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Source and Attenuation Parameters for Induced Seismicity in the Crooked Lake Region of Alberta

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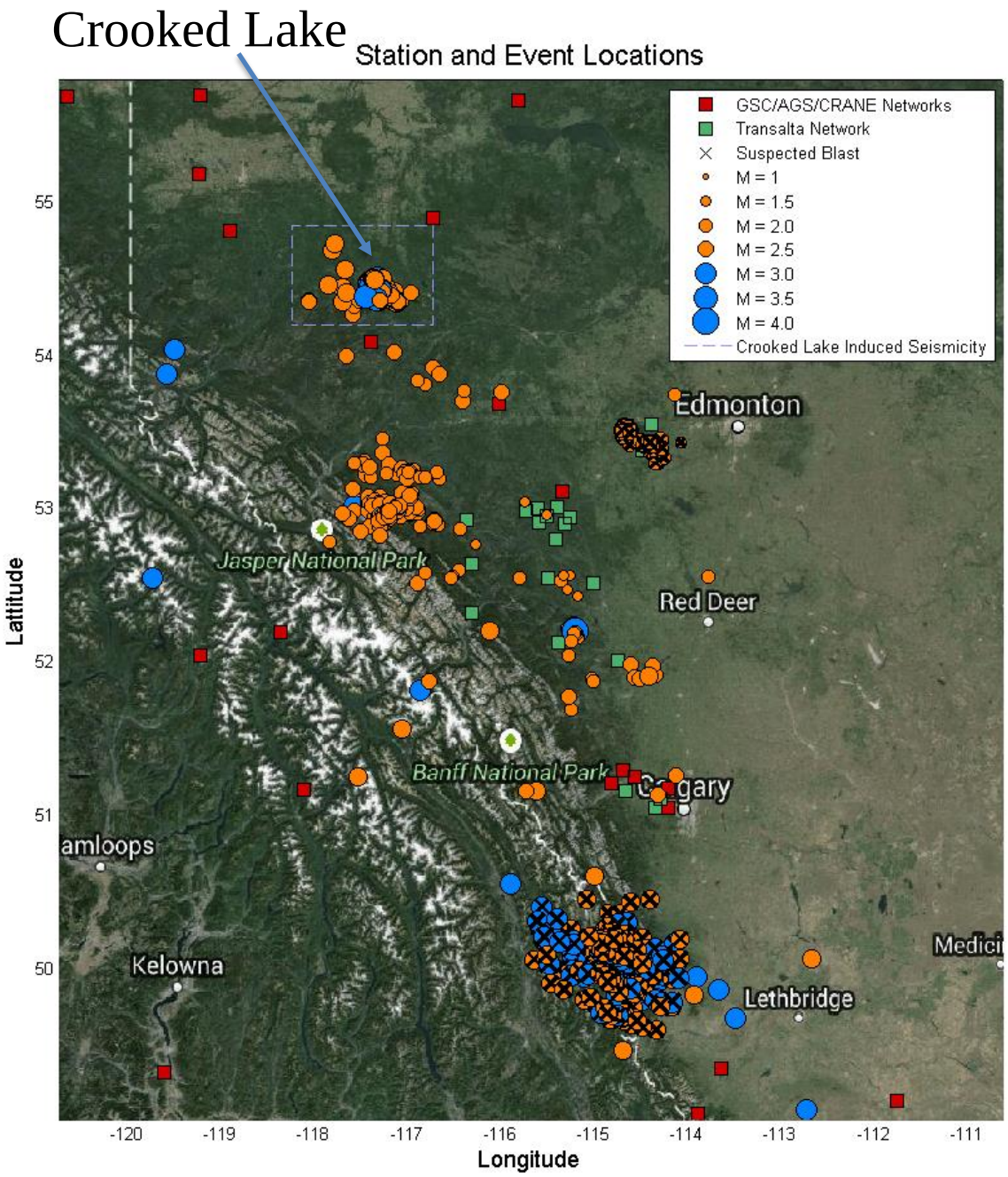
- TransAlta/NMX network installed in western Alberta starting in Sept. 2013
- Since then over 1100 events have been detected across Alberta.
- We use the ground motions from these events to analyze source/ attenuation

- Note: Events in Keep Hills to the West of Edmonton and near Elkford in the Crowsnest Pass are areas where events are suspected primarily to be blasts related to mining activity (x) (not analyzed)



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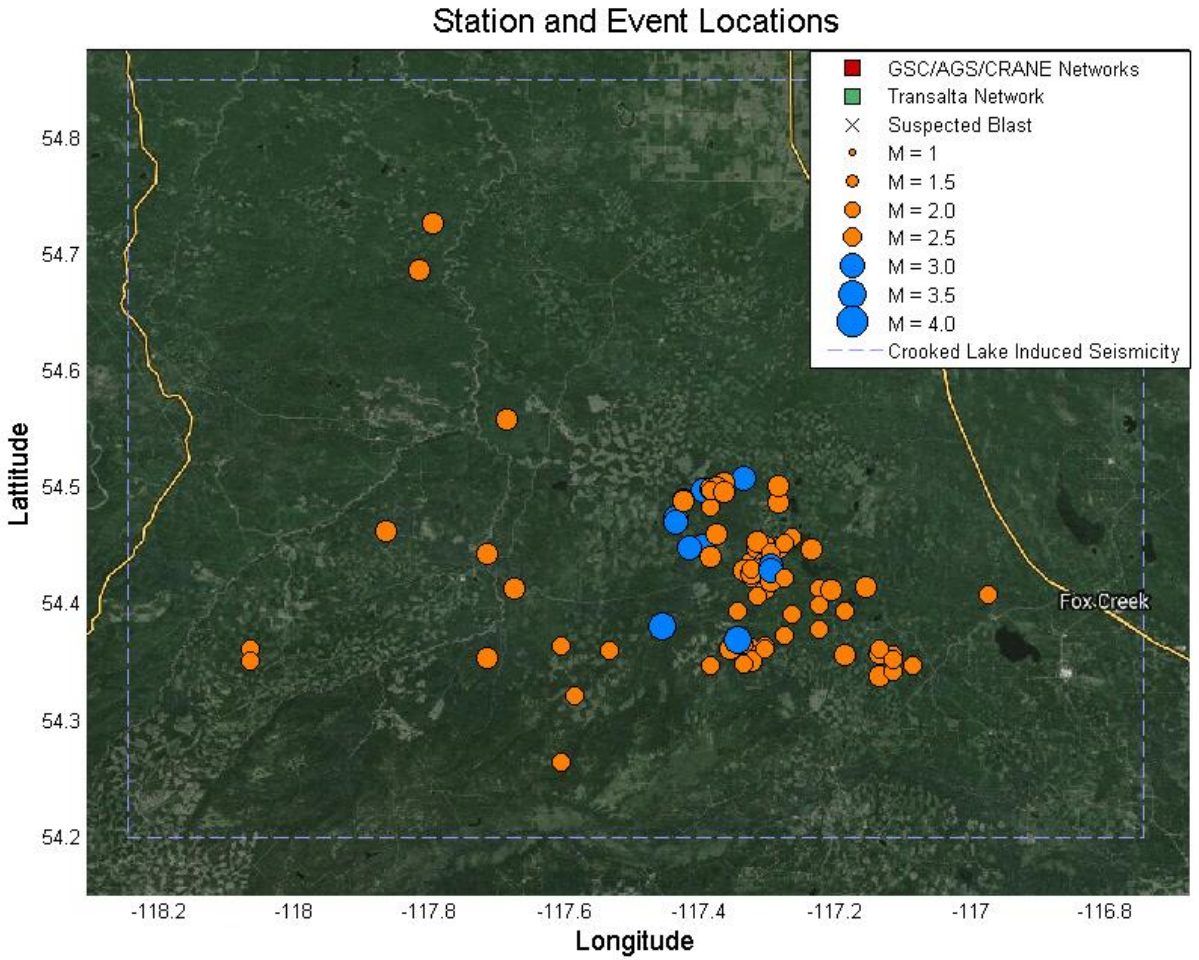
- Over 100 small earthquakes (M_w 2 – 3.5) have been detected near Crooked lake in a sequence that began in December 2013 that is ongoing to present day.
- Much of the database comes from these events
- These events have strong temporal and spatial correlation with hydraulic fracture treatments of wells in the region (Shultz et al., 2015).



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- For each event the moment magnitude (**M**) is estimated using 5% damped pseudo spectral accelerations (PSA) from the vertical component and the hypocentral distance. The Atkinson Greig & Yenier 2014 model (AGY14) is as follows:

$$\mathbf{M} = \frac{\log_{10}(\mathrm{PSA_T}) + \mathrm{C_T} + \log_{10}(\mathrm{Z(R)}) + \gamma_{\mathrm{T}}\mathbf{R}}{1.45}$$

- Where C_T is an empirical calibration term, R is hypocentral distance Z(R) is a geometrical spreading model and γ_T is the anelastic attenuation term.

$$R = \sqrt{D^2{}_{epi} + 5^2}$$

	WNA 1.00 Hz	WNA 3.33 Hz
C_T	-4.25	-3.15
γ_T	0.0035	0.004

$$log_{10}Z(R) = \begin{cases} 1.3log_{10}(R) & R \leq 50km \\ 1.3log_{10}(50) + 0.5log_{10}\left(\frac{R}{50}\right) & R > 50km \end{cases}$$

- $\mathbf{M}_{station}$ is first calculated at each station using only ground motion observations recorded within 300 km hypocentral distance from the event. The average $\mathbf{M}_{station}$ value and the standard deviation is computed and considered as an initial moment magnitude estimate, $\mathbf{M}_i$.

- **M** is then recalculated excluding stations based on the following criteria:

  i) Stations with an $\mathbf{M}_{station}$ value greater than 2σ from $\mathbf{M}_i$ are discarded

  ii) For events with $\mathbf{M}_i < 2.6$ only stations within 150 km are considered

  iii) For events with $\mathbf{M}_i \geq 2.6$ only stations within 300 km are included

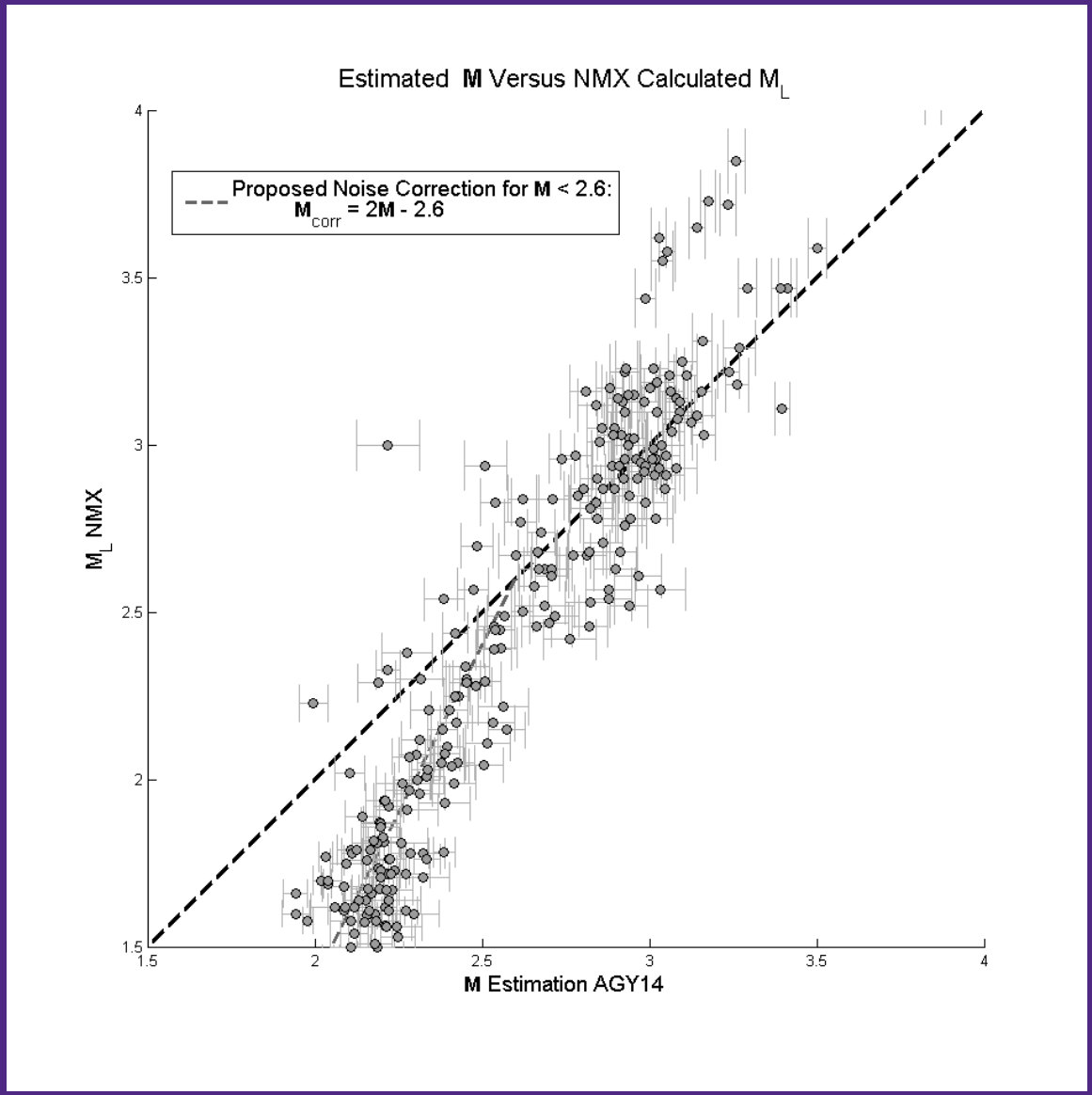
- AGY14 suggests **M** is calculated using the 1.00 Hz PSA values in general. However for events of **M** < 3 using the 3.33 Hz PSA value is preferable as it reduces noise effects that tend to inflate the 1.00 Hz amplitudes. Therefore we use a logic tree while computing **M** as follows:

- i) if **M**(1Hz) < 3 and **M**(3.33Hz) < 3; then **M** = **M**(3.33Hz);

- ii) if **M**(1Hz) ≥ 3 and **M**(3.33Hz) ≥ 3; then **M** = **M**(1.00Hz);

- iii) else; $\mathbf{M} = \frac{\mathbf{M}(1\text{Hz})+\mathbf{M}(3.33\text{Hz})}{\mathbf{2}}$

- The estimated **M** is then compared with with the local magnitude (M_L) determined by Nanometrics.
- For events with **M** greater than 2.6 there is a 1:1 relationship between the two measures.
- For events with **M** less than 2.6 a proposed empirical noise correction is applied.



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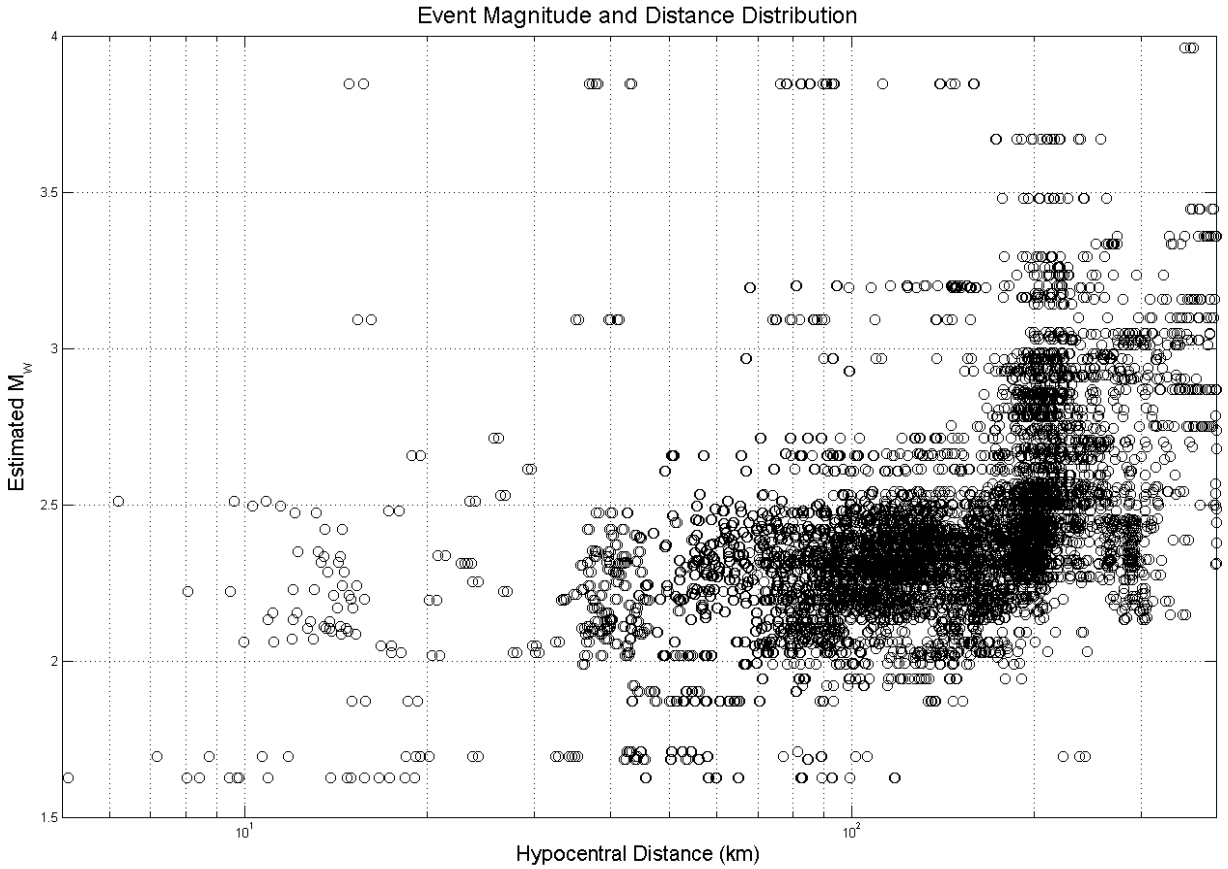

- Magnitude-distance distribution of events in the database
- Very few records at distances less than 70 km

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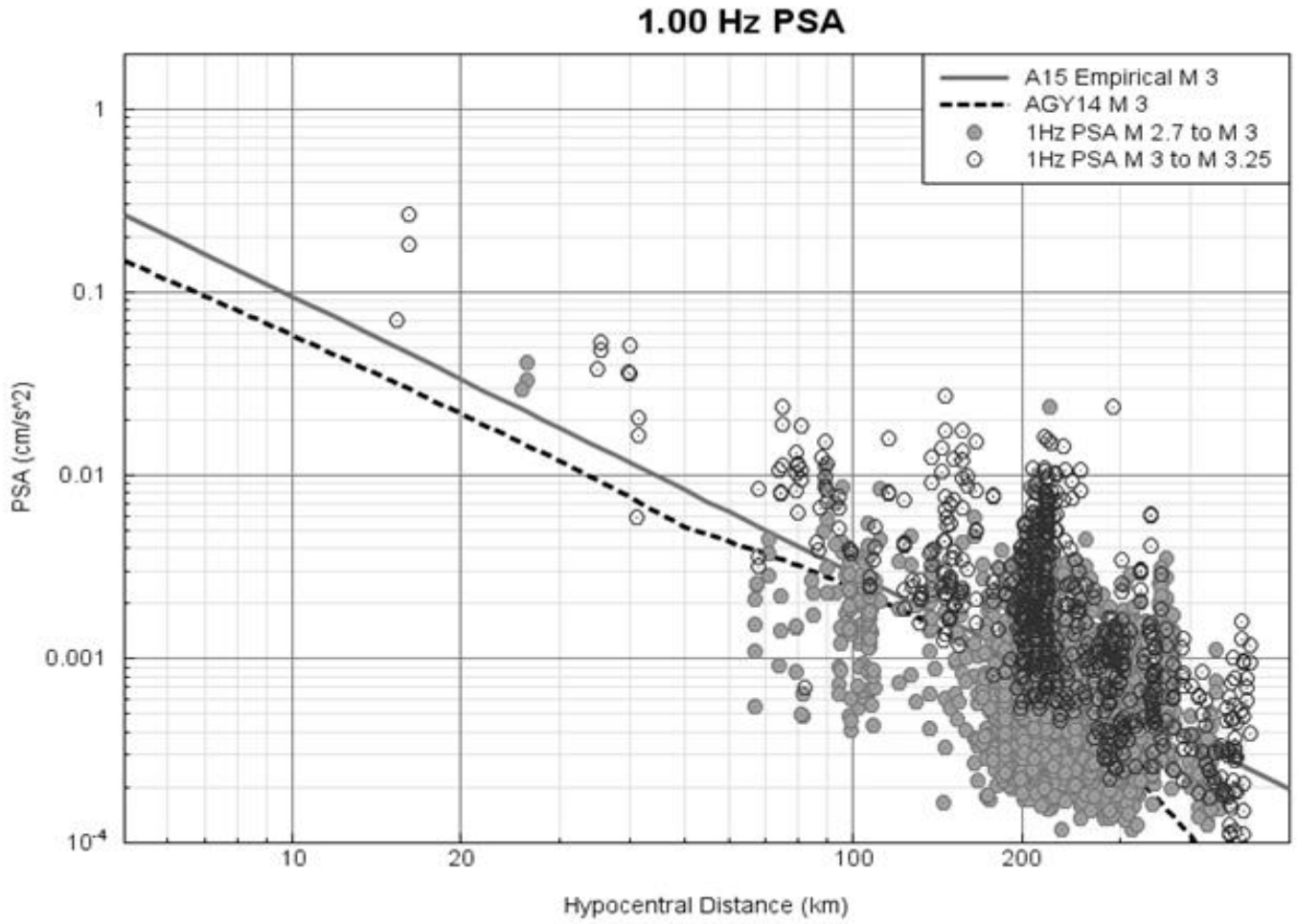

- The Atkinson 2015 (A15) empirical moment magnitude estimation model is calibrated using the NGA-West2 database.

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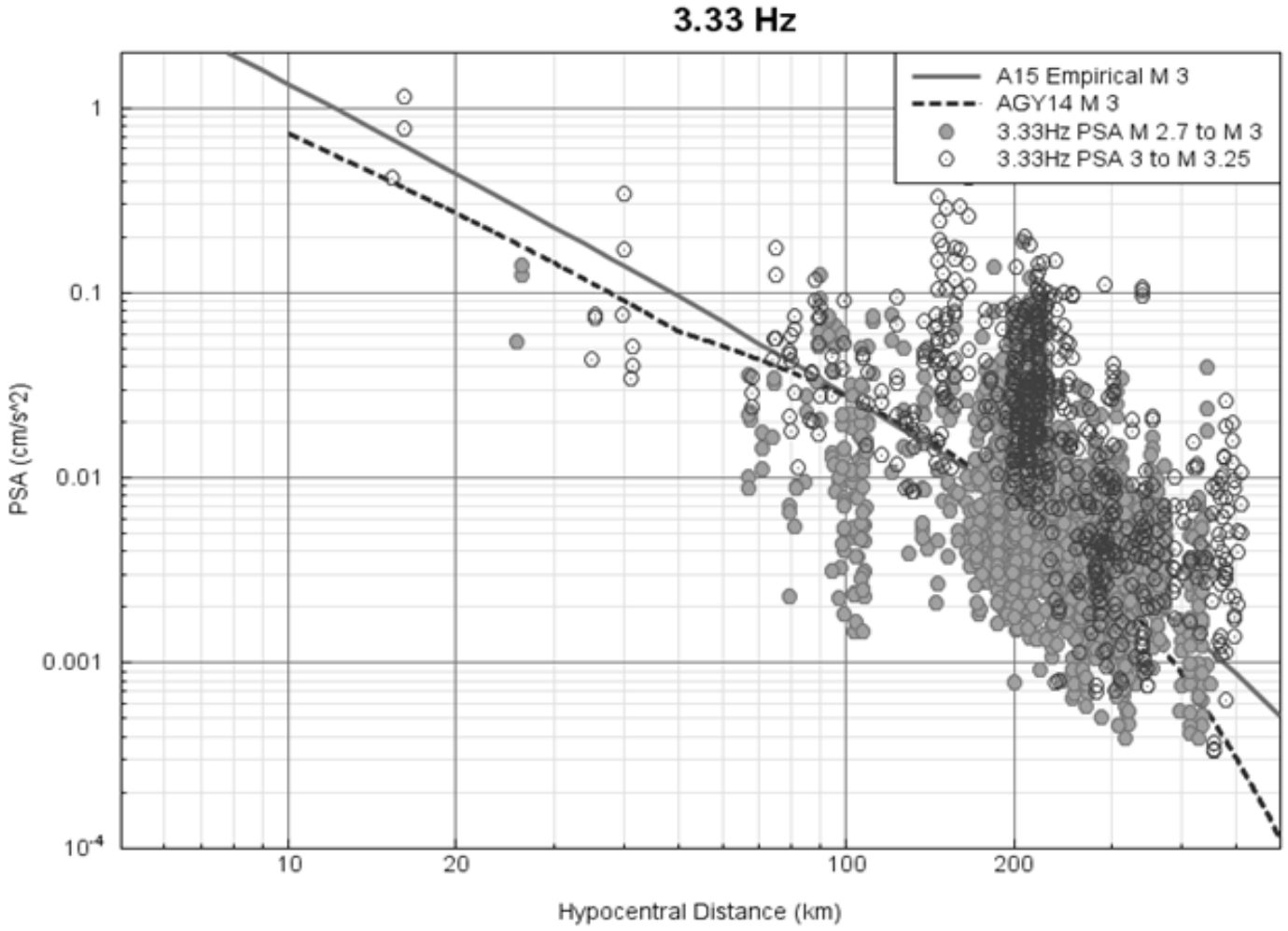
3.33 Hz
A15 Empirical M 3
AGY14 M 3
3.33Hz PSA M 2.7 to M 3
3.33Hz PSA 3 to M 3.25
PSA (cm/s^2)
1
0.1
0.01
0.001
10^-4
10
20
100
200
Hypocentral Distance (km)

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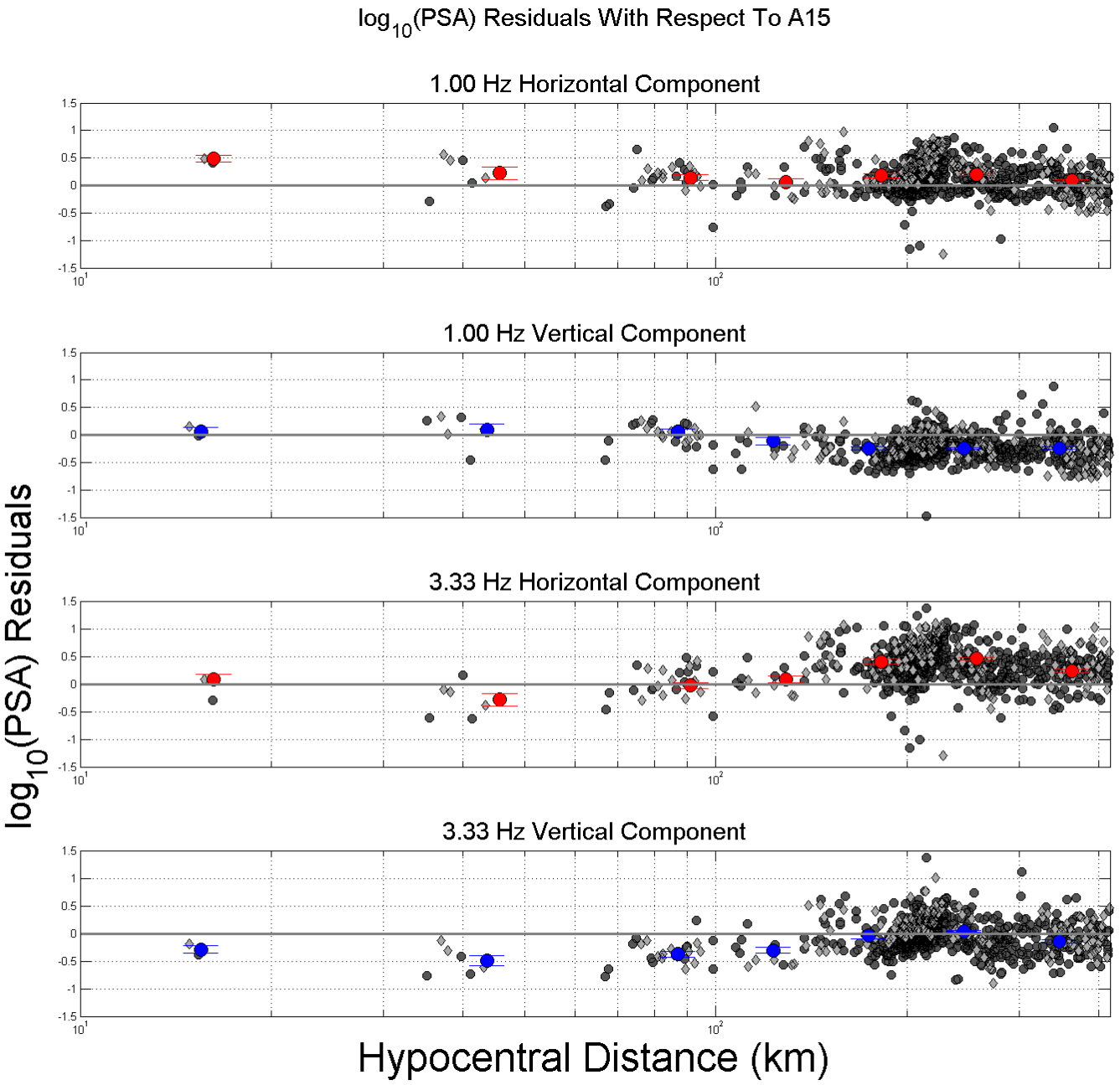
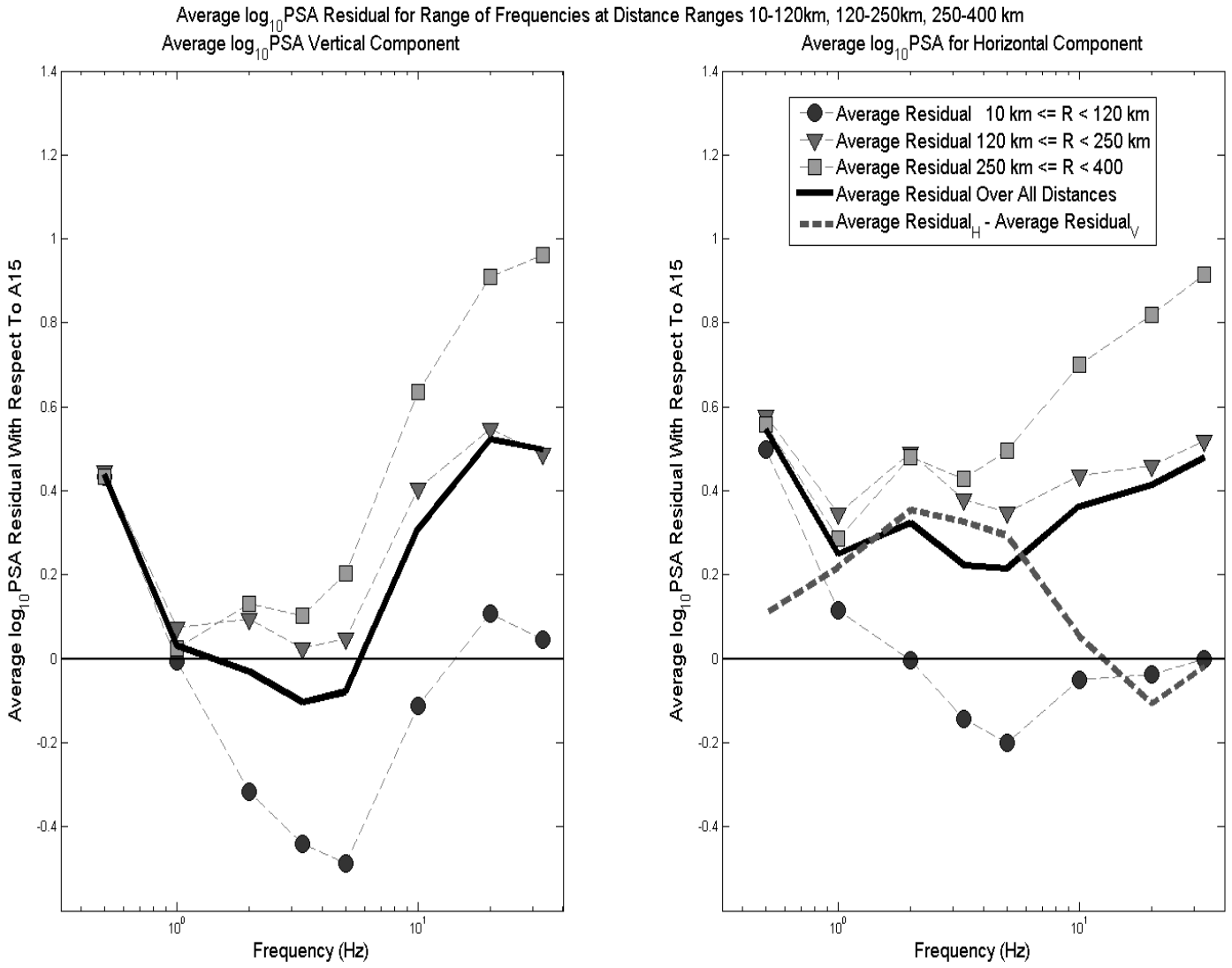
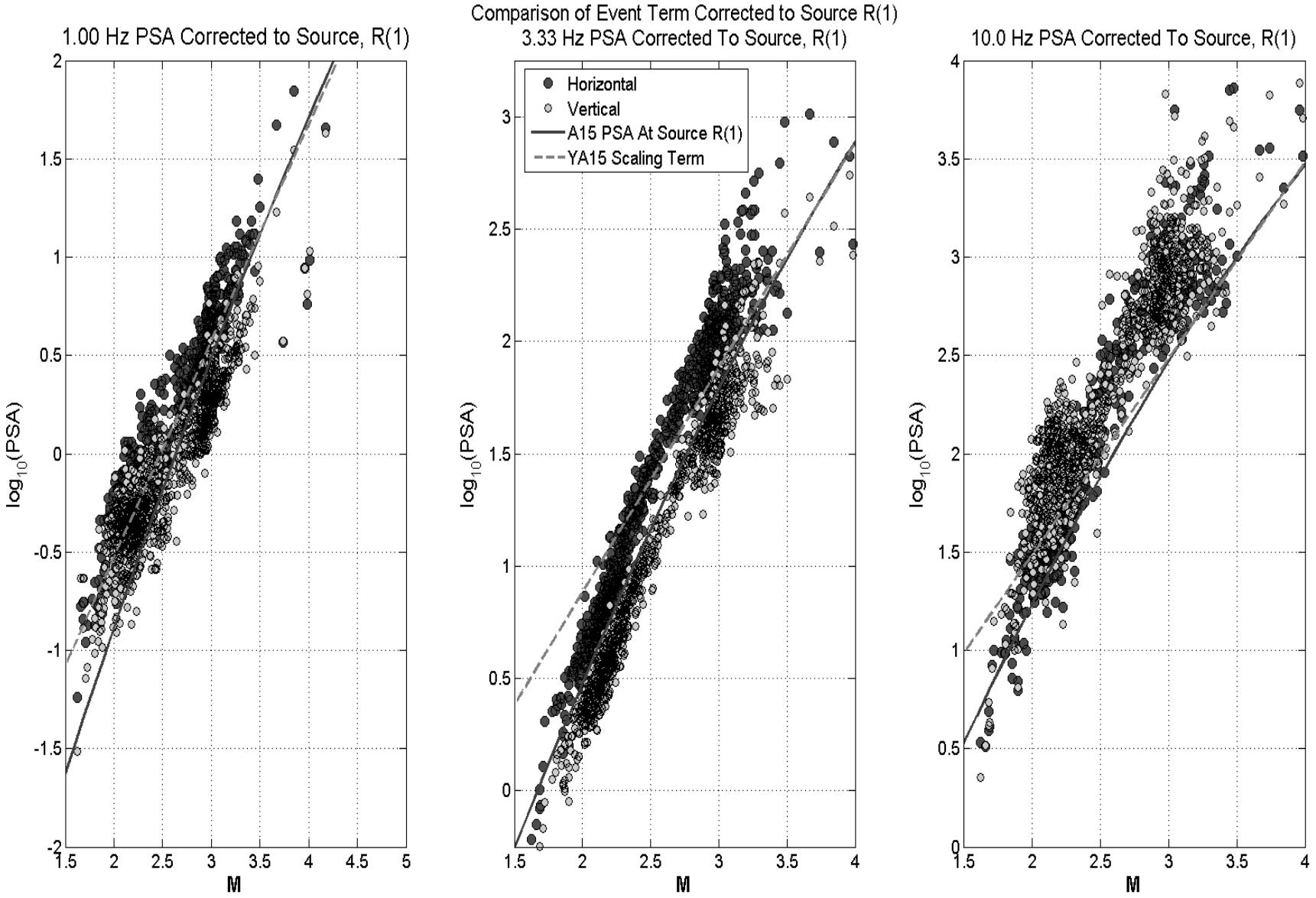


- Log Residuals (Observed-Predicted) are calculated with respect to Atkinson (2015) empirical ground-motion prediction equation for small-to-moderate events in WNA
- No site corrections have been made



- The pronounced amplification in the 2 – 5 Hz frequency band observed on most stations is consistent with expectations for relatively shallow soft soil sites underlain by hard rock.



- Ground motions at frequencies of 1.00 Hz and lower are insensitive to stress parameters in the magnitude range covered in this study. As frequency increases the stress parameter becomes more important.

Concluding Remarks

- Ground motions from small events in Alberta are generally consistent with those for similar size events in California in terms of overall amplitude level and attenuation.
- Further study on events covering a broader distance range will be required to determine the average stress parameters in this region.
- Ground motion observations at close distance, R < 50km, would be particularly valuable as well as a larger number of events overall.
- Within the 2 to 5 Hz frequency range there is a significant site response in the horizontal component. May be reasonable to model site effect terms at the stations with an overall typical site amplification curve.
- At this time it is uncertain whether focal depth effects on the stress parameter overwhelms any difference between natural and induced events.

Thank you

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