G-16 and G-16v2 GROUND MOTION PREDICTION EQUATIONS FOR THE CENTRAL AND EASTERN NORTH AMERICA

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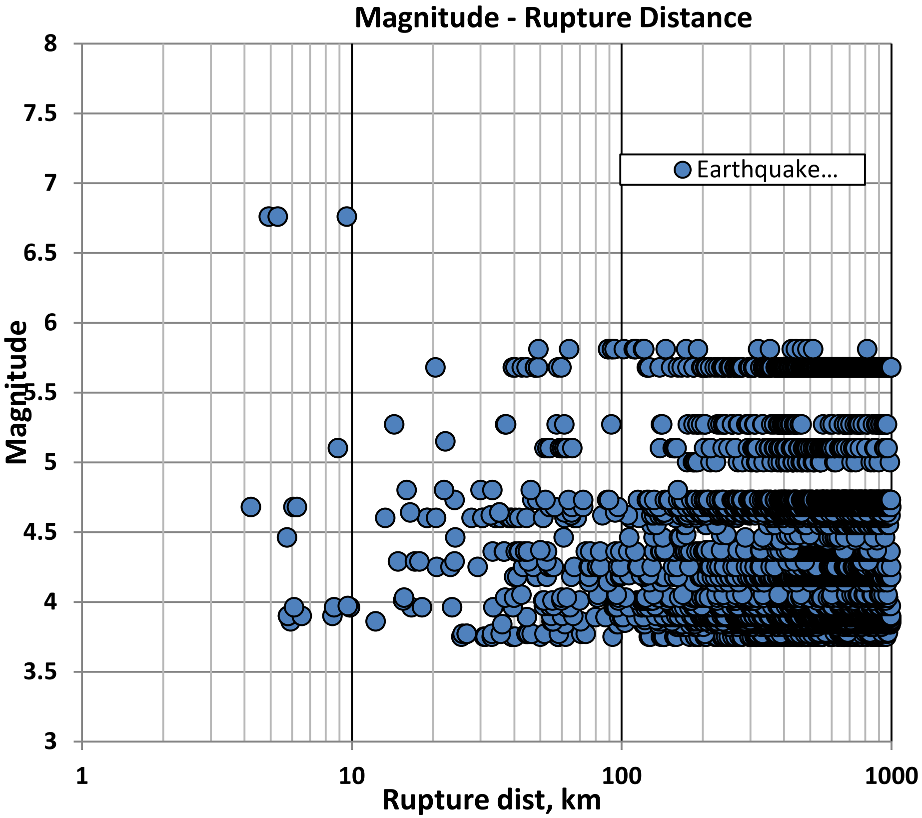
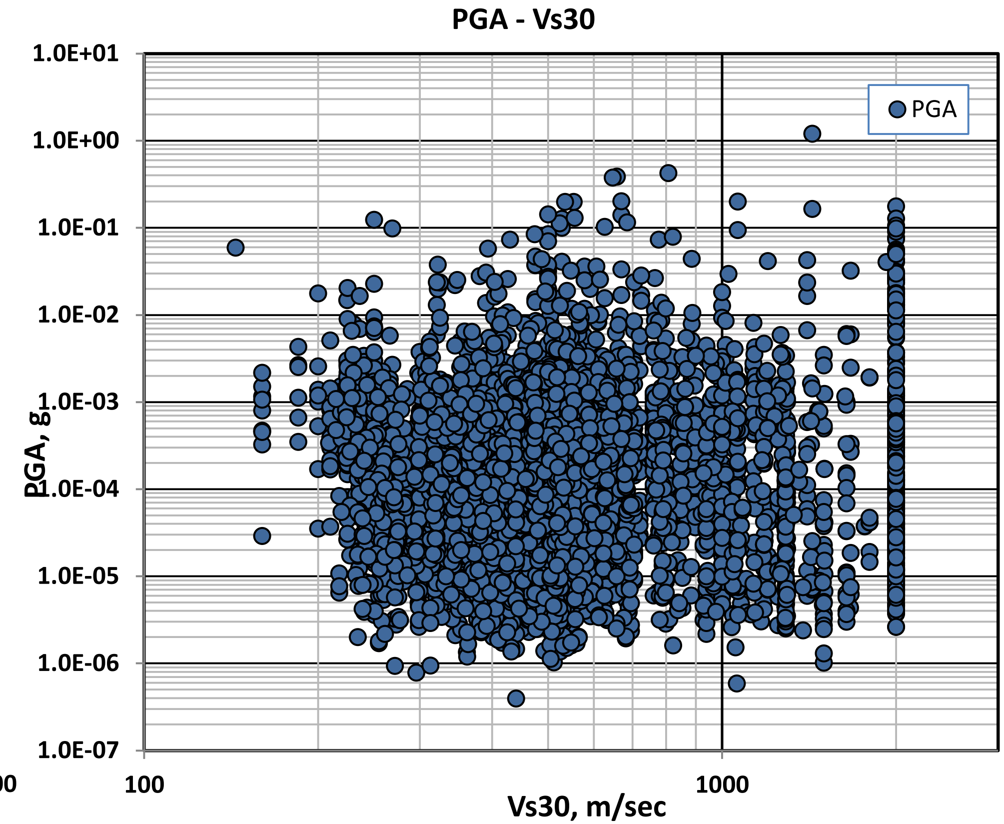
Introduction and Dataset Used

- Two ground motion prediction equations (GMPEs) for the Central and Eastern North America (CENA) have been developed in 2016: G-16 and G-16v2 (published in 2017).
- Both models are based on the Next Generation Attenuation NGA-East database for the horizontal peak ground acceleration (PGA) and 5%-damped pseudo spectral acceleration (PSA) RotD50 component (Goulet et al., 2014).
  - For the GMPEs development I used subset of 5026 data points with $M \geq 3.75$ and fault distances $R \leq 1000$ km.
  - Data with lower magnitudes and larger distances were not used.
  - The dataset includes 48 earthquakes from different regions in the CENA including the Mid-Continent and Gulf Coast regions.

September 2014 NGA-East Database (M>3.75)

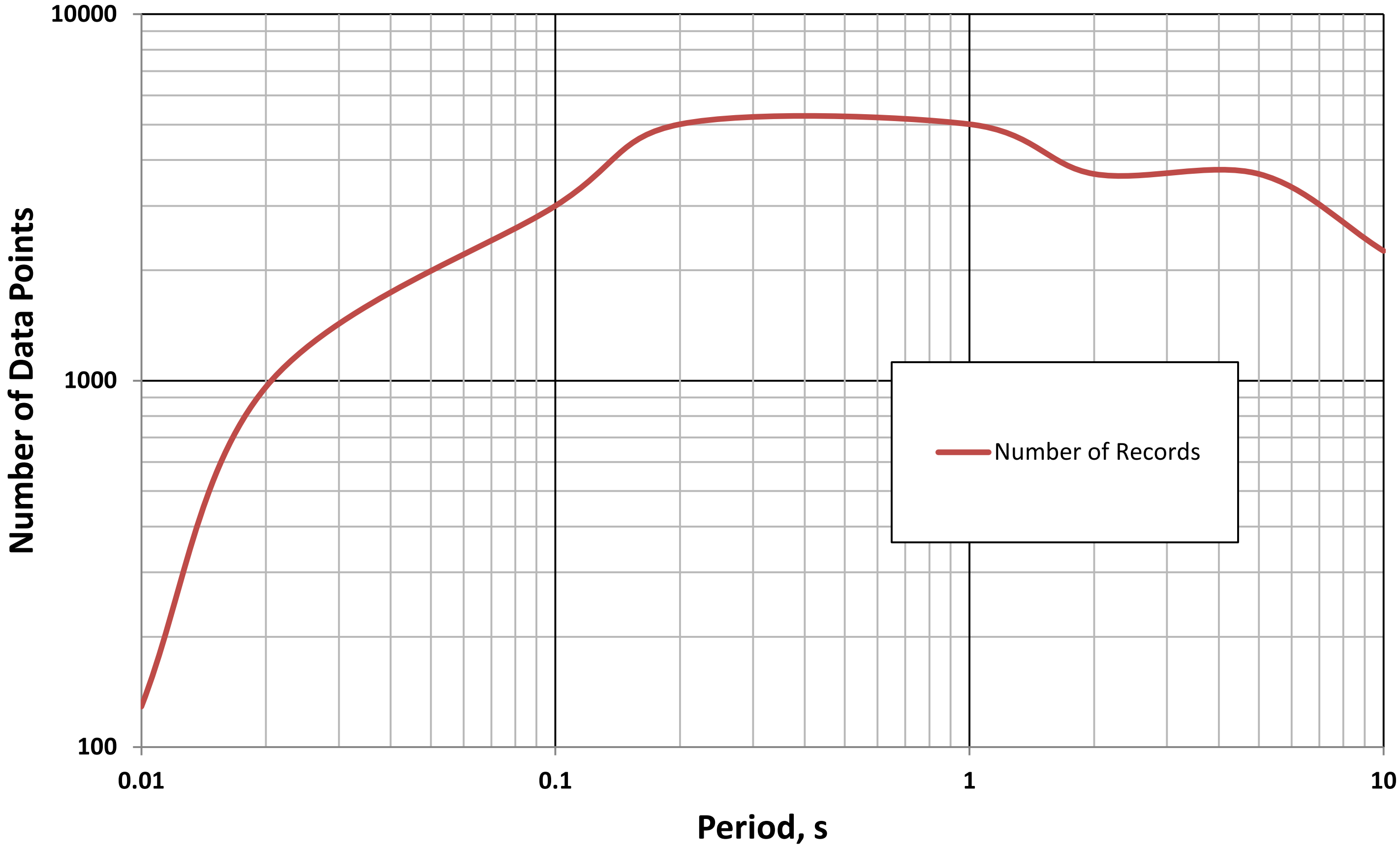




Data in the database are sparse and cover mostly a limited range of moment magnitudes **M**<6.0 with only three data points with **M**>6 from the 1985 **M**=6.8 Nahanni earthquakes.

Effect of non-linearity is not significant since only 2 data points with V_{S30}<300 m/s are ~ 0.1 g.

Period Dependence of the Number of Recordings in the Dataset



There is a clear deficiency of high-frequency recordings in the NGA-East database and the dataset used.

G-16 and G-16v2 Attenuation Models

- Developed GMPEs models are based on the same modular filter based approach developed for active tectonic environment by Graizer and Kalkan (2007, 2009, and 2011).

- There are a number of simplifications relative to the original model developed for active tectonic environment:
  - No bump (oversaturation) in the near-field since there are no empirical data to support it;
  - No basin effect; and
  - No distinguishing between different fault styles.

- G-16 model has a uniform attenuation slope.

- G-16v2 is an alternative and not a replacement to the G-16 model.

- In contrast to the G-16 model, the G-16v2 model has bilinear attenuation slope.

PGA CENA model

$$PGA = G_1 \times G_2 \times G_3 \times G_4 \times \varepsilon_Y$$

The G_1 filter is for magnitude scaling, G_2 is for core attenuation equations, G_3 is for apparent (intrinsic and scattering) attenuation correction, *and* G_4 is for shallow site amplification.

The G-16v2 model has bilinear slope with different attenuation functions:

$$G_2(M,R) = \begin{cases} \dfrac{1}{\sqrt{\left[1-(R_{rup}/R_2)\right]^2 + 4D_2^2(R_{rup}/R_2)}}, & R_{rup} < 70km \Rightarrow \dfrac{1}{R_{rup}} \\ \dfrac{w}{\sqrt{[1-\sqrt{R_{rup}/R_2}\,]^2 + 4D_2^2\sqrt{R_{rup}/R_2}}}, & R_{rup} \geq 70km \Rightarrow \dfrac{1}{\sqrt{R_{rup}}} \end{cases}$$

Where **M** is moment magnitude, R_{rup} is the distance to the fault rupture and R_2 is the corner distance defining the plateau without significant attenuation of ground motion.

Constraining Bilinear Slope

- Conducted testing of the slope of attenuation of the response spectra amplitudes at the 9 spectral frequencies between 0.1 and 100 Hz. Average slope of the distance attenuation within the 50-70 km distance from the fault is about *-1.0* at 7 out of 9 spectral frequencies. For frequencies of 0.5 and 0.2 Hz the slope is about *-1.3*.

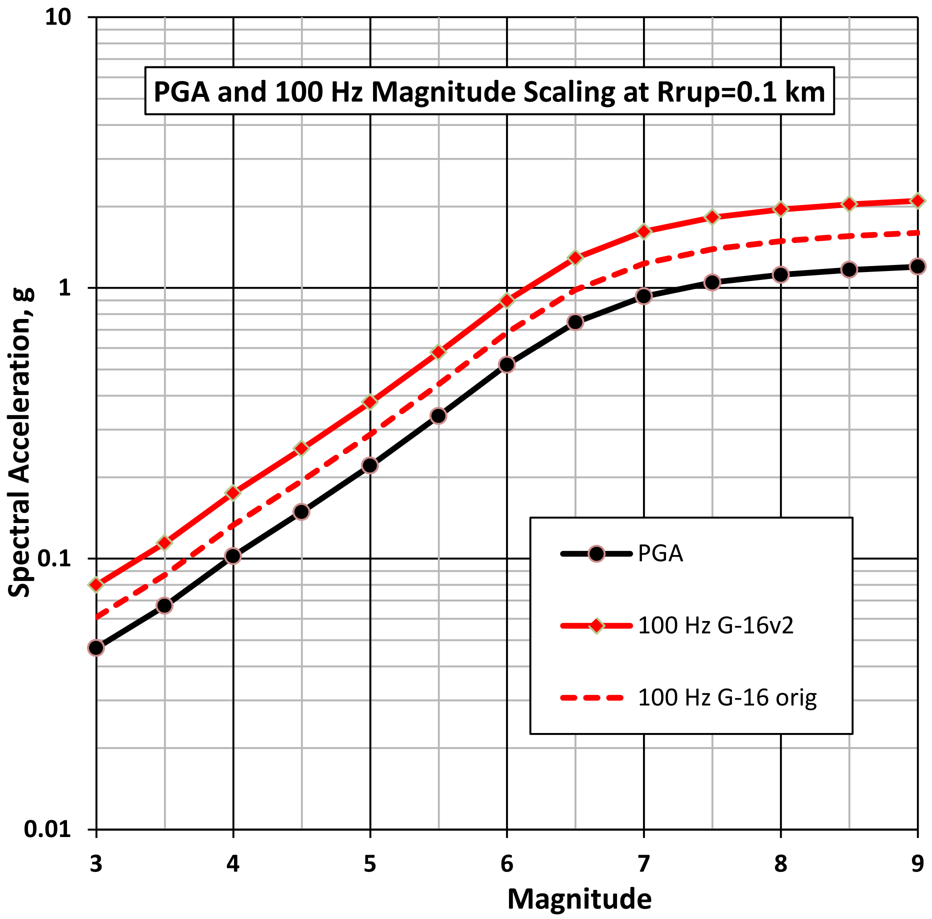
- Taking into account that total attenuation is a combination of geometrical spreading, intrinsic and scattering attenuation it was concluded that classical body-waves geometrical spreading of R^{-1} best fit response spectral accelerations at distances up to 70 km.

- Examined the recorded data for estimating where the change of slope occurs varying the distance from 50 to 100 km, and concluded that distance of about 70 km best fits the transition.

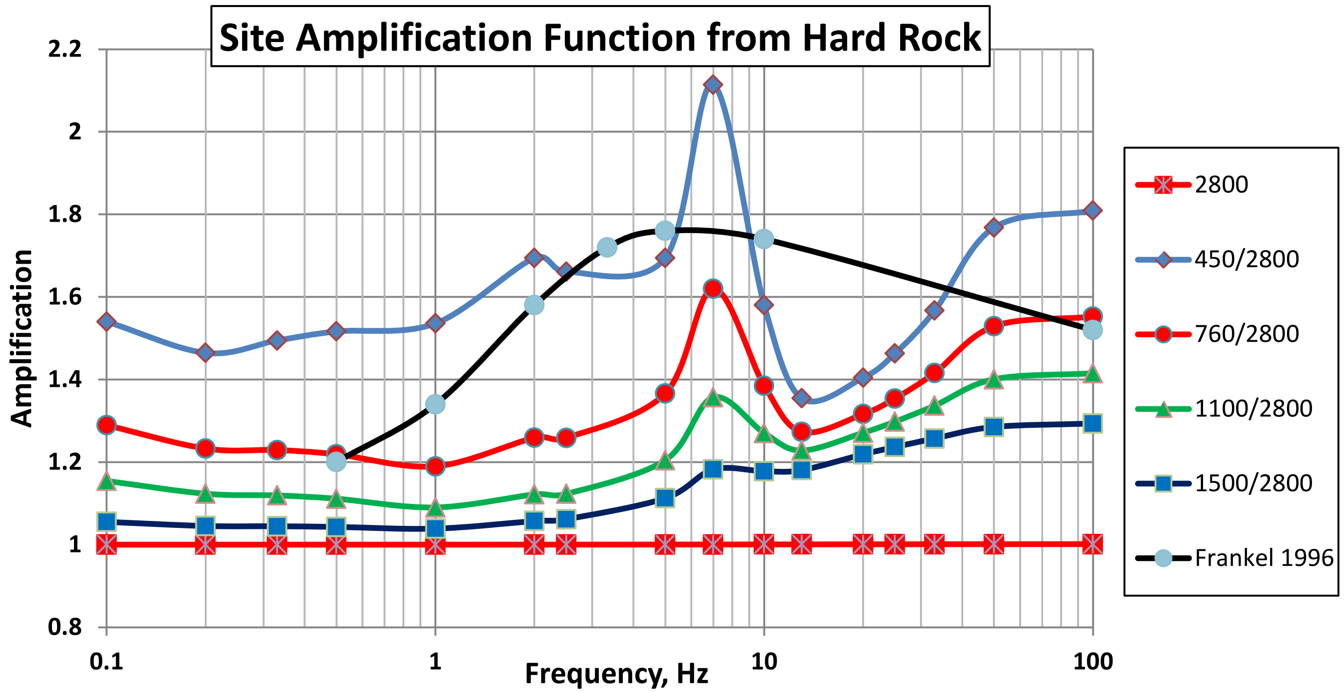
Near-Fault Magnitude and PGA Scaling

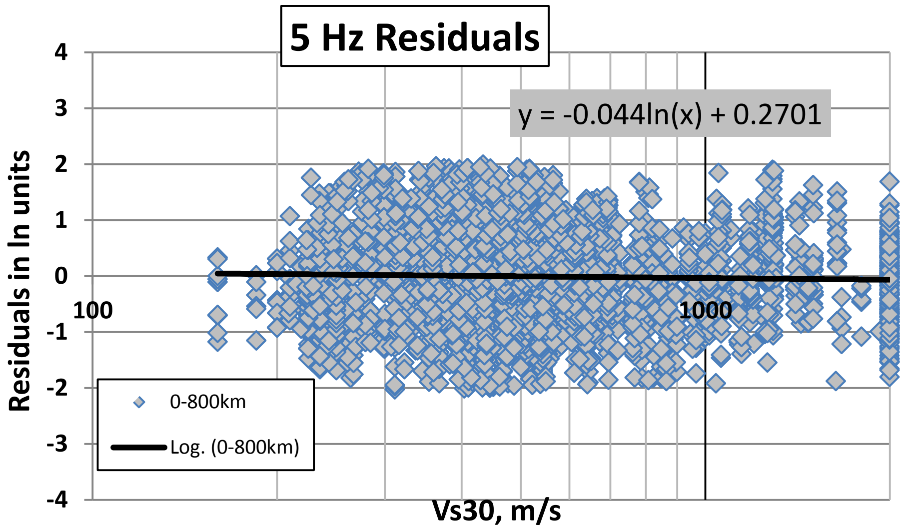
Constraining GMPE coefficients for large magnitudes based on:

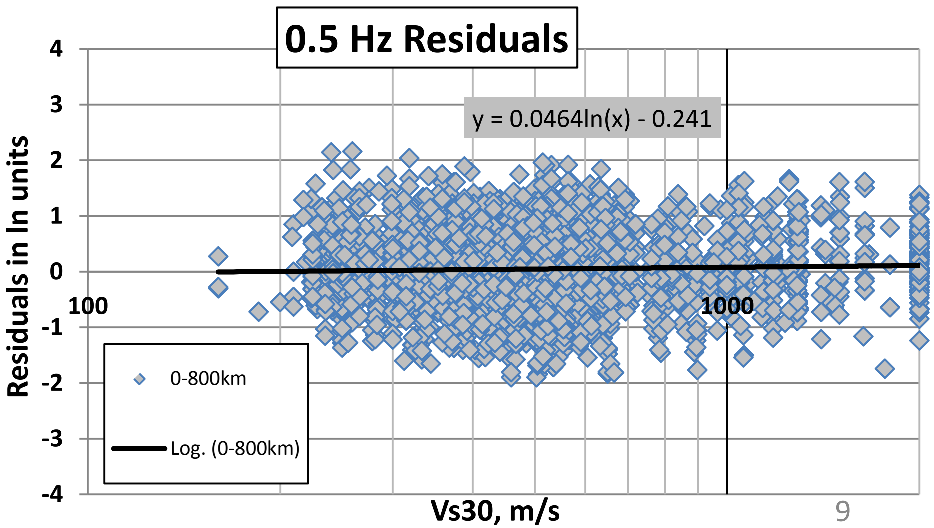
- Ratios of amplitude of earthquakes with 3.75<**M**<6 from the NGA-East database relative to the NGA-West;
- Average stress-drop ratio between CENA and Western US (2-3 times higher); and
- Check against recent ground motion simulations ratios between **M**=5.0 and higher **M** (Atkinson and Assatourians, 2015; Graves and Pitarka, 2015; Olsen and Takedatsu, 2015).



V_{S30} Site Correction



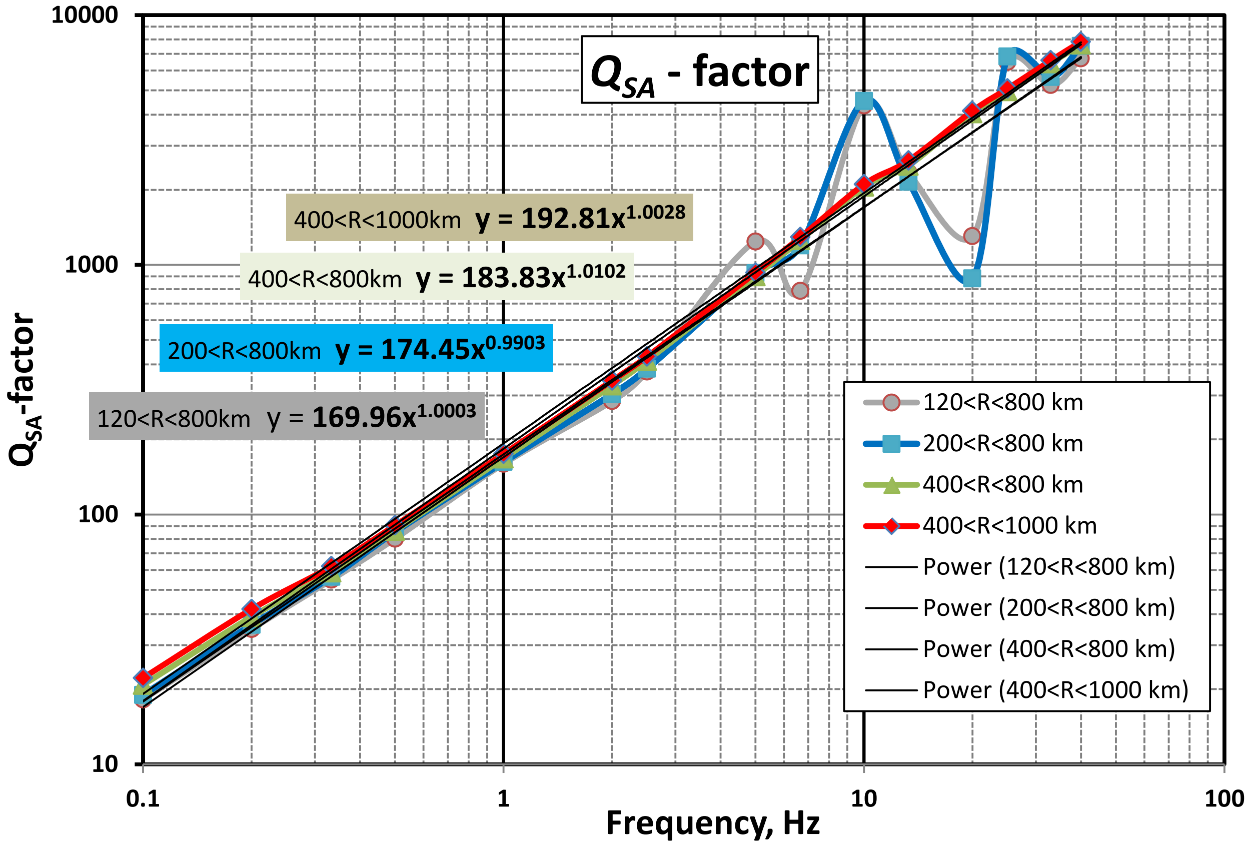




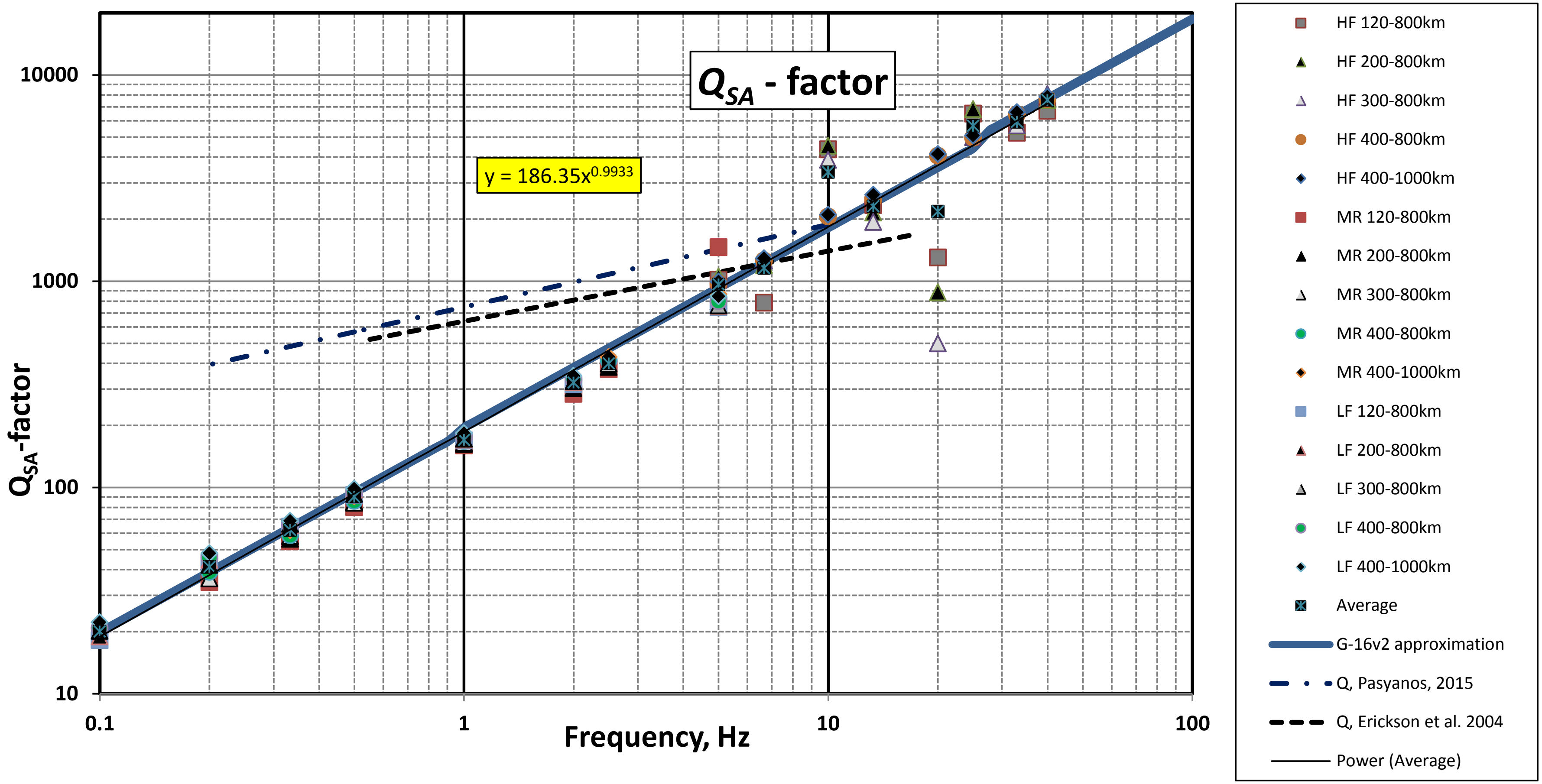
Apparent Attenuation of Spectral Accelerations

Introduced is a new parameter: attenuation factor $Q_{SA}(f)$ representing apparent (intrinsic and scattering) attenuation of 5% damped spectral accelerations. This parameter is different from the classical seismological *Q(f)* determined from Fourier spectra of *S*-, *Lg*- or coda-waves.

To get the $Q_{SA}(f)$ factor, inversions were performed for the 15 frequencies between 0.1 to 40 Hz using different distance ranges. Apparent attenuation of SA amplitudes were found to be significantly different from the typical seismological estimates for the CENA.



Comparing $Q_{SA}(f)$ with Seismological $Q(f)$

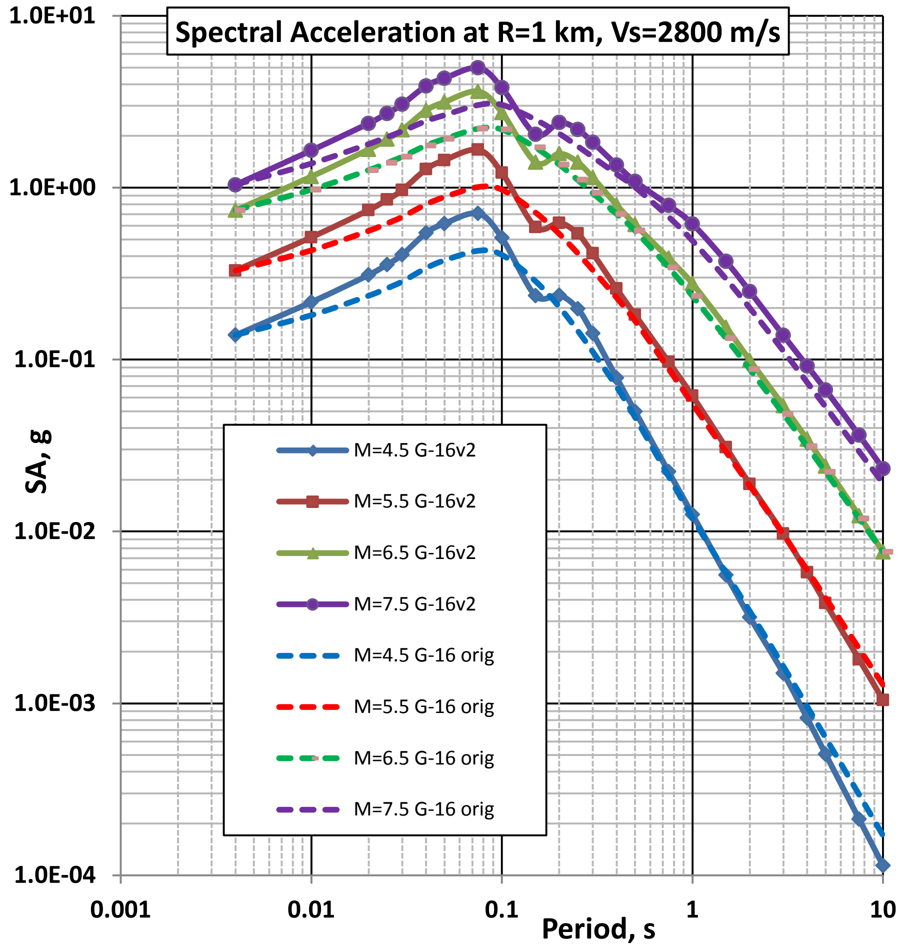


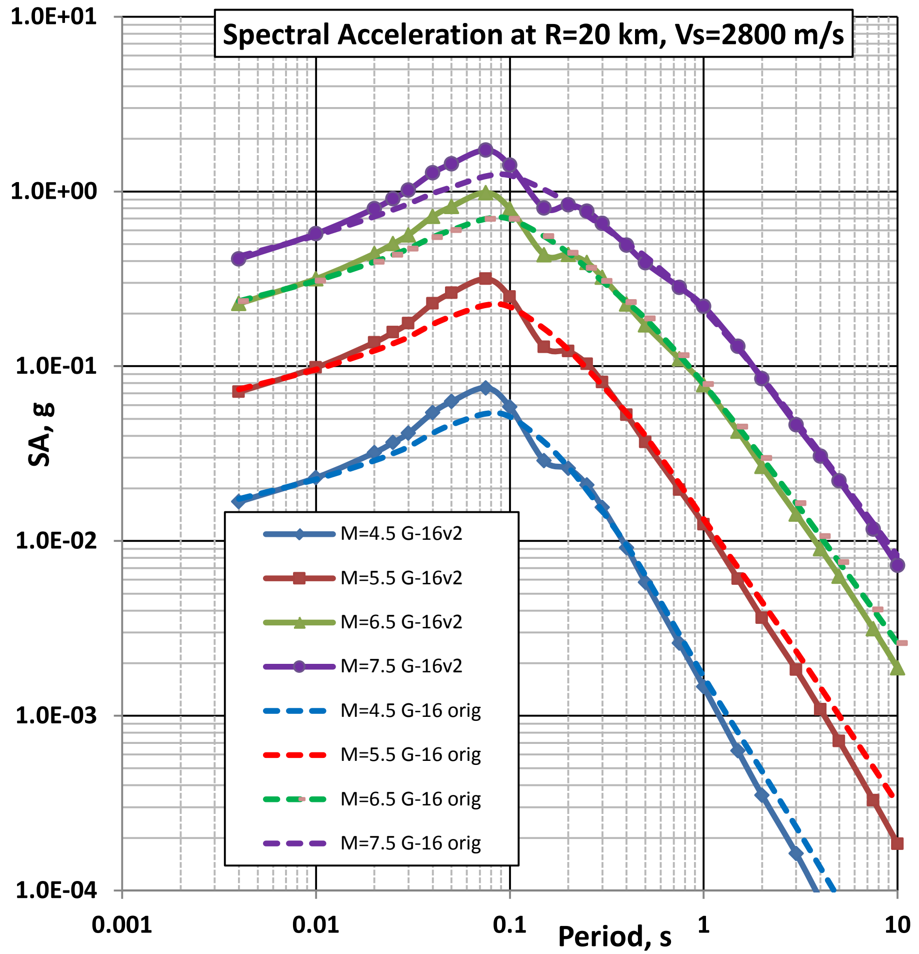
In a frequency range of 0.1-40 Hz the data can be well represented by the power law with the average dependence of:

$$Q_{SA}(f) = 186 f^{0.99}$$

$Q_{SA}(f)$ should be estimated based on actual response spectral acceleration data, and not transferred from seismological measurements.

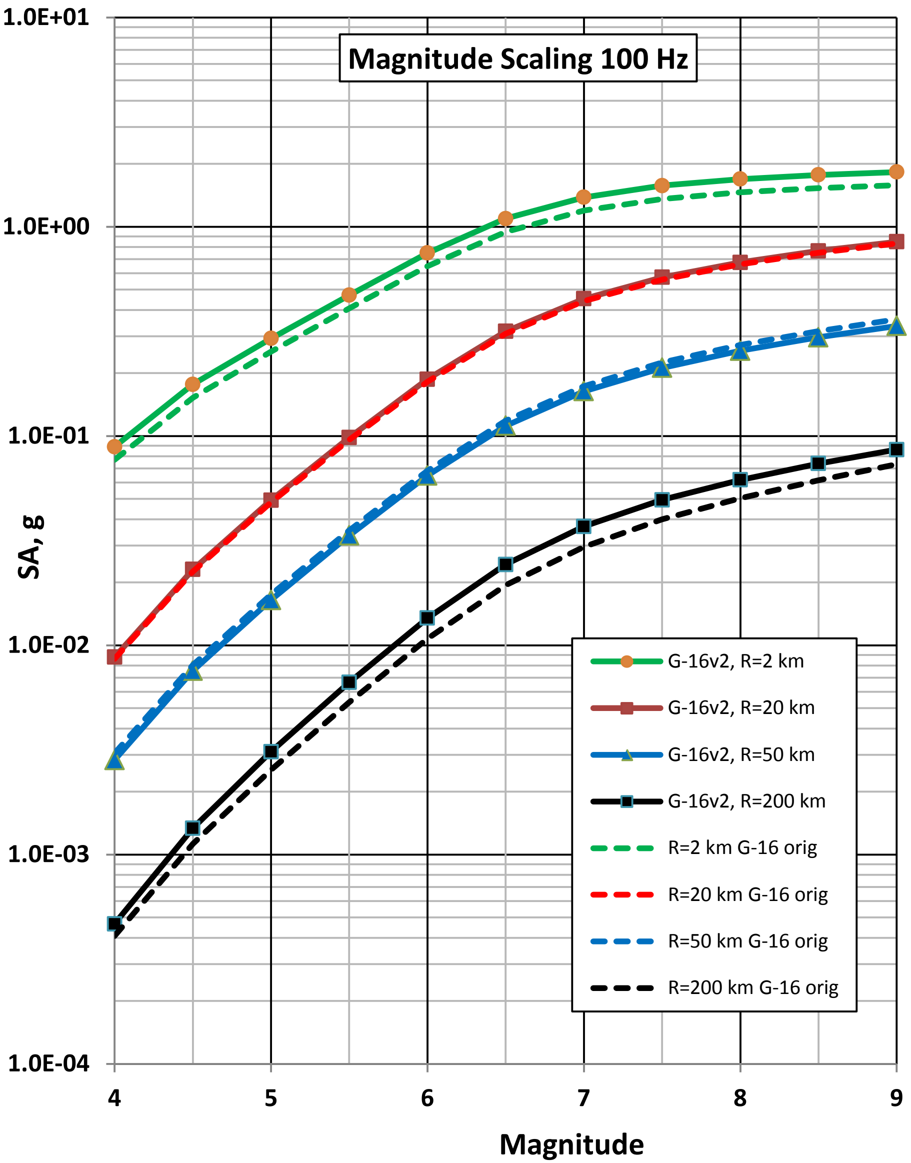
Examples SA Functions at R = 1 and 20 km

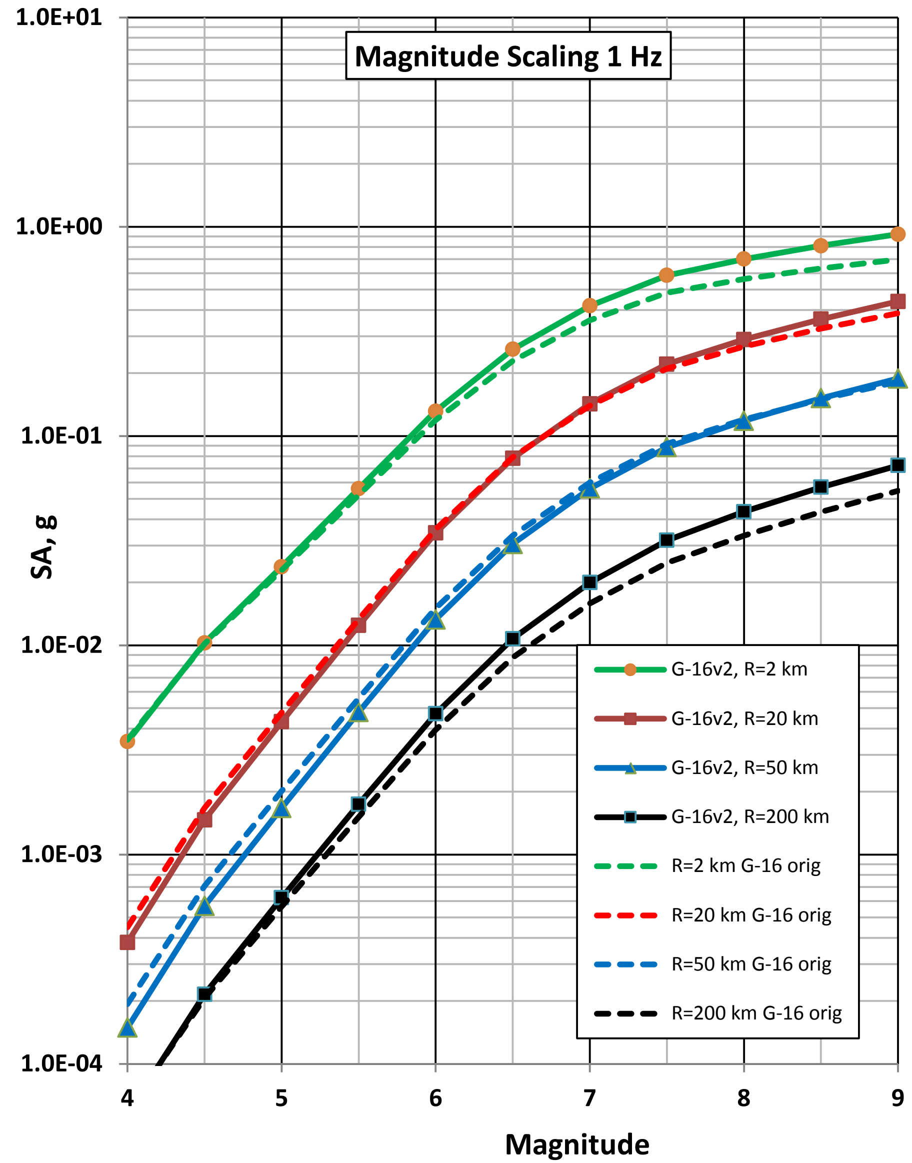




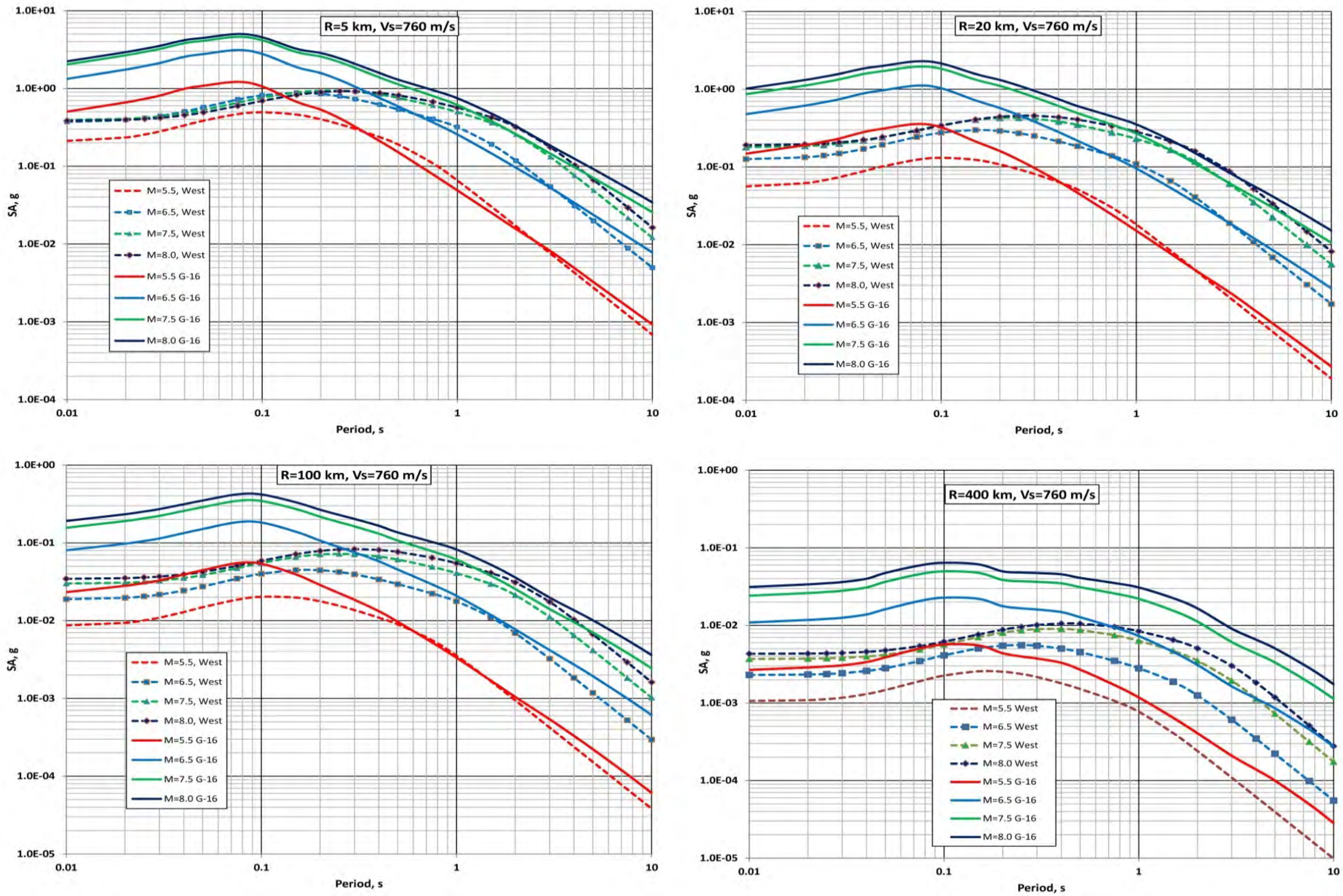
In contrast to the WUS, CENA response spectra flatten at much higher frequencies. In G-16 and G-16v2 models response spectra flatten completely at a frequency of 250 Hz and this corresponds to the value of PGA.

Magnitude Scaling for Hard Rock Vs=2800 m/s



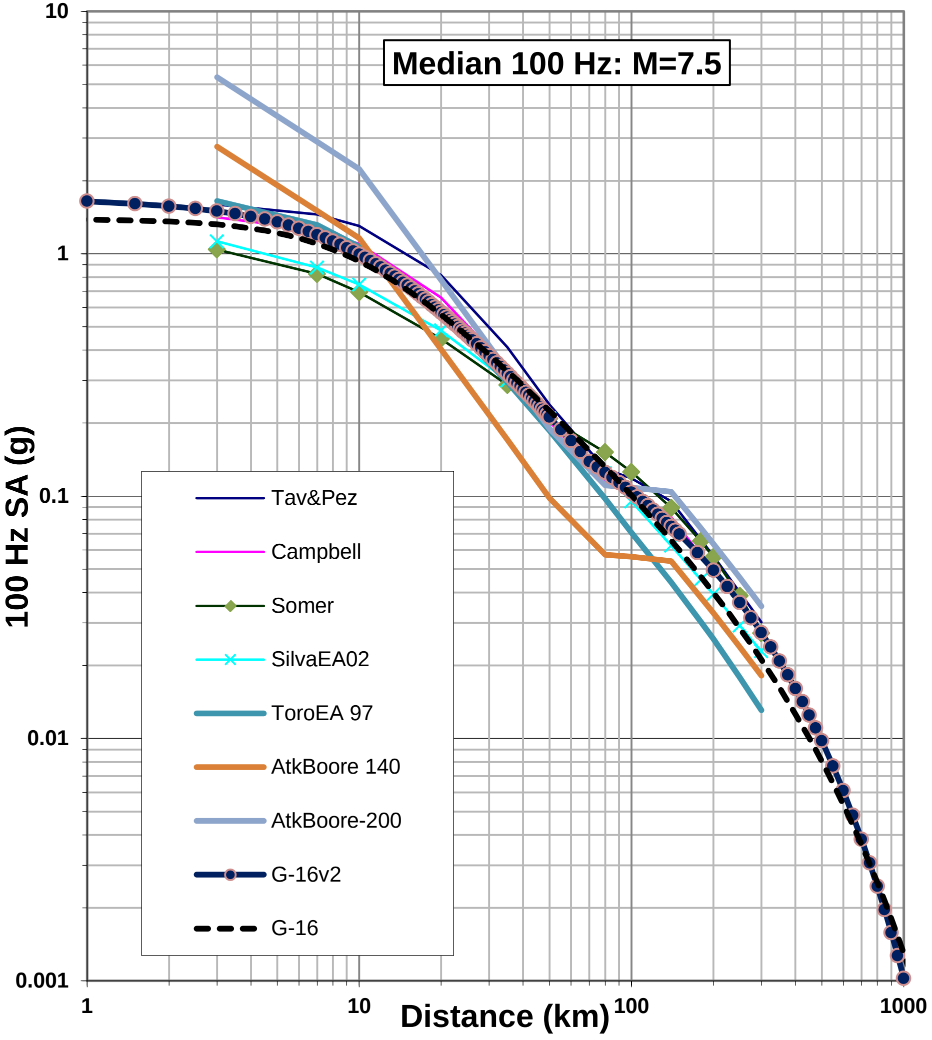


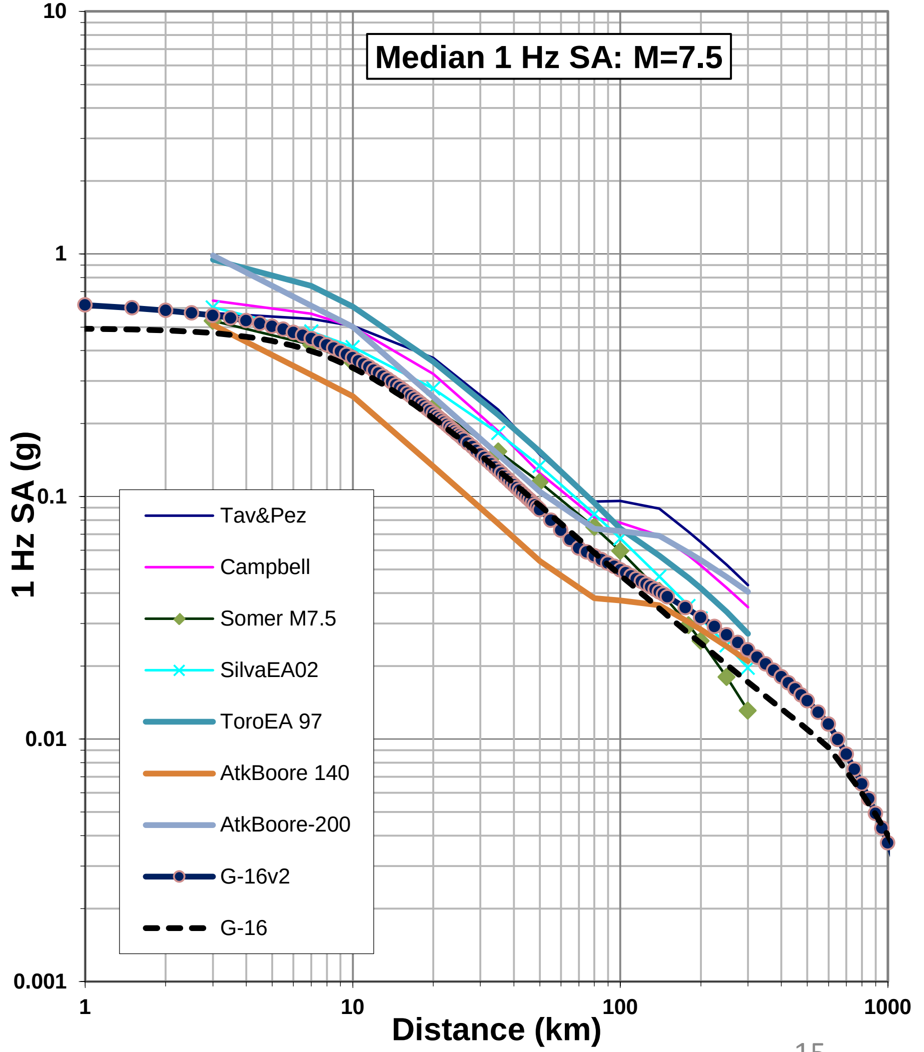
Comparisons of the G-16v2 SA functions for CENA with GK15 for WUS



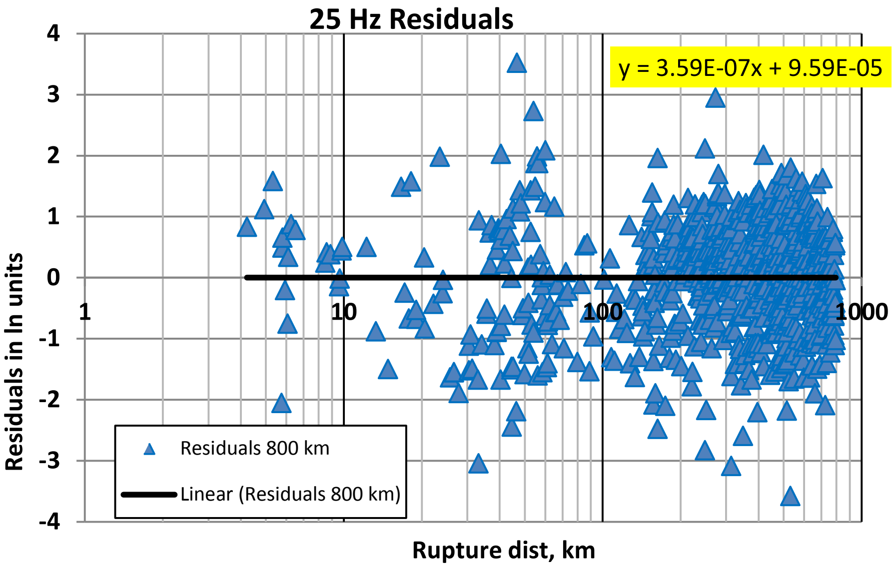
At fault distances up to about 100 km long period components of response spectra are similar in the East and West. At larger distances eastern data are higher at all periods due to higher Qsa.

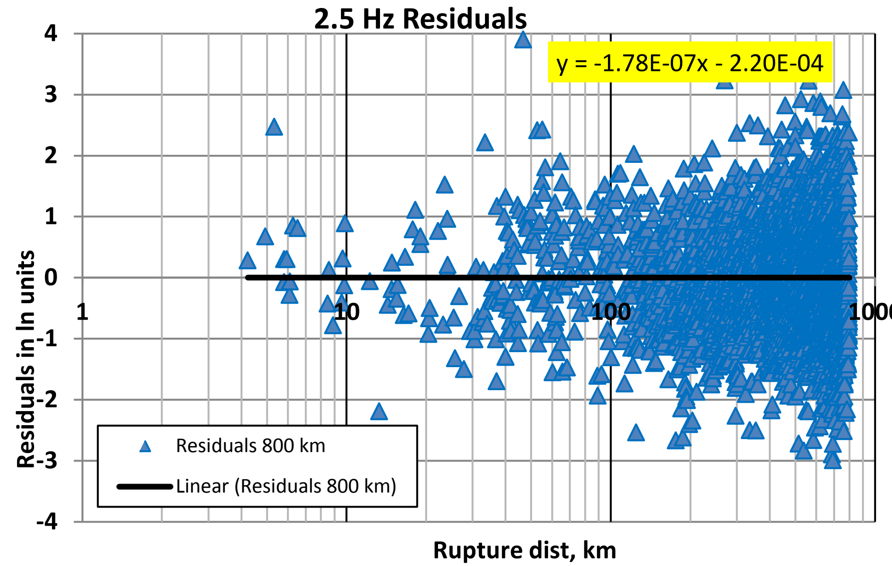
Comparison of G-16v2 Model with G-16 and Individual CENA Models Used by USGS (2014)

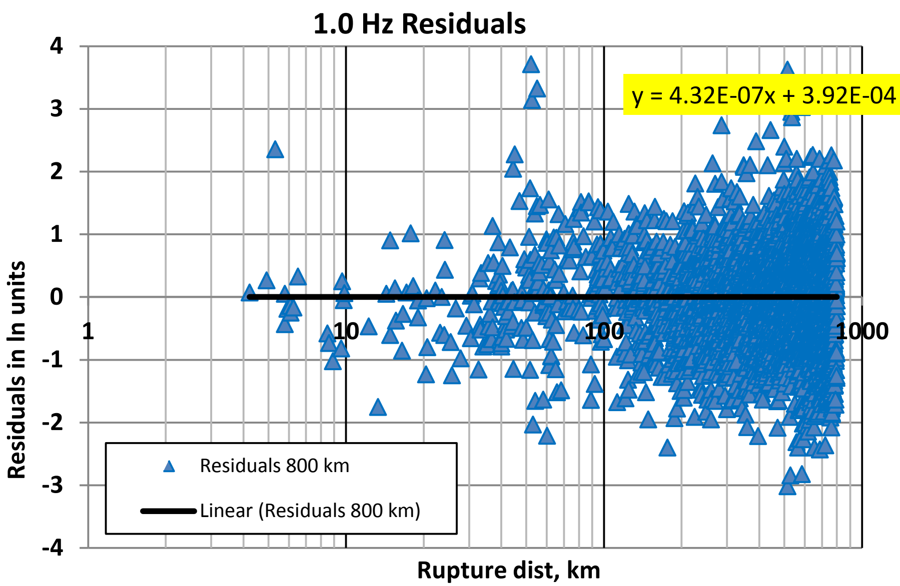


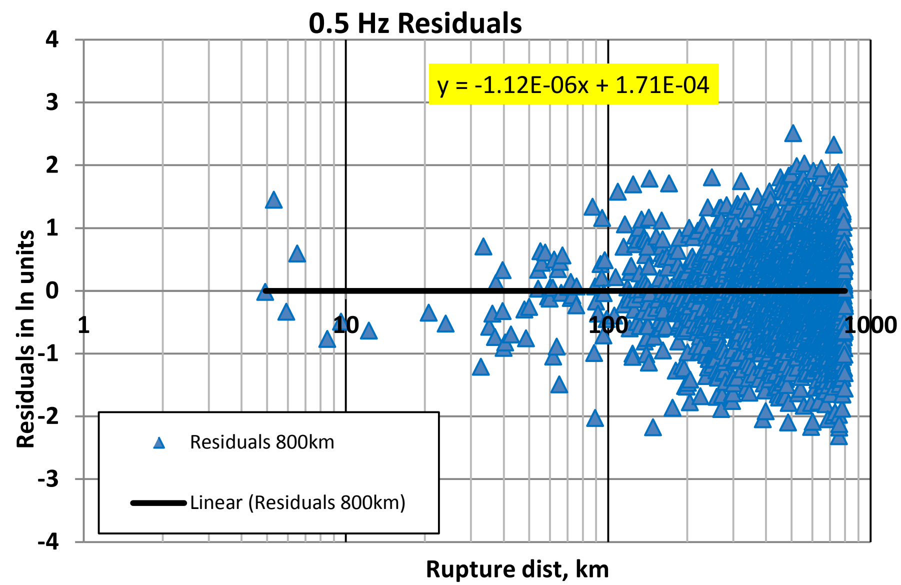


Distance Residuals (in Natural Log Units)

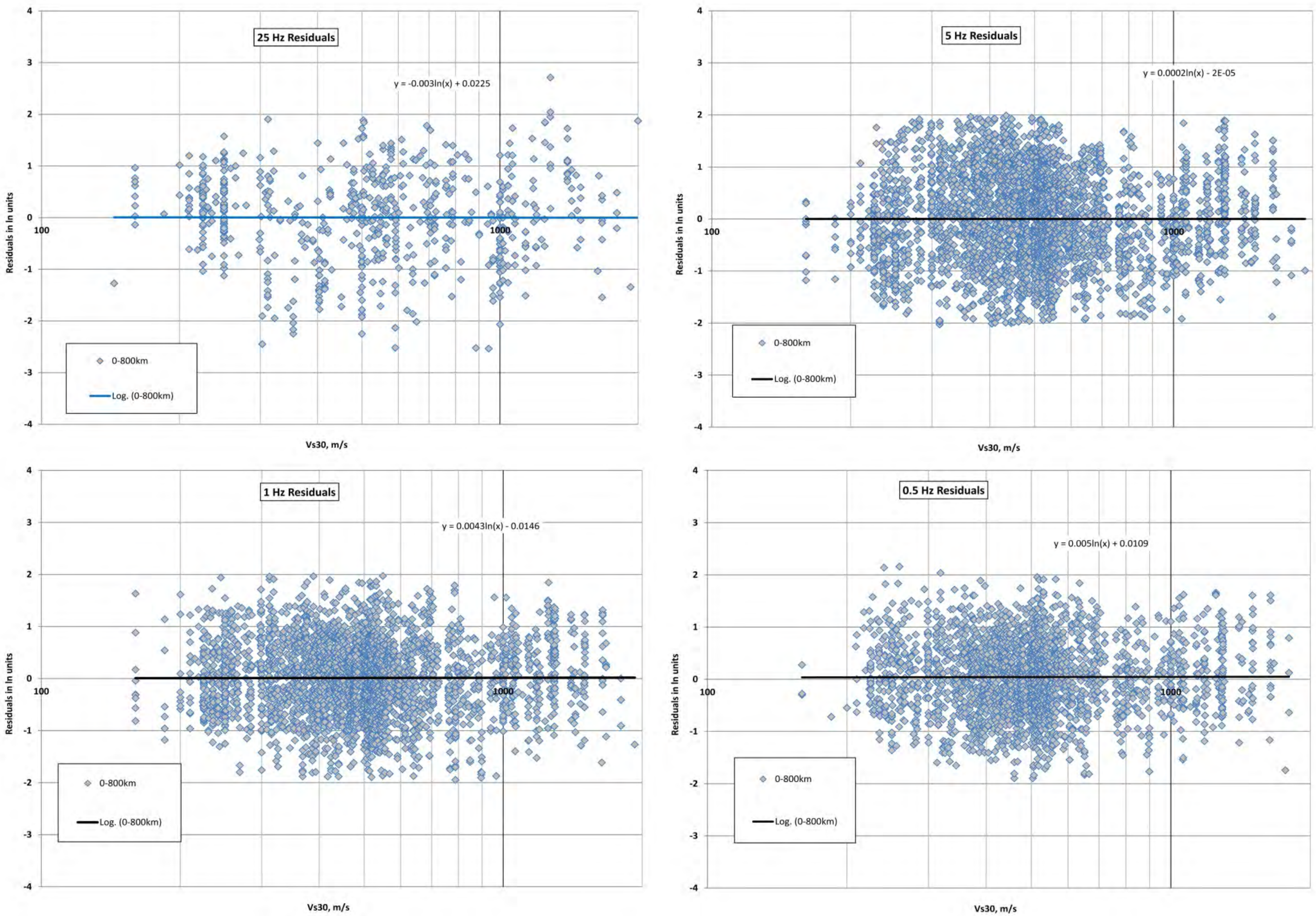




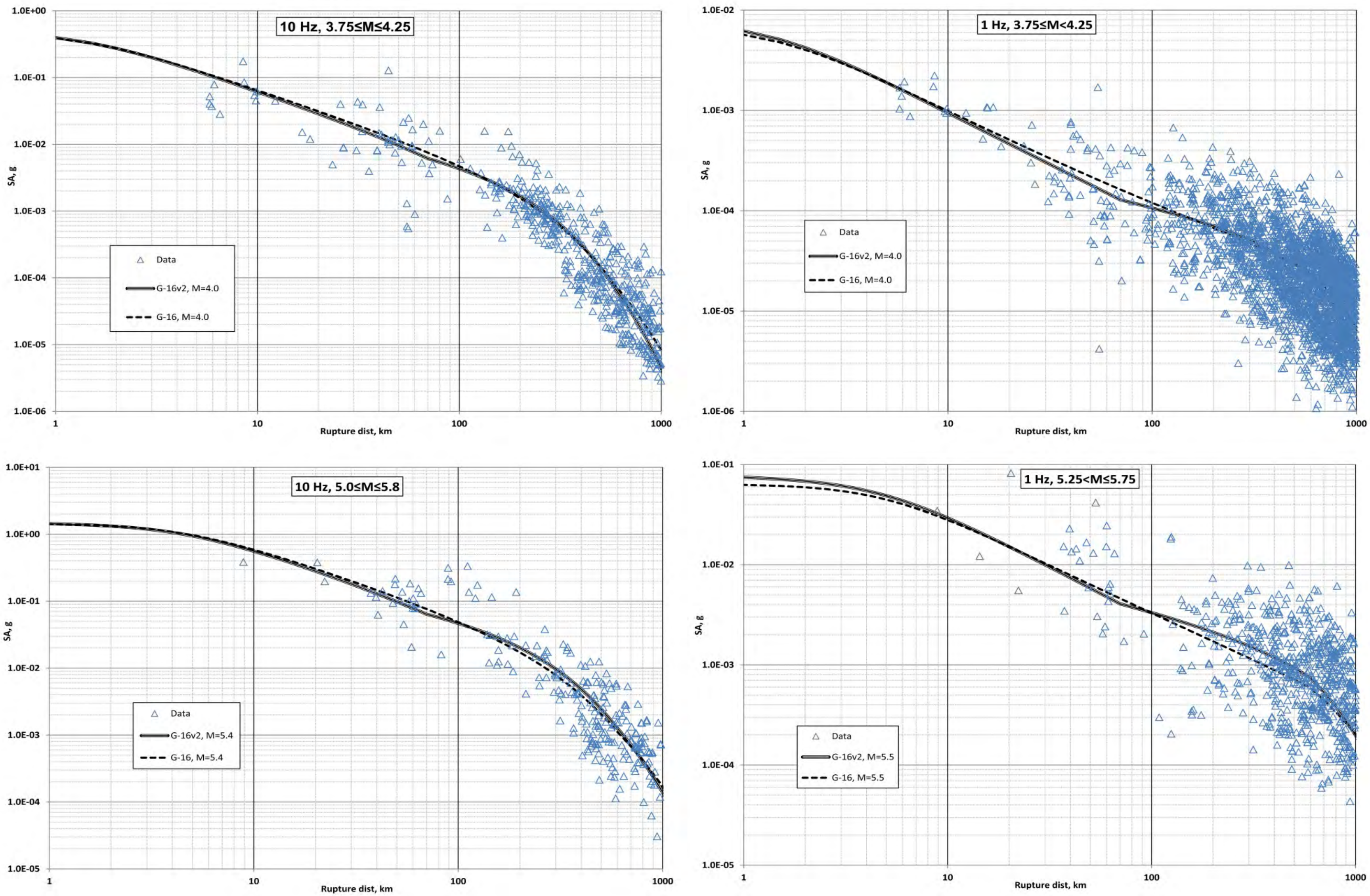




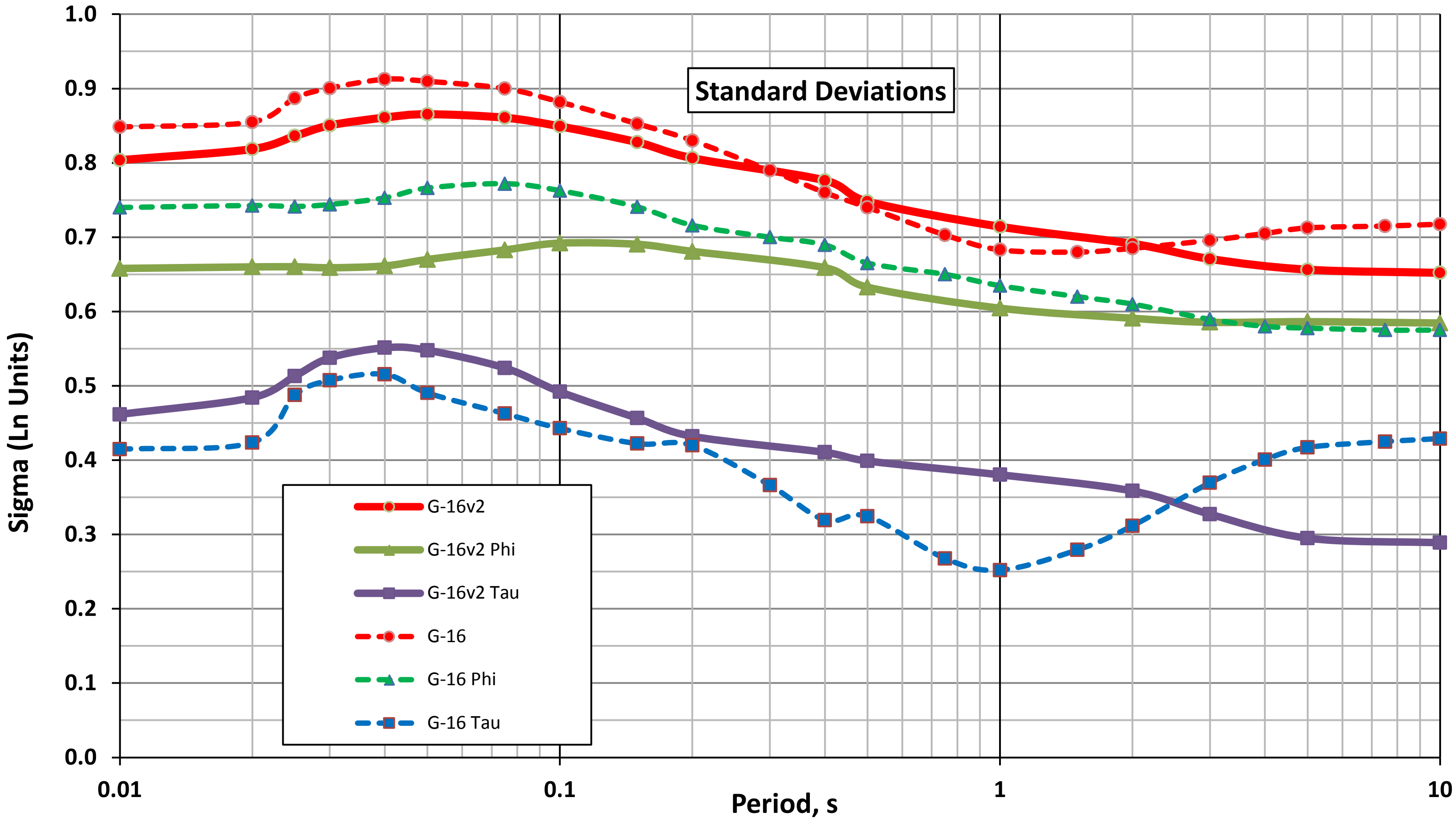
Vs30 Residuals (in Natural Log Units)



Comparison of Models Predictions with Data for M4.0 and M5.5



Standard Deviations of G-16v2 and G-16 Models



Total (σ) and within-event (ϕ) and between-event (τ) standard deviations:

$$\sigma = \sqrt{\phi^2 + \tau^2}$$

Bilinear G-16v2 model demonstrates slight improvement in σ for most periods.

Summary of the G-16 and G-16v2 Models

- GMPEs Summary:
  - CENA stable continental environment
  - Functional forms work for 4.0<Mw<8.5
  - Rupture distances $0<R<1000$ km
  - Period range 0.01 to 10 sec
  - S-wave velocities of $250<V_{S30}<2800$ m/s

- Apparent attenuation of response spectral amplitudes $Q_{SA}(f)$ in G-16v2 should be estimated based on actual response spectral acceleration data, and not transferred from seismological measurements.

- Models are published in:

  G-16 – Bull. Seismol. Soc. Am. 2016, Vol. 106, No. 4, 1600-1612.

  G-16v2 - Bull. Seismol. Soc. Am. 2017, Vol. 107, No. 2, 869-886.