Implementation of Ground Motion Simulation Validation (GMSV) Gauntlets on the Broadband Platform

Report for SCEC Award #15136
Submitted March 31, 2016

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I. Project Overview

A. Abstract

In the box below, describe the project objectives, methodology, and results obtained and their significance. If this work is a continuation of a multi-year SCEC-funded project, please include major research findings for all previous years in the abstract. (Maximum 250 words.)

The SCEC Ground Motion Simulation Validation (GMSV) Technical Activity Group (TAG) aims to develop and implement, via collaboration between ground motion modelers and engineering users, testing/rating methodologies for simulated ground motions to be used in engineering applications. From 2012 to 2014, the GMSV TAG coordinated 20 independent GMSV-related projects funded in response to the annual SCEC request for proposals, as well as 3 complementary projects funded via the SCEC Software Environment for Integrated Seismic Modeling project. At a 2014 progress and planning workshop of the GMSV TAG, the need for a multi-PI collaborative project that builds on the knowledge from these previous projects was discussed. Our project has begun to fill this need by implementing a "gauntlet" of 10 previously-published ground motion validation parameters and corresponding empirical ground motion models on the SCEC Broadband Platform (BBP). Our focus on relatively simple validation parameters (e.g., strong motion duration) and the Broadband Platform is consistent with recommendations from the initial planning workshop of the GMSV TAG in 2011. Our report documents (i) a web conference of the GMSV TAG by which the suite of validation parameters to be implemented on the BBP was selected, (ii) an in-person meeting of the GMSV TAG that discussed the validation comparisons to be made with the implemented ground motion parameters, and (iii) a GMSV TAG workshop where the implemented validation parameters and comparisons were demonstrated to developers and users of the BBP. A GMSV TAG wiki that further documents our BBP implementations is in preparation.

B. SCEC Annual Science Highlights

Each year, the Science Planning Committee reviews and summarizes SCEC research accomplishments, and presents the results to the SCEC community and funding agencies. Rank (in order of preference) the sections in which you would like your project results to appear. Choose up to 3 working groups from below and re-order them according to your preference ranking.

Ground Motion Simulation Validation (GMSV)
Ground Motion Prediction (GMP)
Community Modeling Environment (CME)

C. Exemplary Figure

Select one figure from your project report that best exemplifies the significance of the results. The figure may be used in the SCEC Annual Science Highlights and chosen for the cover of the Annual Meeting Proceedings Volume. In the box below, enter the figure number from the project report, figure caption and figure credits.

Please see the last page of the project report, which was prepared by Nicolas Luco for Greg Beroza and his presentation of the SCEC Science Accomplishments at the 2015 SCEC Annual Meeting. The slides summarizes the published ground motion validation parameters that this project has (or will in the case of the ratio of inelastic over elastic spectral displacement) implemented on the SCEC Broadband Platform.

D. SCEC Science Priorities

In the box below, please list (in rank order) the SCEC priorities this project has achieved. See *https://www.scec.org/research/priorities* for list of SCEC research priorities. *For example: 6a, 6b, 6c*

6e

E. Intellectual Merit

How does the project contribute to the overall intellectual merit of SCEC? *For example: How does the research contribute to advancing knowledge and understanding in the field and, more specifically, SCEC research objectives? To what extent has the activity developed creative and original concepts?*

The simulation of earthquake ground motions allows for physics-based interpolation/extrapolation of the relatively limited amount of available earthquake rupture and ground motion data. Validation of such models, the focus of the SCEC Ground Motion Simulation Validation (GSMV) Technical Activity Group (TAG), is both a fundamental challenge and a necessity for understanding the threat of earthquake ground motions.

F. Broader Impacts

How does the project contribute to the broader impacts of SCEC as a whole? *For example: How well has the activity promoted or supported teaching, training, and learning at your institution or across SCEC? If your project included a SCEC intern, what was his/her contribution? How has your project broadened the participation of underrepresented groups? To what extent has the project enhanced the infrastructure for research and education (e.g., facilities, instrumentation, networks, and partnerships)? What are some possible benefits of the activity to society?*

Through collaboration of earthquake scientists and engineers, the SCEC Ground Motion Simulation Validation (GMSV) Technical Activity Group (TAG) advances the use and understanding of simulated ground motions for engineering applications. Reciprocally, the GMSV TAG improves the science and products of ground motion simulation.

G. Project Publications

All publications and presentations of the work funded must be entered in the SCEC Publications database. Log in at *http://www.scec.org/user/login* and select the Publications button to enter the SCEC Pubications System. Please either (a) update a publication record you previously submitted or (b) add new publication record(s) as needed. If you have any problems, please email *web@scec.org* for assistance.

II. Technical Report

Please see the attached PDF.

2015 Virtual Coordination Workshop

From GMSV Wiki

Objective: To coordinate and obtain feedback on the plans of the *2015* SCEC GMSV TAG research projects (http://collaborate.scec.org/gmsv/Main_Page#Current_Projects) .

PLEASE NOTE: Presentation slides below are the author's property. They may contain unpublished or preliminary information and should only be used while viewing the talk.

Contents

August 27, 2015

Purpose: To coordinate and obtain feedback on 2015 SCEC GMSV TAG research projects.

Agenda:

- Elaboration on purpose of web conference (Luco, ~5 minutes)
- Plans for and progress of "A working group on modeling and integration of the geotechnical layer in SCEC simulations" (Taborda, ~15 minutes) (http://collaborate.scec.org/gmsv_wiki/images/Gmsv-august-site-effects.pdf)
- Discussion (All, ~10 minutes)
- Plans for and progress of "Near source broadband ground-motion modeling of the Canterbury aftershocks and implications for assessing engineering metrics" (Holden, ~15 minutes) (http://collaborate.scec.org/gmsv_wiki/images/Holden_GMV_august2015.pdf)
- Discussion (All, ~10 minutes)
- Progress of "Validation of simulated ground motions relative to seismic geotechnical engineering demand parameters" (Afshari, ~15 minutes) (http://collaborate.scec.org/gmsv_wiki/images/SCEC_meeting_%28Kioumars%29.pdf)
- Discussion (All, ~10 minutes)
- Plans for and progress of "Including scattering in the UCSB broadband modeling method" (Crempien, ~15 minutes) (http://collaborate.scec.org/gmsv_wiki/images/Crempien_talk.pdf)
- Discussion (All, ~10 minutes)
- Recap of web conference & any action items (Luco, ~10 minutes)

Action Items:

- Holden (and Kaiser) will consider validating their simulations using the "gauntlets" of the Broadband Platform Validation

Study and, once available, the GMSV TAG.

- Afshari (and Stewart) and Crempien (and Archuleta) will further compare their duration validation results, with Rezaeian/Zareian/Zhong as well.

Participants: 1) Kioumars Afshari, UCLA; 2) John Anderson, UNR; 3) Ralph Archuleta, UCSB; 4) Jeff Bayless, AECOM; 5) Jacobo Bielak, CMU; 6) Jorge Crempien, UCSB; 7) Greg Deierlein, Stanford; 8) Caroline Holden, GNS; 9) Iunio Iervolino, UNINA; 10) Haydar Karaoglu, CMU; 11) Ting Lin, Marquette; 12) Nicolas Luco, USGS; 13) Leonardo Ramírez Guzmán, UNAM; 14) Sanaz Rezaeian, USGS; 15) Jian Shi, Caltech; 16) Fabio Silva, SCEC; 17) Andreas Skarlatoudis, AECOM; 18) Jonathan Stewart, UCLA; 19) Ricardo Taborda, Memphis; 20) Farzin Zareian, UCI; 21) Peng Zhong, UCI.

July 30, 2015

Purpose: To coordinate and obtain feedback on 2015 SCEC GMSV TAG research projects.

Agenda:

- Elaboration on purpose of web conference (Luco, ~5 minutes)
- Plans for "Impact of Uncertainty in Magnitude-Area Scaling Relations on BBP Broadband Simulations" (Bayless, ~15 minutes) (http://collaborate.scec.org/gmsv_wiki/images/SCEC2015-MA-Scaling-GMSVPresentation-2015-07-28.pdf)
- Discussion (All, ~10 minutes)
- Plans for "Implementation and validation of the newly developed rupture model generator at SCEC broadband platform" (Dalguer, ~15 minutes) (http://collaborate.scec.org/gmsv_wiki/images/SCEC_GMSV_Tag_July30_Dalguer.pdf)
- Discussion (All, ~10 minutes)
- Recap of web conference & any action items (Luco, ~10 minutes)

Participants: 1) Kioumars Afshari, UCLA; 2) John Anderson, UNR; 3) Jeff Bayless, AECOM; 4) Nenad Bijelic, Stanford; 5) Luis Dalguer, swissnuclear; 6) Iunio Iervolin, Naples; 7) Ting Lin, Marquette; 8) Taojun Liu, Western; 9) Nicolas Luco, USGS; 10) Sanaz Rezaeian, USGS; 11) Fabio Silva, SCEC; 12) Paul Somerville, AECOM; 13) Ricardo Taborda, Memphis; 14) Farzin Zareian, UC Irvine.

June 25, 2015

Purpose: To coordinate and obtain feedback on 2015 SCEC GMSV TAG research projects.

Agenda:

- Elaboration on purpose of web conference (Luco, ~5 minutes)
- Plans for "Utilization and validation of CyberShake ground motions for the nonlinear performance-assessment of tall buildings" (Deierlein & Ling, ~15 minutes) (http://collaborate.scec.org/gmsv_wiki/images/SCEC_webConference_2015_06_25_Stanford_Marquette.pptx.pdf)
- Discussion (All, ~15 minutes)
- Plans for "Comparisons of nonlinear response of multi-degree-of-freedom building models to simulated and recorded ground motions" (Zareian & Zhong, ~15 minutes) (http://collaborate.scec.org/gmsv_wiki/images/Peng_GMSV_TAG_Monthly_Webconference_June_2015_final_version.pdf)
- Discussion (All, ~15 minutes)
- Plans for "Toward a framework for GMSV using attenuation relationships, Part 1: Calibration between NGA-West2 predictions, physics-based synthetics, and data" (Taborda, ~15 minutes) (http://collaborate.scec.org/gmsv_wiki/images/Taborda-gmsv-tag-june-2015.pdf)
- Discussion (All, ~15 minutes)

- Recap of plans for "Implementation of GMSV gauntlets on the Broadband Platform" (Rezaeian & Luco, ~10 minutes) (http://collaborate.scec.org/gmsv_wiki/images/150625-gmsv-multiPI_project.pdf)
- Recap of web conference & any action items (Luco, ~5 minutes)

Participants: 1) Kioumars Afshari, UCLA; 2) John Anderson, UNR; 3) Jeff Bayless, AECOM; 4) Nenad Bijelic, Stanford; 5) Greg Deierlein, Stanford; 6) Ting Lin, Marquette; 7) Nicolas Luco, USGS; 8) Leo Ramirez-Guzman, UNAM; 9) Sanaz Rezaeian, USGS; 10) Fabio Silva, SCEC; 11) Andreas Skarlatoudis, AECOM; 12) Jonathan Stewart, UCLA; 13) Ricardo Taborda, CERI; 14) Farzin Zareian, UC Irvine; 15) Peng Zhong, UC Irvine.

May 21, 2015

Purpose: To obtain feedback on the suite of ground motion parameters (with empirical prediction models) to be implemented on the SCEC Broadband Platform.

Agenda:

- Elaboration on purpose of web conference (Luco, ~10 minutes)
- Plans for "Implementation of GMSV Gauntlets on the Broadband Platform" (Rezaeian, ~15 minutes) (http://collaborate.scec.org/gmsv_wiki/images/150520-gmsv-multiPI_project.pdf)
- Feedback (All, ~20 minutes)
- Intro to other 2015 SCEC GMSV TAG research projects, and tentative schedule of their coordination web conferences (Rezaeian, ~10 minutes) (http://collaborate.scec.org/gmsv_wiki/images/150520-gmsv-2015_projects.pdf)
- Recap (Luco, ~5 minutes)

Action Items:

- Stewart recommended that mean period (Rathje et al, 1998 (http://dx.doi.org/10.1061/(ASCE)1090-0241(1998)124:2(150))) be added to the suite of ground motion parameters to be implemented. Before deciding to do so, it will be compared with a similar parameter from Rezaeian that is already in the suite to be implemented.
- Baker pointed out that, in addition to a seismogram, median elastic displacement is an input to inelastic-to-elastic displacement ratio.

Participants: 1) Kioumars Afshari, UCLA; 2) Jack Baker, Stanford; 3) Nenad Bijelic, Stanford; 4) Greg Deierlein, Stanford; 5) Carmine Galasso, Newcastle; 6) Christine Goulet, PEER; 7) Ting Lin, Marquette; 8) Nicolas Luco, USGS; 9) Sanaz Rezaeian, USGS; 10) Andreas Skarlatoudis, AECOM; 11) Jonathan Stewart, UCLA; 12) Ricardo Taborda, CERI; 13) Farzin Zareian, UC Irvine; 14) Peng Zhong, UC Irvine.

SCEC Project 15136 Meeting

From GMSV Wiki

Organizers: Nico Luco and Sanaz Rezaeian
Date: Monday, September 14, 2015 (17:15-18:45)
Location: Hilton Palm Springs Resort, Oasis II Room, Palm Springs, CA (http://www3.hilton.com/en/hotels/california/hilton-palm-springs-PSPPSHF/index.html)
Participants: See below

Contents

Objective

To discuss the use in validation comparisons of previously-discussed ground motion parameters and empirical ground motion prediction equations that are currently being implemented on the SCEC Broadband Platform.

Agenda

5:15-5:25pm - Welcome and purpose of meeting - Luco

5:25-5:35pm - Overview of GMSV gauntlet implementation project (http://collaborate.scec.org/gmsv_wiki/images/Sanaz-150914-gmsv-multiPI_project.pdf) - Rezaeian

5:35-5:40pm - Questions - All

5:40-5:50pm - Ground motion parameters and GMPE's implemented on Broadband Platform (BBP) (http://collaborate.scec.org/gmsv_wiki/images/Silva_BBP_20150914.pdf) - Silva/Maechling

5:50-5:55pm - Questions - All

5:55-6:05pm - Pseudo spectral acceleration validation comparisons implemented for BBP validation exercise (http://collaborate.scec.org/gmsv_wiki/images/1415_Goulet_BBP_20150908.pdf) - Goulet

6:05-6:10pm - Questions - All

6:10-6:20pm - Validation comparisons to be implemented for newly-implemented ground motion

parameters (http://collaborate.scec.org/gmsv_wiki/images/SCEC-2015-GMSV-Presentation-BBP-Future-Validations-2015-09-11.pdf) - Bayless/Skarlatoudis

6:20-6:40pm - Discussion - All

6:40-6:45pm - Summary of discussion - Luco

Participants

1) John Anderson, UNR; 2) Ralph Archuleta, UCSB; 3) Domniki Asimaki, Caltech; 4) Shima Azizzadeh-Roodpish, Memphis; 5) Jeff Bayless, AECOM; 6) Jacobo Bielak, CMU; 7) Nenad Bijelic, Stanford; 8) Brendon Bradley, Canterbury; 9) Jorge Crempien, UCSB; 10) C.B. Crouse, AECOM; 11) Luis Dalguer, SwissNuclear; 12) Greg Deierlein, Stanford; 13) Carmine Galasso, London; 14) Christine Goulet, PEER/SCEC; 15) Rob Graves, USGS; 16) Caroline Holden, GNS; 17) Mehrdad Hosseini, AECOM; 18) Nicolas Luco, USGS; 19) Phil Maechling, SCEC; 20) Kim Olsen, SDSU; 21) Shahram Pezeshk, Memphis; 22) Hoby Razafindrakoto, Canterbury; 23) Sanaz Rezaeian, USGS; 24) Jian Shi, Caltech; 25) Fabio Silva, SCEC; 26) Paul Somerville, AECOM; 27) Seok Goo Song, KIGAM; 28) Ricardo Taborda, Memphis; 29) Karim Tarbali, Canterbury; *30) Alexandra Tsioulou, London;* 31) Farzin Zareian, UCI; 32) Peng Zhong, UCI

Unable to attend: Jack Baker, Stanford; Mayssa Dabaghi, AU-Beirut; Iunio Iervolino, UNINA; Ting Lin, Marquette; Andreas Skarlatoudis, AECOM; Jonathan Stewart, UCLA

Action Items

- *This year:* Finish implementation of the selected ground-motion parameters (GMP's) and their empirical ground-motion models (GMM's) in the Broadband Platform (BBP).
- *This year:* For the newly-implemented GMP's, make use of the comparisons between simulated and recorded ground motions and empirical GMM's that were developed by the BBP Validation Study for elastic pseudo spectral acceleration.
- *This year:* Post Python codes for the newly-implemented GMP's and previously-developed BBP comparison plots and tables on the GMSV TAG wiki.
- *This year:* Convene a workshop to demonstrate use of the newly-implemented GMP's to compare simulated and recorded ground motions and (newly-implemented) empirical GMM's.
- *Next year:* Consider implementing additional GMP's, e.g., pulse period and amplitude, and a combination of peak ground velocity and peak ground displacement.
- *Next year:* Consider implementing revisions to the Anderson GOF parameter(s) that quantify whether simulated ground motions are larger or smaller than recorded ground motions.
- *Next year:* Develop new comparisons of simulated and recorded ground motions and empirical GMM's, e.g., using Bayesian Model Selection.

- This page was last modified on 2 February 2016, at 00:35.

Workshop on Implementation of GMSV Gauntlets on the Broadband Platform

From GMSV Wiki

Organizers: Nico Luco, Christine Goulet, Andreas Skarlatoudis, Jeff Bayless, Phil Maechling, & Fabio Silva
Date: Monday, February 29, 2016 (10:00-16:00)
Location: SCEC Boardroom, University of Southern California, Los Angeles, CA (https://www.scec.org/contact|)
Participants: See below

Contents

Background & Objectives

One of the current projects of the SCEC Ground Motion Simulation Validation (GMSV) Technical Activity Group (TAG) is "Implementation of GMSV Gauntlets on the Broadband Platform." This multi-PI project is building on knowledge from previous SCEC GMSV projects to implement GMSV parameters beyond pseudo spectral acceleration (e.g., the ratio of maximum-direction to median spectral acceleration; see others in the first presentation posted at http://collaborate.scec.org/gmsv/SCEC_Project_15136_Meeting). The objectives of this workshop are to demonstrate use of the newly implemented parameters (and corresponding empirical prediction models) and to obtain feedback from developers and users of the Broadband Platform.

Agenda

Presentation slides may be downloaded by clicking the title of the presentation. PLEASE NOTE: Files are the author's property. They may contain unpublished or preliminary information and should only be used while viewing the talk.

10:00 - 10:05	Welcome and introductions	*C. Goulet for T. Jordan*
10:05 - 10:15	Overview of "Implementation …" Project	*N. Luco & F. Silva*
10:15 - 10:30	Baker *et al* spectral ground motion parameters	*J. Baker*
10:30 - 10:45	Example results from BBP	*C. Goulet*
10:45 - 11:15	Discussion (may be intertwined with presentations)	*All*
11:15 - 11:30	Rezaeian *et al* time-domain ground motion parameters	*S. Rezaeian*
11:30 - 11:45	Example results from BBP	*J. Bayless*
11:45 - 12:15	Discussion (may be intertwined with presentations)	*All*

12:15 - 12:55	*Lunch*	
12:55 - 13:10	Rezaeian *et al* scalar ground motion parameters	*S. Rezaeian*
13:10 - 13:25	Example results from BBP	*N. Luco*
13:25 - 13:55	Discussion (may be intertwined with presentations)	*All*
13:55 – 14:10	Anderson *et al* goodness of fit	*J. Anderson*
14:10 – 14:25	Example results from BBP	*A. Skarlatoudis*
14:25 – 14:55	Discussion (may be intertwined with presentations)	*All*
14:55 – 15:05	*Break*	
15:05 – 15:15	Next steps, e.g., acceptance criteria	*N. Luco*
15:15 – 15:30	Inter-period correlations for Fourier amplitude spectra	*J. Bayless*
15:30 – 16:00	Discussion (may be intertwined with presentations)	*All*

Participants

In-Person: 1) Kioumars Afshari, UCLA; 2) John Anderson, UNR; 3) Jacobo Bielak, CMU; 4) Nenad Bijelic, Stanford; 5) Greg Deierlein, Stanford; 6) Christine Goulet, SCEC; 7) Rob Graves, USGS; 8) Tran Huynh, USC/SCEC; 9) Ting Lin, Marquette; 10) Nicolas Luco, USGS; 11) Phil Maechling, USC/SCEC; 12) Kim Olsen, SDSU; 13) Fabio Silva, USC; 14) Andreas Skarlatoudis, AECOM; 15) Jonathan Stewart, UCLA; 16) Ricardo Taborda, UMemphis; 17) Farzin Zareian, UCI

Remote: 18) Norm Abrahamson, PG&E; 19) Ralph Archuleta, UCSB; 20) Jack Baker, Stanford; 21) Jeff Bayless, AECOM; 22) Brendon Bradley, UCanterbury; 23) Reagan Chandramohan, Stanford; 24) Jorge Crempien, UCSB; 25) Mayssa Dabaghi, AU-Beirut; 26) Steve Hartzell, USGS; 27) Taojun Liu, CU-Boulder/USGS; 28) Morgan Moschetti, USGS; 29) Sanaz Rezaeian, USGS; 30) Karim Tarbali, UCanterbury; 31) Peng Zhong, UCI

Unable to Participate: Domniki Asimaki (Caltech), Gail Atkinson (Western Ontario), Greg Beroza (Stanford), Douglas Dreger (UC-Berkeley), Tom Jordan (USC/SCEC), Paul Somerville (AECOM)

Action Items

For Baker *et al* spectral ground motion parameters ...

- *ASAP:* Implement ratio of inelastic to elastic spectral displacement and its empirical ground-motion model (GMM) on the BBP.
- *ASAP:* Implement empirical ground-motion model for RotD100/RotD50.
- *ASAP:* Revise BPP bias plotting such that they illustrate RotD100/RotD50 for simulations, recordings, and GMMs, rather than (or in addition to) the ratios of these.
- *ASAP:* Adapt existing BBP bias mapping (for pseudo spectral acceleration) to Baker *et al* spectral GMPs.
- *ASAP:* Consider revising the period range of the BBP figures.
- *Later:* After comparing inter-period correlations for Fourier amplitude vs. response spectra, implement one or both.

- *Later:* Implement 2-D spectral displacement orbit plots (the basis for RotD100/RotD50).
- *Later:* Implement a RotD100 ground motion parameter (GMP) and a corresponding GMM.

For Rezaeian *et al* time-domain ground motion parameters ...

- *ASAP:* Resolve time-step issue so that time-domain GMPs for a recording do not vary when compared with different simulations.
- *ASAP:* Plot time-domain GMPs for all realizations on each BBP figure. Consider plotting both horizontal components on each figure.
- *ASAP:* Consider truncating time series in order to focus on levels of engineering interest.
- *Later:* Consider generating BBP figures for the difference measures epsilon and nu.

For Rezaeian *et al* scalar ground motion parameters ...

- *ASAP:* Add the already-implemented Afshari & Stewart (2016) GMM for duration to the BBP figures.
- *ASAP:* Combine the GMPs for the two horizontal components, e.g. by plotting both on each BBP figure or by taking the geometric mean.
- *ASAP:* Adapt existing BBP bias mapping (for pseudo spectral acceleration) to Rezaeian *et al* scalar GMPs.
- *ASAP:* Consider adding a sixth panel for zeta to the BBP figure. The calculation of zeta is already implemented.
- *ASAP:* Consider implementing source/magnitude-scaling figures. Correct for path/distance (and possibly focal mechanism) in such figures.
- *Later:* Implement a more robust GMM for Arias intensity (e.g., Campbell & Bozorgnia, 2012).
- *Later:* Consider replacing w_mid with mean period from Rathje et al (1998).

For Anderson *et al* goodness-of-fit (GOF) parameters ...

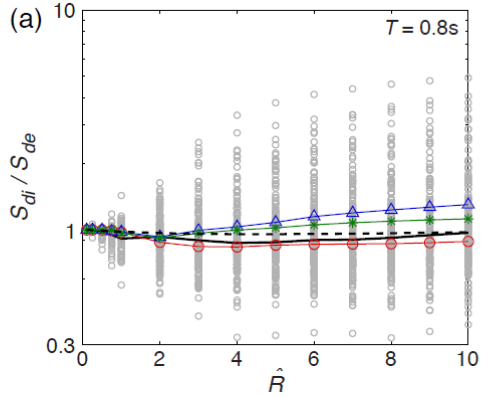
- *ASAP:* QA/verify implementation.
- *ASAP:* Adapt existing BBP bias mapping (for pseudo spectral acceleration) to Anderson et al GOF parameters.
- *Later:* Consider changing the weights used in the current GOF parameters/scores and/or introducing new parameters.

For all parameters ..."

- *ASAP:* Implement a means of distinguishing results from stations with Vs30 "close" to that of the simulations, i.e. 863 m/s.
- *ASAP:* Post Python codes and documentation for parameters and corresponding empirical ground motion models on a SCEC GMSV TAG wiki.
- *Later:* Prepare for post-event "blind" validations.

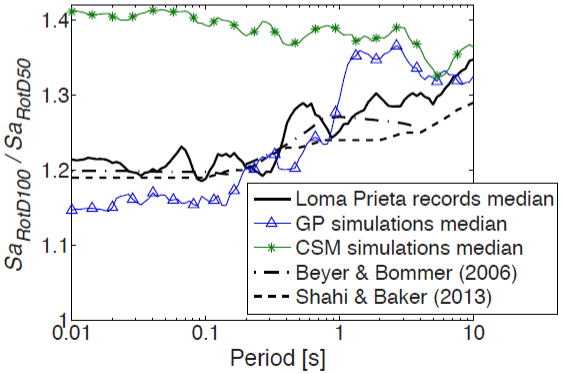
Implementation of Validation Gauntlets …

Inelastic Spectral Displacement
Elastic Spectral Displacement

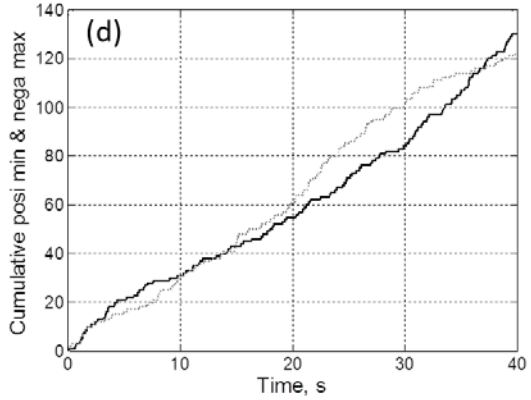


Ground motion parameters important for engineering applications are being implemented on the Broadband Platform

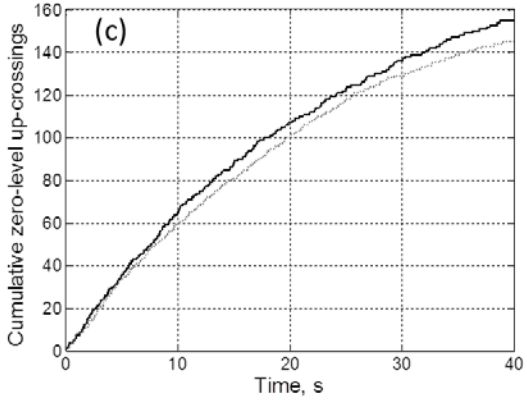
Maximum Horizontal Spectral Acceleration
Median Spectral Acceleration



Evolution of Bandwidth



Evolution of Frequency, Predominant Frequency, & Rate of Change of Frequency with Time



Evolution of Intensity, Arias Intensity, Significant Duration, & Arias Intensity / Significant Duration