Jeff Bayless [AECOM]

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Regional Attenuation Models in Central and Eastern North America Using the NGA-East Database

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Poster #1
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Abstract

The anelastic attenuation term found in Ground-Motion Prediction Equations (GMPEs) represents the distance dependence of the effect of intrinsic and scattering attenuation upon the wavefield as it propagates through the crust, and contains the frequency-dependent quality factor, $Q(f)$, which is an inverse measure of the effective anelastic attenuation. In this work, regional estimates of $Q(f)$ in Central and Eastern North America (CENA) are developed using the NGA-East regionalization (Dreiling et al., 2014). The technique employed uses smoothed Fourier amplitude spectrum (FAS) data from well-recorded events in CENA as collected and processed by NGA-East. Regional $Q(f)$ is estimated using an assumption of average geometrical spreading applicable to the distance ranges considered. Corrections for the radiation pattern effect and for site response based on V_{s30} result in a small, but statistically significant improvement to the residual analysis. Apparent $Q(f)$ estimates from multiple events are combined within each region to develop the regional models. Models are provided for three NGA-East regions: The Gulf Coast, Central North America, and the Appalachian Province. Consideration of the model uncertainties suggests that the latter two regions could be combined. There was not sufficient data to adequately constrain the model in the Atlantic Coastal Plain region.

Tectonically stable regions are usually described by higher $Q(f)$ and weaker frequency dependence (η), while active regions are typically characterized by lower $Q(f)$ and stronger frequency dependence, and the results are consistent with these expectations. Significantly different regional $Q(f)$ is found for events with data recorded in multiple regions, which supports the NGA-East regionalization. An inspection of two well-recorded events with data both in the Mississippi embayment and in southern Texas indicates that the Cramer (2017) Gulf Coast regionalization may be an improvement to that of NGA-East for anelastic attenuation. The $Q(f)$ models developed serve as epistemic uncertainty alternatives in CENA based on a literature review and a comparison with previously published models.

(1) Ground Motion Data

The database utilized is a subset of the PEER NGA-East database compiled (Goulet et al. 2014). It includes events with **M** > 2.5, at distances up to 1500 km, recorded in CENA since 1988.

The ground-motion parameter used in the analysis is the smoothed Effective Amplitude Spectrum (EAS) (Hollenback et al., 2015). The EAS is the orientation-independent horizontal component FAS of ground acceleration. The EAS is calculated for an orthogonal pair of FAS as:

$$EAS(f) = \sqrt{\frac{1}{2}\left[FAS_{HC1}(f)^2 + FAS_{HC2}(f)^2\right]}$$

The NGA-East project also divided CENA into four regions based on the geologic and tectonic setting. These regions are shown in Figure 1 (reproduced from Goulet et al., 2015; Figure 1.2). The regions are numbered as: (1) the Gulf Coast, (2) Central North America (CNA), (3) the Appalachian Province, and (4) the Atlantic Coastal Plain.

Over 2,000 recordings from 53 earthquakes are identified as candidates for the analysis, each with at least 5 ground motion recordings. Figure 2 shows a magnitude versus rupture distance scatterplot of the data utilized at f=1 Hz.

(2) Approach

The procedure taken to estimate the apparent $Q(f)$ for a given earthquake is as follows:

- Gather the EAS data and metadata. Filter by region as needed. The unmodified data are denoted EAS_{raw}.
- Calculate the site response adjustment for each record, F_{Site}.
- Calculate the radiation pattern effect adjustment for each record, F_{Rad}.
- Adjust the EAS_{raw} for site effects (to obtain EAS_{Site}) for radiation pattern effects (to obtain EAS_{Rad}), and for both effects ($EAS_{RadSite}$).
- Follow the Cramer (2017) procedure for estimating apparent $Q(f)$. Assuming $1/\sqrt{R}$ geometrical spreading, fit the attenuation of the EAS at frequency f to

$$ln[EAS(f)] = A(f) + b\, ln[R_{rup}] + c(f)R_{rup}$$

  where $A(f)$ is a regression constant, $b = -0.5$, R_{rup} is the closest distance to the rupture, and $c(f)$ is the apparent anelastic attenuation coefficient.
- Estimate the apparent $Q(f)$ from $c(f)$ by

$$Q(f) = \frac{-\pi f}{c(f)\beta_0}$$

This process is repeated for each earthquake in the dataset for 10 log-spaced frequencies ranging from to 1 to 20 Hz, and for each of EAS_{raw}, EAS_{Site}, EAS_{Rad}, and $EAS_{RadSite}$. These four variations of the ground motions are analyzed to assess the effectiveness of the site and radiation pattern corrections on apparent $Q(f)$ estimates. This effectiveness is quantified through analysis of the residual standard deviations (σ_{Resid}) and the standard error of the c coefficient estimates (se_c)

Please see the paper (https://doi.org/10.1177/87552930211018704) for a description of the site and radiation pattern adjustments.

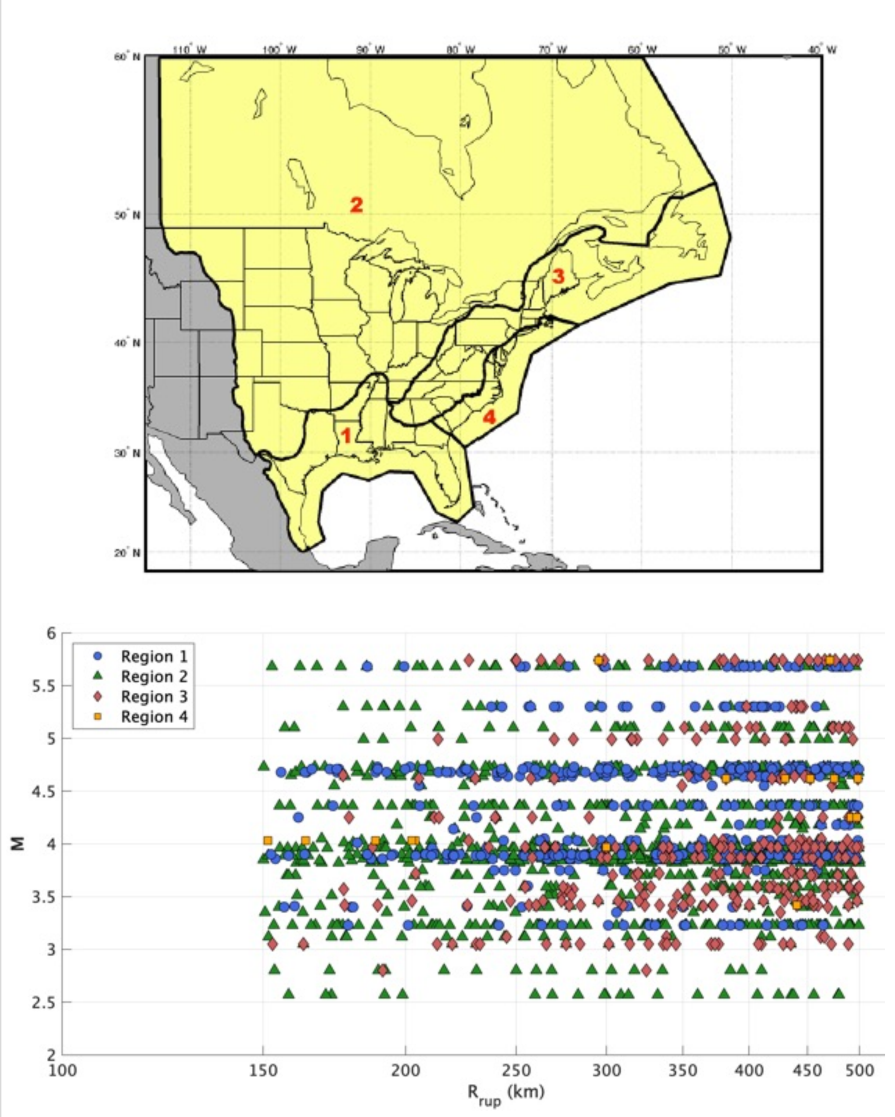

Figure 1: Top, a reproduction of Goulet et al. (2015) Figure 1.2, showing the four CENA regions: (1) the Gulf Coast, (2) Central North America (CNA), (3) the Appalachian Province, and (4) the Atlantic Coastal Plain. Bottom, magnitudes and distances of the database by region.

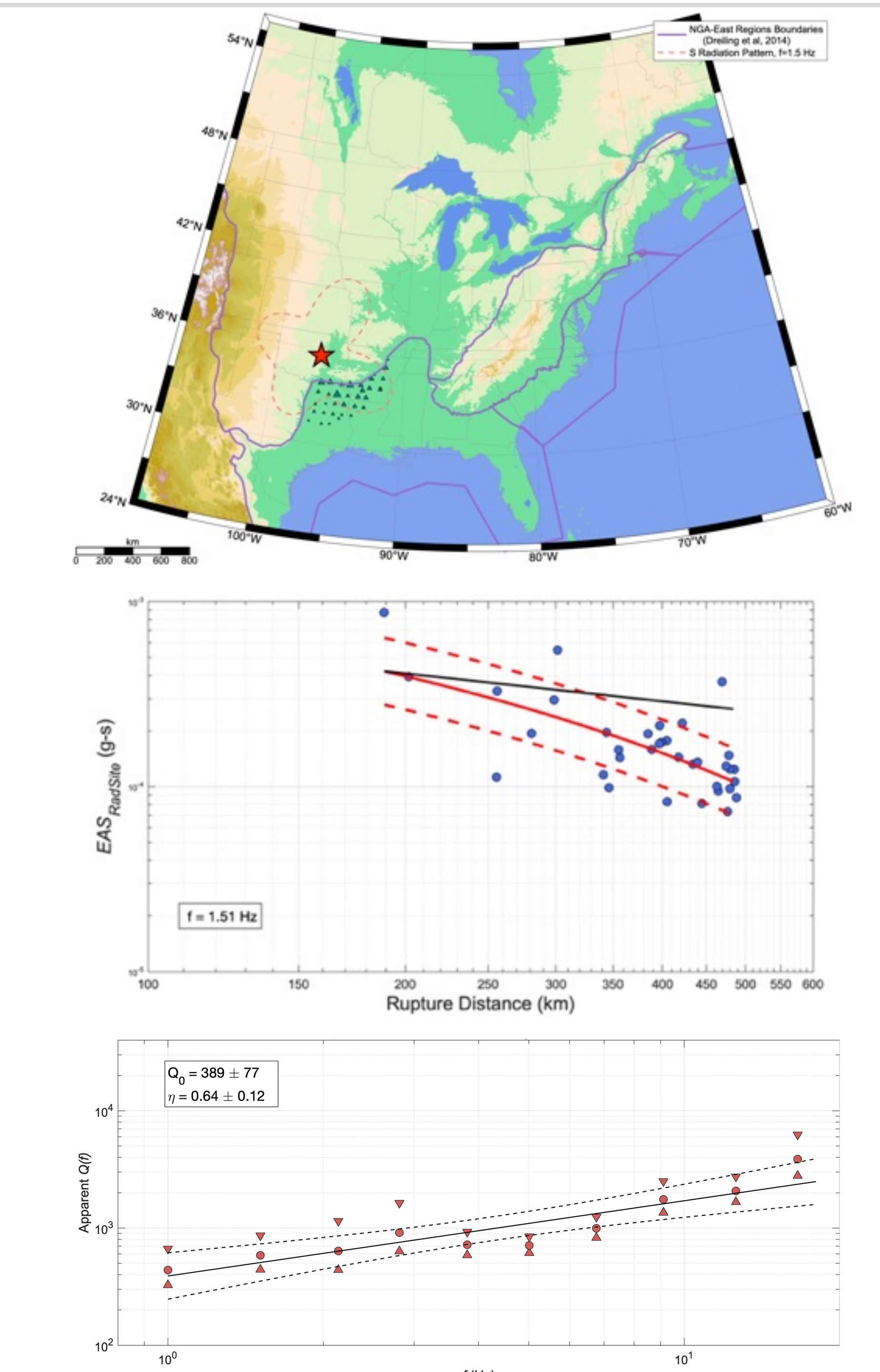

Figure 2: See description in (3) Results

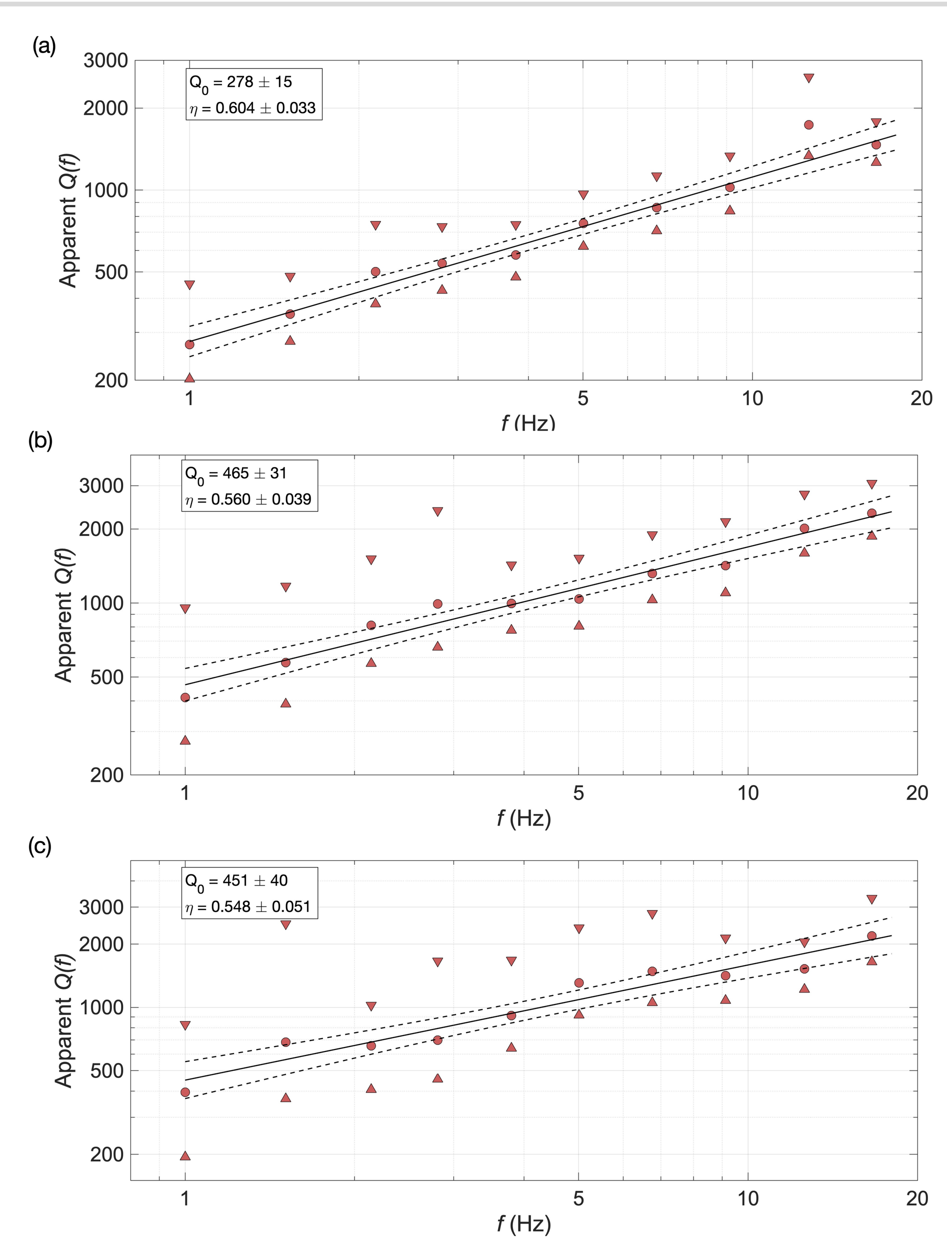

Figure 3: Results for (a) the Gulf Coast, (b) the CNA, and (c) the Appalachian Province showing the $\bar{Q}(f)$ (filled circles) and standard deviations (triangles) of the event-based results. The mean fit (solid line) with 95% confidence intervals (dashed lines) are shown. Values of Q_0 and η are given in each panel.

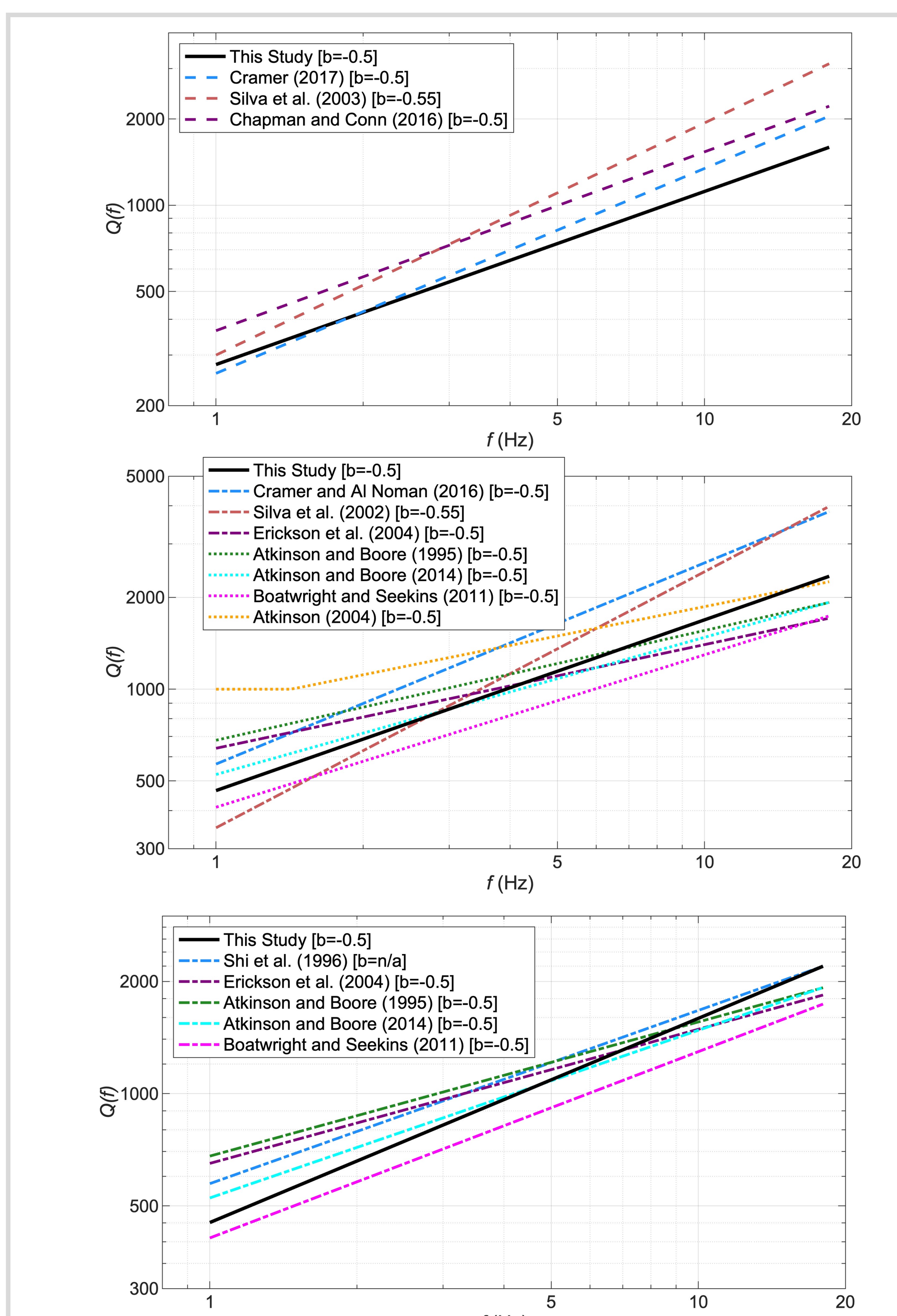

Figure 4: Comparison of mean Q(f) models for (top) the Gulf Coast region, (middle) the CNA or ENA regions, and (bottom) the Appalachian Province region.

(3) Results

The event-based estimates of apparent *Q(f)* are calculated as shown in Figure 2, which is an example from the **M**4.7 Sparks earthquake. At the top of the figure, the map shows the earthquake epicenter (red star) and recording stations in Region 1 (green triangles) used in the inversion. The 2-dimensional S radiation pattern at $f = 1.5$ Hz is shown by the dashed line. In middle, the attenuation with distance at $f = 1.5$ Hz of the data, along with the mean fit of the attenuation (red) plus and minus one standard deviation. The black curve is the geometric spreading attenuation rate ($b = -0.5$) and $Q(f)$ models the departure from this rate. At bottom, the apparent $Q(f)$. The mean (filled circles) and standard error (triangles) are given along with the mean fit (solid line) and 95% confidence intervals for the mean fit (dashed lines).

To develop a model for each region, the mean of the event-based estimates is taken. Figure 3 shows the mean *Q(f)* (circles) with standard deviations (triangles) for the three regions. The best fit of the mean to the form $Q_{region}(f) = Q_0 f^{\eta}$ is also shown with 95% confidence intervals (dashed lines). The regional model coefficients from this fit are listed in the table below, along with their standard errors.

Region	Region Name	Q_0	se_{Q_0}	η	se_η
1	Gulf Coast	278	15	0.60	0.03
2	Central North America (CNA)	465	31	0.56	0.04
3	Appalachian Province	451	40	0.55	0.05

(4) Summary and Conclusions

The goals of this study were to investigate and document differences in regional $Q(f)$ using the PEER NGA-East regionalization (Dreiling et al., 2014), and to provide regional $Q(f)$ models that can be used as epistemic alternatives to other existing models. This study uses smoothed FAS data from well-recorded events in the CENA as collected and processed by PEER NGA-East (Goulet et al., 2014) and uses an assumption of average geometrical spreading applicable to the distance ranges considered, a correction for the radiation pattern effect, and a correction for site response based on V_{s30}. Apparent $Q(f)$ from multiple events are combined within each region to develop the regional models.

$Q(f)$ is usually modeled with the form $Q(f) = Q_0 f^{\eta}$, where Q_0 is the Q value at 1 Hz, and η is the slope parameter. Using this form, models are developed for three regions as defined by PEER (Dreiling et al. 2014): The Gulf Coast, Central North America, and the Appalachian Province. Consideration of the $Q(f)$ model uncertainties suggests that the Central North America and Appalachian Province regions could be combined. There was not sufficient data to adequately constrain the model for a fourth region, the Atlantic Coastal Plain.

Significantly different regional $Q(f)$ is found for events with data recorded in multiple regions, which supports the NGA-East regionalization of the Gulf Coast and Central North America. An inspection of two events recorded in the Dreiling et al. (2014) Gulf Coast region with data both in the northernmost Mississippi Embayment (Memphis region within the Dreiling et al., 2014 Gulf Coast region) and to the west (Texas area, within the Dreiling et al., 2014 Gulf Coast region) reveals higher Q_0 estimates in the Memphis region, indicating that the Cramer (2017) Gulf Coast regionalization may be an improvement to that of NGA-East for anelastic attenuation. This region is a candidate for potential refinement with respect to attenuation models in future investigations.

The regional models are consistent with expectations; the tectonically stable regions (CNA, Appalachian Province) are usually described by higher $Q(f)$ and weaker frequency dependence (η), and the Gulf Coast model is characterized by lower $Q(f)$ and stronger frequency dependence. The $Q(f)$ models developed serve as epistemic uncertainty alternatives in CENA based on a literature review and a comparison with previously published models (Figure 4).