2012 SCEC Report

US-Japan Collaboration on Strong Ground Motion Prediction Techniques

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Abstract

1. Implementation of the Irikura Recipe on the SCEC Broadband Strong Motion Simulation Platform

We received a Linux version of the code in which the GUI components had been stripped out. In particular, there was no Linux version of the GUI that is used to construct the earthquake source model, including the discrete asperities. It was therefore necessary to convert the GUI code into Linux. We also needed to adapt the Irikura Recipe to use the standard source representation used on the SCEC Broadband Platform, which is distinctly different from the source representation required as input by the Irikura Recipe.

2. US-Japan Collaboration on Strong Ground Motion Prediction Techniques

We have selected strong ground motion recordings of California earthquakes from the PEER database, and are analyzing average attenuation characteristics of the data using the same regression formula used by our Japanese counterparts. We will compare the regression coefficients that we obtain with those obtained by our Japanese counterparts using Japanese data in the same distance and magnitude range, and compare biases and standard deviations. We have developed earthquake rupture models for a suite of the scenario earthquakes which for magnitudes up to 7.0 are the same ones that are being used in the SCEC Broadband Validation Project to compare the simulations against ground motion prediction equations, which are fairly well constrained by data. We are now preparing to transfer the rupture models of these earthquakes to our Japanese counterparts for their use in their simulation methods, and to receive the rupture models from our Japanese counterparts for us to use in our ground motion simulation method.

Intellectual Merit

The objective of this project is to compare strong motion simulation methods in California and Japan. Each side is simulating the ground motions of scenario earthquakes using their method but with the source parameters developed by the other side for the same scenario. This exchange of source parameters is important because SCEC's experience has been that differences in source characterization are the main causes of differences in ground motion simulations performed using different simulation methods (SDSU, UCSB, and URS) on the SCEC Broadband Ground Motion Simulation Platform. We are also implementing the Irikura Recipe for strong motion simulation, developed in Japan, on the SCEC Broadband Strong Motion Simulation Platform.

Broader Impacts

The SCEC Broadband Platform's SRF file contains a full description of the spatial and temporal evolution of rupture on the fault, which is partly stochastic. In contrast, the Irikura Recipe, which is used in Japan, is based on a deterministic model of asperities embedded within a background zone. This project has expanded the scope of the SCEC Broadband Strong Motion Simulation Platform to include the Irikura Recipe, and increased the understanding of differences in approaches to strong ground motion simulation between California and Japan.

Introduction

This project consists of two components:

1. Implementation of the Irikura Recipe on the SCEC Broadband Strong Motion Simulation Platform

2. US-Japan Collaboration on Strong Ground Motion Prediction Techniques

1. Implementation of the Irikura Recipe on the SCEC Broadband Strong Motion Simulation Platform

The Earthquake Research Committee (ERC) Headquarters for Earthquake Research Promotion of Japan (HERP) published the National Seismic Hazard Maps for Japan (2005) in March 2005 (Fujiwara et al., 2006). The maps include Scenario Seismic Hazard Maps for Specified Seismic Source Faults (ERC, 2006). These maps show the distribution of strong shaking caused by individual earthquakes. To generate these maps, the ERC used the strong ground motion prediction method termed the Irikura Recipe. This method includes a standardized procedure for modeling a source and the subsurface structure, as well as a recommended method for performing the calculations required for predicting strong ground motion. The procedure for source modeling is based on that proposed by Irikura and Miyake (2001a), which has most recently been updated by Irikura and Miyake (2011). The method and all of the parameters that it uses are clearly documented in Irikura and Miyake (2011) and are not repeated here.

The implementation of the Irikura Recipe by NIED is described in a Japanese language manual (NIED, 2011). This method uses stochastic Green's functions, which are most suitable for short period ground motion simulations. The implementation of a newer version of the Irikura Recipe, whose software version will be released at the end of 2013, is described by Morikawa et al. (2011). That version is a hybrid method that combines stochastic Green's functions at short periods with rigorous Green's functions at the longer periods. The median value and random variability of long period ground motions calculated using the long period method has been studied by Yamada et al. (2010).

The computer code for the Irikura Recipe was originally provided by Dr Fujiwara of NIED in the form of a GUI code, which is not compatible with the Linux basis of the SCEC Broadband Platform. It was therefore necessary to generate a Linux version of the code in order to implement it on the Broadband Platform. We received from Dr Fujiwara a Linux version of the code in which the GUI components had been stripped out. In particular, there was no Linux version of the GUI that is used to construct the earthquake source model, including the discrete asperities. It was therefore necessary to convert the GUI code into Linux. We also needed to adapt the Irikura Recipe to use the standard source representation used on the SCEC Broadband Platform, which is distinctly different from the source representation required as input by the Irikura Recipe. We were assisted in both of these major software tasks by Dr Yajie Lee, a former employee of URS now working at ImageCat Inc., Long Beach.

We ran the GUI version of the code and obtained the same result as obtained by NIED for a specified test case. We also compiled the Linux version of the code and verified that the output it produced was the same as that produced by the GUI version of the code for a test case provided by NIED.

Altogether there are three main components of the SCEC Implementation of the NIED version of the Irikura Recipe: Source model, stochastic Green's function calculation, and ground motion synthesis. These three components are now described in turn.

Irikura Recipe Code Components

1) Convert SRF format to Irikura asperity format) [Linux/Windows, prepared by URS]

The SCEC Broadband Platform's SRC file contains the basic geometry of the fault rupture: orientation, length and width. The seismic moment Mw is calculated from the fault area. These parameters are referred to as the "outer parameters" by the Irikura Recipe.

The SCEC Broadband Platform's SRF file contains a full description of the spatial and temporal evolution of rupture on the fault, which is partly stochastic. In contrast, the Irikura Recipe is based on a deterministic model of asperities embedded within a background zone, containing parameters that are referred to as "inner parameters." To adapt the SCEC SRF file to the Irikura Recipe, it was necessary to derive an Irikura asperity model from the stochastic slip distribution provided in the SRF file. This involved the following steps:

Steps:

Resample the SRF file to a standard grid size (2 x 2 km)

Run the asperity picker code ASPICK (Somerville et al., 1999, code prepared by Dr Takao Kagawa) to identify asperities defined by the recipe

Input the asperities into the code that generates sgfsrc.dat Irikura asperity file

Test to demonstrate that the result of this process provides an asperity model that resembles the stochastic slip distribution of the input SRF file.

Requirements:

- CSV file: defines fault geometry
    - Built from SRC file. [Matlab]
- INI file: lists many parameters
    - Built from SRC file, Vmod file, SRF file [Matlab]
- SRF file

The output is:

- sgfsrc.dat file: rupture asperity output

2) Stochastic Green's Function Calculation: statgreen [C++, prepared by NIED]

Requirements:

- fault parameter file:
- station file: lists lat, lon, station name
    - Built from BBP station list. [Matlab]
- velocity model file: in 3D
    - Built from 1D BBP model [Matlab]
- PHASE.DAT: specifies phase spectrum.

The output is:

- GF's for each site

3): Ground Motion Synthesis: greenscale [C++; prepared by NIED]

Requirements:

- sgfsrc.dat file: from step 1
- station file: same as from step 2
- fault parameter file: same as from step 2

The output is:

- one acceleration seismogram, and one filtered and unfiltered velocity seismogram at each site

Example Implementations

Example implementations of the Irikura Recipe for the Loma Prieta and Northridge Earthquakes are given in Appendix 1, listing input parameters and showing goodness of fit figures.

2. US-Japan Collaboration on Strong Ground Motion Prediction Techniques

The purpose of this project is to complete our collaboration with Japanese colleagues in the comparison of strong motion prediction techniques, begun in our existing project. The Japanese side of the collaboration is headed by Professor Hiroshi Kawase of Kyoto University and funded by the Japan Society for the Promotion of Science.

Objectives

The plan for this collaborative project was prepared by Professor Hiroshi Kawase of Kyoto University. The funding for the Japanese collaborators comes from JSPS. There are two main objectives of the project. The first, which is Part 2 of the JSPS Research Plan, is to compare the strong motion simulation methods of the two sides. Specifically, each side will simulate the ground motions of scenario earthquakes using their method but with the source parameters developed by the other side for the same scenario. This exchange of source parameters is important because SCEC's experience has been that differences in source characterization are the main causes of differences in ground motion simulations performed using different simulation methods (SDSU, UCSB, and URS) on the SCEC Broadband Ground Motion Simulation Platform. Exchanging the source parameters will facilitate identification of the differences between the simulation methods. We plan to do all of the ground motion simulations for this project on the SCEC Broadband Ground Motion Simulation Platform An important aspect of these simulations is their representation of site amplification effects, as described further below.

The second main objective, which is Part 1 of the JSPS Research Plan, is for each side to compare the level, rate of attenuation, and random variability (sigma) of their simulated ground motions with those of recorded strong motion data, as represented by ground motion prediction models (GMPE's) such as the NGA west models (Abrahamson et al., 2008). This will serve to identify whether there are systematic differences between Japanese and California ground motions, both recorded and simulated. We will focus on differences both in their median ground motion values and in their random variability (sigma). This objective is consistent with the consensus that was reached at the SCEC Ground Motion Simulation Validation (GSMV) Planning Workshop, held on January 10, 2011, that SCEC should validate their broadband simulations against GMPE's in parallel with validation against recorded ground motions from discrete past earthquakes, because the credibility of strong motion simulations would be enhanced if they were shown to be consistent with ground motion prediction equations such as the NGA models.

Background

It is commonly assumed that ground motions of shallow crustal earthquakes in different tectonically active regions are similar. For example, the NGA ground motion prediction equations are based on a worldwide strong motion data set of crustal earthquakes in tectonically active regions. The P.I.'s were involved in the development of ground motion prediction equations for shallow crustal earthquakes in Japan (Zhao et al., 2006a), which are used by the USGS in generating the US National Seismic Hazard Maps. However, these models used a different method (site period derived from H/V response spectral ratio; Zhao et al., 2006b) for representing site amplification effects instead of Vs30 (the average shear wave velocity in the upper 30 meters) used in the NGA models. This makes it difficult to compare the Zhao et al. (2006a) model with the NGA models, which are also not representative of California alone.

Because of the abundance and high quality of the Japanese data (including both surface and downhole recordings) and metadata (especially site characteristics) from K-Net and Kik-net, many investigators have analyzed the random variability in those data. For example, the P.I.'s (Goulet and Bayless, 2011) compared sigma at the surface of stiff sites with that in downhole sites, and did not find large differences. It is commonly understood that there are systematic differences in site amplification characteristics between Japan and California for sites having the same Vs30 value, which may be attributable to systematic differences in shear wave velocity profiles, with typical Japanese profiles showing a stronger gradient from softer soils to harder rock than in California. For example, Atkinson and Casey (2003), Oth et al. (2011) and Ghofrani et al. (2012, in press) have observed site response characteristics in Japan, including significant high frequency amplification, that are different from those in California. These differences will be carefully considered, because they have the potential to cause differences in both median ground motion values and in their random variability (sigma) between Japan and California.

Project Meetings

We held the kickoff meeting of this project in Santa Barbara in August 2011, and met with our Japanese counterparts at the 2012 AGU Meeting to discuss progress made during the first year of the project, and to develop a work plan for the second year of the project.

Part 1. Empirical Approach

We have selected strong ground motion recordings of California earthquakes from the PEER database, and are analyzing average attenuation characteristics of the data using the same regression formula used by our Japanese counterparts. We are coordinating with our Japanese counterparts in the representation if site amplification effects in the analysis of the data. We will compare the regression coefficients that we obtain with those obtained by our Japanese counterparts using Japanese data in the same distance and magnitude range, and compare biases and standard deviations.

Part 2. Simulation Approach

We have developed earthquake rupture models for a suite of the scenario earthquakes listed in Table 1. For magnitudes up to 7.0, these earthquakes are the same ones that are being used in the SWUS project to compare the simulations against ground motion prediction equations, which are fairly well constrained by data. The earthquakes for magnitudes larger than 7 are designed to provide a comparison between the simulation procedures for earthquakes whose ground motions are not well constrained by data. We are now preparing to transfer the rupture models of these earthquakes to our

Japanese counterparts for their use in their simulation methods, and to receive the rupture models from our Japanese counterparts for us to use in our ground motion simulation method.

Table 1: Scenario Earthquake Parameters

Mw	Mech	Dip	Depth to Top
6.2	Strike-slip	90	3
6.6	Reverse	45	4
6.6	Reverse	45	0
7	Strike-slip	80	0
7.5	Strike-slip	80	0
7.5	Reverse	45	0
8.0	Strike-slip	80	0

Our Japanese counterparts have prepared an easy method for generating inner-fault parameters based on the Irikura Recipe from outer-fault parameters, which can be used in theoretical and semi-empirical strong motion simulation. They have also prepared the standard semi-empirical simulation software based on the Kawabe-Kamae formulation, together with the simple hybrid software in order to combine simulated ground motions in the short period range with theoretical ones in the long period range. They also constructed empirical site amplification factors from the engineering bedrock level to the soft soil surface for different ranges of Vs30. They are now validating these software sets with the strong motion data for several damaging crustal earthquakes in Japan. In the meantime they are preparing to use the SCEC methodology in the strong motion prediction for the same earthquakes.

Related Work

Paul Somerville is currently assisting SCEC in the SWUS project, which involves the implementation of four additional strong motion simulation procedures: Irikura Recipe; Composite Source Model (John Anderson), EXSIM (Gail Atkinson), and Point Source Stochastic (Dave Boore) on the Broadband Platform (Attachment 2), validation of these as well as three existing simulation methods, and their use in simulation of strong ground motions for three nuclear power plant sites in California and Arizona. In previous work, the PI's, working with Phil Maechling, have been heavily involved in the construction of the SCEC Broadband Strong Motion Simulation Platform and in the testing and validation of multiple ground motion simulation procedures on it.

References

Fujiwara, Hiroyuki, Shinichi Kawai, Shin Aoi, Nobuyuki Morikawa, Shigeki Senna, Kyoko Kobayashi, Toru Ishii, Toshihiko Okumura and Yuzuru Hayakawa (2006). National Seismic Hazard Maps of Japan. Bull. Earthq. Res. Inst. Univ. Tokyo Vol. 81, p. 221-232. http://www.eri.u-tokyo.ac.jp/BERI/pdf/IHO81304.pdf

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Irikura, K. and H. Miyake (2011). Recipe for Predicting Strong Ground Motion from Crustal Earthquake Scenarios, Pure Appl. Geophys. 168 (2011), 85–104. DOI 10.1007/s00024-010-0150-9.

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Yamada, M., S. Senna, and H. Fujiwara (2011). Statistical Analysis of Ground Motions Estimated on the Basis of a Recipe for Strong-motion Prediction: Approach to Quantitative Evaluation of Average and Standard Deviation of Ground Motion Distribution. Pure Appl. Geophys. 168 (2011), 141–153. DOI 10.1007/s00024-010-0159-0

Appendix 1. Example Implementations of the Irikura Recipe

A. Loma Prieta earthquake

1) 'make_param.exe'

- **CSV file**:
  - Mw = -6.94
  - Fault endpoint lon/lat = -121.644 36.968
  - Ztor (km) = 3.85
  - L, W (km) = 40 18
  - Strike, Dip (degree) = 128 70
  - Origin Type = 1
  - Number of Asperities = 1
- **INI file:**
  - 'Ro_sb' = 2650
  - 'Vs_sb' = 3250
  - 'Mo_s' = 1.61E+17
  - 'Sigma_s' = 2.640
  - 'Rad_pat' = 0.4384
  - 'D_s' = 1.434
  - 'Vs_pq' = 3250
  - 'Myu' = 2.80E+10
  - 'DesVel' = 0.72*(Vs at hypocenter) = 2340
  - 'Ro_pq' = 2650
- **SRF file:** lomap_v12_8_0_fs.srf
- **Fault file:** LP _sgfsrc.dat
  - Min/max stress: 3.32/17.99
  - Min/max slip: 1.068/3.170

2) statgreen [C++]

- **fault parameter file**
  - 'FAULT-PLANE-CENTER-LATITUDE/LONGITUDE' = 37.05769 -121.861763
  - 'FAULT-PLANE-CENTER-DEPTH(GL-m)' = 8222.3104
  - 'HYPOCENTER-LATITUDE/LONGITUDE' = 37.04314364 -121.87599441
  - 'HYPOCENTER-DEPTH(GL-m)' = 17710.4662
  - 'SAMPLING-FREQUENCY(Hz)' = 120
  - 'SAMPLING-TIME(sec)' = 120

- ‘ELEMENT-DENSITY(g/cm3)’ = 2.65
- ‘SEISMIC-BEDROCK-DENSITY(g/cm3)’ = 2.65
- ‘ELEMENT-SWAVE-VELOCITY(m/sec)’ = 3.25
- ‘SEISMIC-BEDROCK-SWAVE-VELOCITY(m/sec) ’ = 3.25
- ‘ELEMENT-MOMENT(Mos) ’ = 1.61E+17
- ‘ELEMENT-STRESS-DROP(PA)’ = 2.64E+17
- ‘RADIATION-PATTERN’ = 0.4384
- ‘FMAX’ = 6.0
- ‘M’ = 5.437
- ‘Q-VALUE(A1)’ = 100
- ‘Q-VALUE(A2) Q = A4(A3 > f(Hz))’ = 0.69
- ‘Q-VALUE(A3)’ = 1.0
- ‘Q-VALUE(A4)’ = 200.0
- ‘L(km)’ = 2.0
- ‘W(km)’ = 2.0
- ‘Ds’ = 1.434012
- ‘myu’ = 2.80E+10
- ‘Vr’ = 0.72*(Vs at hypocenter) = 2.340
- ‘offset’ = 0.0

- **velocity model file:**
  - Trimmed to depth of 3850 m (which is equal to fault’s Ztor)
  - X-axis coordinate ranges from 0-199
  - Y-axis coordinate ranges from 0-199
- **PHASE.DAT:** random phase, copied from original example package.

Result

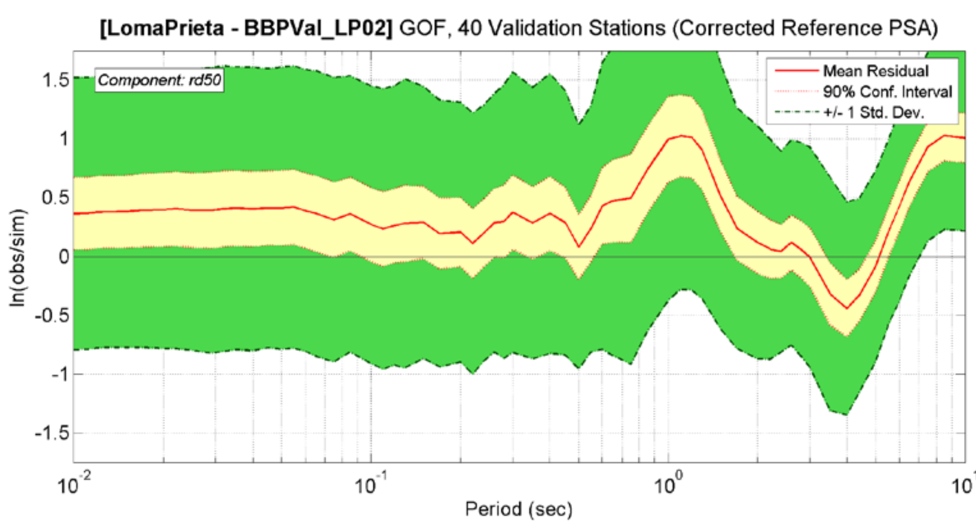

Figure 1. Goodness of fit of recorded response spectra, corrected to hard rock site conditions, to ground motions simulated using the Irikura Recipe for 40 stations of the 1989 Loma Prieta

earthquake. The red line shows the mean residual, and the yellow bands show the 90% confidence interval of the mean. This shows that there is no significant bias in the prediction of the recorded response spectra for periods between 0.01 and 0.6 seconds and 2 to 3 seconds, and the simulations underpredict the recorded response spectra at other periods. The green bands show the standard deviation of a single measurement.

B. **Northridge Earthquake**

1) 'make_param.exe'

- **CSV file**:
    - Mw = -6.73
    - Fault endpoint lon/lat = -118.423 34.2963
    - Ztor (km) = 5.0
    - L, W (km) = 20 26
    - Strike, Dip (degree) = 122 40
    - Origin Type = 1
    - Number of Asperities = 1
- **INI file:**
    - 'Ro_sb' = 2700
    - 'Vs_sb' = 2800
    - 'Mo_s' = 1.17E+17
    - 'Sigma_s' = 2.640
    - 'Rad_pat' = 0.4384
    - 'D_s' = 1.3779
    - 'Vs_pq' = 2800
    - 'Myu' = 2.12E+10
    - 'DesVel' = 0.72*(Vs at hypocenter) = 2016
    - 'Ro_pq' = 2700
- **SRF file:** nr_v12_11_0_fs.srf
- **Fault file:** NR_sgfsrc.dat
    - Min/max stress: 4.22/34.94
    - Min/max slip: 1.142/2.519

2) statgreen [C++]

- **fault parameter file**
    - 'FAULT-PLANE-CENTER-LATITUDE/LONGITUDE' = 34.271250 -118.570001
    - 'FAULT-PLANE-CENTER-DEPTH(GL-m)' = 8002.7057
    - 'HYPOCENTER-LATITUDE/LONGITUDE' = 34.20206011 -118.54530479
    - 'HYPOCENTER-DEPTH(GL-m)' = 17470.0796
    - 'SAMPLING-FREQUENCY(Hz)' = 120
    - 'SAMPLING-TIME(sec)' = 120
    - 'ELEMENT-DENSITY(g/cm3)' = 2.70
    - 'SEISMIC-BEDROCK-DENSITY(g/cm3)' = 2.70

- 'ELEMENT-SWAVE-VELOCITY(m/sec)' = 2.80
- 'SEISMIC-BEDROCK-SWAVE-VELOCITY(m/sec) ' = 2.80
- 'ELEMENT-MOMENT(Mos) ' = 1.17E+17
- 'ELEMENT-STRESS-DROP(PA)' = 2.64E+17
- 'RADIATION-PATTERN' = 0.4384
- 'FMAX' = 6.0
- 'M' = 5.345
- 'Q-VALUE(A1)' = 100
- 'Q-VALUE(A2) Q = A4(A3 > f(Hz))' = 0.69
- 'Q-VALUE(A3)' = 1.0
- 'Q-VALUE(A4)' = 200.0
- 'L(km)' = 2.0
- 'W(km)' = 2.0
- 'Ds' =1.377866
- 'myu' = 2.12E+10
- 'Vr' = 0.72*(Vs at hypocenter) = 2.016
- 'offset' = 0.0

- **velocity model file:**
  - Trimmed to depth of 5000 m (which is equal to fault's Ztor)
  - X-axis coordinate ranges from 0-199
  - Y-axis coordinate ranges from 0-199
- **PHASE.DAT:** random phase, copied from original example package.

Result

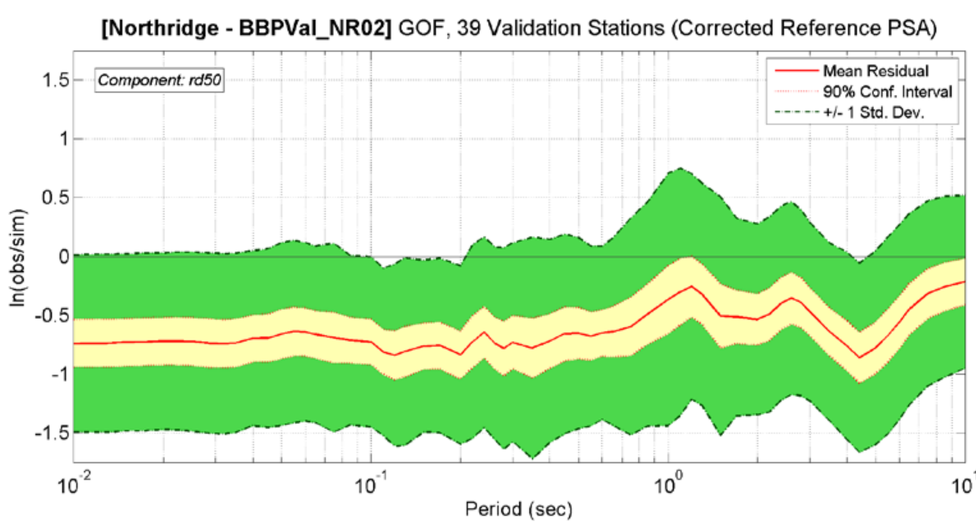

Figure 2. Goodness of fit of recorded response spectra, corrected to hard rock site conditions, to ground motions simulated using the Irikura Recipe for 39 stations of the 1994 Northridge earthquake. See Fig.1 for explanation. The recorded ground motions are significantly overpredicted at all periods.