Hybrid Empirical Ground-Motion Prediction Equations for Eastern North America Using NGA Models and Updated Seismological Parameters

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Tavakoli, B. and S. Pezeshk. (2005) "Empirical-Stochastic Ground-Motion Prediction for Eastern North America." *Bulletin of the Seismological Society of America*, **95**(6), December, pp. 2283-2296, doi:10.1785/0120050030.

Outline

- Hybrid Empirical Method
- Seismological Parameters Used for Stochastic Ground-Motion Modeling
- Hybrid Empirical Ground-Motion Prediction Equations for Eastern North America

Hybrid Empirical Method

- The hybrid empirical method (Campbell, 2000, 2003) is a procedure to develop GMPEs in areas with sparse ground motions.
- In the hybrid empirical method, the target region (ENA in this study) ground motions are predicted from the host region (WNA in this study) empirical GMPEs using modification factors between two regions.
- These theoretical modification factors are calculated as the ratio of stochastic simulations of ground motions for two regions.
- Using regional seismological parameters in simulations, the adjustment factors reflect the regional differences in source, path, and site.
- In the hybrid empirical method, the empirically derived ground-motion models for the host region are mapped onto the target region considering the seismological regional disparities.

Hybrid Empirical Method

Hybrid Empirical Method:

$$Y^{ENA}_{estimated} = Y^{WNA}_{empirical} \times \underbrace{\frac{Y^{ENA}_{stochastic}}{Y^{WNA}_{stochastic}}}$$

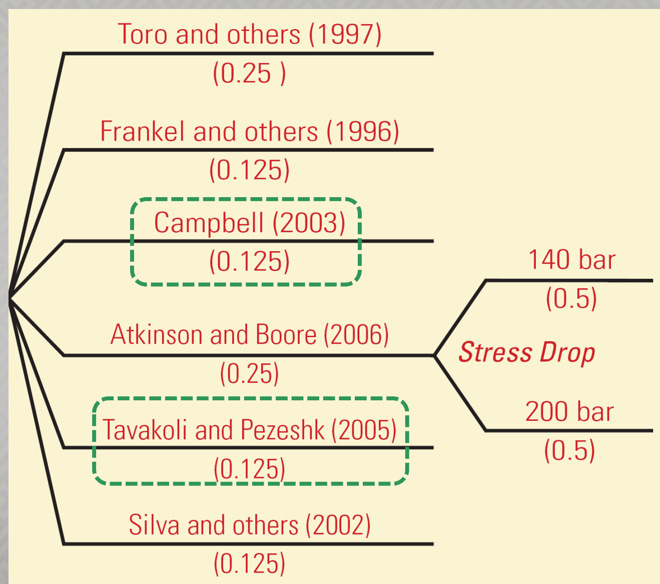
Adjustment factor

(accounts for earthquake source, wave propagation and site-response differences between the two regions)

The hybrid empirical method is used by several authors to develop ground-motion prediction equations in ENA (Campbell, 2003, 2007, 2008; Tavakoli and Pezeshk, 2005).

Hybrid Empirical Method

Ground-motion models used in 2008 National hazard map:



Hybrid Empirical Method

- The purpose of this study is to update the Tavakoli and Pezeshk (2005) model to derive a new hybrid empirical GMPE for ENA using five new ground-motion prediction models developed by the PEER center (Power *et al.*, 2008) for WNA.

- Furthermore, recent new information on ENA seismological parameters such as stress parameter, geometric spreading, anelastic attenuation, and site response term are used to update the GMPE.

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Stochastic Simulations

- In this study, the computer program gm_td_drvr, one of the SMSIM programs is used to perform the point-source stochastic simulation of ground-motion amplitudes for both WNA and ENA.
- To mimic the finite-fault effects in point-source simulations, the effective distance, R'_{rup}, of Atkinson and Silva (2000) is used in stochastic simulations.

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$$R'_{rup} = \sqrt{R_{rup}^2 + h^2}$$

$$\log h = -0.05 + 0.15M$$

Stochastic Simulations

Seismological Parameters:

- ENA ⇨ Atkinson and Boore (2006), Atkinson *et al.* (2009), and Boore (2009)

- WNA ⇨ Atkinson and Silva (1997, 2000)

Seismological Parameters for ENA

Stress Parameter

- Boore *et al.* (2010) determined the stress parameter for eight well-recorded earthquakes in ENA.

- They showed that estimates of $\Delta\sigma$ are correlated to the rate of geometrical spreading at close distances using SMSIM point-source simulations.

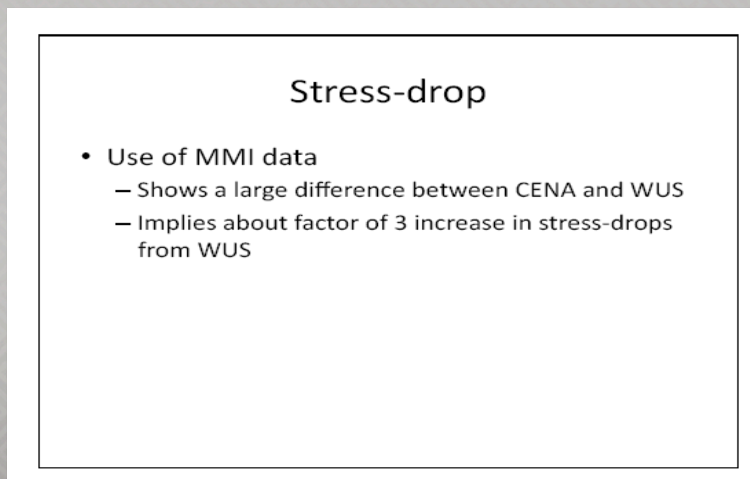
- They evaluated a geometric-mean $\Delta\sigma$ of 250 bars for the Atkinson (2004) attenuation model. (Saguenay earthquake is included)

- Atkinson and Assatourians (2010) found a stress parameter of 250 bars for the magnitude 5.0 Val-des-Bois Quebec earthquake.

- Atkinson et al. (2009) and Boore (2009) found that the stress parameter of 250 bars should be used in SMSIM simulations in order to attain agreement with the Atkinson and Boore (2006) finite-fault predictions.

Seismological Parameters for ENA

"The stress parameter Δσ=250 bars is used in point-source stochastic simulations."



Seismological Parameters for ENA

Path Model

- Boore *et al.* (2010) found that stress parameter is strongly tied to the choice of geometrical spreading.
- The path model of Atkinson (2004) is used in this study for the stochastic simulations to be consistent with the use of Δσ=250 bars.

Seismological Parameters for ENA

Site Effects

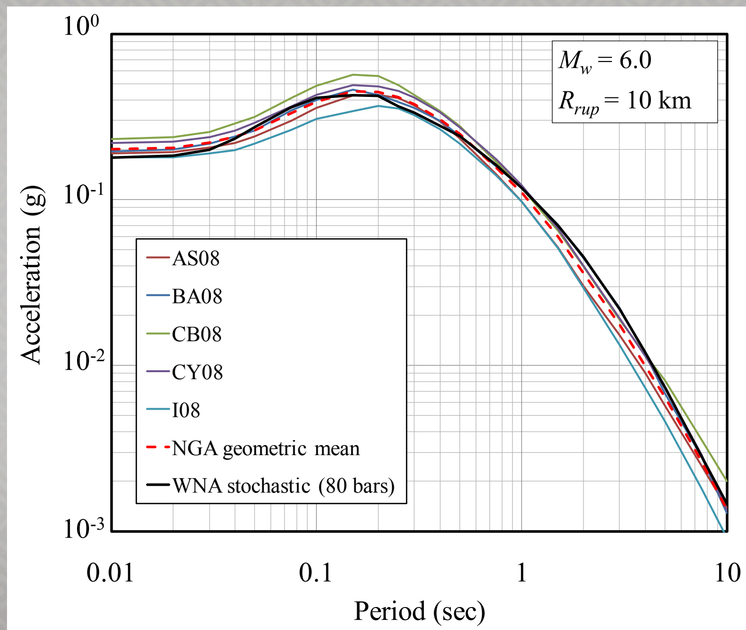
- The empirical site amplifications and the kappa value used in Atkinson and Boore (2006) for hard-rock sites (NEHRP site class A, $V_{s30} \geq 2000$ *m/s*, κ_0=0.005) are employed in the simulations.
- This choice is made to be consistent with the use of $\Delta\sigma$=250 bars.

Seismological Parameters for WNA

Stress Parameter

- Atkinson and Silva (2000) introduced two-corner-frequency point-source spectrum model for California.
- The double-corner-frequency source model and the Brune single-corner frequency spectrum with the stress parameter of 80 bars was close for moment magnitudes (M_w) less than 6.0.
- In this study, a stress parameter of 80 bars is used for the point-source stochastic simulations for WNA using the Brune single-corner frequency model.

Seismological Parameters for WNA



Seismological Parameters for WNA

Path Model

- The path model of Raoof *et al.* (1999) is used in this study for the simulation of ground motions in WNA. The same model used in Atkinson and Silva (2000).

Seismological Parameters for WNA

Site Effects

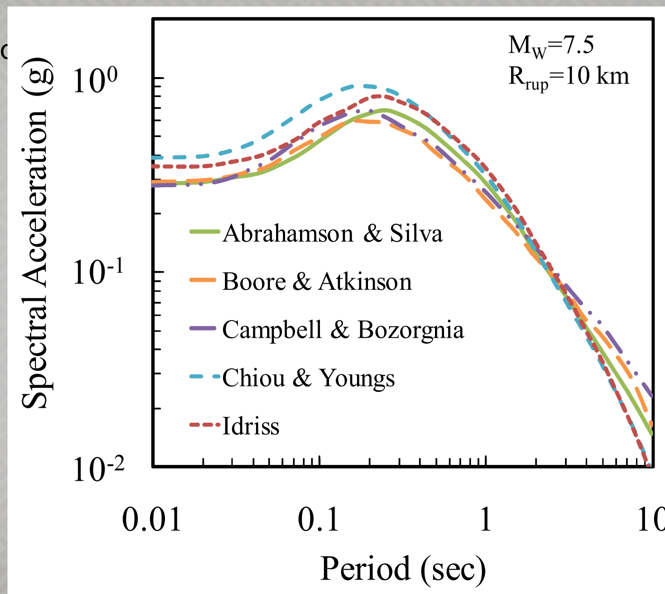
- Atkinson and Silva (2000) used the amplifications for generic rock sites introduced by Boore and Joyner (1997) for WNA to derive a model for California ($V_{s30} \geq 620$ *m/s*).
- We used the κ_0 value of 0.04 for the rock sites in WNA (Atkinson and Silva, 1997; Anderson and Hough, 1984).

Seismological Parameters

Parameter	WNA	ENA
Source spectrum model	Single-corner-frequency ω^{-2}	Single-corner-frequency ω^{-2}
Stress parameter, $\Delta\sigma$ (bars)	80	250
Shear-wave velocity at source depth, β_s (km/s)	3.5	3.7
Density at source depth, ρ_s (gm/cc)	2.8	2.8
Geometric spreading, $Z(R)$	$\begin{cases} R^{-1.0}; R < 40\,km \\ R^{-0.5}; R \geq 40\,km \end{cases}$	$\begin{cases} R^{-1.3}; R < 70\,km \\ R^{+0.2}; 70 \leq R < 140\,km \\ R^{-0.5}; R \geq 140\,km \end{cases}$
Quality factor, Q	$180 f^{0.45}$	$\max(1000, 893 f^{0.32})$
Source duration, T_s (sec)	$1/f_a$	$1/f_a$
Path duration, T_p (sec)	$0.05R$	$\begin{cases} 0; & R \leq 10\,km \\ +0.16R; & 10 < R < 70\,km \\ -0.03R; & 70 < R \leq 130\,km \\ +0.04R; & R > 130\,km \end{cases}$
Site amplification, $A(f)$	Boore and Joyner (1997)	Atkinson and Boore (2006)
Kappa, κ_0 (sec)	0.04	0.005

Ground-Motion Models in WNA

- The gro… …he PEER NGA project … ground-motion models



Hybrid Empirical Ground-Motion Prediction Equations for Eastern North America

- Median hybrid empirical estimates of ENA ground motion are obtained by scaling the WNA empirical relations using theoretical modification factors.
- The model is evaluated for moment magnitudes 5.0 to 8.0 and for rupture distances up to R_{rup} = 1000 km.
- The hybrid empirical estimates are used in a nonlinear least-square regression to develop the GMPEs.

Hybrid Empirical Ground-Motion Prediction Equations for Eastern North America

$$\log(\bar{Y}) = c_1 + c_2 M_W + c_3 M_W^2 + (c_4 + c_5 M_W) \times \min\{\log(R), \log(70)\}$$
$$+ (c_6 + c_7 M_W) \times \max[\min\{\log(R/70), \log(140/70)\}, 0]$$
$$+ (c_8 + c_9 M_W) \times \max\{\log(R/140), 0\} + c_{10} R$$

where

$$R = \sqrt{R_{rup}^2 + c_{11}^2}$$

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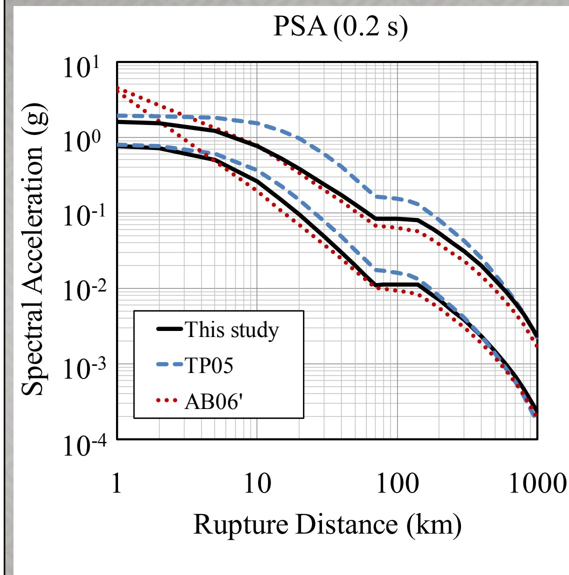
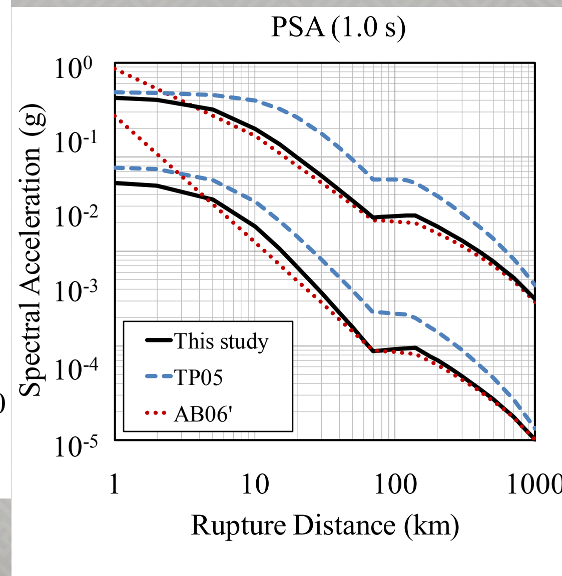
where

$$R = \sqrt{R_{rup}^2 + c_{11}^2}$$

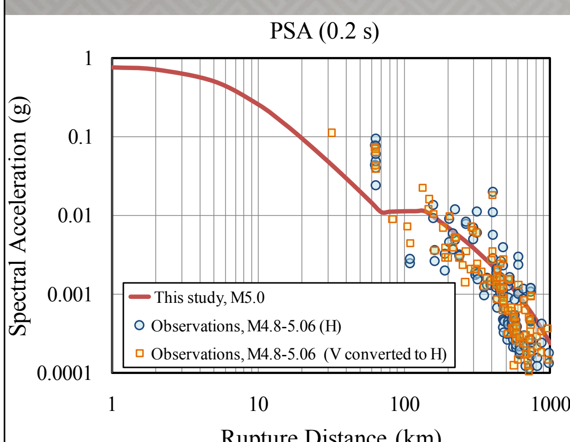
The mean aleatory standard deviation of to be associated with the predictions is defined as a function of earthquake magnitude and is modeled as follows:

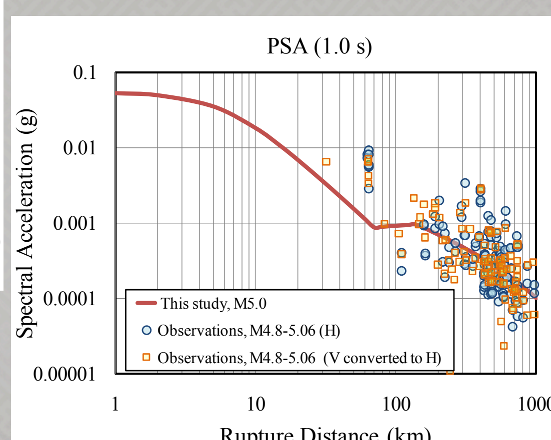
$$\sigma_{\log(\bar{Y})} = \begin{cases} c_{12} M_w + c_{13} & M \le 7 \\ -6.95 \times 10^{-3} M_w + c_{14} & M > 7 \end{cases}$$





AB06' : Modified version of Atkinson and Boore (2006) model based on new data (Atkinson and Boore, 2011).





ENA ground-motion observations from Assatourians and Atkinson (2010).

Issues

- The benefits and shortcomings of the method and the potential "work-around" to shortcomings if they exist
- How much your arguments are supported by data and by the broader technical community

Issues

- The choice of stress parameter for both host and target region plays an important role in the HEM estimations, especially at high frequencies (PGA).
  - For, the host region, this parameter can be constrained with empirical data. For the target region, due to lack of strong motions stress parameter is not well constrained.
  - The issue is that whether the stress parameter from small event can be used for the large events as well.
  - One alternative is to use the same magnitude scaling observed in the host to constrain the stress parameter in target. This procedure may result in using the same degree of magnitude scaling in both regions and cancel out this effect. On the other hand the purpose of using HEM is to map the same magnitude scaling observed in host to target. Therefore, by using e.g., the small magnitude stress parameters for both WNA and ENA it can be assumed that the HEM do the rest and model the same magnitude scaling observed in the WNA for ENA.

- In WNA the dependency of stress parameters with magnitude is observed using a point-source stochastic model. This dependency might be weakened if higher order stochastic model, where the definition of stress parameter is different, is used to model ground-motions. Therefore, the choice of stress parameter should be exclusively limited to the specific stochastic model being used in HEM.

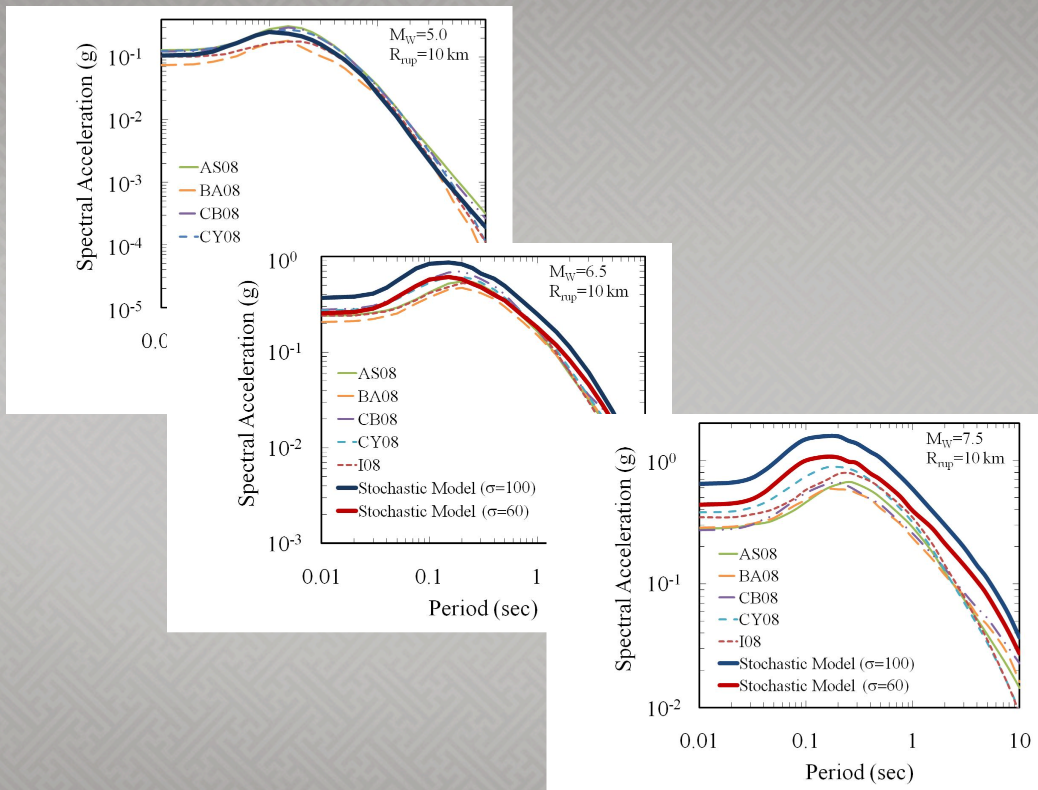
- As shown in Boore et al. (2010) the stress parameter is correlated with the choice of path effect in the inversion problem of going from observations to the stochastic predictions. Therefore, the choice of stress parameter should be consistent with the path effect being used in the stochastic simulations. On the other hand, based on the systematic difference between path effect between WNA and ENA, the choice of path effect, affect the shape of HEM estimations. Therefore, enough evidence and rationalizations should be used to select the path effect for both WNA and ENA. Using different alternatives with appropriate weighting to consider the epistemic uncertainty is recommended.

Issues

- The choice of stress parameter for both host and target region plays an important role in the HEM estimations, especially at high frequencies (PGA).
  - For, the host region, this parameter can be constrained with empirical data. For the target region, due to lack of strong motions stress parameter is not well constrained.
  - The issue is that whether the stress parameter from small events can be used for the large events as well.

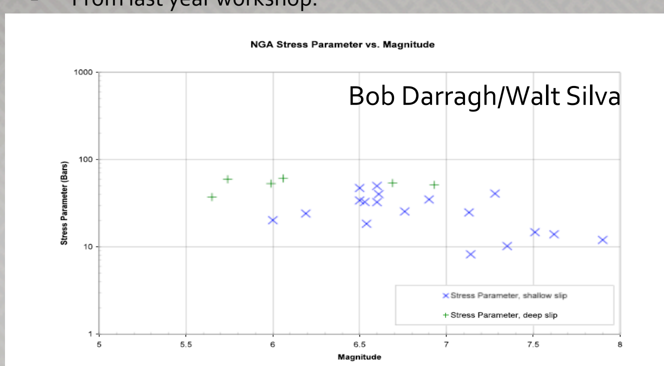
Issues

- Magnitude Dependence
  - In WNA the dependency of stress parameters with magnitude is observed using a point-source stochastic model.
  - This dependency might be weakened if various stochastic models, where the definition of stress parameter is different, is used to model ground-motions.
- Therefore, the *choice of stress parameter should be exclusively limited to the specific stochastic model being used in HEM*.



Issues

- From last year workshop.



Estimates of stress parameter computed for the 24 NGA earthquakes verses magnitude (**M**). Shallow slip defined as greater than (or equal) 20% moment released to a depth of 5 km. Deep slip with less than 20% moment released over the top 5 km of the crust.

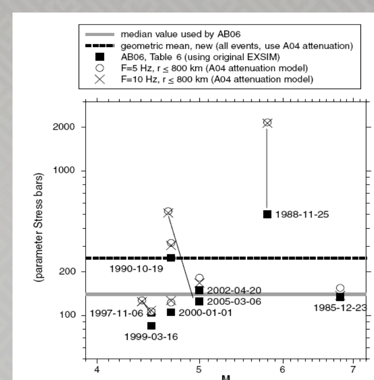


Figure 14. Summary of stress parameters. For two earthquakes (6 November 1997 [1997-11-06] and 6 March 2005 [2005-03-06]) the magnitude used in Atkinson and Boore (2006) and that used here differed; lines connect old and new stress parameters for these events (and also for the 25 November 1988 [1988-11-25] event, where there is a very large difference in stress parameters).

Boore et al. (2010)

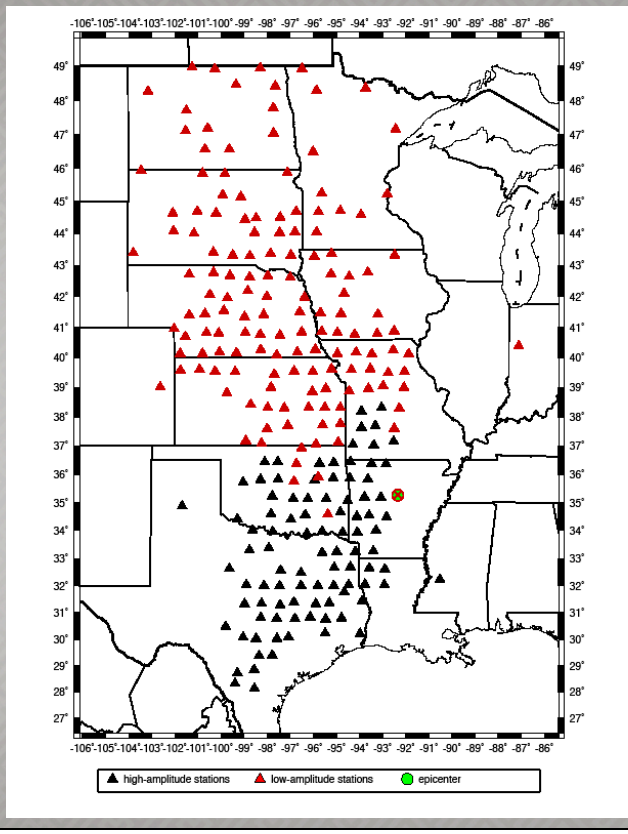
From inversion for strike slip:
56 bars for 5.5, 45 bars for 6.5, 24 bars for 7.5
Slightly less for Normal.

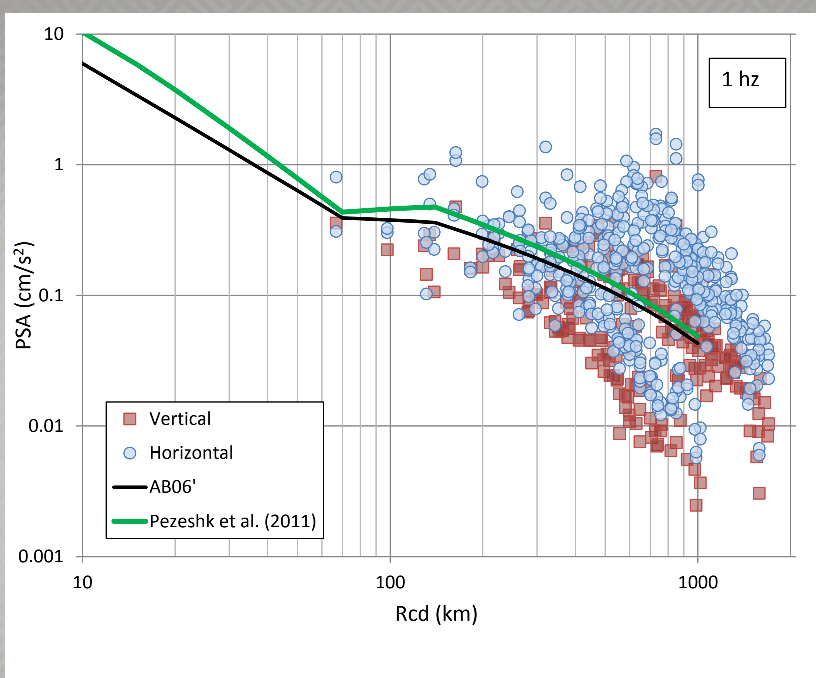
Issues

- As shown in Boore et al. (2010) the stress parameter is correlated with the choice of path effect in the inversion problem of going from observations to the stochastic predictions.
- Therefore, the choice of stress parameter should be consistent with the path effect being used in the stochastic simulations.
- Therefore, enough evidence and rationalizations should be used to select the path effect for both WNA and ENA.

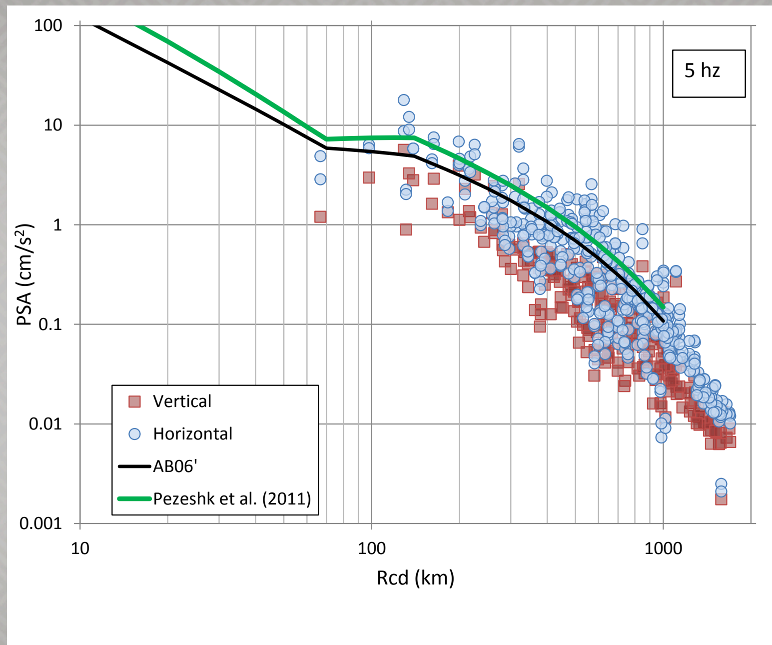
Issues

- Transfer of WNA empirical model properties to ENA
  - Sediment/basin effects
  - Hanging wall effects
- Seismological models
  - Regionalization of ENA





Arkansas M4.7



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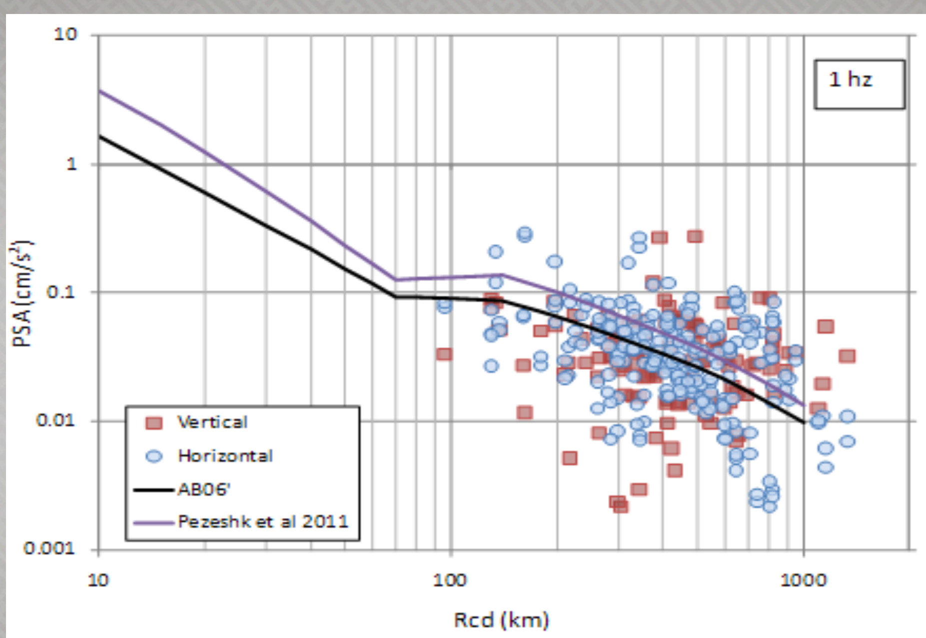

M4.2 Arkansas 20 Nov 2010

Thank You!

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