USGS NSHMP Workshop

GMPE residuals using the NGA-East database: accounting for mixed effects

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Data and analysis options

- NGA-East v3.0 (August 2012) database
- Used geometric mean of as-is components
- Kept only events recorded at at least 5 stations
- Used limited bandwidth based on filter corners
- Residuals for PGA, 0.2, 0.5, 1.0 and 2.0 sec.
- Multiple variations on limits
  - All Ms and M>4
  - All Rs, R<200, R<1000
  - With and without the Gulf Coast…
- R_{jb} and R_{rup} taken as R_{epi} and R_{hypo}
- V_{s30} set to 760 m/s for computations (USGS site factors applied to HR)
- V_{s30} reported on plots based on
- Measured (~100 sites total)
  - Inferred or estimated (from NGA-East Geotech WG, personal priority selection)

Caveat: Range of data considered for examples exceeds GMPE development limits, presentation for proof of concept only

Models considered

- Frankel et al. (1996)
- Toro et al. (1997) modified by Toro (2002)
  - Mid-Continent
  - Gulf Coast
- Silva et al. (2002)
- Campbell (2003)
- Atkinson (2008) as modified by Atkinson & Boore (2011)*
- Atkinson & Boore (2006) as modified by Atkinson & Boore (2011)*
- Somerville et al. (2001)
- Somerville et al. (2009) – Australia, Cratonic
- Pezeshk et al. (2011)

All corrected from hard rock (V_{s30}~2800 m/s) to BC boundary (V_{s30}=760 m/s) using USGS site factors (Frankel et al. 1996) except * which include a site effects terms

Residuals analysis

GMPE explanatory parameters : M_e, r_{es},…

GMPE coefficients

$$\ln y_{es} = \mu_{es}(X_{es}, \theta) + \delta_{total}$$

Recorded ground motion for earthquake e, station s

Median GMPE predictions for earthquake e, station s

Difference between recording and median prediction.

Total residuals

$$\delta_{total} = \left[\ln y_{es}\right]_{Rec} - \left[\ln \mu_{es}\right]_{GMPE}$$

Residuals analysis - Partitioning

GMPE explanatory parameters : M_e, r_{es},…

GMPE coefficients

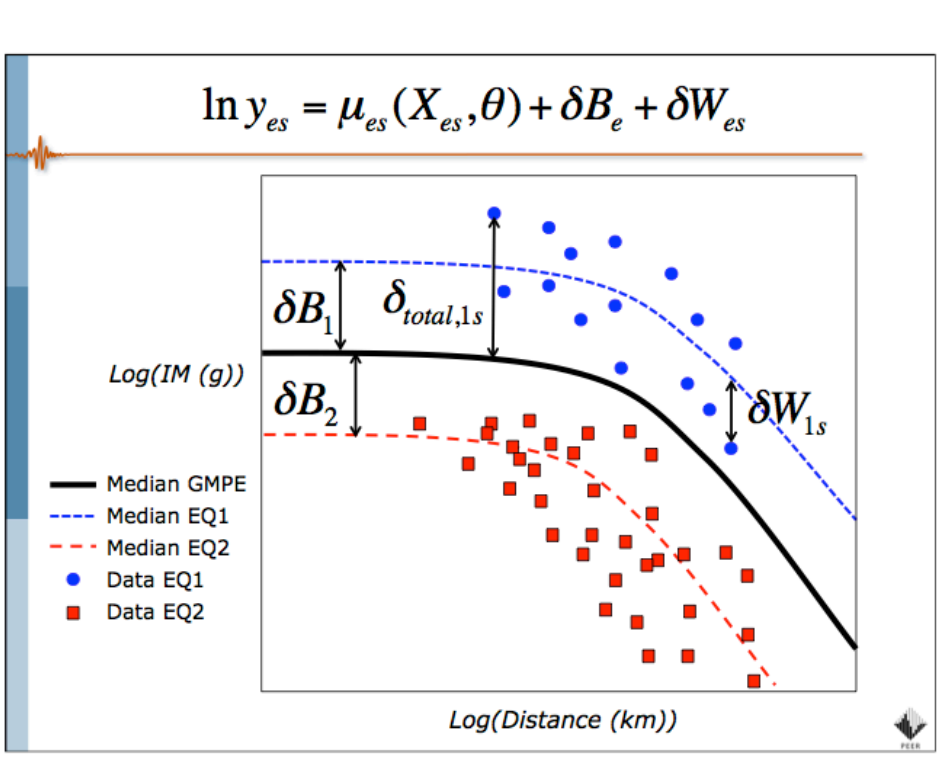
$$\ln y_{es} = \mu_{es}(X_{es},\theta) + \delta B_e + \delta W_{es}$$

Recorded ground motion for earthquake e, station s

Median GMPE predictions for earthquake e, station s

Between-event residual

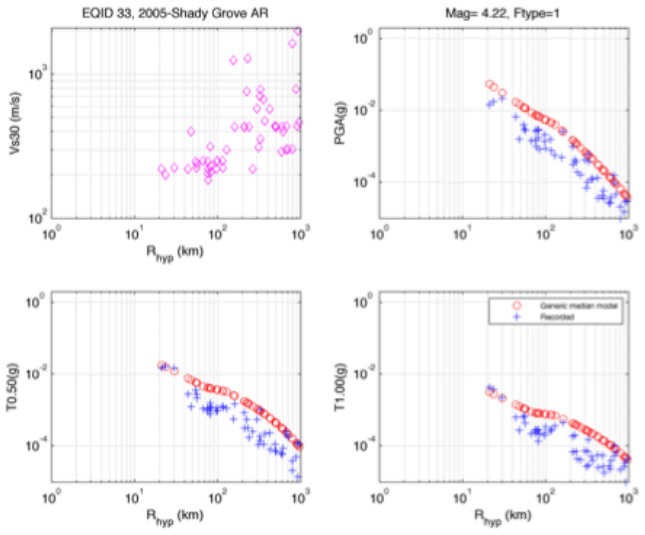
Within-event residual



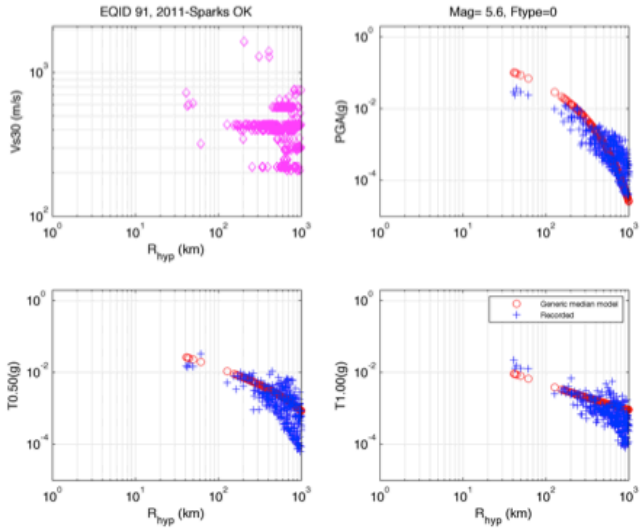
Using residuals to evaluate GMPEs

- Total and between-event residuals useful to assess ability of GMPE to model attenuation (data/GMPE slopes similar or not)

Ground motions comparison – examples – resonnable slope match



Ground motions comparison – examples – steeper slope for GC, use different GMPE!

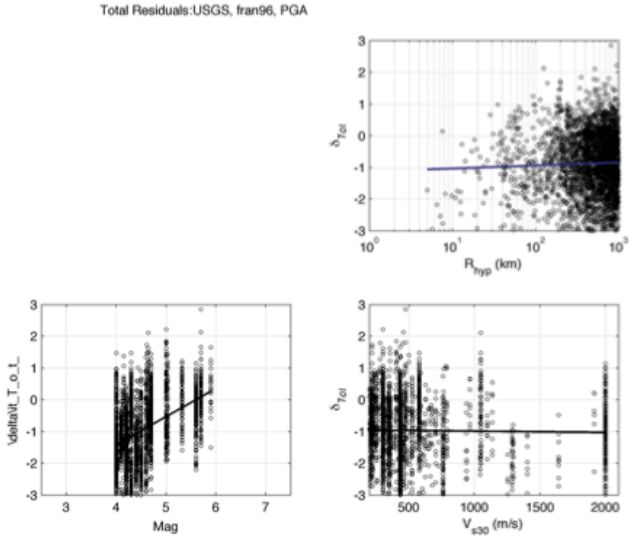


Using residuals to evaluate GMPEs

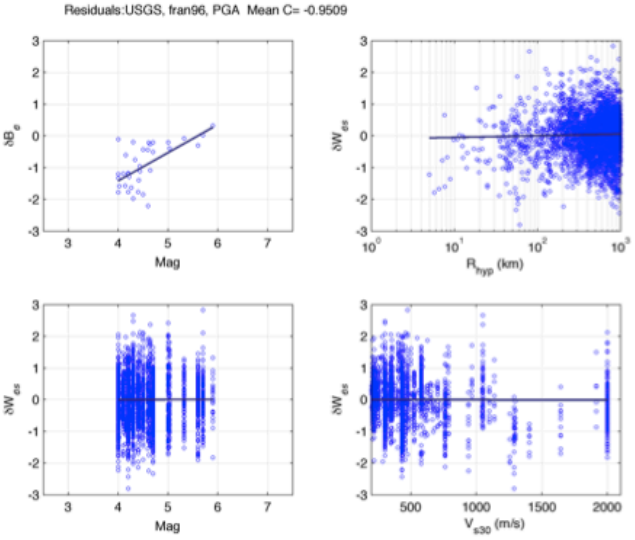
- Total and between-event residuals useful to assess ability of GMPE to model attenuation (slopes similar or not)
- Total residuals give an idea of the overall misfit
  - Uneven sampling of events: mean should not be zero in general. A few well-recorded events with high or low stress-drop may "pull" the residuals in a given direction
- Separated residuals (within- and between- event)
  - Addresses uneven sampling and correlation in dataset: changes the weighting of data points, not one single event controls the interpretation

Be careful with trade-offs for correlated data sets (e.g. small events recorded on a given site condition or large events in a specific region)

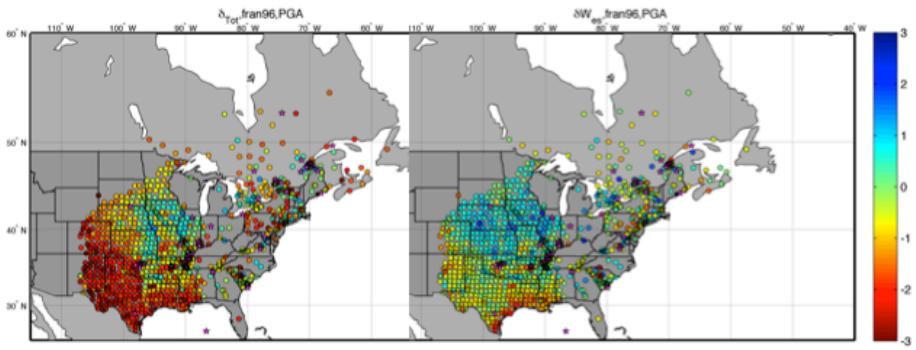
Total residuals – example Frankel et al. 96



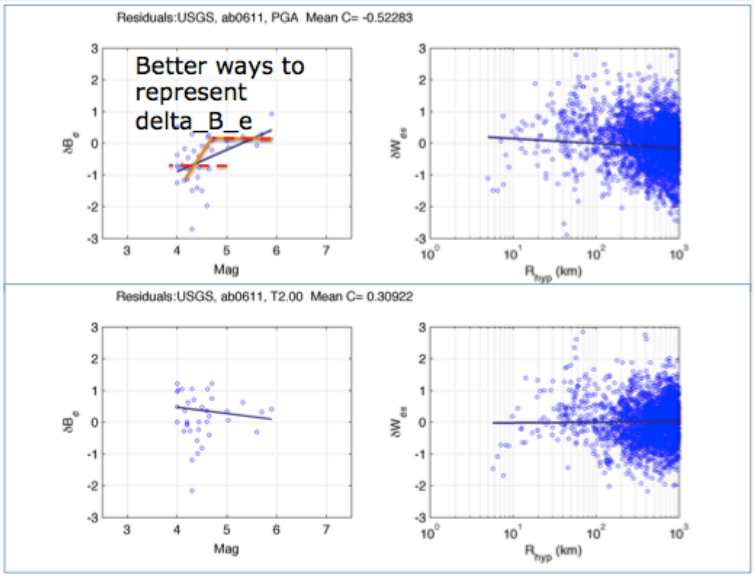
Mixed-effects residuals – example Frankel et al. 96



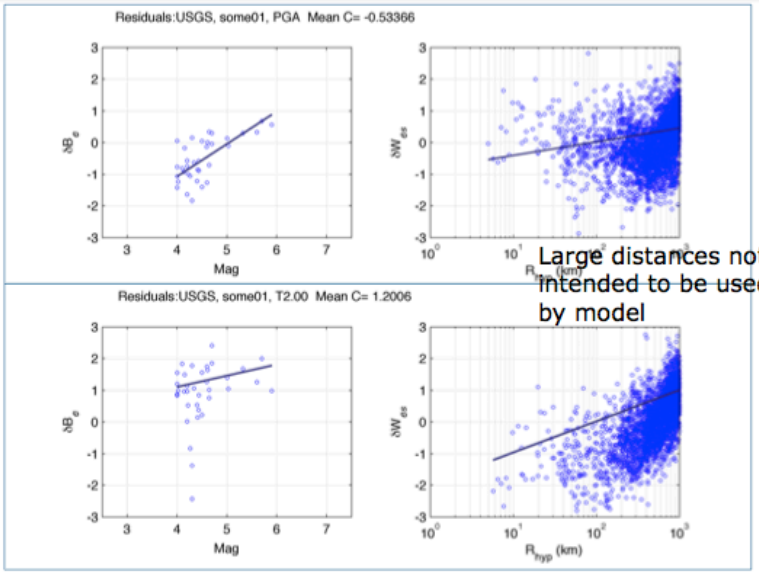
Total and Mixed effects residuals – example - Frankel et al. 96



Issue – trend in event terms Atkinson and Boore 06-11



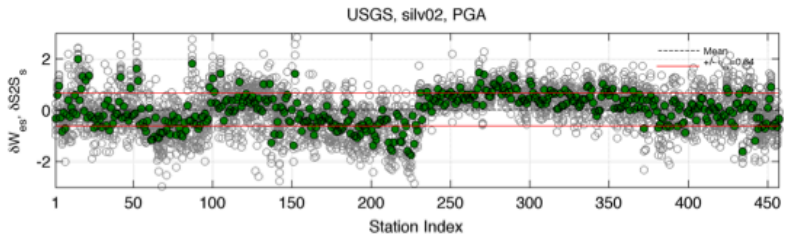
Issue – trend in event terms Somerville et al. 01



Large distances not intended to be used by model

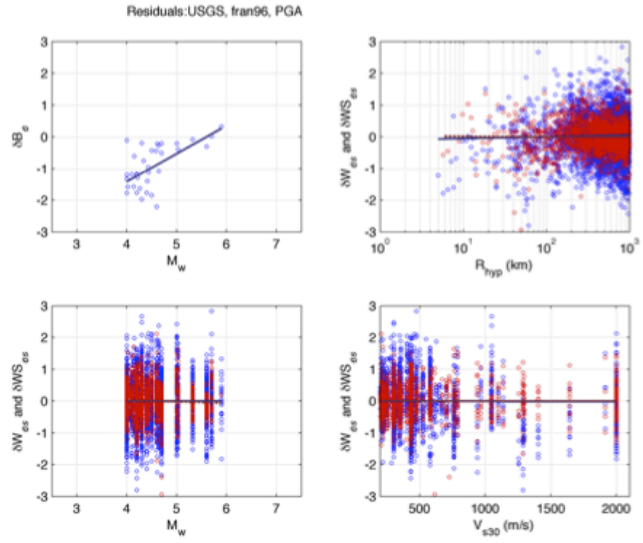
Accounting for repeatable site effects

- Only use stations with 5+ recordings
- Compute average within-event residuals to get site term at each station

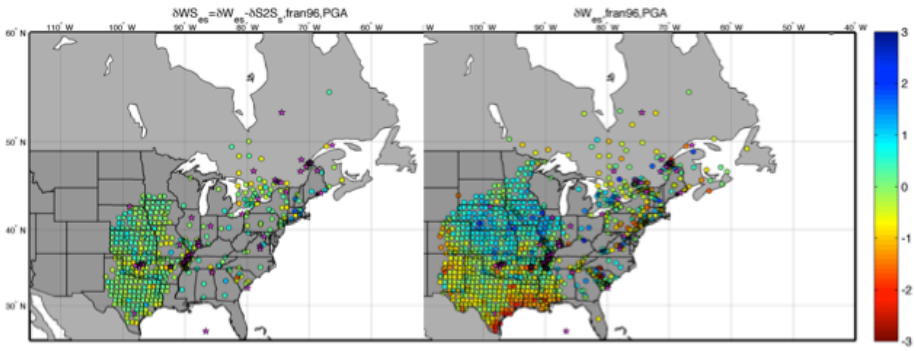


- Remove those site terms to get to site-corrected within-event residuals

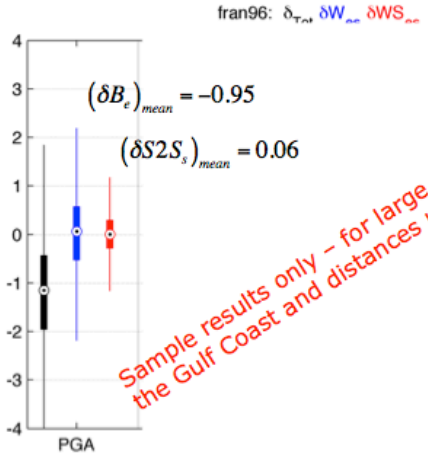
Within-event and site-corrected within-event residuals – Frankel et al. 96



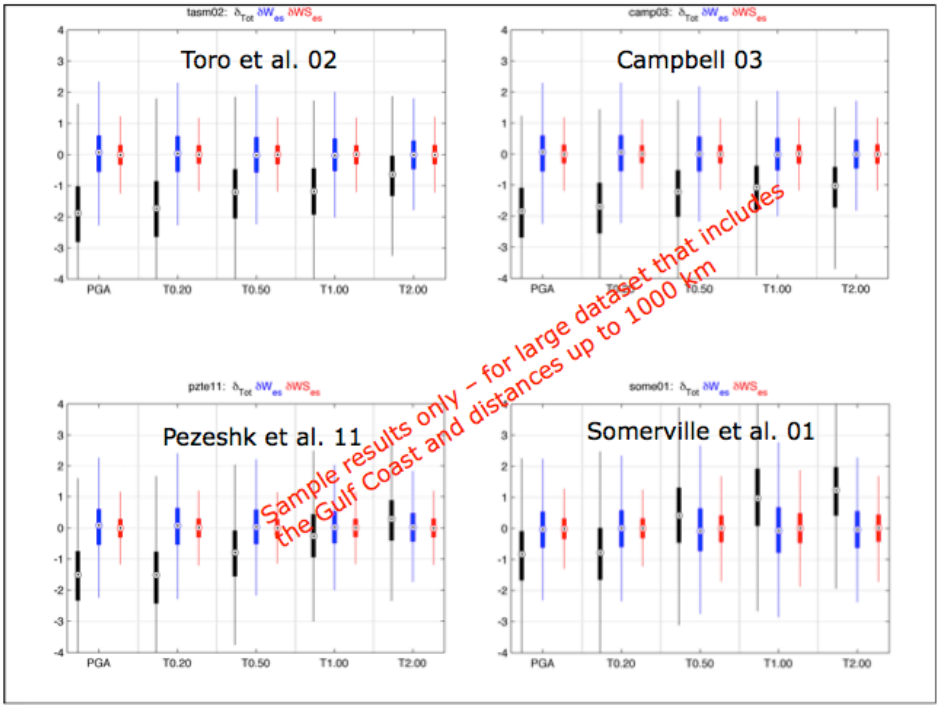
Total and Mixed effects residuals – example - Frankel et al. 96



Summary results



Sample results only – for large dataset that includes the Gulf Coast and distances up to 1000 km



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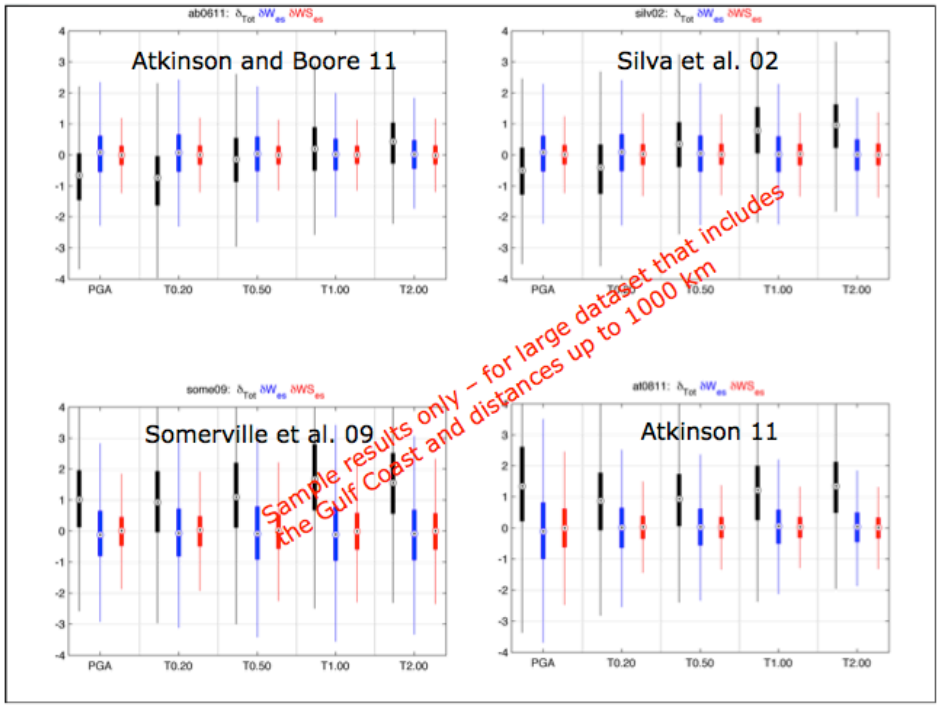
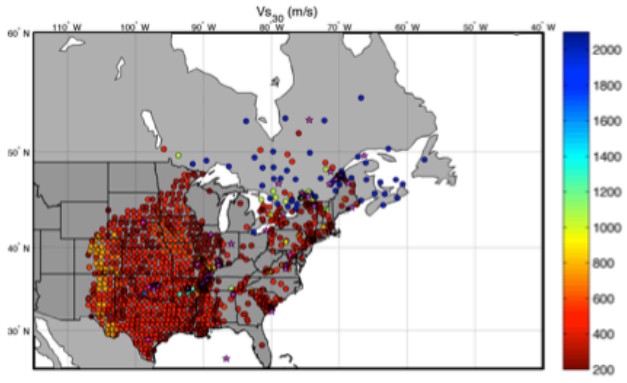


Looking at residuals – understanding GMPE fit to data

- Residuals analyses that account for mixed effects allow to remove potential bias from unevenly sampled datasets
- Further removing systematic site effects may be very useful in the assessment – especially for USGS where site conditions are fixed (BC boundary)
  - Currently, Vs30 poorly constrained in the CEUS
  - Site terms do not require knowledge of side conditions
- Binning of results (M, R, Vs30) may be a good approach

Looking at residuals – understanding GMPE fit to data

- Issue - what events/stations to keep?
  - Look at data on a per-event basis to understand attenuation fit and potential other data correlations.
  - What to do with "triggered" events (injection, other events)?
  - Regionalization?
- What site-correction factors to use?
  - We have site terms, no reliable site conditions
- Evaluation
  - Compare results between GMPEs
  - Assess slopes in residuals – favor GMPEs with smaller event term slopes, and overall centered trends
  - Careful not to extrapolate to larger M where there is no data to constrain the fit!!!

Vs30 map – measured+best estimates