Nanometrics

Probabilistic Induced Seismicity Hazard Analysis for Fox Creek, Alberta

Emrah Yenier, Sepideh Karimi, Dario Baturan,
Gail Atkinson, Ryan Schultz, and Kristine Haug

Western University · Canada

Alberta Energy Regulator

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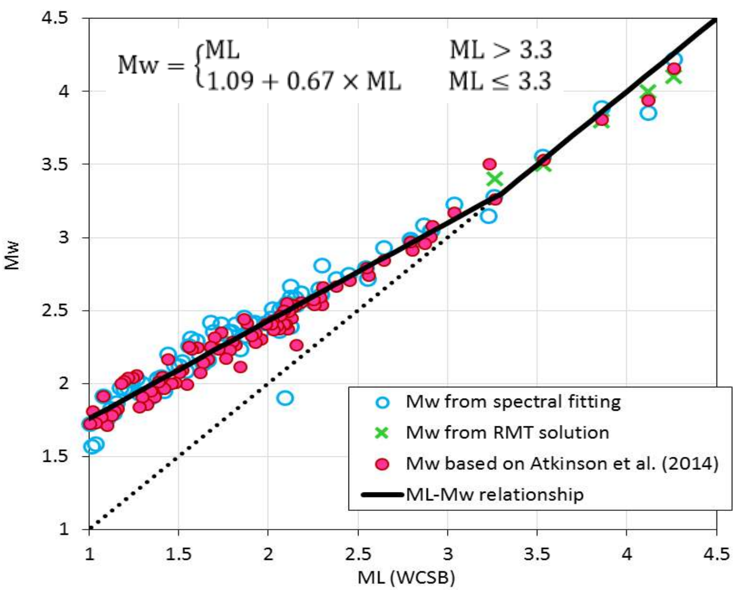
Introduction

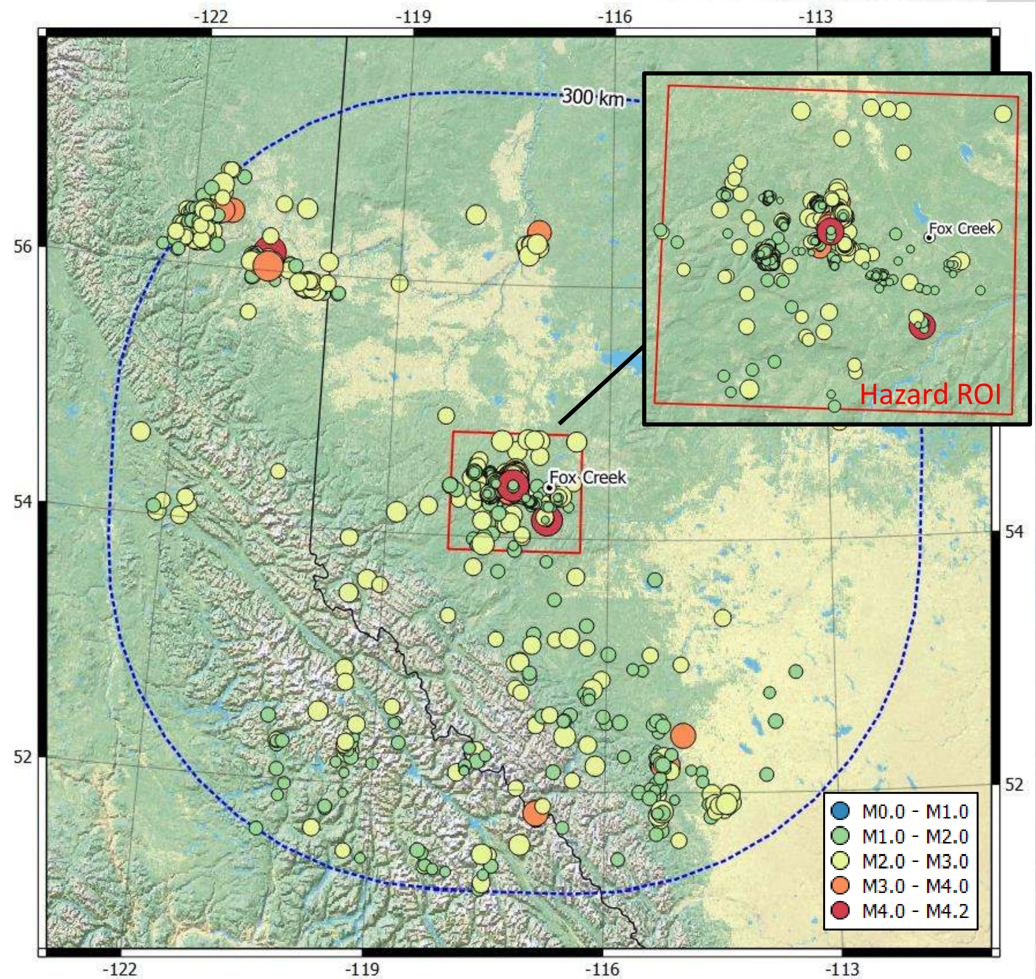
- In response to the recent seismic activity in the region, Alberta Energy Regulator (AER) has put in place staged protocols to mitigate risks associated with induced seismicity. AER also started a project to conduct a preliminary study on the probabilistic seismic hazard analysis (PSHA) of induced seismicity in Fox Creek region.
- Seismic hazard from induced earthquakes differs from tectonic events due to its complex relationship to hydrocarbon production, economic forces and public policy decisions.
- In this study, spatio-temporal attributes of induced events are approximated by performing probabilistic hazard analysis on an annualized basis, assuming a Poisson process. Hazard maps are generated by combining uncertainties in earthquake location, magnitude, frequency and ground motions.
- The study resulted in annual induced seismicity hazard maps for peak ground acceleration and response spectra at periods of engineering interest for alternative annual rates of exceedance (0.2% and 0.04%).

Induced Seismicity Catalog

Compiled from regional public (~Mc2) and local private (~Mc1) arrays within 300km of Fox Creek:

- January 2013 – February 2016
- For duplicates, origin info of local events is obtained from the associated local network
- Blast events (based on event timing and proximity to active quarries/mines) are excluded
- Event magnitudes are first determined based on WCSB ML model (Yenier, 2016), which are then converted to Mw based on a regional ML-Mw relationship.



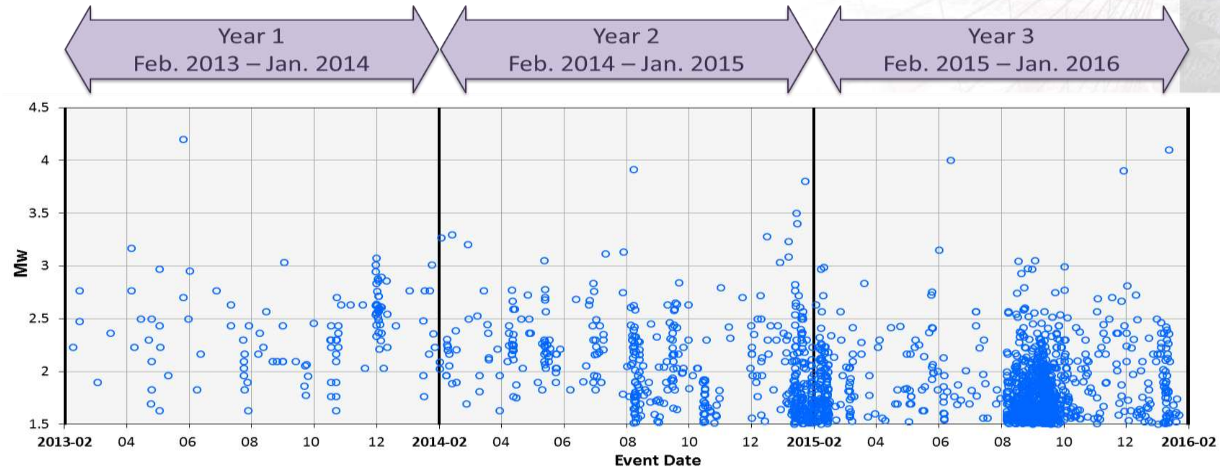


Temporal Induced Seismicity Zones

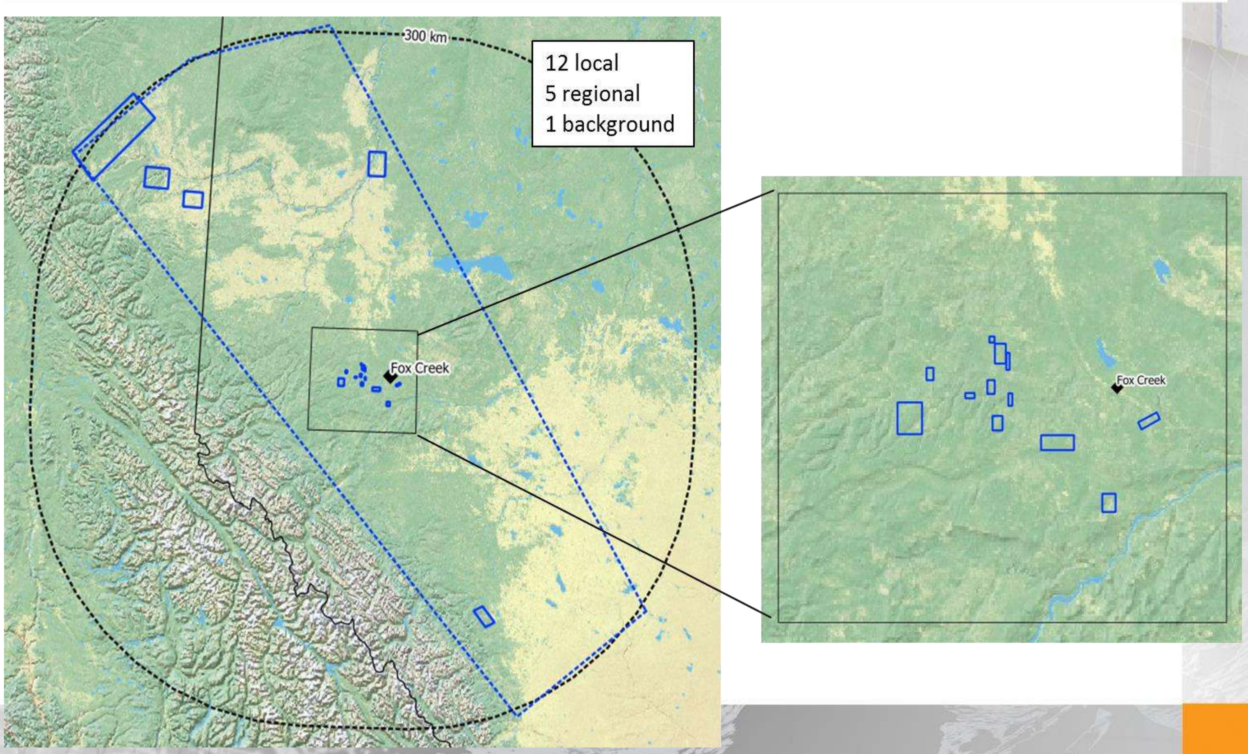
Earthquake catalog is divided into 3 consecutive one-year time windows, and hazard is calculated for each year separately.

Observed seismic sequences are examined in time and space domains to understand the spatio-temporal attributes of induced seismicity.

Each sequence is modeled as a separate induced source zone with associated recurrence parameters.



Induced seismic zones for 2015



Recurrence Relationships

Three classes of b-values are identified, considering the overall spread of magnitude recurrences that are normalized to attain N(M≥1.5)=100:

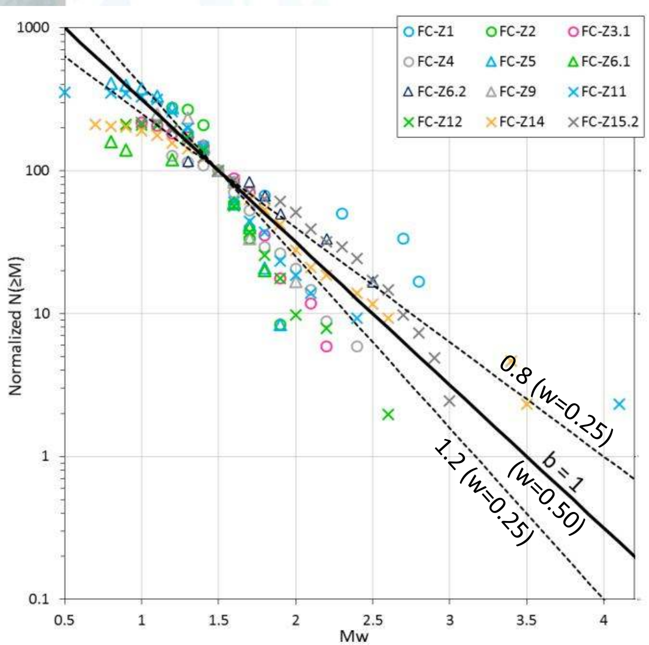
- Default (b = 1.0, standard tectonic value)
- Mild (b = 0.6)
- Steep (b = 1.6)

A stronger emphasis is given on the default b-value, unless there is a compelling evidence for steep or mild b-value:

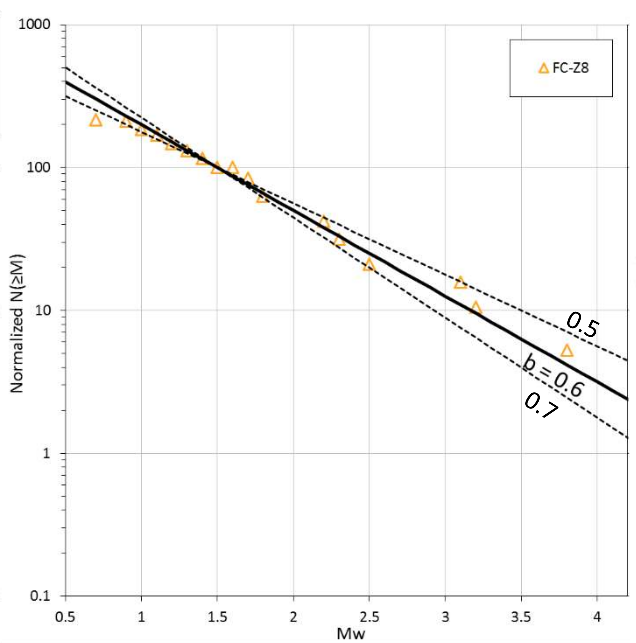
- Significantly small likelihood of observed N(M≥2.5) relative to its expected value estimated from observed N(M≥1.5) based on the default b=1 assumption.

A low and high branches are defined for each b-value class to account for the epistemic uncertainty.

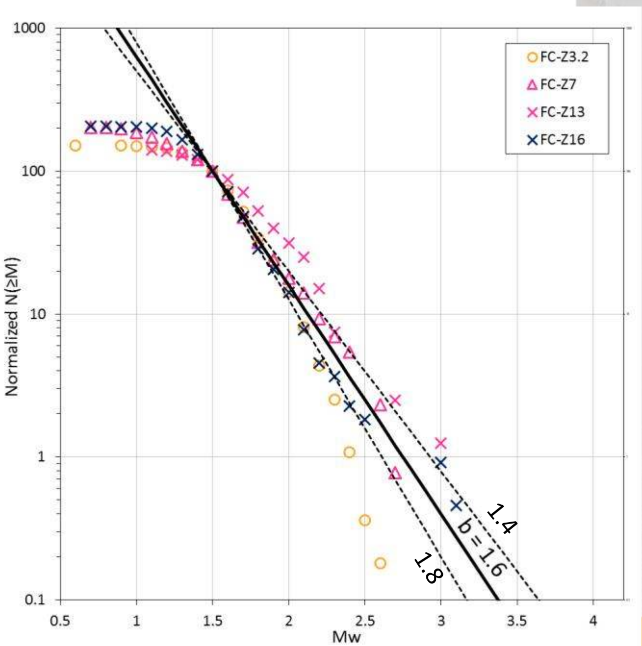
Default (b = 1.0)



Mild (b = 0.6)



Steep (b = 1.6)

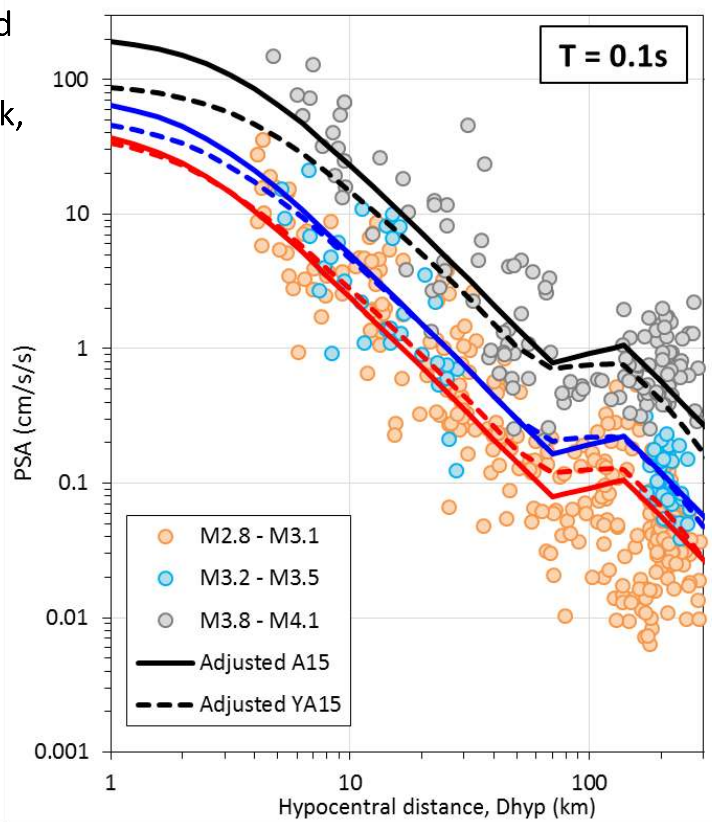


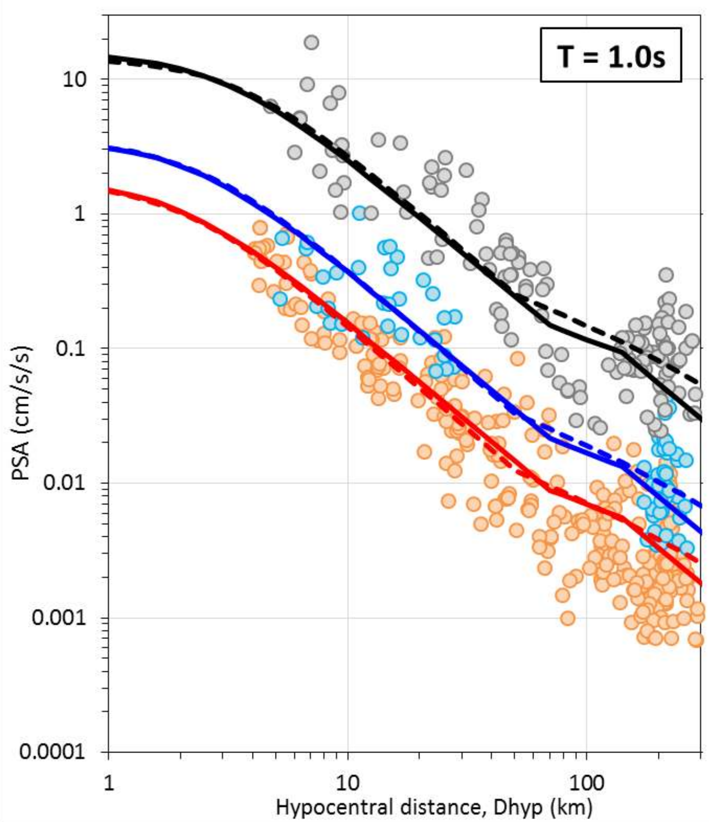
GMPE Suite

Two alternative published GMPEs (Atkinson 2015; Yenier and Atkinson 2015) are adjusted for the regional source and attenuation attributes, using the referenced empirical approach (Atkinson, 2008).

$$\log Y_{Fox\ Creek} = \log Y_{Host} + \Delta C_0 + \begin{cases} 0 & R < 70\text{km} \\ \Delta b \log(R/70) & 70 \leq R < 140\text{km} \\ \Delta b \log(140/70) & R \geq 140\text{km} \end{cases}$$

GMPEs are developed for the average site condition in Fox Creek, which is assumed to be NEHRP D.





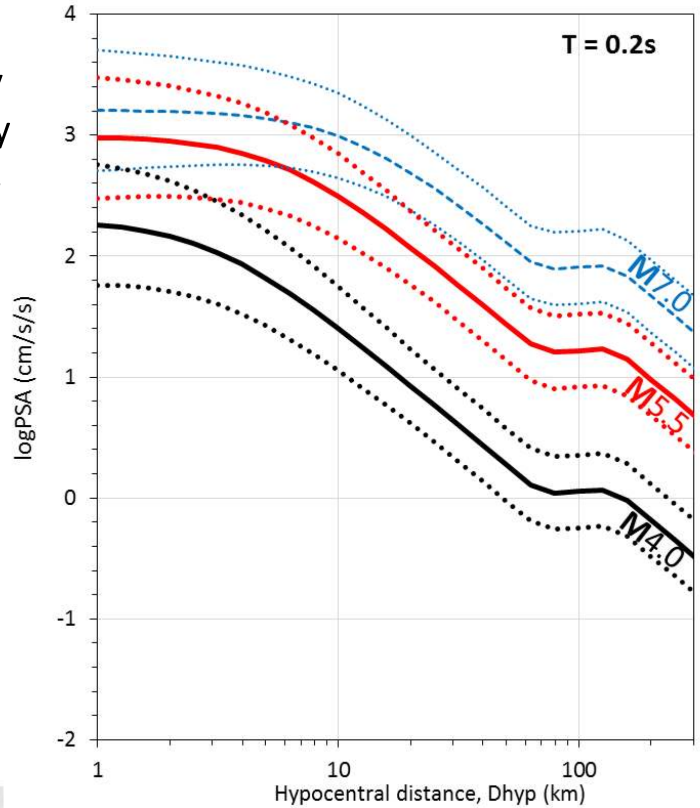
GMPE Suite

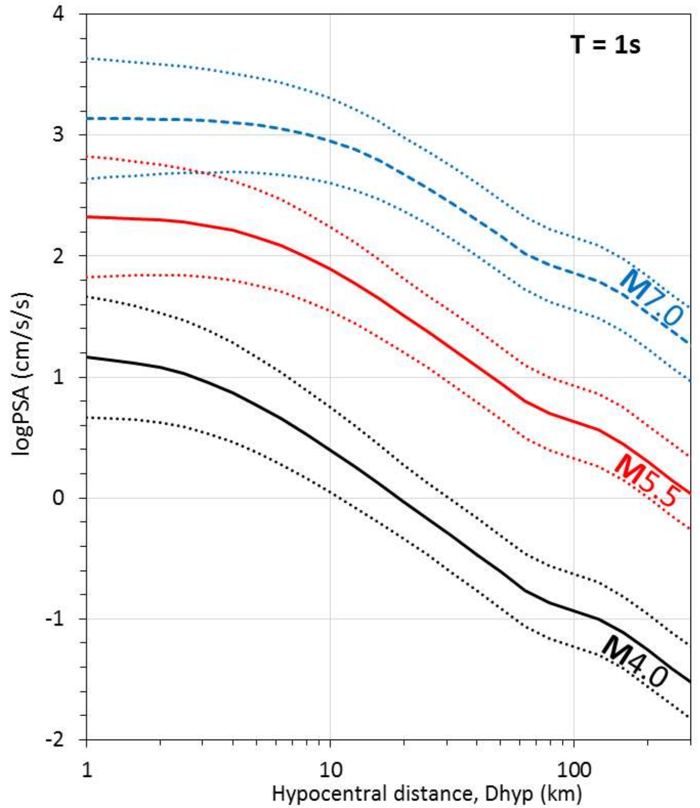
The adjusted A15 model is chosen as the center branch (w=0.50) for the GMPE suite due to its better agreement with the observed amplitudes.

Lower (w=0.25) and upper (w=0.25) GMPE branches are defined in a way that

- The epistemic uncertainty (Δ) is not less than that considered in NBCC for WNA models
- Branches wide enough to capture the discrepancy between adjusted YA15 and A15 models
- Branches accommodate the ground motion residuals at short distances
- Recognized problem in extrapolation to M>6 to be resolved in future studies

Aleatory uncertainty (σ) recommended by Atkinson and Adams (2013) for NBCC is adopted.



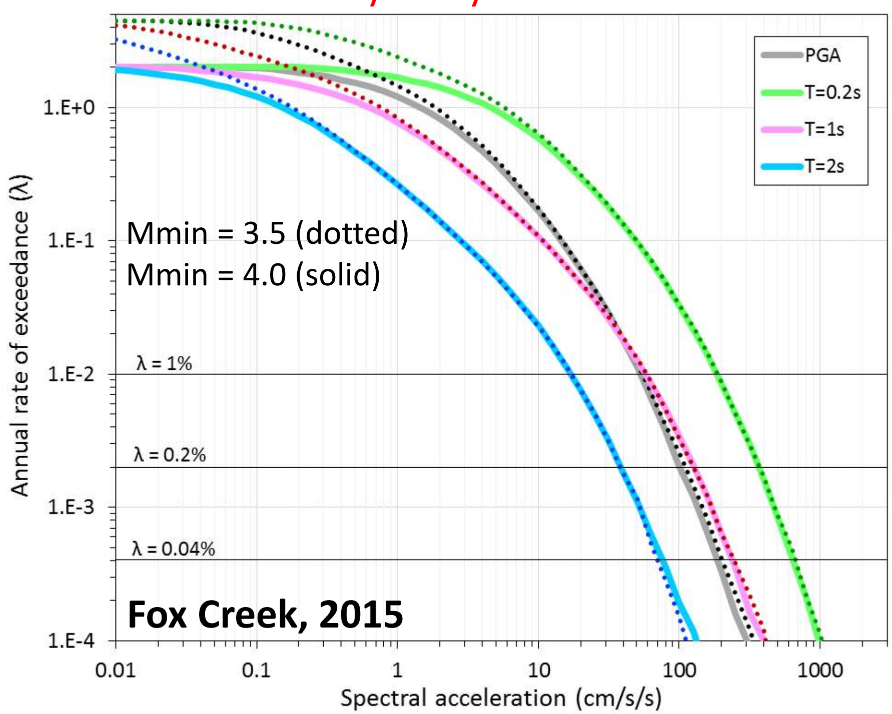


Hazard Analysis

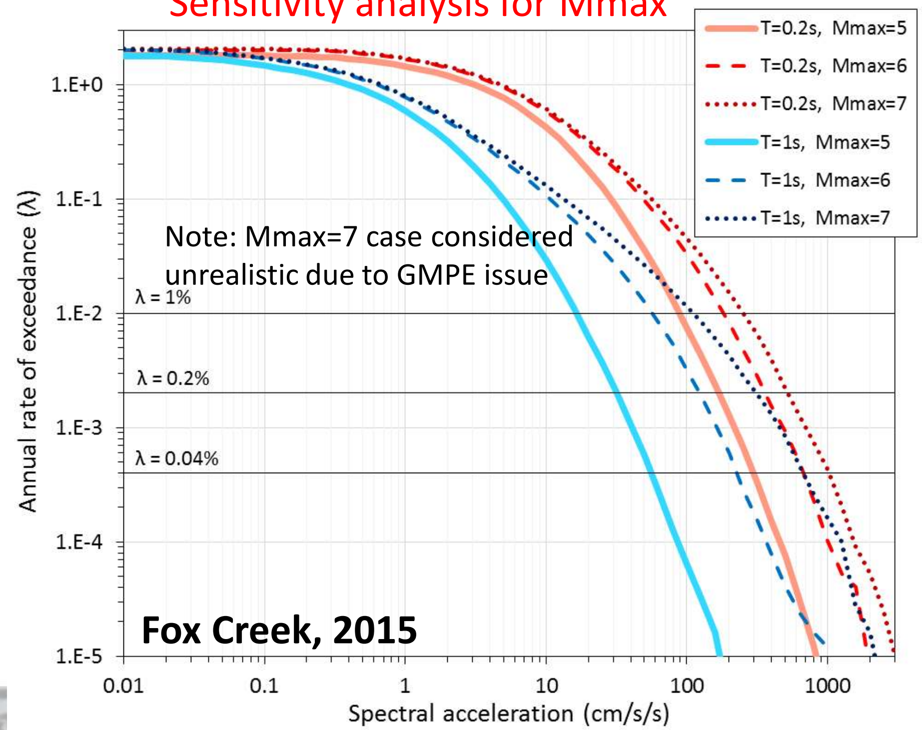
- Spatio-temporal patterns of induced events depend on economic forces and public policy decisions.
- To capture this non-stationary behavior, annual hazard analysis is conducted for 2013, 2014 and 2015, considering the induced seismic zones within each year via Monte-Carlo simulation technique.
- An open-source software, EqHaz (Assatourians and Atkinson, 2013) is used for the analysis.

Parameter	Value
Minimum magnitude, M_{min}	M4.0 (1.0)
Maximum magnitude, M_{max}	Center: M6.0 (0.5) Low: M5.0 (0.3) High: M7.0 (0.2)
Source depth, d	Center: 3.5 km (0.6) Low: 2.5 km (0.2) High: 4.5 km (0.2)

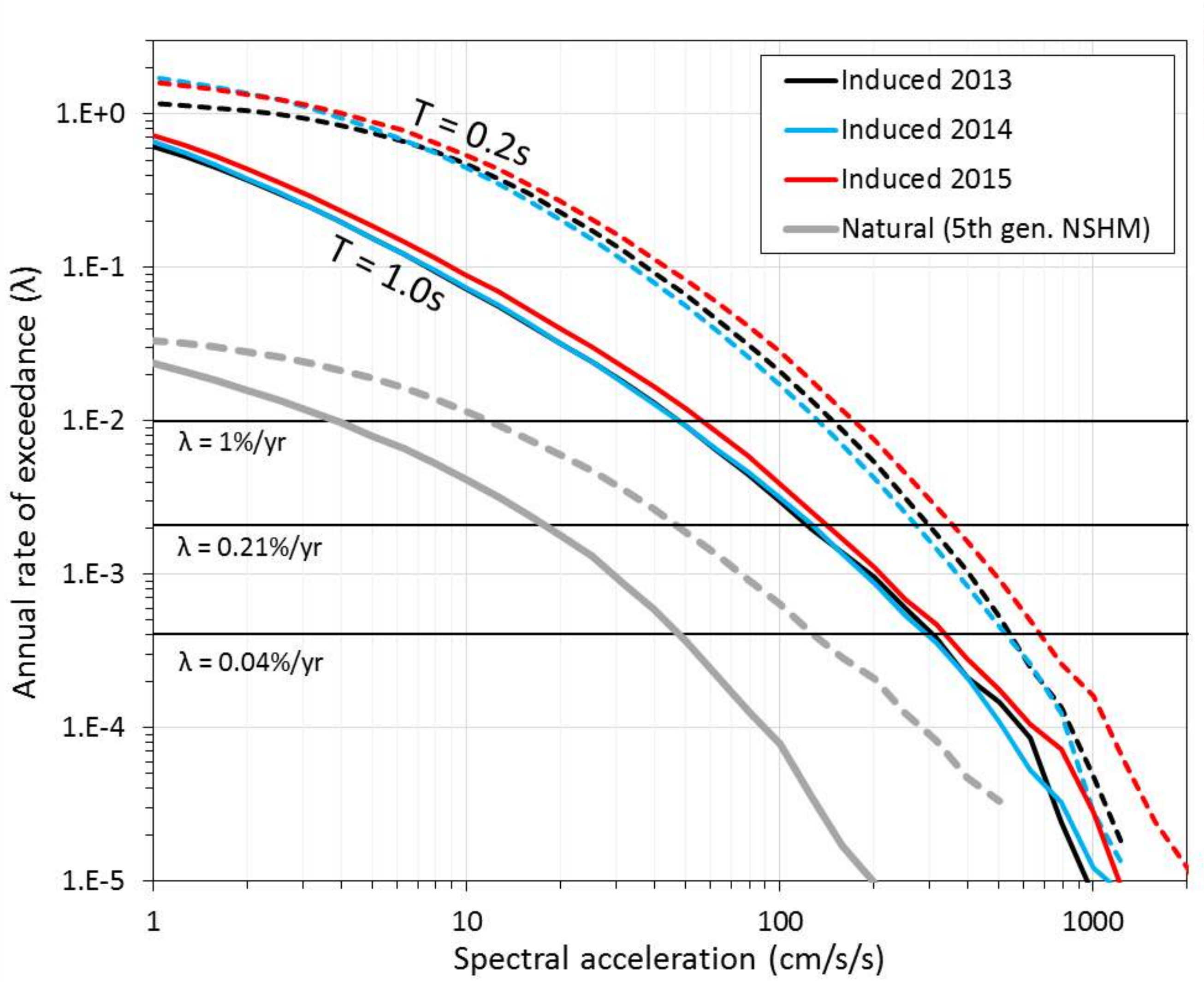
Sensitivity analysis for Mmin



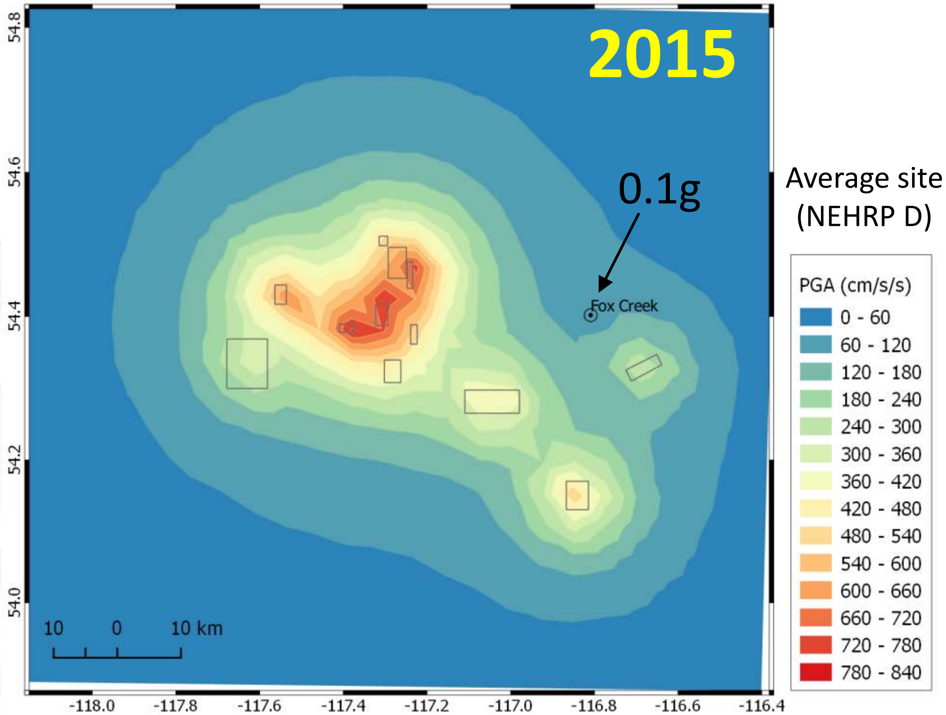
Sensitivity analysis for Mmax

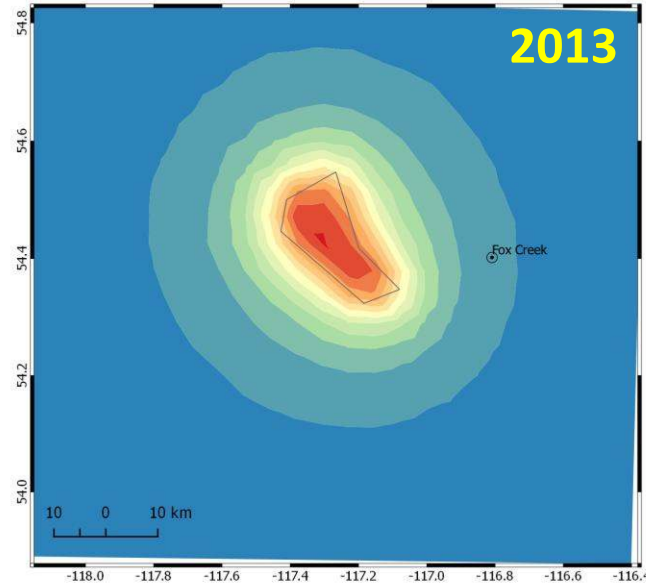


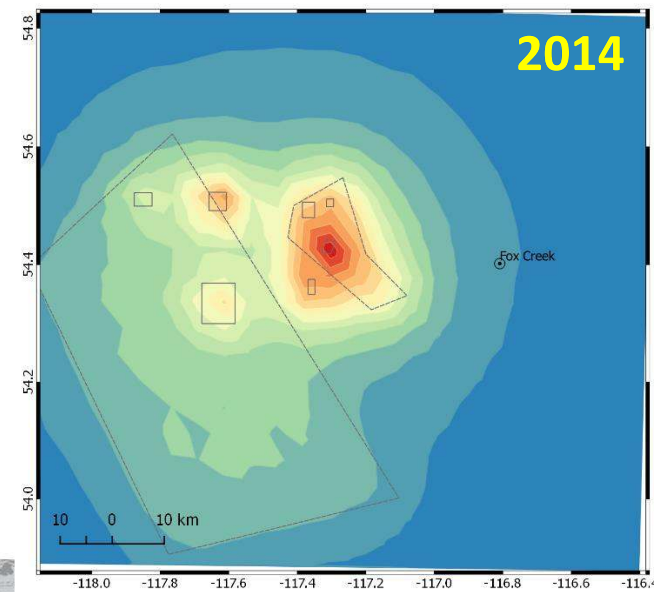
Hazard Curves for Fox Creek

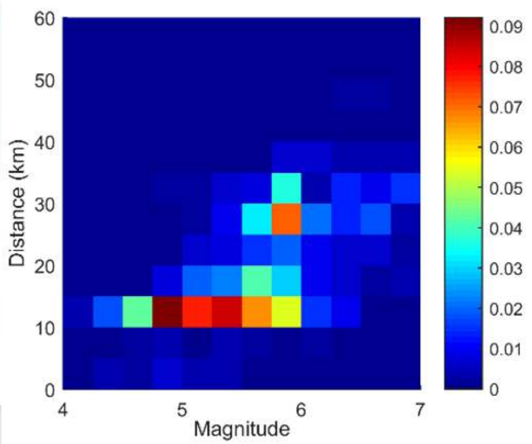


Hazard Maps: PGA (0.2%/yr)









Deaggregation of induced seismic hazard for Fox Creek (2015 PGA, 0.2%/yr)

Summary

- A preliminary probabilistic seismic hazard analysis is conducted for induced earthquakes near Fox Creek.
  - Spatial-temporal variation of induced seismicity is mimicked by modeling observed seismic sequences in annually-binned catalogs and performing a separate hazard analysis for each year.
  - A GMPE suite is developed from two regionally-adjusted predictive models that match the overall amplitude and attenuation attributes of the observed ground motions.
  - A logic-tree approach is adopted to account for uncertainties in maximum magnitude, focal depth, magnitude recurrence relations and ground motion estimates.
- Sensitivity analysis indicated that hazard estimates are largely depend on Mmax.
- Overall hazard level is dominated by induced seismicity, which attains much larger annual rate of occurrences (1-2 order of magnitude) than the background natural seismicity.
- PGA at the town of Fox Creek is 0.1g and 0.2g for 0.2% and 0.04% annual rate of exceedance.
- Deaggregation of the seismic hazard suggests much of the estimated hazard due to the potential occurrence of M>5 earthquakes.
- Refinement of some elements needed in future studies

Thank You