Recent Advances in Development of Ground Motion Prediction Equations

Yousef Bozorgnia, Ph.D., P.E.

Executive Director,

Pacific Earthquake Engineering Research Center (PEER),

University of California, Berkeley

Ground Motion "Mega" Research Projects at PEER

- **NGA-West2**
  - Ground motion hazard in active tectonic regions
- **NGA-East**
  - Ground motion hazard in low seismicity regions
- **NGA-Sub**
  - Ground motion hazard in Subduction regions
- **GEM**
  - Global Earthquake Model

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NGA-West2

Next Generation Attenuation (NGA) Models for Shallow Crustal Earthquakes in Active Tectonic Regions

NGA-West1

- **NGA-West1 (Original NGA Project)**
  - PEER compiled a very comprehensive **database** of ground motions recorded in **shallow crustal earthquakes in active tectonic regions**
  - Numerous **supporting research studies** were also carried out
  - In 2008, Next Generation Attenuation (**NGA**) ground motion prediction equations (**GMPEs**) were developed
  - USGS adopted the NGA-West1 GMPEs for the US National Seismic Hazard Maps
  - **NGA-West2 is a follow-up of NGA-West1**

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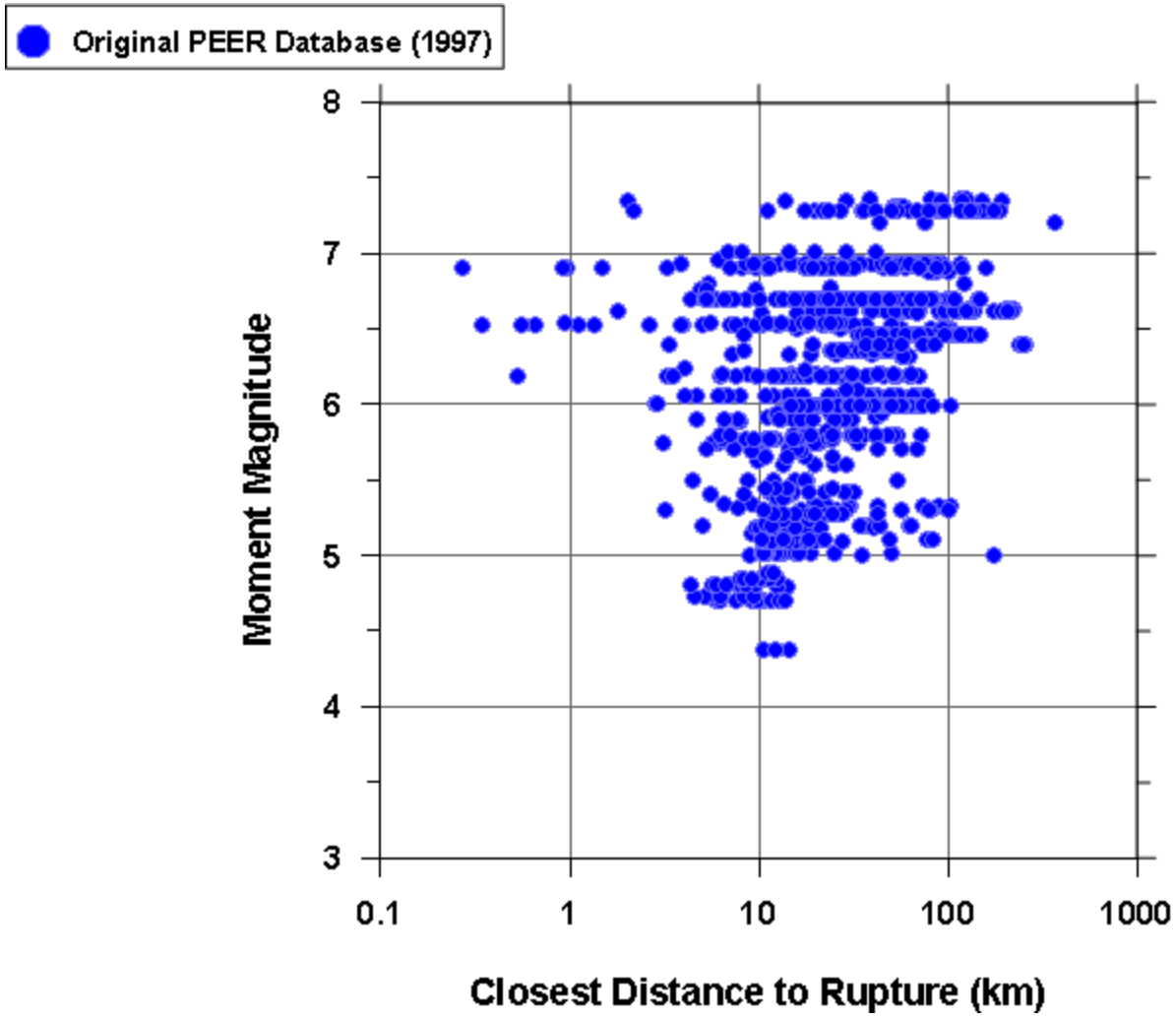
NGA-West2 Sub-Projects

Update worldwide database



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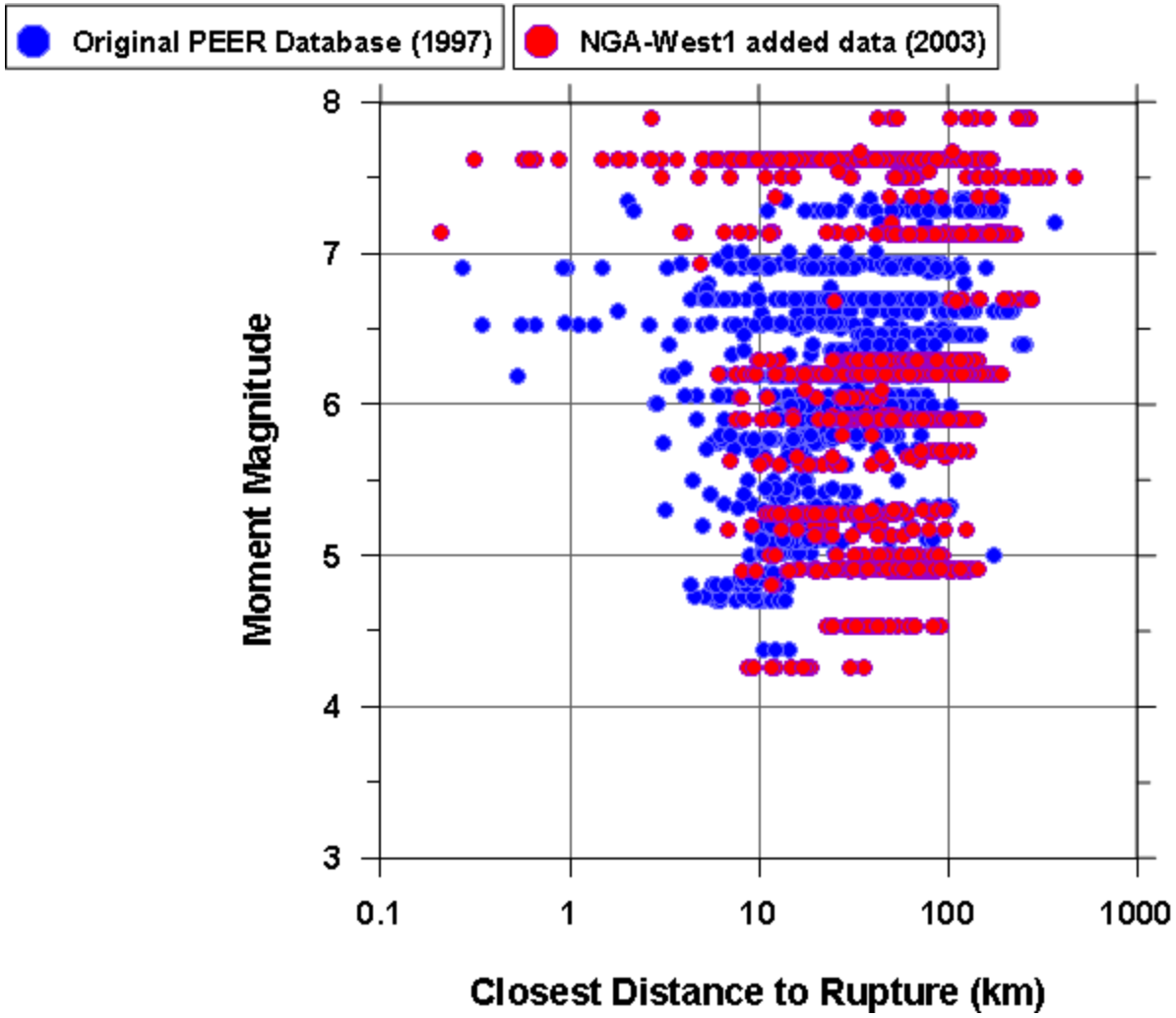

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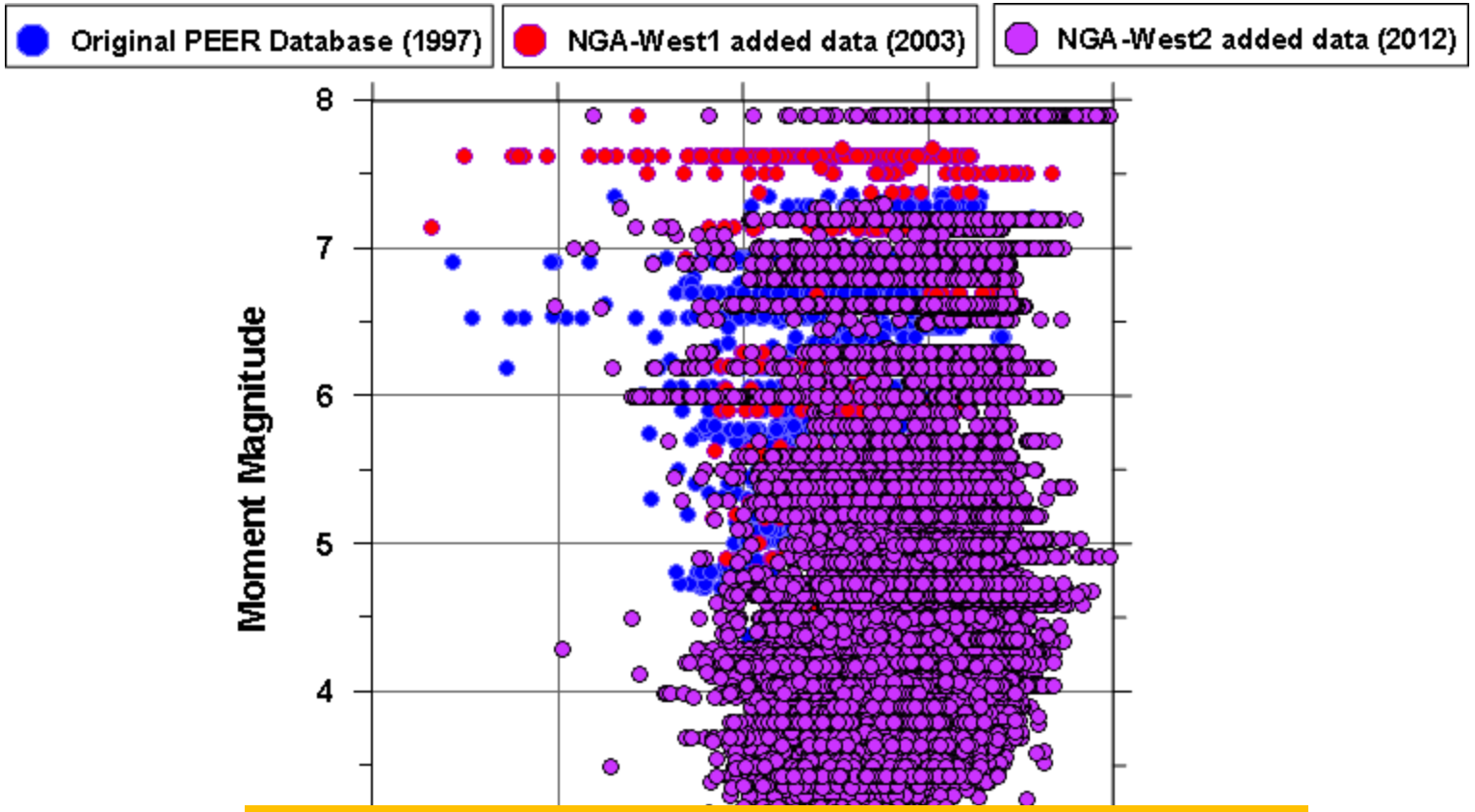
Update worldwide database



NGA-West2 database includes over 21,000 three-component recordings… over 63,000 records

From NGA-West1 to NGA-West2 the size of database was increased by a factor of 5.5

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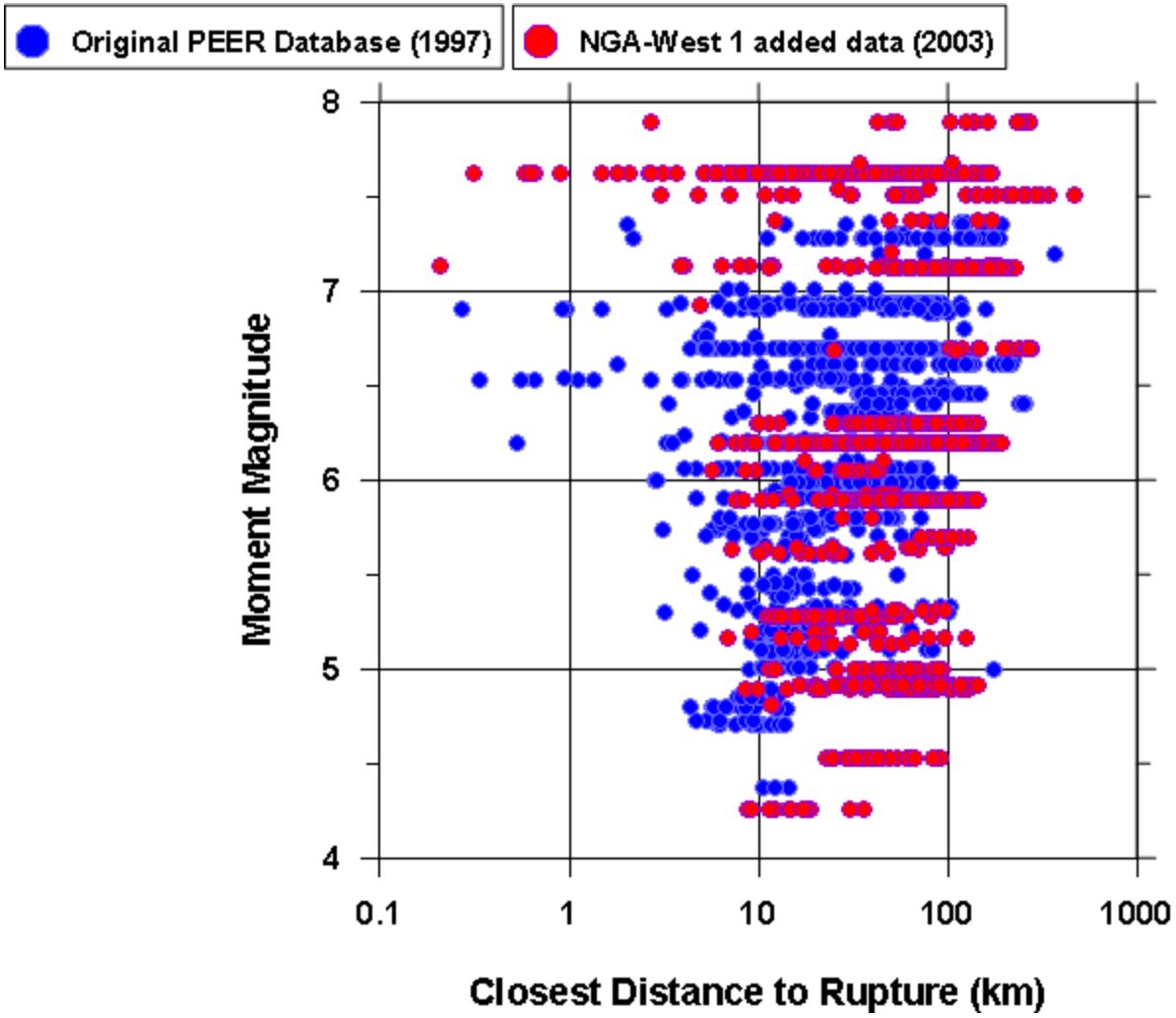
Moderate-to-large magnitude worldwide database



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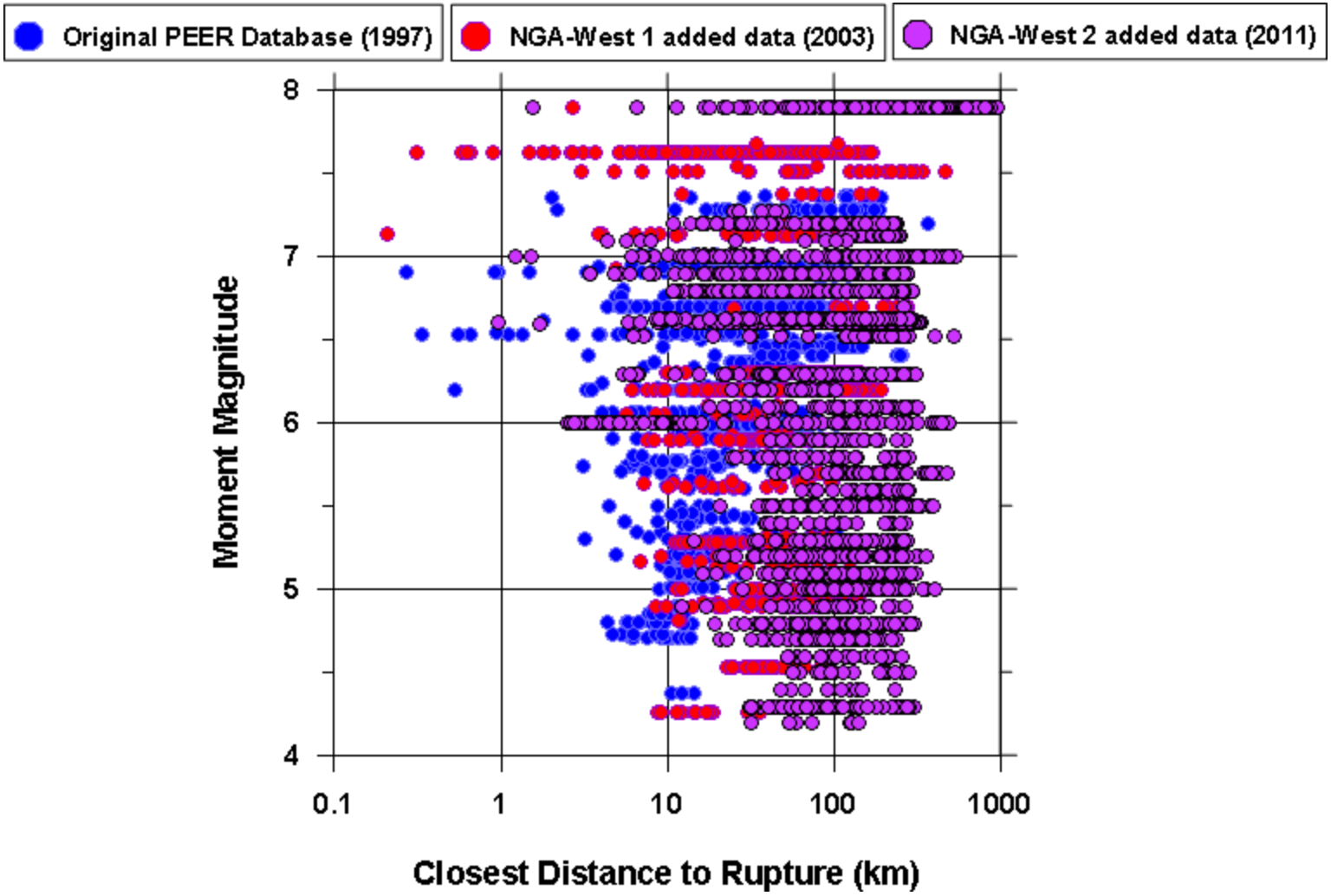
Moderate-to-large magnitude worldwide database



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Examples of data added to NGA-West2 database

Earthquake Name*	Year	M	N Rec	Rrup Range (km)
Tottori, Japan	2000	6.61	414	1-333
Niigata, Japan	2004	6.63	530	8-300
Chuetsu-oki, Japan	2007	6.8	616	10-300
Iwate, Japan	2008	6.9	367	5-280
El Mayor-Cucapah, CA	2010	7.2	238	11-240
Darfield, New Zealand	2010	7	114	1-540
Christchurch, New Zealand	2011	6.1	104	2-440
Wenchuan, China	2008	7.9	263	1-1500
L'Aquila, Italy	2009	6.3	48	5-230

*subset of added events

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Comparison of NGA-West1 & NGA-West2 databases

Data Set	# EQs	# Rec	Sa Type	Damping	Periods (sec)
NGA-West1	173	3,551	AR, GMRotI50	5%	0.01 - 10
NGA-West2	610	19,400	AR, RotDnn	0.5-30%	0.01 - 20

AR= As-recorded

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RotDnn definition

- At each period, rotate horiz. components,
- RotD**50** = 50 percentile,
- RotD**100** = **max**,
- RotD**00** = **min**
- Motivation: Users can use the maximum rotated motion

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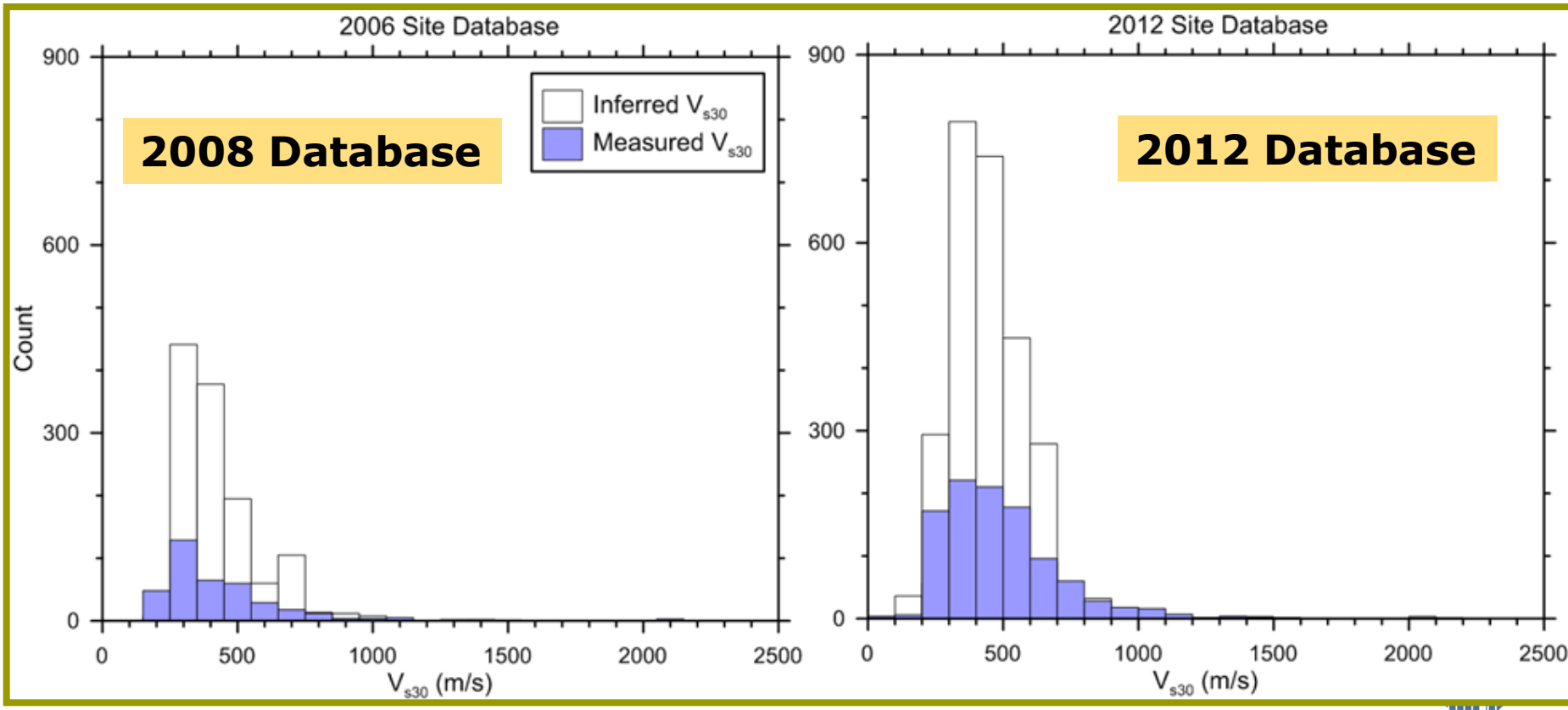
Vs30 distribution

- Measurements versus inferred values (estimated by various methods such as slop, geology,…)



Courtesy: Jon Stewart

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Why did we add small magnitude data?

- **Motivation**:
  - NGA-West1 models over-predicted motions for small magnitude
  - In the future, we can analyze multiple events recorded at same site to characterize the site variability (single-station Sigma)
  - In the regions that have mainly small magnitude data, they can compare NGA with their data

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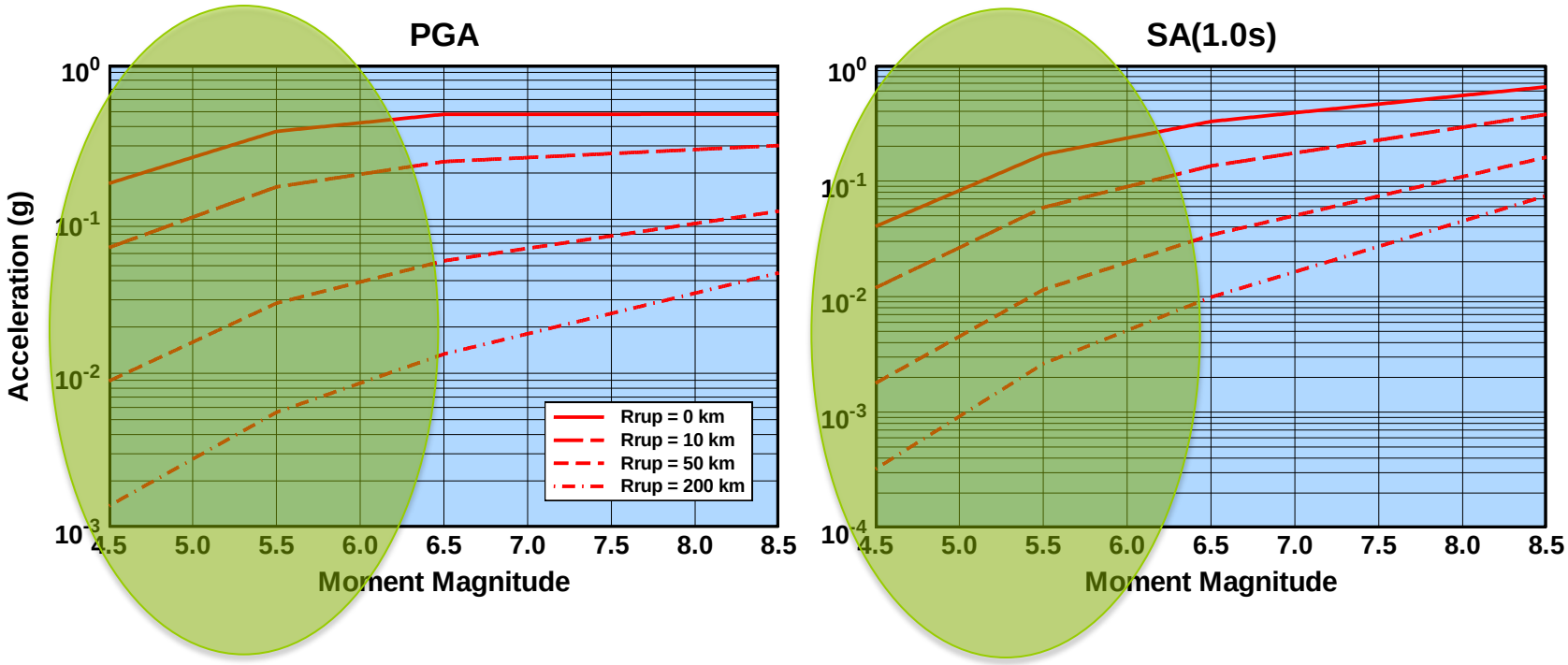
Magnitude scaling at small magnitude



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Public availability of the database

- On May 15, 2013, the flatfiles for horizontal components were posted at PEER web site
  - **http://peer.berkeley.edu/ngawest2/databases/**
  - All metadata
  - Spectral ordinates (RotD50) values at more than 100 periods
- Flatfile of the vertical ground motion will be posted in September 2013

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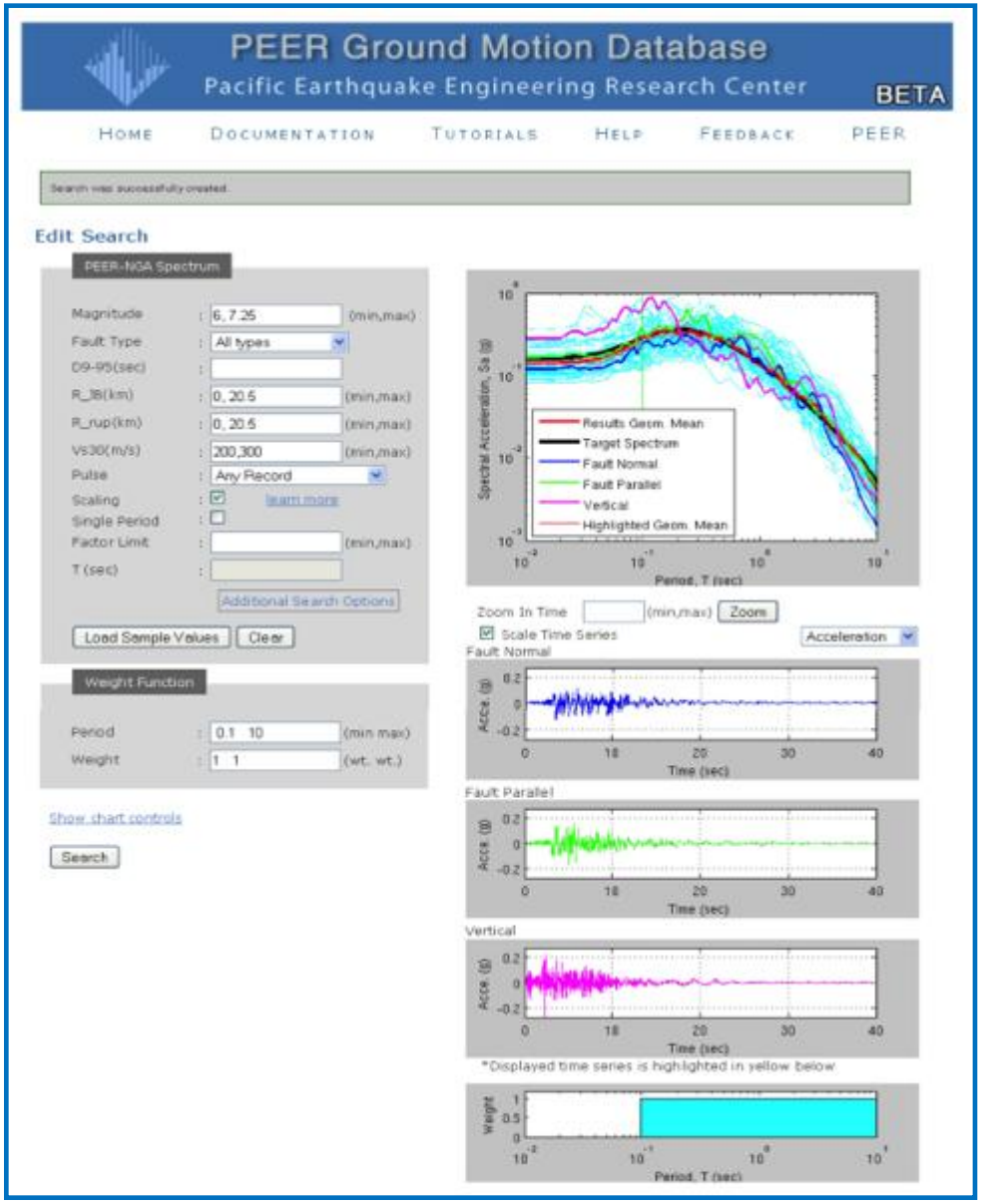
Public availability of the database

- Actual time series ("time-histories") will be available for download in Fall 2013
  - PEER web site will be updated to give more choices to the users to search and download



Update NGA GMPEs for horizontal motion

- Using the latest database, and
- Using supporting research on:
  - HW/FW model using simulations data
  - Update of nonlinear soil response
  - New classification of “main shock” vs “aftershocks”
  - Directivity of ground motion
  - …

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NGA-West2 GMPE Developer Teams

- Abrahamson-Silva-Kamai (ASK)
- Boore-Stewart-Seyhan-Atkinson (BSSA)
- Campbell-Bozorgnia (CB)
- Chiou-Youngs (CY)
- Idriss (I)

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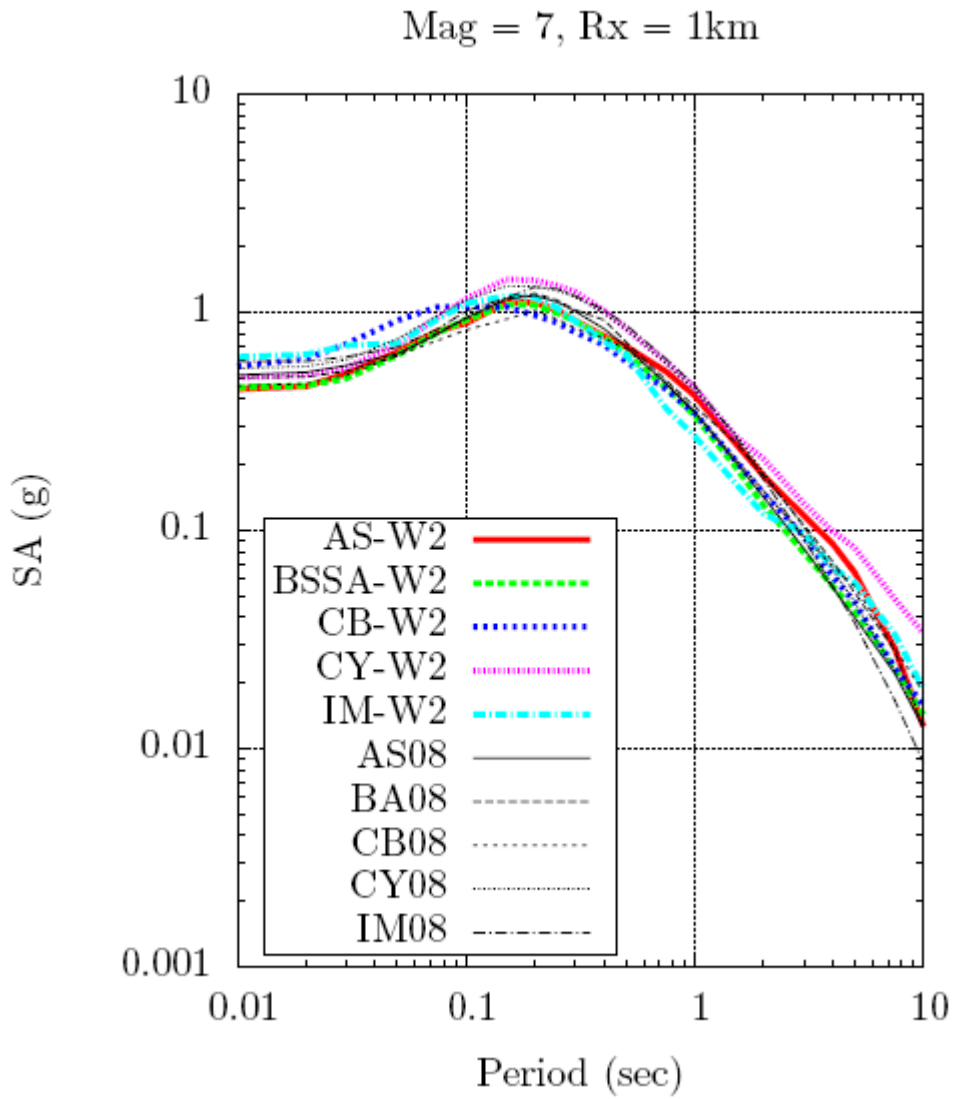
Comparison of NGA-West2 GMPEs: Strike-Slip, Vs30=760m/s



Courtesy: Nick Gregor

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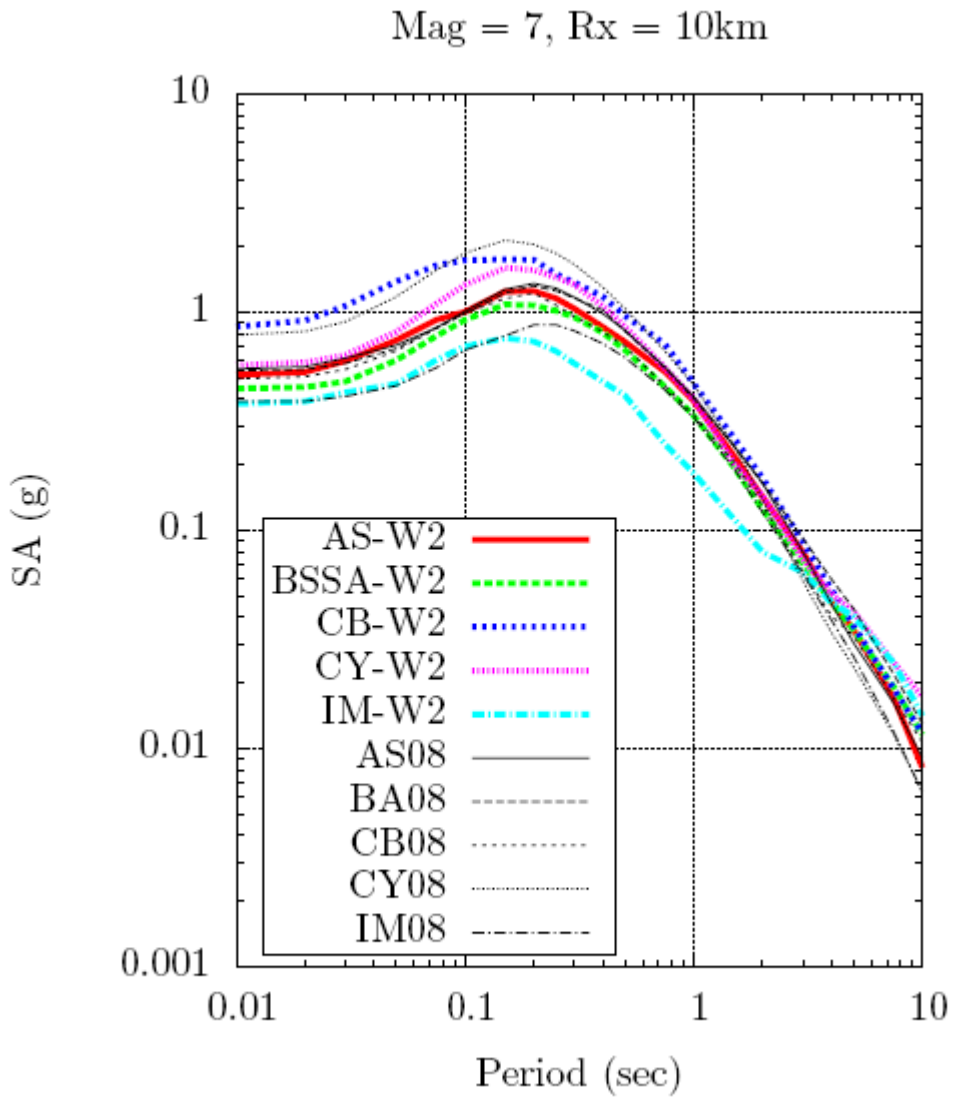
Comparison of NGA-West2 GMPEs: Reverse, HW, Dip=45, Vs30=760m/s



Courtesy: Nick Gregor

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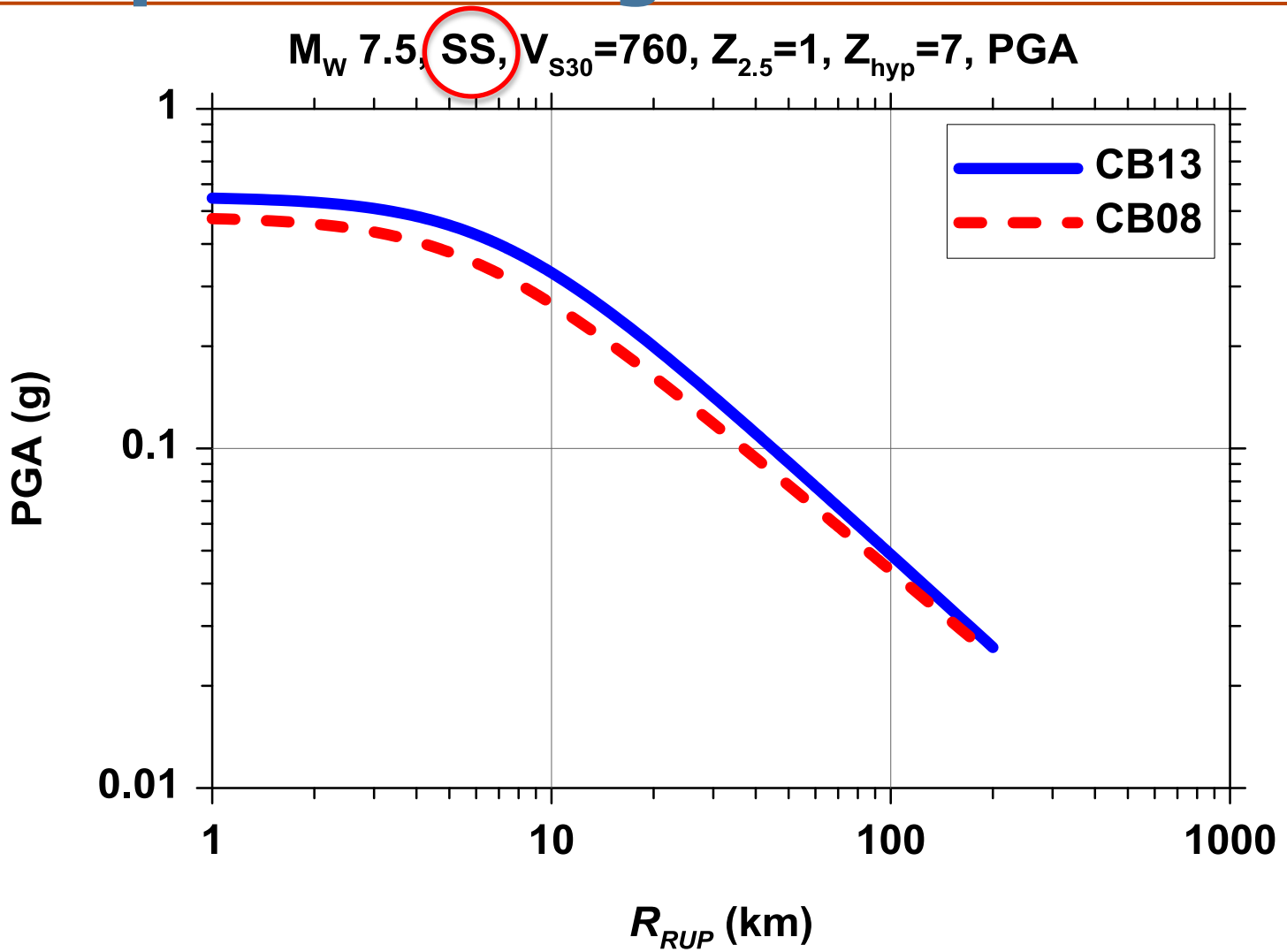
Specific example: Campbell-Bozorgnia 2013 model



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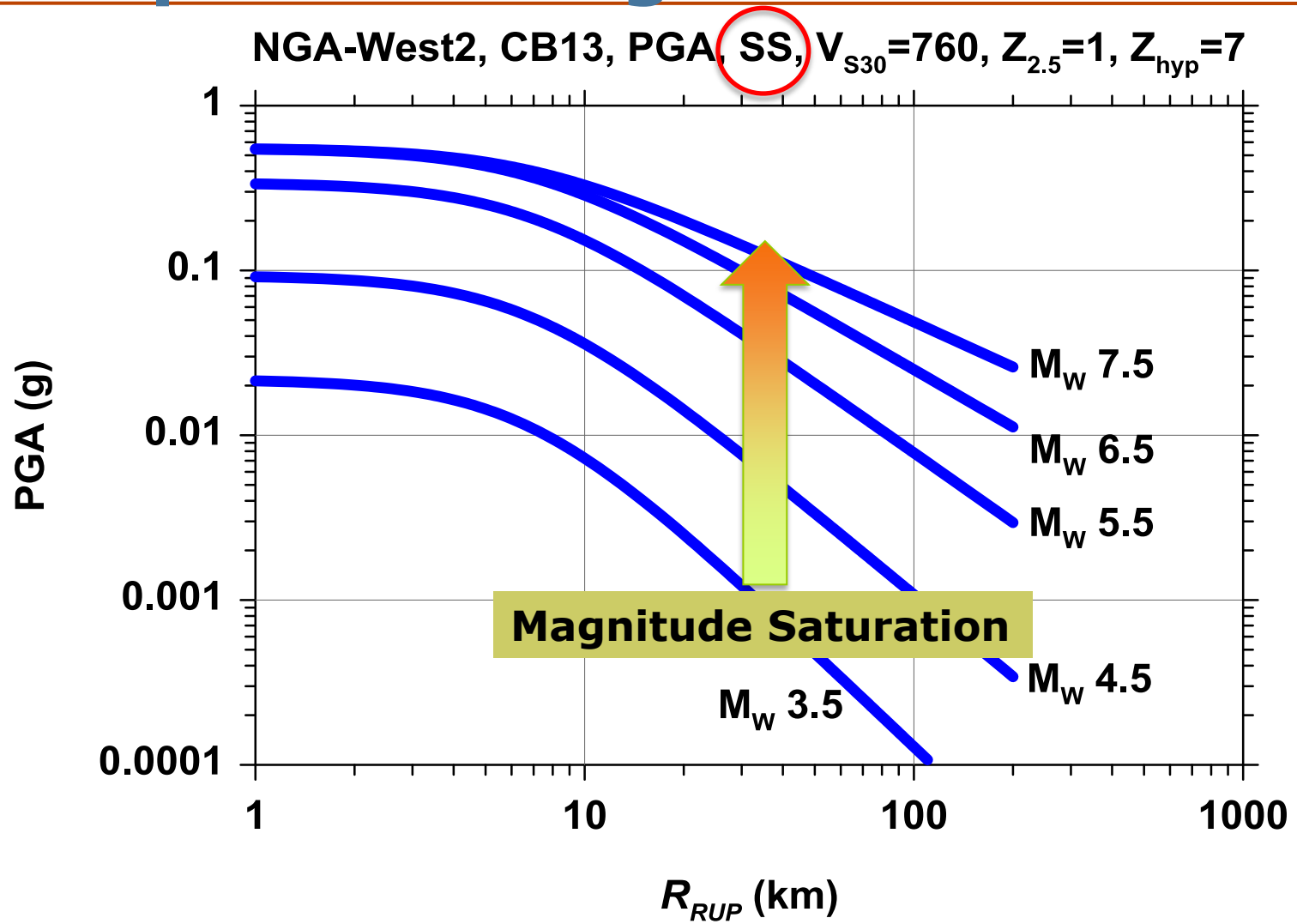
Specific example: Campbell-Bozorgnia 2013 model



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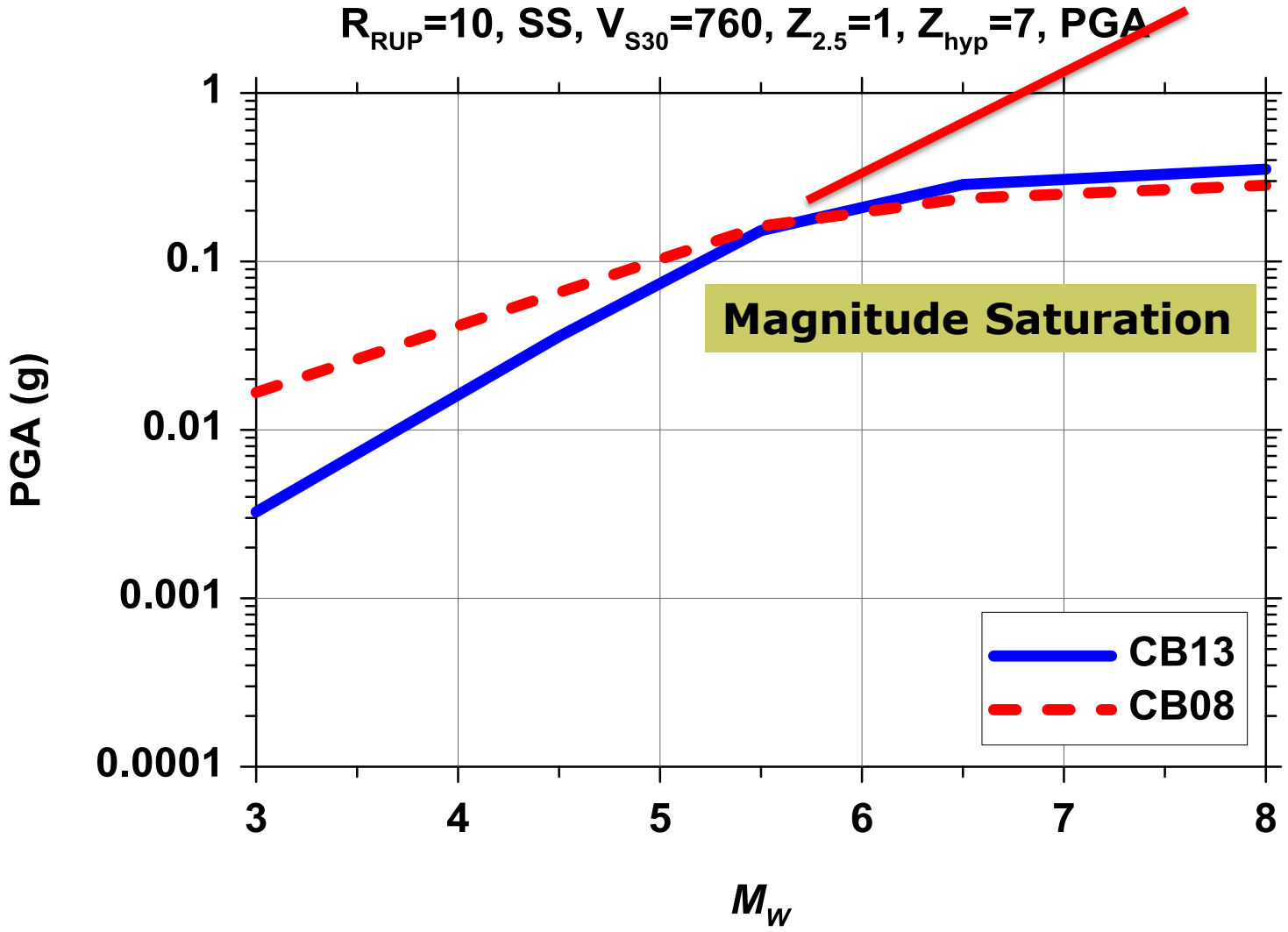
Campbell-Bozorgnia 2013 model: Magnitude scaling



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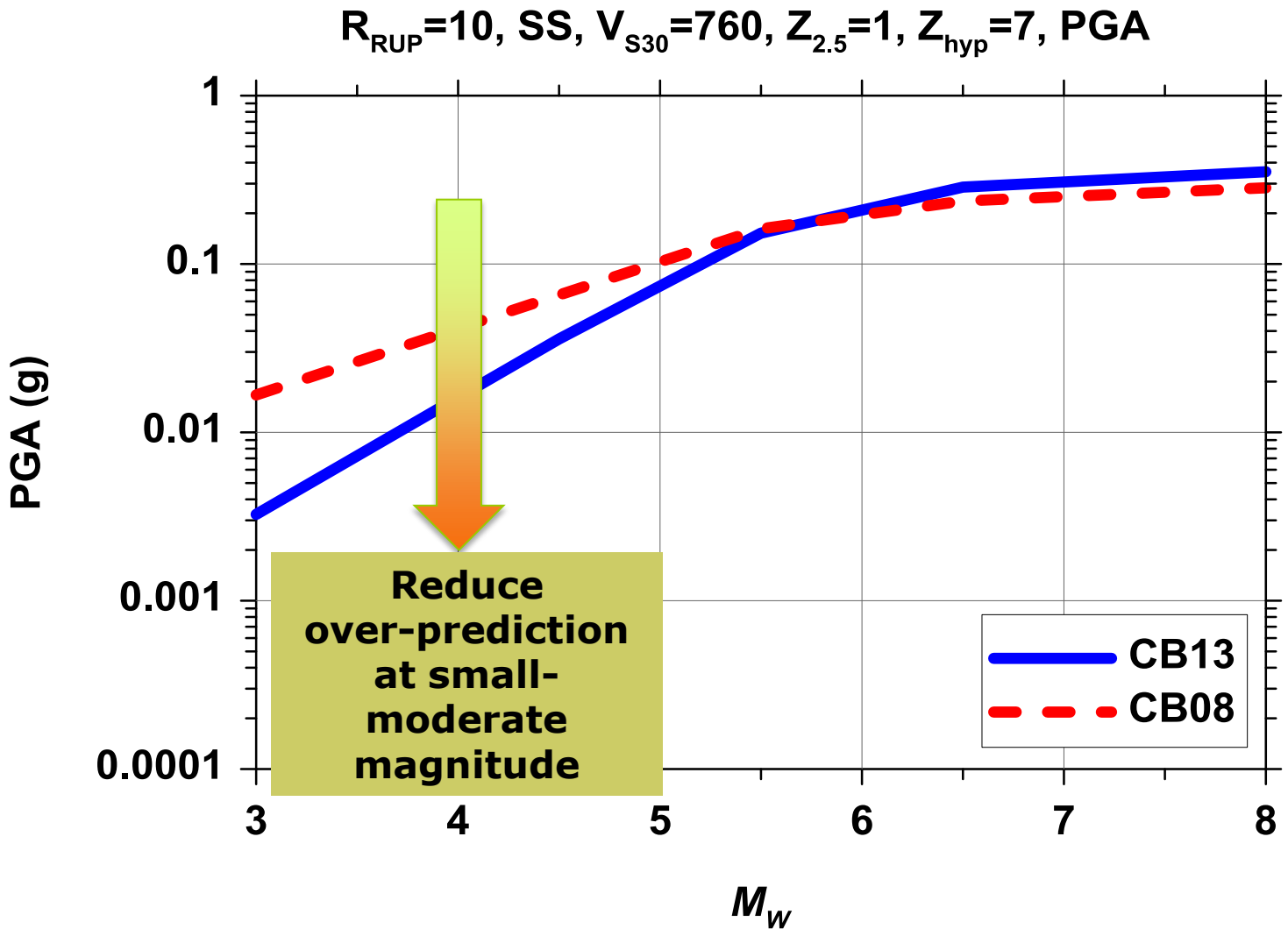
Campbell-Bozorgnia 2013 model: Magnitude scaling



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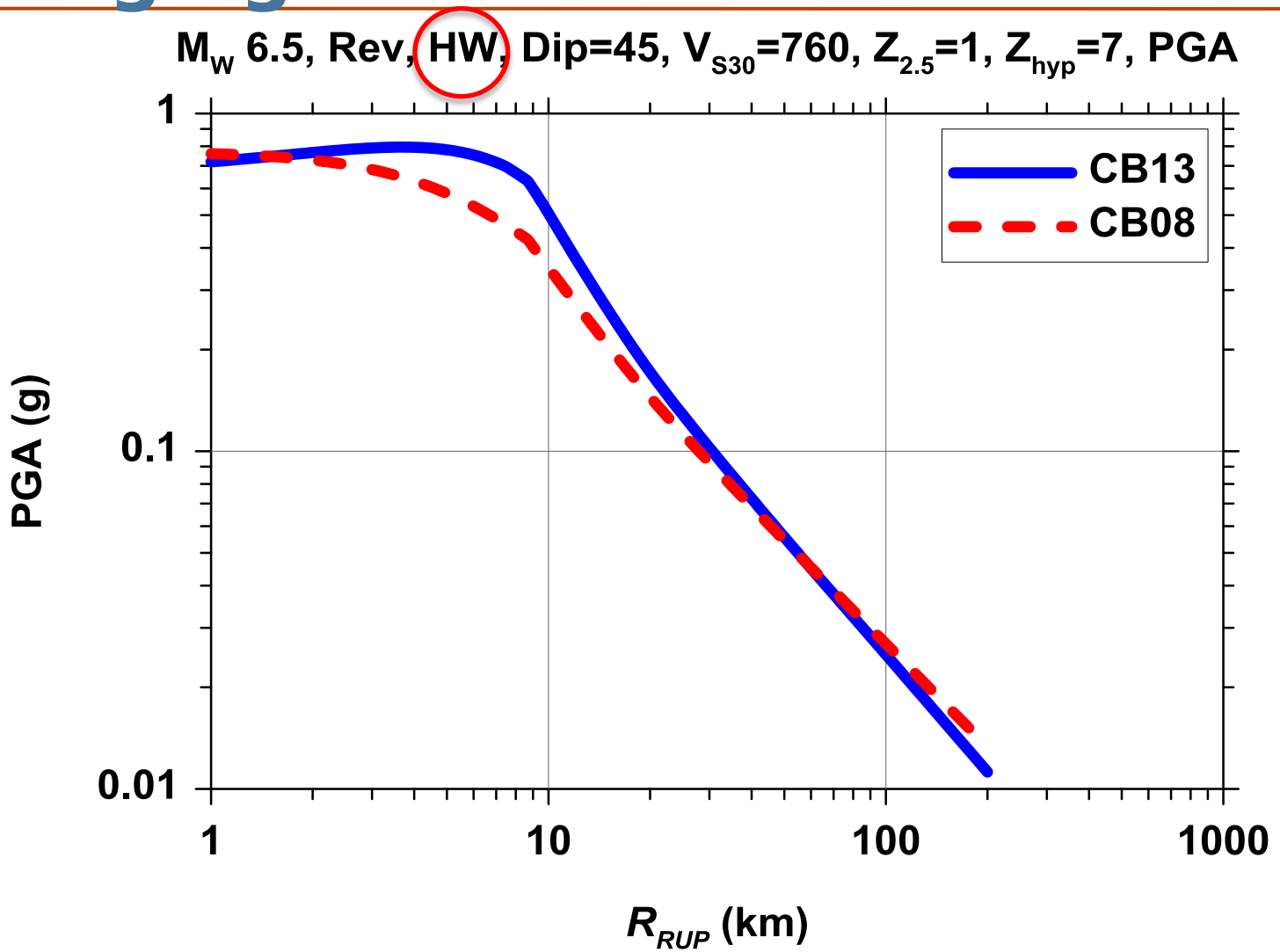
Campbell-Bozorgnia 2013 model: Hanging-wall effects



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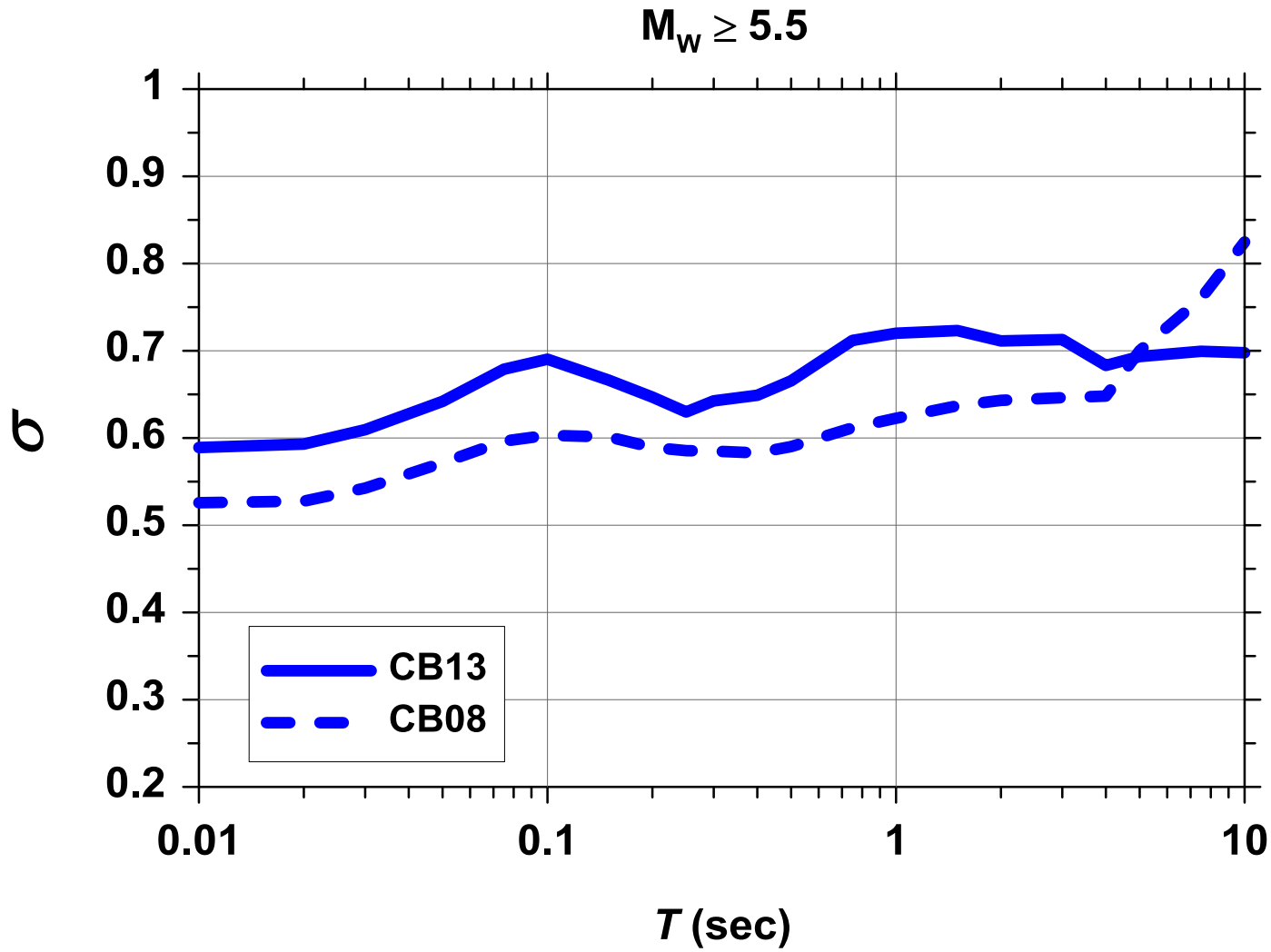
Campbell-Bozorgnia 2013 model: Standard deviation: Total



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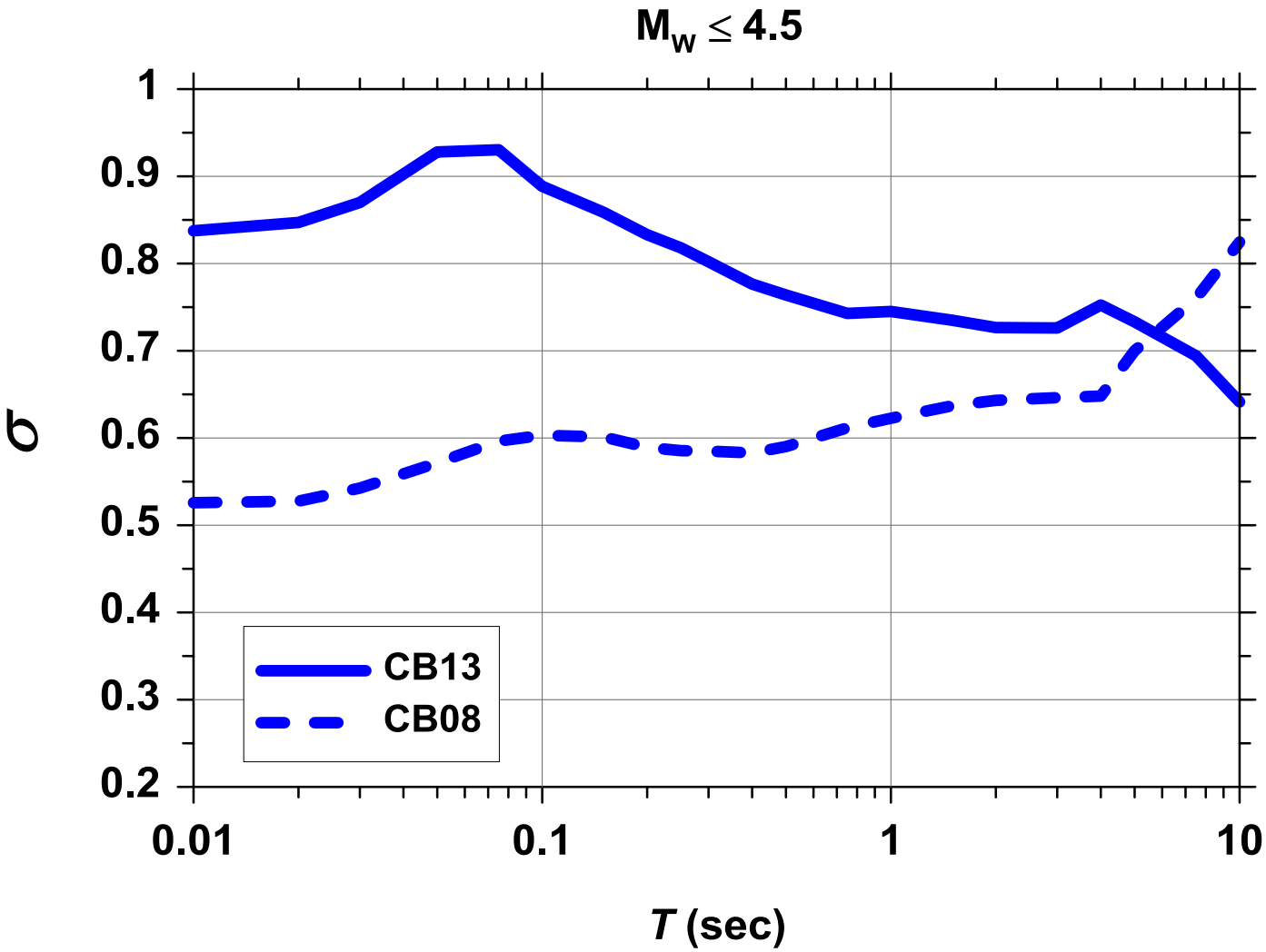
Campbell-Bozorgnia 2013 model: Standard deviation: Total, Small Mag



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Regionalization of GMPE

- We found up to about 80km the behavior of distance attenuation of ground motion is almost universal
- Distance attenuation beyond 80km, can be regionalized. Different **Anelastic attenuation**:
  - Japan/Italy: Higher attenuation rate
  - China: Lower attenuation rate
  - Than the rest of the world
- We found that soil amplification in Japan slightly different than California for V_{s30}>200m/sec; and very different for V_{s30}<200m/sec

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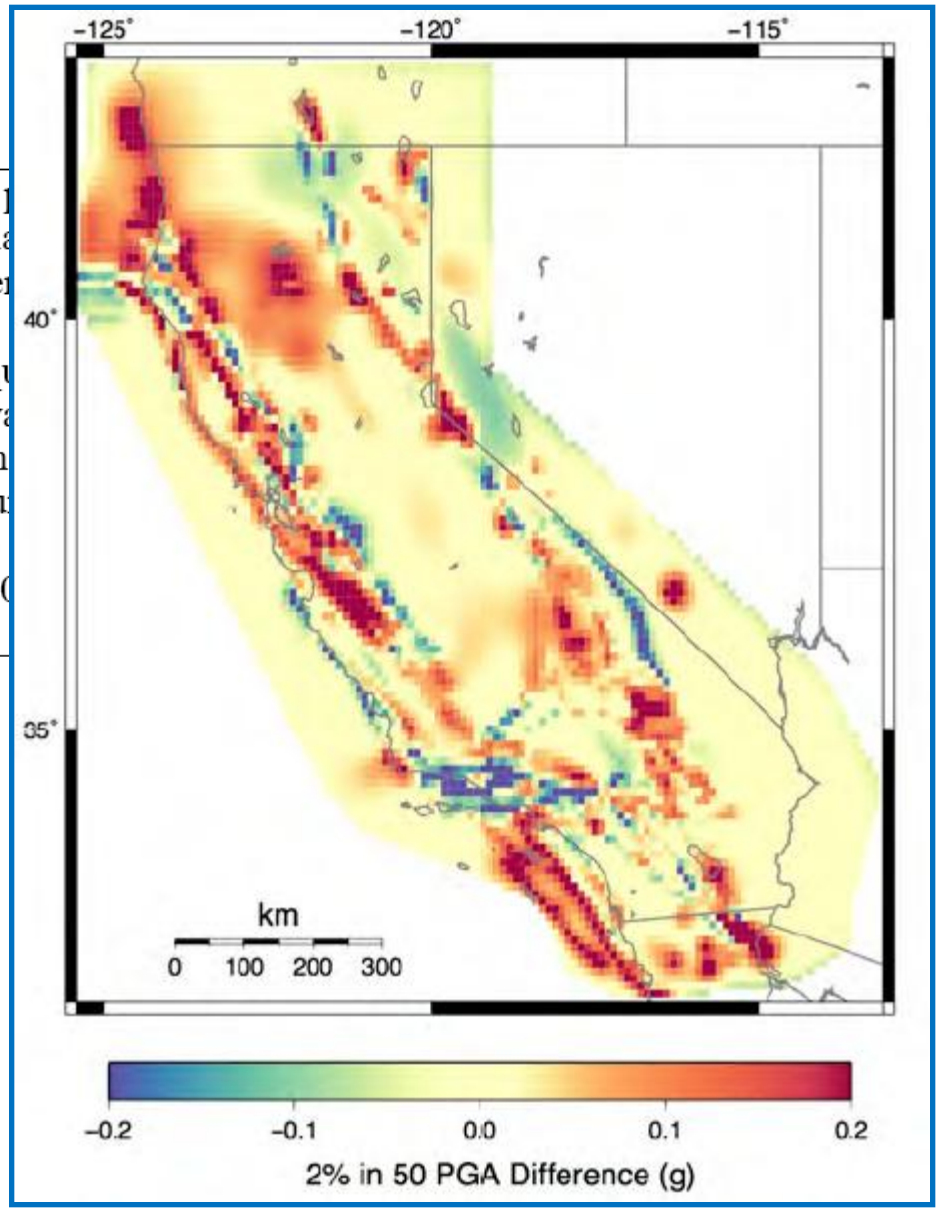
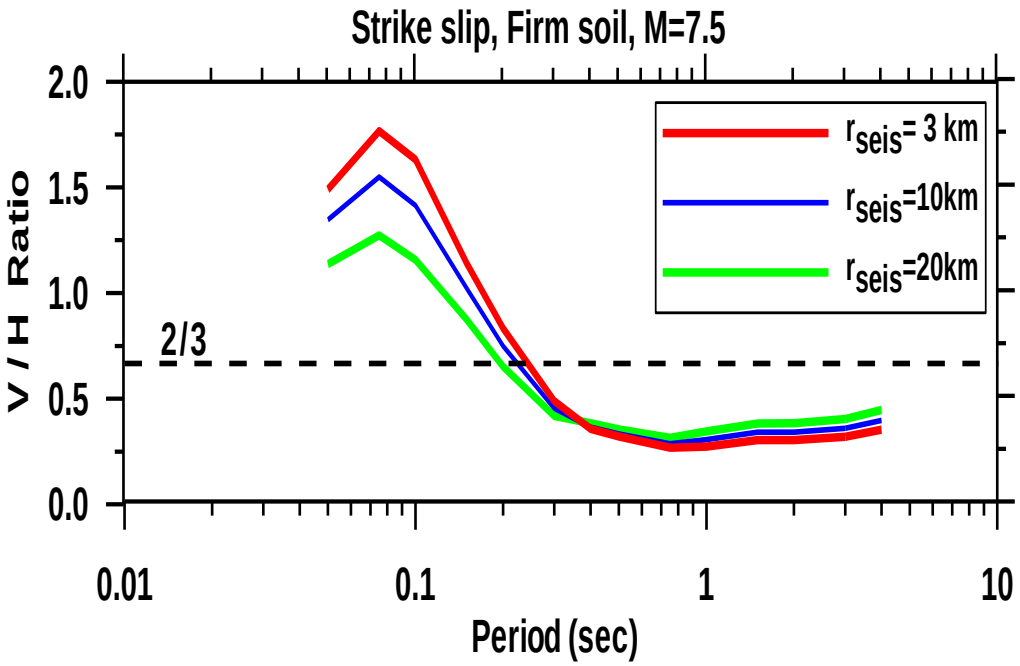
USGS has reviewed and adopted NGA-West2 GMPEs for the next US National Hazard Maps

Ground Motion Models	1. Reassess earthquake ground motion earthquakes and subduction zone rela 2. Adjust the additional epistemic uncer availability. 3. Update ground motion prediction equ NGA ground motion database, re-eva ground motion study, and included n stable continental regions. New grou WUS, 9 for the CEUS, and 4 for the 4. Increase distances from 200 km to 3 motions are calculated.



Develop GMPEs for vertical component

- NGA-West1 models predicted only horizontal ground motions
- Recorded data have shown that vertical ground motion can be large at the sites close to active faults
- Vertical GMPEs will be available in **September 2013**



Do not use 2/3 to scale horizontal motion to get vertical

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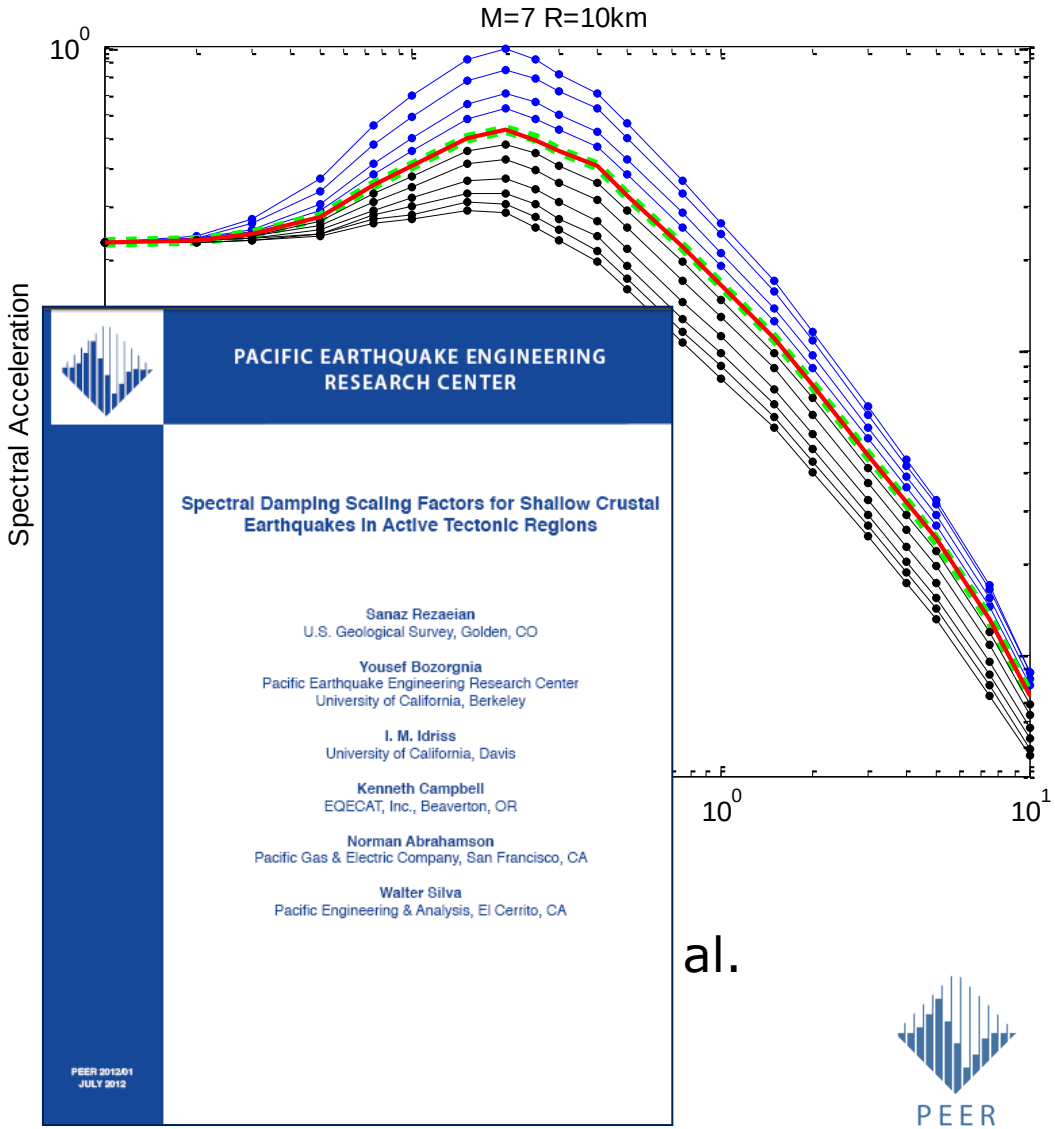
Damping scaling of response spectra

- Scale GMPEs for damping other than 5%:

  0.5% to **30%**

- Damping scaling model is final; PEER report already published



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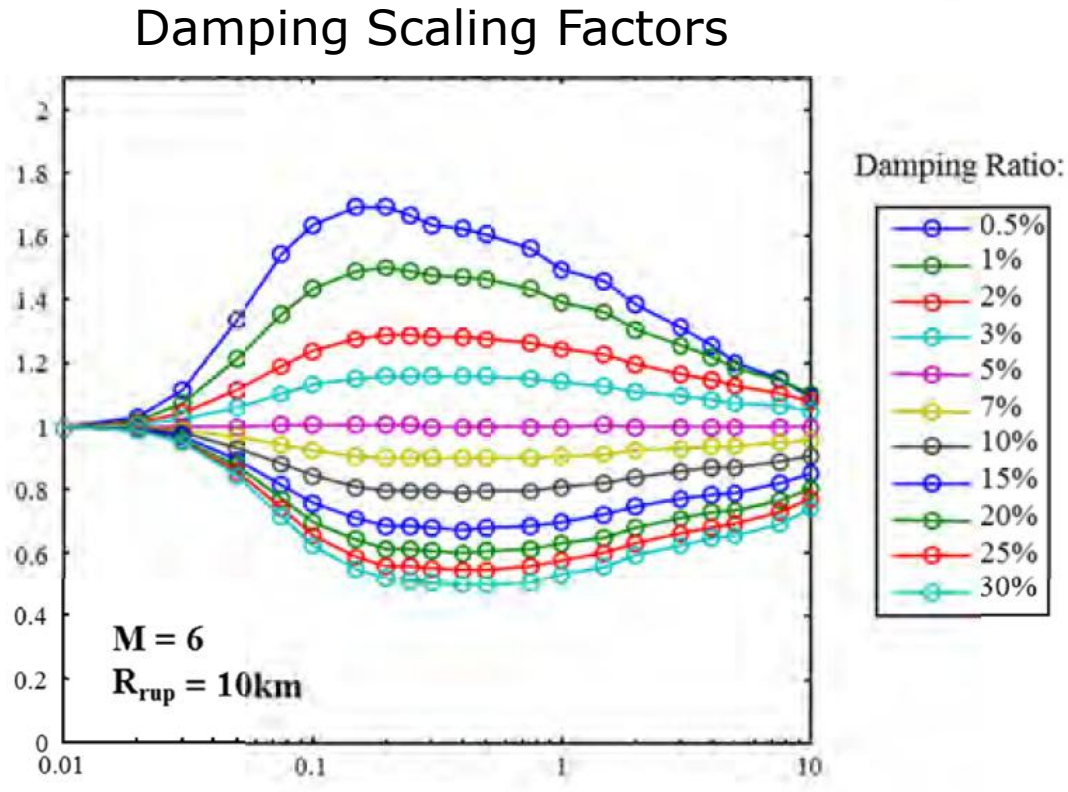
Damping scaling of response spectra

- We have a model to scale spectral ordinates as a function of
  - Damping
  - Magnitude
  - Distance



❖Duration was important, but took care of the effects approximately through magnitude and distance

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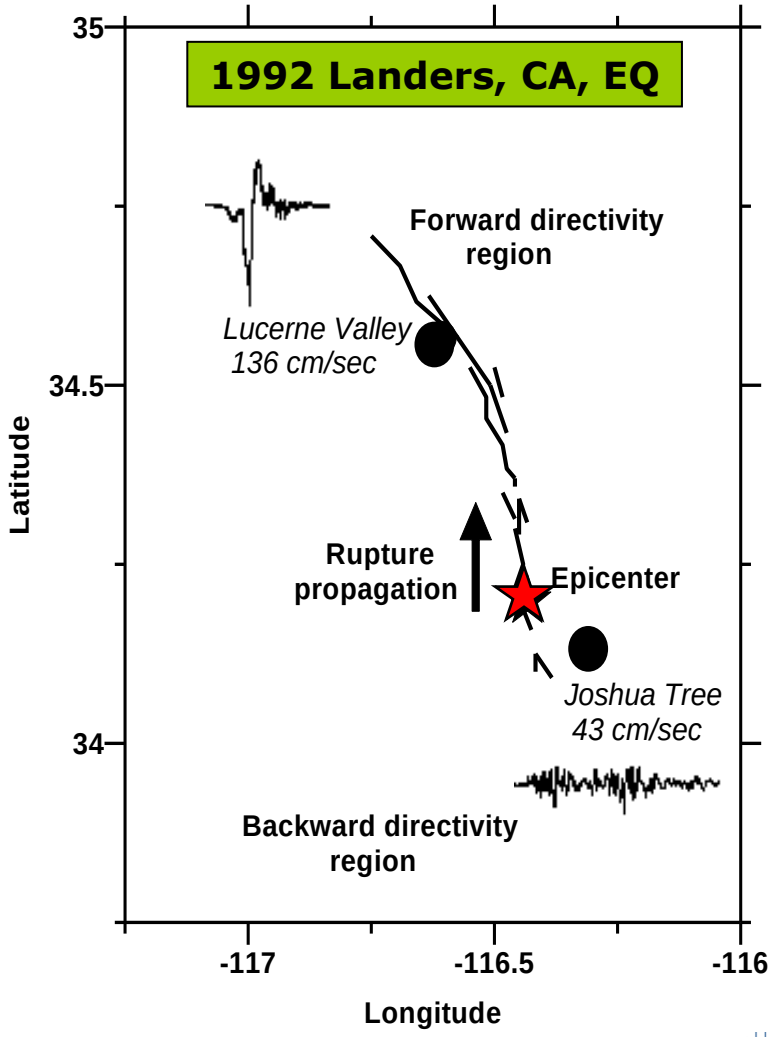
Directivity

- NGA-West1 models did not explicitly include directivity of ground motion
- Five directivity models have been developed
  - Wide-band and narrow-band models
- This effort will continue in 2013-14



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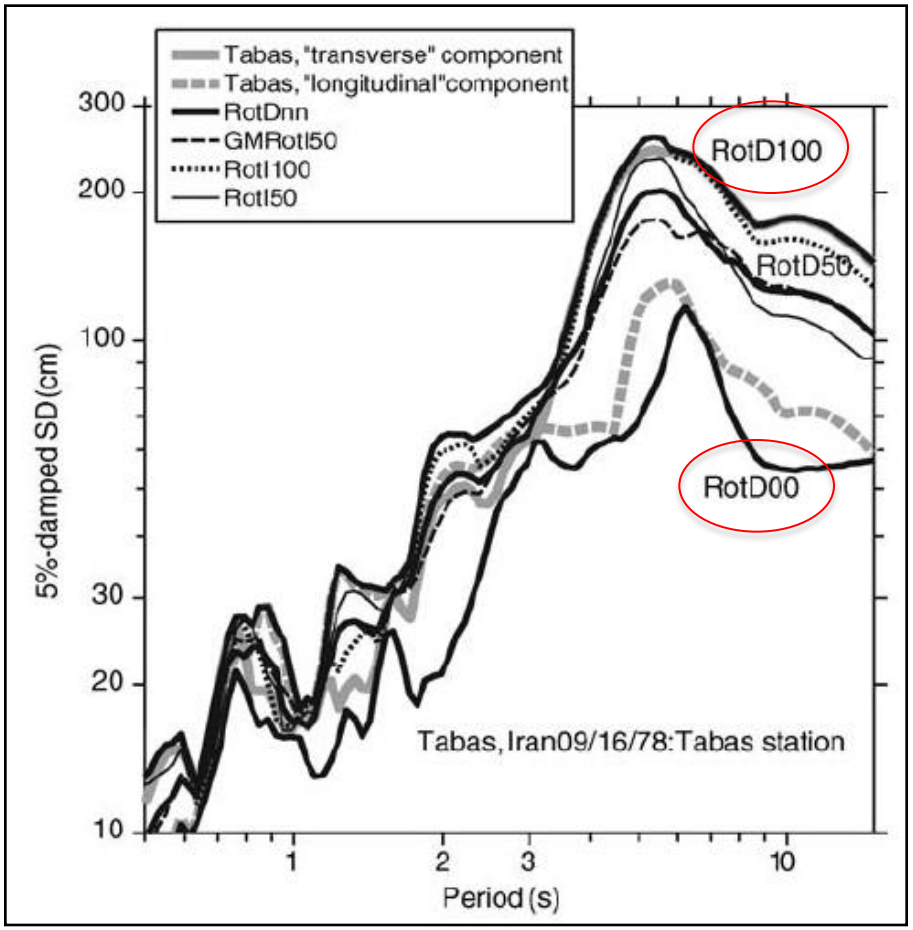
Directionality (Polarization)

- NGA models are for "geometric mean" horizontal components
- Develop max and min rotated spectra, as a function of mag, distance,…
- Examine relationship of max/min spectra with RotD50 (50 percentile) spectra



Ref: Boore (2010)

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Site Response

- NGA-West1 site amplification factors are inconsistent with NEHRP site amplification factors
- Goal: To make NEHRP and NGA site amplifications consistent
  - Propose changes in NEHRP factors
- This is both scientific and consensus-building task
- Final report will be available to the public in **August 2013**

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Many people have been involved in NGA-West2

- **Technical Coordination Committee**:
  - Abrahamson, Bozorgnia, Campbell
- **External reviewers and oversight committee**:
  - Chris Wills, Mark Petersen, John Anderson, Roger Borcherdt, Silvia Mazzoni, Farzad Naeim
- **Funding agencies representatives:**
  - Badie Rowshandel & Tom Shantz

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People involved in NGA-West2 per Tasks

- **Database**: Ancheta, Darragh, Chiou, Silva, Stewart, Seyhan, Graves, Wooddell, Katke, Boore, Kishida, Al Atik, NGA developers
- **GMPE Developers**:
  - Abrahamson & Silva
  - Campbell & Bozorgnia
  - Chiou & Youngs
  - Boore-Stewart-Seyhan-Atkinson
  - Idriss
- **Damping:** Rezaeian, Bozorgnia, Idriss, Abrahamson, Campbell, Silva & GMPE developers

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People involved in NGA-West2 per Tasks (Cont'd)

- **Vertical:** GMPE developers
- **Directivity:** Spudich, Chiou, Baker, Shahi, , Bayless, Watson-

Putting together pieces of a complicated puzzle through a coordinated multidisciplinary Team Work

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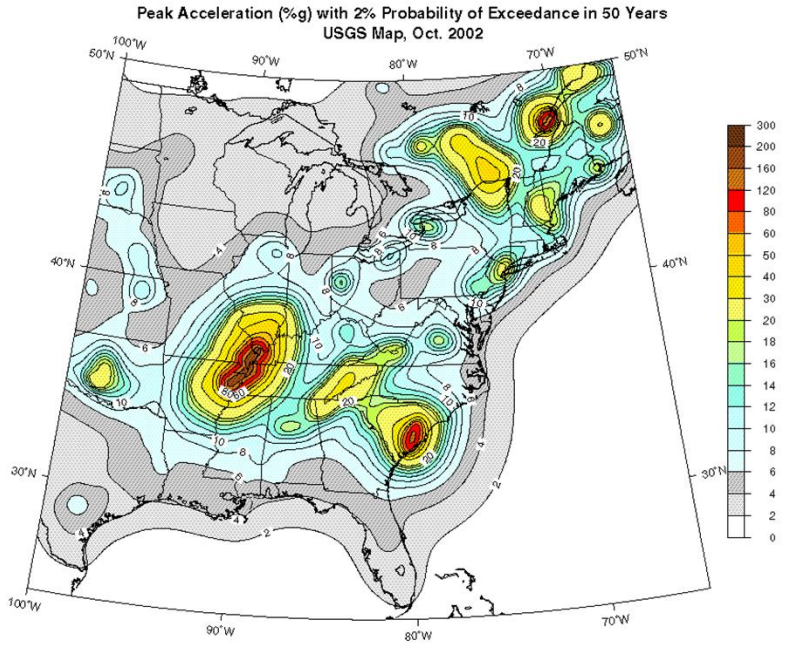
NGA-East Project

NGA- East

- Goal: To develop next generation Ground Motion Prediction Equations (GMPEs) for Central & Eastern US
- Stable Continental Regions (SCRs)
- Sponsors: **NRC, EPRI, USGS, DOE**



U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

EPRI

USGS

U.S. DEPARTMENT OF ENERGY

NGA-East: Selected Sub-Projects

- **Database**:

  Compile a database of recorded motions from CEUS and other Stable Continental Regions (SCRs)

- **Geoetchnical Engineering**:

  Linear and nonlinear site responses; reference rock condition; reference "Kappa"; …

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NGA-East: Selected Sub-Projects

- **Source-Site Path**: Investigate geometrical spreading steeper than 1/R; Q; …

- **Ground Motion Simulation:** Generate calibrated & validated simulated GMs for CEUS to be used by GMPE developers

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NGA-East: Selected Sub-Projects

- **GMPE Development**
  - Next generation attenuation models for CEUS; applicable to **magnitude 4-8**, **distances of 0-1000 km**
  - 5% damped response spectra at periods **0.01 to 10 sec**
- **Project will be completed by May 2015**

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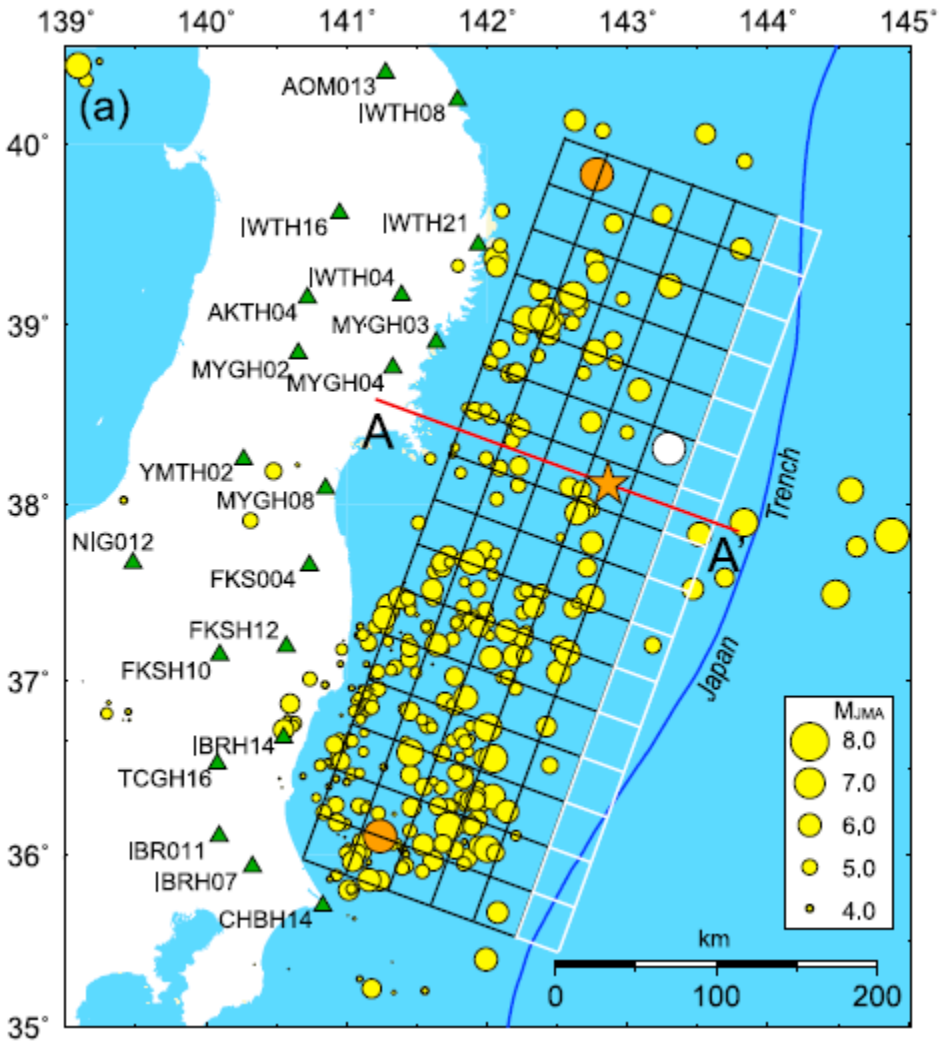
NGA-Subduction

NGA-Sub: Phase I; Collection of Data from Tohoku and 2010 Chile EQs

- In collaboration with Prof. Midorikawa
- For Tohoku EQ, PEER **already processed**:
  - More than 427 recordings for the main shock
  - About 7 foreshocks (about 600 recordings total)
  - About 45 aftershocks from M 6–7.7 (>3000 recordings total)



Courtesy: Yokota, et al (2011)

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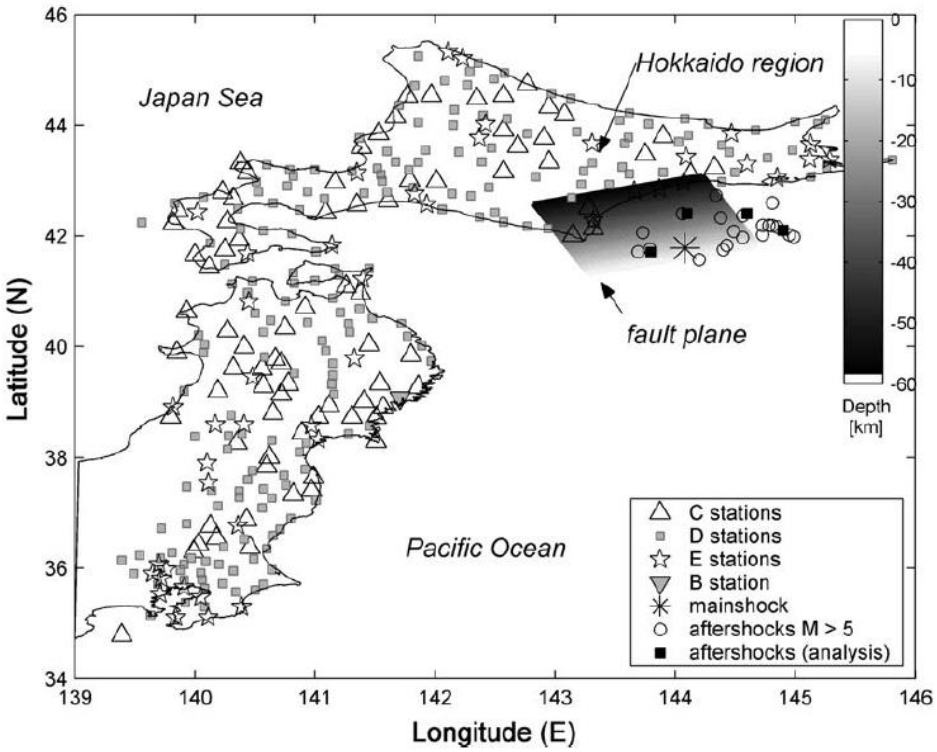
NGA-Sub: Phase II

- **Phase II**: Collection and processing of data and metadata from other subduction earthquakes worldwide:
  - Other Japan EQs, e.g., 2003 Tokachi-Oki EQ, M 8.3
  - Alaska, Chile, Mexico, Peru, Taiwan, CSZ, …
- Collect and process aftershock data
- Develop new GMPE for subduction



Reference: Tokachi-Oki EQ, by Macias, Atkinson, and Motazedian (2008)

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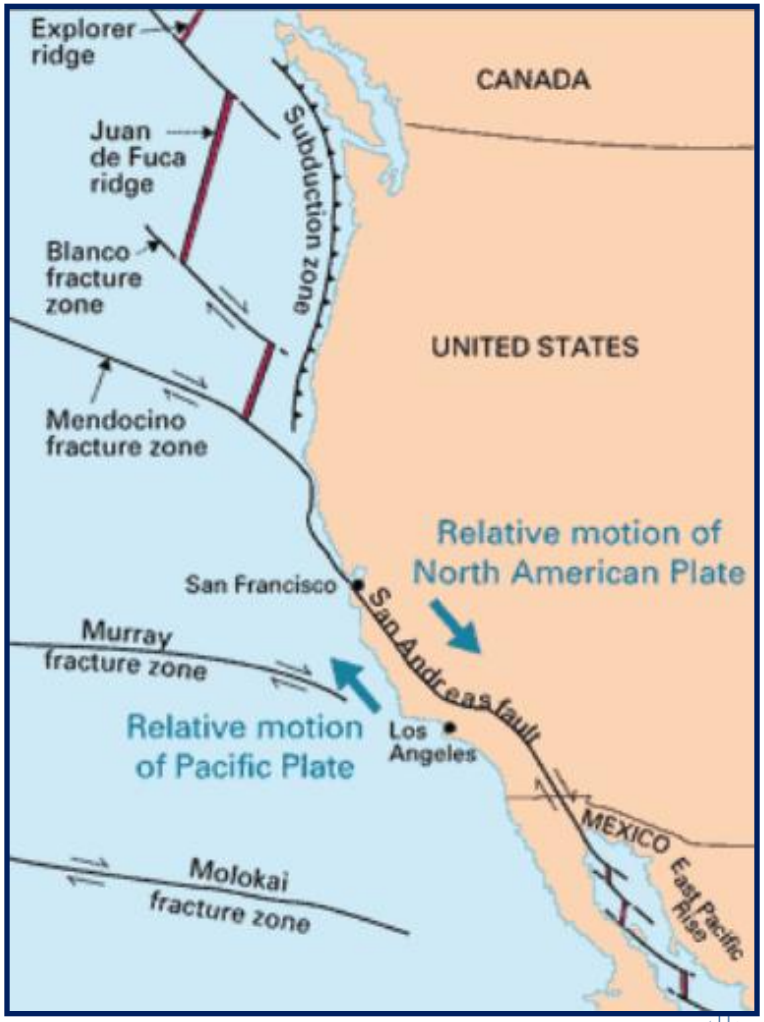
NGA-Sub: Phase III

- **Phase III** (pending funding):
- Carry out validated simulations to fill the gap in empirical data
- Develop multiple GMPEs by multiple developer teams (epistemic uncertainty)
- Examine directivity
- To be completed by **May 2016**



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GEM Global GMPEs Project

- **GEM**: **G**lobal **E**arthquake **M**odel
  - An international non-profit organization
- The PEER **project goal** is to select a set of GMPEs for **global PSHA**, by using a collaborative approach
  - To be used for global hazard and risk analyses by GEM
- **PEER Team:** 27 international experts from around the world
- **Schedule**: On April, 30, 2013 seven final reports were submitted to the GEM Foundation

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On-Going & Future Work

- **NGA-Subduction** and **NGA-East** are on-going
- We are preparing proposal for **NGA-West3**
  - Expanding the applicability of GMPEs for harder rock and softer soil
  - Inclusion of "Kappa" in GMPEs
  - Inclusion of topographic effects
  - Inclusion of simulation (+ empirical data)
  - …
- **PEER is very interested in collaborating with Japan, China, Korea and Taiwan on all ground motion hazard issues**

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THANK YOU!