

What Do Ground-Motion Prediction Equations Tell Us About Motions Near Faults?

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Short Answer: Not Much

- So, why the title of the talk?
- Contents of talk
 - NGA-West 2 Project
 - Develop global database
 - Ground motions near faults
 - Inferring fault slip as a function of space and time (source processes)
 - Spatial variability (source and propagation processes)
 - Scaling of ground motions with magnitude at near and intermediate distances (source processes)
 - Observed scaling
 - Simulated scaling
 - Stochastic simulations
 - Application to simulate M scaling

PEER NGA-West 2 Project Overview

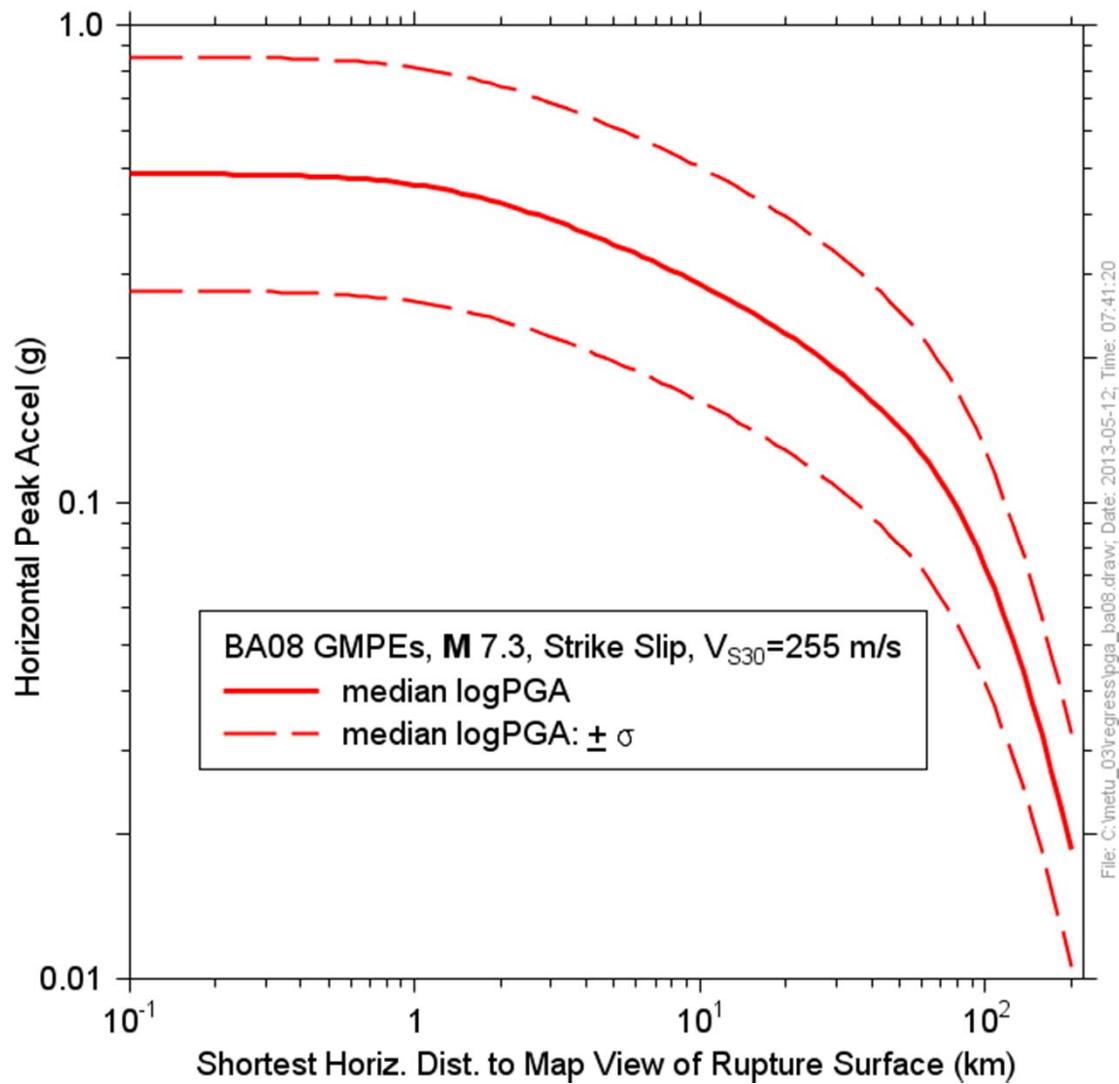
- Goal of Project
 - Derive equations for the prediction of various measures of ground shaking from **crustal earthquakes in active tectonic regions**, as a function of **M**, R, site condition, etc.
- This is the second of two NGA projects. The results of the first project were published in 2008.

Ground-Motion Prediction Equations (GMPEs)

- What are GMPEs?
 - Simple equations giving the mean and standard deviation of measures of ground motion as a function of magnitude, distance, site conditions, and perhaps other variables
- How are GMPEs used?
 - Specify motions for seismic design
 - Individual structures
 - Constructing hazard maps used in building codes
 - Convenient summary of average M and R variation of motion from many recordings
 - Source scaling
 - Path effects
 - Site effects

Ground-Motion Prediction Equations (GMPEs)

$$\ln Y = F_E(\mathbf{M}, mech) + F_{P,B}(R_{JB}, \mathbf{M}) + F_{S,B}(V_{S30}, R_{JB}, \mathbf{M}) + \varepsilon_n \sigma(\mathbf{M}, R_{JB}, V_{S30})$$



PEER NGA-West 2 Project Overview

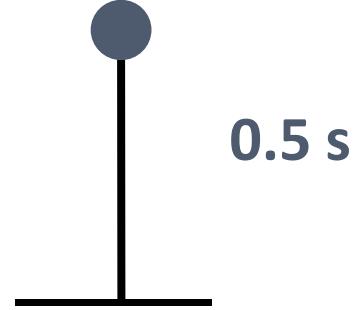
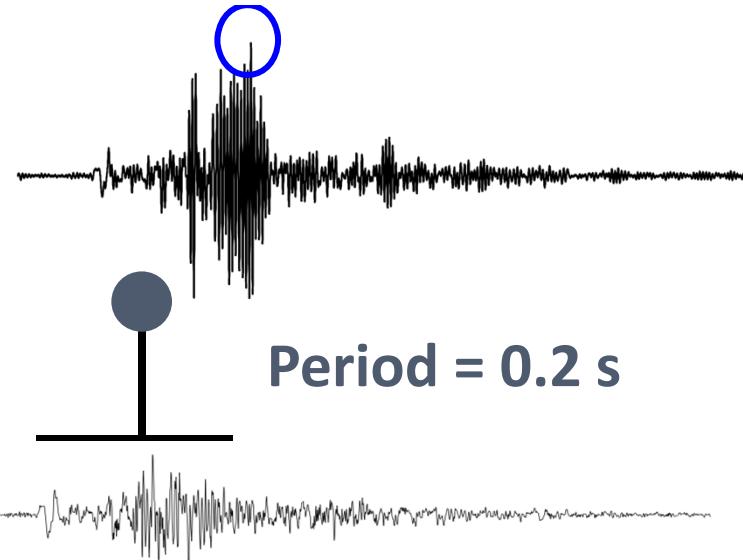
- **Developer Teams (each developed their own ground-motion predictions equations (GMPEs))**
 - Abrahamson, Silva, and Kamae (ASK13)
 - Boore, Stewart, Seyhan, and Atkinson (2 additional members added to the BA08 team) (BSSA13)
 - Campbell & Bozorgnia (CB13)
 - Chiou & Youngs (CY13)
 - Idriss (I13)
- **Supporting Working Groups**
 - Directivity
 - Site Response
 - Database
 - Directionality
 - Uncertainty
 - Vertical Component
 - Adjustment for Damping

PEER NGA-West 2 Project Overview

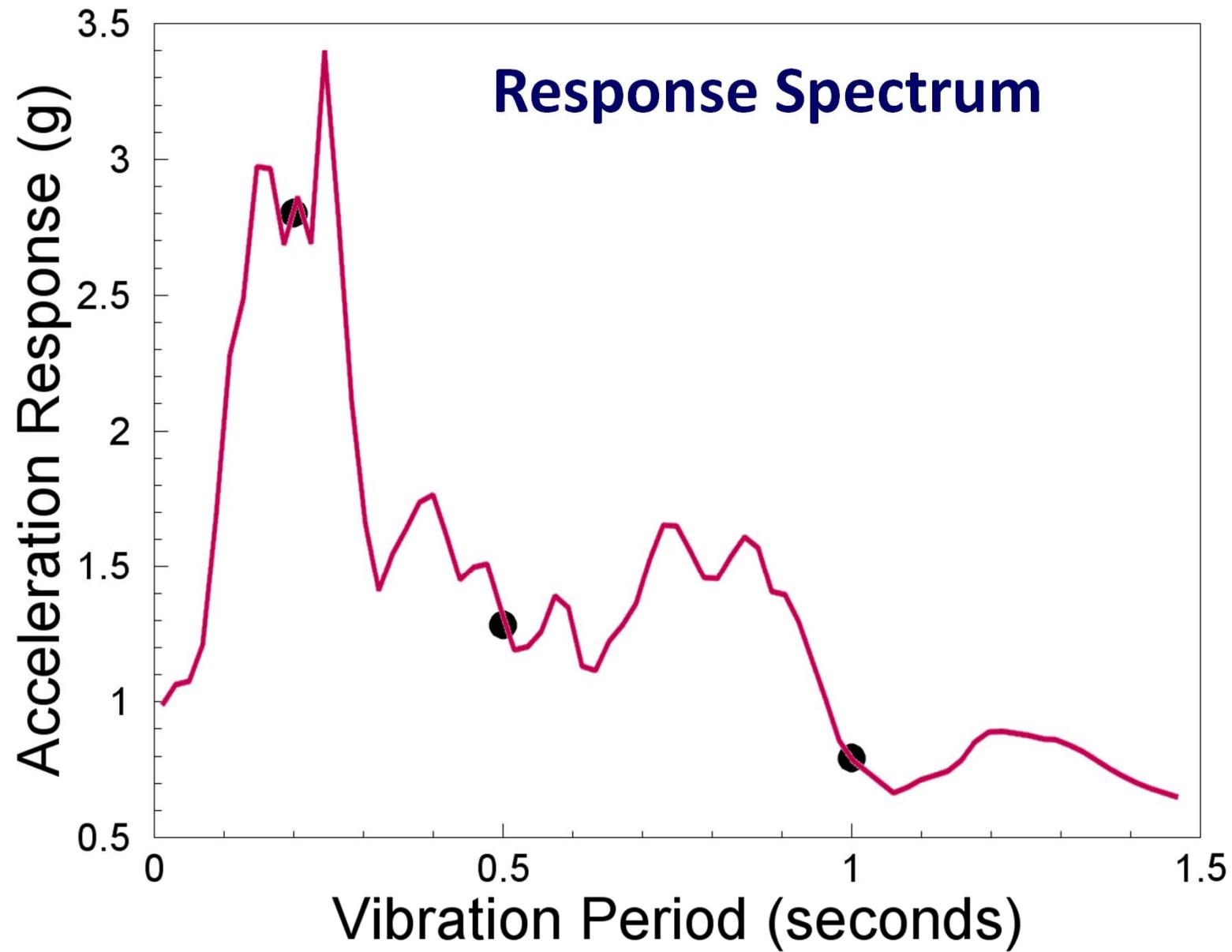
- All developers used subsets of data chosen from a common database
 - Metadata (e.g., magnitude, distance, etc.)
 - Uniformly processed strong-motion recordings
 - U.S. and foreign earthquakes
 - Active tectonic regions (**subduction, stable continental regions are separate projects**)
- The database development was a major time-consuming effort

NGA-West2 Status

- Some tasks have already been completed
 - Databases, damping scaling, directivity, directionality, site response
 - Draft final reports are being reviewed internally and externally
- Draft of GMPEs for horizontal components have already been submitted to the USGS:
 - Feedback from the USGS National Hazard Maps, internal and external reviewers
- Final reports and the database are now publically available:
 - <http://peer.berkeley.edu/ngawest2/final-products/>
 - <http://peer.berkeley.edu/ngawest2/databases/>



Courtesy of J. Bommer



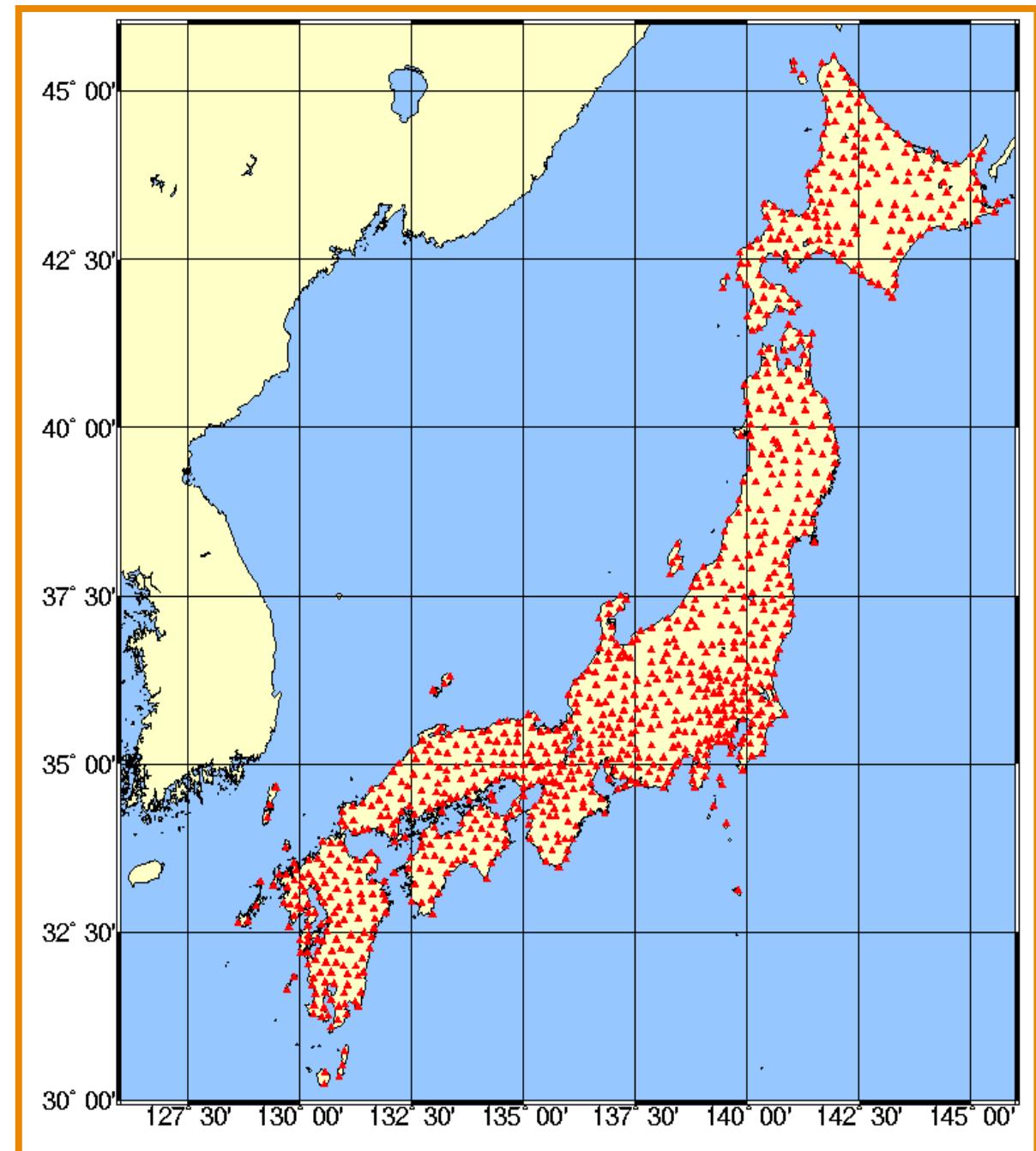
Courtesy of J. Bommer

Kyoshin Net (K-NET)

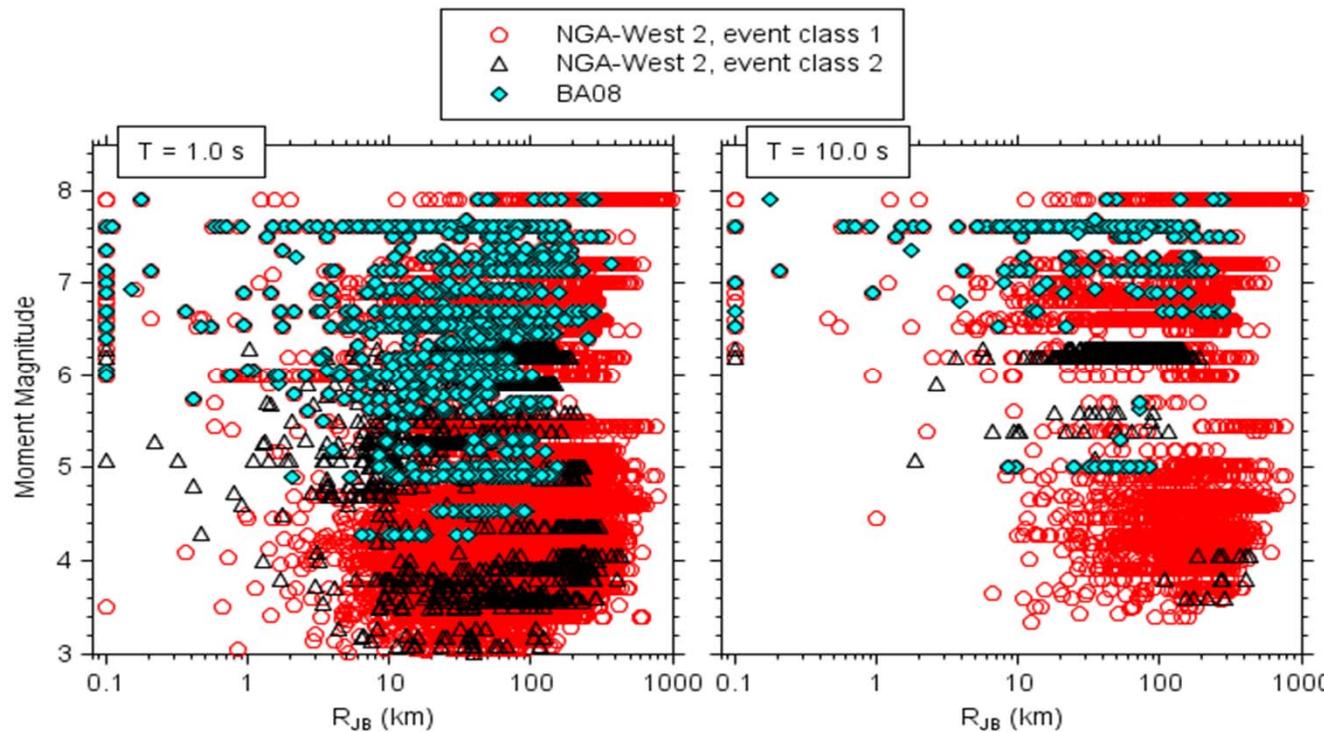
Japanese strong motion network

<http://www.k-net.bosai.go.jp>

- 1000 digital instruments installed after the Kobe earthquake of 1995
- free field stations with an average spacing of 25 km
- velocity profile of each station up to 20 m by downhole measurement
- data are transmitted to the Control Center and released on Internet in 3-4 hours after the event
- more than 2000 accelerograms recorded in 4 years



PEER NGA-West 2 Strong-Motion Database



- >600 (173) worldwide shallow crustal events from active tectonic regions
- >21,000 (3551) recordings (mostly 3-components each) uniformly processed strong motion stations
- M 3.0 (4.2) to 7.9 (7.9)

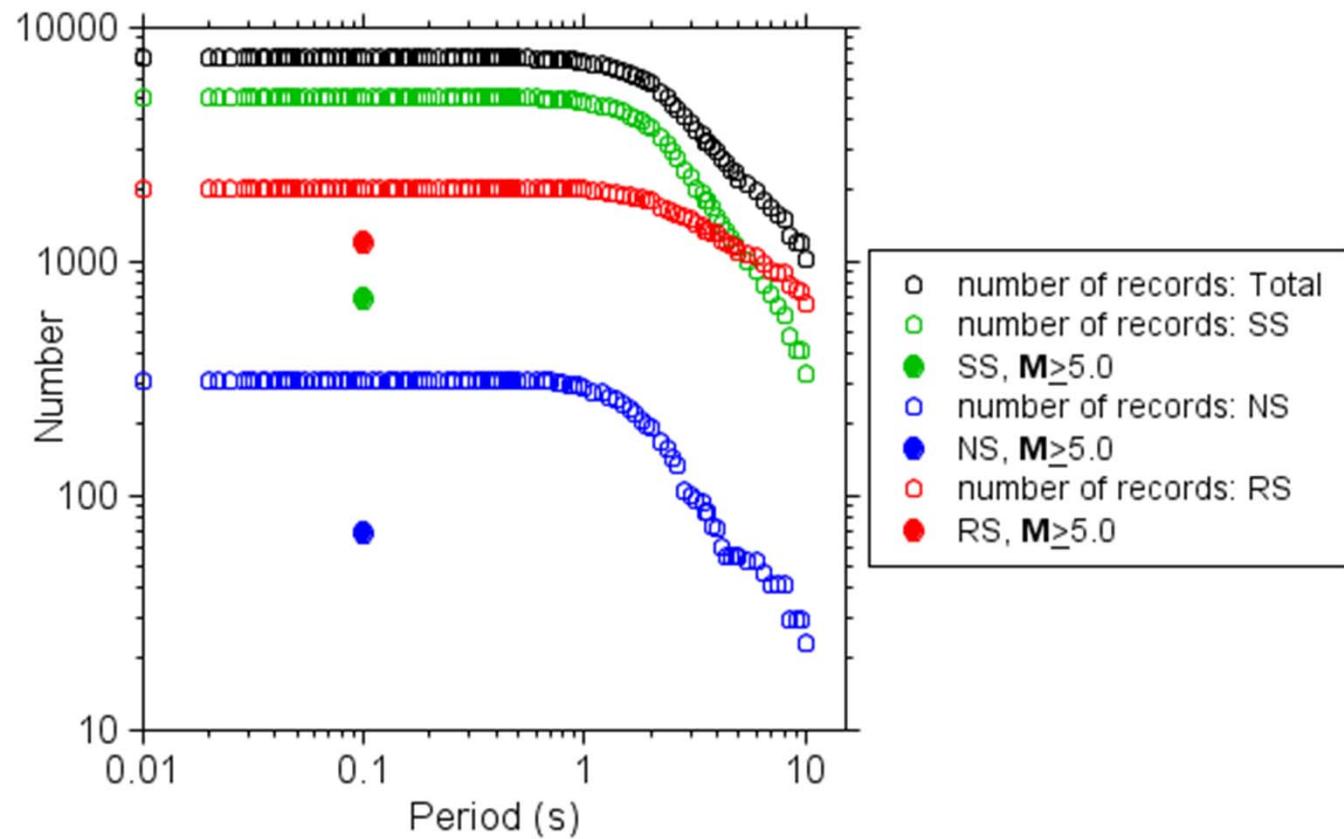
Blue = Previous NGA

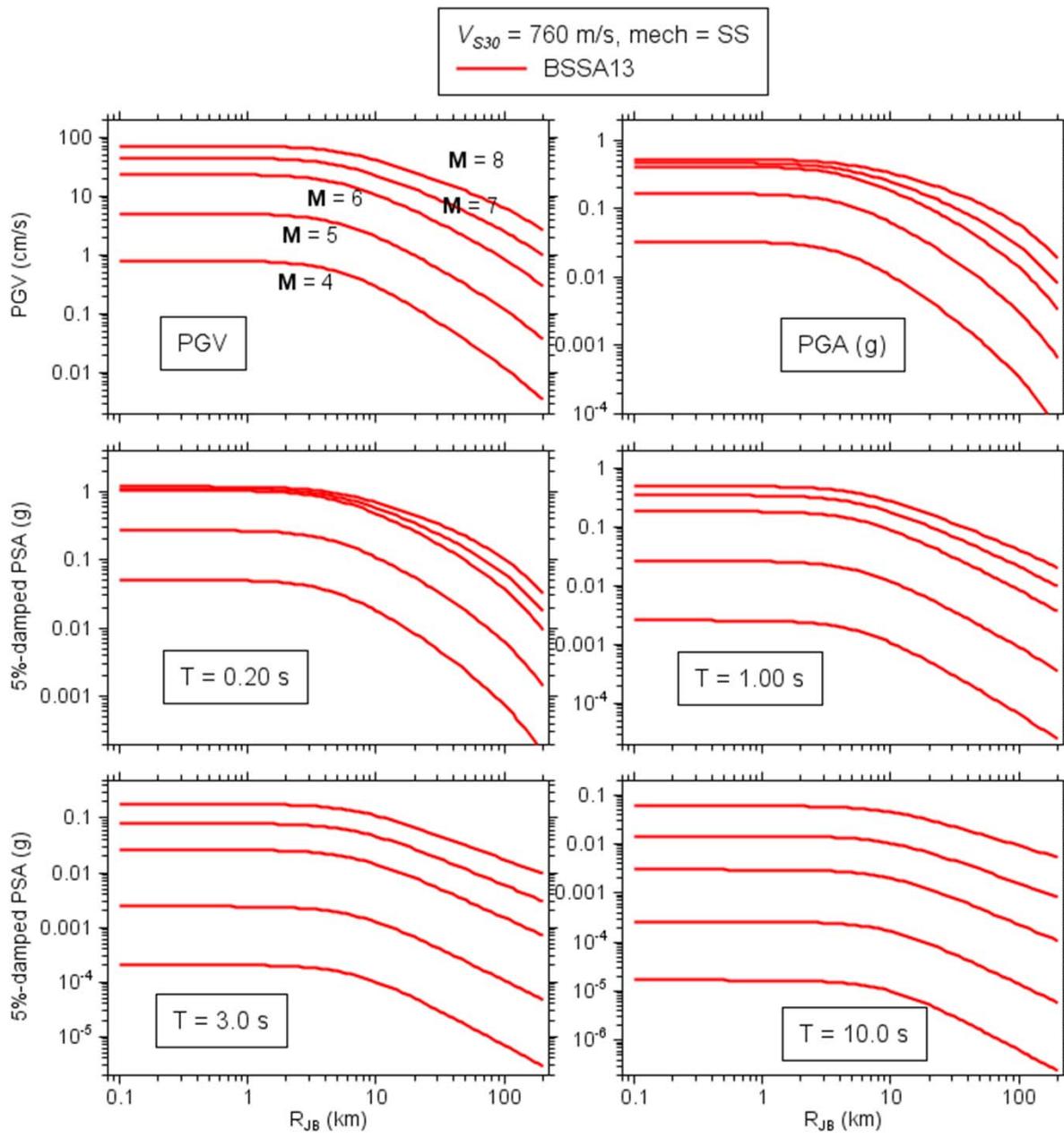
Examples of data added to NGA-West2 database

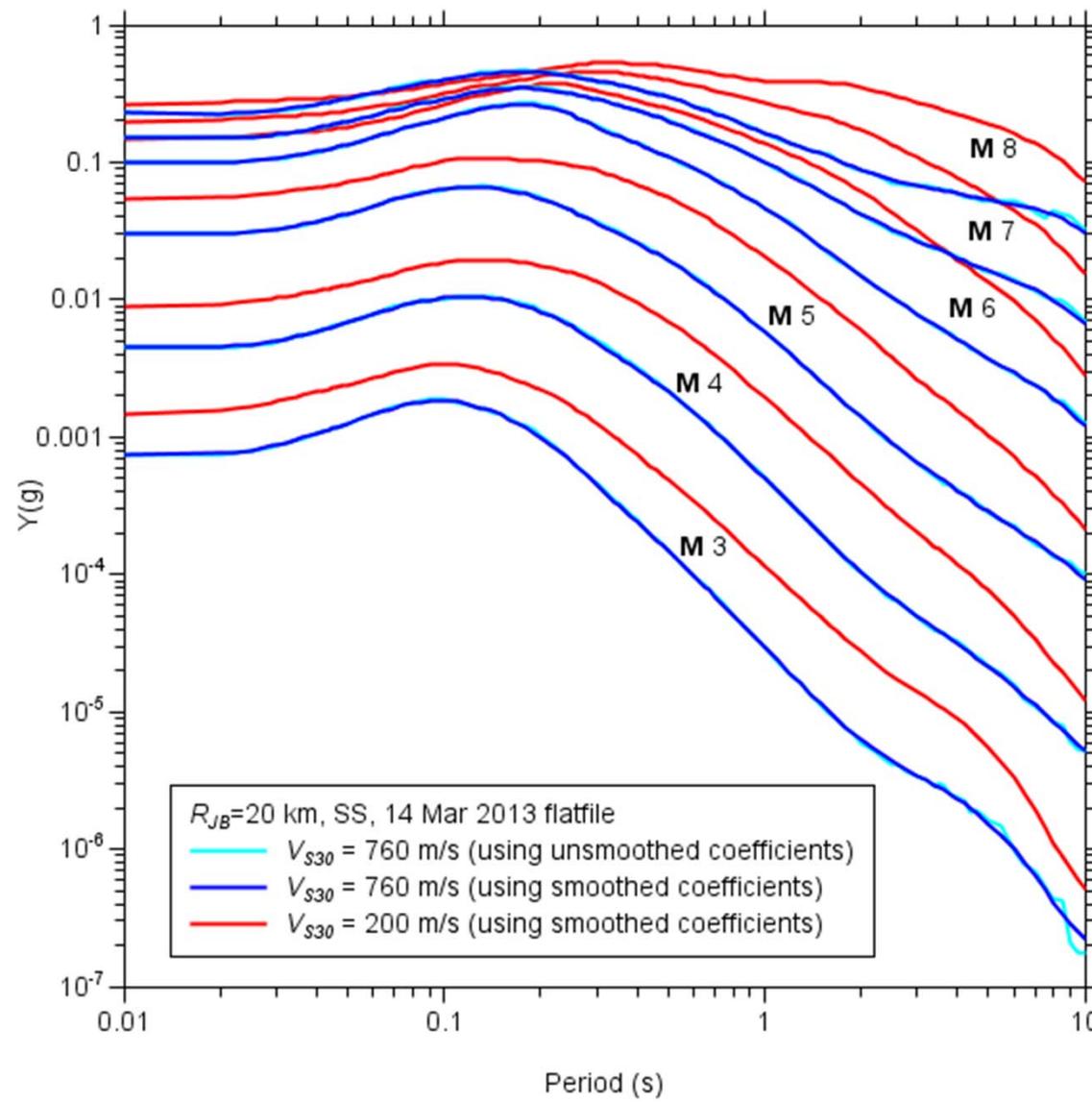
Earthquake Name*	Year	M	N Rec	Rrup Range (km)
Tottori, Japan	2000	6.6	414	1-333
Niigata, Japan	2004	6.6	530	8-300
Chuetsu-oki, Japan	2007	6.8	616	10-300
Iwate, Japan	2008	6.9	367	5-280
El Mayor-Cucapah, CA	2010	7.2	238	11-240
Darfield, New Zealand	2010	7.0	114	1-540
Christchurch, New Zealand	2011	6.1	104	2-440
Wenchuan, China	2008	7.9	263	1-1500
L'Aquila, Italy	2009	6.3	48	5-230

*subset of added events

Number of records used for BSSA13 base-case GMPEs







How the NGA-West 2 Project Fits into this Talk

- The database created in the project contains uniformly processed data and carefully screened metadata (e.g., V_{S30}) that can be used in studies of near-fault ground motions
 - Amplitude variations
 - Polarization complexities
- The GMPEs provide a summary of many data (used for studies of source, path, and site effects)
 - Scaling with magnitude

Ground Motions Near Faults

Large Earthquakes with Near-Fault Recordings of Ground Motion

- 1999 Kocaeli, Turkey (**M** 7.5)
- 1999 Chi-Chi, Taiwan (**M** 7.6)
- 1999 Duzce, Turkey (**M** 7.1)
- 2002 Denali Fault, Alaska (**M** 7.9)
- 2004 Parkfield, California (**M** 6.0)
- 2008 Wenchuan, China (**M** 7.9)

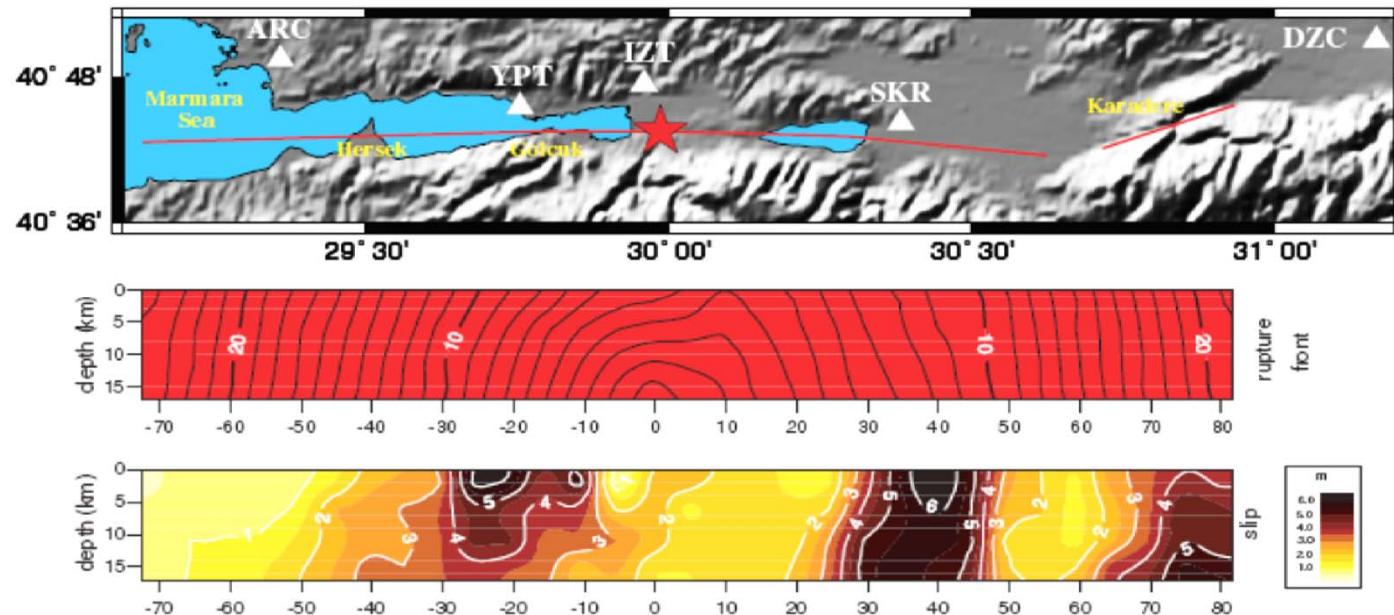
Numbers of Records in PEER NGA-West 2 Database for 3 Near-fault Distance Ranges

Event	Type	M	R _{JB} <2 km	R _{JB} <5 km	R _{JB} <10 km
Kocaeli	SS	7.6	2	3	4
Chi-Chi	RS	7.5	18	23	42
Duzce	SS	7.1	2	7	9
Denali	SS	7.9	1	1	1
Parkfield	SS	6.0	19	41	63
Wenchuan	RS	7.9	5	6	6

Note that being close is not the same as being in the fault zone. This is particularly true for non-vertical faults (usually RS, NS faults).

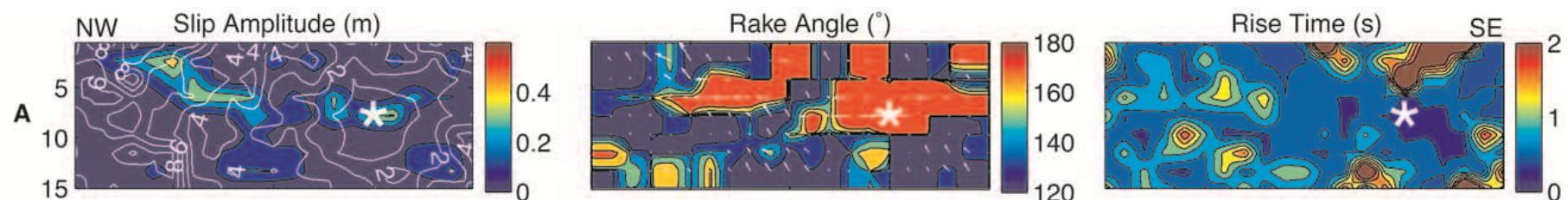
Near-fault records are usually used in determinations of fault slip as a function of space and time: the 1999 Kocaeli, Turkey (**M** 7.5)

From Bouchon et al. (2002)



2004 Parkfield, California (**M** 6.0)

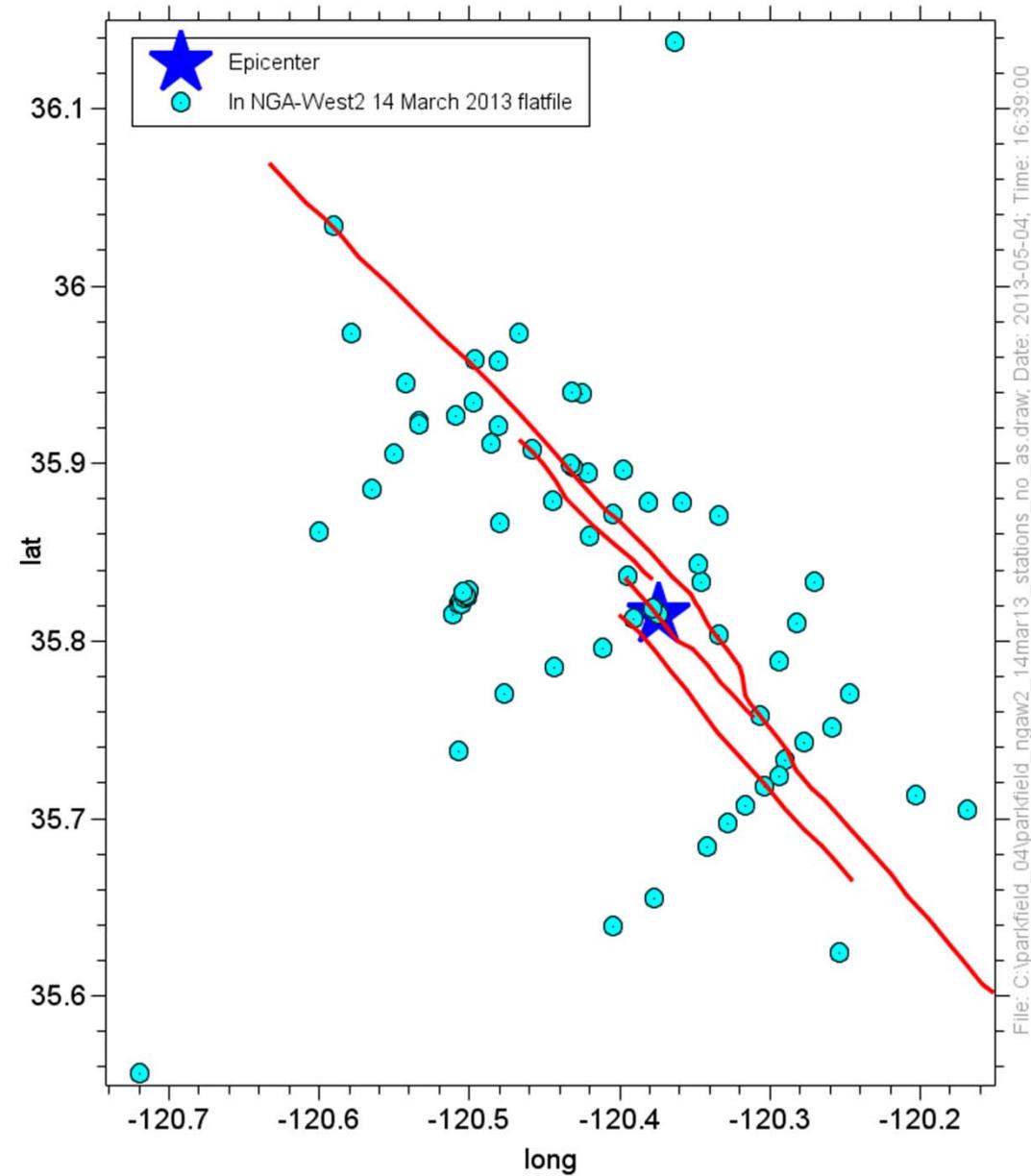
From Liu et al. (2006)



The records also tell us about spatial variability of motions near faults

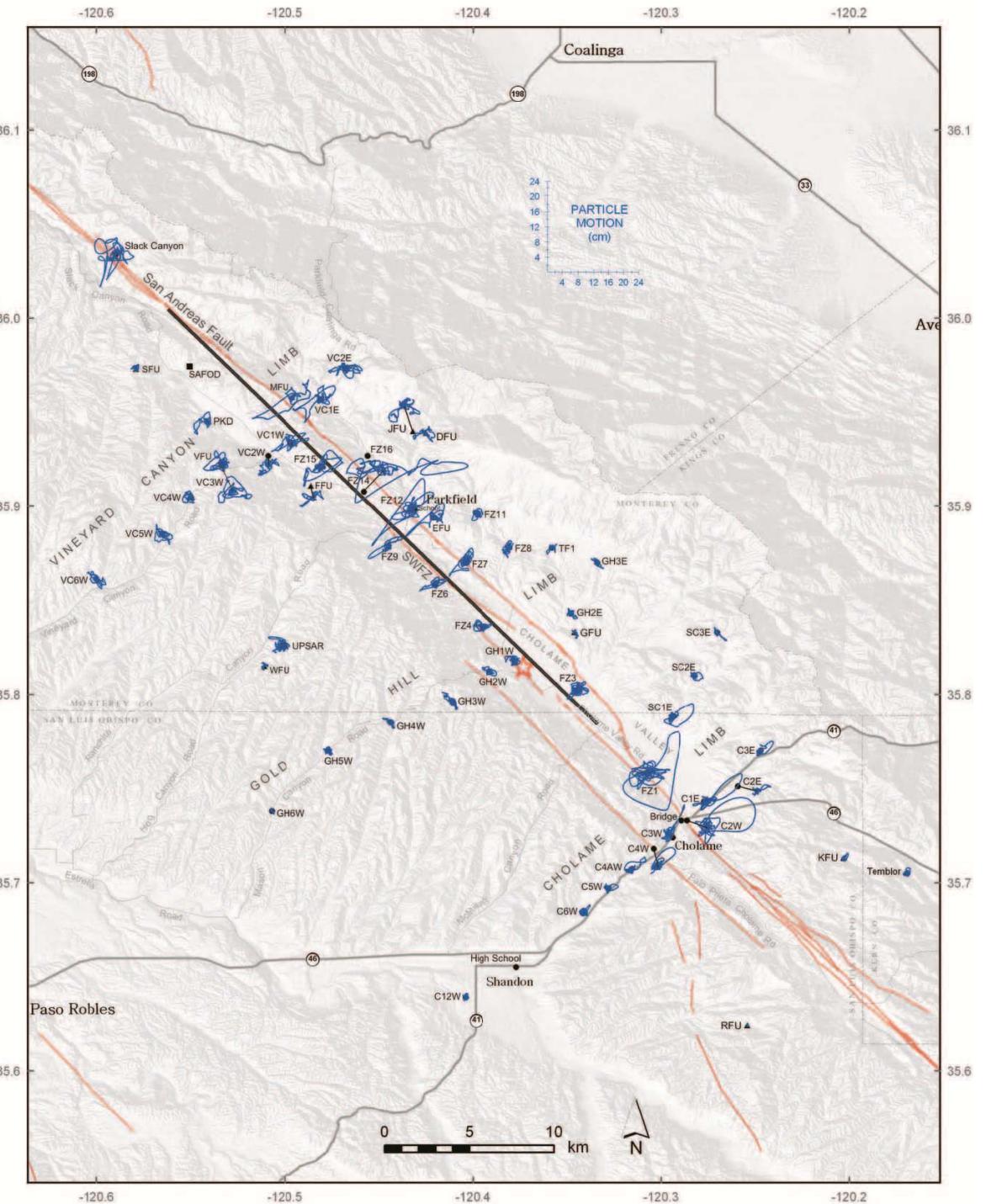
Parkfield 2004

Most Extensively
Observed Earthquake
to Date in the Near-
Fault Region



Coherent polarization and spatial variations in amplitude for displacements

Figure 14. Displacement particle motions calculated from the recorded accelerations at each station. The motions in the central part of the faulting are mostly low, and largest at the ends. The simplified line source fault model used in determining fault distances is shown for reference (end points 35.784° N, 120.334° W and 36.005° N, 120.562° W).



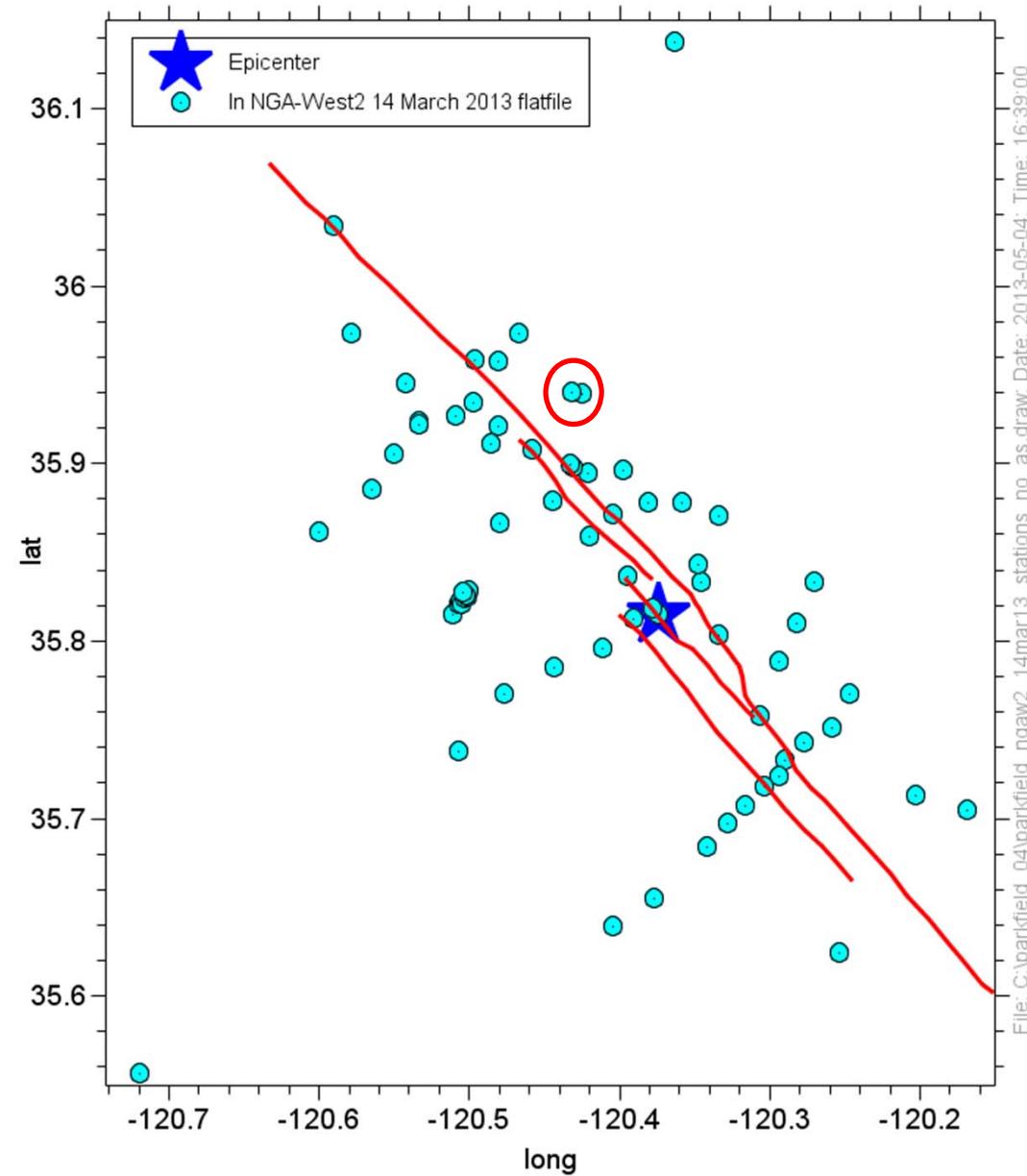
Sources of Variability

- Nonuniform fault slip
- Site geology
- Fault zone effects

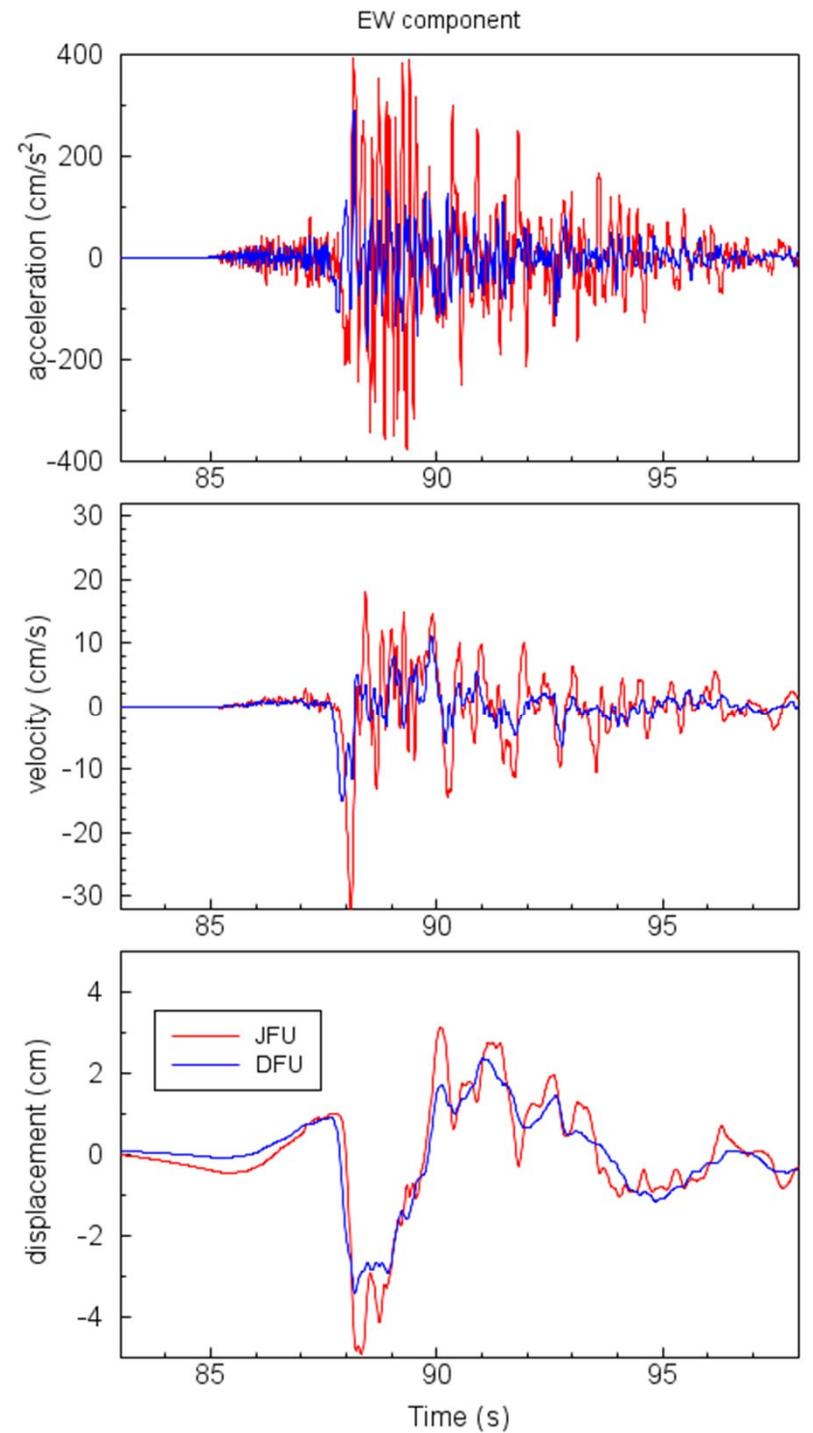
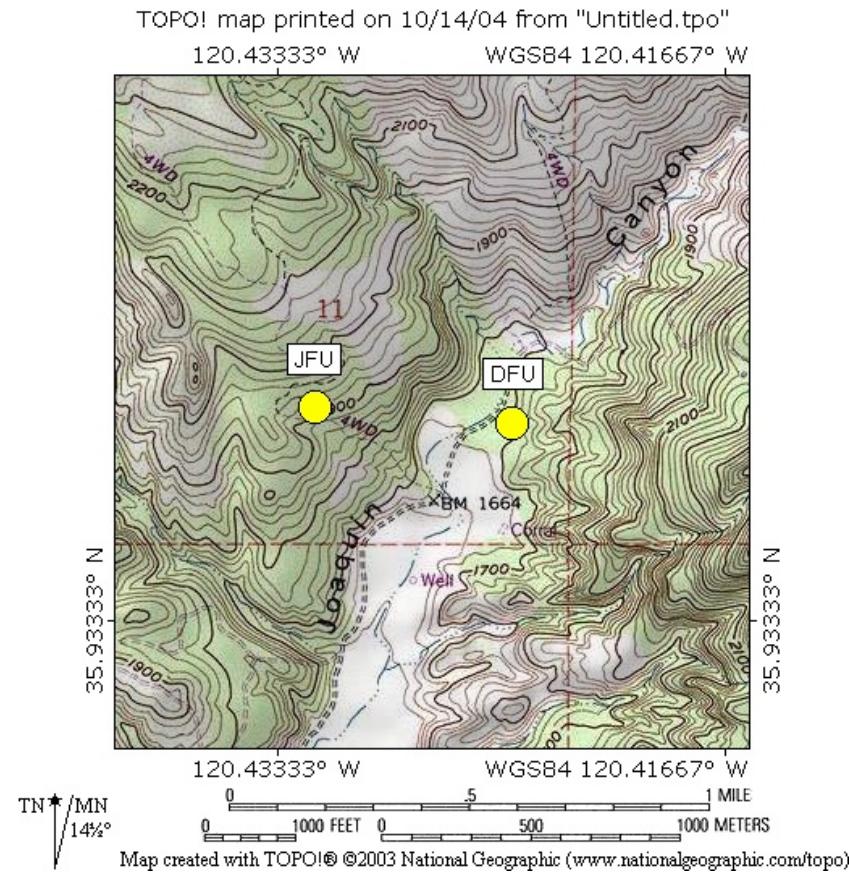
The records also tell us about spatial variability of motions near faults

Parkfield 2004

Most Extensively
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Fault Region



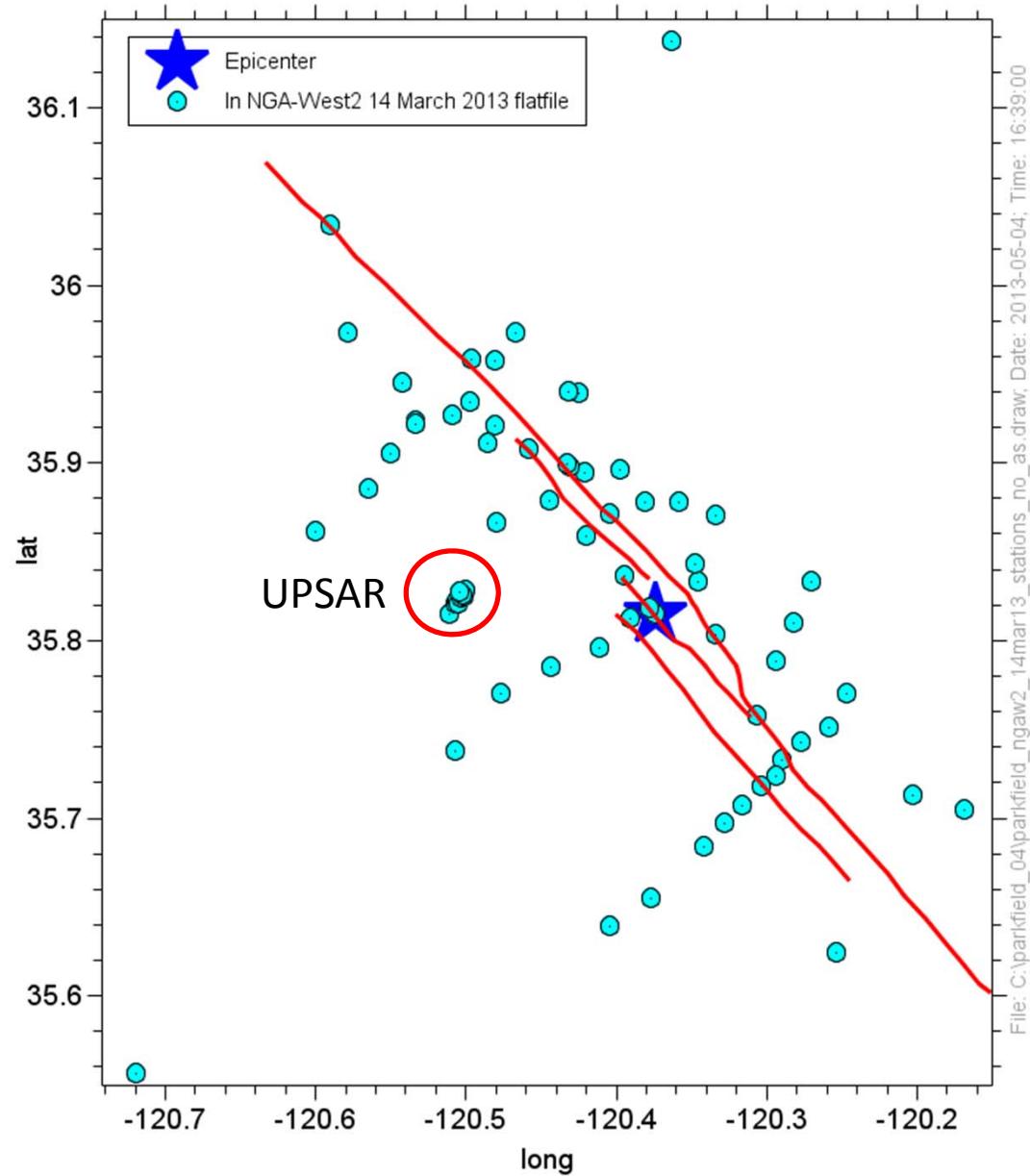
Spatial variations depend on frequency content of the motion—for a given station separation, expect more variability for higher frequency motions



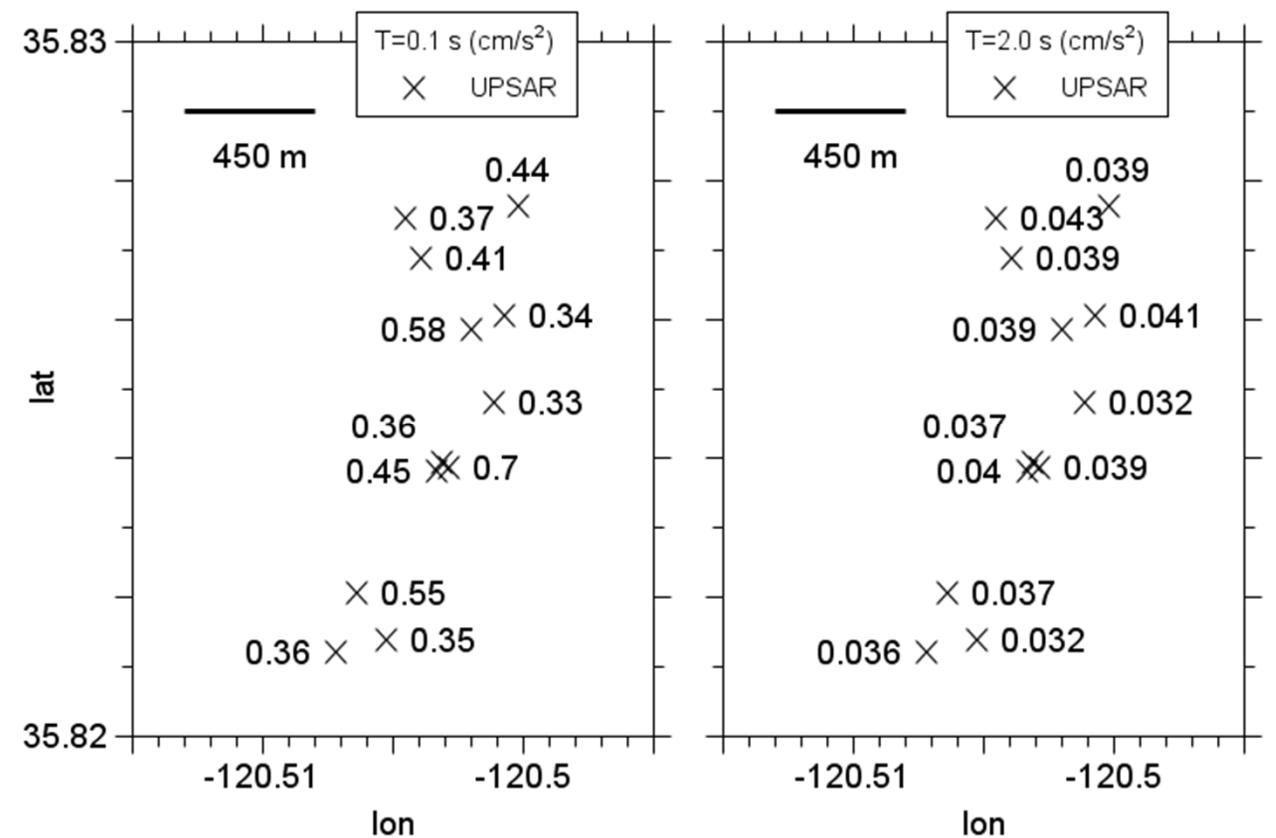
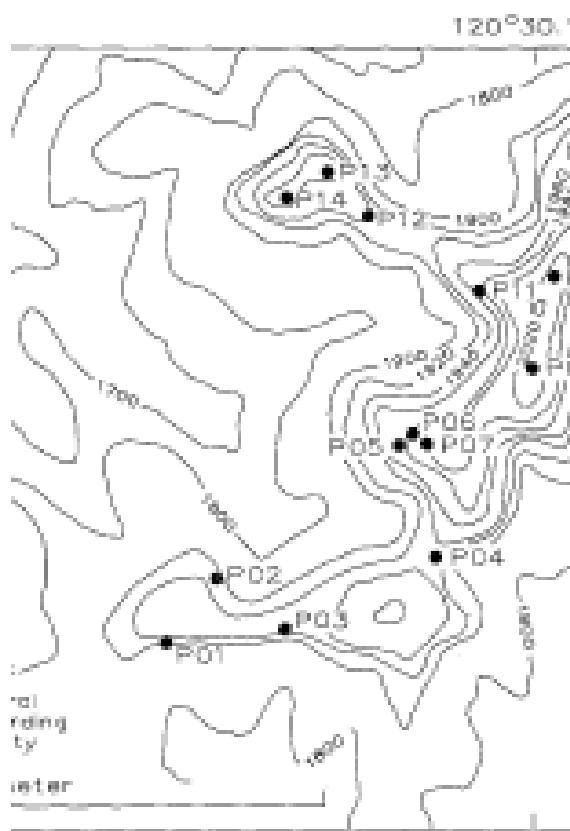
The records also tell us about spatial variability of motions near faults

Parkfield 2004

Most Extensively Observed Earthquake to Date in the Near- Fault Region



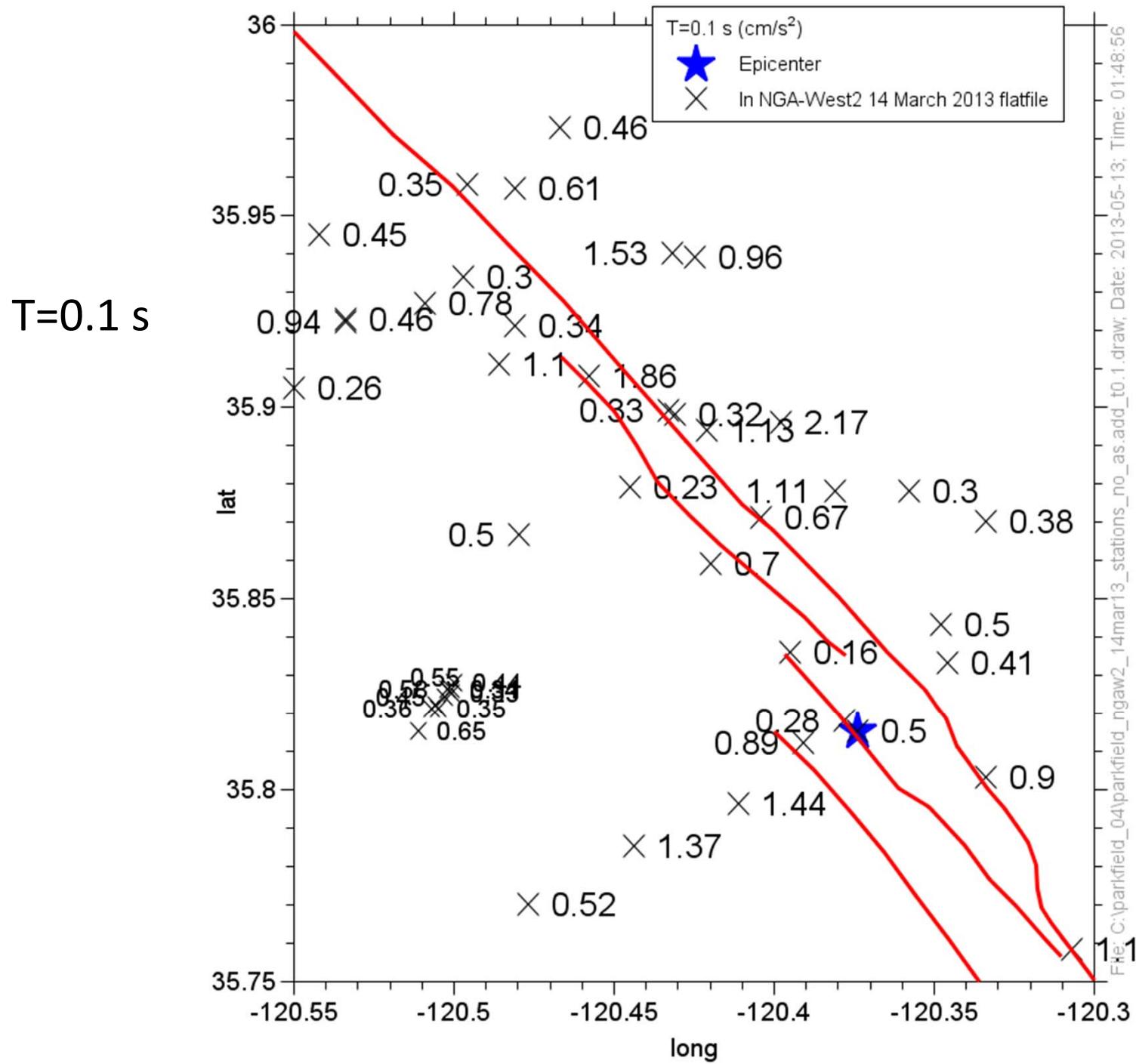
USGS Parkfield Dense Seismograph Array (UPSTAR) Recordings of the 2004 Parkfield Earthquake



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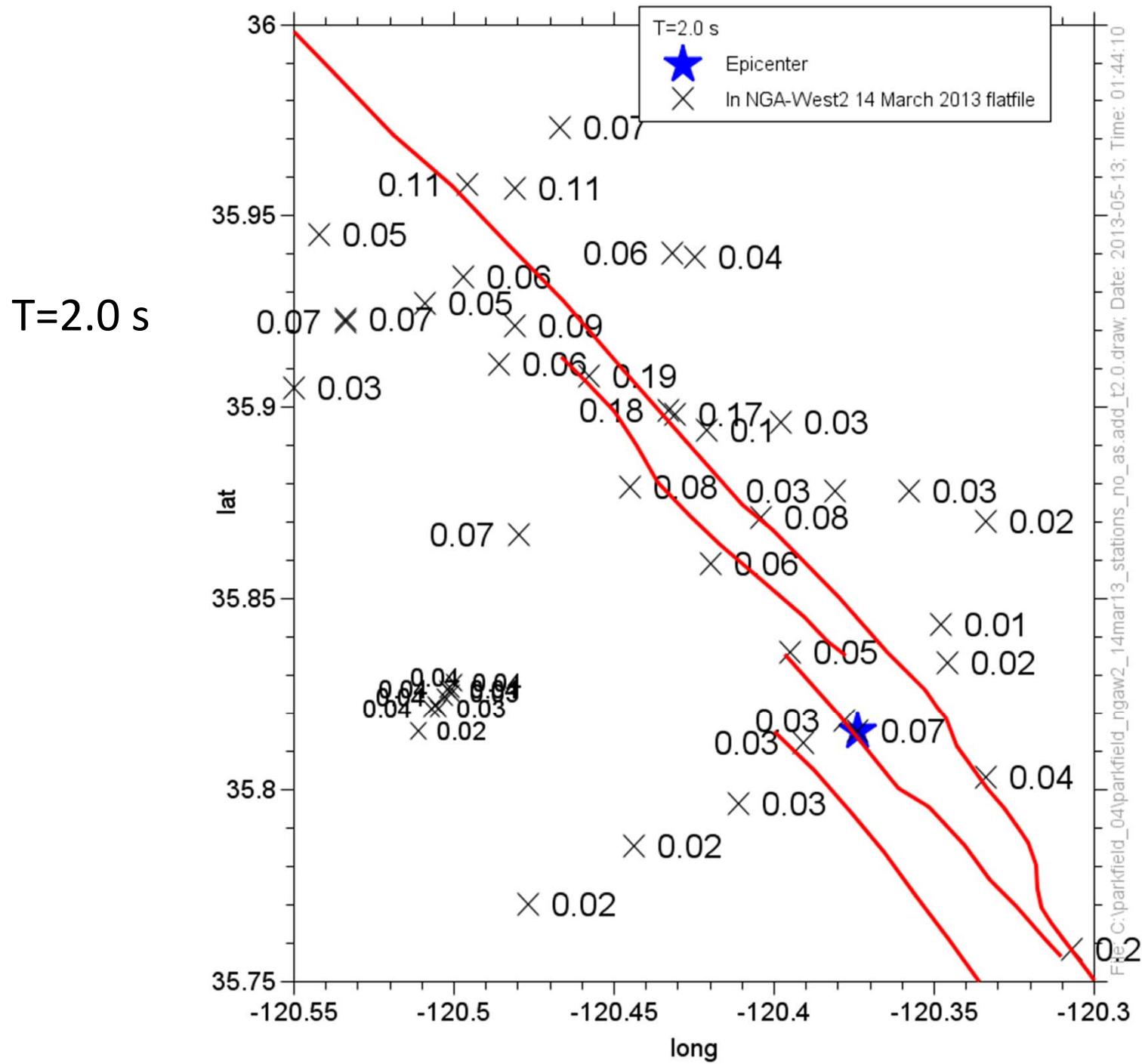
From Fletcher et al. (1992)

Less variability for longer period motion

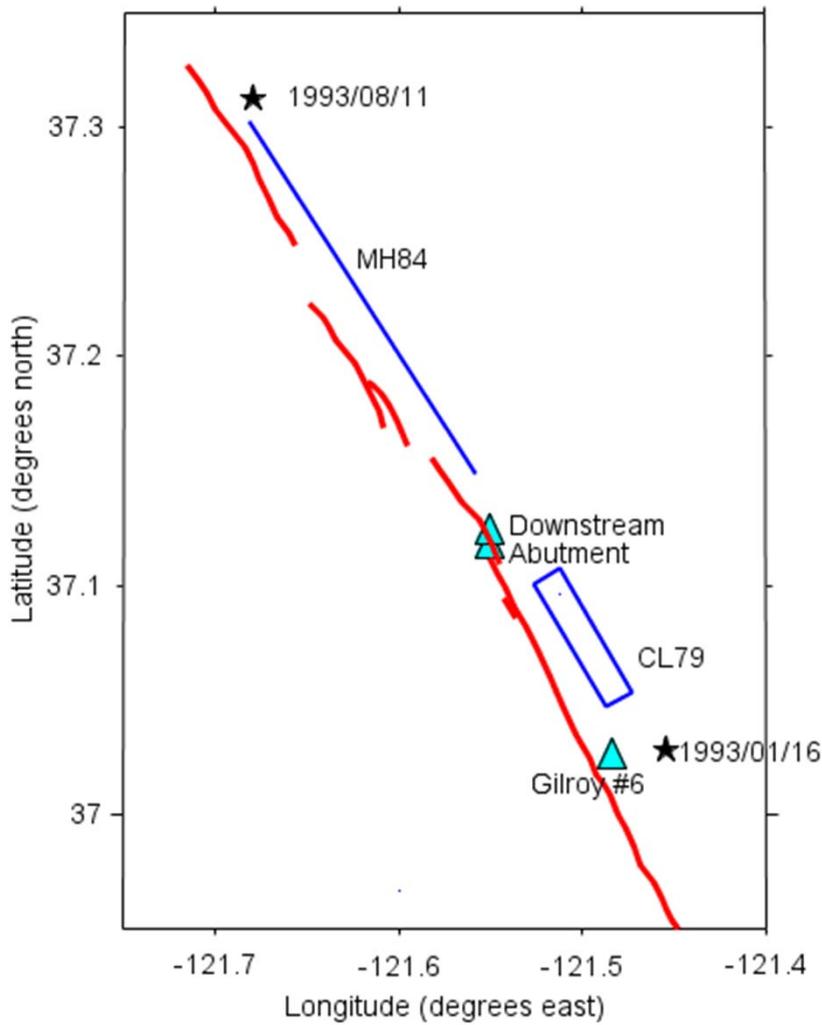


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Fig.1

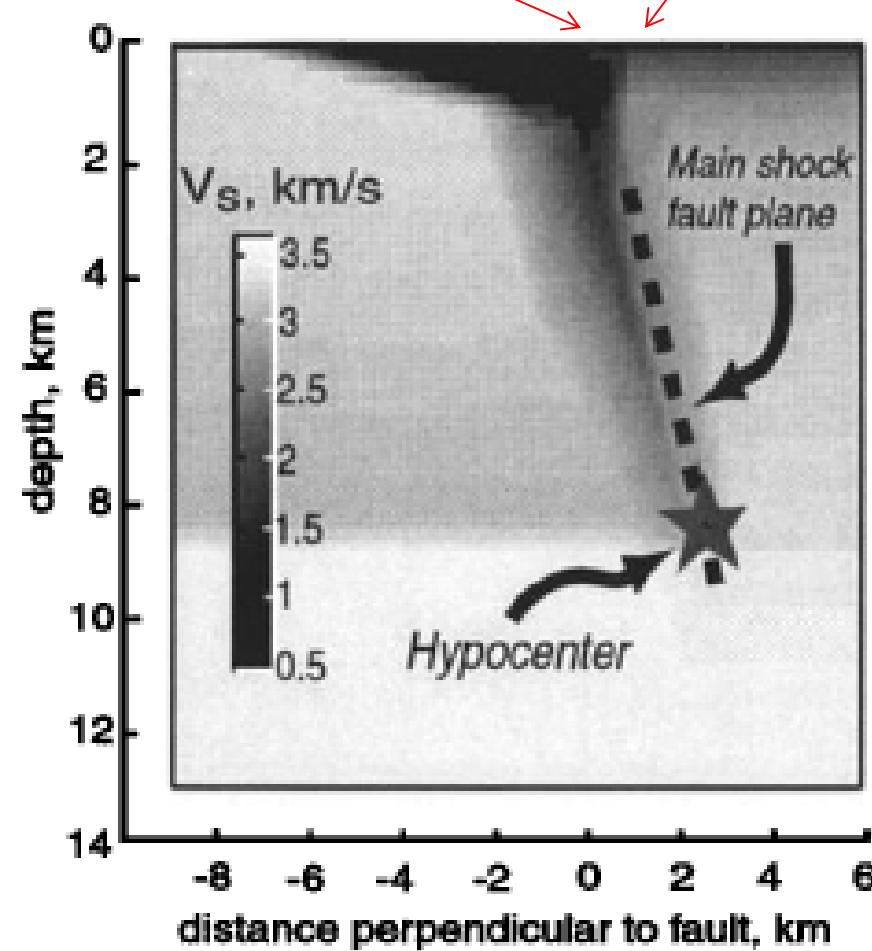


Recordings near the Calaveras Fault Zone



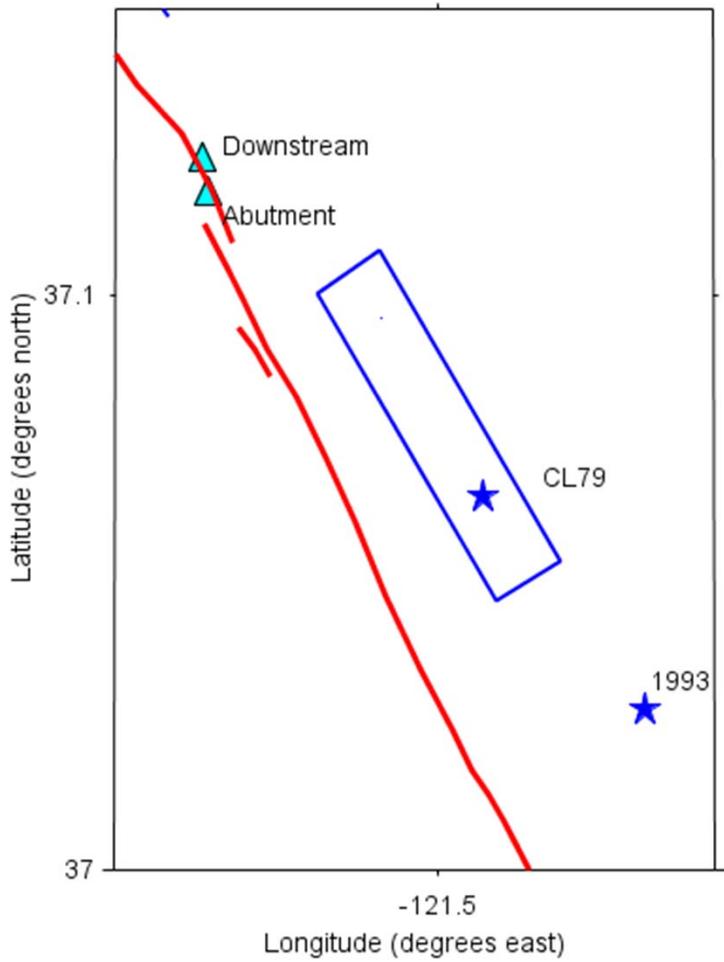
Coyote Lake downstream in the fault zone with $V_{s30}=295$ m/s

Gilroy #6 on a ridge to the east of the fault, with $V_{s30}=663$ m/s

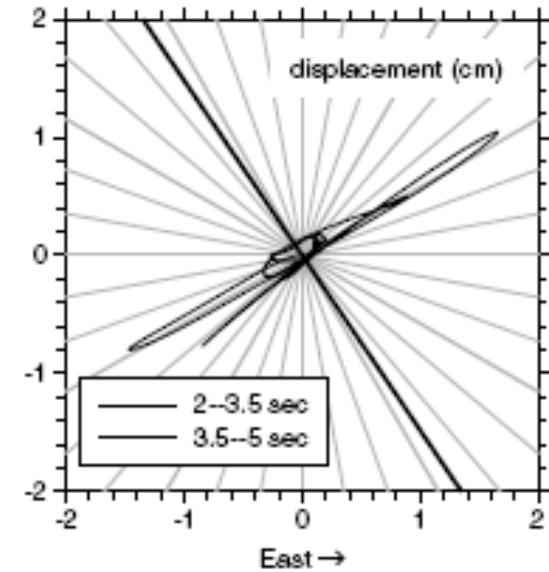
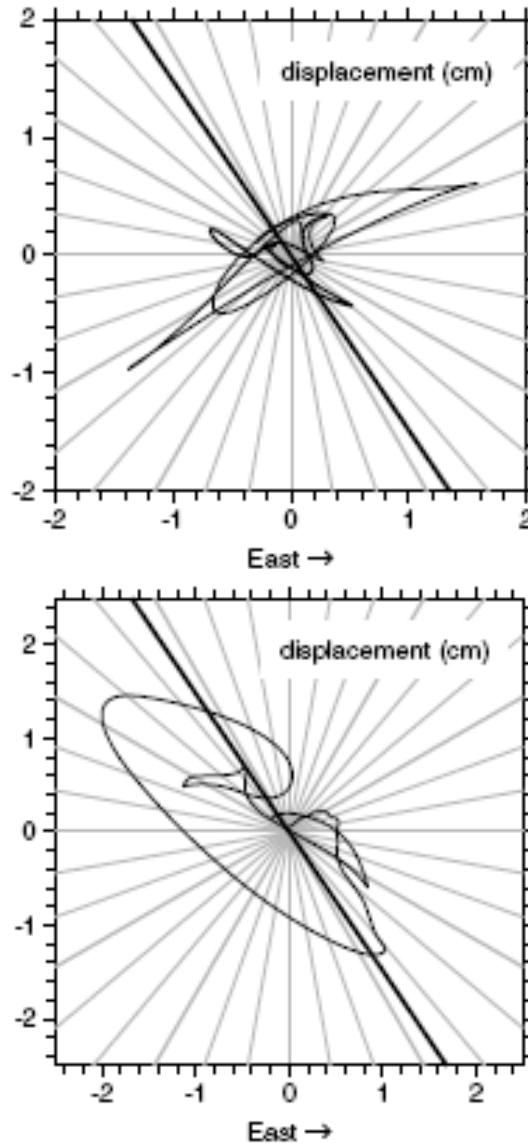


From Spudich and Olsen (2001)

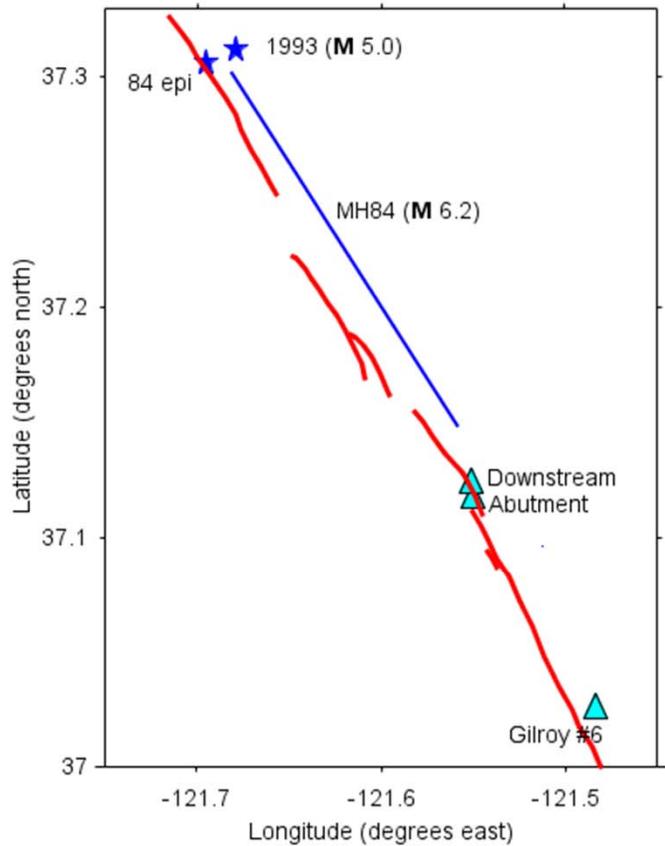
1993 (M 5.1): abutment, downstream



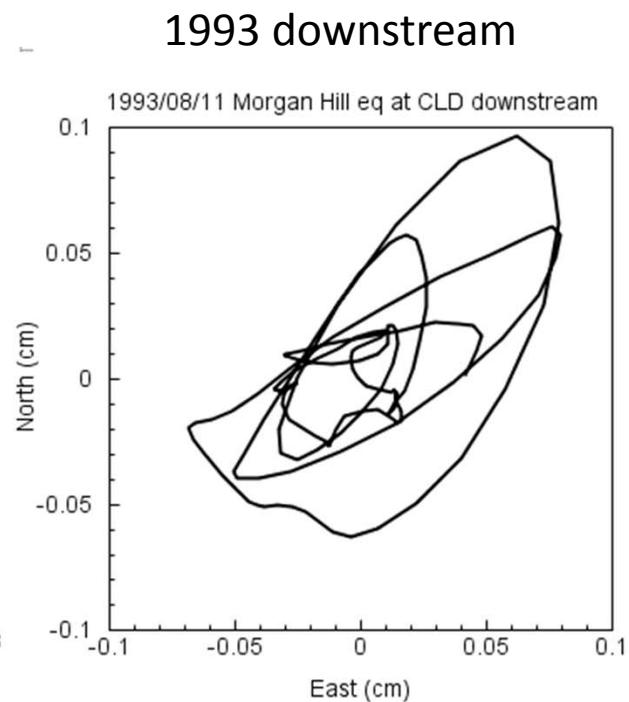
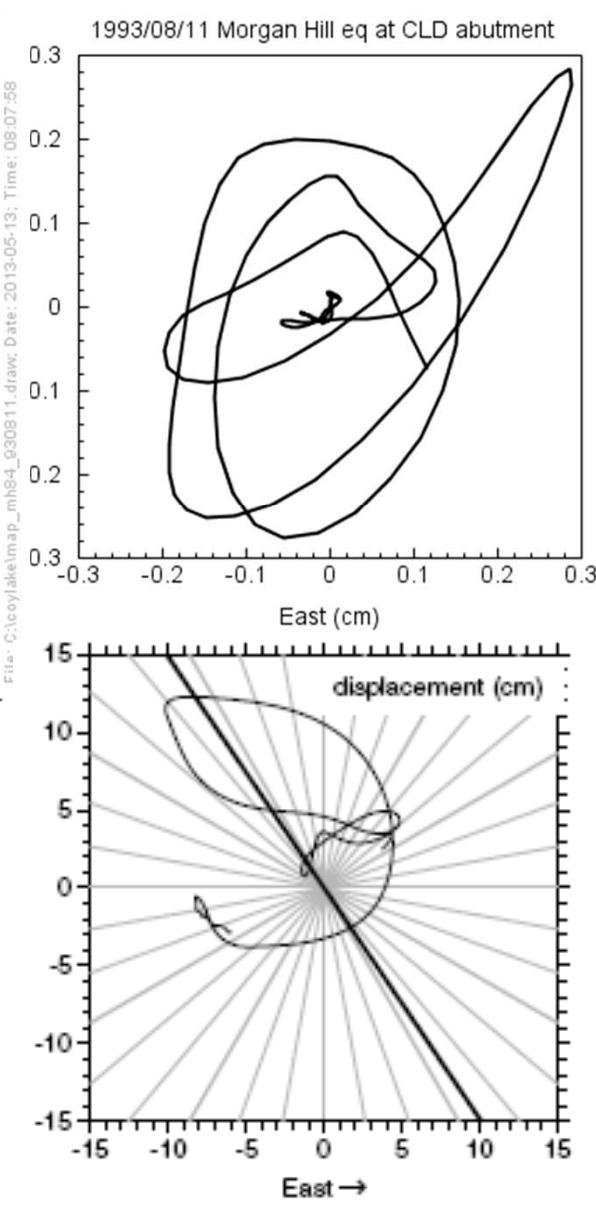
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CL79 (M 5.7):
abutment



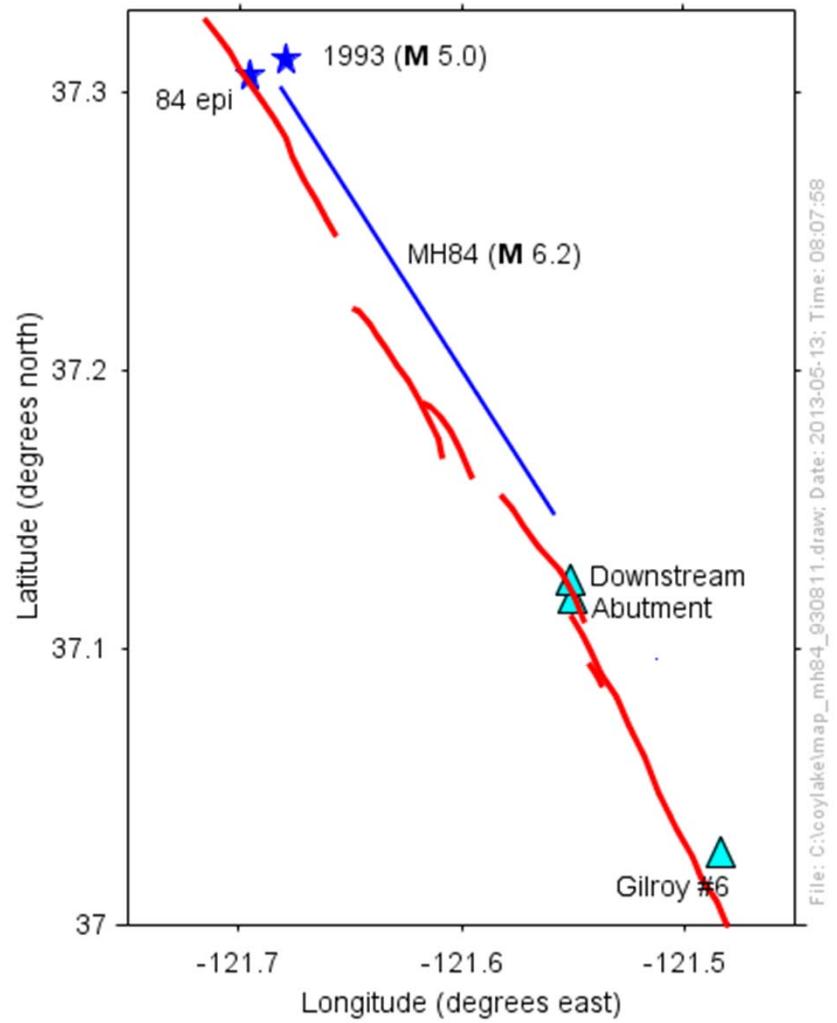
MH84



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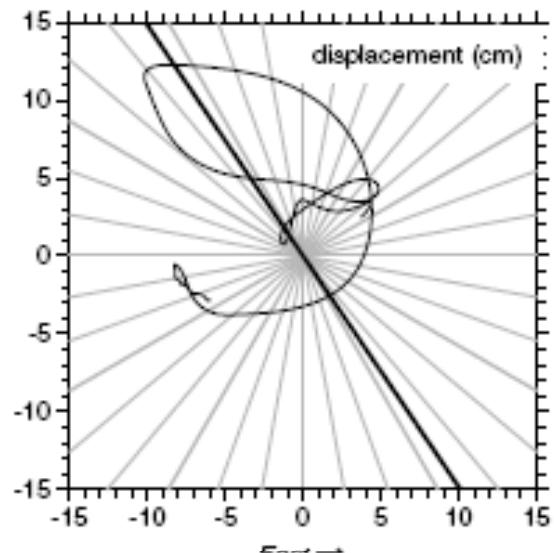
S-wave portion for 1993 is more fault normal than fault parallel, in contrast to MH84 at the abutment station

1984 Morgan Hill

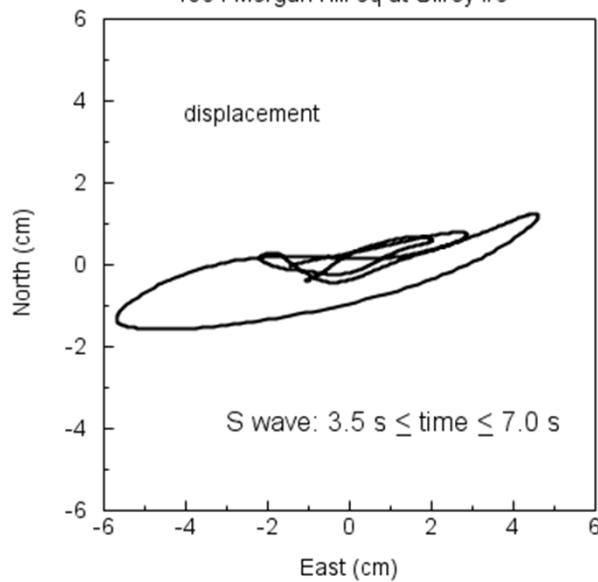


Abutment

Gilroy #6



1984 Morgan Hill eq at Gilroy #6

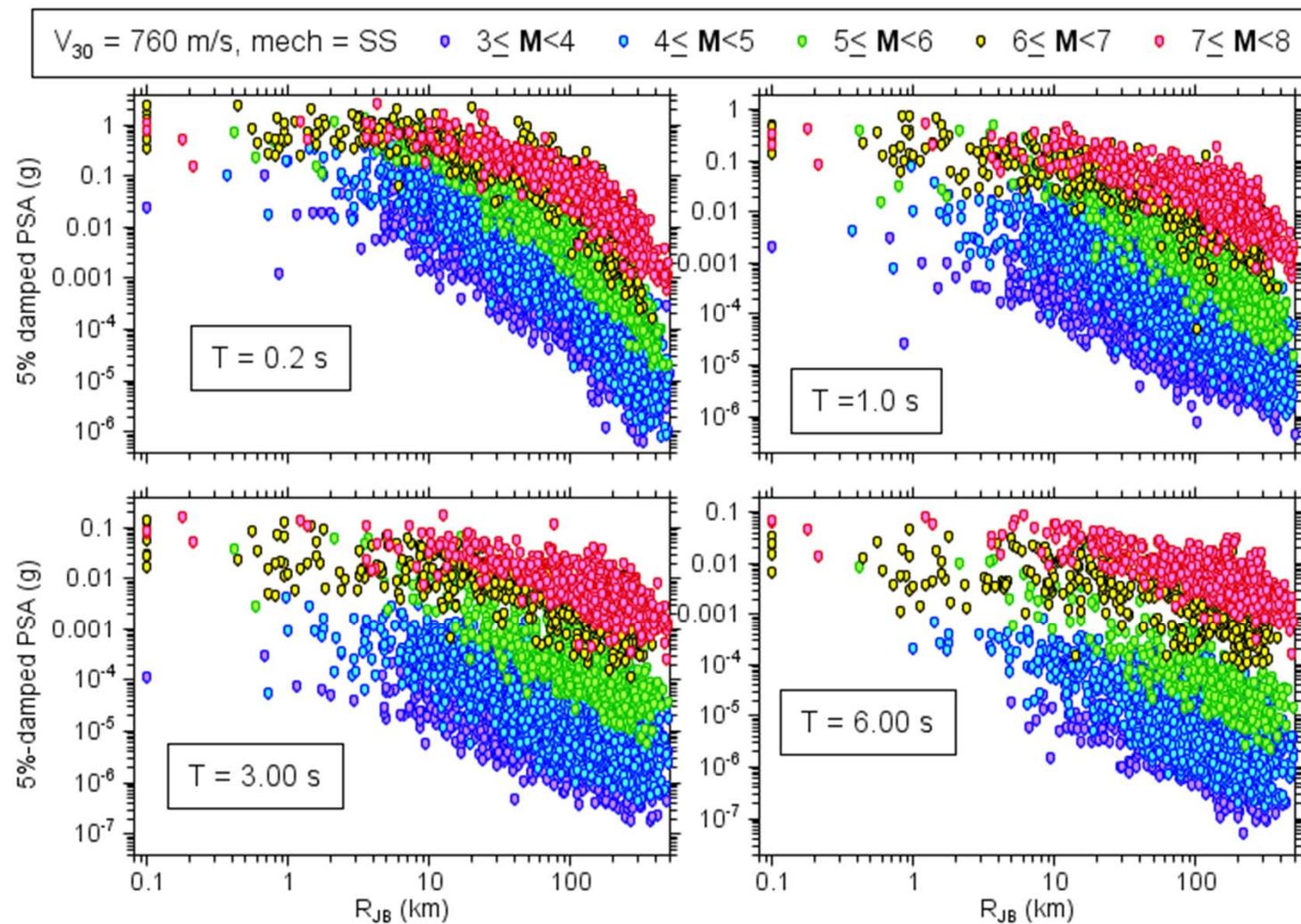


Sources of Variability

- Nonuniform fault slip
- Site geology
- Fault zone effects

Scaling of Motions with Magnitude at Near and Intermediate Distances

- Data
- Data plus GMPEs
- Data plus simulations



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 8_vs_760_mech_1(ss)_t_0.2_1.0_3.0_6.0.draw

SIMULATIONS

- Stochastic method fundamentals
- Finite-fault modification
- Source/path/site params for the simulations

Stochastic modelling of ground-motion: Point Source

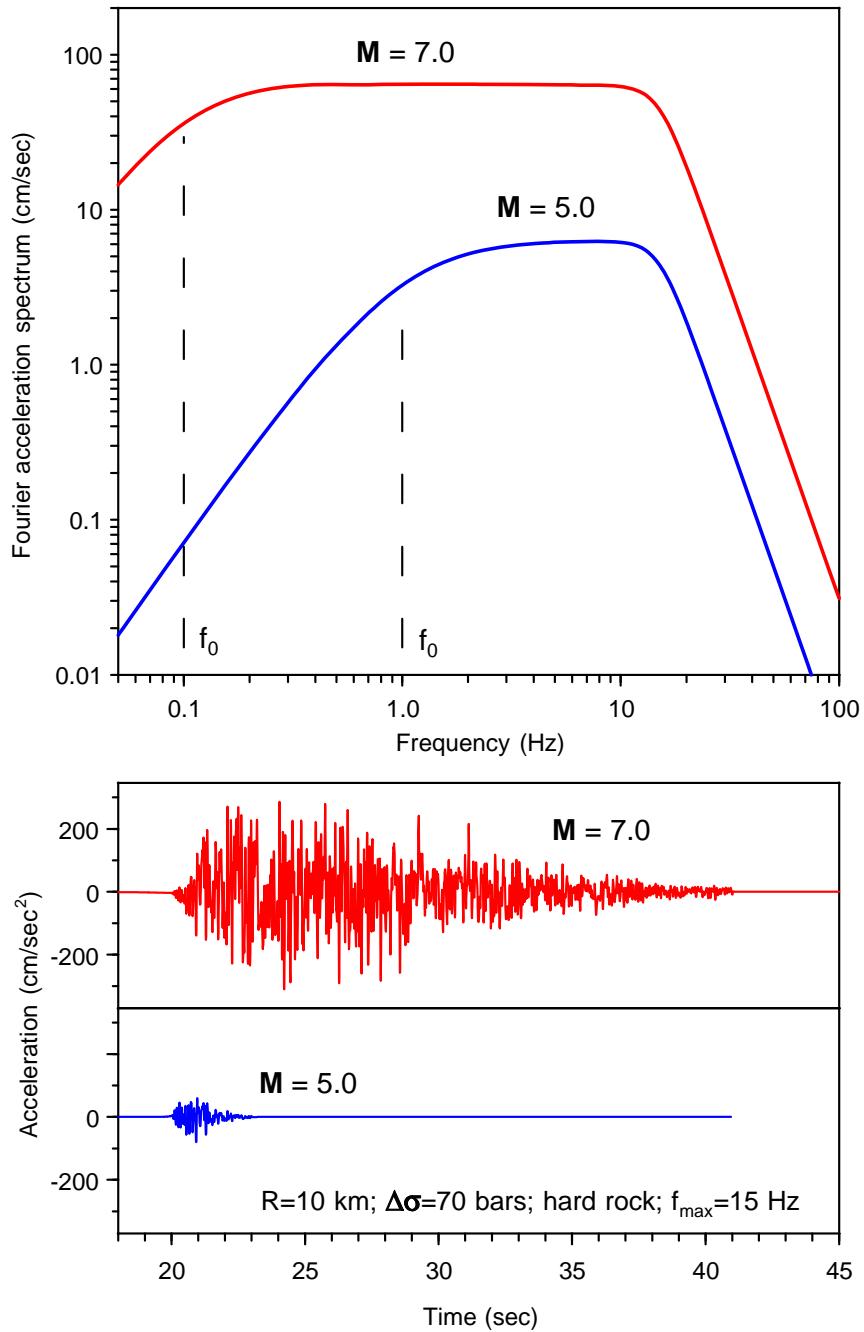
- Deterministic modelling of high-frequency waves not possible (lack of Earth detail and computational limitations)
- Treat high-frequency motions as filtered white noise (Hanks & McGuire , 1981).
- combine **deterministic target amplitude** obtained from simple seismological model and **quasi-random phase** to obtain high-frequency motion. Try to capture the essence of the physics using simple functional forms for the seismological model. **Use empirical data when possible to determine the parameters.**



Basis of stochastic method

Radiated energy described by the spectra in the top graph is assumed to be distributed randomly over a duration given by the addition of the source duration and a distant-dependent duration that captures the effect of wave propagation and scattering of energy

These are the results of actual simulations; the only thing that changed in the input to the computer program was the moment magnitude (5 and 7)

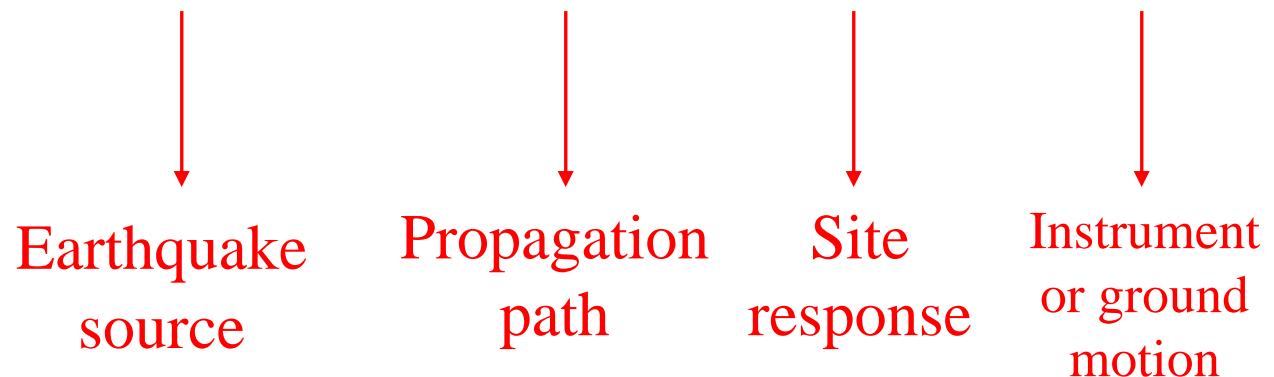


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Target amplitude spectrum

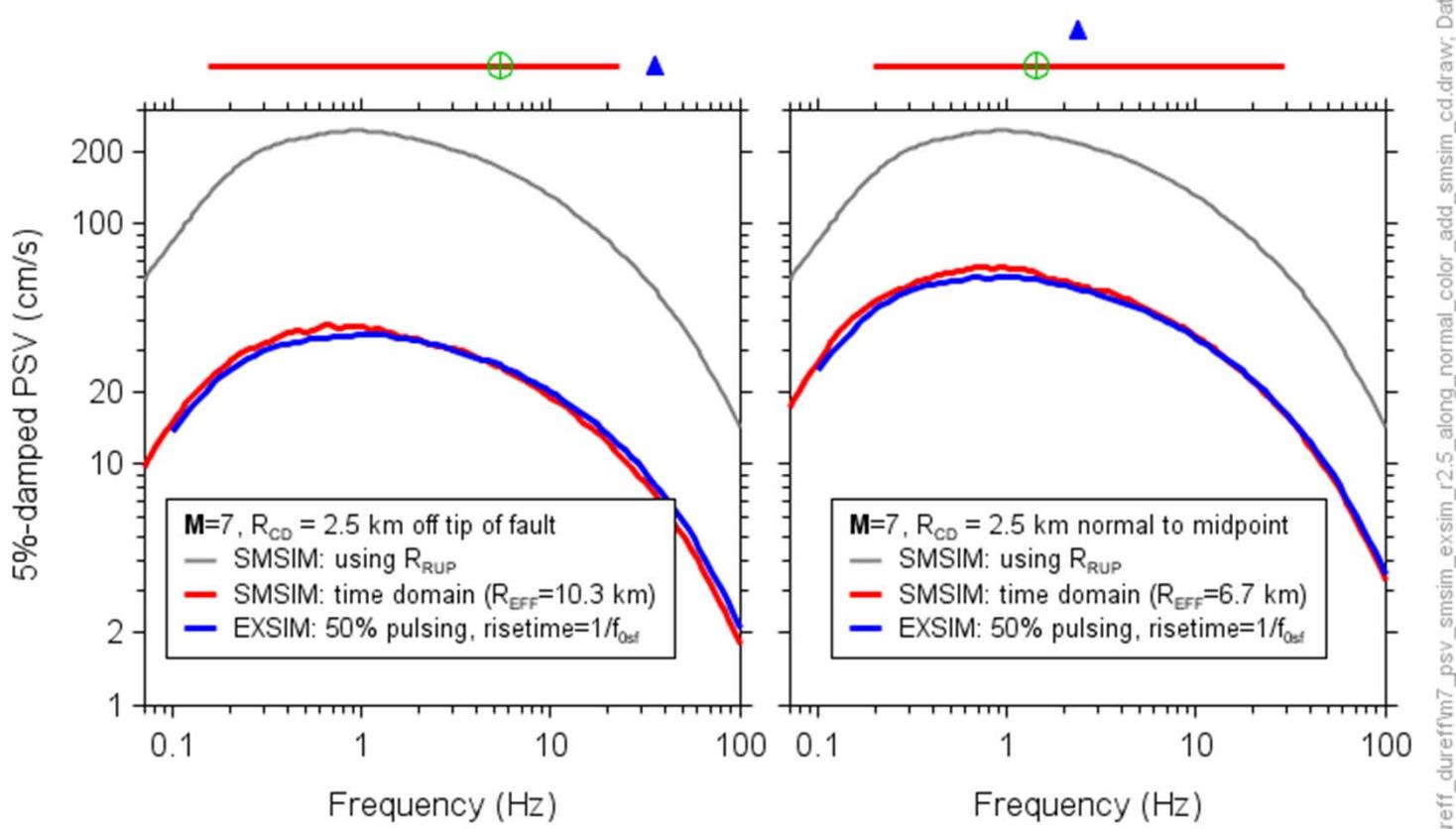
Deterministic function of source, path and site
characteristics represented by separate multiplicative filters

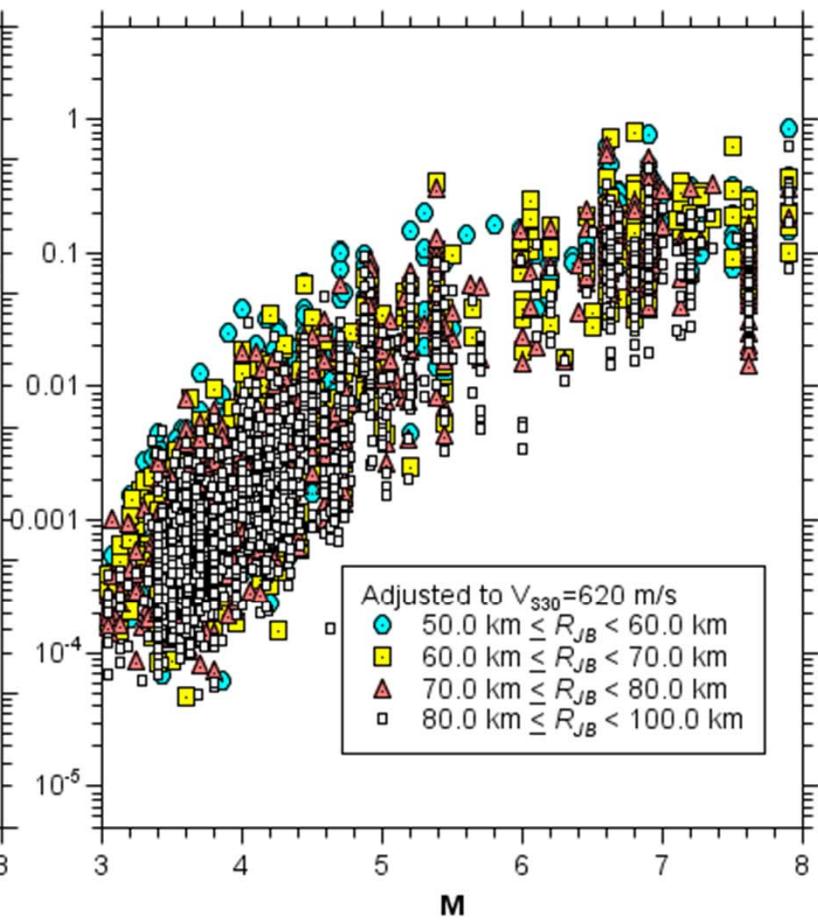
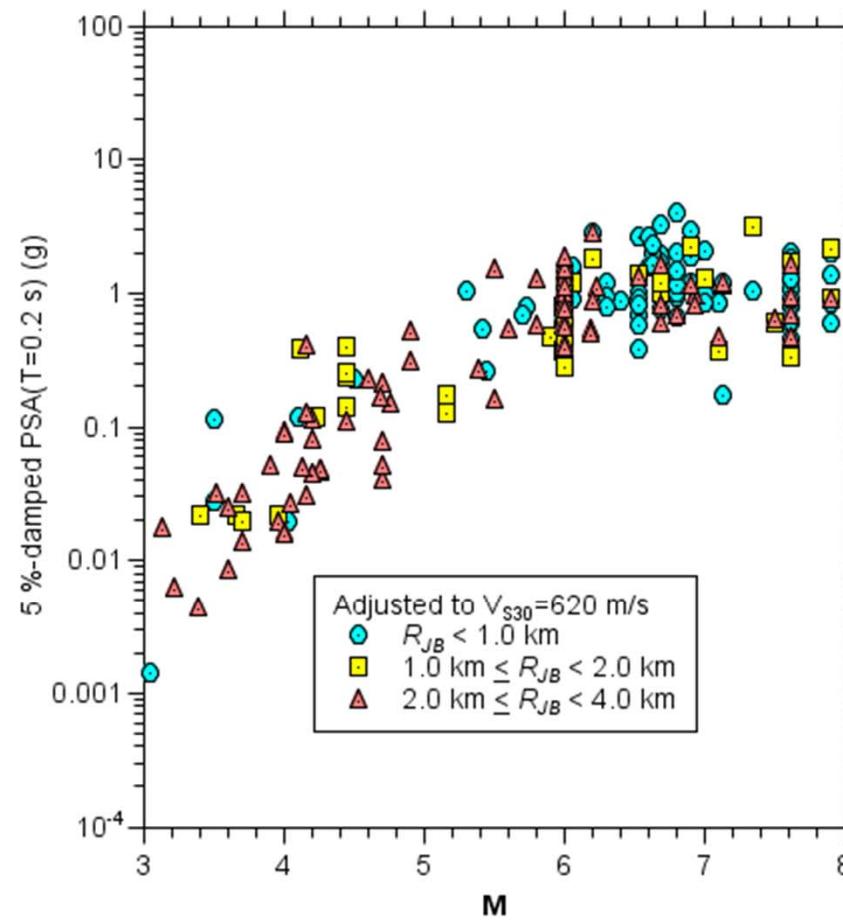
$$Y(M_0, R, f) = E(M_0, f) \times P(R, f) \times G(f) \times I(f)$$

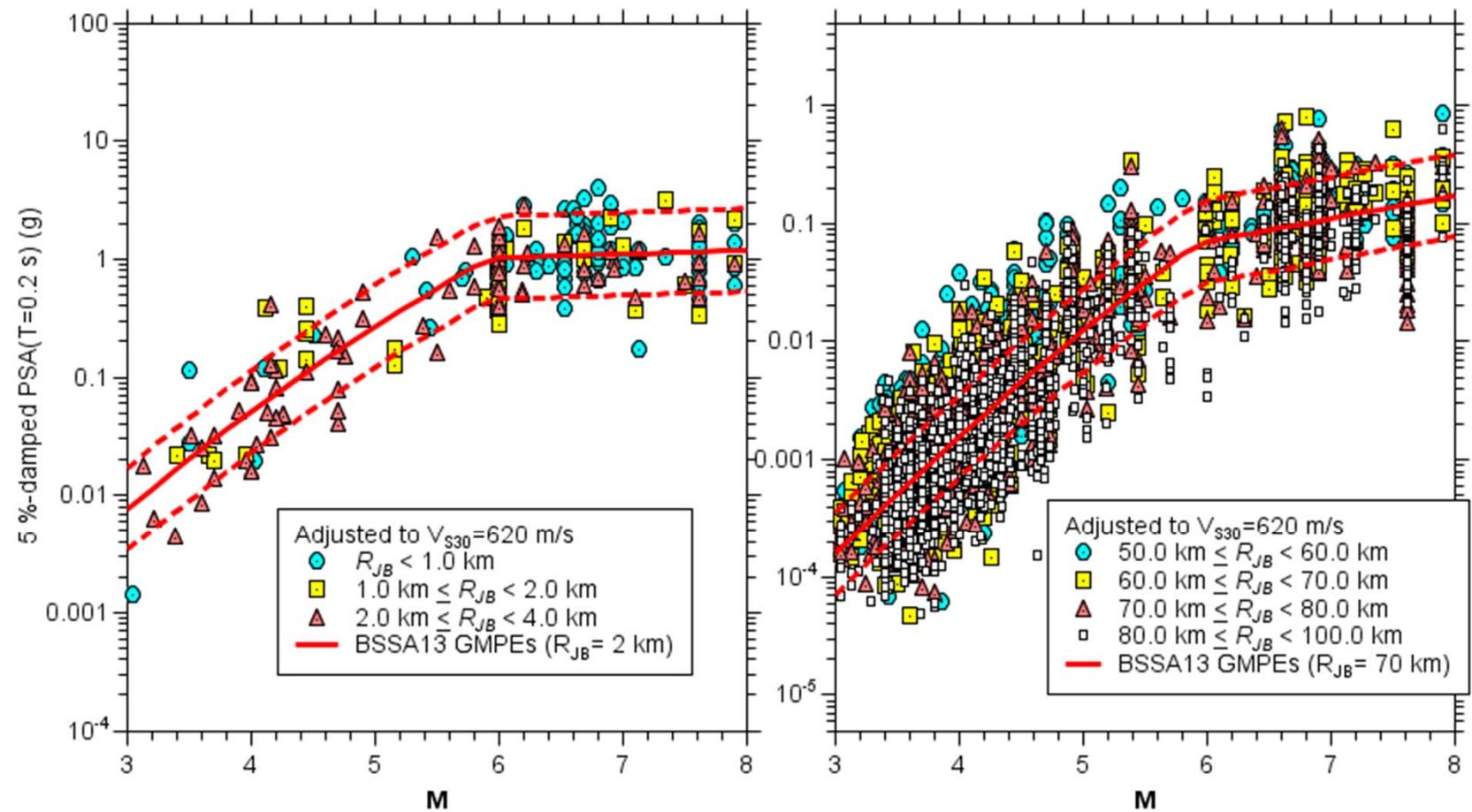


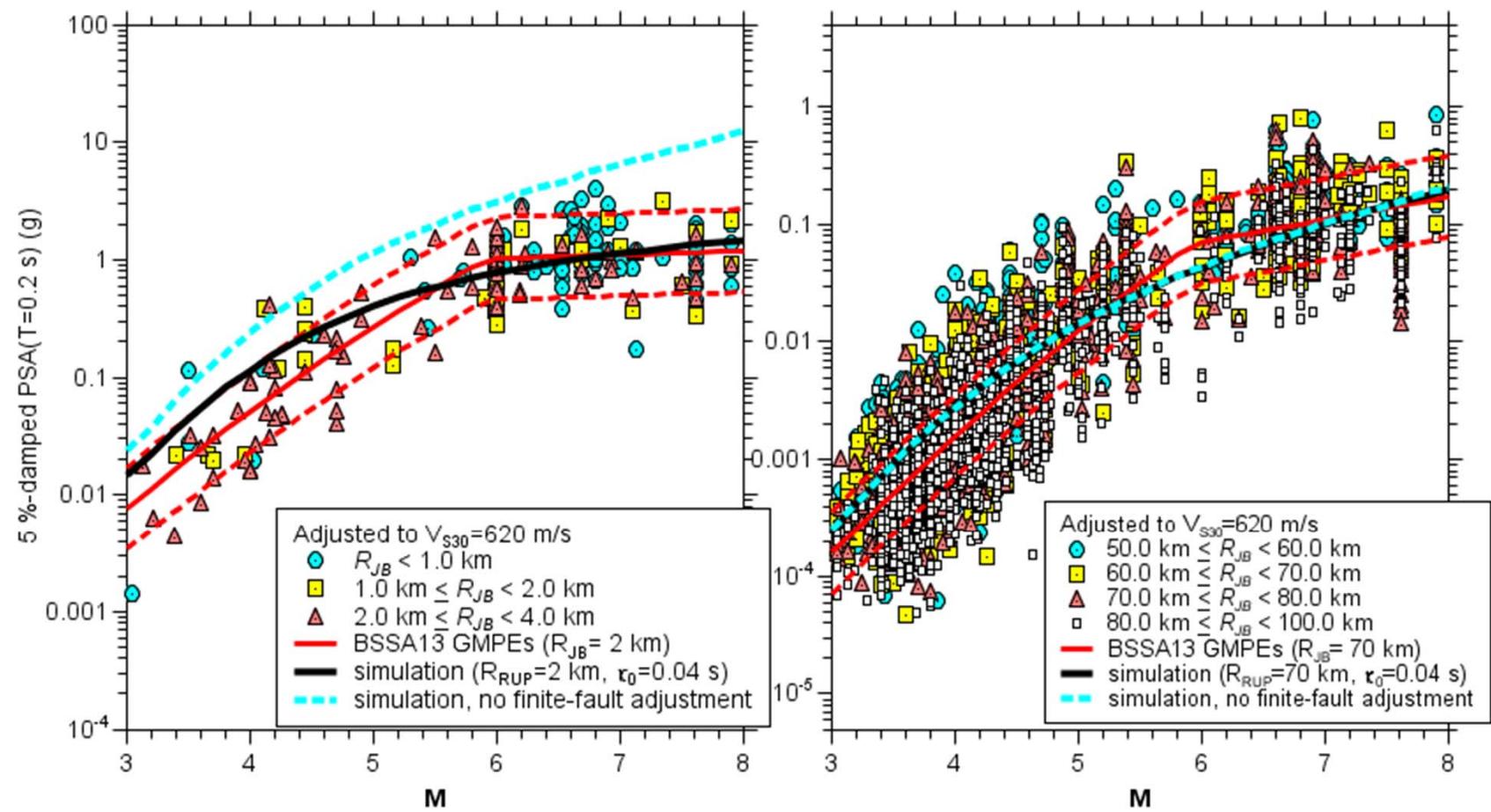
**THE KEY TO THE SUCCESS OF THE MODEL LIES IN BEING
ABLE TO DEFINE FOURIER ACCELERATION SPECTRUM
AS $F(M, DIST)$**

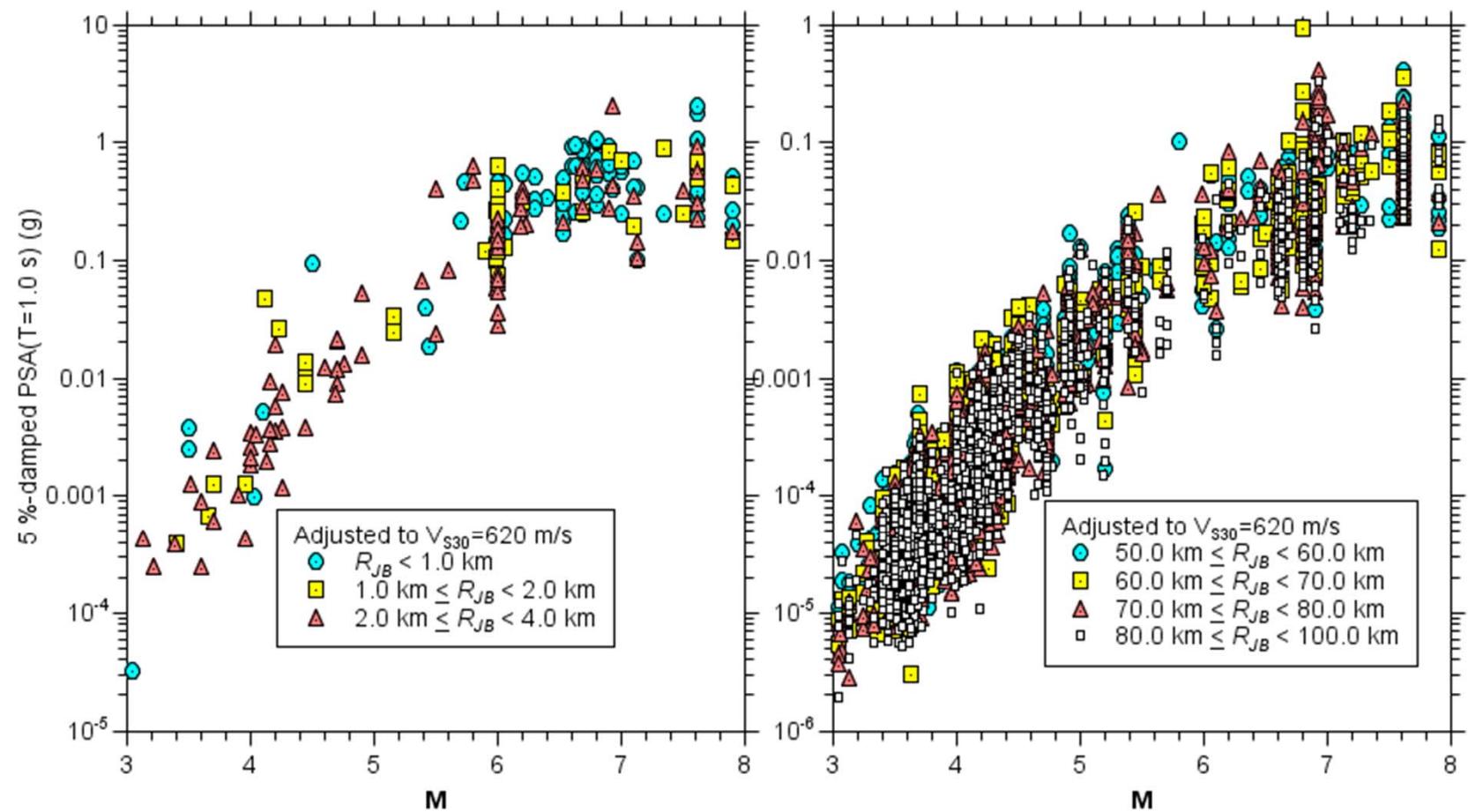
Finite-Fault Adjustments

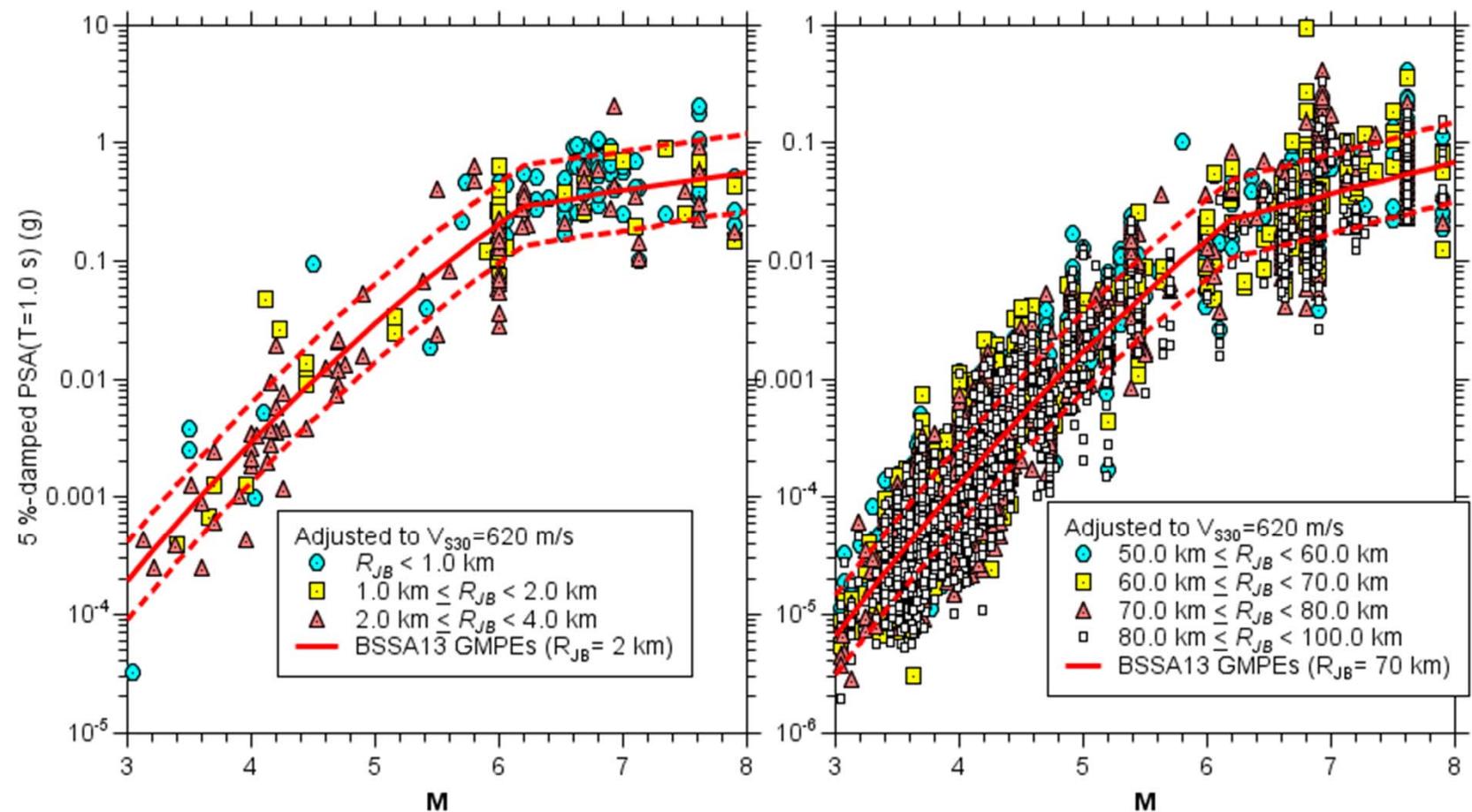


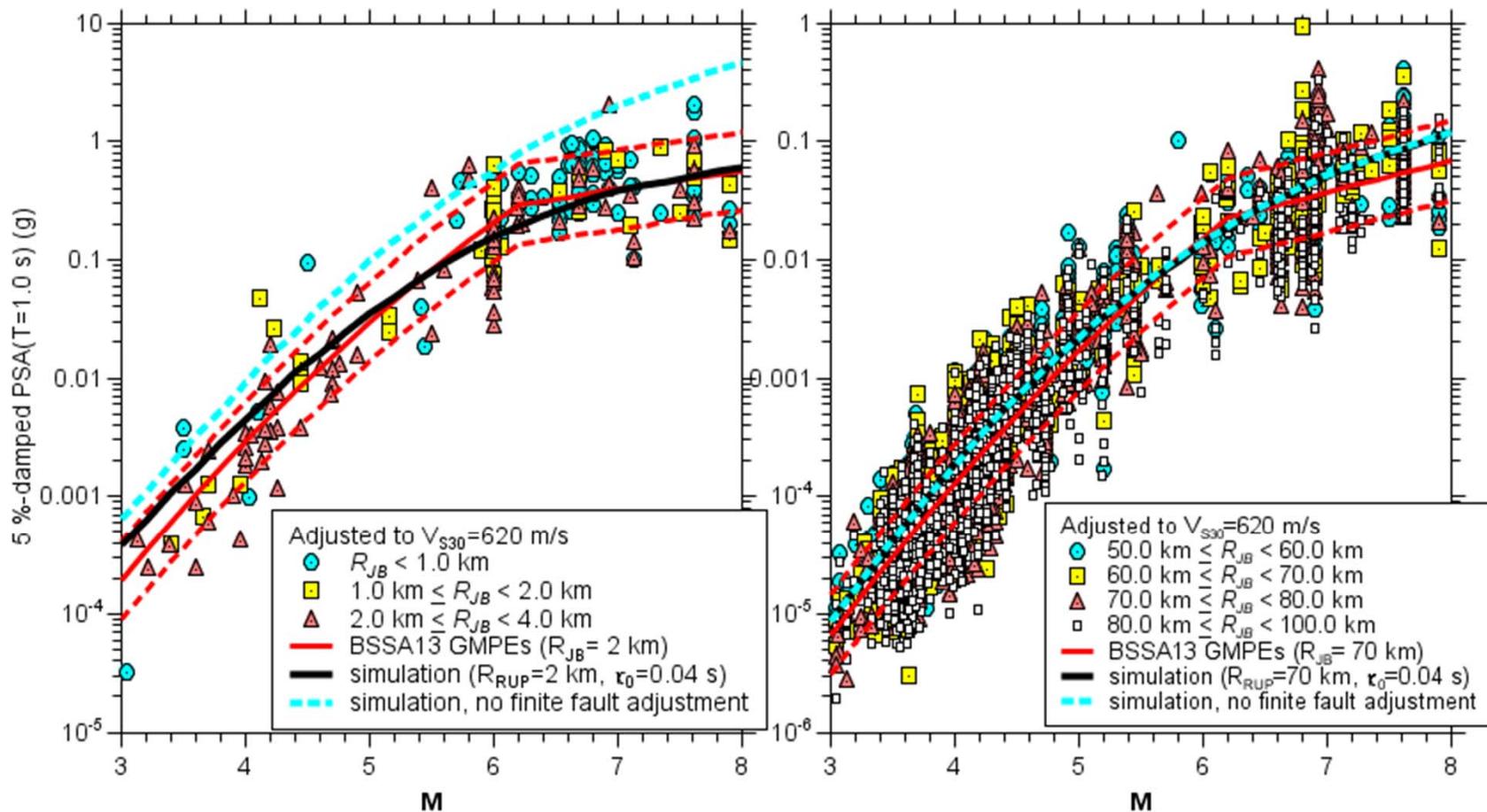


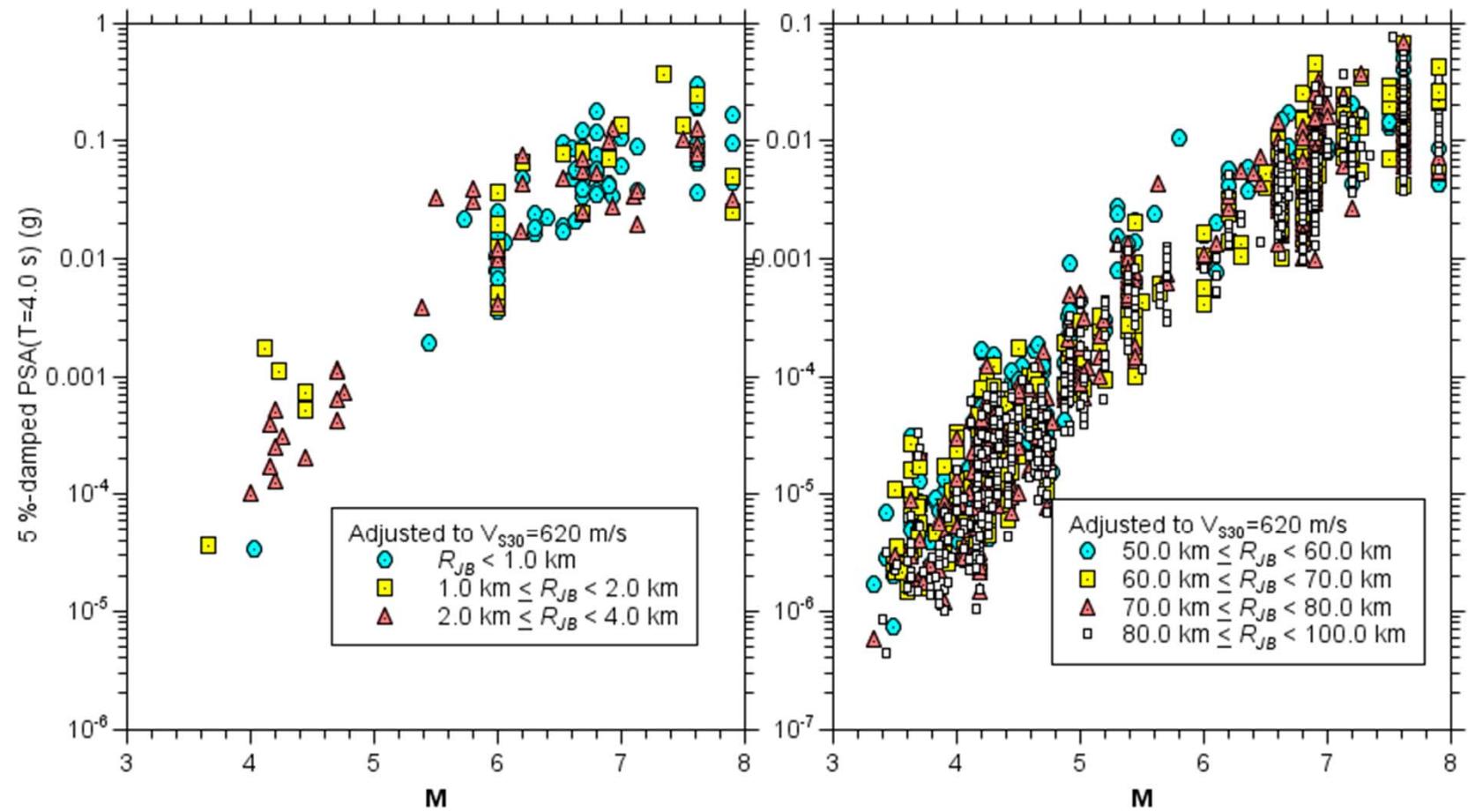


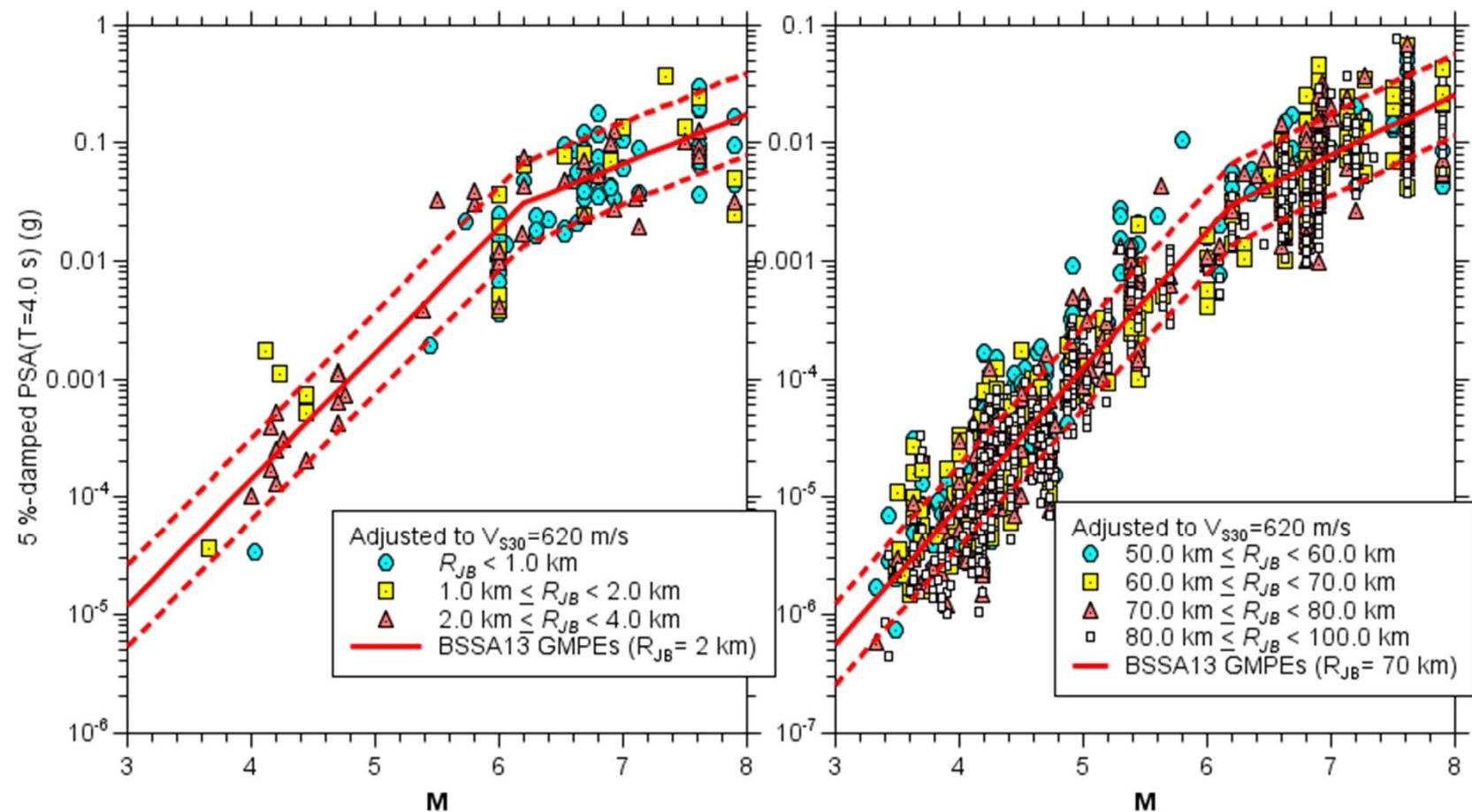


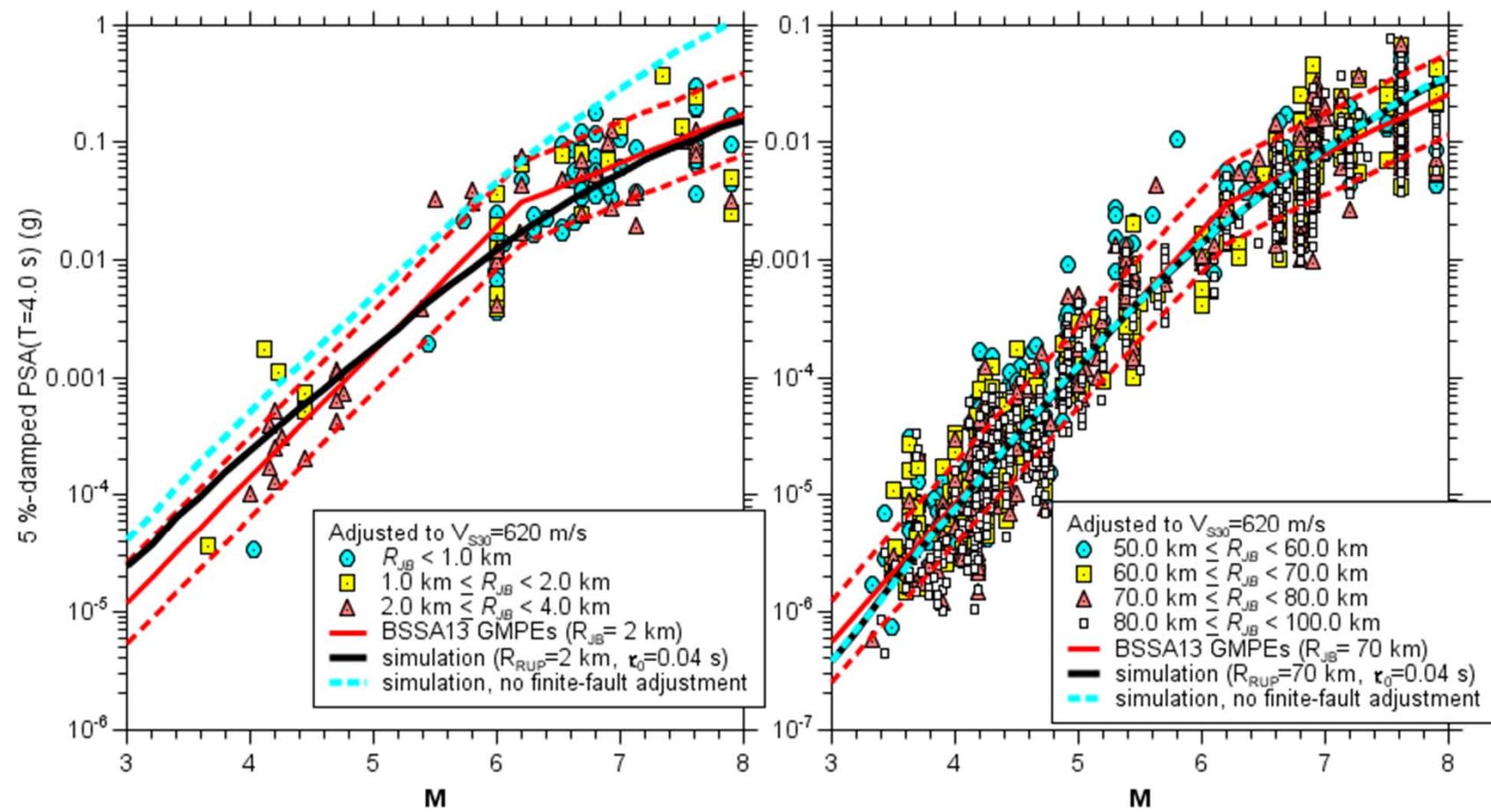










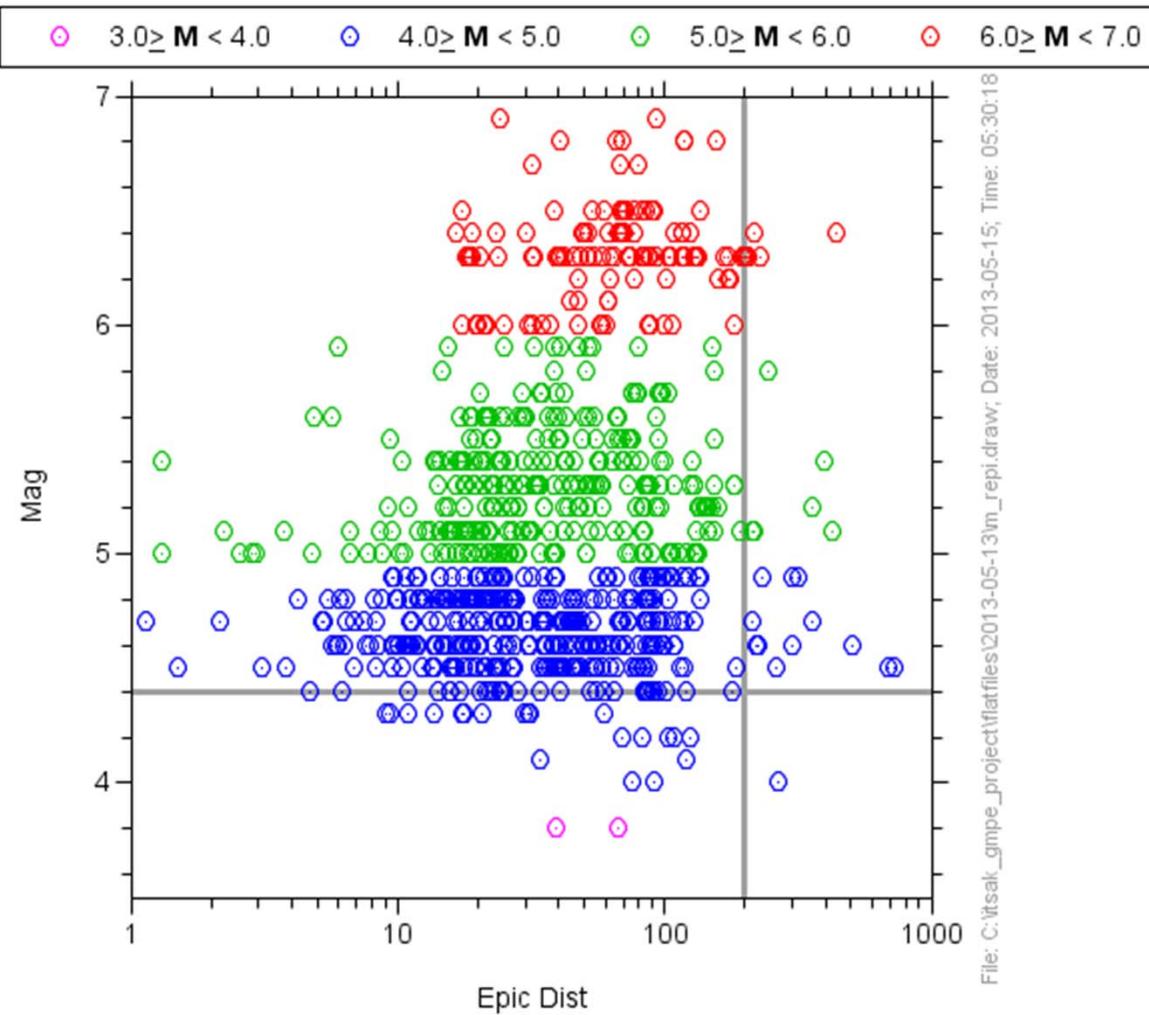


Summary

- In spite of the large dataset, there are relatively few records from crustal fault zones
- Fault zone records show significant variability in amplitude and polarization, but unraveling the causes of this variability is difficult
- The magnitude-to-magnitude increase of motions at a given distance becomes smaller as magnitude increases, with short-period motions at near-fault distances having almost complete saturation for large magnitudes
- The magnitude scaling is largely reproduced by simple models of the source and path effects

GMPEs for Greece

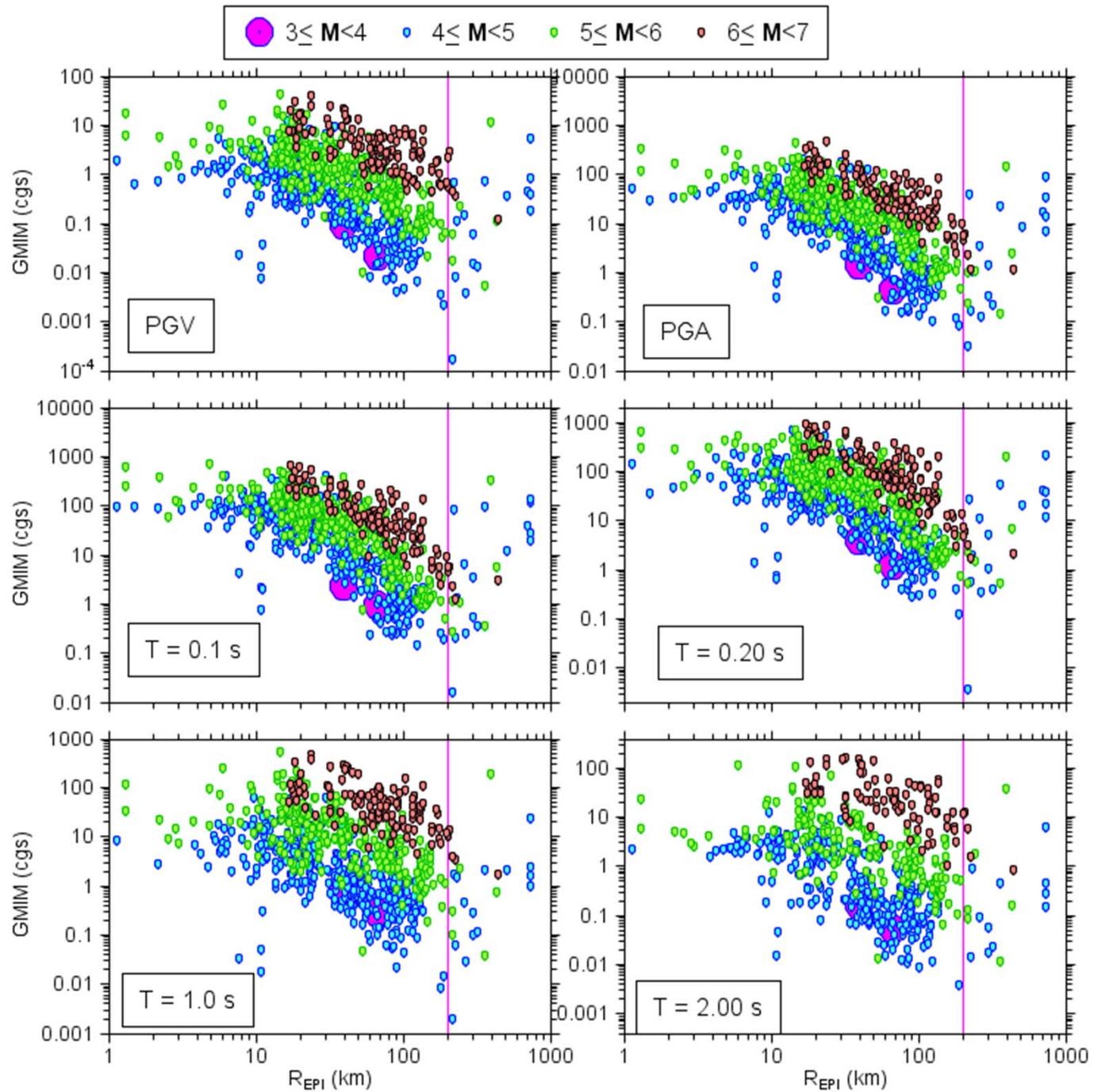
- There is an on going project involving many people to derive GMPEs for Greece
- The dataset is almost complete for larger earthquakes (primarily $M > 4.0$)
- The next figures show the distribution of the data in M-R space, as well as the magnitude and distance scaling for several ground-motion intensity measures (GMIMs).



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- Note reasonable distribution of data for $10 < R < 200$ km and $M > 4.3$
- There few close recordings for $M > 5.4$
- The data distribution will influence the choice of functional forms for the GMPEs, as well as what coefficients can be free in the regression

- Stronger M dependence for longer periods, as for the NGA-West 2 data
- Clearly defined distance decay
- Some outliers that need to be checked for errors in instrument gain and other metadata (**M**, R, etc)



Thank you