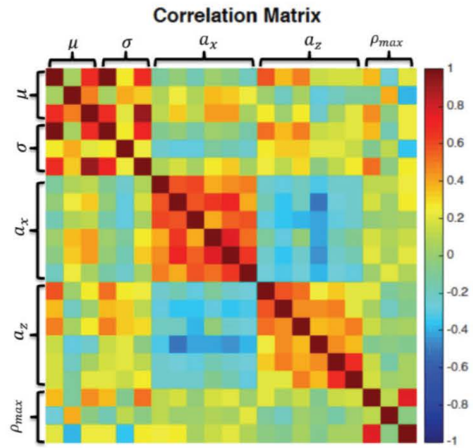
For autocorrelation, $\rho_{\max}$ is one and rD_x and rD_z are zero by definition. rD_x and rD_z are excluded in this study. Thus, 21 model parameters are considered in total (6 for 1-point statistics and 15 for 2-point statistics).

First test for 50 realizations



Second test for 50 realizations

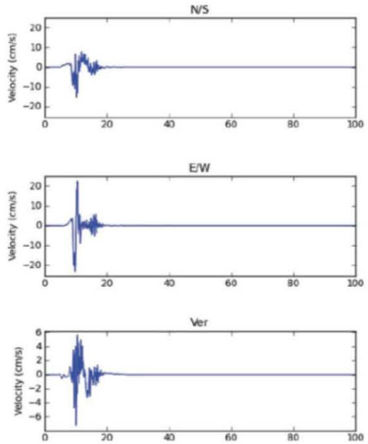




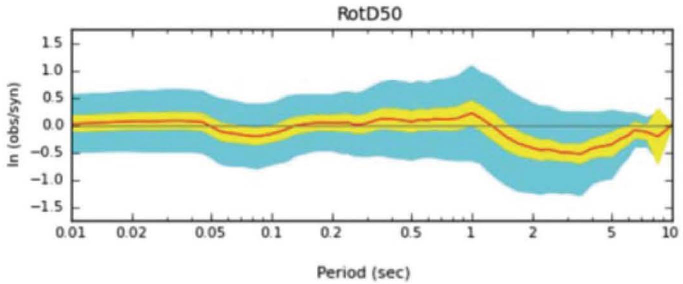
Song (2016)

SCEC BBP Validation

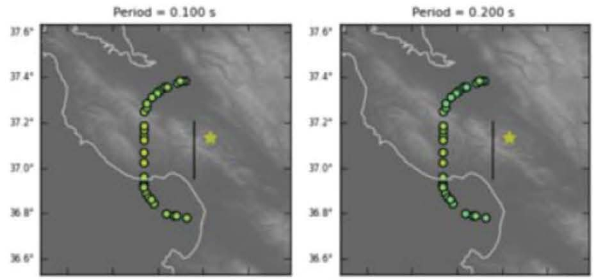
Three-component synthetic velocity seismograms for station 23km from fault



Goodness of Fit (GOF) Bias plots comparing simulation results against observed ground motions



Map-based GOF plots



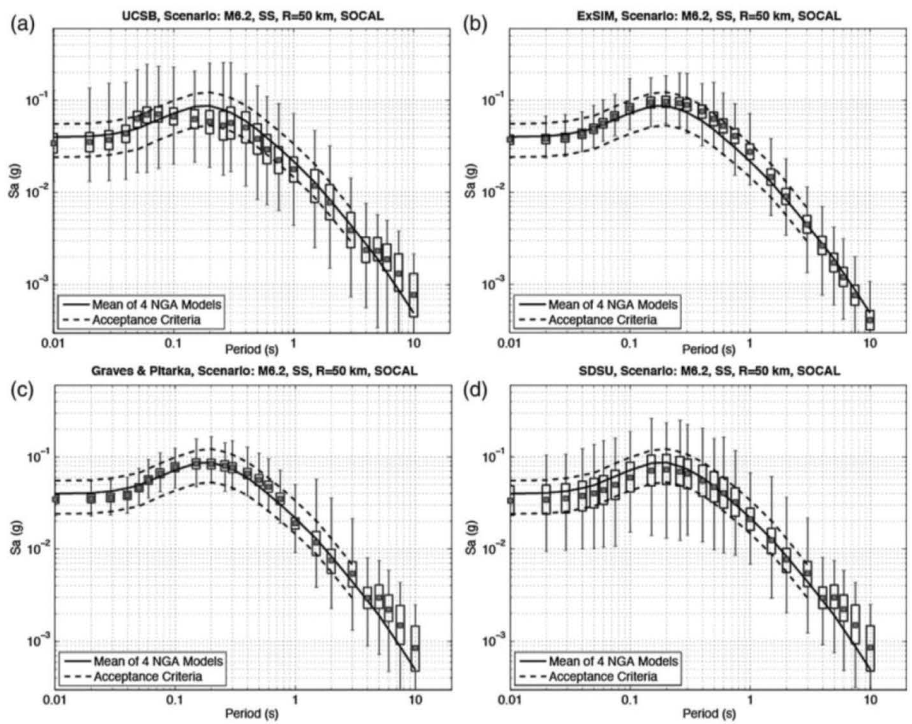


Table 1
Distance Metric

	Simulation Method				
Period (s)	**UCSB**	**EXSIM**	**G&P**	**SDSU**	**GMPE**
0.01–0.1	0.38	0.36	0.67	0.57	0.53
0.1–1	0.08	0.23	0.01	0.18	0.03
1–3	0.16	0.10	0.05	0.04	0.11
>3	***1.19***	0.34	0.83	0.87	0.13

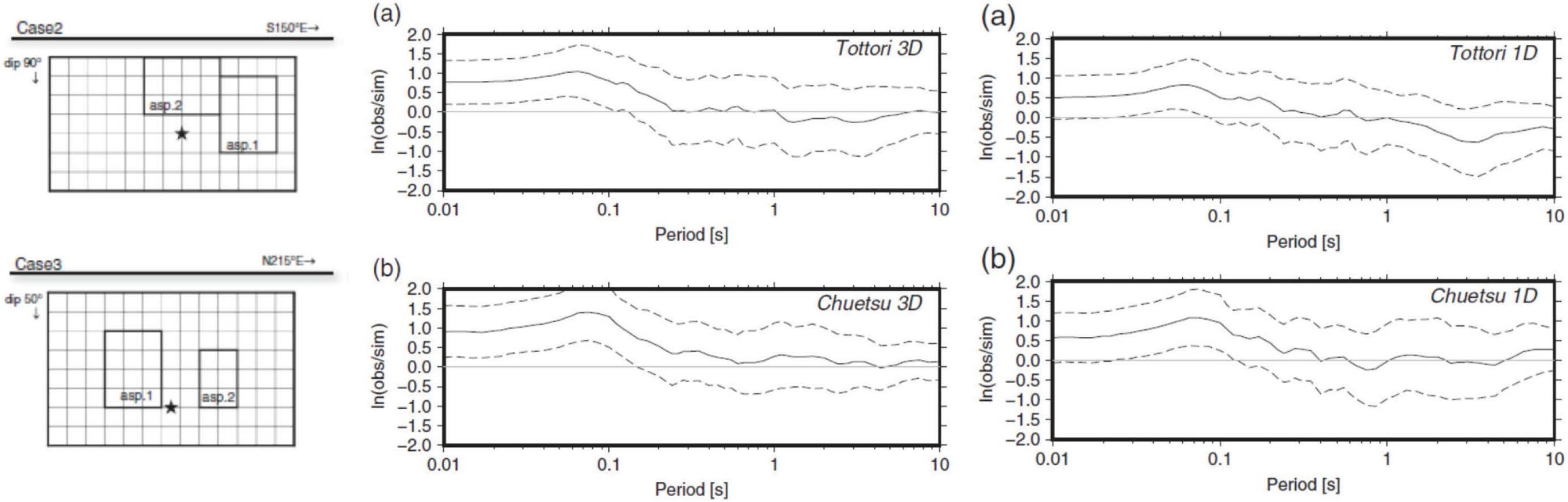
mean of zero in a given bin. For this reason, our interpretations are based not on within-bin means, but instead upon a combined goodness-of-fit (CGOF) parameter, taken as the equally weighted sum of the absolute value of the mean residuals and the mean of the absolute value of the residuals:

$$\mathrm{CGOF} = \frac{1}{2}\left|\langle \ln(\mathrm{data}/\mathrm{model})\rangle\right| + \frac{1}{2}\langle\left|\ln(\mathrm{data}/\mathrm{model})\right|\rangle, \qquad (1)$$

in which $\langle\rangle$ denotes computation of the mean and $||$ the absolute value.

Dreger et al. (2015), Meachling et al. (2015)

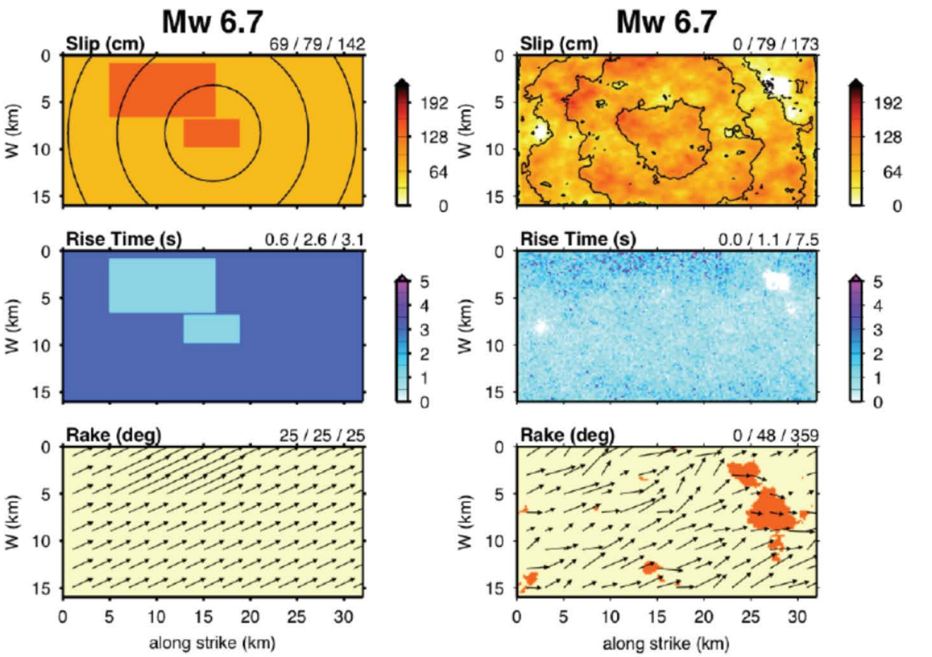
SCEC BBP Validation and Recipe (1)
Iwaki et al. (2016)

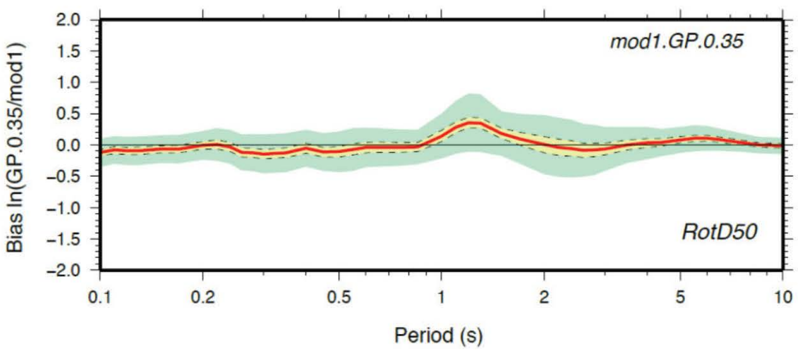


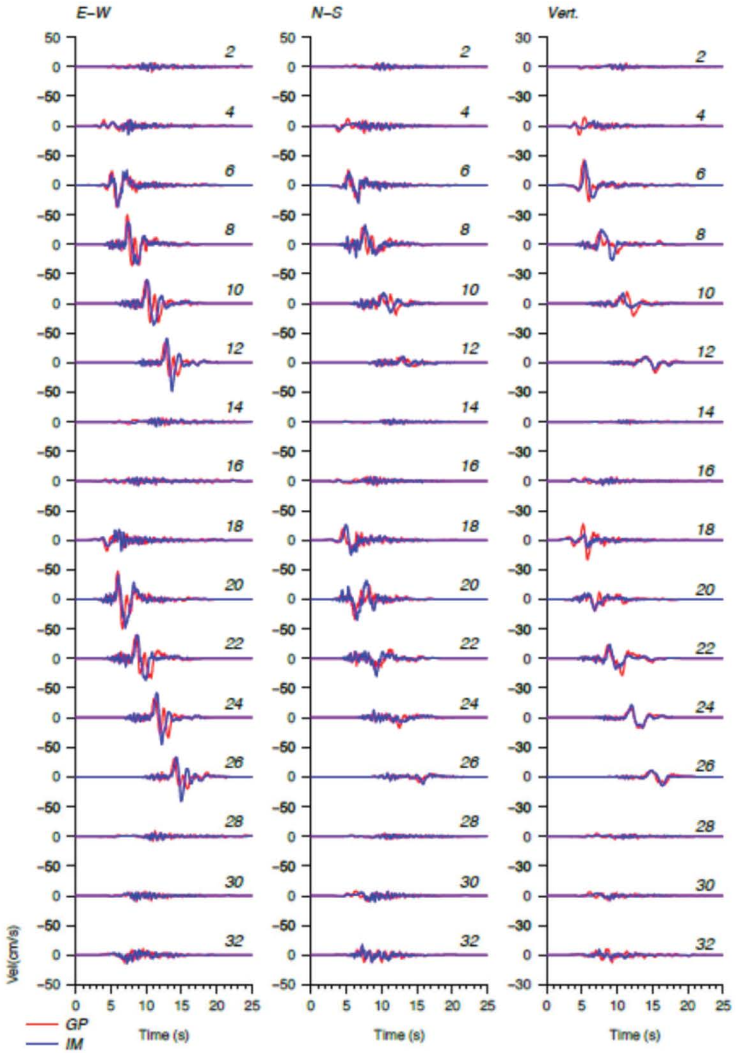
	SCEC Broadband Platform	Recipe
Source Model	Heterogeneous and complex	Characterized source model (definitive & simpler)
Velocity Model	Long-period: 3-D or 1-D Short-period: 1-D or scattering	Long-period: 3-D Short-period: 1-D with site response
Simulation	Hybrid method	Hybrid method & EGF method
Validation	Past earthquakes & GMPEs (5% pseudospectral acceleration)	Past earthquakes & GMPEs (ground motion, pulse, seismic intensity)

SCEC BBP Validation and Recipe (2)
Pitarka et al. (2015)

a) IM (mod1) b) GP.0.35 (← GP.0.85)







0.1-10 Hz velocity

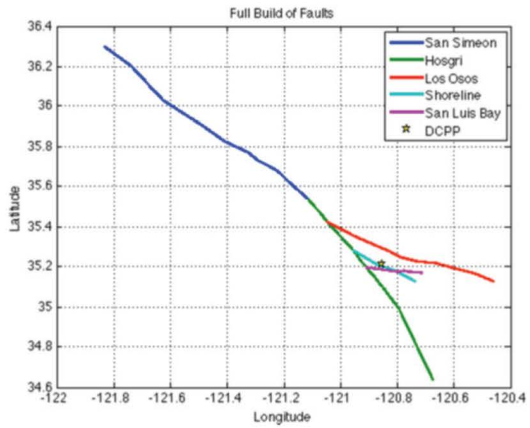
既往SSHACにおけるSCEC BBP
SCEC BBP on SSHAC

Table 2: Focused questions for Workshop #2 Presenters: Session "CANDIDATE FFS METHODS: Results of SCEC BBP Validation Evaluation"

Topic	Speaker	Questions / Topics to be addressed at WS #2
Overview of the validation process – Part A and B	Goulet	Summarize Part A and Part B of the validation effort (do not include the evaluation effort) How were the acceptance criteria derived and are the acceptance criteria still consistent with the range of ACR GMPE's for California?
SCEC Evaluation Committee findings	Dreger	What models are ready for general application? What were the uses of Part A and Part B evaluations for evaluating the models (which was most important?)? Were any other relevant additional metrics considered?
Discussions: *Strength and weakness of simulations models; Technical bases for applicability of the methods.*	All	Based on Sept 26 2013 SCEC meeting, is the output of the BBP consistent with the expectations from your method? Is there anything in the simulations that stand out as problematic? Is there anything intrinsic to the method that would preclude using it to simulate very large magnitudes (M~8.0)? – Are there constraints on the use of the magnitude-area relationship that you apply for your simulation method? – Are there implications that arise from specifications of a minimum rupture width for large magnitudes? Can the model be applied to both surface and buried ruptures? – Are the Green's functions adequately sampling the shallow depth? – How is the source modified in the top few kilometers of the crust (e.g. rise time, rupture velocity, etc...)? Are there any limits in how close to the fault the ground motion simulations may be used? How is kappa incorporated into the simulations?

Wooddell (2013)

Magnitude	GP	SDSU	CSM	EXSIM	UCSB
5.5	60	50	15	100	15
6.0	50	50	15	100	15
6.5	10	10	12	100	2
6.6	10	10	12	100	2
7.0	1	1	4	50	1
7.3	1	1	4	50	1
7.5*	1	1	3	50	1
7.7*	0.5	0.5	2	50	--



SWUS SSHAC Level3 (2014)

まとめと留意事項 Summary & Concern

- SCEC BBPは第三者による震源モデルおよび地震動の再現性と，複数の手法について同一基準を用いた評価が可能な場を提供している
- 評価は Part A および Part B の1枚平面断層で実施されている
- 複数セグメントや長大断層，海溝型地震については未検討である
- 欧州の地震動予測手法は未導入
- 対象とする地震動の質は NGA-West2 に準拠しており，厳選されている
- 時刻歴波形での評価がなされていない．すなわち，近地強震動パルスと長周期地震動の応答レベルが同等となる場合がある．2011年東北地方太平洋沖地震のように，複数の波群から構成される場合もあるので，時刻歴や継続時間にたちもどった検証が必要

- SCEC BBP provides several source modules to validate ground motions.
- Parts A and B validations are for a single fault plane of crustal events, neither for multi-segment rupture nor subduction events.
- Not yet to include European-based source modules.
- Quality control of ground motions is well done based on NGA-West2.
- Tend to validate PSA, rather than ground motion time histories and durations.

参考文献
References

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