

Goodness-of-fit Criteria for Rupture Dynamics Code Validation?

Needs for a Goodness of Fit Measure

Many comparisons (11 exercises, ~11 groups, ~20 locations for time series, 7 time series + rupture time contours -> 10^4 comparisons)



Would be useful to depict the fit by a single number



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Time-Series File

Benchmark: tpv5 (The Problem, Version 5)

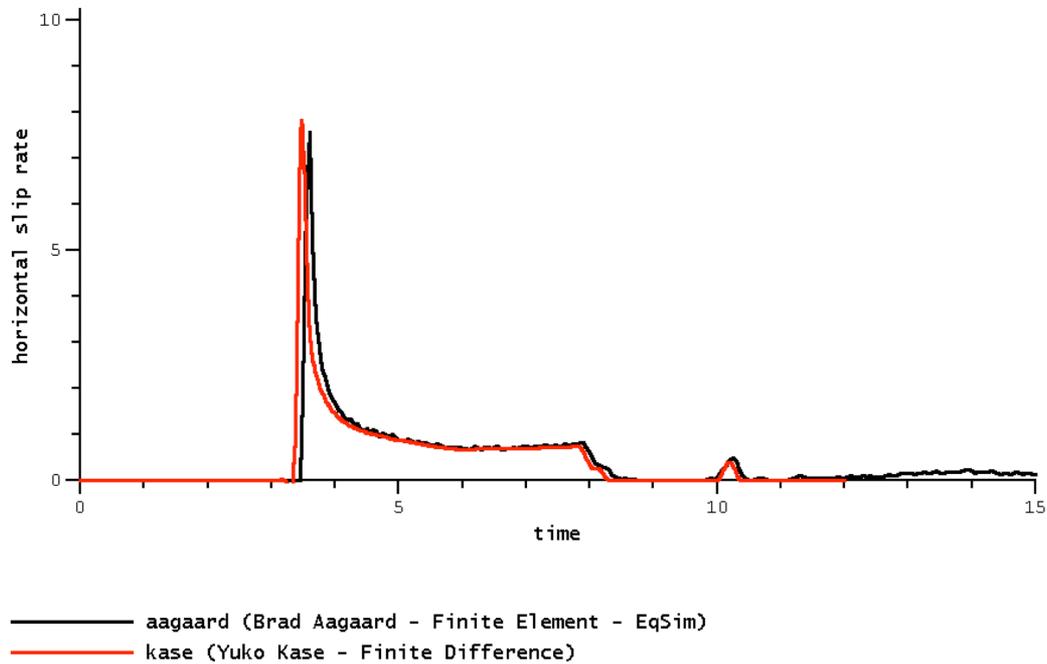
File: faultst000dp000 (strike 0.0 km, dip 0.0 km)

Field: h-slip-rate (horizontal slip rate)

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Time-Series File

Benchmark: tpv9 (The Problem, Version 9)

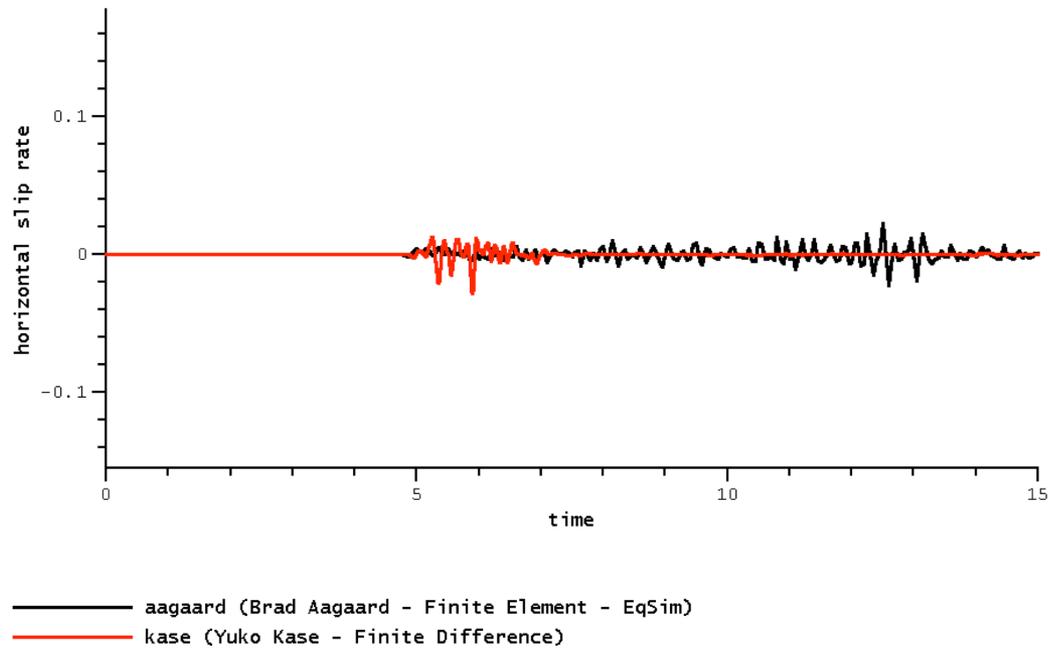
File: faultst000dp000 (strike 0.0 km, dip 0.0 km)

Field: h-slip-rate (horizontal slip rate)

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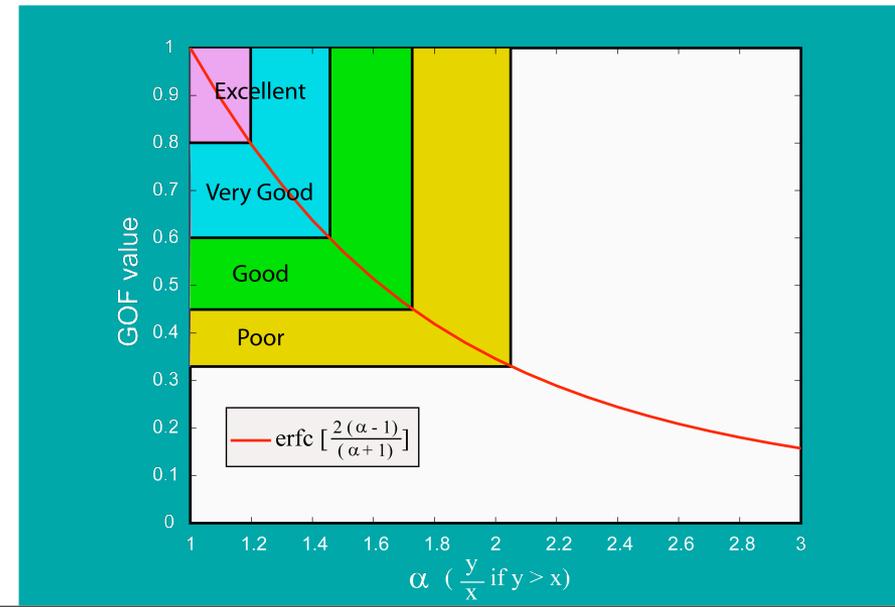
'Goodness of Fit' (GOF_MO)

- Normalized residual (NR): used to ensure an unbiased comparison, and this residual doesn't 'break' if one of the values is equal to zero
- Complimentary error function (*erfc*): to generate a value between 0-1, then multiplied by 100 for a final score of 0-100 with a score of 100 representing a perfect fit
- Re-sampled (decrease dt) to a power of 2 (filtering and FFT)
- Filtered to user defined bandwidth
- 3 component GOF_MO values

$$NR = \frac{2 * \sqrt{(x - y)^2}}{x + y}$$

$$GOF_MO(NR) = 100 * erfc(NR)$$

$$erfc(z_0) = 1 - \frac{2}{\pi} * \int_0^{z_0} \exp(-t^2) \partial t$$



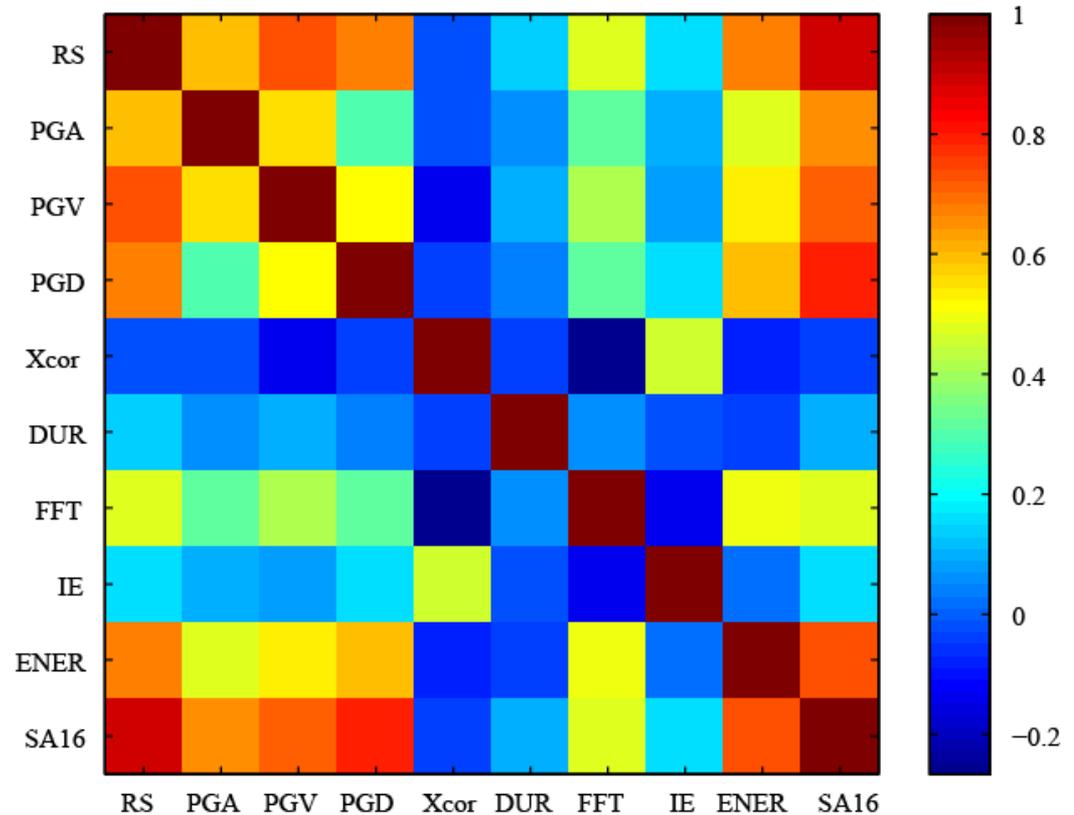
Metrics

(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
- Fourier Amplitude Spectrum

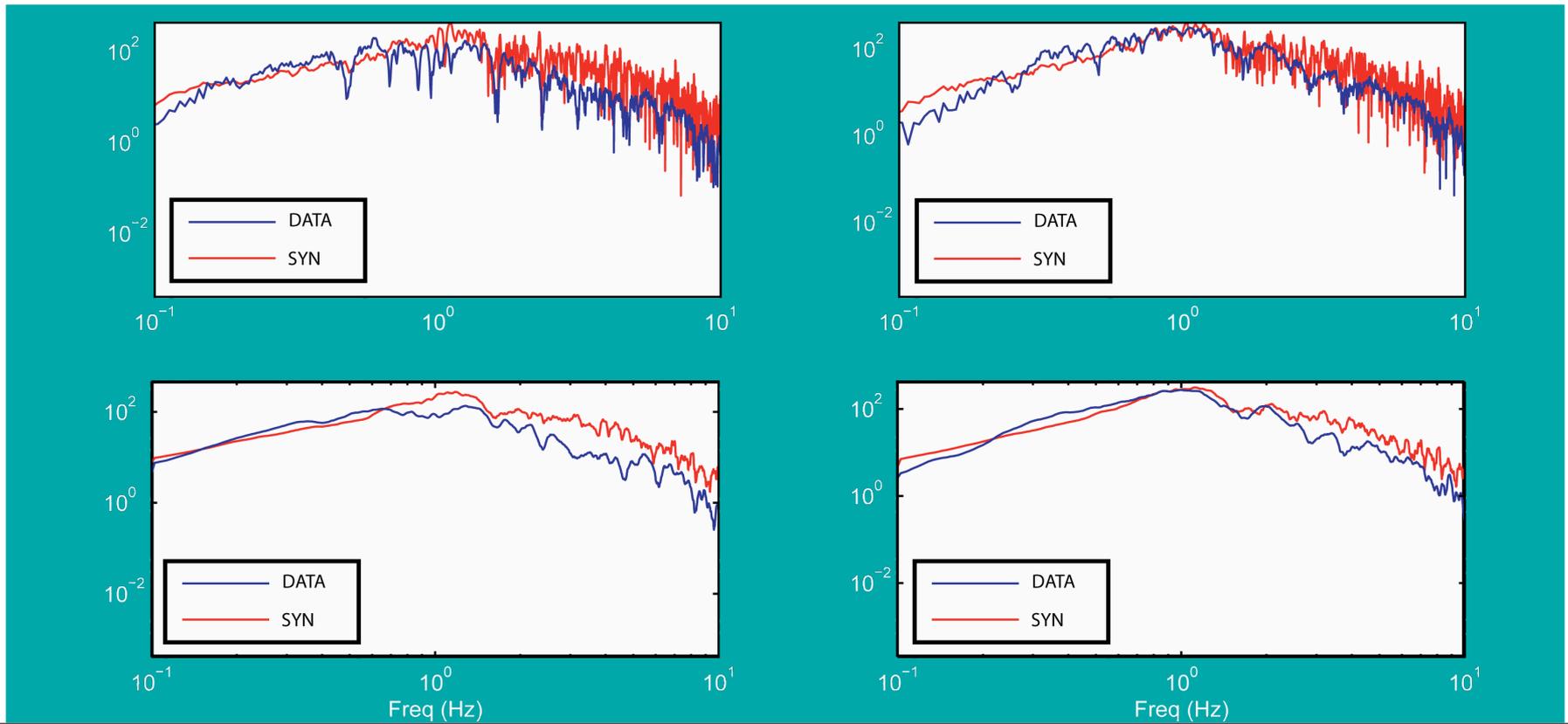
Redundancy

- 33 stations
- 3 components
- 99 calculations



Spectral Metric

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

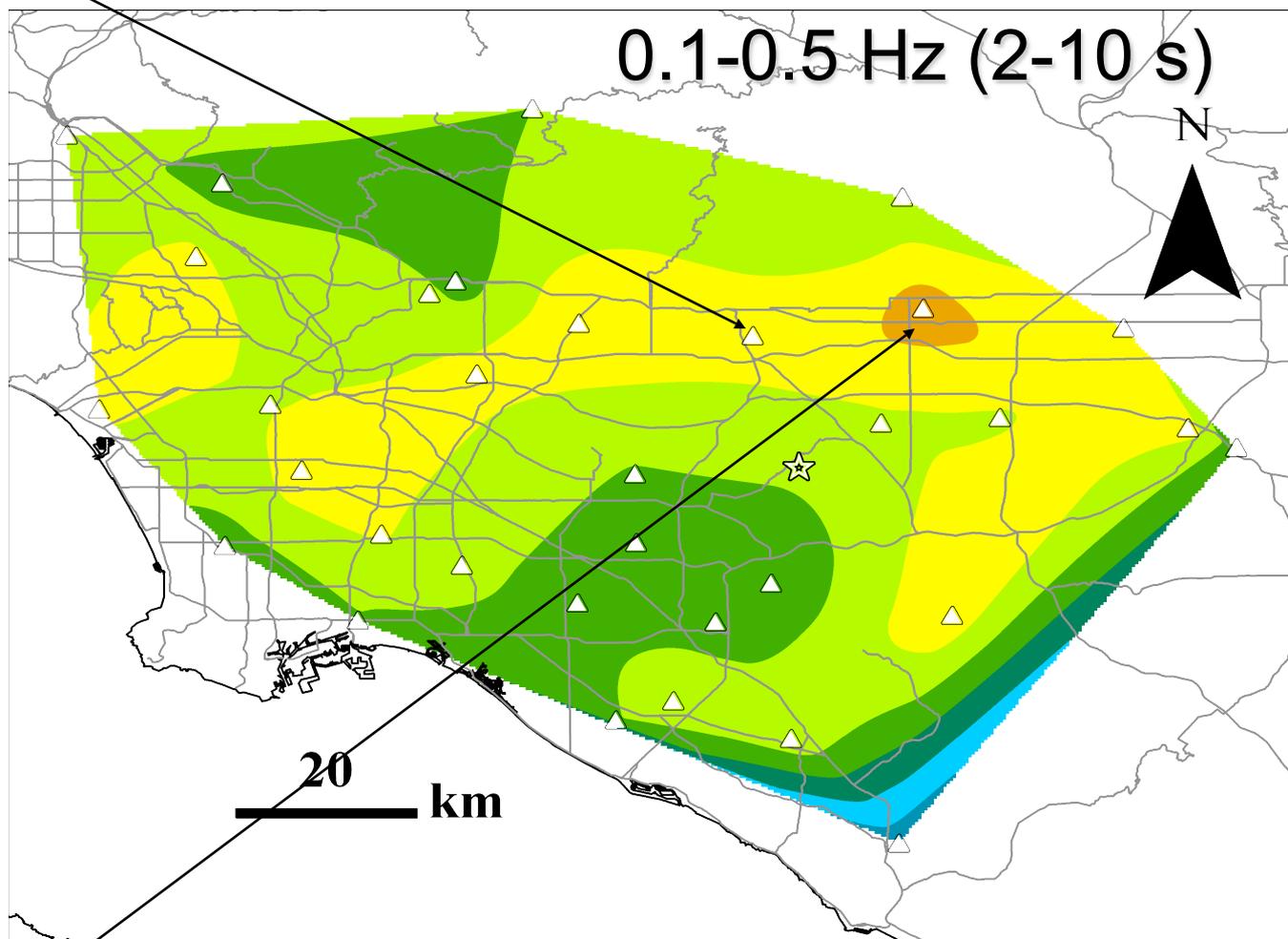
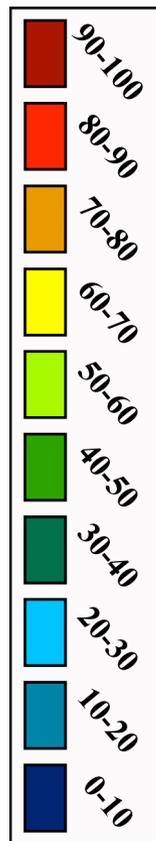
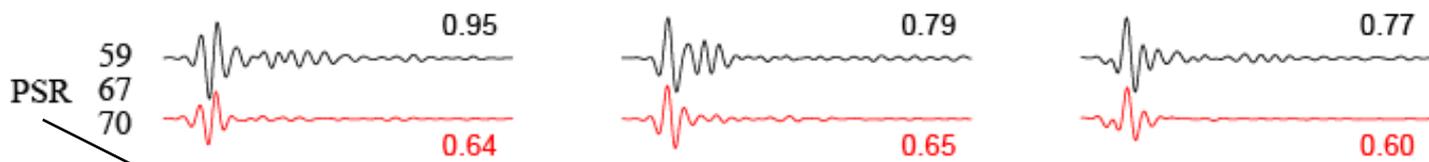


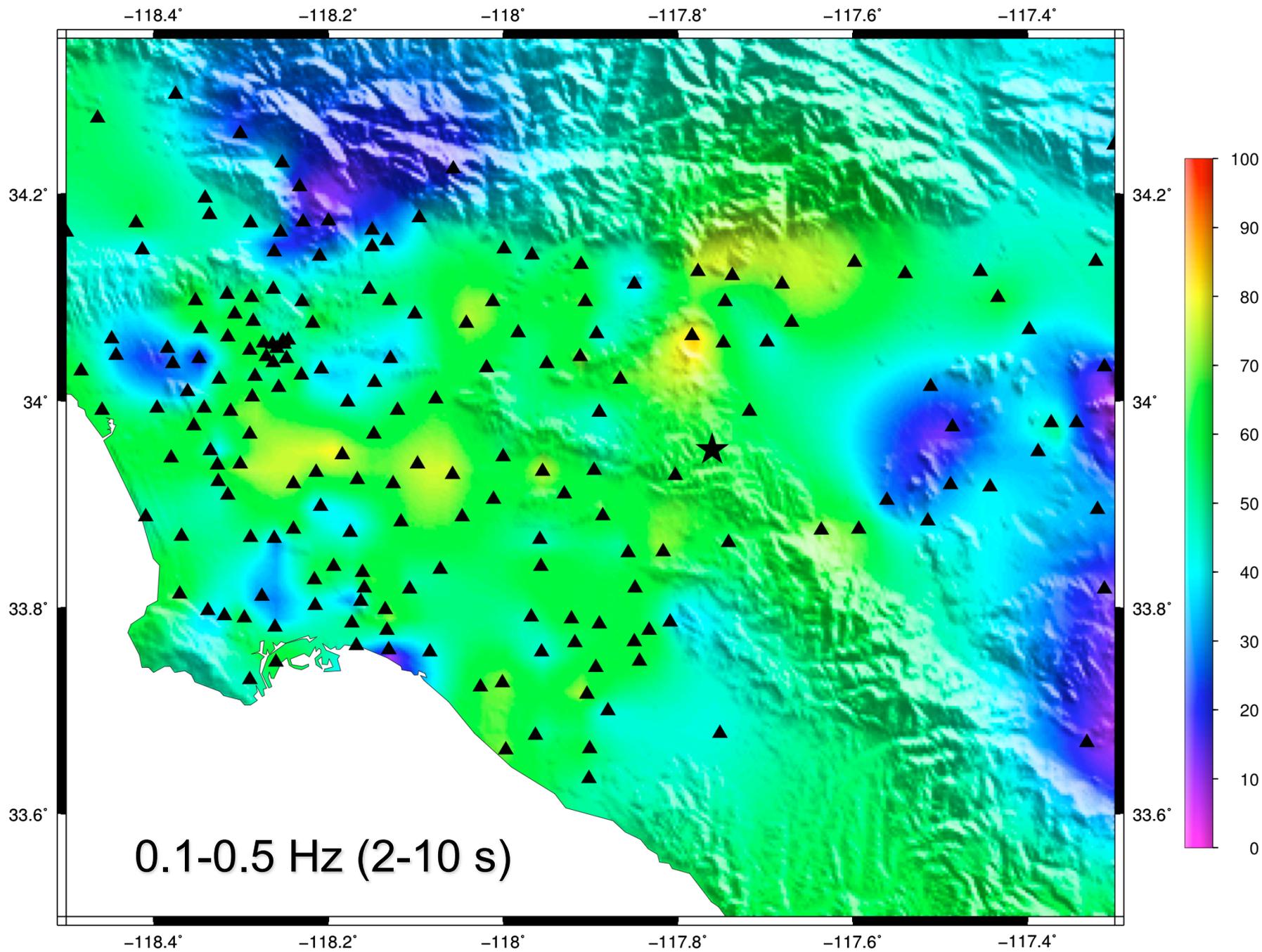
Weights

- User supplies a list of weights (w_i)
- Weights are normalized by the sum of the weights (K_i)
- Normalized weights are applied to each metric GOF value (μ_i) for the overall site and component GOF values
- If appropriate time shifts have been applied, cross-correlation is an option.

Example: 2008 Mw5.4 Chino

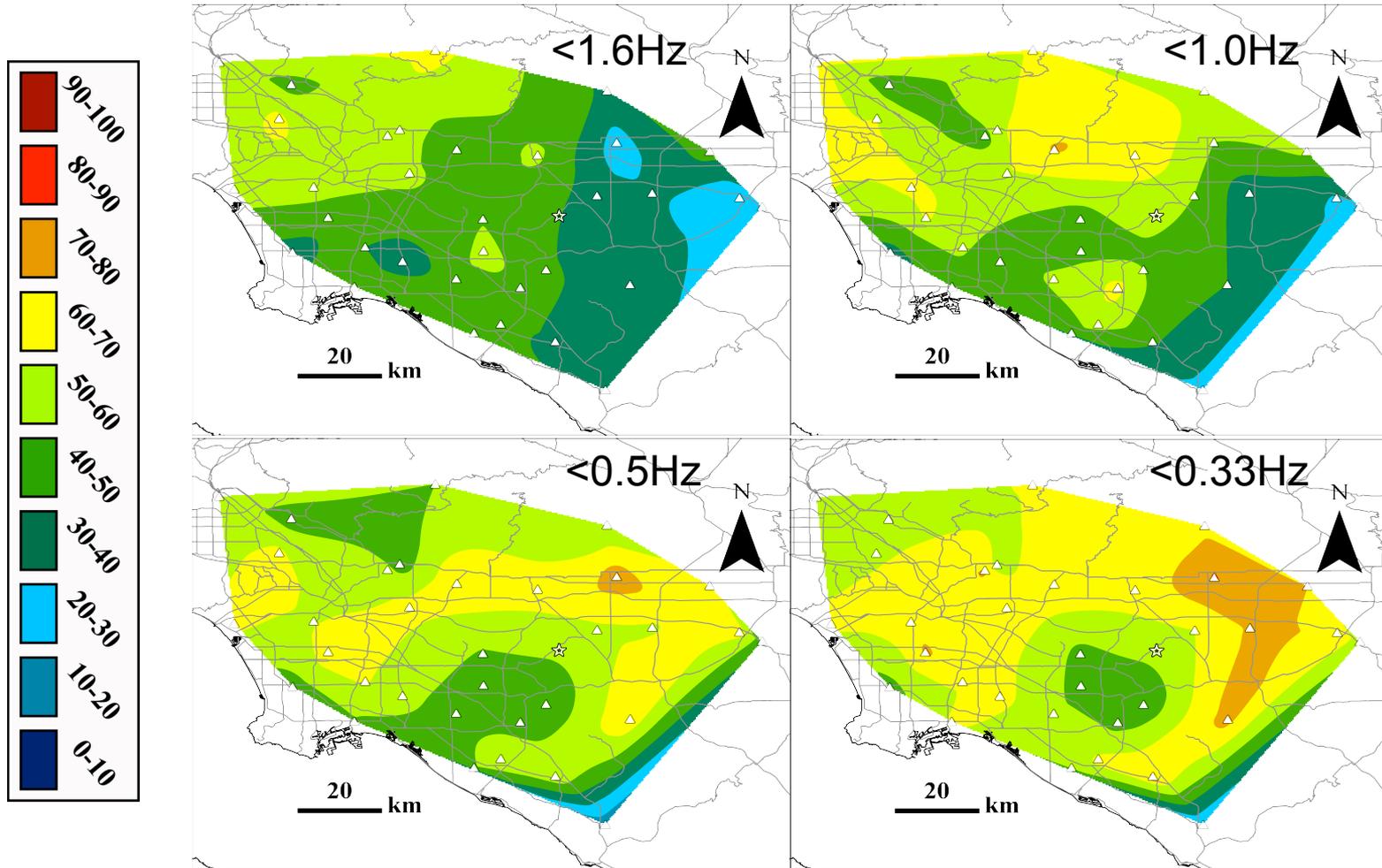
- Metrics applied: Average of Spectral Acceleration, Fourier spectrum, PGA, PGV, PGD, total cumulative energy and energy duration





➤ As expected, the fit tends to improve as the upper cut-off frequency decreases.

'Overall' GOF



Application of GOF_MO to Rupture Dynamics Validation?

1. Peak Acceleration (PGA) (slip acceleration)
2. Peak Velocity (PGV) (slip rate)
3. Peak Displacement (PGD) (slip)
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. Fourier Amplitude Spectrum
11. Shear stress time series

Implement GOF on the comparison site as web-based tool??

WebSims: A Web-based System for Storage, Visualization, and Dissemination of Earthquake Ground-motion Simulations

Kim B. Olsen
 San Diego State University

Geoffrey Ely
 University of Southern California

INTRODUCTION

Synthetic time histories from large-scale three-dimensional dynamic rupture or ground-motion simulations generally constitute large data sets, which typically require hundreds of megabytes, gigabytes or even terabytes of storage capacity (see, e.g., Olsen *et al.* 2008, 2009). For a seismologist analyzing rupture propagation or an earthquake engineer performing seismic hazard analysis, accessing large simulation output can be a tedious and error-prone procedure. For example, manual extractions of synthetic ground-motion records at a few sites of interest, or sliprate functions at desired locations on the fault, are subject to potential misinterpretation of site coordinates, units, or coordinate system orientation. If ground-motion synthetics or source-time functions are requested for a larger area (for example, to analyze site effects or rupture variability) additional problems may arise, such as bandwidth-related transfer delays, compatibility of storage devices used for dissemination, and time-consuming metadata assembly. Finally, the user may need to reformat the synthetics to apply post-processing steps, such as filtering or graphical display.

To circumvent these problems we have developed a user-friendly Web application (WebSims) that allows fast plotting, processing, storage, and dissemination of rupture and ground-motion simulations. WebSims allows interactive access to large multidimensional gridded synthetic data sets. Since there is a unique time history at each grid point for each scenario, static storage of plot images for each point would require extraordinary amounts of disk space. Thus, clearly, plots must be created dynamically. WebSims uses software that allows on-the-fly extraction and plotting of synthetic seismograms via a Web browser.

In terms of plotting and filtering features, but via different software, WebSims builds on a recent Web-based system used for validation of dynamic rupture simulations (Harris *et*

al. 2009). However, an important difference from Harris *et al.*'s software is that WebSims is designed to manipulate large amounts of time series from simulations on a regular grid in a selected geographic area. WebSims also allows the option to simultaneously analyze the sliprate functions on the fault as well as the synthetic seismograms from the radiated waves. This option allows the user to interactively examine the source description for causes of amplification and other remarkable features in the ground-motion simulations. Another important application of WebSims is to facilitate verification of synthetic seismograms. For example, Bielak *et al.* (2009) compared ground velocities at selected sites for three different code bases, analyzing, among other features, the effects of anelastic attenuation, absorbing boundary effects, and media averaging. In the future, such analyses can be greatly facilitated by the availability of systems such as WebSims, which will eliminate the tedious manual handling, reformatting, and dissemination of synthetic time series after a series of simulations that may be required to understand the effects of various model parameters.

DESCRIPTION OF WEBSIMS

WebSims is accessed through a Web browser. The user selects an earthquake scenario from a searchable catalog, which brings up maps of the fault and the area where sliprate histories and ground-motion synthetics, respectively, are available. We use maps of the rupture times, final slip, and peak sliprate distributions to locate the sliprate time histories, and a map of the peak ground velocities (PGVs) to locate the ground-motion histories. By clicking on an arbitrary site location, or by entering the site coordinates in an entry field, the corresponding time series are extracted from the underlying database of synthetics. The user has the option to lowpass filter (zero-phase, two-pole Butterworth) the selected time series to a desired bandwidth, a feature that can be useful in the presence of high-frequency numerical noise. WebSims also has the option to cross-plot time series from several scenarios at a desired site location, which allows the user to map differences in source (rupture time, peak sliprate, rise time, etc.) as well as ground-motion characteristics (arrival times, peak amplitudes, etc.). Below each time series plot, links are provided to download the raw time series data to the user's local disk for further processing or analysis.

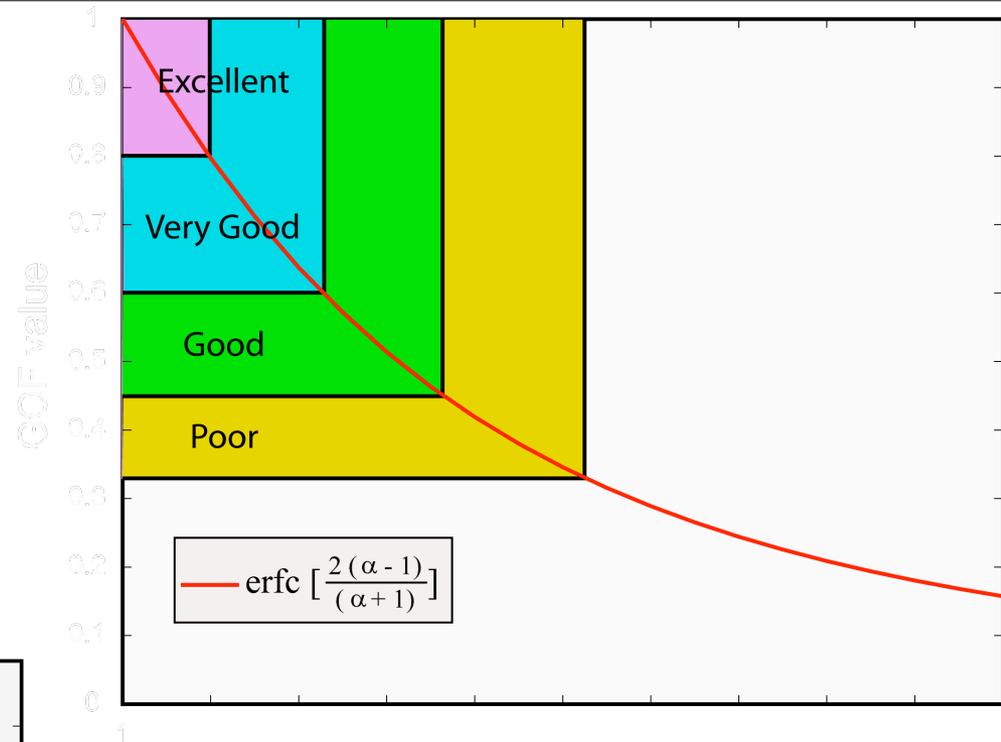
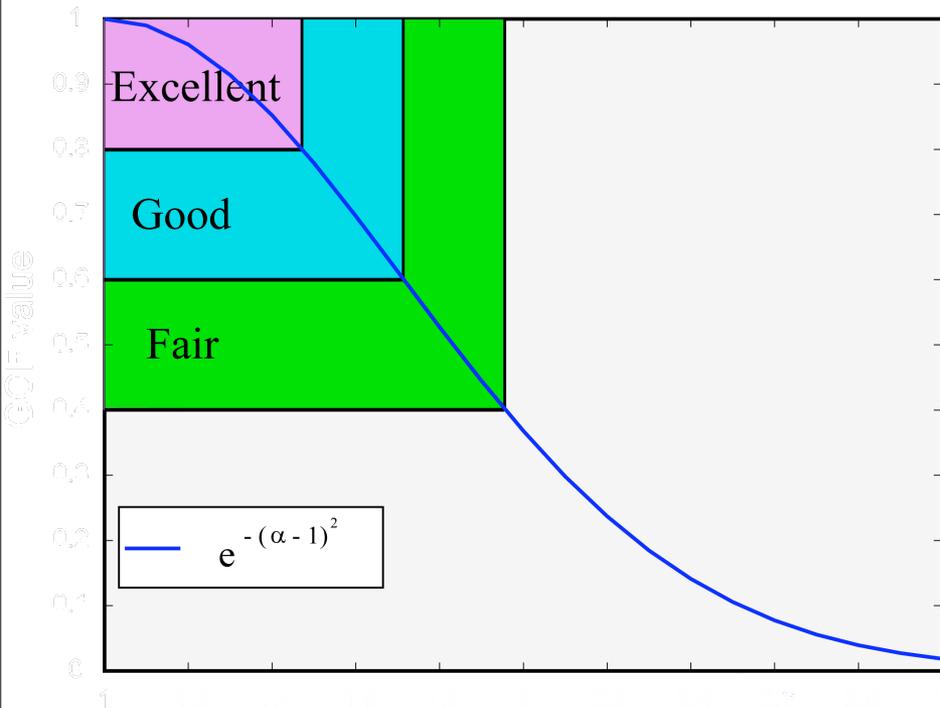
WebSims can also display two-dimensional maps (snapshots) of ground motion or sliprate. The time of the snapshot is selected by clicking the time axis of a time series plot or by using the entry field. The resulting snapshot image can, in turn,

Kim B. Olsen and Geoffrey Ely
WebSims: A Web-based System for Storage, Visualization, and Dissemination of Earthquake Ground-motion Simulations
Seismological Research Letters
80(6): 1002-1007

<http://scec.usc.edu/websims>

Comparison to Anderson (2004)

$10 * GOF_An (\alpha = 1.4724) = 80.0$
 $GOF_MO(\alpha = 1.4552) = 60.0$



$10 * GOF_An (\alpha = 2.0246) = 35.0$
 $GOF_MO(\alpha = 1.9871) = 35.0$