TransAlta Workshop, Oct. 27 2016: Induced-seismicity hazard for critical infrastructure and the effect of exclusion zones

Gail Atkinson

(with acknowledgement to many collaborators, especially Ghofrani and Assatourians)

NSERC/TransAlta/Nanometrics Research Chair in Hazards from Induced Seismicity

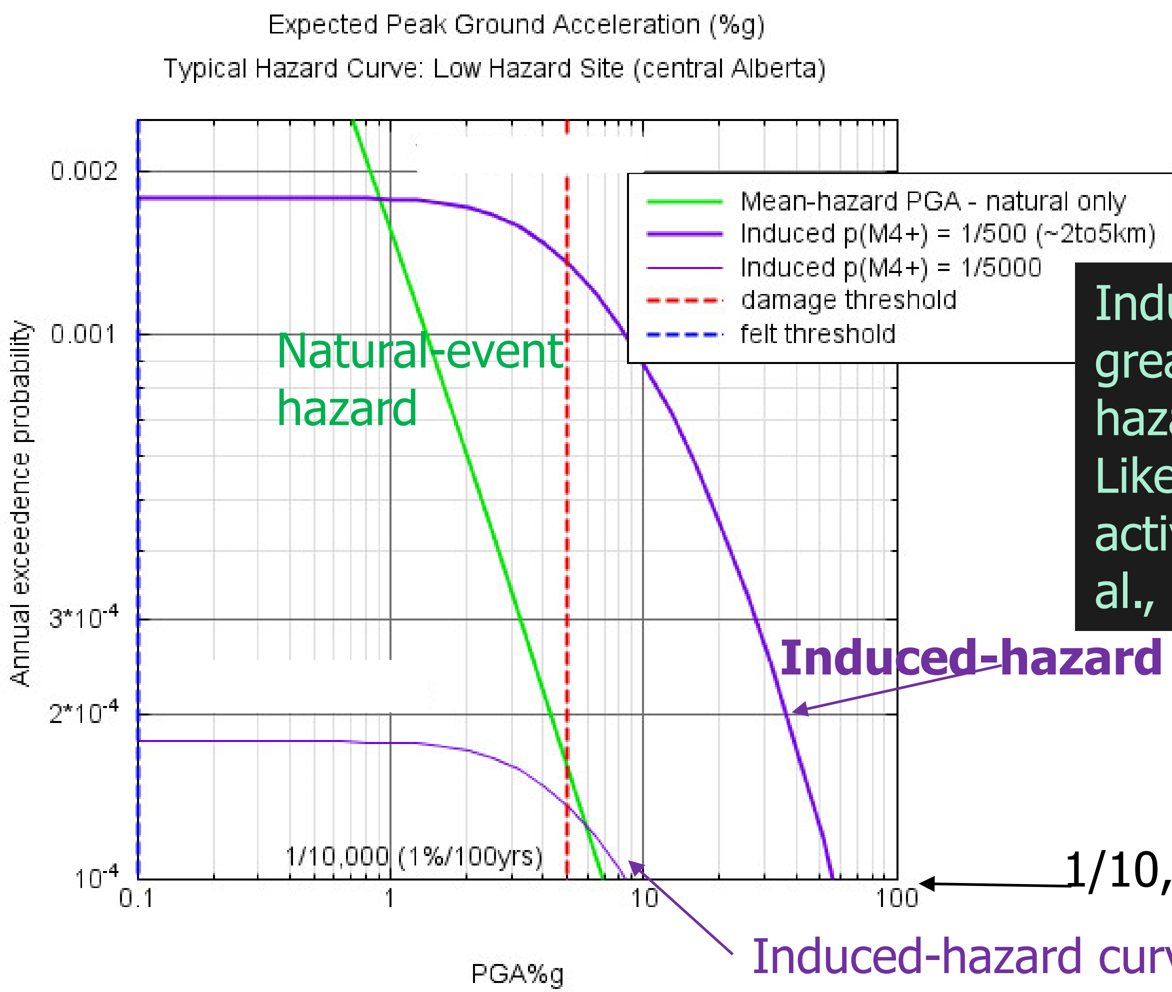
Western UNIVERSITY · CANADA

Overview

- Motivation: effect of induced seismicity from hydraulic fracturing on hazard at low probabilities
- Analysis of Hazard from events triggered by hydraulic fracture wells (HF wells)
- Ground Motions from Induced Events and their variability
- Effect of exclusion zones on hazard
- Discussion/Conclusions

Motivation:

Preliminary comparison of natural vs. induced seismicity hazard -PGA (central Alberta, operation at 2 to 5 km, with assumed likelihood of ~1/500 to 1/5000 for inducing a cluster that produces 1 or more **M**>3. Hazard calc with Mmin>4 (G-R b-value=1, Mmax in the range from 4.5 to 6.0); Atkinson, Ghofrani and Assatourians, 2015



Induced-seismicity hazard may greatly exceed natural-seismicity hazard in low-hazard area. Likelihood of inducing anomalous activity is critical. (Atkinson et al., 2015, SRL

Induced-hazard curve IF likelihood is 1/500

1/10,000 p.a. safety target for dams

Induced-hazard curve IF likelihood is 1/5000

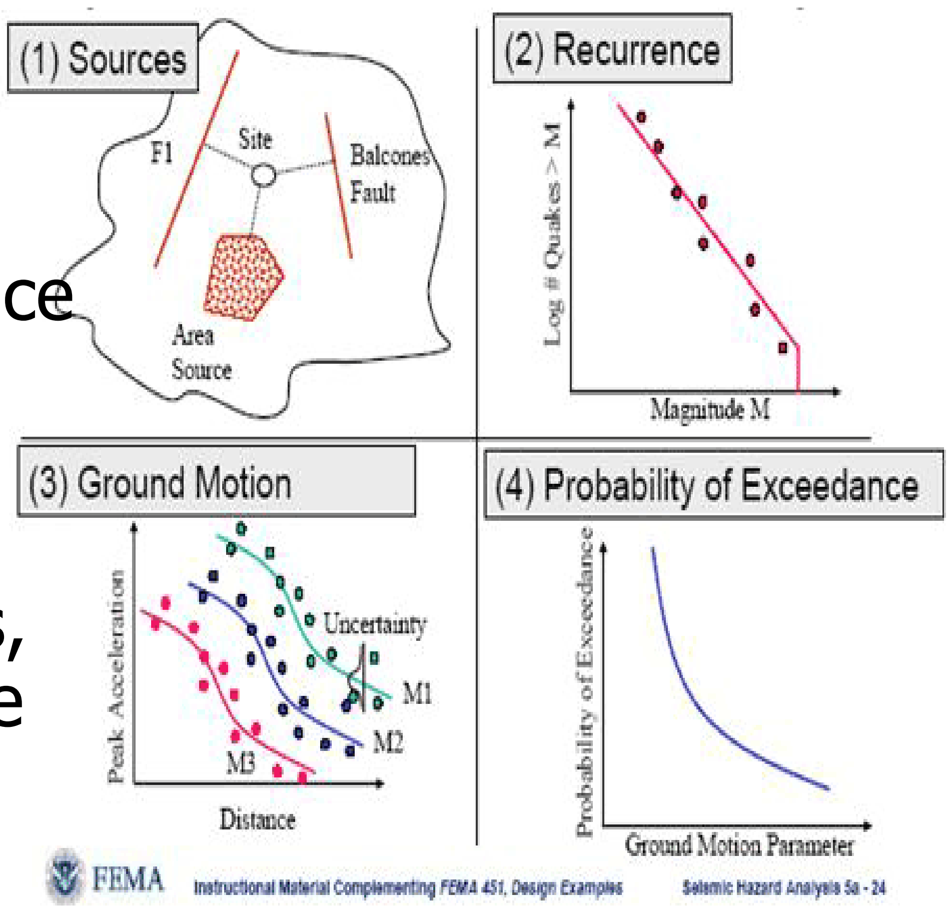
Seismic hazard assessment
– based on a target structural reliability that is keyed to the consequences of failure

- 1/2500 per annum (= 2% in 50 years) for building code (NBCC)
- 1/10,000 p.a. (=1% in 100 years) for dams and most other critical structures (CSA, CDA, etc.)

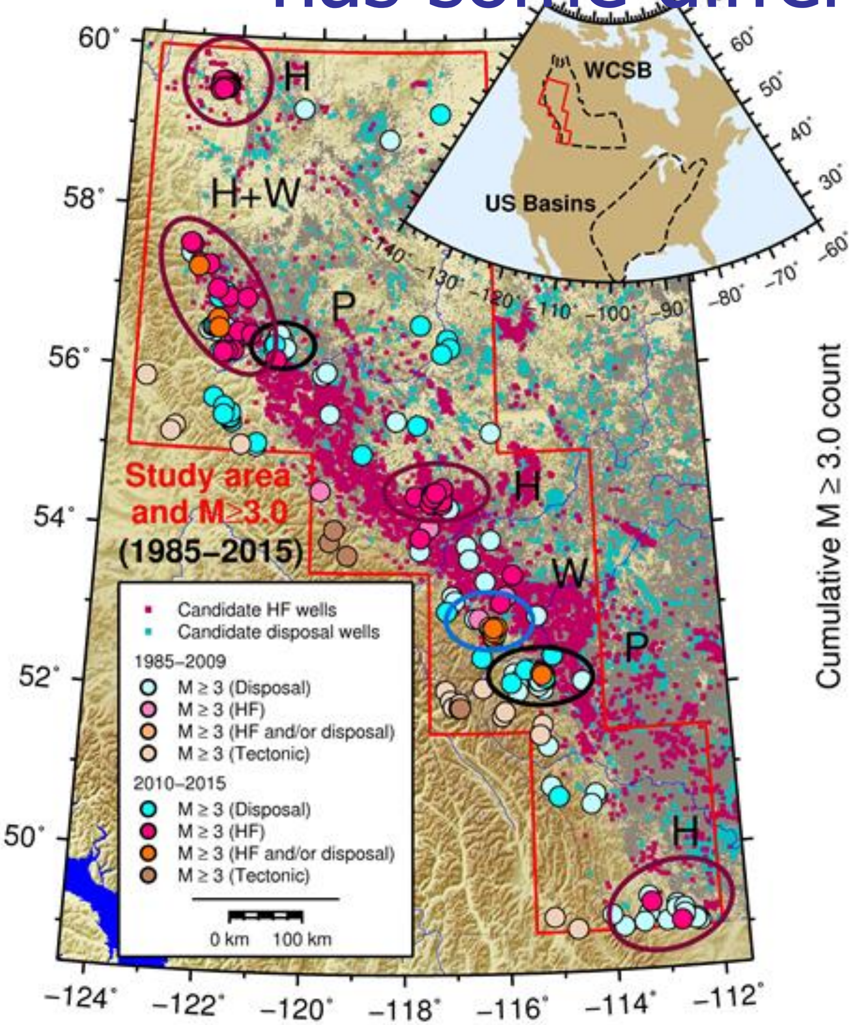
There is a well-established probabilistic seismic hazard framework to calculate hazard at a site, at least for natural seismicity

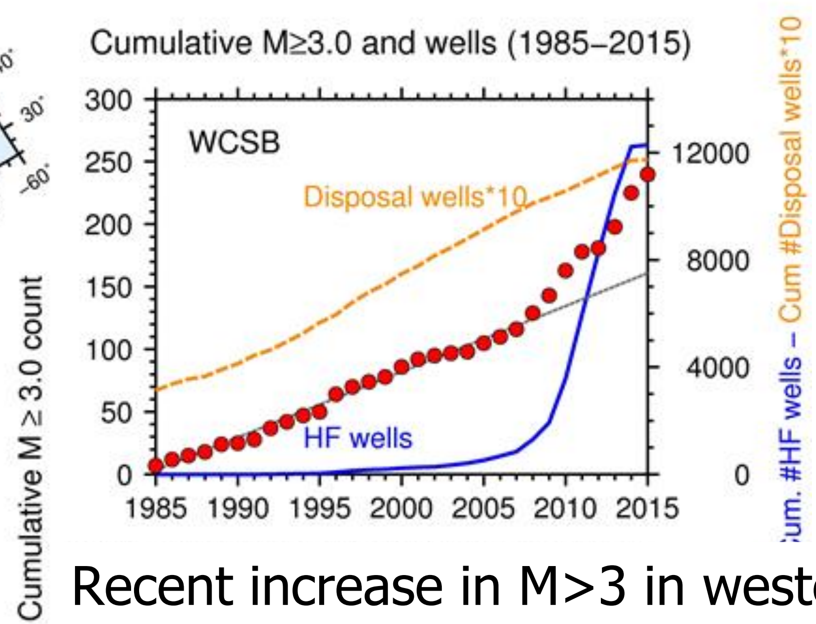
Elements of the seismic hazard framework

1) Identify seismic sources
2) Quantify rates of occurrence for each source, as a function of magnitude
3) Define expected ground motions from earthquakes, as a function of magnitude and distance
4) Perform an integration to find the probability of exceeding damaging levels of motion



Induced seismicity in western Canada -has some differences from U.S.





Recent increase in M>3 in western Canada Sedimentary Basin (WCSB) coincides with increase in hydraulic fracturing in horizontal wells (HF wells).

Examine statistical relationship between seismicity and HF wells.

(Atkinson et al., 2015 SRL)

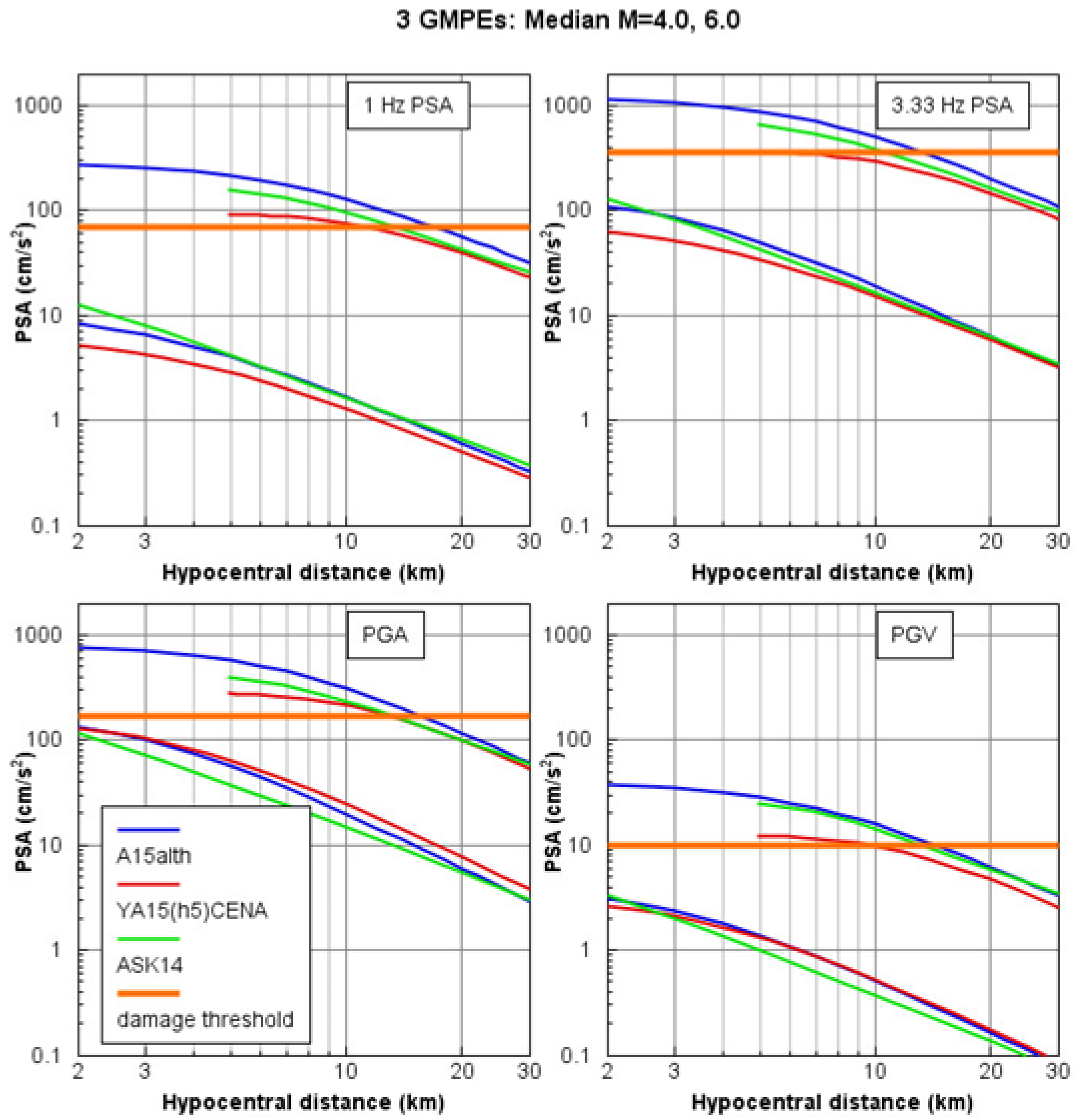
Rate parameters for induced events associated with HF wells: Ghofrani & Atkinson, 2016 GRL study

- Subdivide region into cells of 10 km radius and evaluate relationship between **M**>3 seismicity and HF wells in each cell
- Use Monte Carlo techniques to assess likelihood of an active cell (i.e. a cell with one or more HF wells operating) being associated with an earthquake sequence containing ≥1 event of **M**≥3
- This likelihood, combined with the Gutenberg-Richter relation (*b*-value of 1) is used to assess rate of induced events of all **M**, on a per-annum, per-area basis
- This rate is 0.01 to 0.03 per annum for **M**≥3 (for a radius of 10 km)
- Implied rates: 0.01 **M**≥3, 0.001 **M**≥4, 0.0001 **M**≥5, 0.00001 **M**≥6

Ground-motion prediction equations for hazard assessment:
Some preliminary conclusions on GMPEs that are good proxies for induced events, considering stress drop and near-source scaling issues

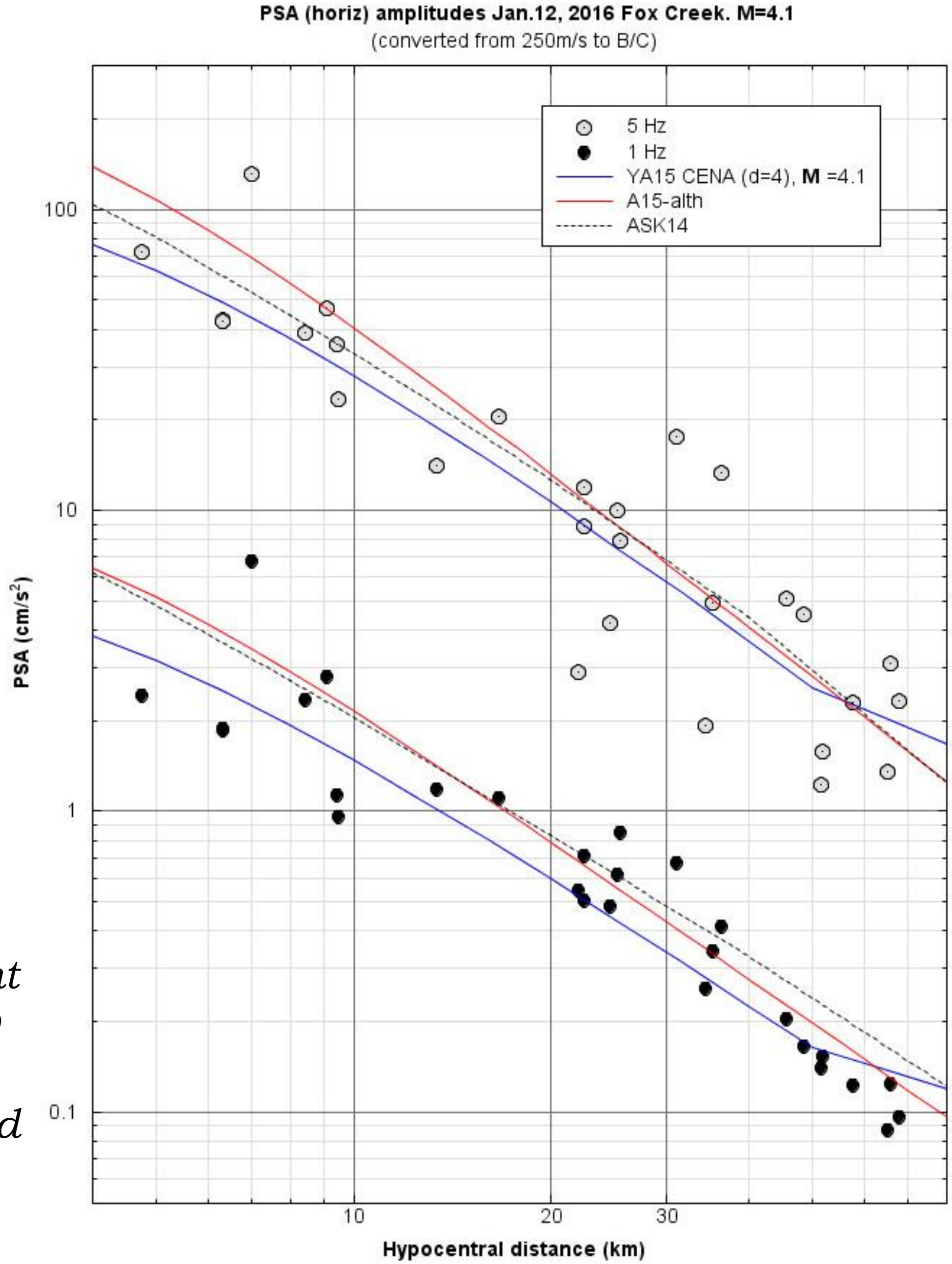
3 published GMPEs are (roughly) suitable for induced-event hazard analyses

- Yenier and Atkinson, 2015 (from eastern North America, natural + induced) (YA15)
- Atkinson, 2015 (from shallow California, NGA-W2 data with scaling attributes appropriate for induced events) (A15)
- Abrahamson et al., 2014 (from shallow California, NGAW2 – works if implemented with “unspecified” depth to top of rupture, to force average depths) (ASK14)



A recent example from Fox Creek, Alberta: M4.1 Jan 12

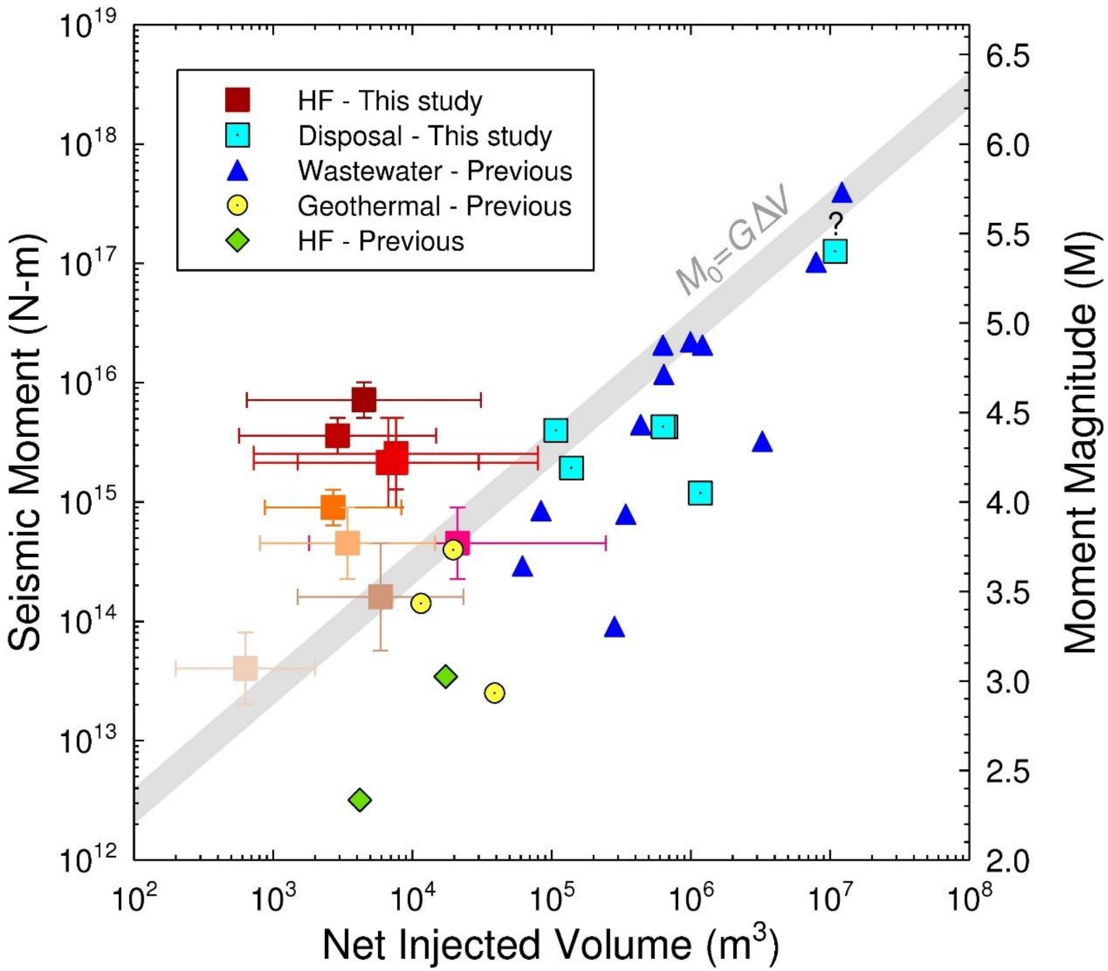
- Response spectra at 1Hz, 5Hz, compared to a few GMPE alternatives (YA15, A15(alt-h), ASK14)
- Note good distribution in distance, allowing both level and shape of GMPEs to be determined
- This is the only event in Alberta/B.C. for which we have good data – need more like this!



*Observed horizontal-component PSA at 1 and 5 Hz (symbols) for **M**4.1 induced event near Fox Creek, Alberta (converted from D to B/C) compared to GMPEs (lines). Assumed focal depth of 4 km for YA15 and A15. Figure from Yenier et al., 2015*

A note on maximum magnitude: does not appear to be related to fluid volume

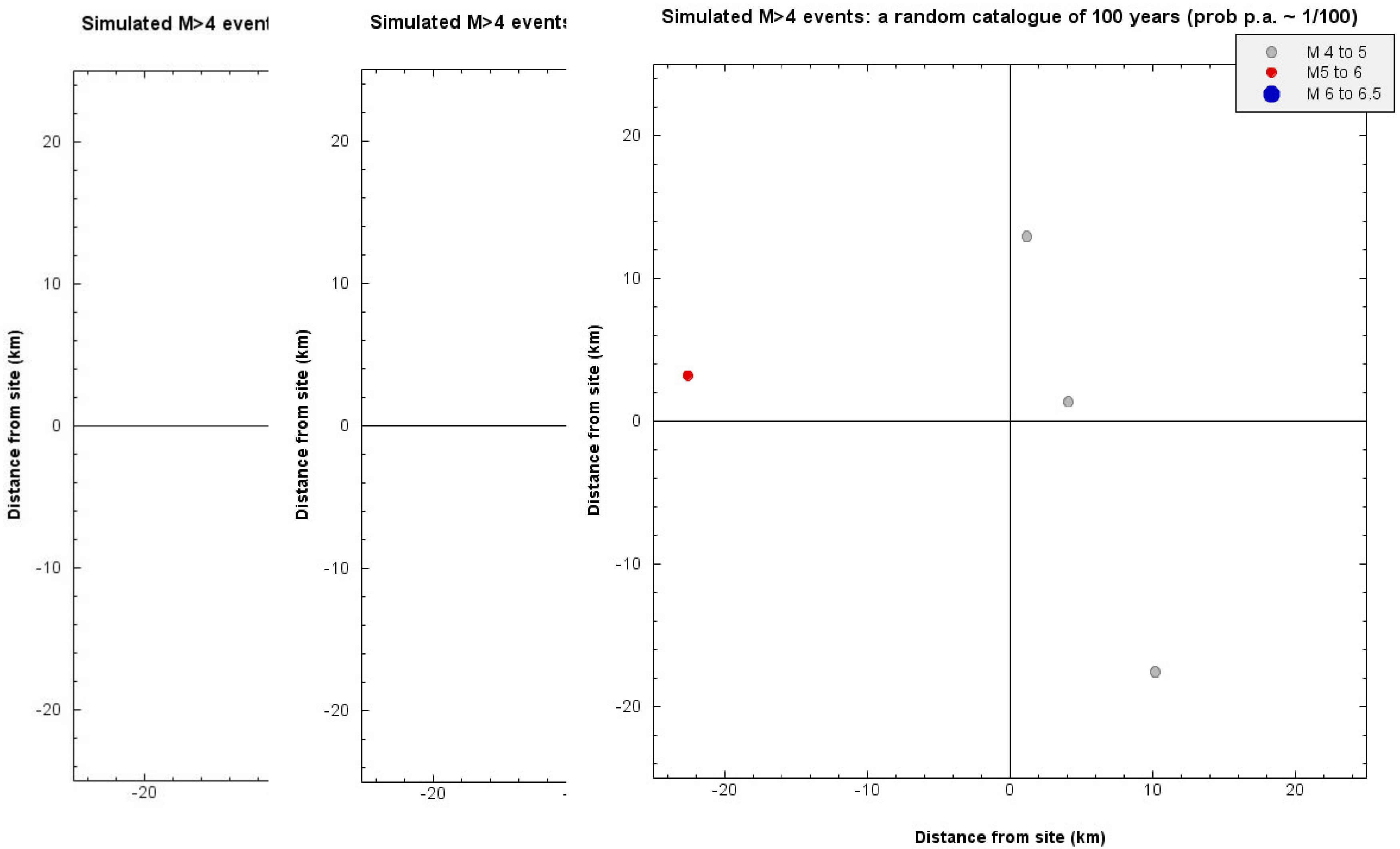
- examine fluid volumes for 9 well-documented cases of seismicity associated with HF wells in western Canada
- Sum fluid volumes injected over every stage of all well completions within 5km radius for 1 month prior to event
- Magnitudes do not appear to be constrained by relationship of McGarr (2014) between moment release and injected volume
- Therefore assume Mmax may be close to tectonic values (assumed Mmax = 5.0, 6.0, 6.5 with weights 0.2, 0.3, 0.5)



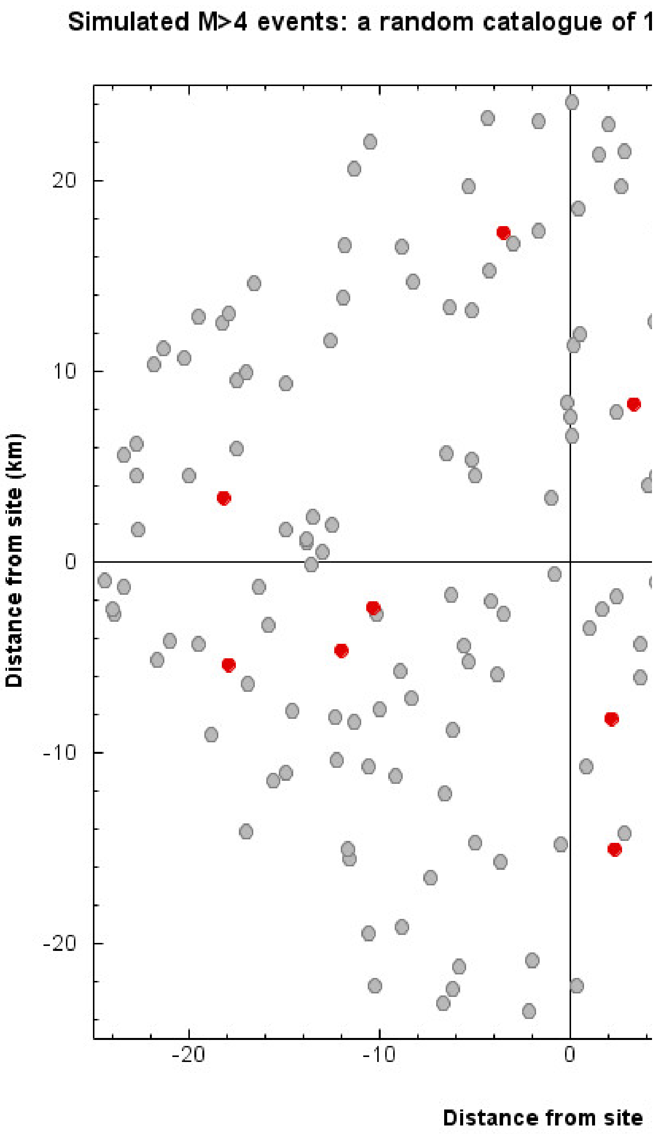
Evaluate effect of induced seismicity from hydraulic fracture treatments near a site using a generic, regional probabilistic seismic hazard analysis (PSHA)

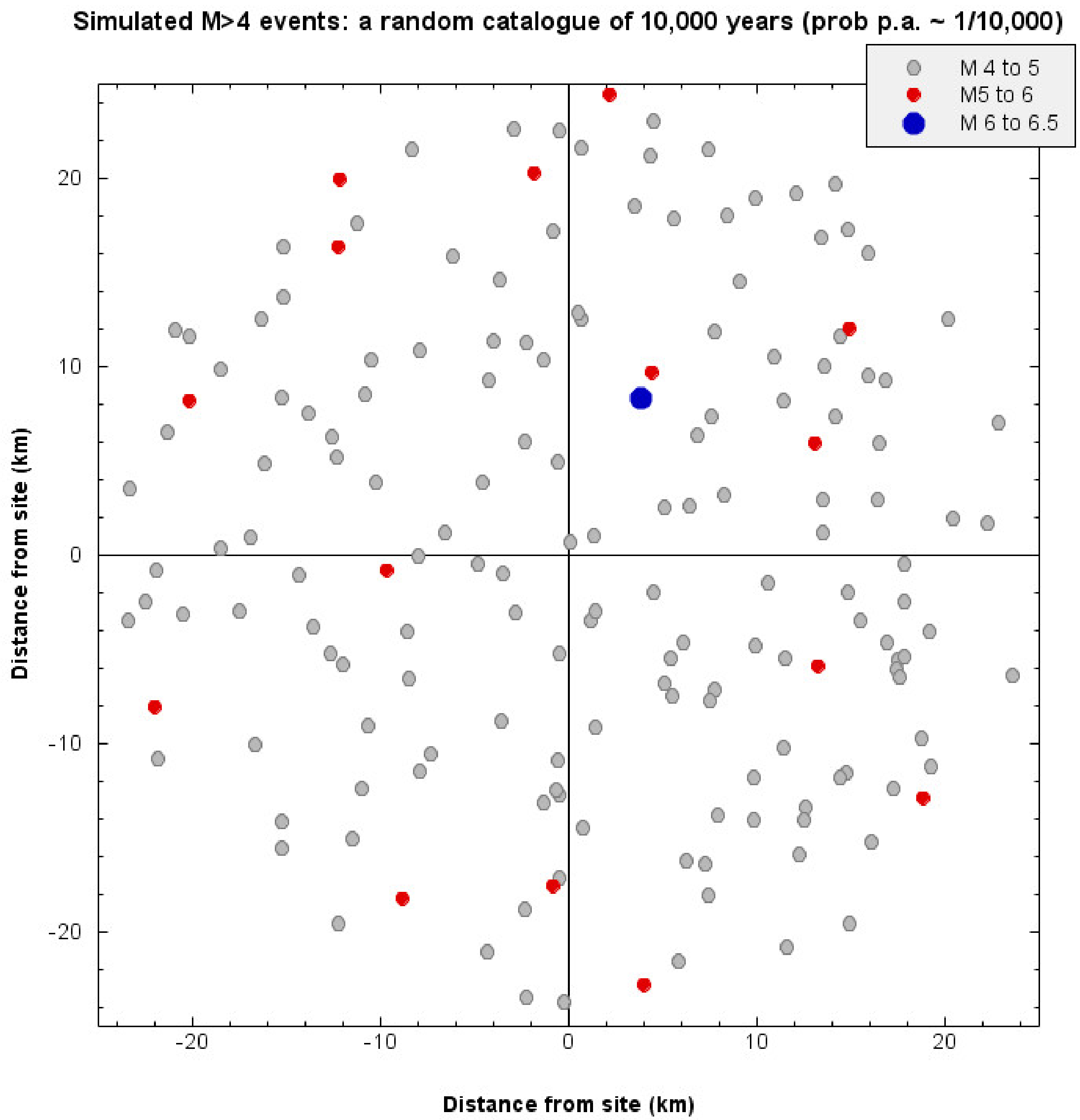
- Assume the rate parameters from Ghofrani&Atkinson, 2016 statistical study (with b-value of 1, and distribution of Mmax from 5.0 to 6.5)
- Use EQHaz (Assatourians and Atkinson, 2013) to simulate earthquake catalogues that could be realized over many trials (Monte Carlo)
- Suite of 2 GMPEs (representative suite approach), based on considering models that appear to be applicable to induced events (develop middle, lower alternatives; preliminary; using A15, ASK14, YA15)

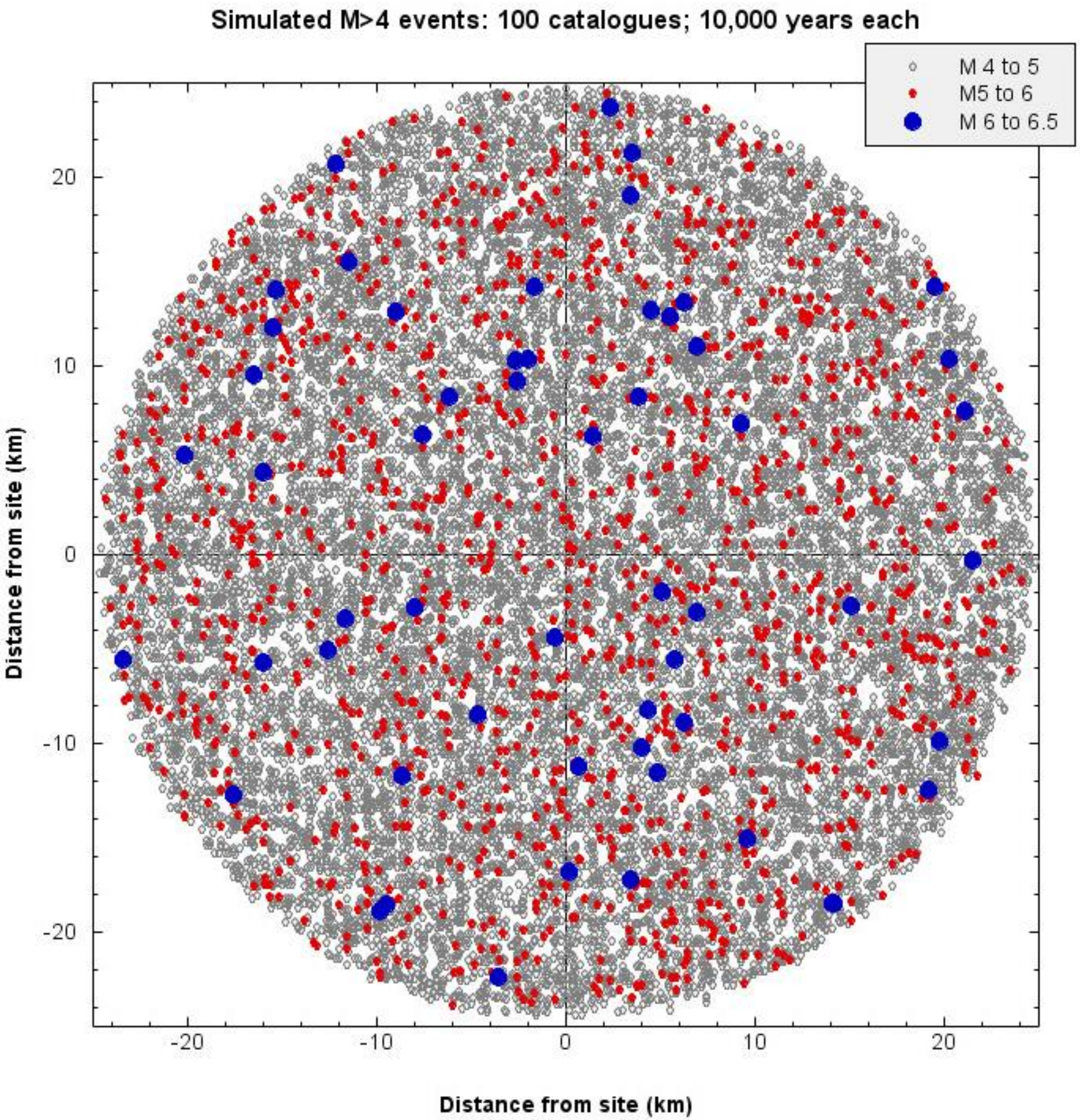
Simulated Catalogues: random 100 year snapshots



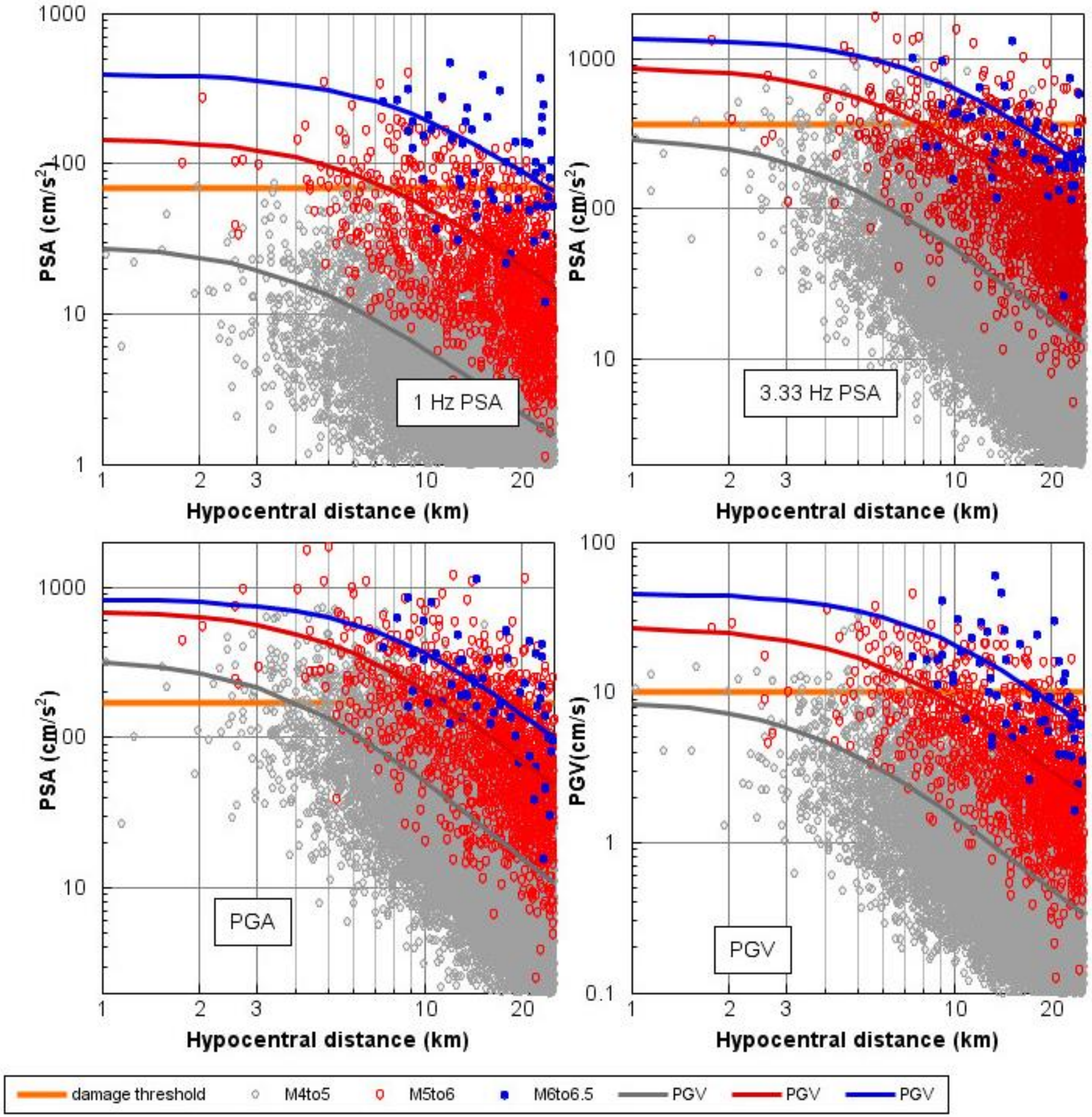
Simulated Catalogues: random 10,000 year snapshots





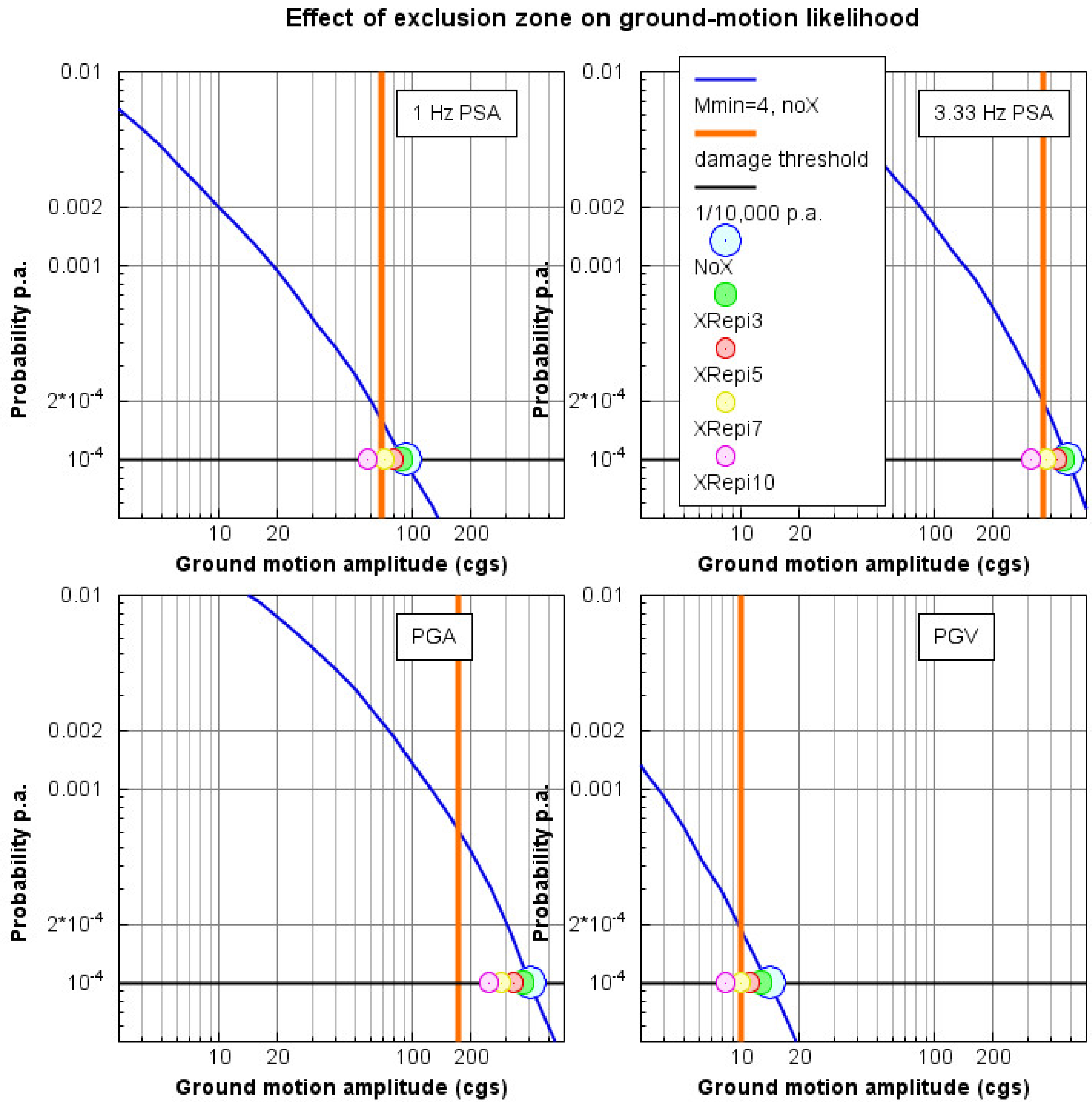


Simulated Catalogues: 100 catalogues of 10,000 years



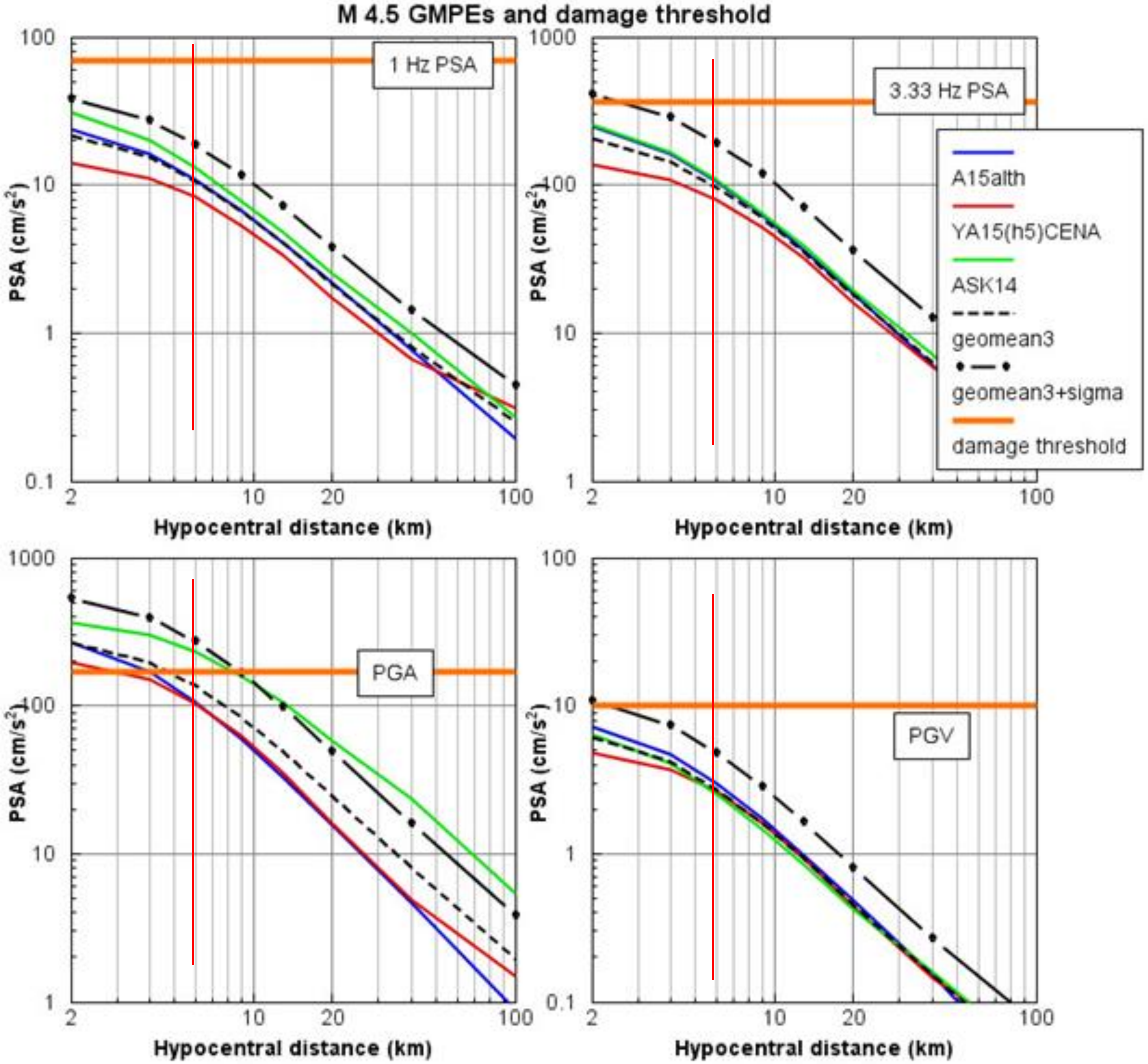
Ground motions generated from all 100 catalogues of 10,000 years (including variability):

if our goal is to have no greater than 1/10,000 p.a. chance of exceeding damage threshold (MMI=VI), we need to have no more than 100 exceedences of orange line… in our 100 x 10,000yr catalogues



Hazard curves and effect of exclusion zones: 1/10,000 p.a. motions from HF wells are above damage threshold;

exclusion zones of 3, 5, 7, 10 km (epicentral distance) lower the expected amplitude.... But there is still a potential hazard from larger events at >10 km



What does a 5-km set-back of HF operations from critical infrastructure preclude, in very simple terms?

Consider a representative event of M=4.5, with ground-motions at median plus sigma (this is ~1/10,000 event for a well)

Median+sigma motions for **M**4.5 below damage threshold except for PGA, with 5km setback

Conclusions

- Hazards from induced seismicity pose a real and as-yet-poorly-understood risk to critical infrastructure
- The development of set-backs will reduce the hazard, but there is still a significant contribution from larger events (**M**>5.5) that might occur at >10 km
- Ground-motion variability is a significant factor that impacts hazard and the effectiveness of set-backs
- A combination of a set-back of ~5 km from high-consequence infrastructure, coupled with monitoring network around critical infrastructure to continuously update knowledge of hazards in the 5 to 20 km distance range, may be an effective strategy
- There may be a need to adjust setbacks in near-real time to adapt to changing assessments of hazard