Development of Source-Depth Adjustment Model

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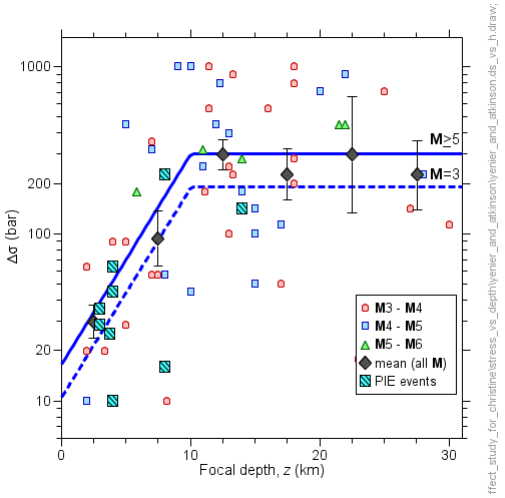
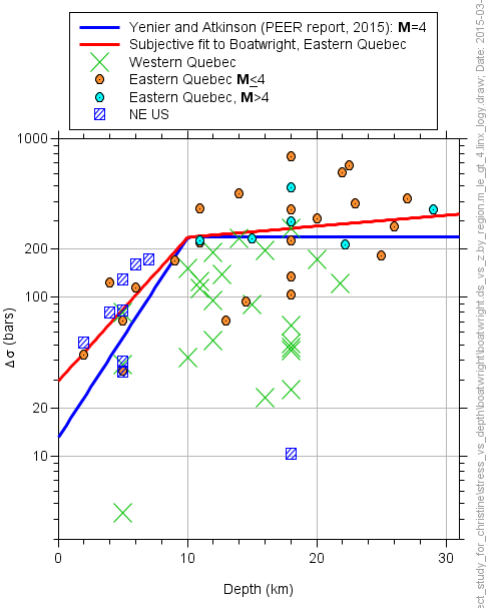
Motivation

- Median ground-motion models submitted to PEER for use in the NGA-East project where for a range of Magnitude and Distance and the NGA-East reference site condition but variations in source depth were not required for submission.
- Only 2 submitted ground-motion models investigated how ground motions vary with source depth (PEER, YA).
- YA and PEER submitted predictions for Z_{HYP} = 10km.
- For application to hazard there needs to be a recommendation for adjusting ground-motion predictions for source depth.

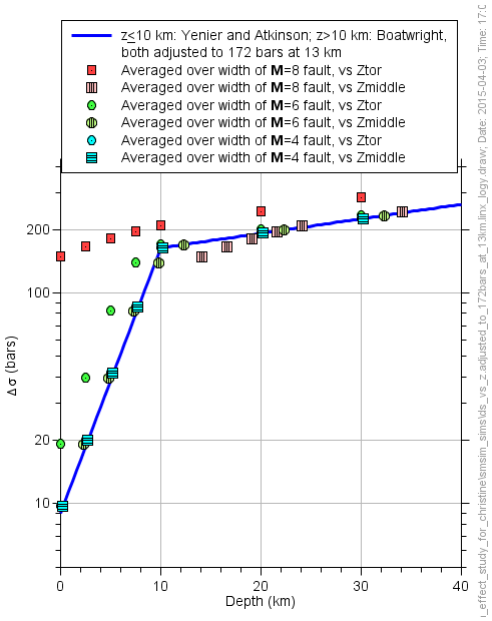


Yenier and Atkinson's stress parameters as a function of focal depth. The lines are their equations.

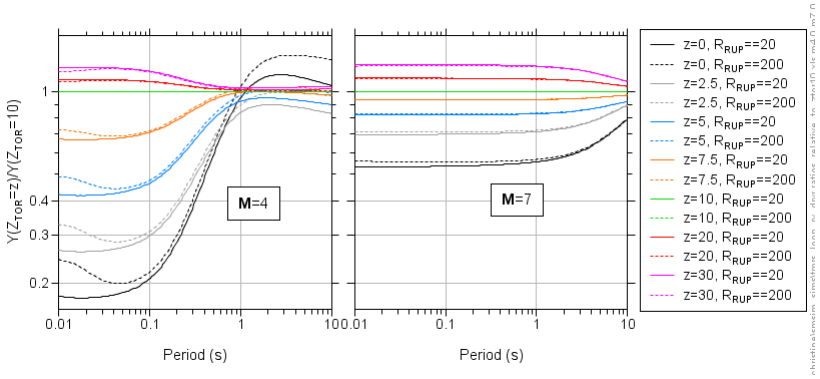


Boatwright's stress parameters as a function of focal depth. The eastern Quebec points are subdivided into events with magnitudes less than and greater than 4. The western Quebec symbols have been enlarged so that the two of the values at a depth near 5 km can be seen. The lines are from Yenier and Atkinson for **M**=4 and a subjective fit by DMB to Boatwright's values.

The stress parameter – depth function used in the simulations. Shown is the function from the inversions discussed earlier, as well as the stress parameters used in the simulations for three magnitudes (**M**=4, 6, and 8); these parameters were derived by an averaging of a power of over the width of the fault for each magnitude.

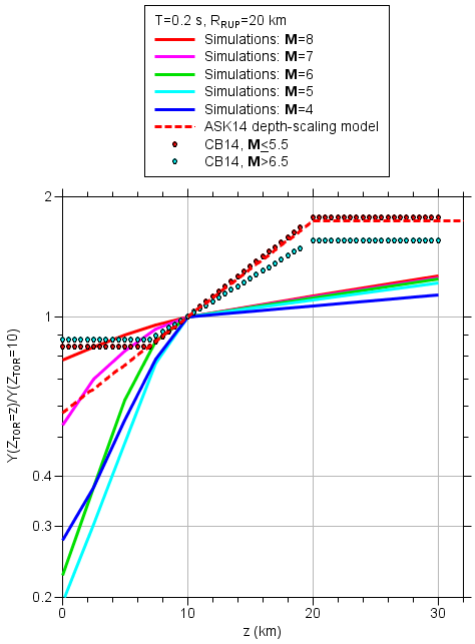


Some features predicted from simulation that are seen in the empirical results:
- Stronger depth scaling at short periods for small **M** than large **M** (because of averaging Ds over fault width)
- Lack of scaling for small **M** and large T because on moment side of corner frequency
- Still have depth dependence for larger **M** at longer T because can be on side of corner frequency influence by Δσ (even though Δσ is averaged over depth)



Ratio of simulated motions from point sources at depths z (in km) and 10 km, for **M**=4 and **M**=7 and two values of Rrup, 20 km and 200 km. The relation between Δσ and z discussed above was used in choosing the to be used for the point source at each depth z.

Ratio of simulated T=0.2 s response spectra from point sources at the indicated depth Ztor=z and Ztor=10 km, for **M**=4, 5, 6, 7, and 8 and Rrup=20 km. The stress parameter used in the simulations was from an average of over the fault width for each magnitude event.



Development

- Recommended source-depth adjustment model is based on the scaling of the three NGA-West2 models that consider variations of ground motion with source depth.
- It is constrained by the source-depth scaling implied by the PEER NGA-East model where applicable.
- A sufficient range of source depth is covered in the NGA-East database for **M** < 5.5 but not above. NGA-West 2 models were used to guide how source-depth scaling changes with magnitude.

Development

- Alternatives are considered for centering the source-depth adjustment model as a function of magnitude.
- NGA-West 2 models that consider scaling of ground motion with source-depth: CB14 (Z_{HYP}, Mag dependent), CY14 (Z_{TOR}, Mag dependent), ASK (Z_{TOR}, Mag independent).
- All source-depth models are simple additive terms on the natural log of median ground motion.

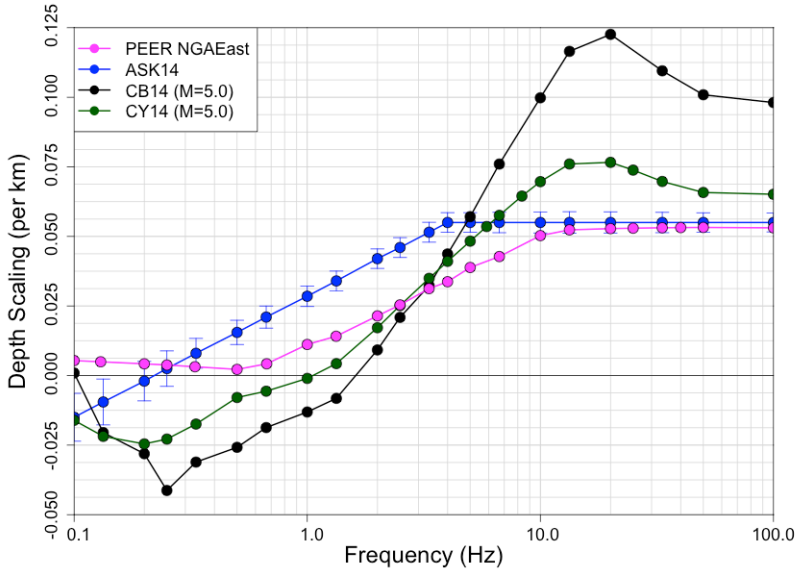
$$\ln\left(y_{ij}\right)=f\left(\mathbf{M},R,V_{S30}\ldots\right)+f_{Depth}$$

PEER NGA-W2 Source-Depth Models

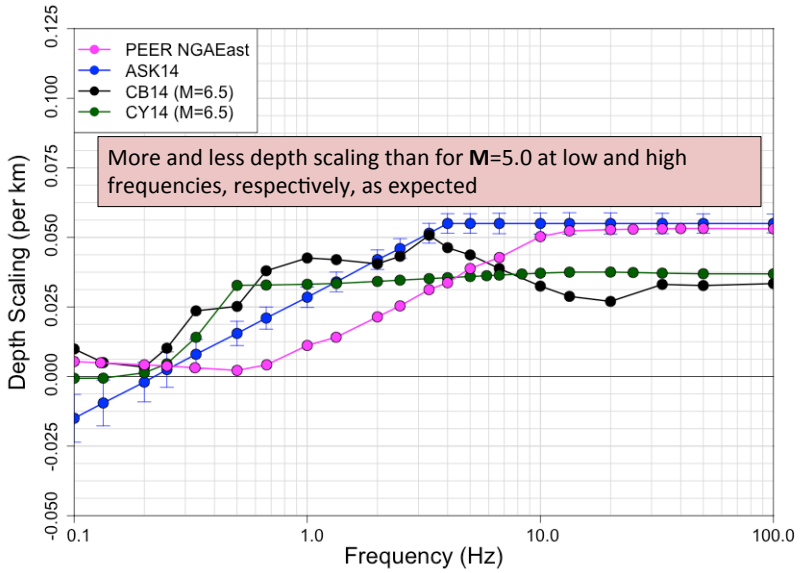
(all have linear dependence on depth in specified depth ranges)

- ASK14: $f_{Depth}=a_{15}\frac{Z_{TOR}}{20},Z_{TOR}\le 20\,\mathrm{km}$
- CB14: $f_{Depth}=f_{Z_{HYP},H}f_{Z_{HYP},\mathbf{M}}$
- CY14: $f_{Depth}=f_{Z_{TOR},\mathbf{M}}\Delta Z_{TORi}$

Source-Depth Scaling (**M**=5)



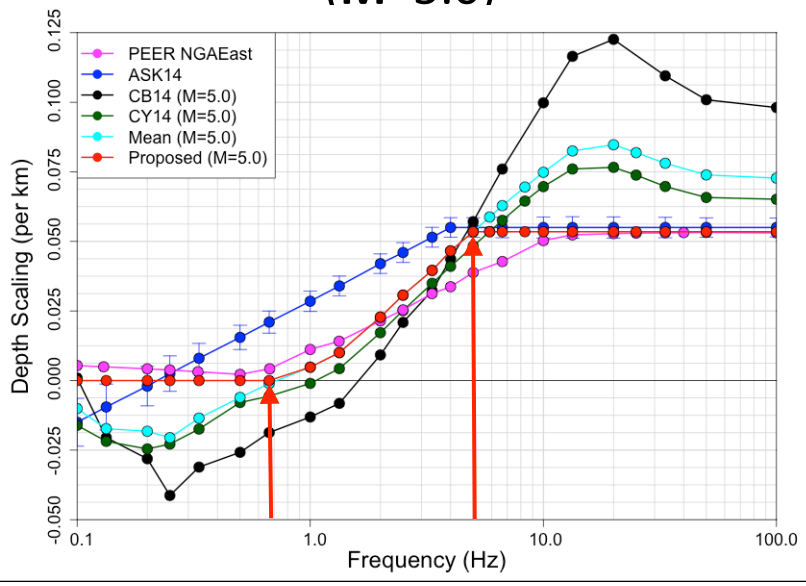
Source-Depth Scaling (**M**=6.5)



Proposed Source-Depth Scaling

- The proposed source-depth scaling model is based on an average of the NGA-West2 source depth scaling models at **M**=5.0 and **M**=6.5.
- At **M**=5.0 the average is constrained by the source-depth scaling of the PEER NGA-East model at high (> 5 Hz) and low (≤ 0.667 Hz) frequencies.

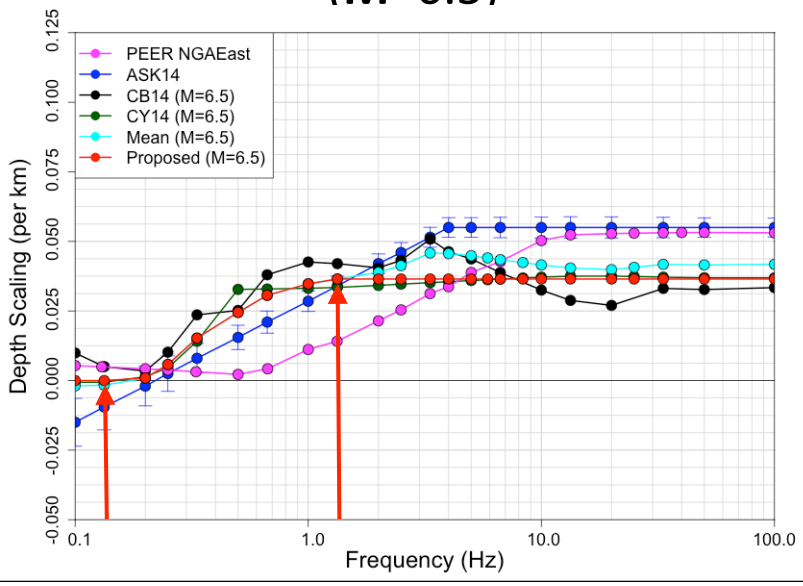
Proposed Source-Depth Scaling (**M**=5.0)



Proposed Source-Depth Scaling (**M**=5.0)

- 5 Hz was selected as the upper break point in frequency because this is the frequency at which the average of the NGA-West2 models reaches the level of scaling of the PEER NGA-East model.
- On the low frequency side the average was simply forced not to be negative because the PEER NGA-East model does not go negative.

Proposed Source-Depth Scaling (**M**=6.5)



Proposed Source-Depth Scaling (**M**=6.5)

- At **M**=6.5 the average of the NGA-West2 models is used between 0.2 and 1.333.
- Above 1.333 Hz it is forced to be flat.
- This is about the frequency where the two magnitude dependent models start to level off.
- We do not want to adopt a more complicated shape with frequency at a magnitude range where there is not enough data to inform us, so assume flat.
- Below 0.2 Hz we did not allow the model to be negative, in order to follow the PEER NGA-East model.

Proposed Source-Depth Scaling

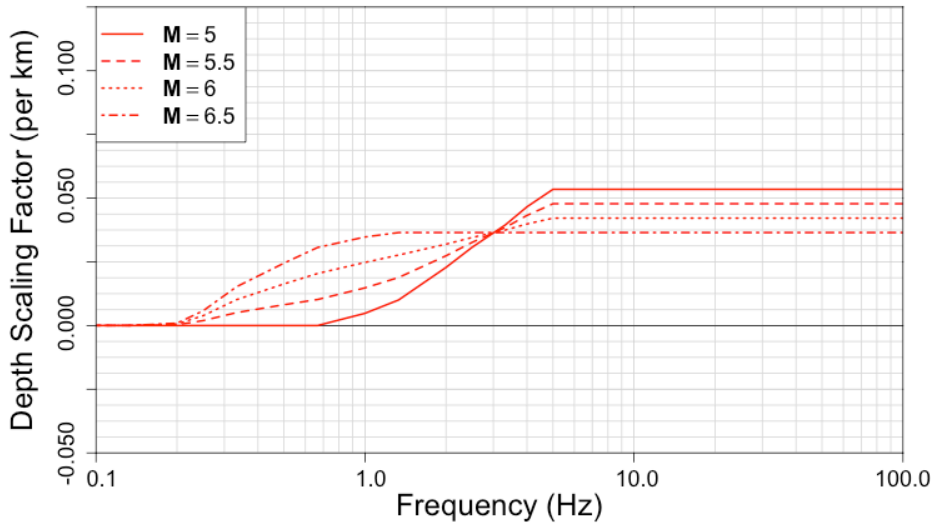
$$f_{Depth} = f_{Z_{TOR},\mathbf{M}} f_{Z_{TOR},Z}$$

- For source-depth scaling factors we adopt a simple model to incorporate the magnitude dependence

$$f_{Z_{TOR},\mathbf{M}} = \begin{cases} b_1 & \mathbf{M} \le 5.0 \\ b_1 + \frac{b_2(\mathbf{M}-5.0)}{1.5} & 5 < \mathbf{M} \le 6.5 \\ b_1 + b_2 & 6.5 < \mathbf{M} \end{cases}$$

- b_1 and b_2 are frequency dependent.

Proposed Source-Depth Scaling



Proposed Centering

$$f_{Depth} = f_{Z_{TOR},\mathbf{M}} f_{Z_{TOR},Z}$$

- For centering Z_{TOR} we …

Unused

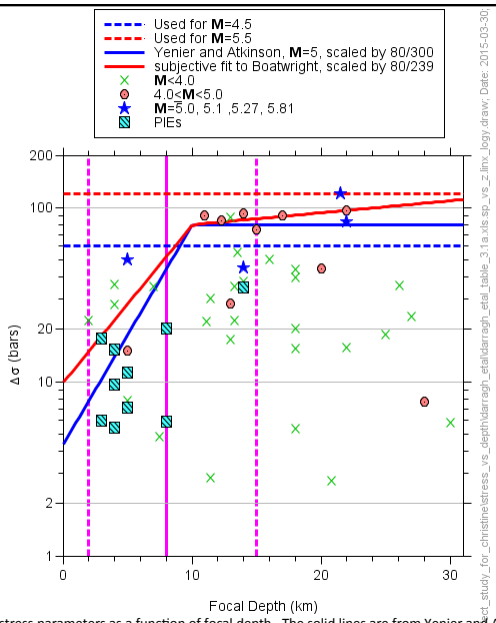
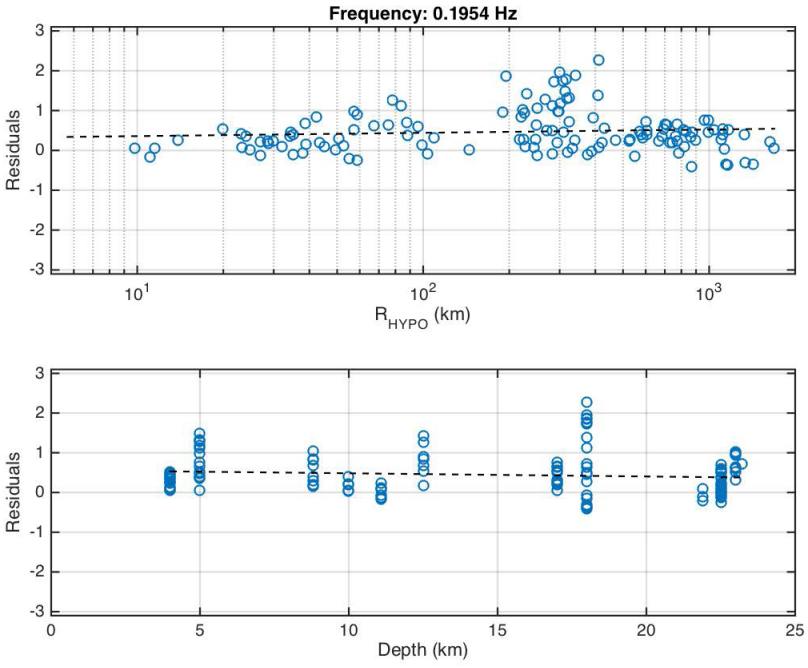


Figure 10. Darragh et al.'s stress parameters as a function of focal depth. The solid lines are from Yenier and Atkinson for **M**=4 and a subjective fit by me to Boatwright's values for eastern Quebec. Those lines were adjusted downward by the indicated factors to account for the differences in the seizes of . The horizontal dashed lines are values in Darragh et al.'s depth-dependent model for two magnitudes; the vertical magenta lines show the range of depths used in Darragh et al.'s simulations (but they did not allow any depth dependence of in their simulations—see caption to Figure 8).



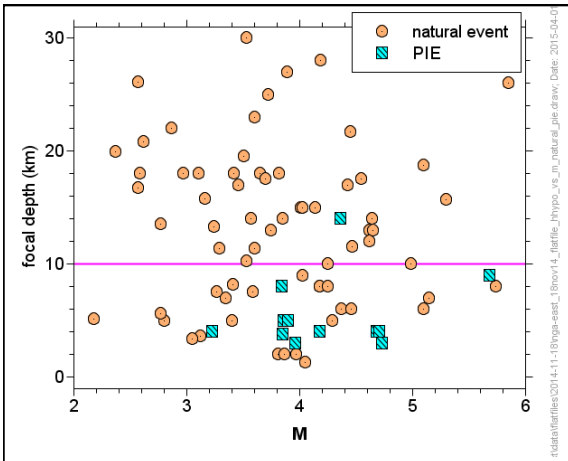


Figure 18. Focal depth—magnitude scatterplot for events in the 18 November 2014 NGA-East flatfile.

Source-Depth Models

- CB14

$$f_{Depth} = f_{Z_{HYP},H} f_{Z_{HYP},\mathbf{M}}$$

$$f_{Z_{HYP},H} = \begin{cases} 0 & Z_{HYP} \le 7 \\ Z_{HYP} - 7 & 7 < Z_{HYP} \le 20 \\ 13 & Z_{HYP} > 20 \end{cases}$$

$$f_{Z_{HYP},M} = \begin{cases} c_{17} & \mathbf{M} \le 5.5 \\ \left[c_{17} + \left(c_{18} - c_{17} \right) \left(\mathbf{M} - 5.5 \right) \right] & 5.5 < \mathbf{M} \le 6.5 \\ c_{18} & \mathbf{M} > 6.5 \end{cases}$$

Source-Depth Models

- CY14

$$f_{Depth} = f_{Z_{TOR},\mathbf{M}} \Delta Z_{TORi}$$

$$f_{Z_{TOR},\mathbf{M}} = \left\{ c_7 + \frac{c_{7b}}{\cosh\left(2 \cdot \max\left(\mathbf{M}_i - 4.5, 0 \right) \right)} \right\} \qquad \Delta Z_{TORi} = Z_{TORi} - E\left[Z_{TOR} \right]$$

– Reverse and Oblique-Reverse

$$E\left[Z_{TOR} \right] = \max\left[2.704 - 1.226 \max\left(\mathbf{M} - 5.849, 0 \right), 0 \right]^2$$

– Strike-slip and Normal

$$E\left[Z_{TOR} \right] = \max\left[2.673 - 1.136 \max\left(\mathbf{M} - 4.790, 0 \right), 0 \right]^2$$

Source-Depth Models

- ASK14

$$f_{Depth} = a_{15}\frac{Z_{TOR}}{20}, Z_{TOR} \le 20\,\text{km}$$

$$f_{Depth} = a_{15}, Z_{TOR} > 20\,\text{km}$$

- PEER NGA-East

$$f_{Depth} = c_9\frac{Z_{HYP}}{20}$$

- Coefficients for all models are frequency dependent.

Source-Depth Scaling (**M**=8.0)