Southern California Earthquake Center

GMSV Workshop 4/3/13

Validation of broadband ground-motion synthetics using earthquake engineering-relevant metrics

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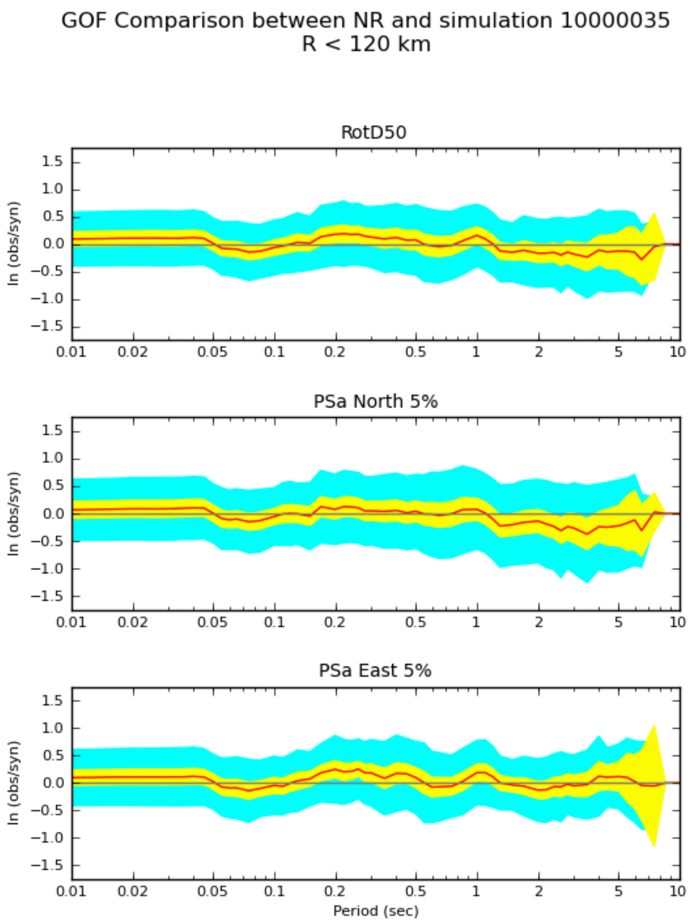
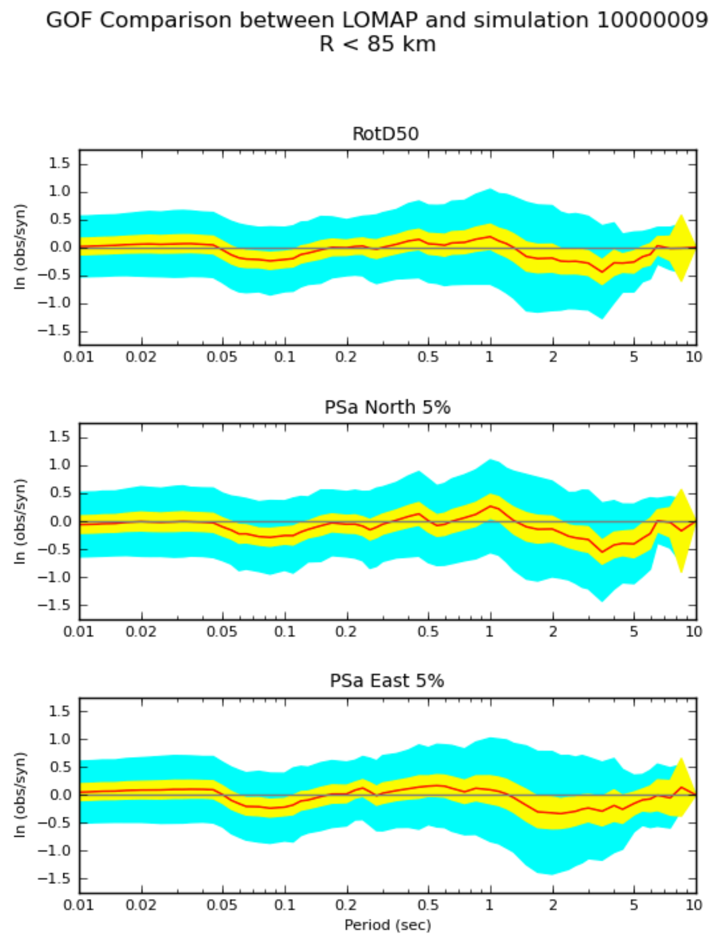
SCEC

an NSF+USGS center

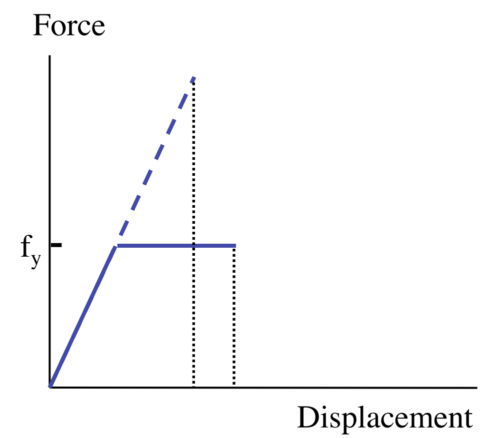
BB Platform: Elastic SAs Fit Data



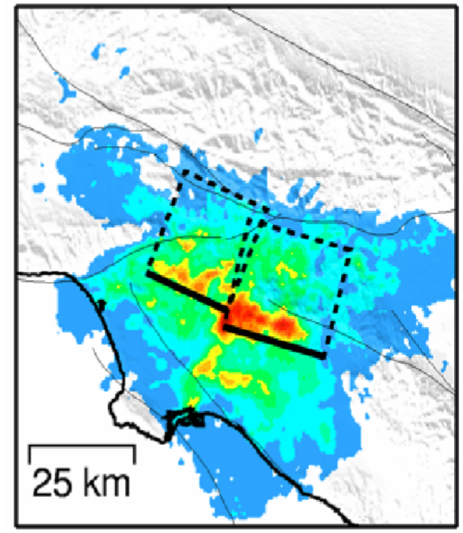


Nonlinear Response Spectra

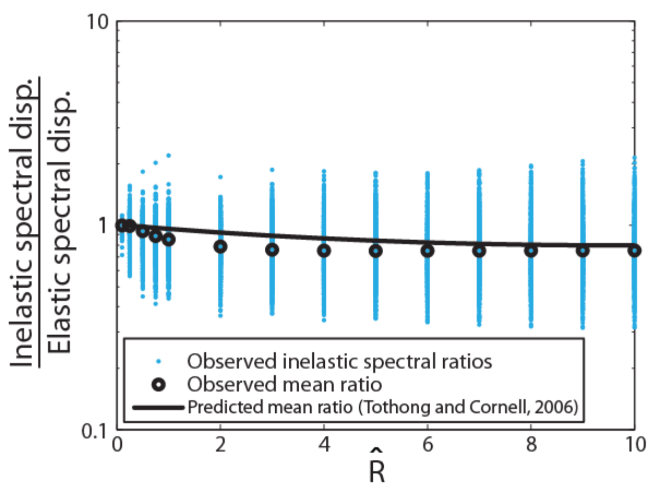
- One step up in complication and realism
- Also tied to engineering intuition
- Can still be tied to statistics of recorded ground motions
  - Predictive model available (e.g., Tothong and Cornell, 2006)
  - Relatively insensitive to most parameters besides magnitude and site nonlinearity



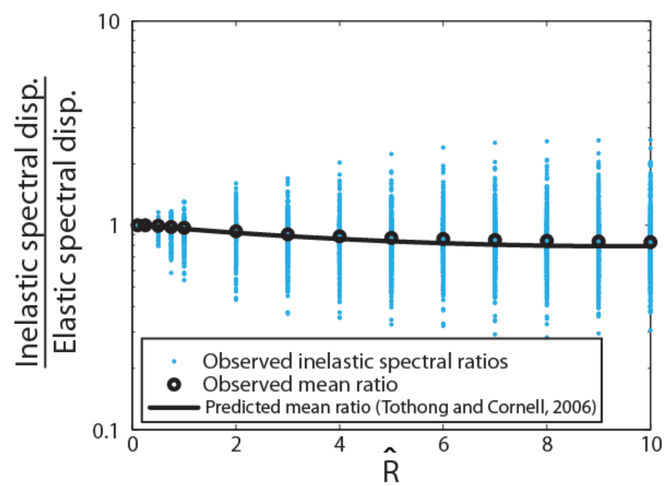
Nonlinear Response Spectra: Long Periods



Simulated ground motions



Observed ground motions



$T = 4s$

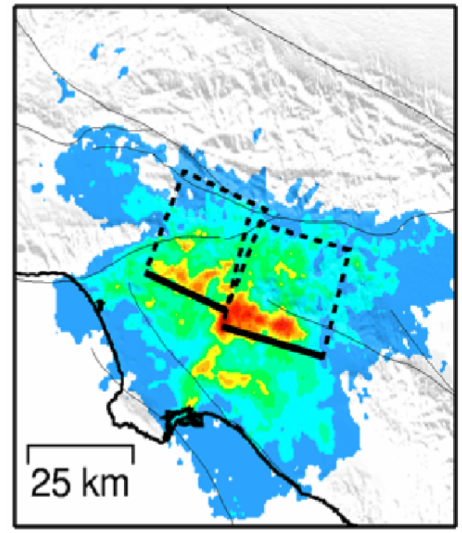
Record criteria:

$M > 6.5$

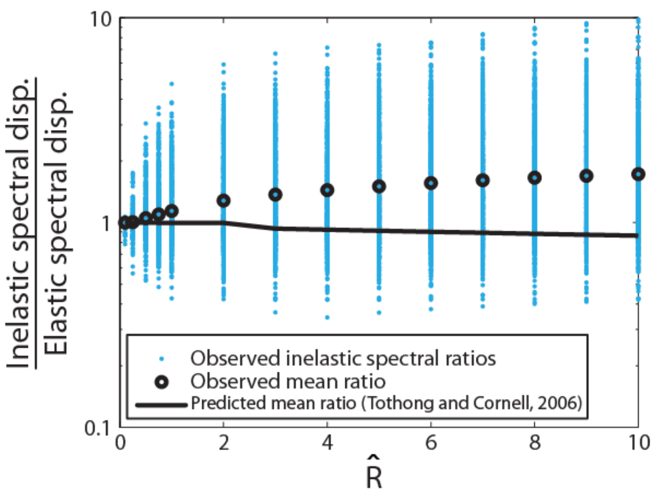
$V_{S30} > 300$ km/s

Expected level of nonlinearity

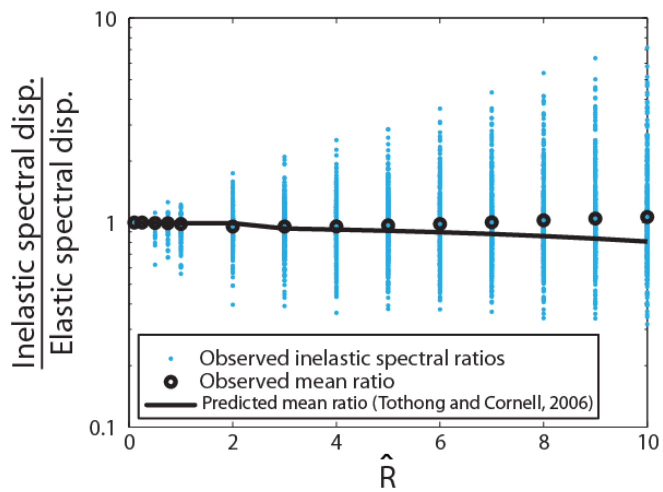
Nonlinear Response Spectra: Intermediate Periods



Simulated ground motions



Observed ground motions



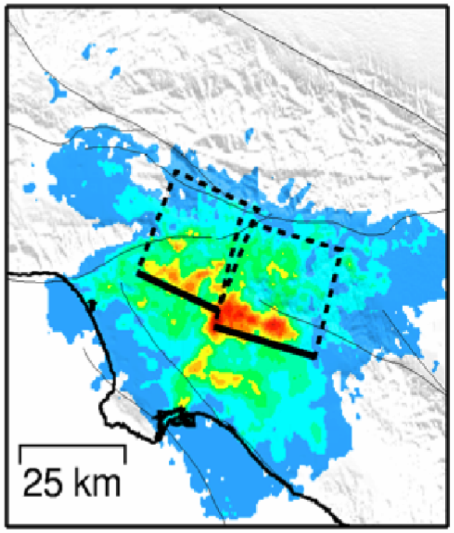
T = 1s

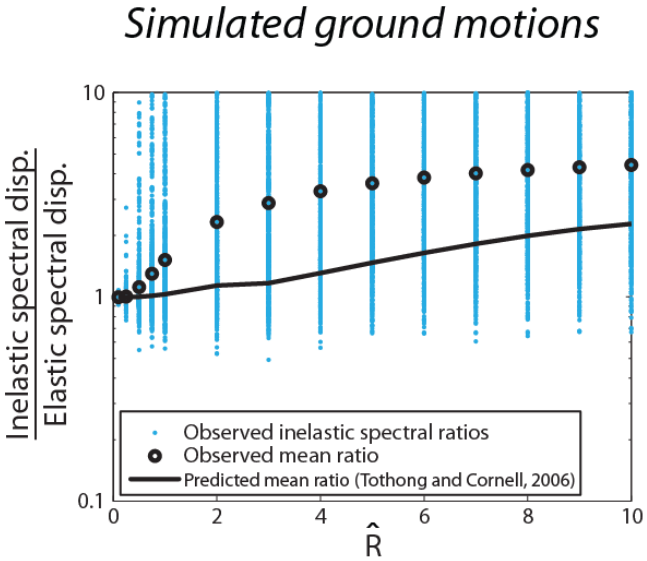
Record criteria:

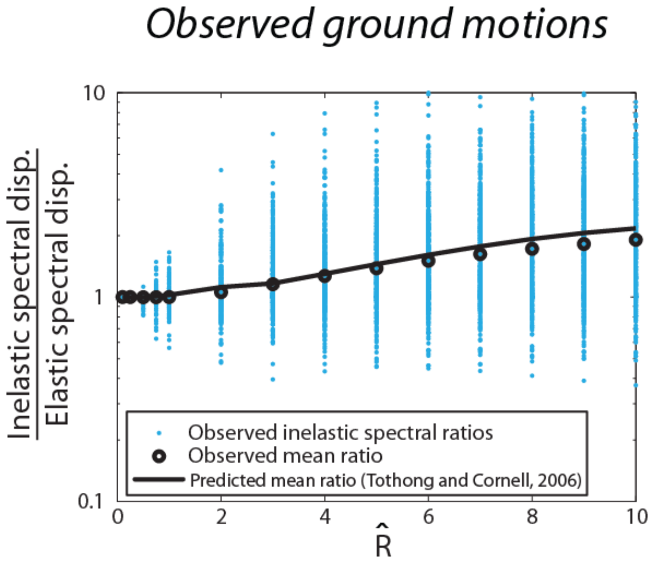
M > 6.5

V_{s30} > 300 km/s

Nonlinear Response Spectra: Short Periods





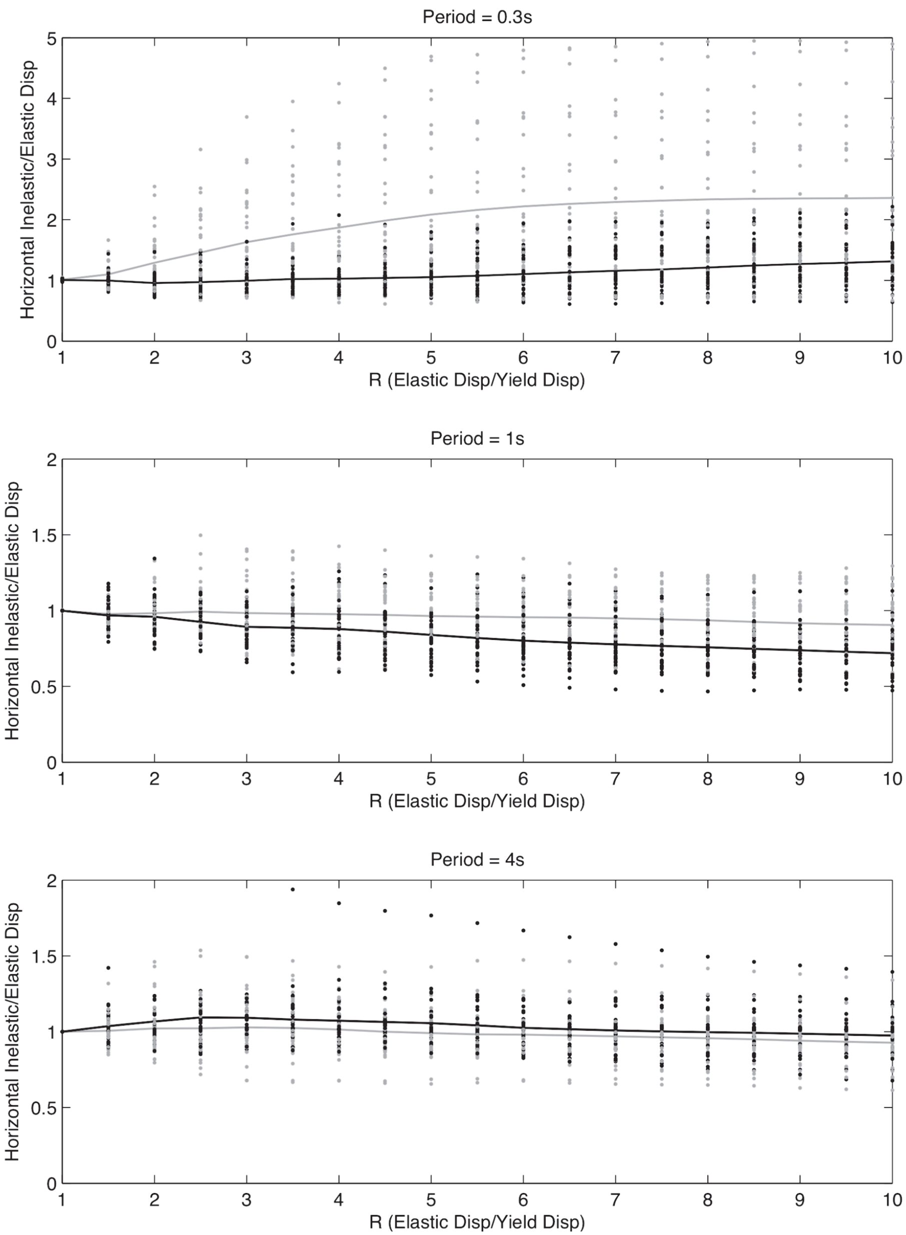


T = 0.3s

Record criteria:

M > 6.5

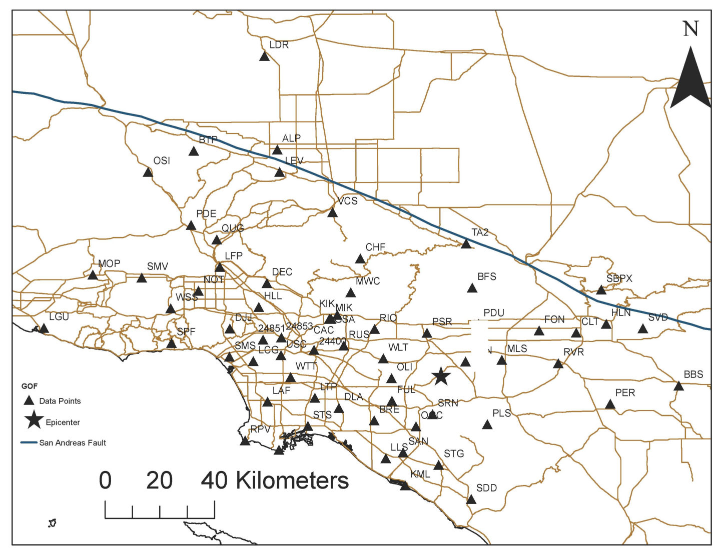
V_{S30} > 300 km/s



M5.4 Chino Hills

IE ratios derived from data (gray) and synthetics (black). Dots are results from the 33 stations, and the solid lines are the corresponding mean values.

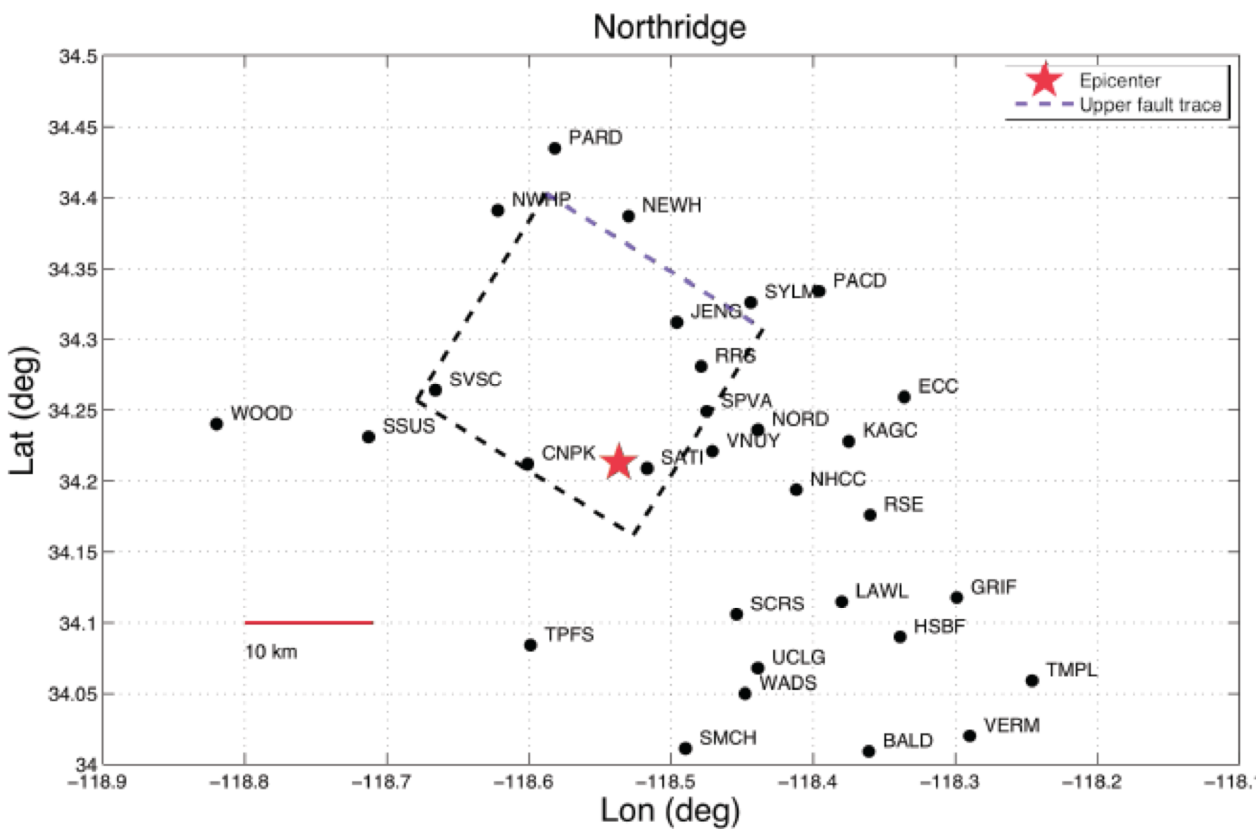
Calculated using SDSU BB module



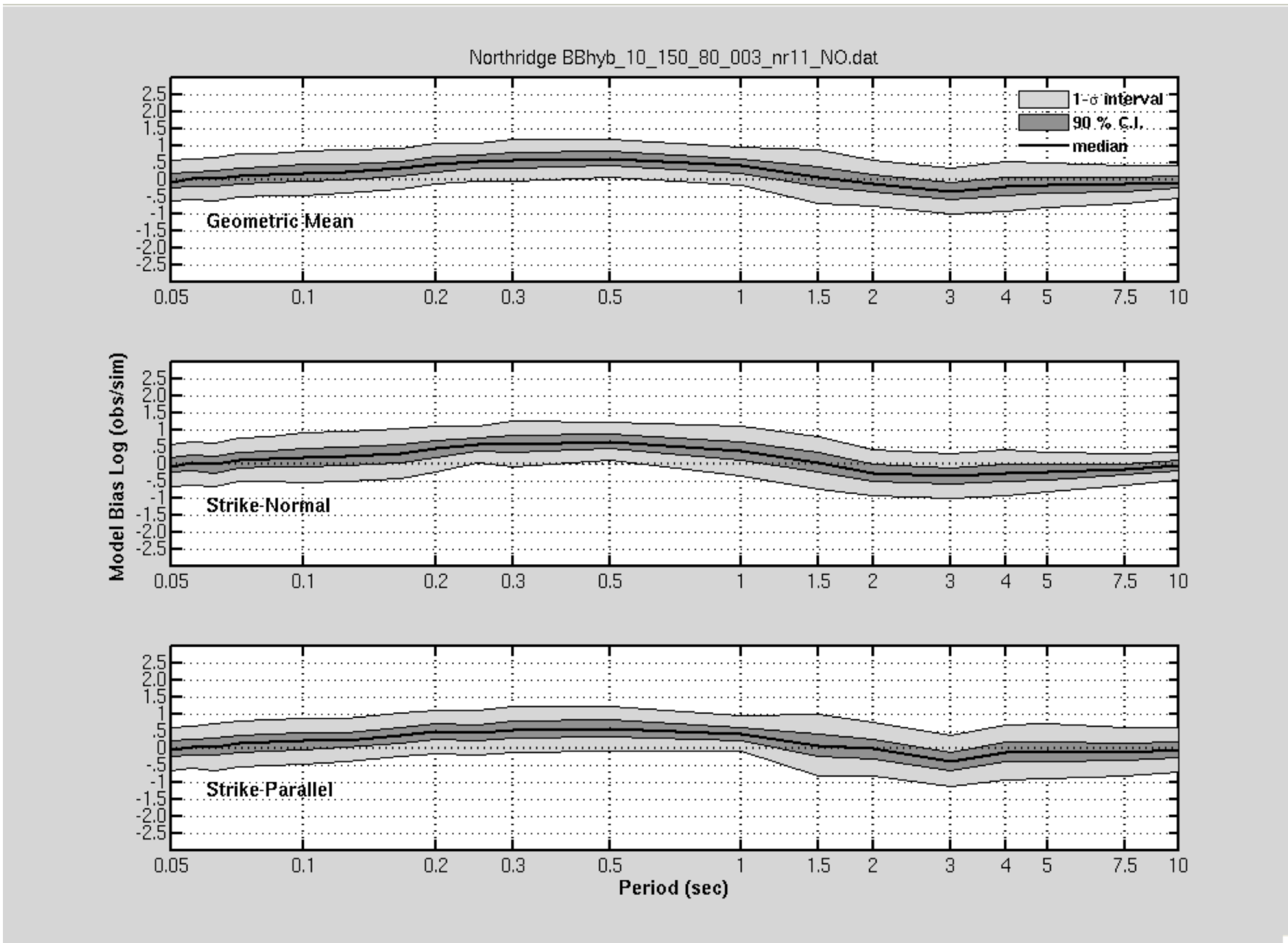
S O U T H E R N   C A L I F O R N I A   E A R T H Q U A K E   C E N T E R

1994 Northridge

Northridge

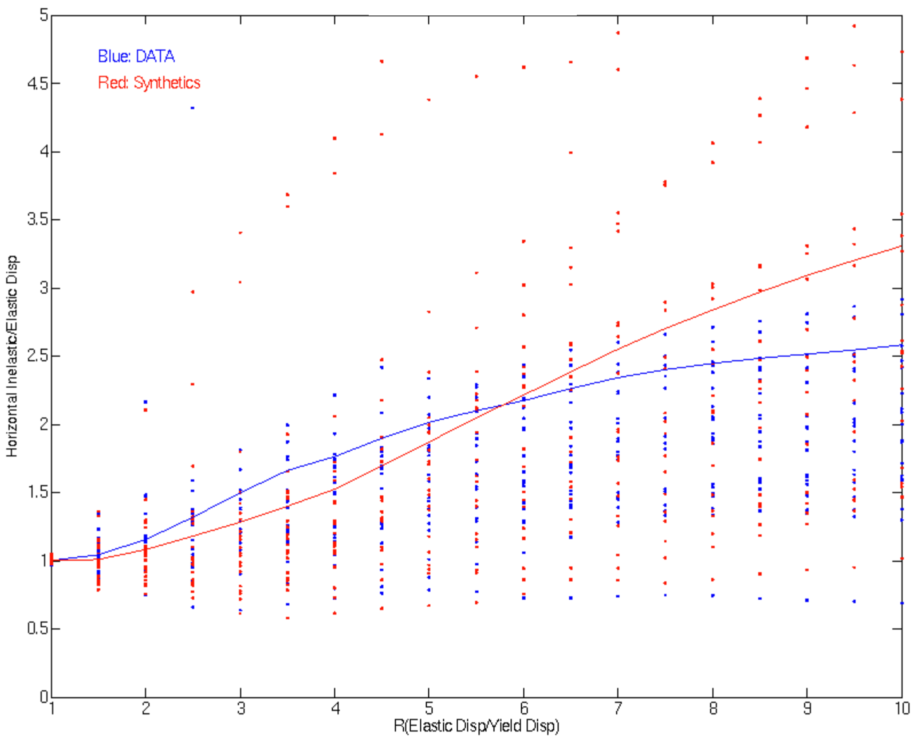


Bias of Elastic SAs

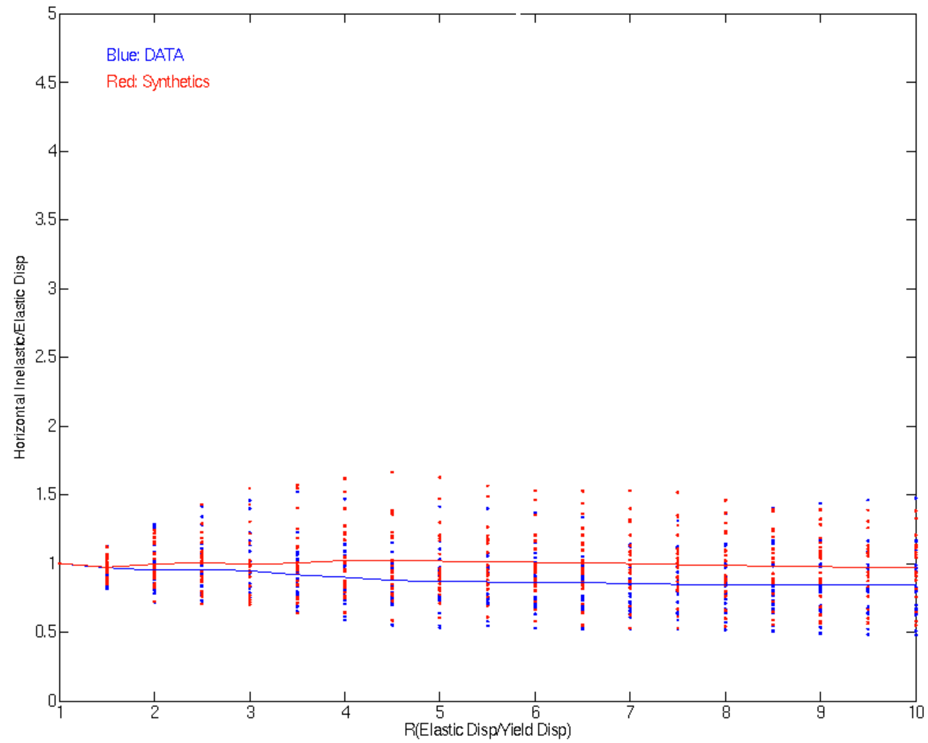


Northridge IE Ratios

0.3s

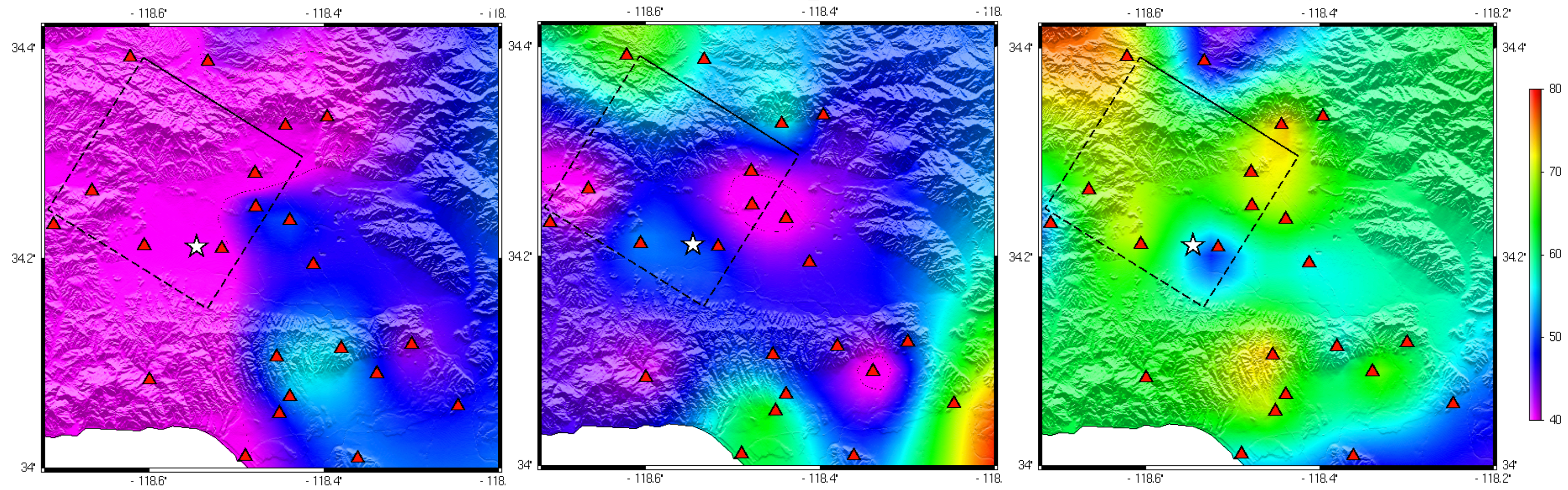


1.5s

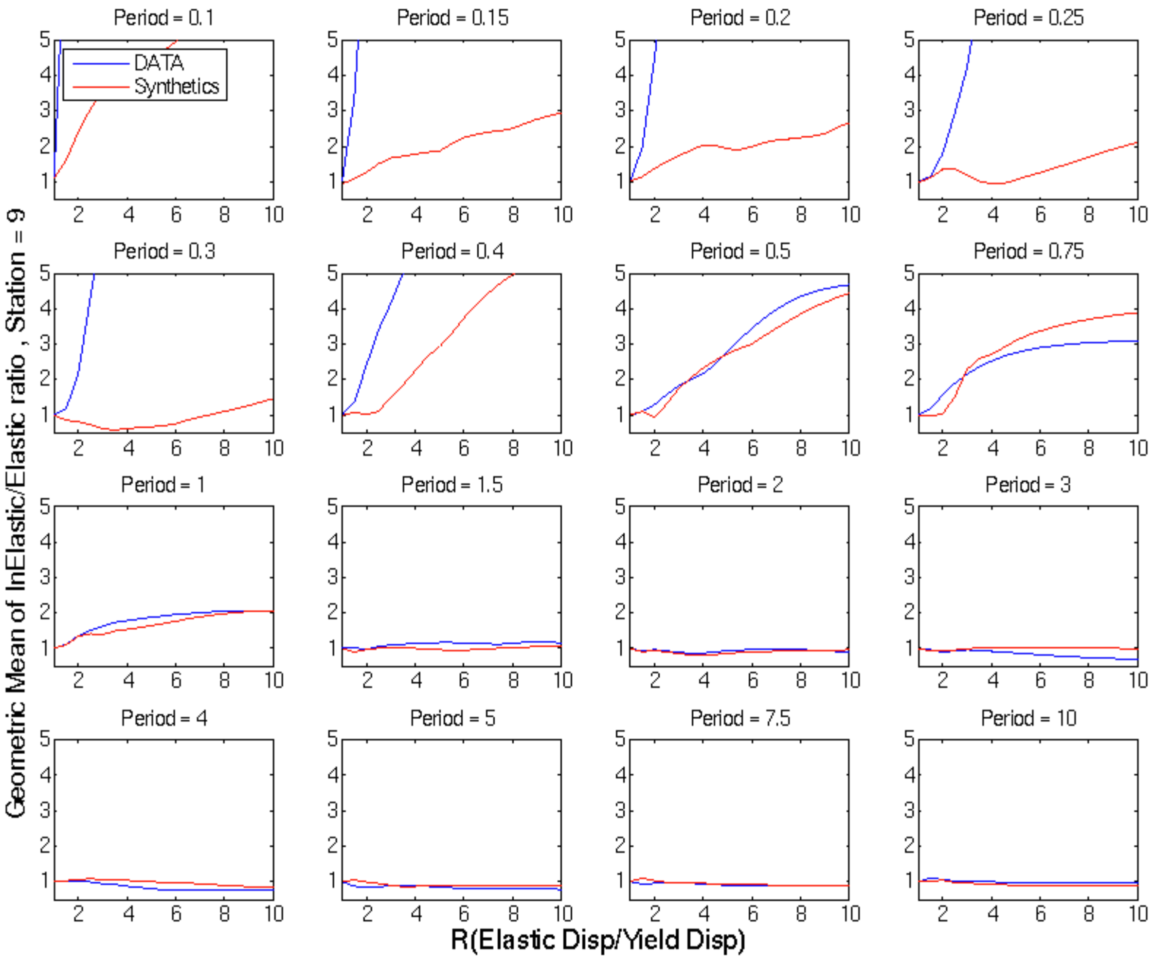


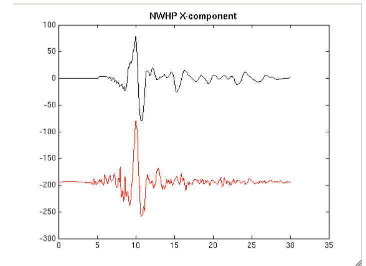
GOF of IE Ratios

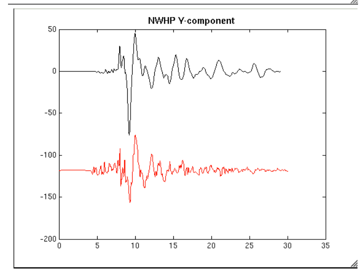
GOF of Geometric mean for IE ratios (period=shorter, medium, longer)

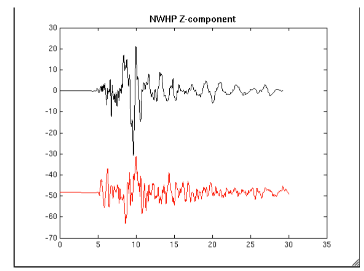


NWHP

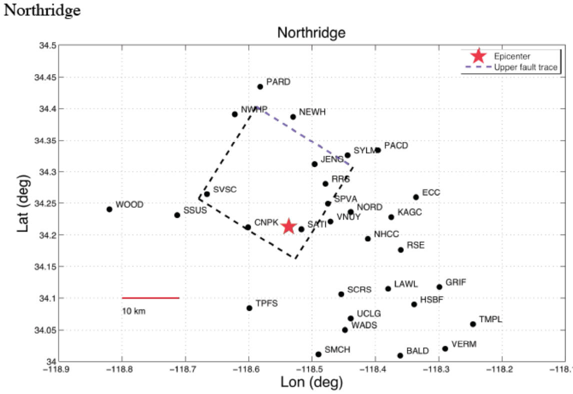




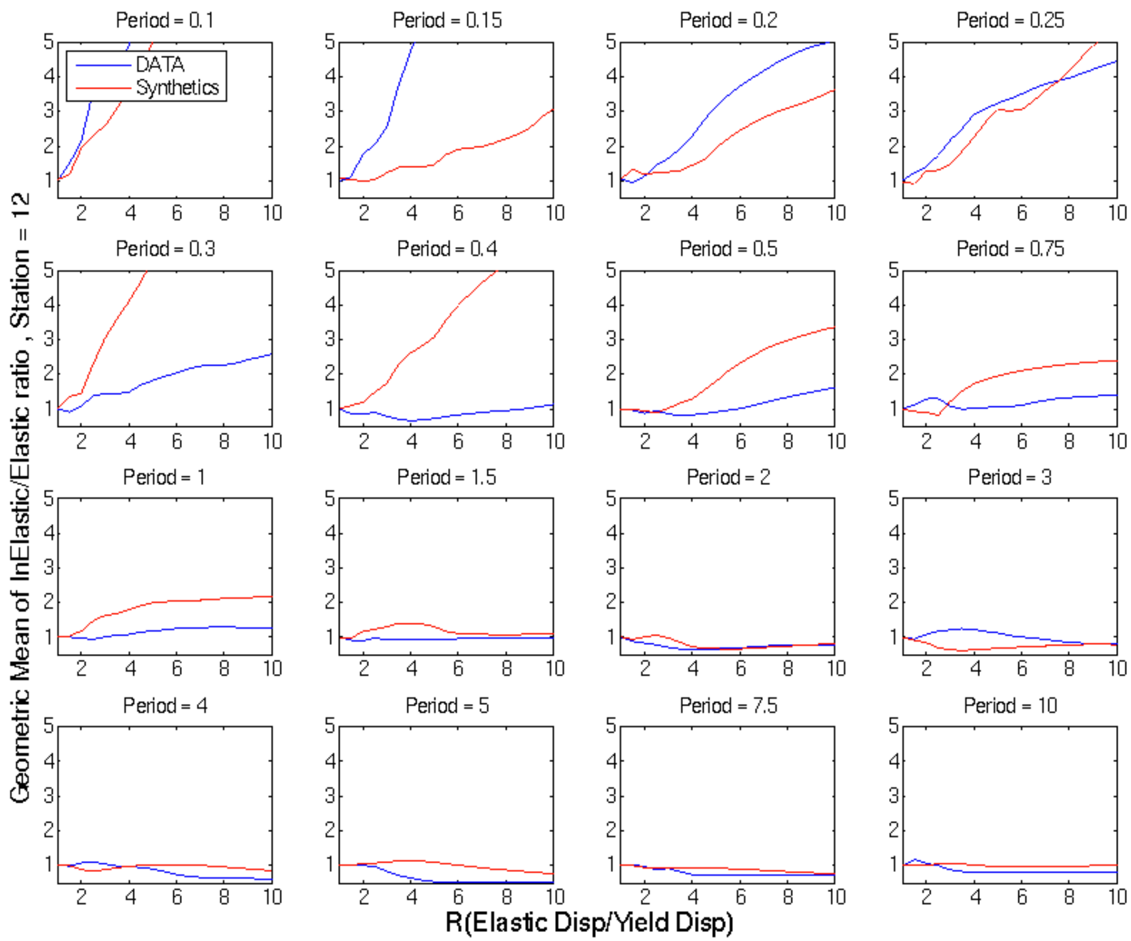


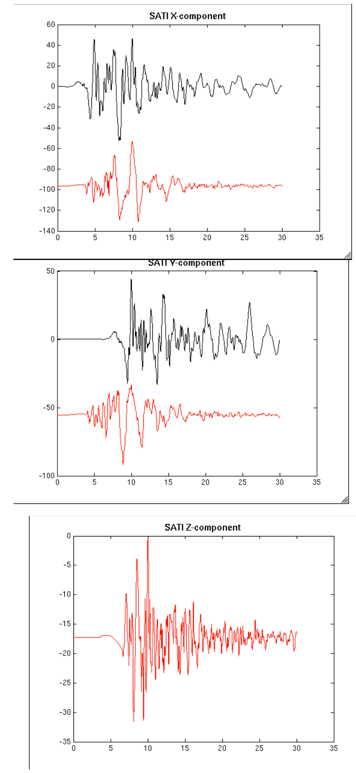


Northridge

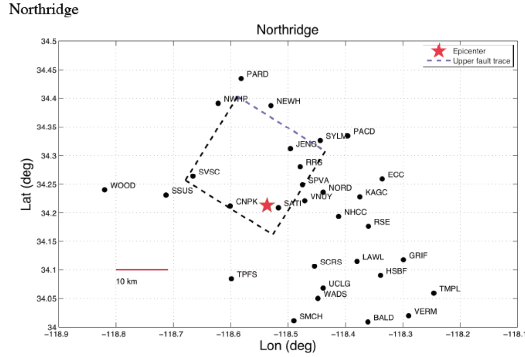


SATI





Northridge



Summary

- Median elastic SAs are routinely fit to data
- IE ratios for data and synthetics are very close for periods between 0.4 and 10 s, but start to diverge at shorter periods, for SDSU and URS BB module
- Puente Hills simulations from 2006 (Graves and Pitarka BB module) overpredict IE ratios in data for 1s and shorter
- Chino Hills simulations from 2010 (M5.4, SDSU BB module) underpredict IE ratios in data for 1s and shorter
- Northridge simulations from 2012 (M6.7, SDSU BB module) generally underpredict IE ratios in data for 0.2s and shorter

Summary (Cont.)

- Although elastic SAs often fit data for short-period simulations, IE ratios may be off
- Results suggest the need for refining the BB methods when used to compute IE ratios at shorter and intermediate periods. Future work should include additional scenarios, and compute the IE ratios using additional modules
- What is causing the IE ratio misfit when elastic SAs are approximately fit???
- How can BB modules be improved to produce more realistic IE ratios???

Ⓔ

Goodness-of-fit Criteria for Broadband Synthetic Seismograms, with Application to the 2008 M_w 5.4 Chino Hills, California, Earthquake

Kim B. Olsen[1] and John E. Mayhew[1,2]

Kim B. Olsen and John E. Mayhew: Goodness-of-fit Criteria for Broadband Synthetic Seismograms, with Application to the 2008 Mw 5.4 Chino Hills, Califonia, Earthquake, *Seismological Research Letters* **80(6)**: 1002-1007

Online material: Description of metrics and comparison of our goodness-of-fit (GOF) method to other proposed GOF measures.

INTRODUCTION

Broadband synthetics obtained from scenario simulations of earthquakes with a frequency content between 0 and 10 Hz, referred to hereafter as "BBSs," are playing an increasingly important role in seismic hazard analysis. An example is the Great Southern California ShakeOut, the largest disaster response exercise in U.S. history and an annual event since 2008 (Jones *et al.* 2008). The drill was the first to be based on BBSs, in this case for an **M** 7.8 scenario earthquake on the southern San Andreas fault. Another example of the important role of synthetic ground motions is the increasing awareness of the advantages of using site-specific ground-motion time series, rather than empirical intensity measures or scaled time series from different sources or locations, for more realistic non-linear dynamic analysis of buildings and performance-based earthquake engineering. BBSs appear to be one of the only viable alternatives to the very limited amount of strong-motion time series, particularly in the near-field from large earthquakes.

Effectively meeting demands of this sort for realistic BBSs requires careful validation against recorded data. BBSs are currently achieved by combining deterministic low-frequency (LF) synthetics up to a maximum frequency (*fmax)* of typically 1–2 Hz with high-frequency (HF) stochastic synthetics above this upper cutoff frequency (see, for example, Graves and Pitarka 2004; Liu *et al.* 2006; Mai *et al.* forthcoming). Visual inspection has been used for decades to claim success or failure of the ability of simulations to match observations (or synthetics derived from an alternative numerical method). However, at shorter periods such visual waveform fits are not practical, likely due to chaotic source and path variability. For example, specific intensity measures tend to be more practical and relevant than actual waveform fits at higher frequencies.

Candidates for metrics to measure the misfit for BBSs include commonly used ground-motion intensity measures such as peak ground acceleration (PGA), peak ground velocity (PGV), peak ground displacement (PGD), and spectral acceleration (SA), as well as shaking duration—parameters often used by seismologists and earthquake engineers to assess ground motion simulations and estimate building response. For example, Star *et al.* (forthcoming) compared ShakeOut and Puente Hills BBSs (obtained from kinematic source descriptions) to recent Next Generation Attenuation (NGA) relations in terms of PGA, PGV, and SA at several periods. Similarly, Olsen *et al.* (2008, 2009) compared TeraShake and ShakeOut LFs, respectively, obtained from dynamic rupture propagation, to NGA relations in terms of PGV and SA at a period of 3 s. However, if the BBSs are to be used routinely for seismic risk analysis (*e.g.*, the ShakeOut scenario), non-linear dynamic analysis of buildings, or performance-based earthquake engineering, further empirical validation of ground-motion parameters relevant to engineering procedures is required. An example of such a structural engineering-specific metric is the ratio between inelastic and elastic response spectra (IE ratio). As a pioneering effort to demonstrate the usefulness of this metric, Baker and Jayaram (2008, hereafter referred to as BJ08) showed that the mean and standard deviation of IE ratios for a subset of BBSs in the Los Angeles region for several **M** 7.15 scenario earthquakes on the Puente Hills fault (Graves and Somerville 2006) were generally consistent with those for observations. However, they did find discrepancies, particularly at shorter periods, at soft-soil site locations and when strong directivity effects were present in the simulations, and they recommended further study to reconcile these differences. BJ08 is unique in the sense that it focused on properties that are known to affect the response of structures to earthquake ground motion.

In this study we present a new goodness-of-fit (GOF) method for the validation of BBSs, consisting of a combination

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2. Now at: ExxonMobil Exploration Company, Houston, Texas

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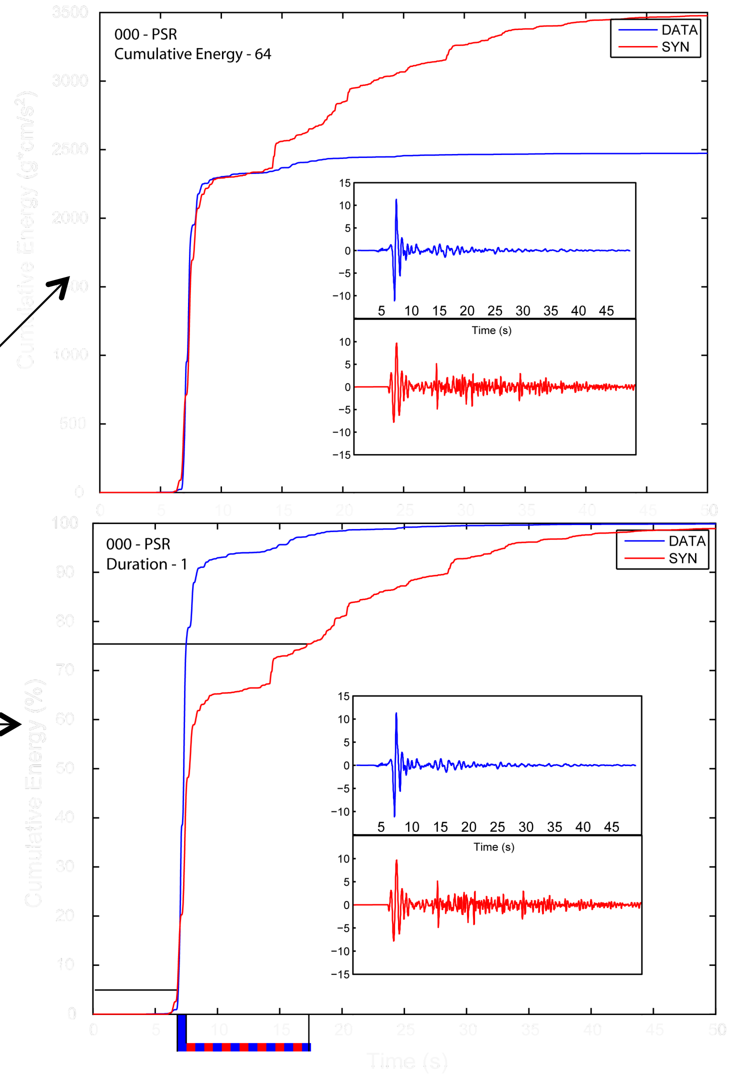
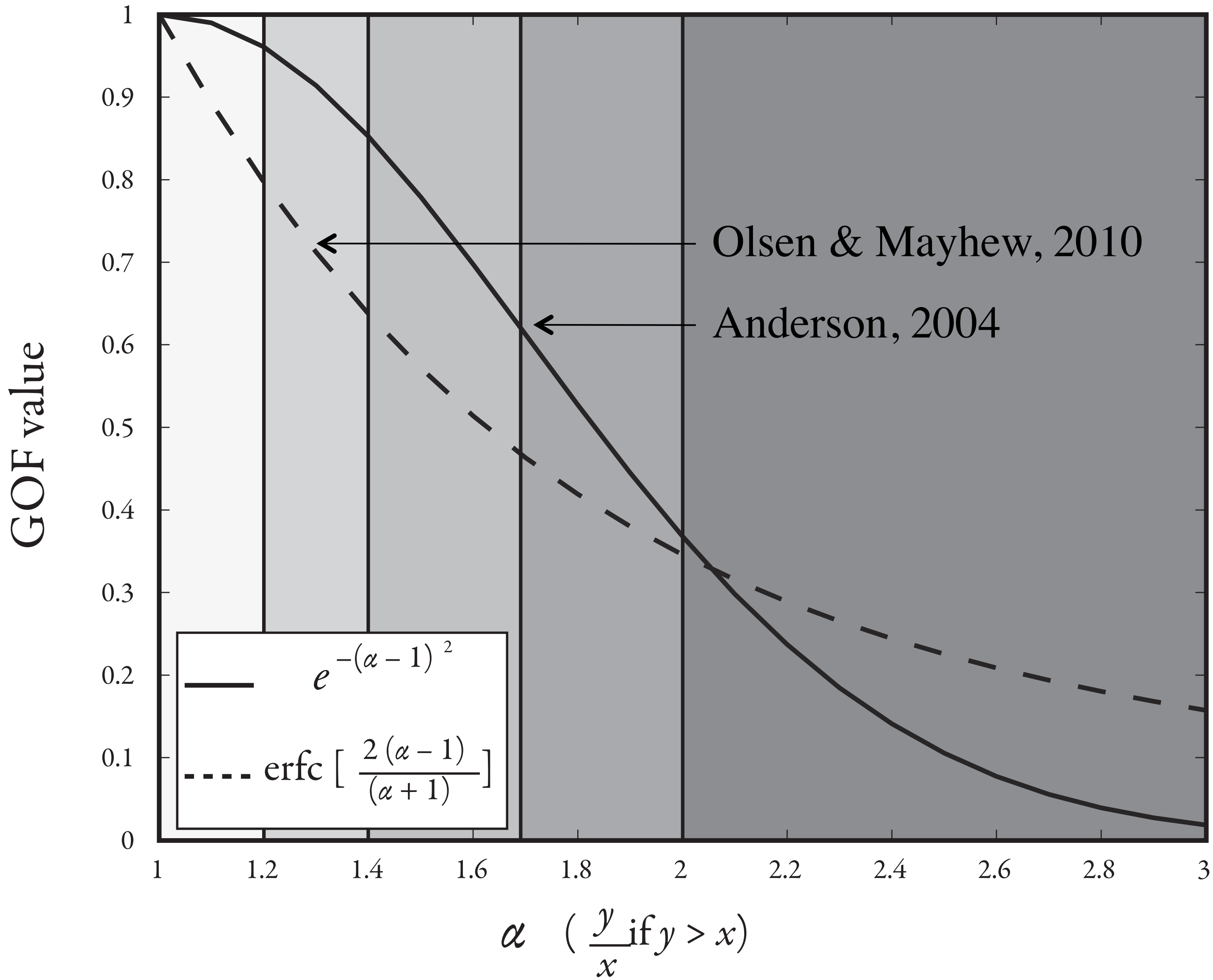
Metrics Olsen and Mayhew 2010
(developed for broadband ground motion synthetics)

1. Peak Acceleration (PGA)
2. Peak Velocity (PGV)
3. Peak Displacement (PGD)
4. Inelastic/Elastic Ratios (I/E)
5. Response Spectra (0.1-10s)
6. SA at 16 NGA periods
7. Cumulative Energy Density
8. Energy Duration
9. Cross-Correlation
10. Smoothed Fourier Amplitude Spectrum

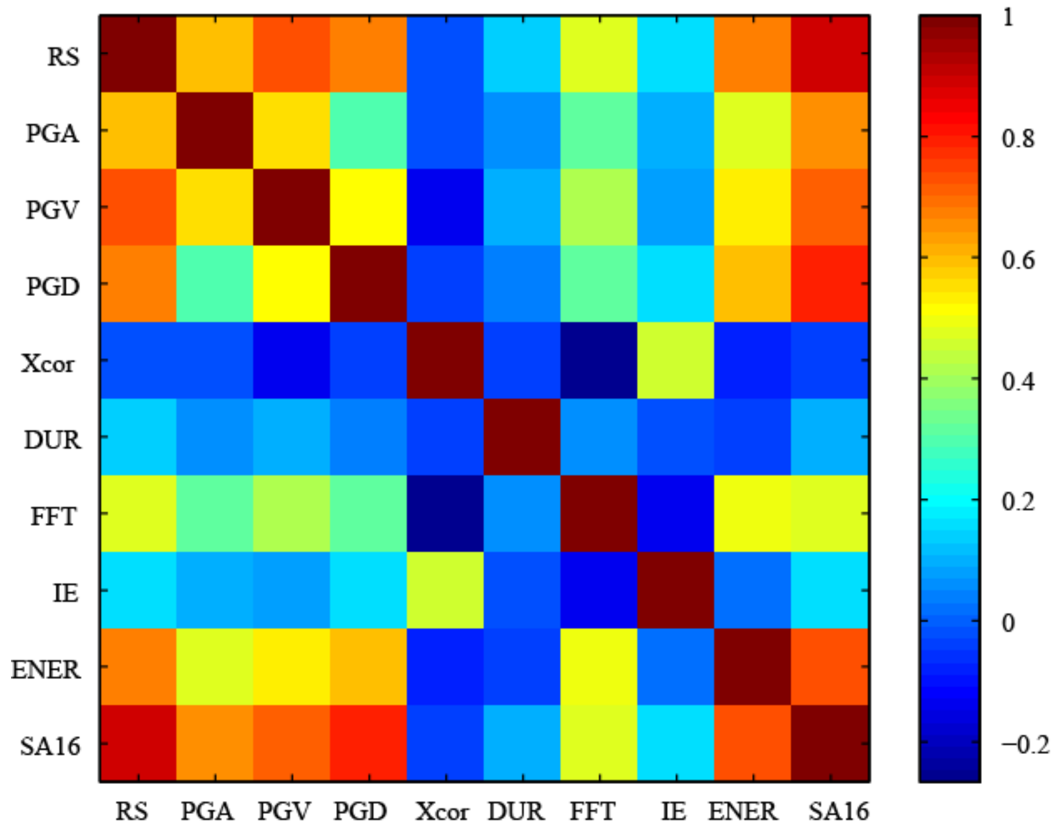


Comparison of GOF scales



Redundancy (Correlation Matrix)

- 33 stations
- 3 components
- 99 calculations

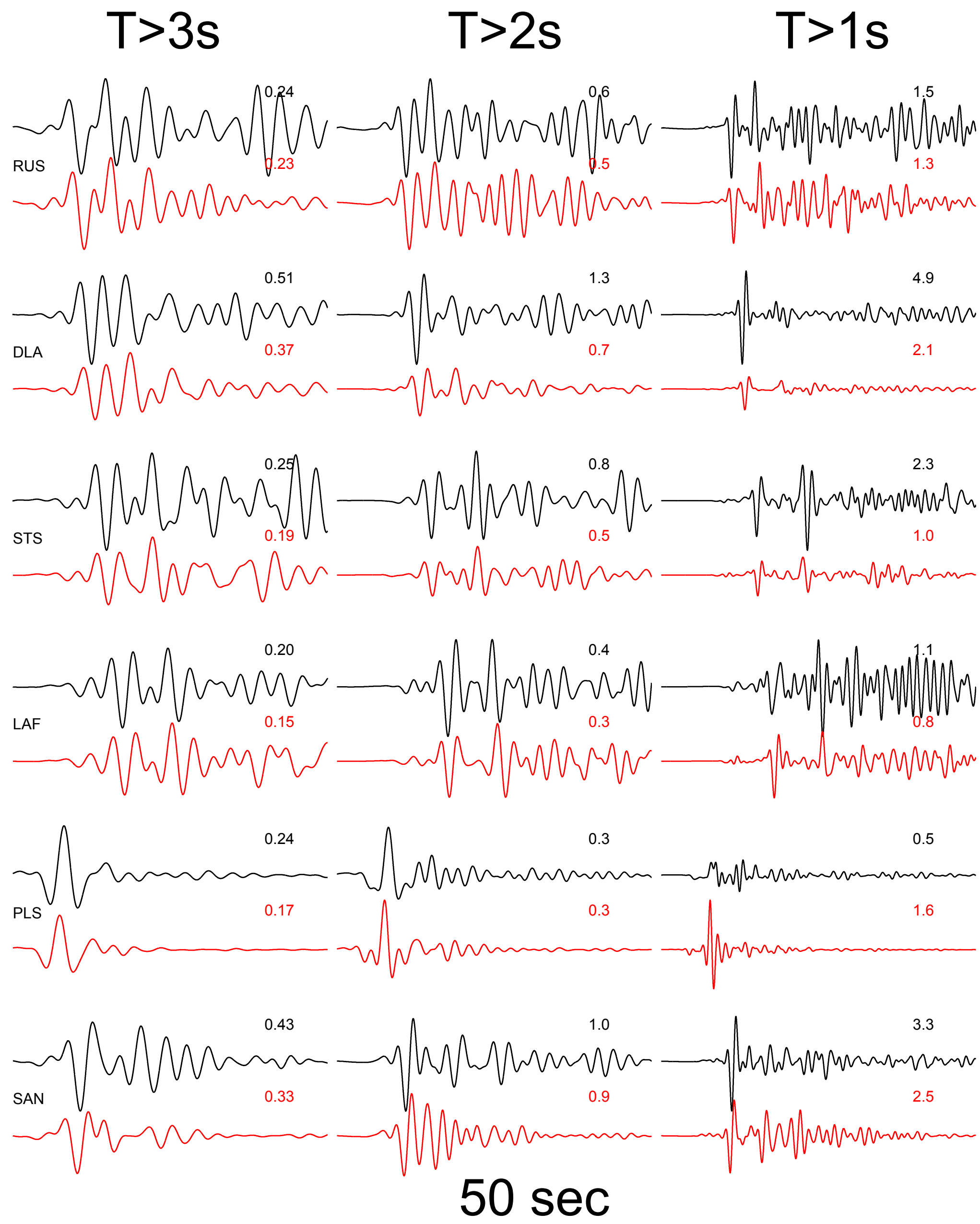


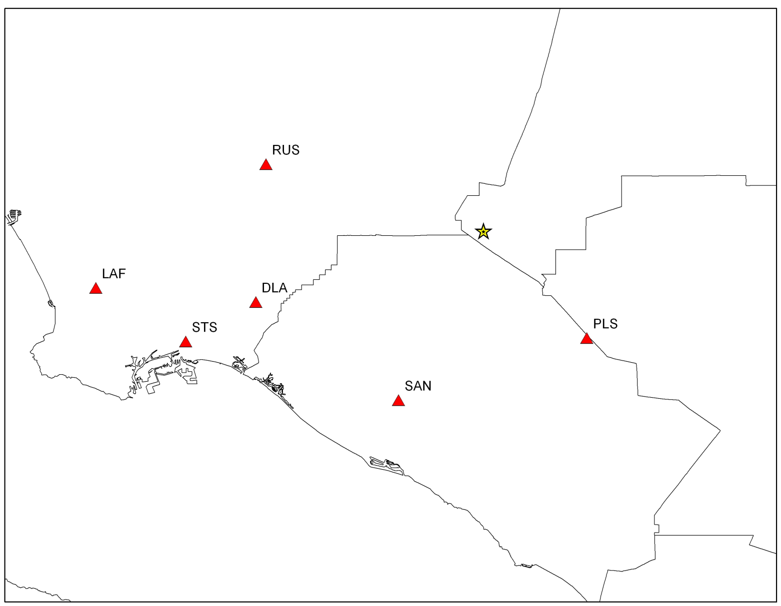
M_w5.4 Chino Hills 0.1-1Hz

Point source simulation

CVM4 (CMU etree)

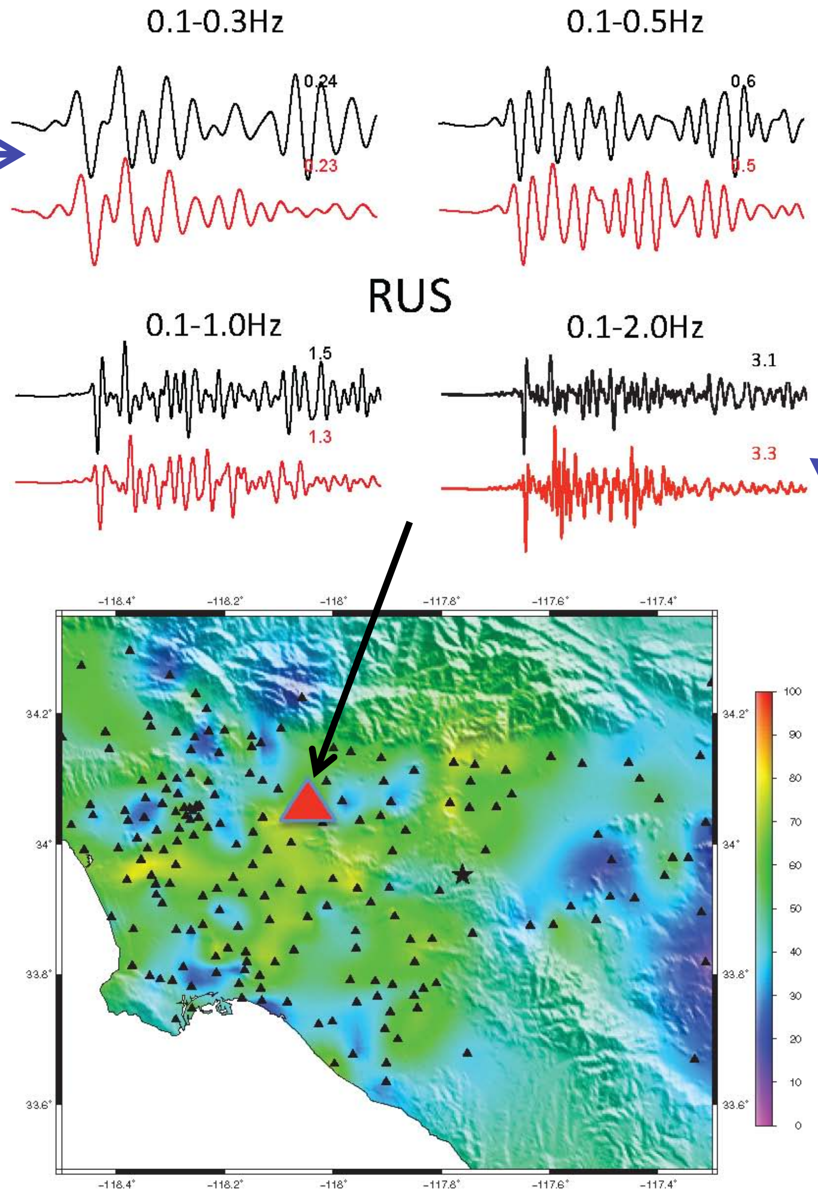
V_s(min)=500 m/s





Advancement of the CVM's accuracy

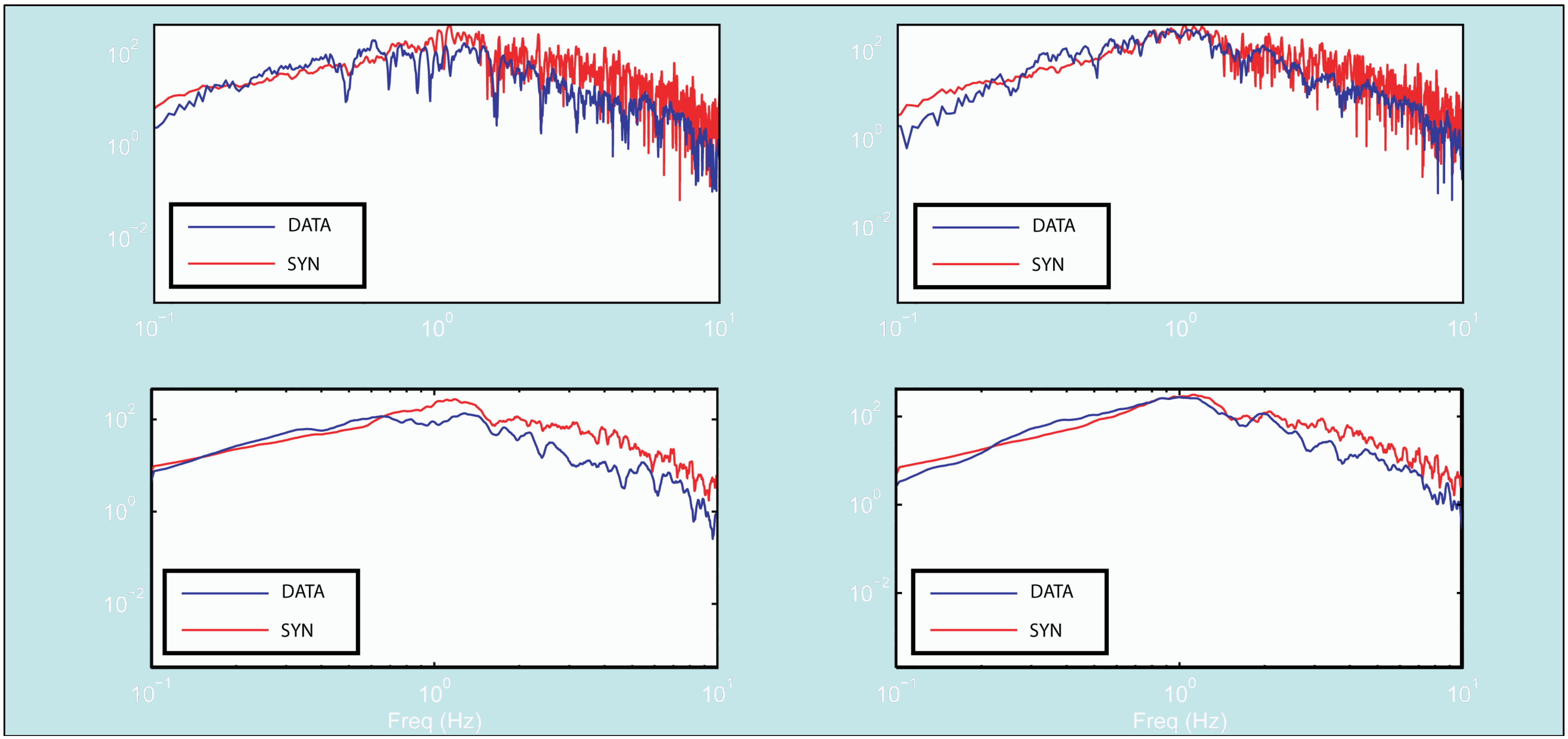
representing 'early' SCEC validations



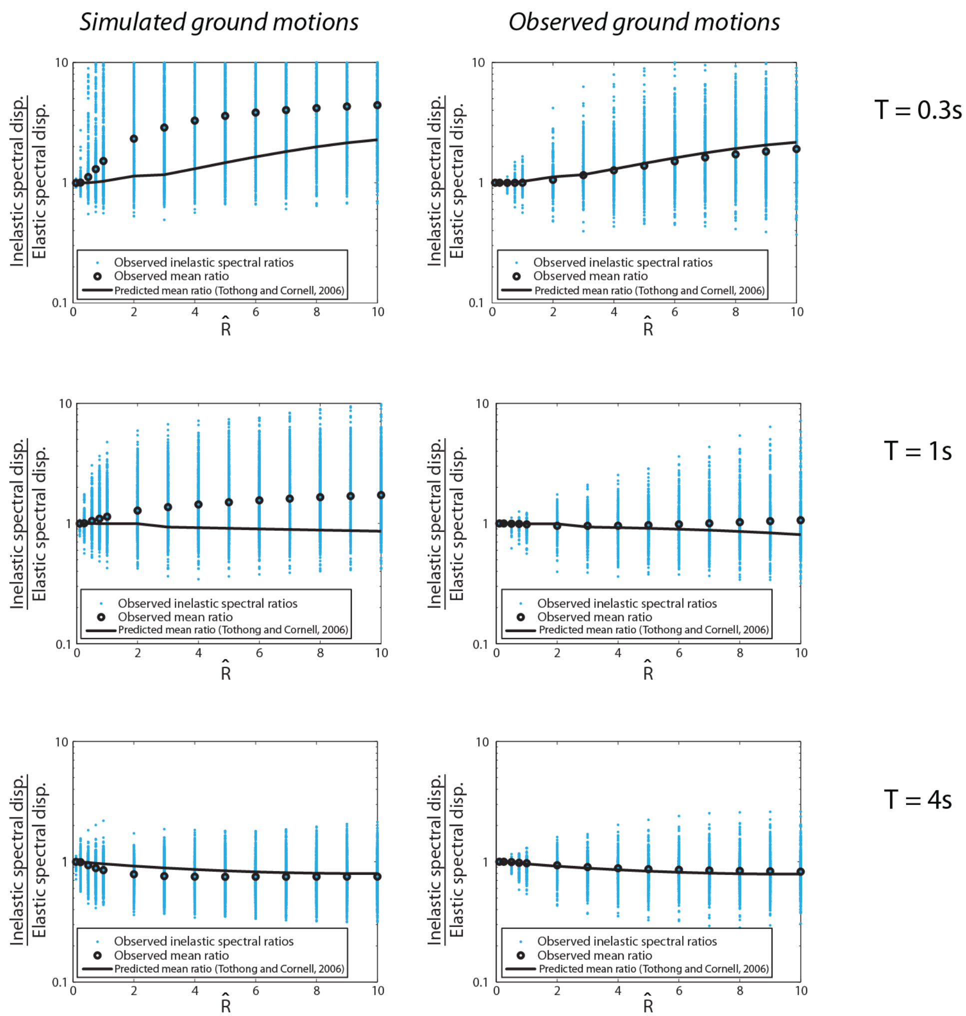
recent SCEC validations

Spectral Metric

- Smoothing of the Fourier amplitude spectrum (cm/s)

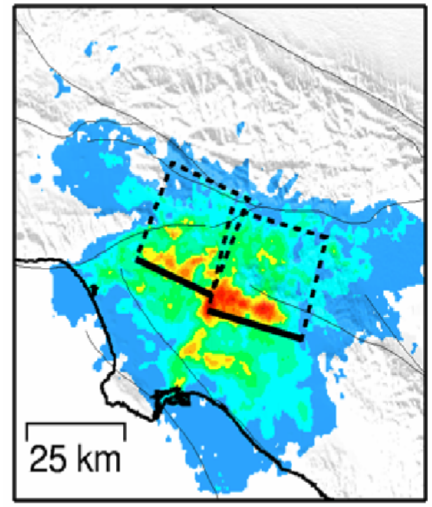


Nonlinear response spectra

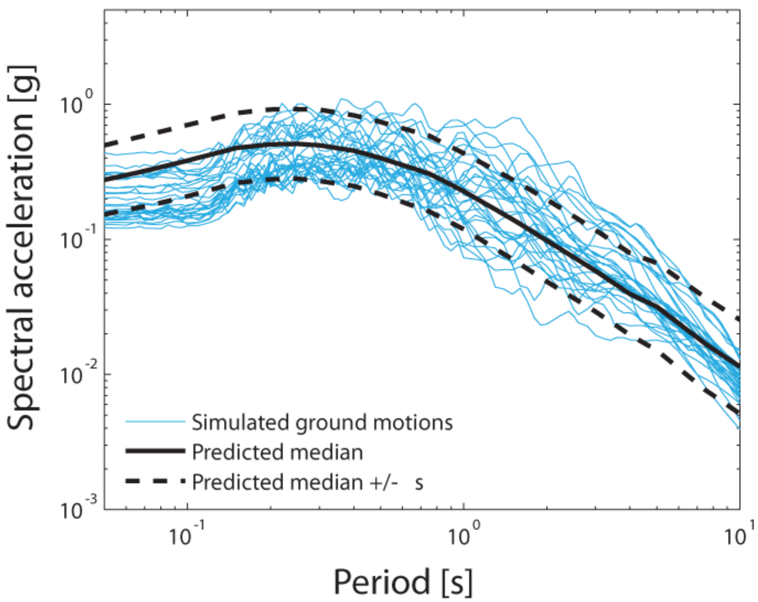


Elastic Response Spectra

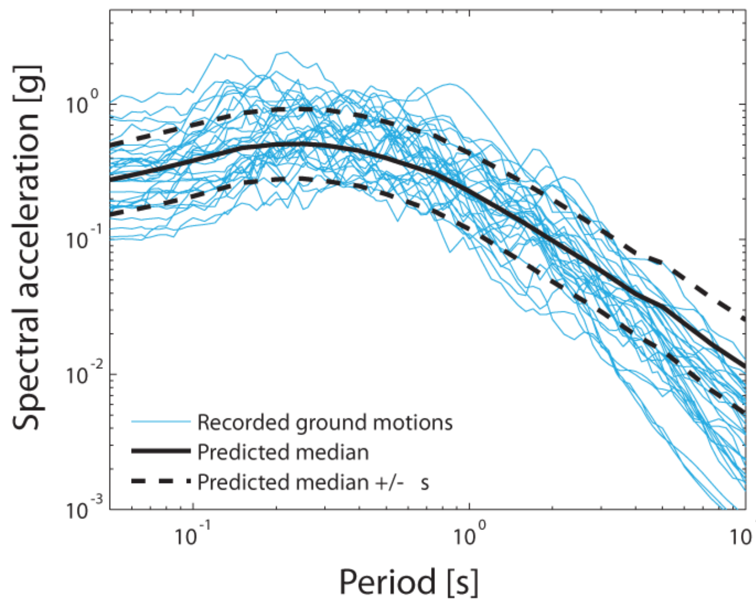
- Engineering-relevant ground motion metric



Simulated ground motions



Comparable observed ground motions



$M \approx 7$
$R \approx 15$ km
$V_{s30} > 300$ km/s
No directivity

Nonlinear Response Spectra

- One step up in complication and realism
- Also tied to engineering intuition
- Can still be tied to statistics of recorded ground motions
  - Predictive model available (e.g., Tothong and Cornell, 2006)
  - Relatively insensitive to most parameters besides magnitude and site nonlinearity