5^{th} Generation Seismic Hazard Model for the National Building Code of Canada

Trevor Allen

Natural Resources Canada

The GSC's Public Safety Geoscience Program

Reduce economic, social & environmental impacts from natural hazard events.

PSG delivers targeted and national-scale assessments for hazards such as earthquakes, tsunamis, onshore and offshore slope failures, space weather events and volcanoes.

PSG undertakes geohazard research that contributes to increasing public safety and reducing future losses, developing tools, standards and guidelines for quantitative hazard and risk assessment and mitigation, e.g., via regular updates to the *National Building Code of Canada*.

Damage to masonry building, 2011 Christchurch earthquake (Becker Fraser photos)

Japanese tsunami, 2011 (AFP)

Eruption of Mt.St.Helens, 1980 (AFP)

Acknowledgements

- Co-workers at NRCan:
  - John Adams
  - Stephen Halchuk
  - Garry Rogers

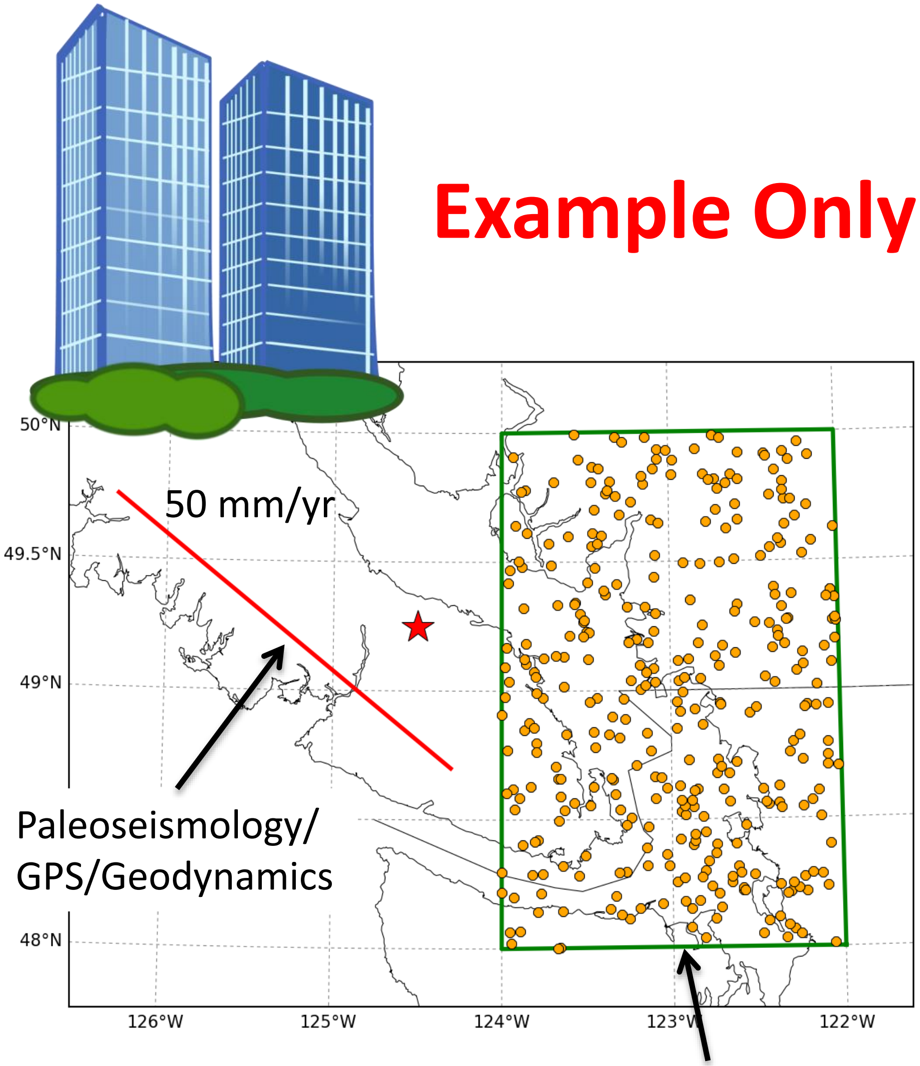
- Members of the Ground Motions working group:
  - Gail Atkinson
  - Tuna Onur
  - Adrian Whiteman
  - Liam Finn
  - SCED Committee

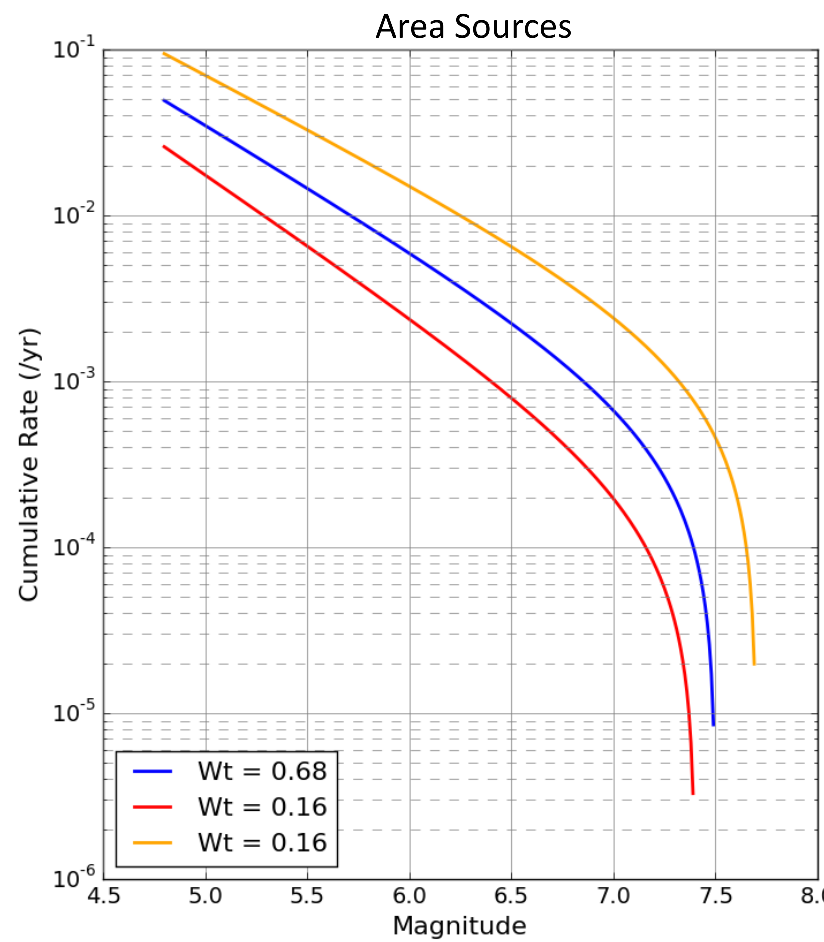
Talk Outline

- PSHA 101
- History of seismic hazard assessment in Canada
- The 2015 hazard model:
  - Model updates (earthquake sources, ground motions, etc)
  - Changes in calculated hazard
- Site factors
- Summary of the 2015 NBC hazard values
- Towards the 2020 NBC

PSHA 101 – Earthquake Sources

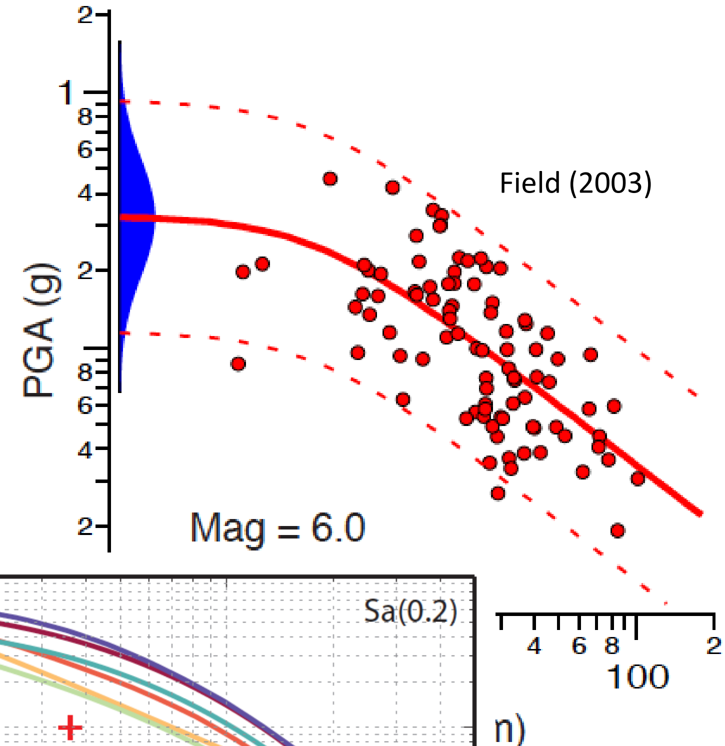
Example Only

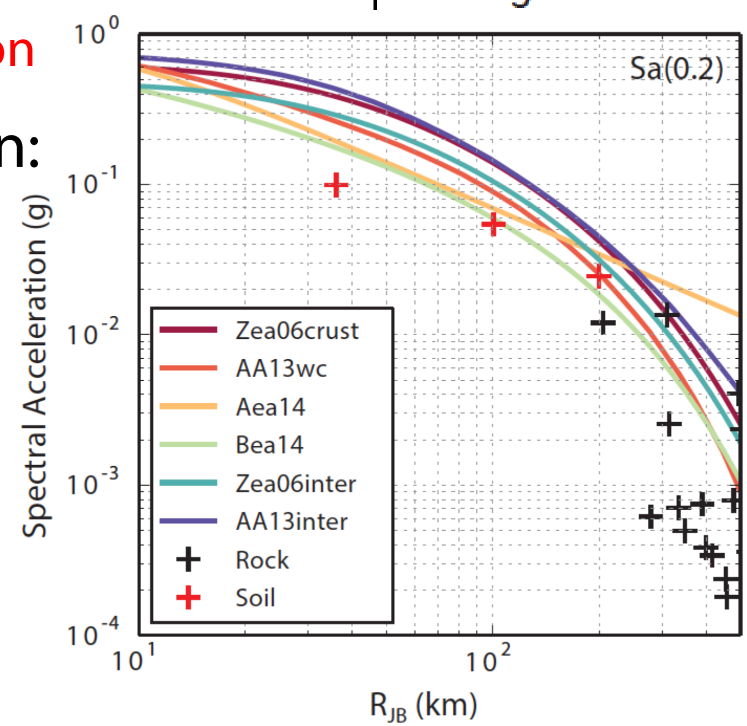




PSHA 101 – Ground Motion

- Ground motion models (GMMs or GMPEs) estimate the expected (median) ground shaking intensity measures:
  - Peak Ground Acceleration (PGA)
  - Peak Ground Velocity (PGV)
  - Response spectral acceleration
- Ground shaking depends on:
  - Magnitude
  - Source-to-site distance
  - Site condition
  - Earthquake mechanism
  - Hanging wall/footwall effect

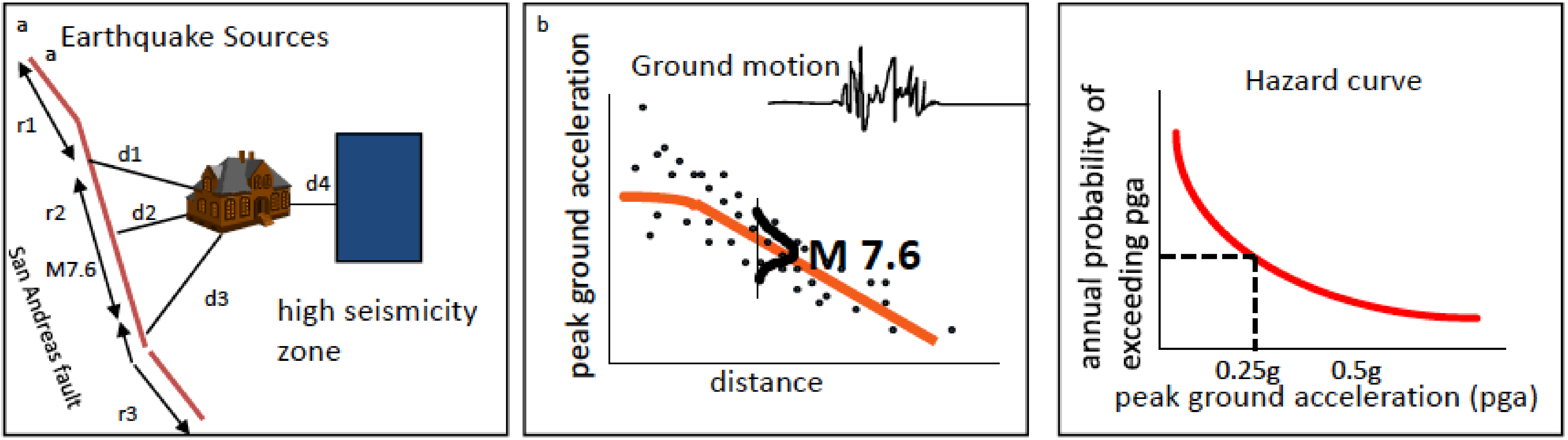




28 Oct 2012
MW 7.8 Haida Gwaii

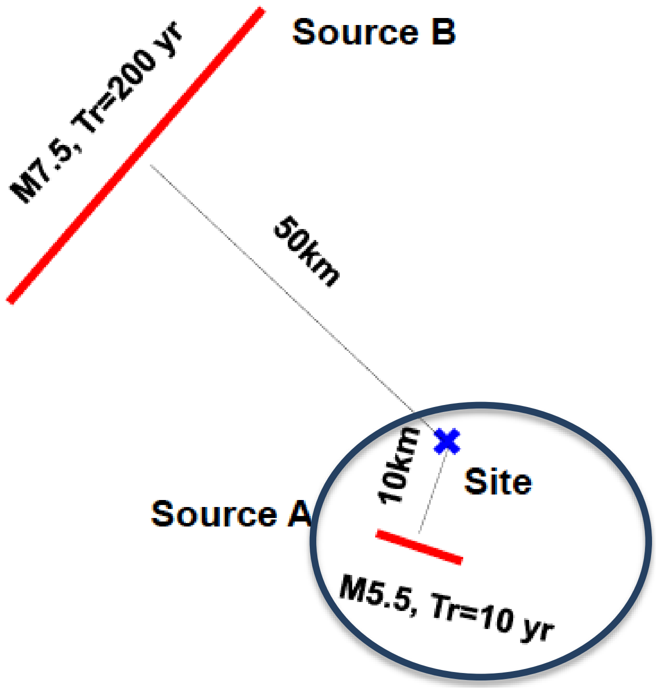
PSHA 101 – Making a Hazard Map

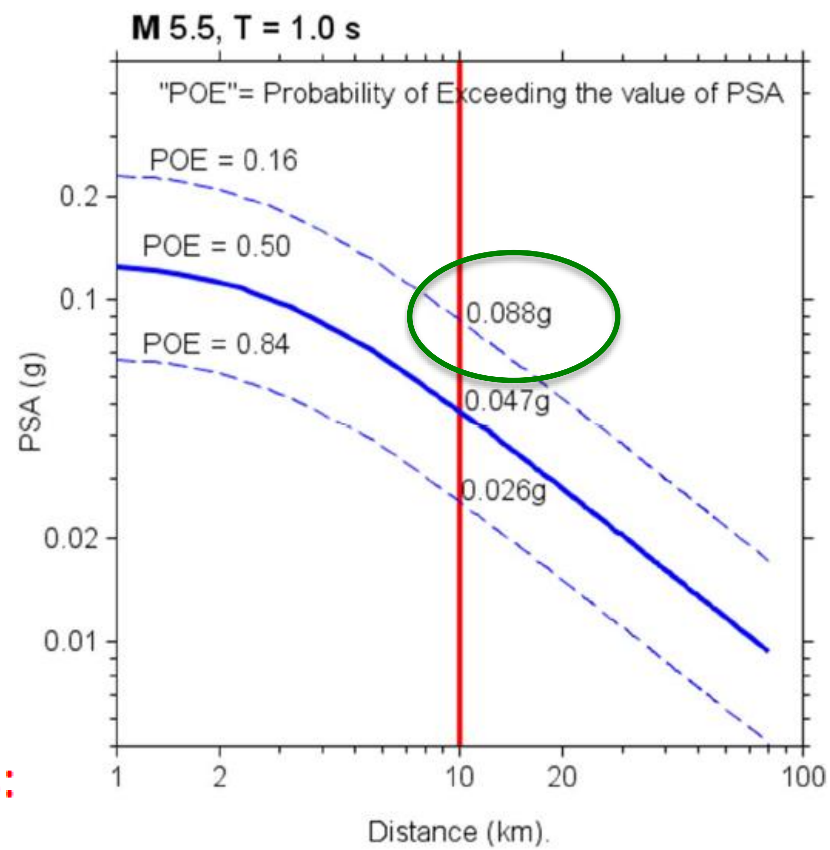
The PSHA methodology



Boore, 2014

PSHA 101 – Constructing a Hazard Curve





Annual probability that earthquake occurs:

Source A: 1/10 = 0.10

Source B: 1/200 = 0.005

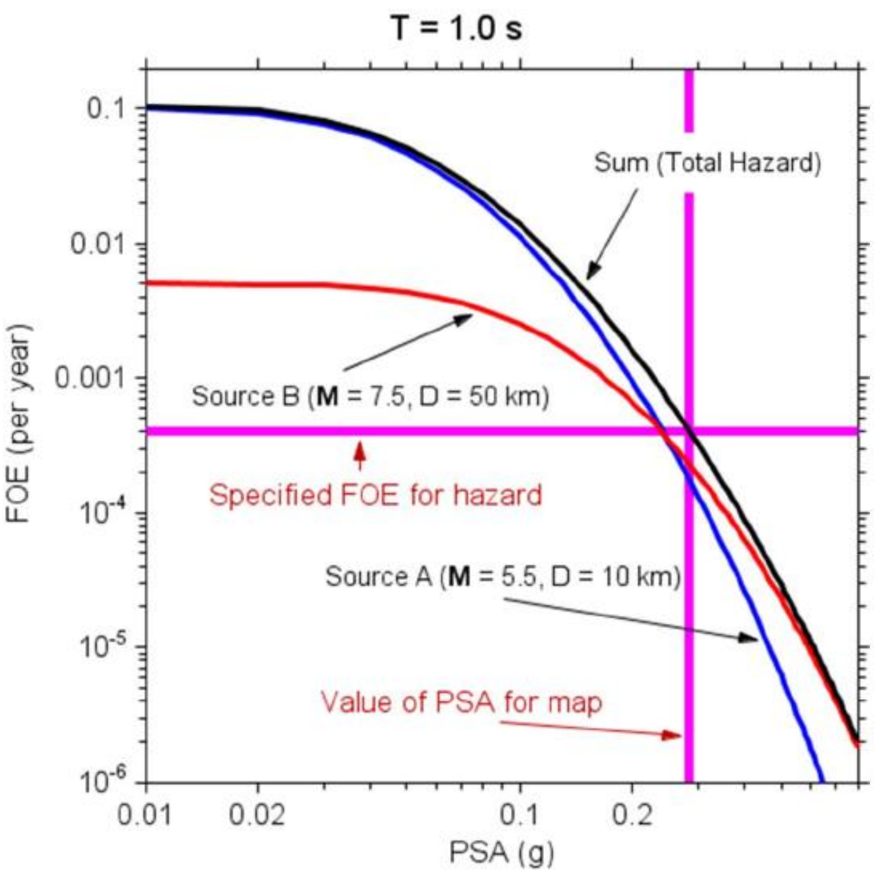
For 0.088g, FOE = 0.10 x 0.16 = 0.016

FOE = Frequency of Exceedance

Boore, 2014

PSHA 101 – Constructing a Hazard Curve

- Plot the resulting FOE for the response spectral value
- Do this for all possible ground motions from Source A to make a hazard curve for Source A
- Combine hazard curves for all sources to make the final hazard curve
- Pick off value for hazard map at the required FOE



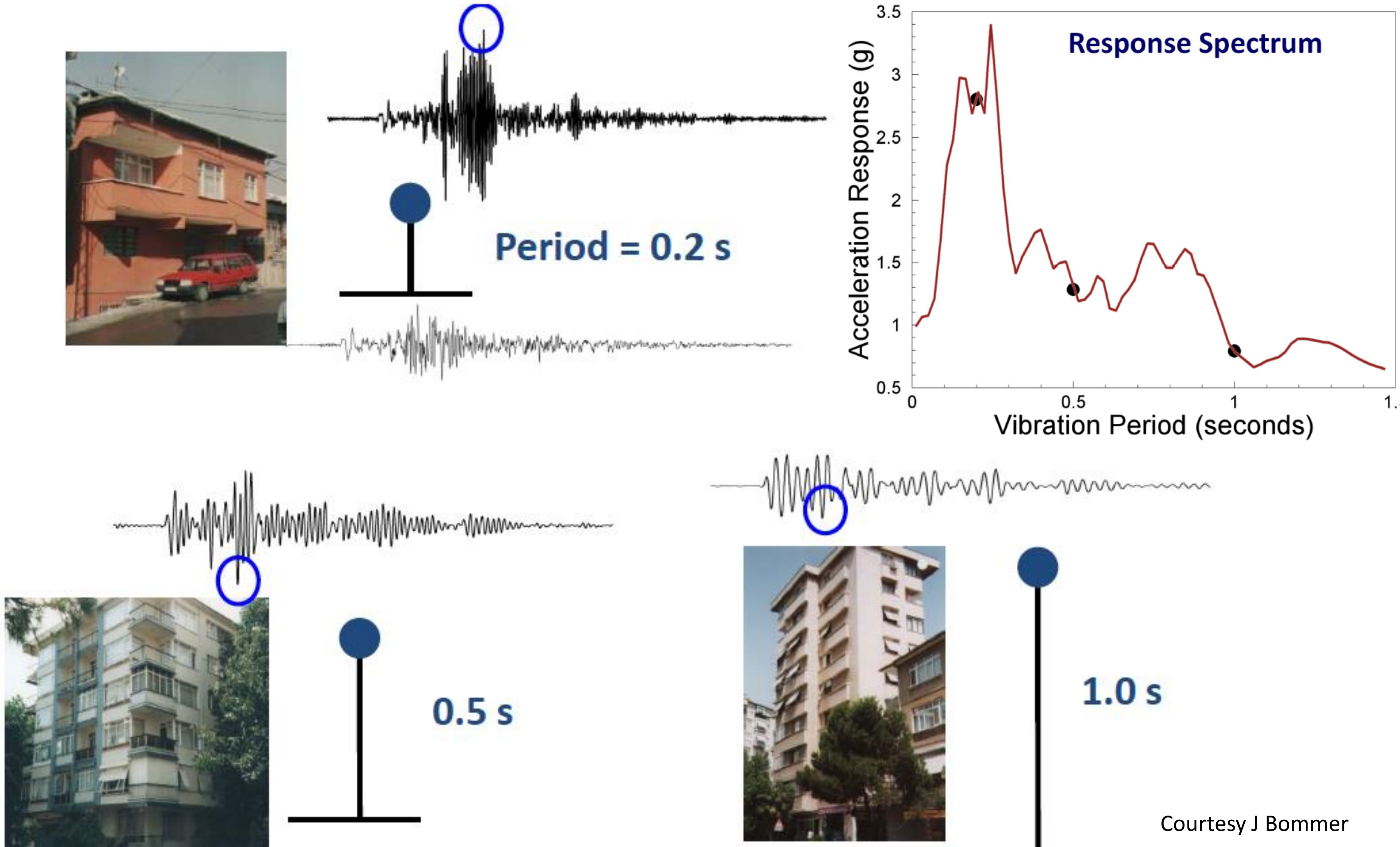
Boore, 2014

PSHA 101 – What are Response Spectra?

- The maximum response of a single-degree-of-freedom (SDOF) damped oscillators that have a range of resonant periods for a given input ground-motion
- Buildings can often be represented by SDOF oscillators
- Thus, a response spectrum can provide the motion of an arbitrary structure to a given input motion

Boore, 2014

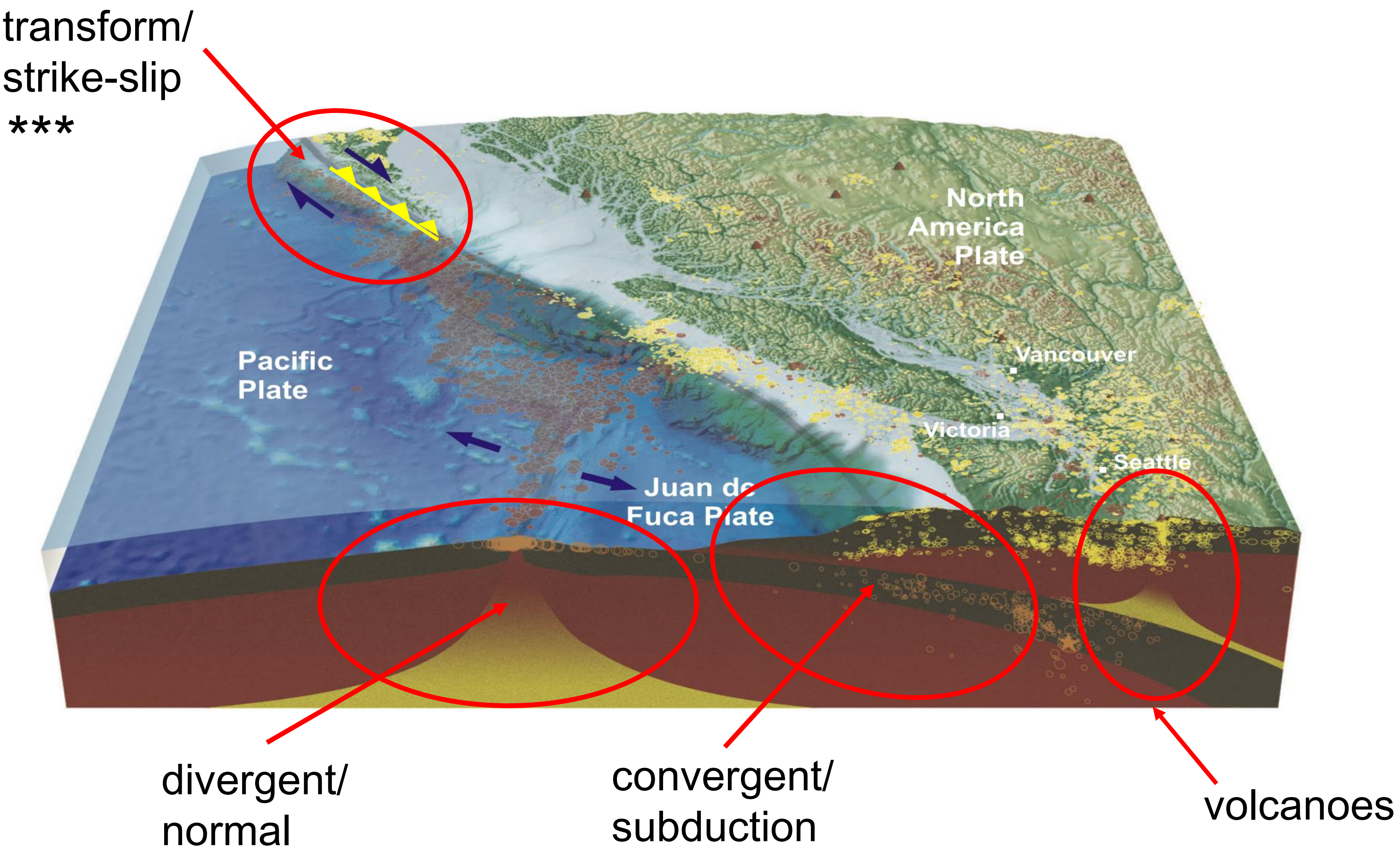
PSHA 101 – What are Response Spectra?



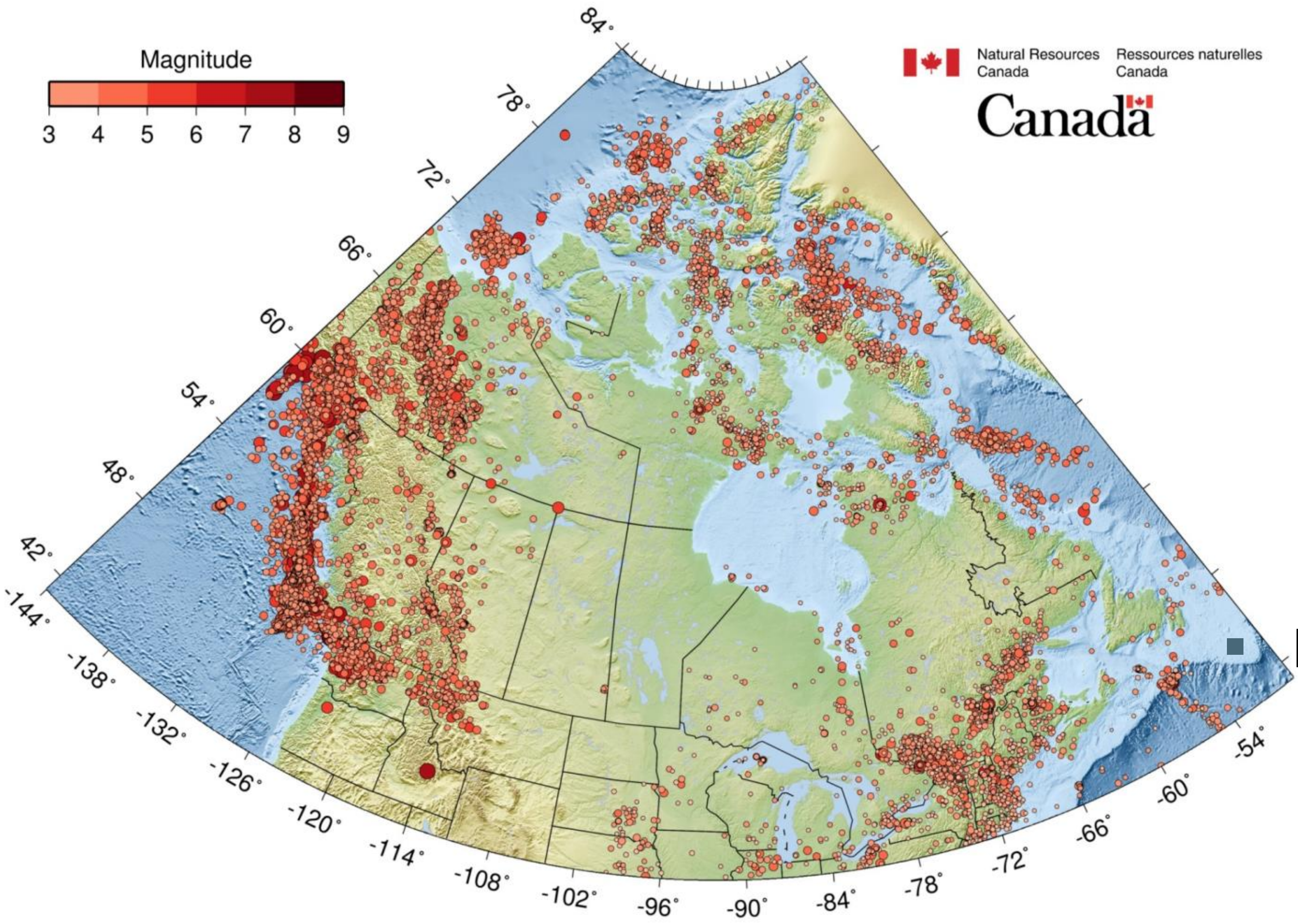
Courtesy J Bommer

Canada

Sources of Seismic Hazard in BC

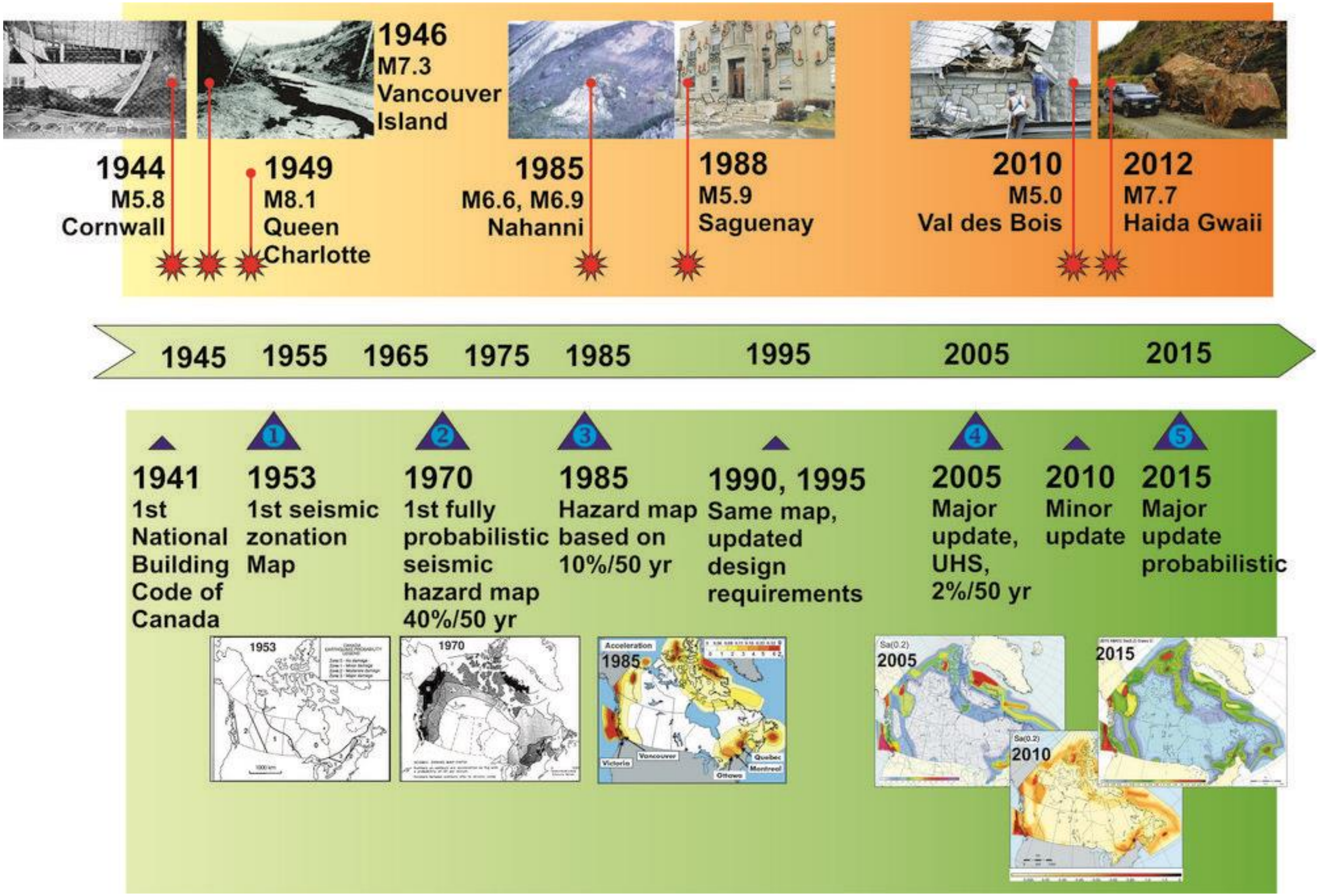


Sources of Hazard



- West:
  - Cascadia interface
  - In-slab (landward)
  - QCF strike-slip
  - Yukon crustal faults
  - Mackenzie/Richardson Mtns
  - Beaufort Sea
  - Divergent Pacific/Juan de Fuca plate
- East:
  - St Lawrence Rift/Charlevoix
  - WQSZ
  - Baffin Bay

National Building Code of Canada Evolution



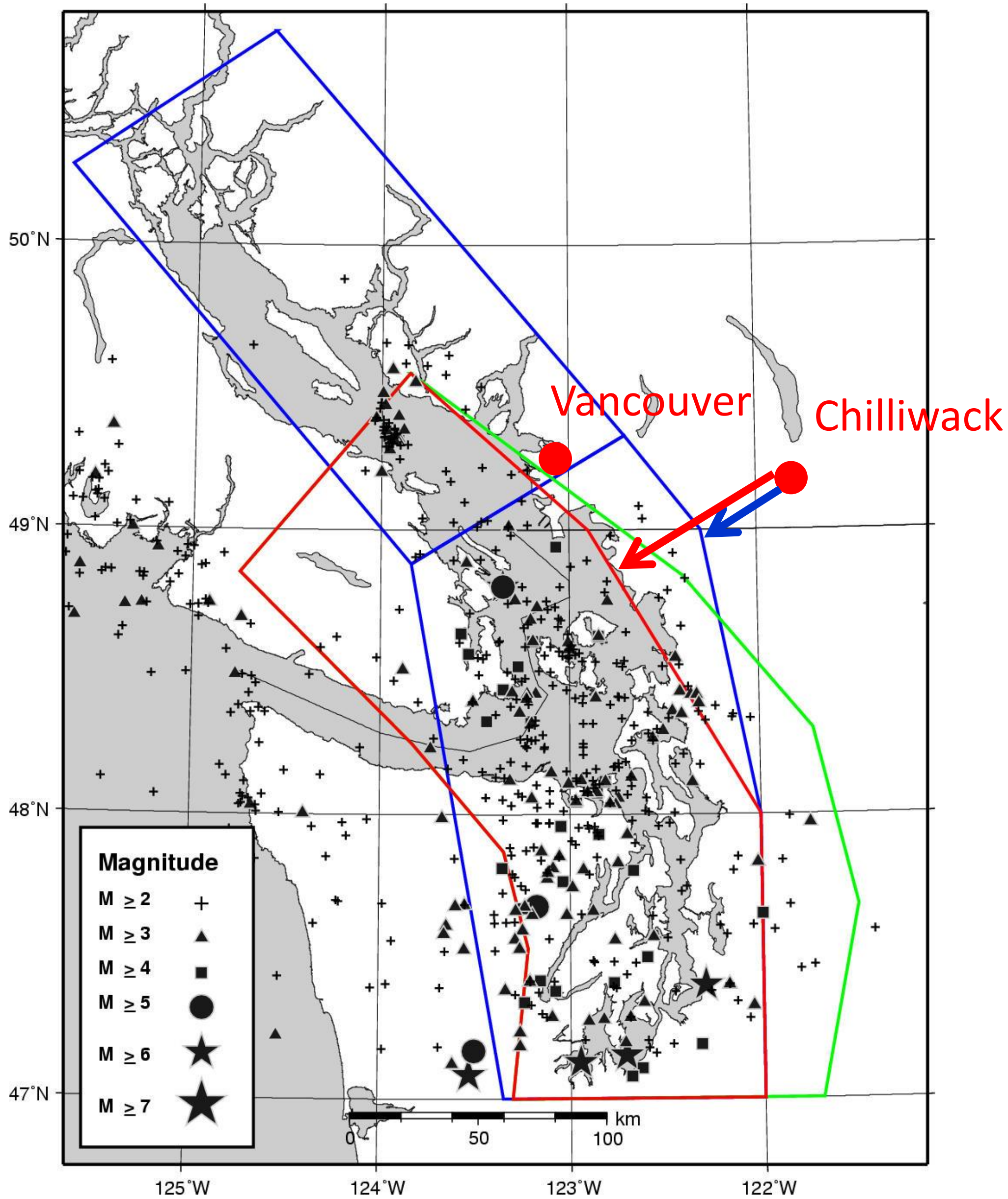
The National Building Code Cycle

- The National Building Code (NBC) of Canada is updated on a 5-year cycle
- The Standing Committee for Building Design (SCED) is appointed at the beginning of the cycle
- A number of task/working groups are established to update specific aspects of the code at the beginning of the cycle (e.g. seismicity, foundations, columns, base isolation, etc)
- Proposed changes to the NBC are presented to the SCED where they are debated through participatory peer review
- Proposed changes are voted on and corresponding adjustments are made to the code and code commentary
- At the end of cycle, the Canadian Commission on Building and Fire Codes accepts code changes and publishes the NBC
- The Provinces then review the codes and modify building regulations accordingly – lag between NBC and regulations
- ***Repeat!***

5th Generation Improvements for NBC 2015

- Probabilistic combination of all sources including Cascadia
- Explicit inclusion of crustal faults (QCF, Yukon)
- Updated earthquake catalogue in M_W
- Modern ground motion models (Atkinson & Adams, 2013)
- More ground-motion periods [PGA, PGV, Sa (0.2-10 s)]
- Improved treatment of uncertainty
- Mean rather than median hazard

Revised Geometry of In-slab Sources

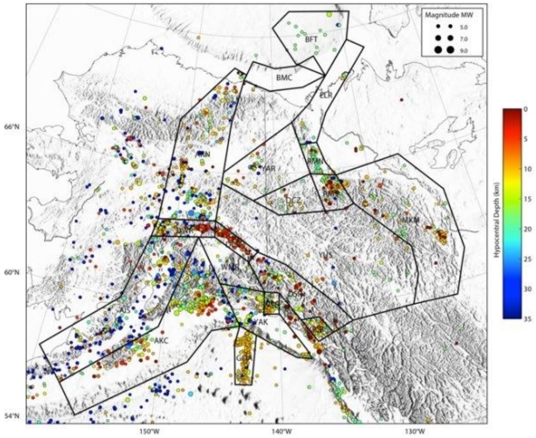


- Boundaries better understood & better defined
- In-slab zones affecting lower mainland
- Green and blue sources 2010
- Red source 2015
- 2015 source is farther away from many lower mainland sites, therefore hazard drops (at short periods) from 2010

Canada

Western Arctic Areal Source Zone Characterisation

Earthquakes



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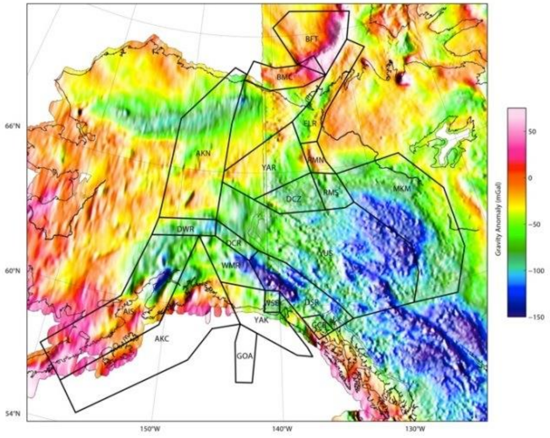
Gravity



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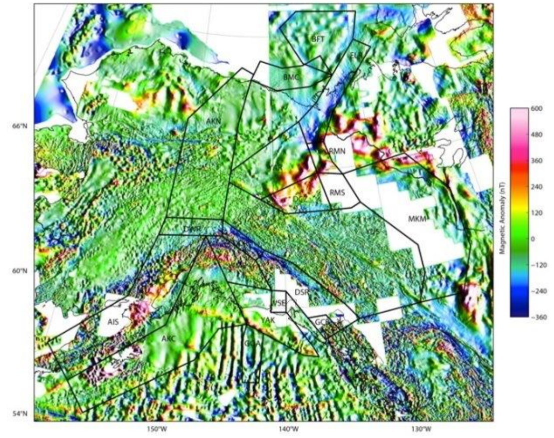
Magnetics



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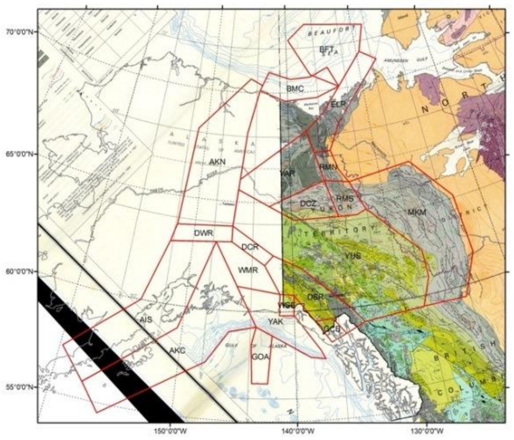
Tectonic Elements



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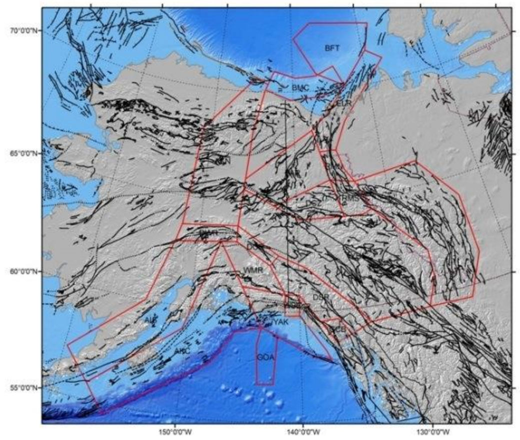
Crustal Faults/Structure



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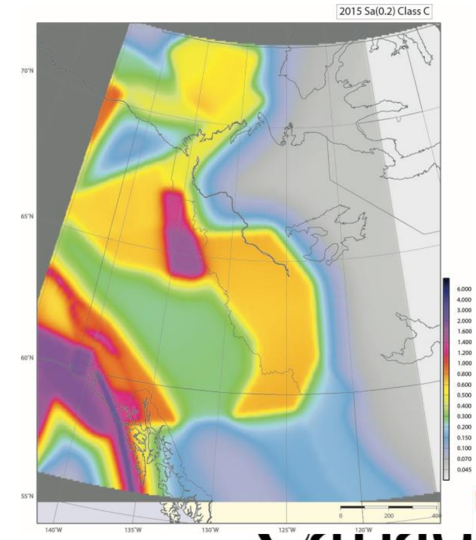
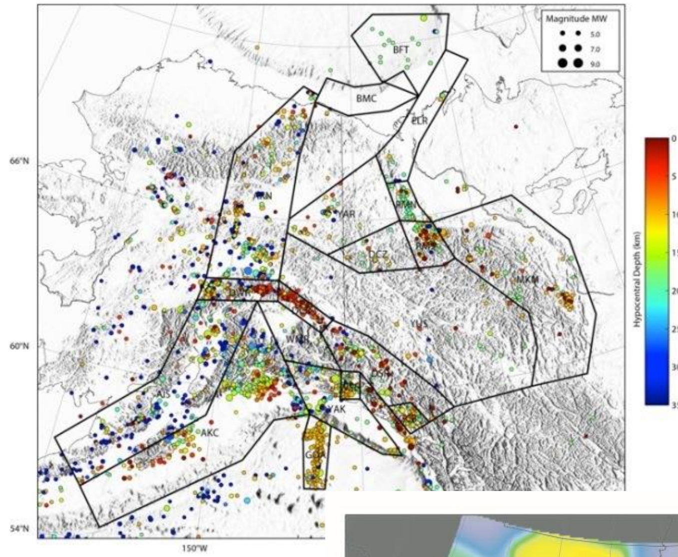
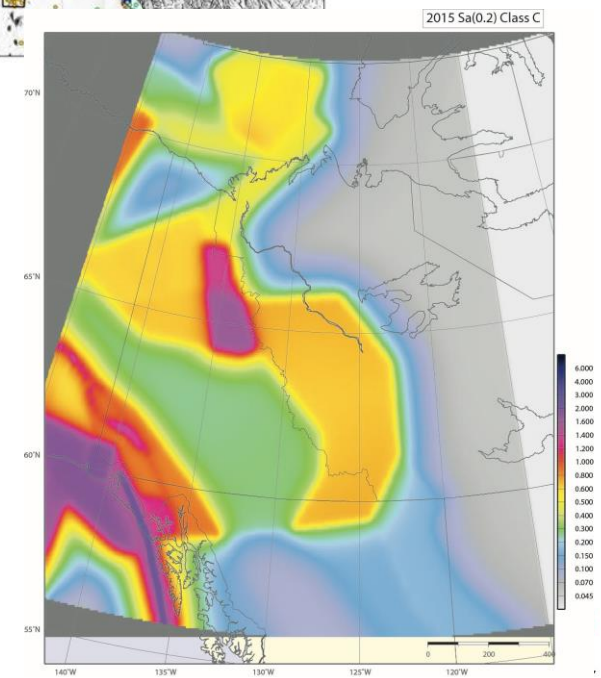
Hazard



Sensitivity of Hazard to Area Sources

- The multi-tiered GIS framework has allowed for improved characterisation of seismotectonic domains
- Hazard is sensitive to the placement of areal source zones
- Improved earthquake catalogue and geological and geophysical information have confined seismicity smaller areas
- Probabilistic combination of multiple source models (or a smoothed seismicity model) would minimise source zone effects





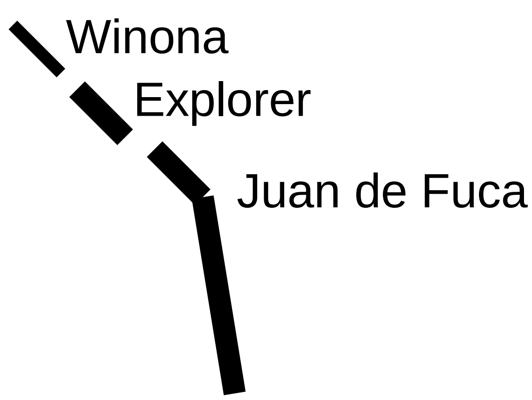
Replacement of:

- **2010 <u>deterministic</u> ~~Cascadia~~ Juan de Fuca approach**
- **by 2015 <u>probabilistic</u> subduction zone (SZ) interface models**

Cascadia Model now includes:

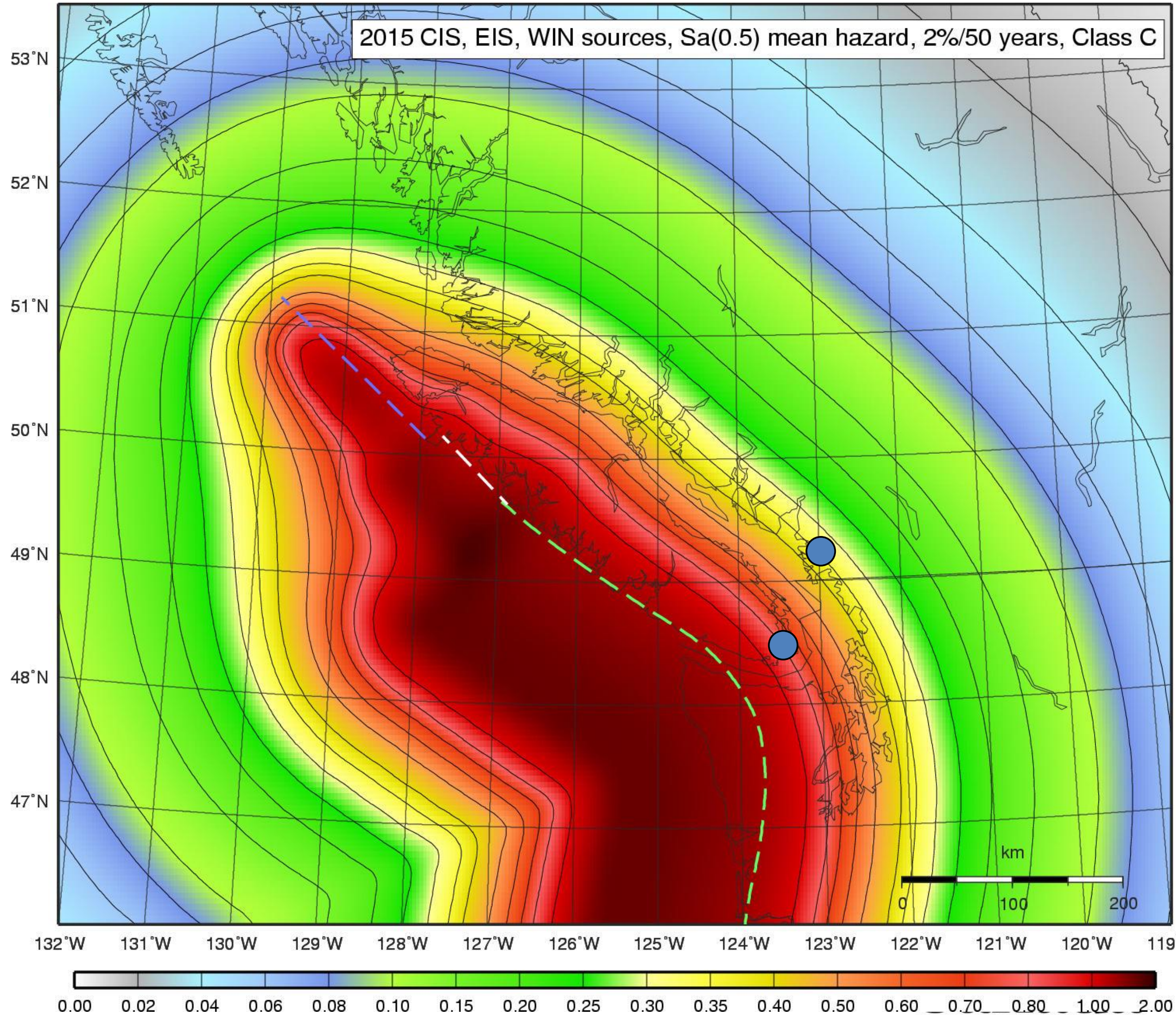
- updated Juan de Fuca SZ model
- new Explorer SZ model
- new Winona SZ model

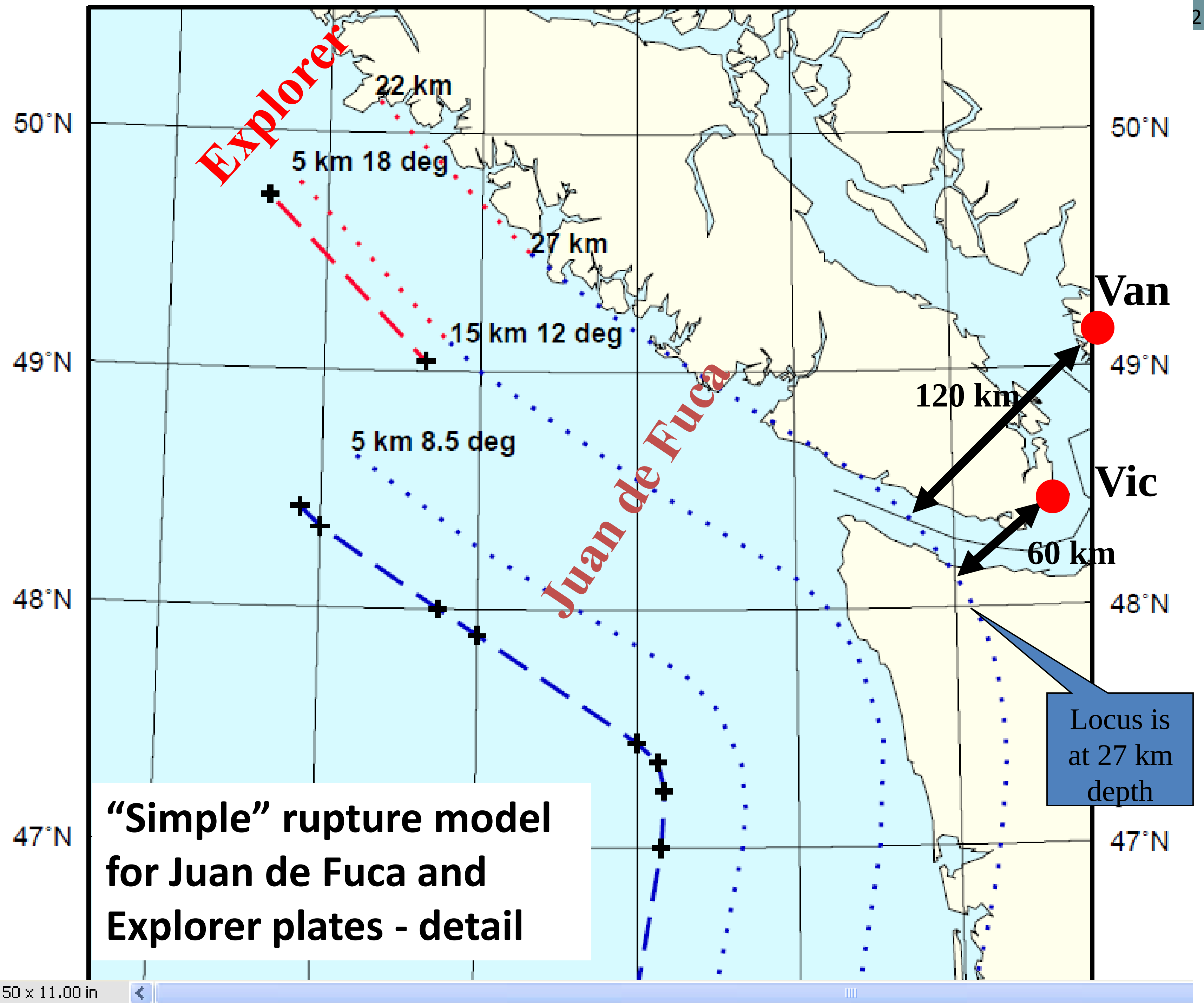
These are <u>segments</u> of the **Cascadia** subduction zone



2015 Probabilistic Cascadia

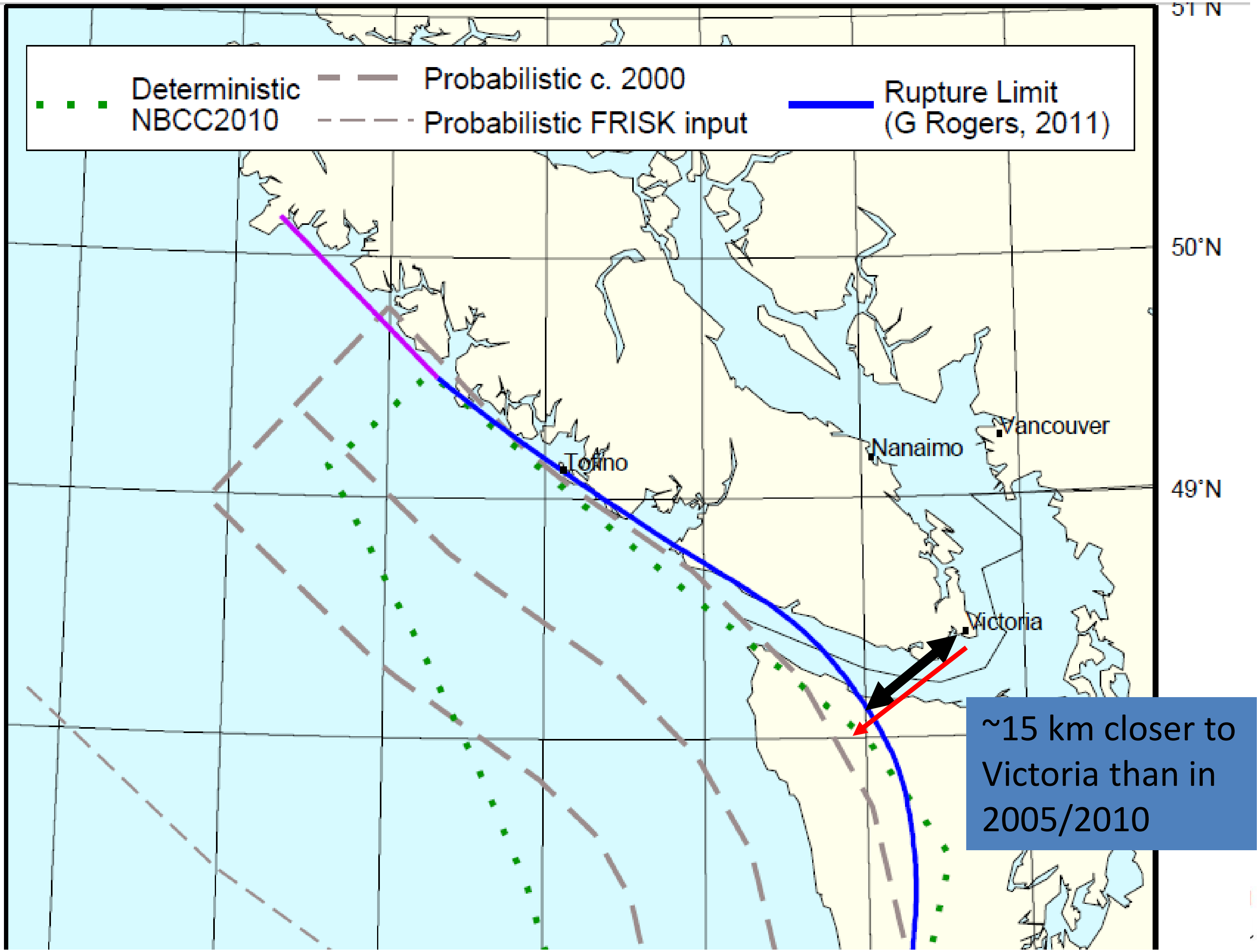
- Sa(0.5) for 2%/50 years for just the Juan de Fuca + Explorer + Winona sources
- this is the new "Cascadia"
- Note Vancouver and Victoria





"Simple" rupture model for Juan de Fuca and Explorer plates - detail

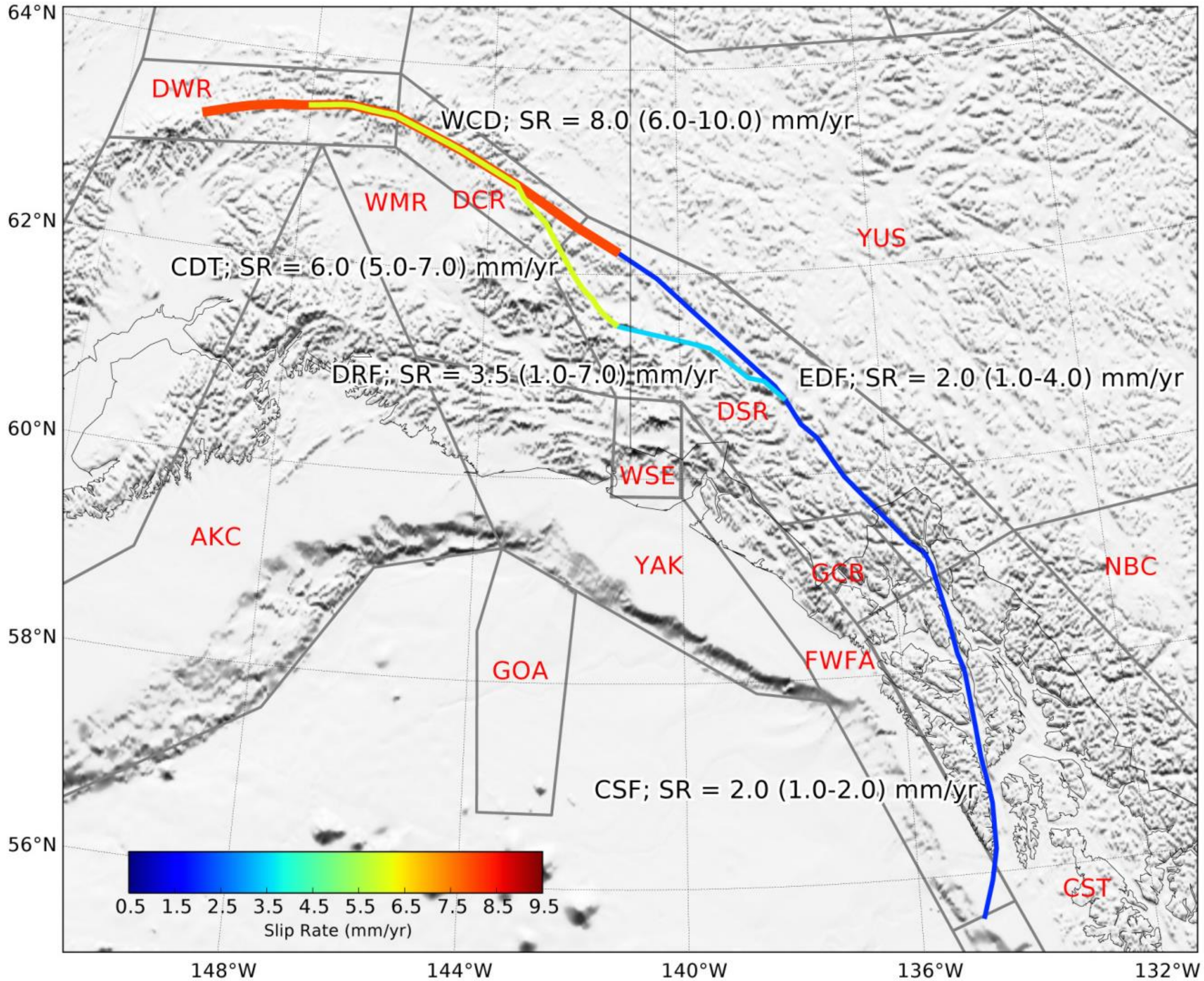
2010-2015 Juan de Fuca Comparisons



Juan de Fuca Complete-Rupture Rates

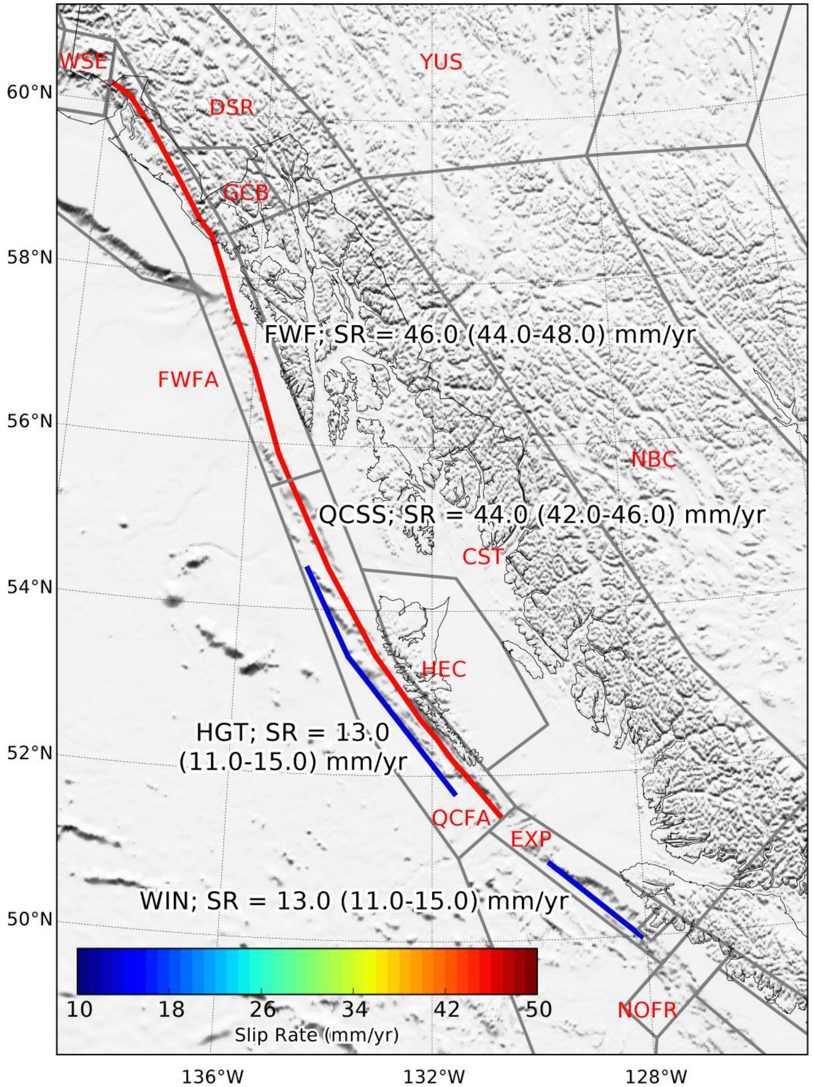
- 10,000-year history (after Goldfinger *et al.*)
- Assume that each rupture is complete, end-to-end
  - all M~9
- Protypical event:
  - occurs every 550 years;
  - ruptures length of 1020 km and width of 125 km;
  - has a magnitude of approximately 9.0
- Earthquakes range in magnitude from 8.5 - 9.1
  - Seismic hazard is not very sensitive to the exact magnitude when earthquakes get this big

Active Faults – Alaska & Yukon



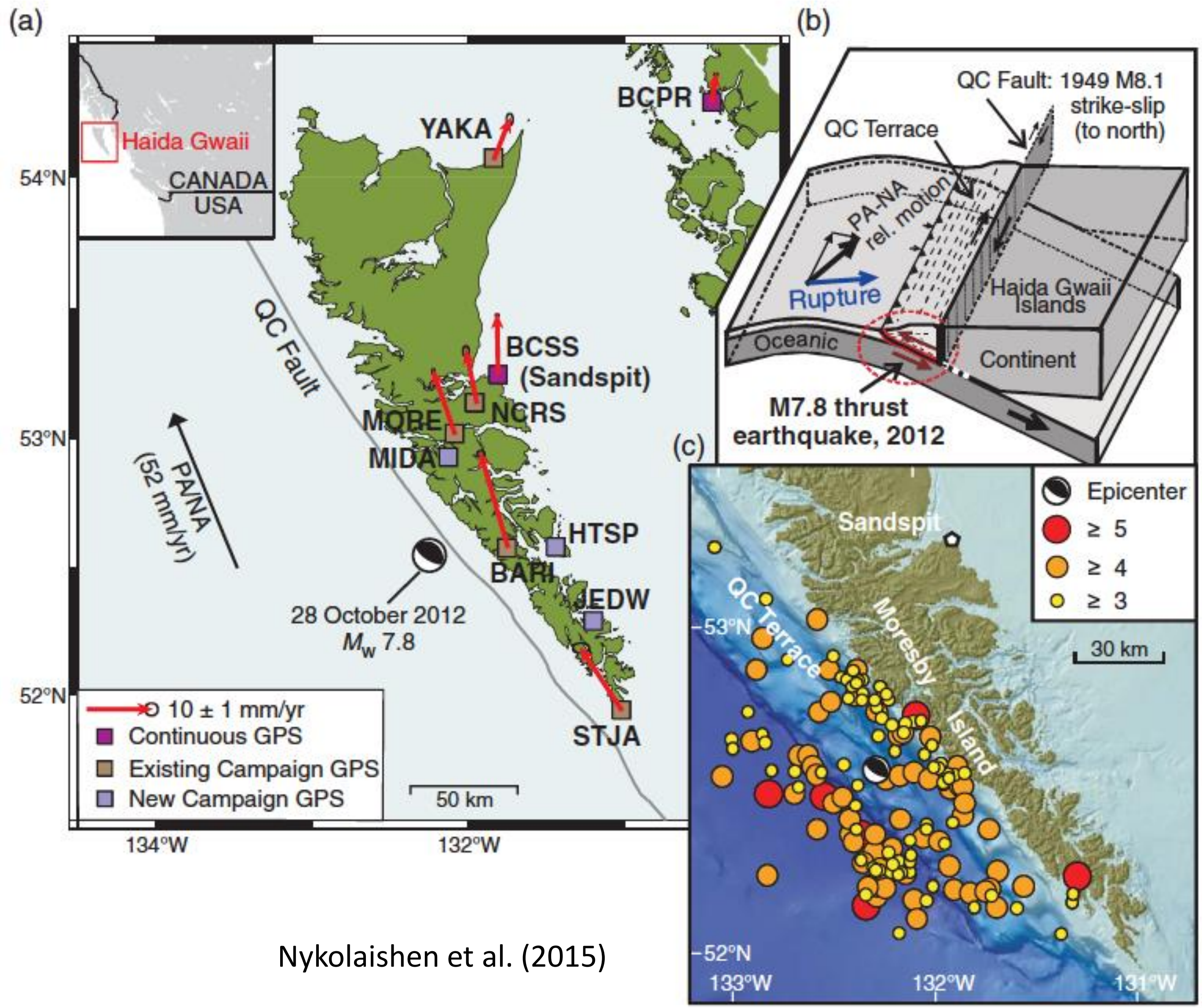
- Crustal fault geometry defined by geological mapping and topographic features
- Slip rates determined from published GPS and paleoseismic observations in Canada and Alaska (Matmon et al., 2006; Leonard et al., 2007)
- Mmax defined by fault area using average of five active crustal A to M_W scaling relationships
- Mmin of M_W 6.5
- Faults assume 0.5 G-R, 0.5 "Characteristic" weighting

Active Faults – Offshore



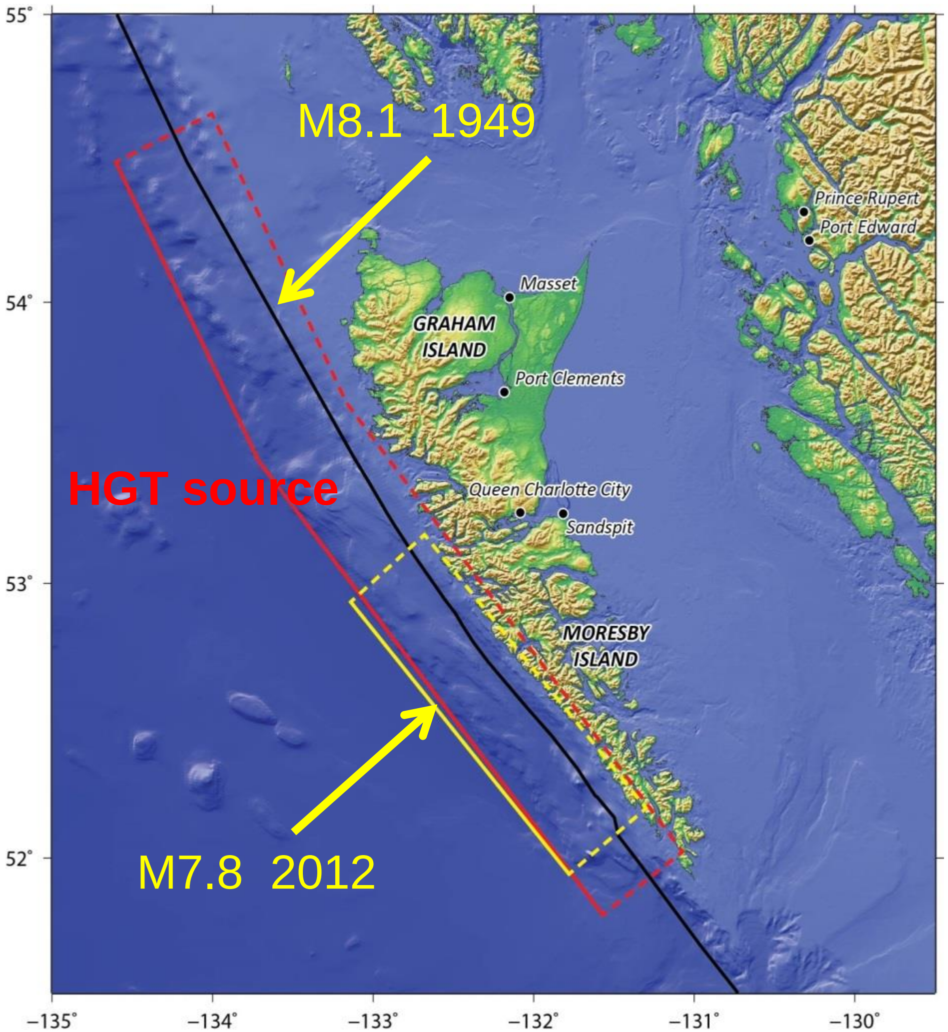
- Queen Charlotte (QCF) & Fairweather (FWF) transform faults:
  - Slip rates from GPS slip rates
  - Assumed 5% of slip due to off-fault seismicity (i.e. aerial source)
- Included Haida Gwaii thrust (HGT) source:
  - Source of the 2012 MW 7.8 event
  - Convergence of approx. 13 mm/a (Mazzotti et al., 2003)
  - Source area based on length of accretionary wedge
  - Estimated Mmax 8.0
- Included Winona thrust (WIN) source:
  - Assumed convergence of 13 mm/a (Leonard et al., 2012)
  - Is Winona active?
  - 0.25 G-R; 0.25 Characteristic; 0.5 Aseismic

2012-10-28 M_W 7.8 Earthquake



Nykolaishen et al. (2015)

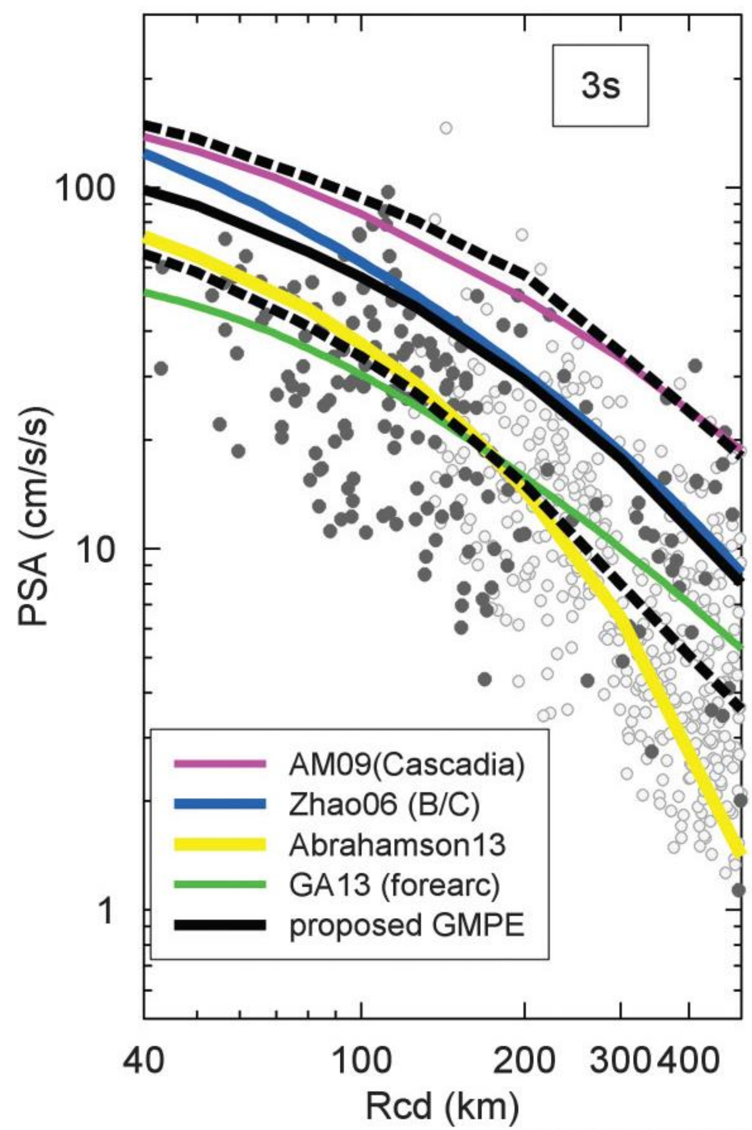
New Haida Gwaii Thrust Fault Source



- Northern segment of HGT has not ruptured
- The case could be made for treating southern segment as time-dependent

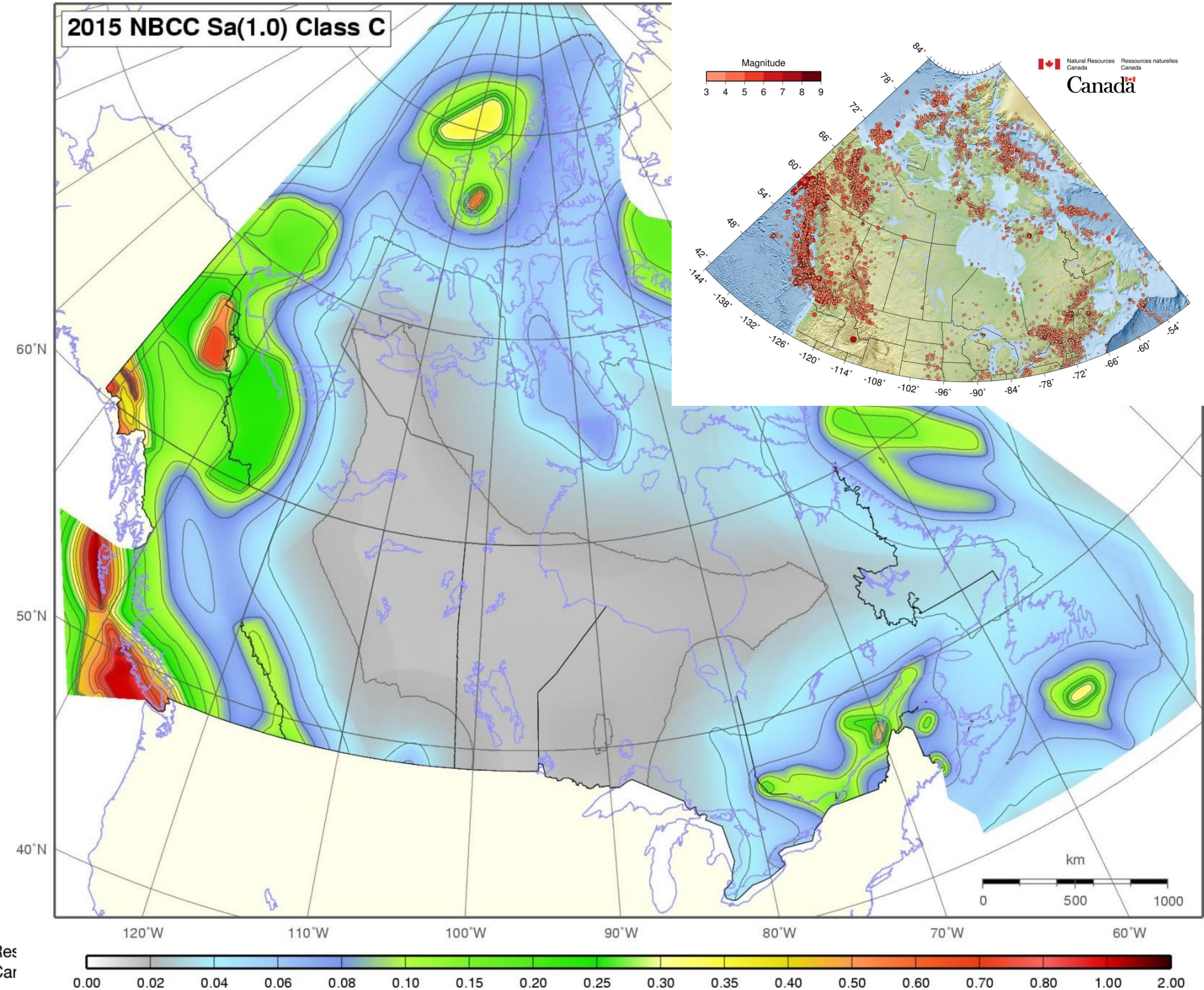
Ground Motion Models

- "Representative suite" vs weighted GMM approach
  - Atkinson and Adams (2013) Can. J. Civ. Eng.
- 4-5 GMMs for any tectonic environment
- Approach gives similar hazard results as a weighted-GMM approach with same GMMs (Atkinson *et al.*, 2014)
- Approach is simpler to compute

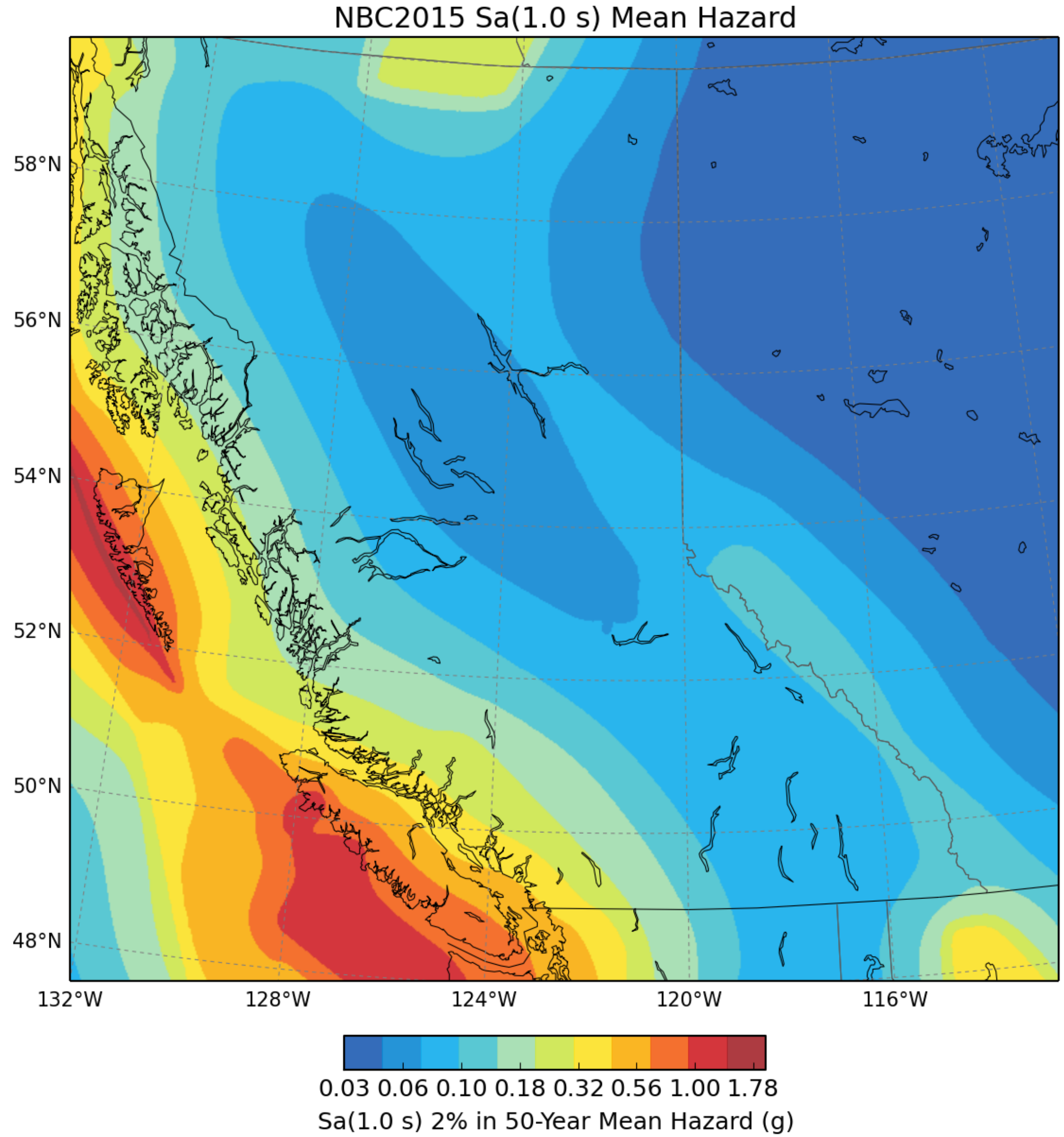


2015 Long-Period Hazard Map

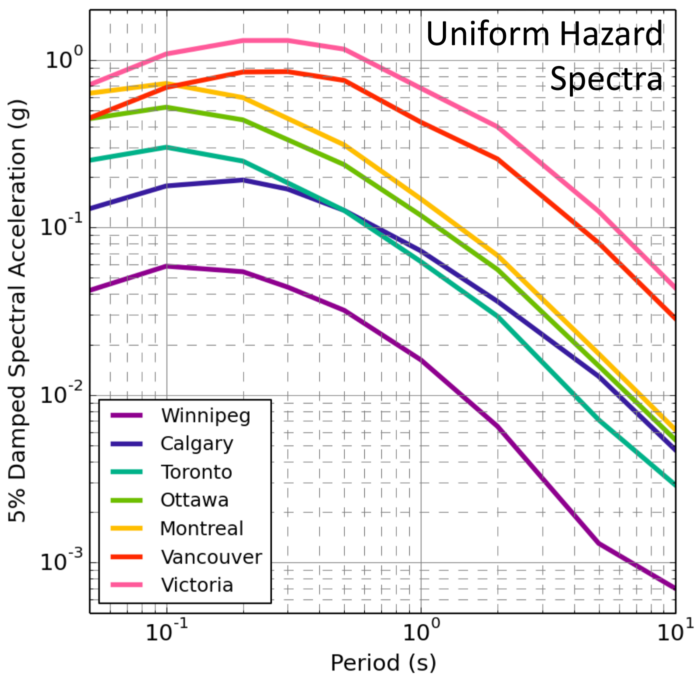
Sa(1.0);
2% / 50 year;
Site Class C



2015 NBCC Hazard Example

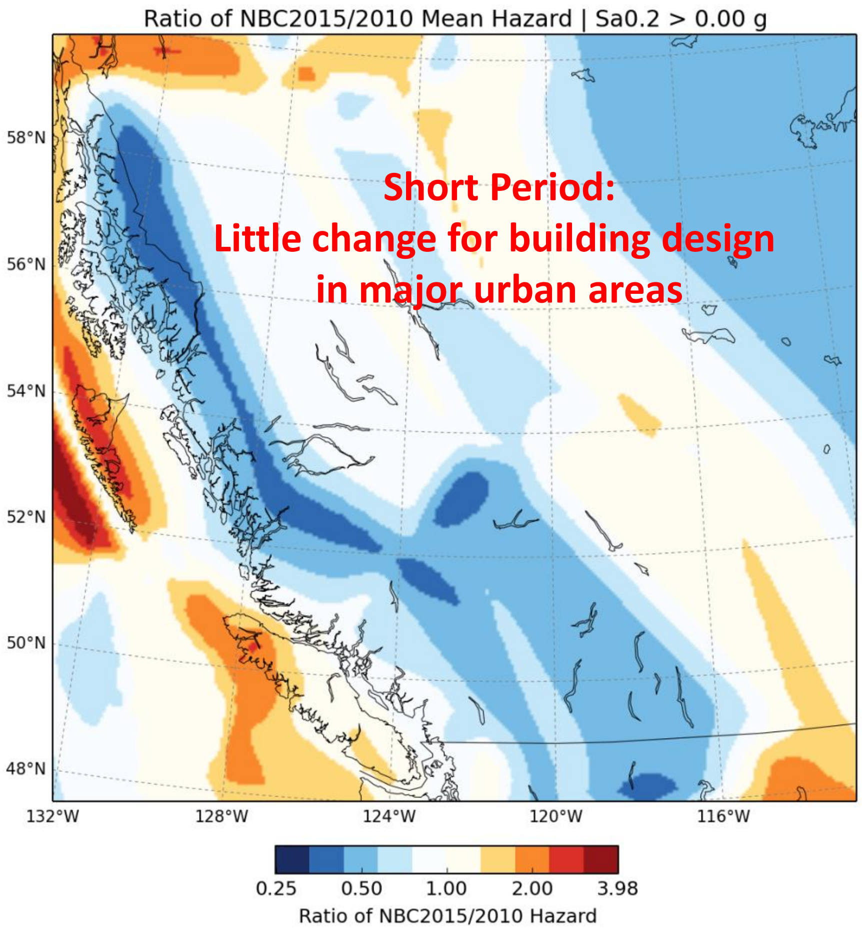


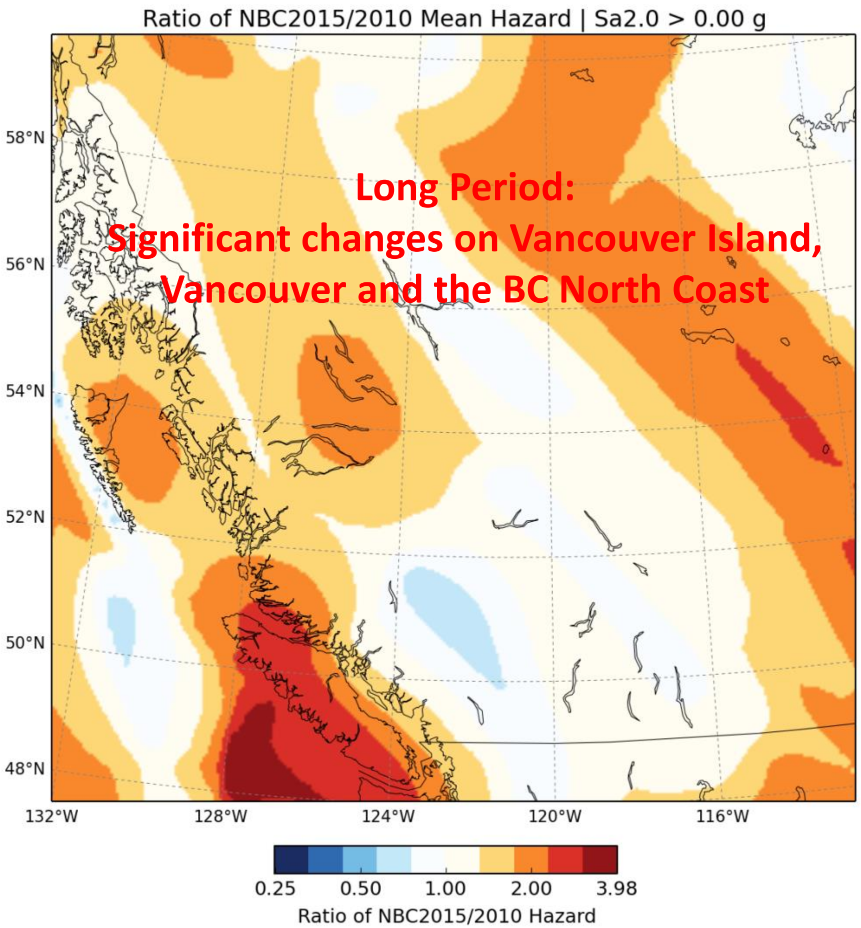
- Major contributors to seismic hazard in western Canada are the Cascadia subduction zone and the Queen Charlotte Fault system
- New fault sources included in 2015 NBC: Explorer segment, Winona basin & Haida Gwaii thrust



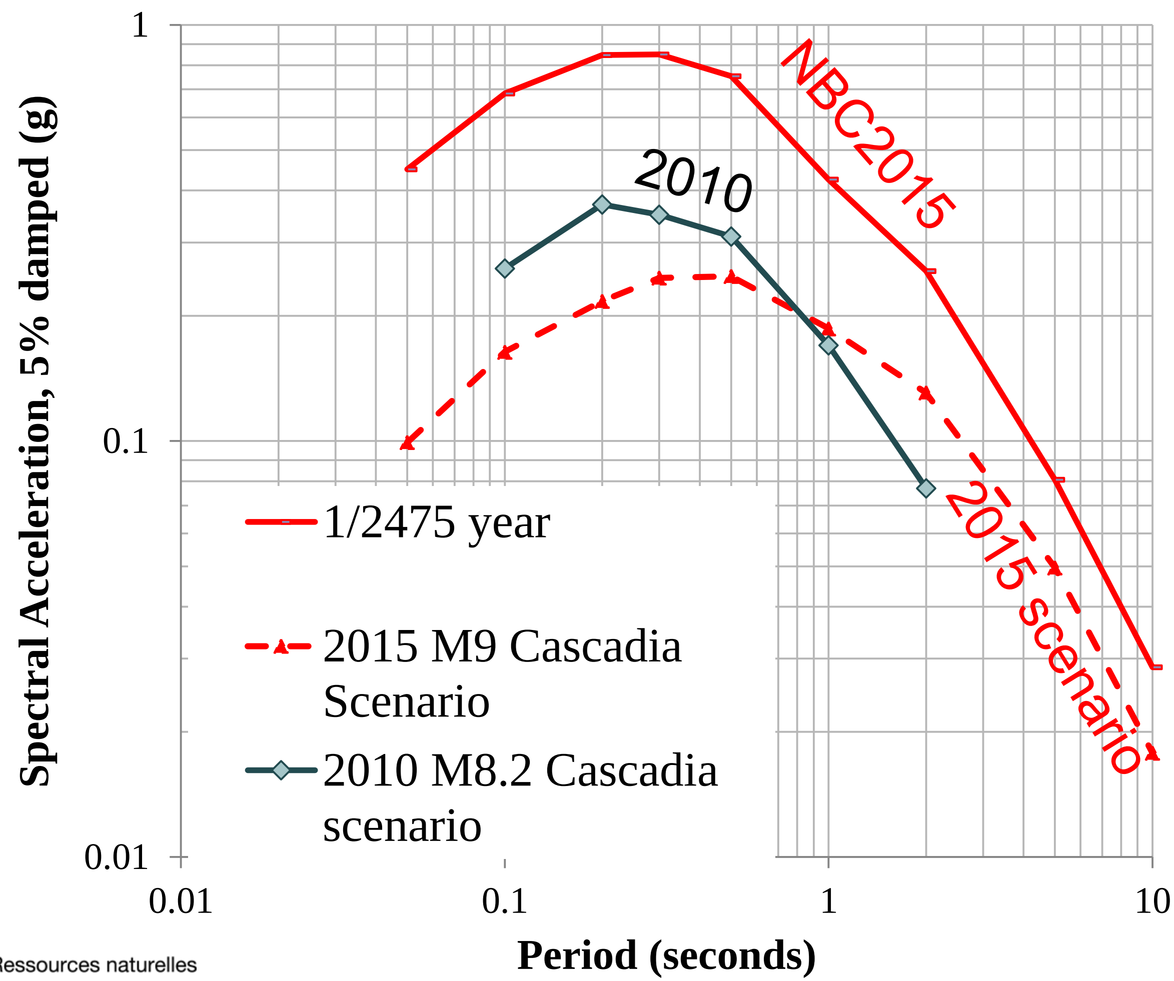
NBC 2015/2010 Changes

- Ratios of 2015/2010 hazard values for different periods of ground shaking
- Low rise (1-3 story) residential are most affected by short-period motions
- High-rise buildings, large & horizontal infrastructure (e.g. pipelines) affected by long-period motions

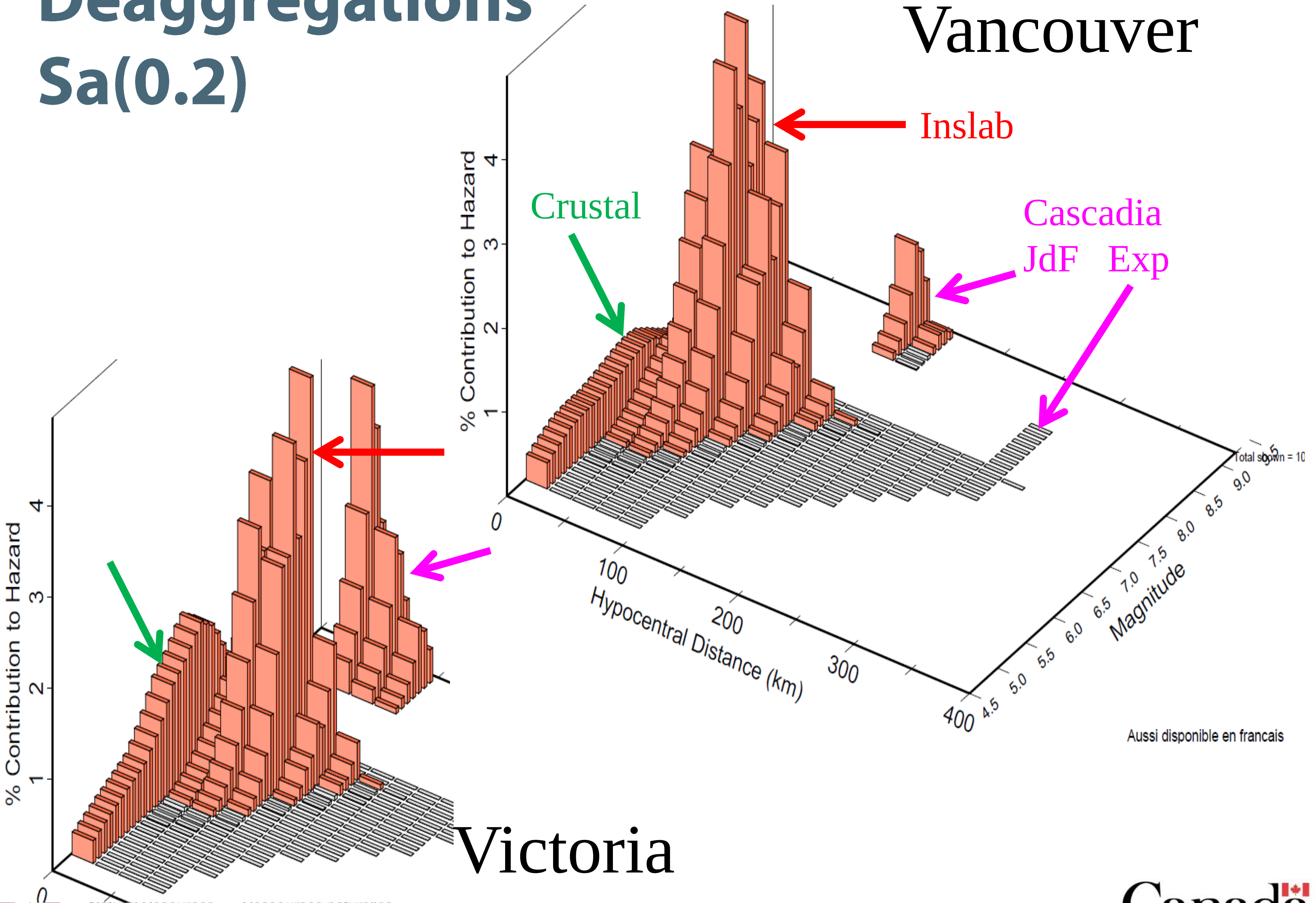




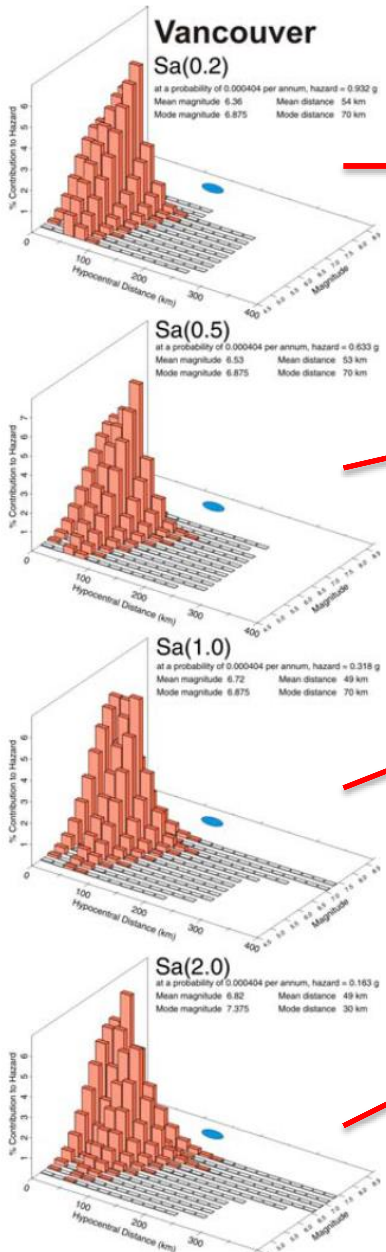
NBC 2015 Vancouver UHS vs 2010 and 2015 Cascadia (JdF) Scenarios



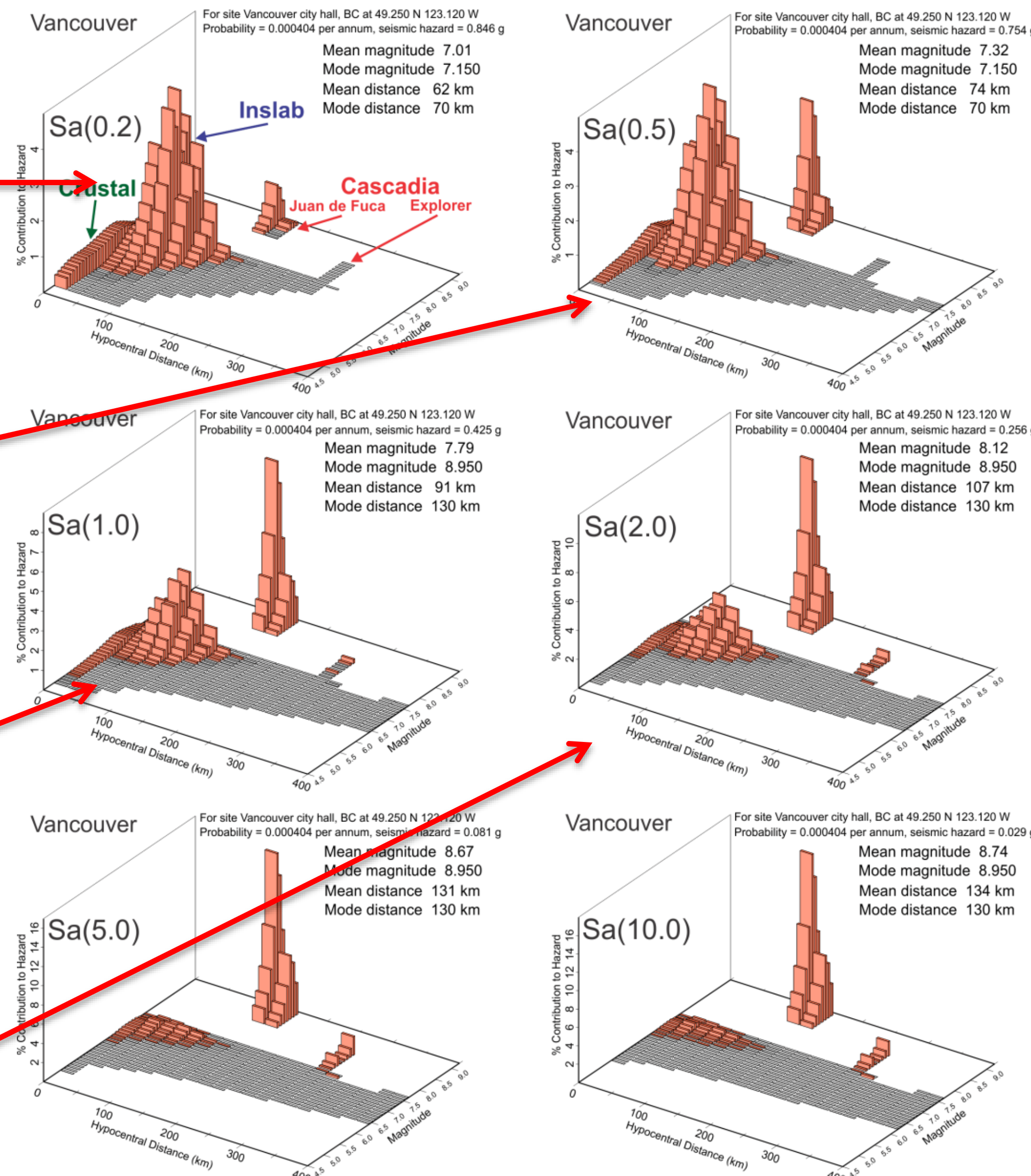
Deaggregations Sa(0.2)



2010 vs 2015

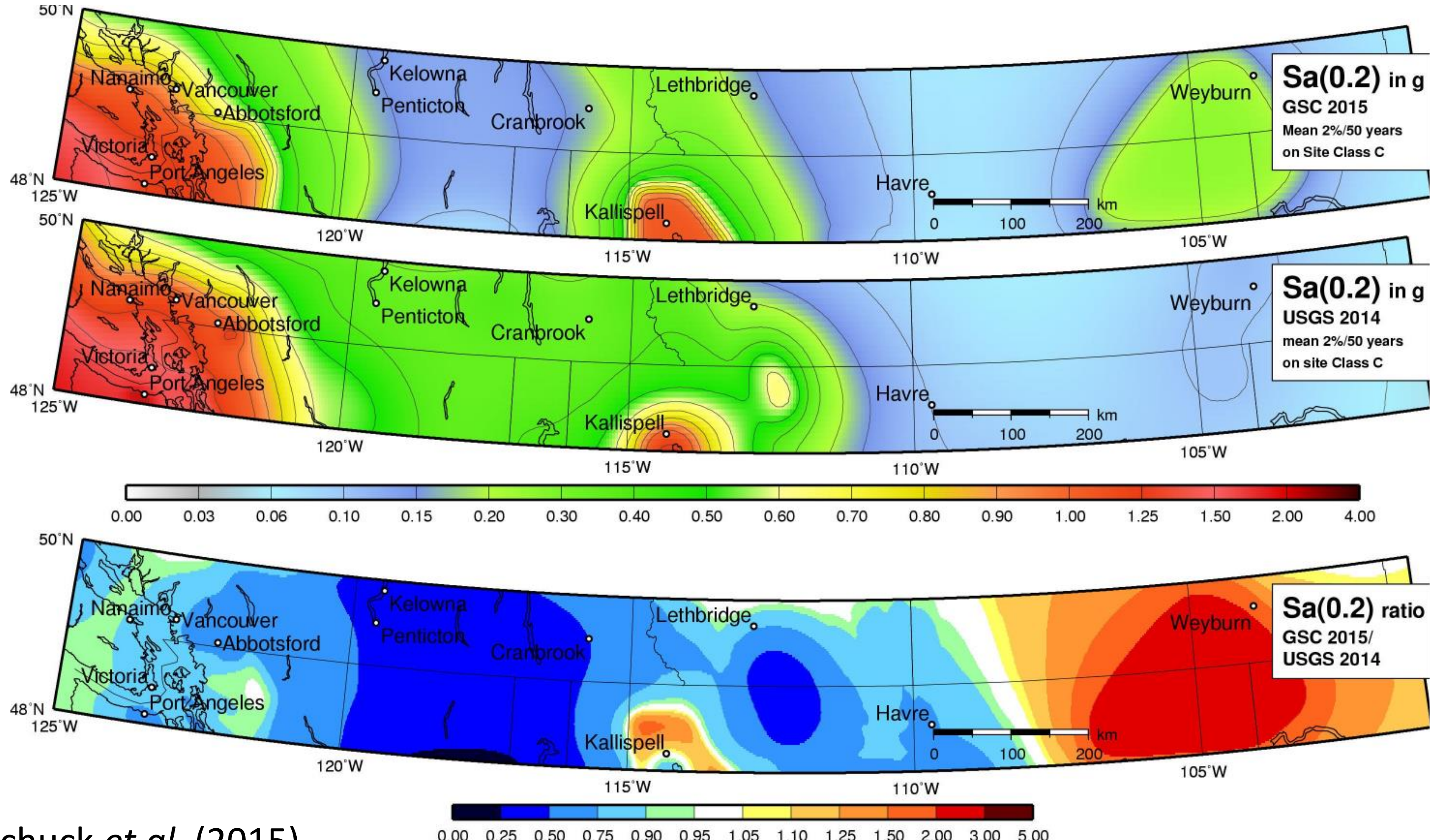


Halchuck et al (2007)



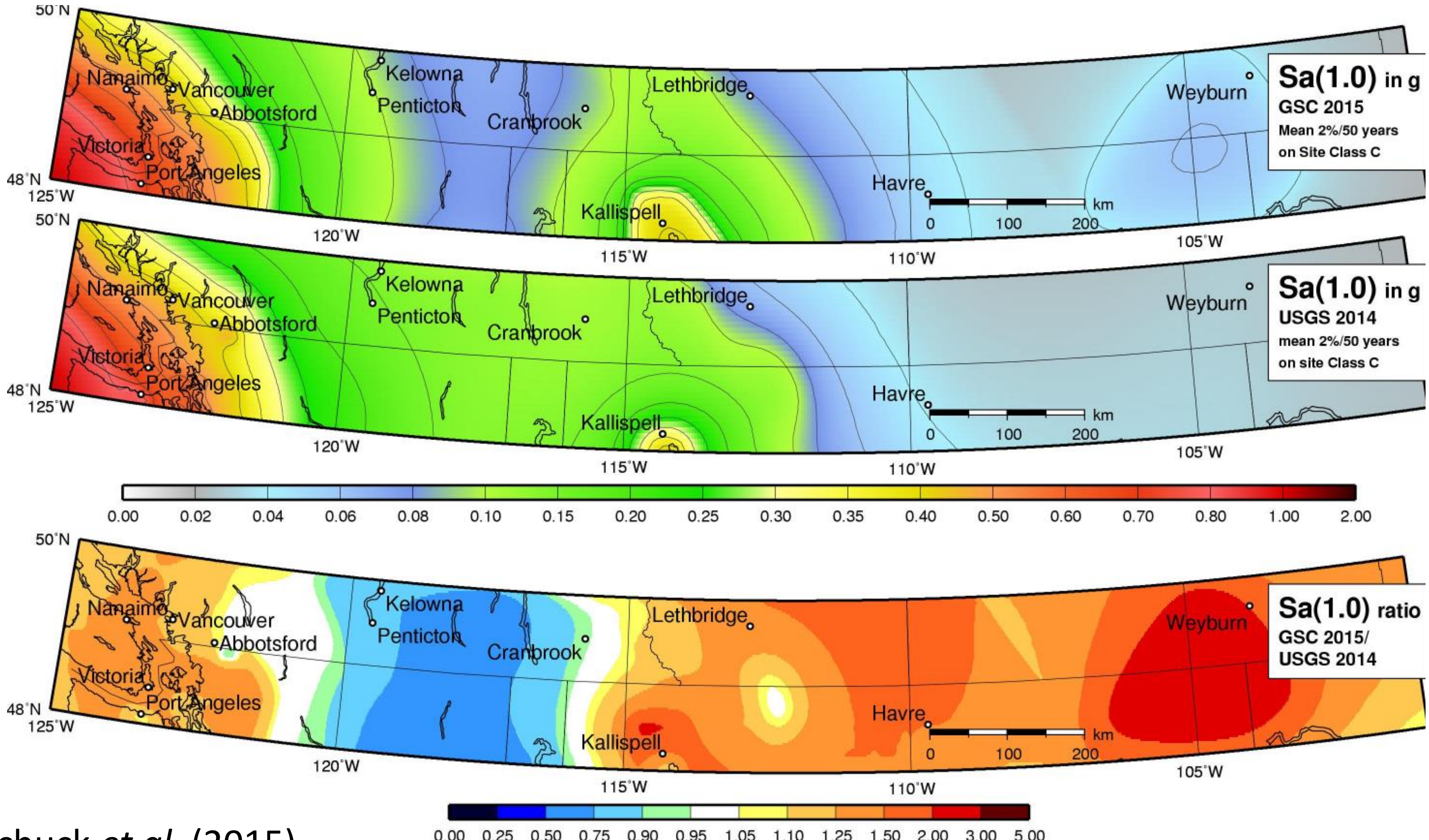
Rogers et al (2015)

NRCan/USGS Cross Border Comparison (0.2 s) – Pacific Northwest



Halchuck *et al.* (2015)

NRCan/USGS Cross Border Comparison (1.0 s) – Pacific Northwest



Halchuck *et al.* (2015)

Western border region cities comparison

Location	GSC Sa(0.2)	USGS Sa(0.2)	GSC/USGS	GSCC Sa(1.0)	USGS Sa(1.0)	GSC/USGS
Vancouver, BC	0.85	1.1	0.78	0.42	0.42	1.0
Victoria, BC	1.3	1.5	0.85	0.68	0.62	1.1
Seattle, WA	-	1.8		-	0.60	
Kelowna, BC	0.14	0.33	0.44	0.091	0.14	0.65
Spokane, WA	-	0.36		-	0.14	

USGS values adjusted to NBC Soil Class C (Vs30=450 m/s)

Soil Factors

- In 1985 NBC used Rock or Firm Ground
- In 2005 Fa and Fv factors were introduced:
  - reference condition = Site Class C
- For 2015:
  - The reference ground condition remains Site Class C
  - now specified as having a V_{S30} of 450 m/s
  - Fa and Fv values are replaced by F(T)

Limitations with Fa and Fv

- Based on pre-1994 data
- Averaged over period ranges & not very precise at every period:
  - Fa 0.1-0.5 s; Fv 0.4-2.0 s
- Fa was a mean factor but Fv was a mean plus 1 sigma factor
- No factor for PGA (often Fa used as a proxy)
- No obvious factor applicable for 5 and 10 s values

F(T) Factors for NBC2015

- Fa and Fv have been replaced by F(T)
  - equivalent F(PGA) and F(PGV) factors have been added
- The amplification factors are based on soil records from the Next Generation Attenuation-West1 database
  - Note: NGA-West2 data and models now available
- For consistency with the backbone GMM used for western crustal earthquake shaking, F(T) values are taken from Boore-Atkinson 2008

Application of F(T): PGA_{ref}

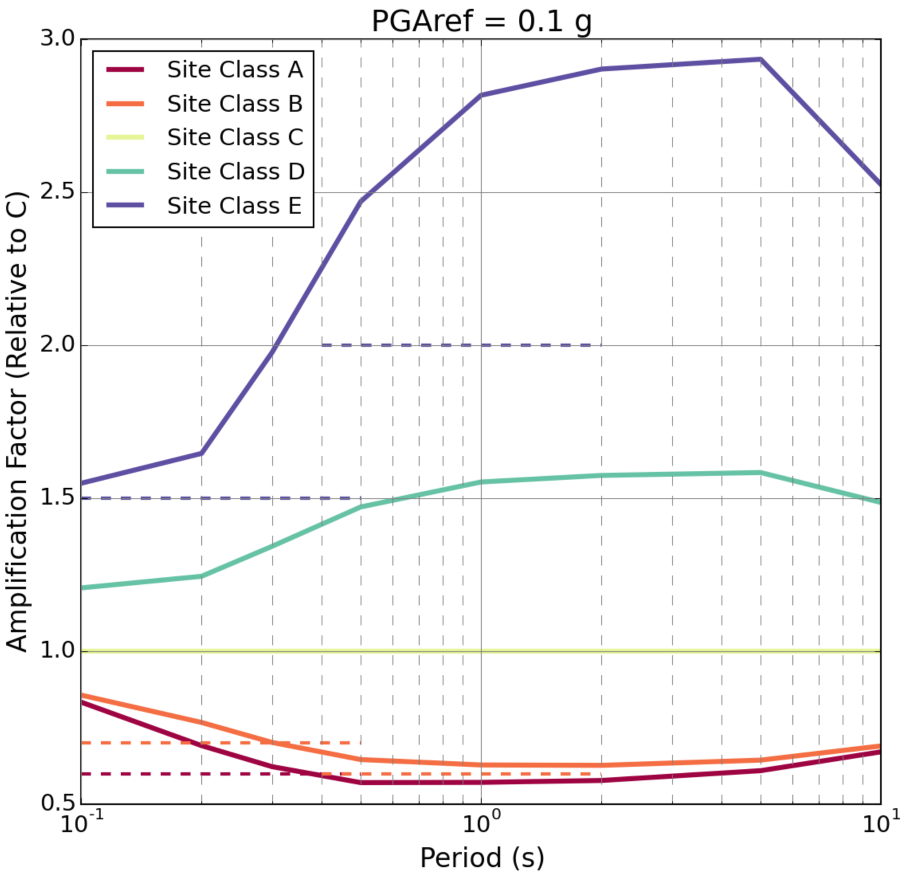
- The old Fa and Fv tables were functions of soil class and Sa(0.2 s) and Sa(1.0 s) shaking intensity respectively
- New F(T) tables are tied to PGA
- An adjustment is required because equivalent PGA values are associated with less damaging shaking in eastern Canada

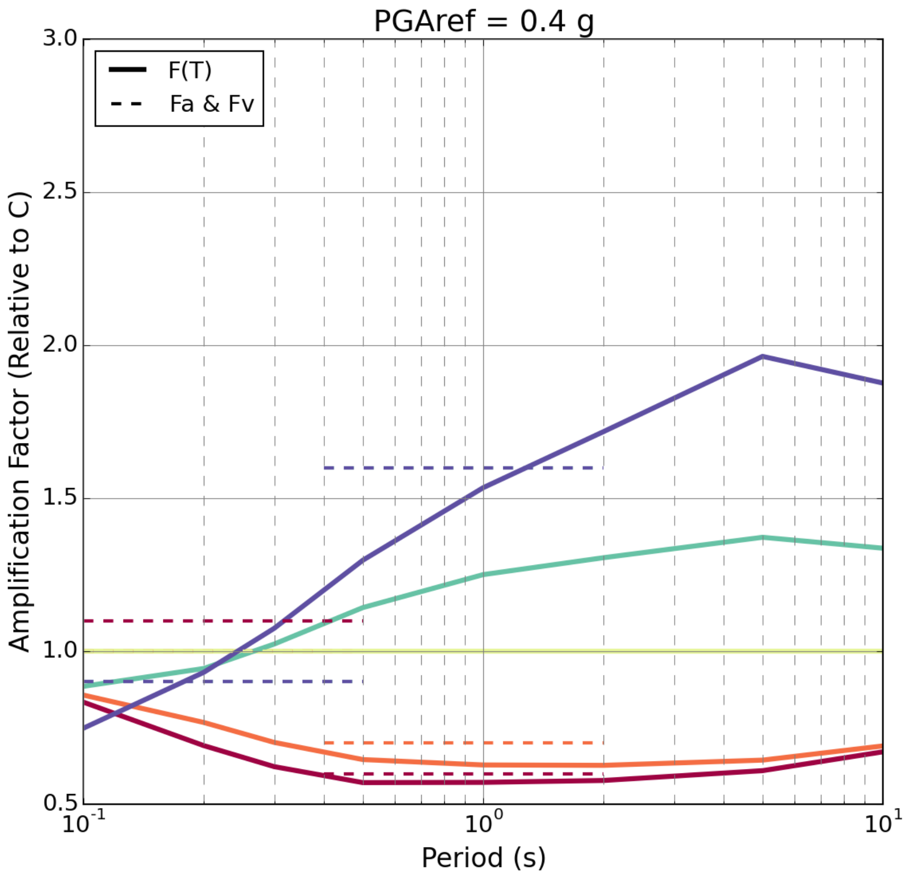
From the NBC:

- 4.1.8.4 Sentence 4. For the purposes of determining the values of F(T) to be used in the calculation of design spectral acceleration, S(T), in Sentence 4.1.8.4.(9), and of F(PGA) and F(PGV), the value of PGA_{ref} to be used with Tables 4.1.8.4.B. to 4.1.8.4.I. shall be taken as:
  - a) 0.8 PGA where the ratio Sa(0.2)/PGA < 2.0 (i.e. East), and
  - b) 1.0 PGA otherwise (i.e. West).

F(T) Factors for NBC2015

Relative to Site Class C





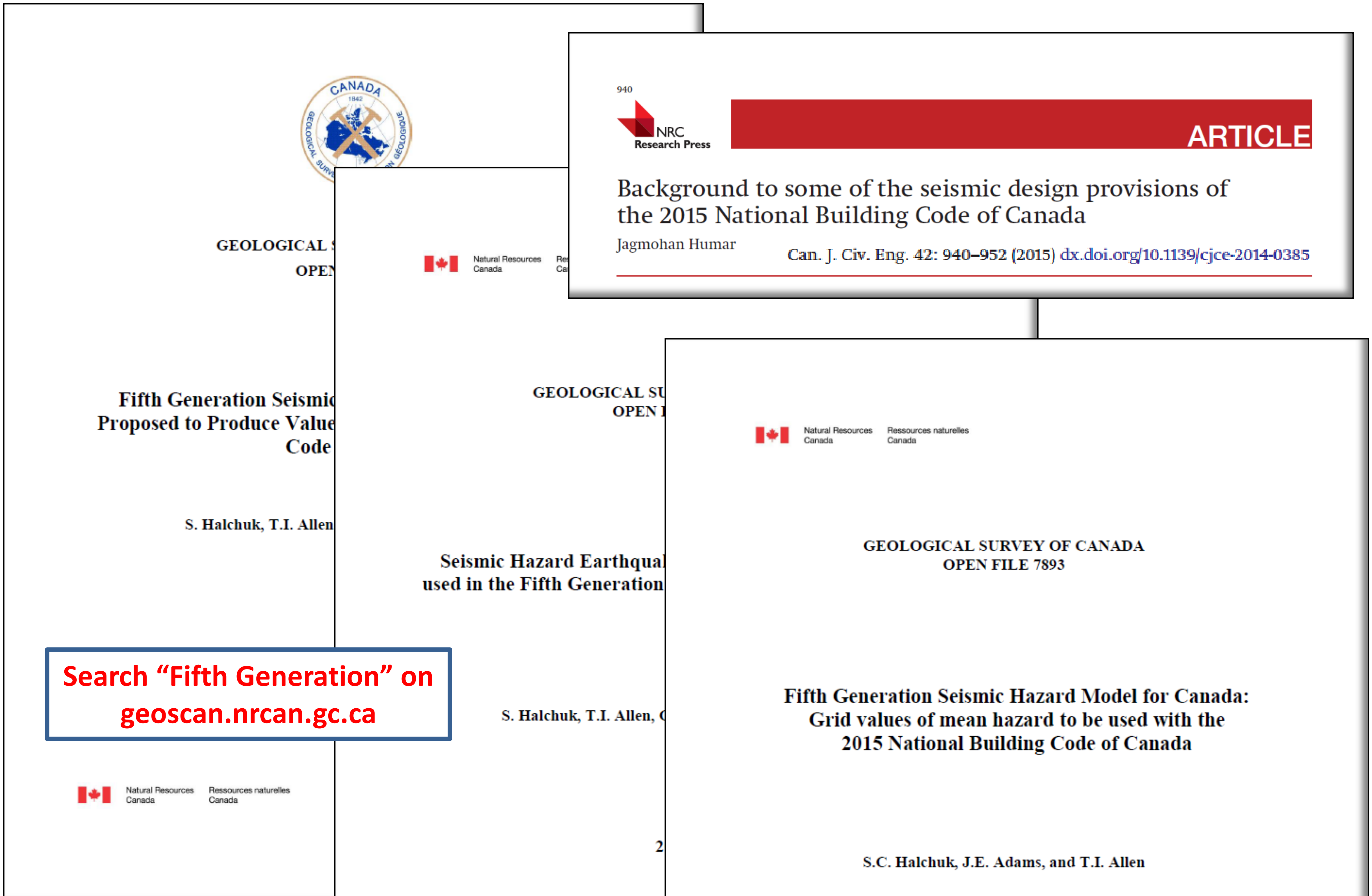
F(T) Factors for NBC2015

Site Class	Values of F(T) for T = 1.0				
	PGAref ≤ 0.1	PGAref = 0.2	PGAref = 0.3	PGAref = 0.4	PGAref≥0.5
A	0.57	0.57	0.57	0.57	0.57
B	0.63	0.63	0.63	0.63	0.63
C	1.0	1.0	1.0	1.0	1.0
D	1.55	1.39	1.31	1.25	1.21
E	2.82	2.08	1.74	1.53	1.39

Take Home Messages

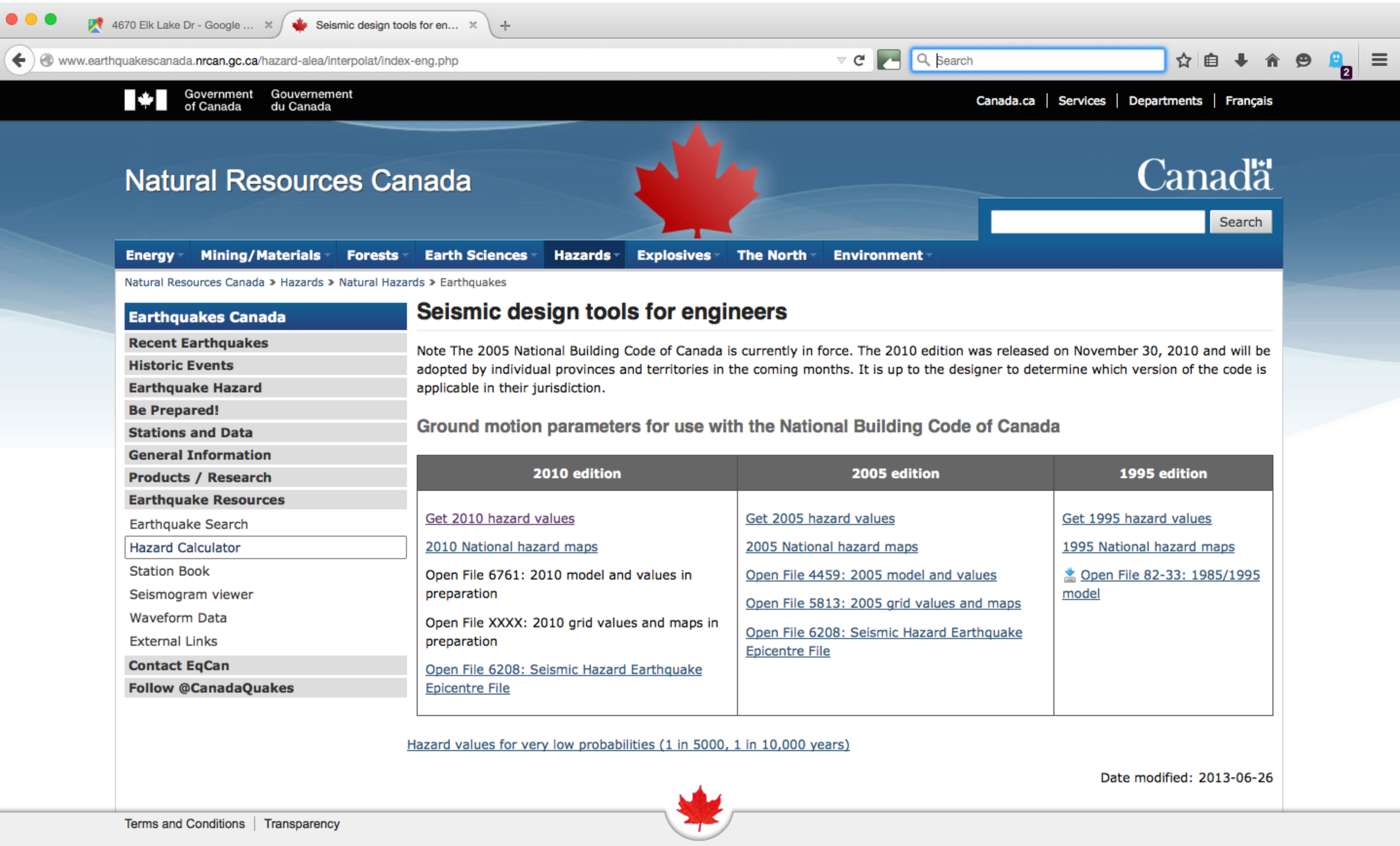
- New seismic hazard model has had its first significant update since 2005:
  - Updated catalogue
  - Revised area sources
  - New fault sources
- New ground-motion models (Atkinson & Adams, 2013)
- Long-period hazard increases in Victoria & Vancouver due to the probabilistic Cascadia source
- Short period hazard on the west coast is dominated by in-slab sources
- NBC soil factors Fa & Fv have been replaced by F(T)

2015 NBC Documentation



Search "Fifth Generation" on geoscan.nrcan.gc.ca

Web Tools (to be updated)



4670 Elk Lake Dr - Google ...

Seismic design tools for en...

www.earthquakescanada.nrcan.gc.ca/hazard-alea/interpolat/index-eng.php

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Seismic design tools for engineers

Note The 2005 National Building Code of Canada is currently in force. The 2010 edition was released on November 30, 2010 and will be adopted by individual provinces and territories in the coming months. It is up to the designer to determine which version of the code is applicable in their jurisdiction.

Ground motion parameters for use with the National Building Code of Canada

2010 edition	2005 edition	1995 edition
Get 2010 hazard values	Get 2005 hazard values	Get 1995 hazard values
2010 National hazard maps	2005 National hazard maps	1995 National hazard maps
Open File 6761: 2010 model and values in preparation	Open File 4459: 2005 model and values	Open File 82-33: 1985/1995 model
Open File XXXX: 2010 grid values and maps in preparation	Open File 5813: 2005 grid values and maps	
Open File 6208: Seismic Hazard Earthquake Epicentre File	Open File 6208: Seismic Hazard Earthquake Epicentre File	

Hazard values for very low probabilities (1 in 5000, 1 in 10,000 years)

Date modified: 2013-06-26

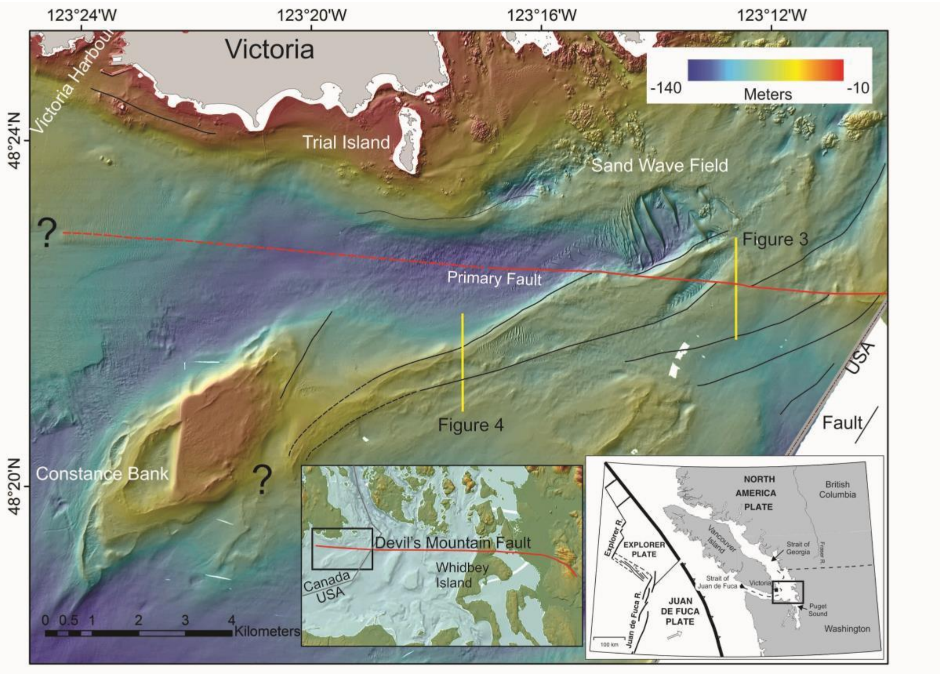
Terms and Conditions | Transparency

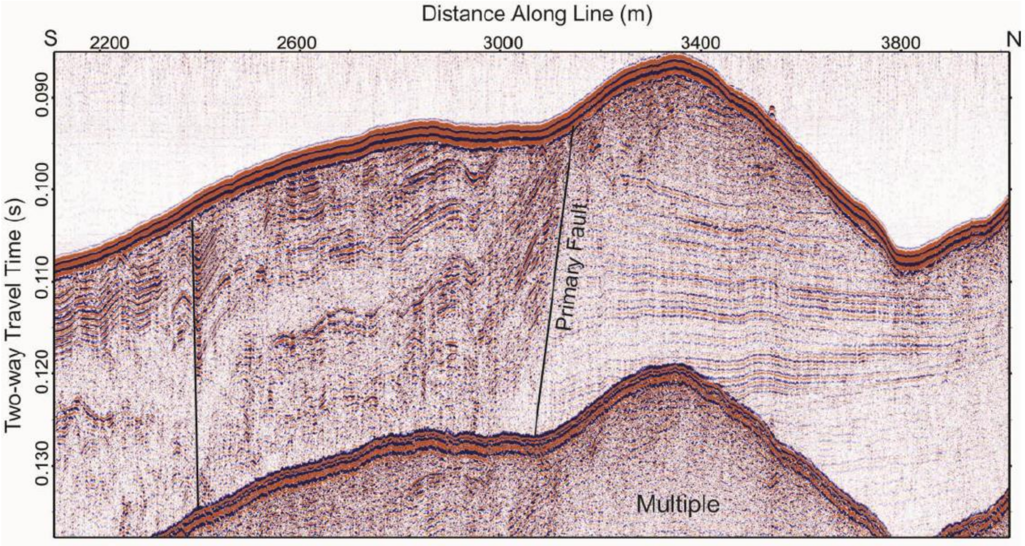
NBC 2020: Research Priorities

- Adopt new PSHA software (e.g. OpenQuake/USGS)
- Harmonised AK-Canada-USA earthquake catalogue
- Assessment and/or development of new ground-motion attenuation models
- Identification of crustal faults
- Evaluation/inclusion of smoothed seismicity models
- Evaluate sensitivity of catalogue declustering
- Explore risk-targeted hazard (Allen et al., 2015)
- Inclusion of induced seismicity (e.g., Atkinson et al., 2015)

Crustal Faults - Devil's Mountain Fault

- The Devil's Mountain Fault has recently been extended from mainland North America to just off the Victoria coast
- 6 km wide deformation front west of the Canada/US border
- Holocene activity has disrupted upper Quaternary strata
- Potential of producing earthquakes of magnitude 7 or larger
- How do we include this in PSHA assessments?





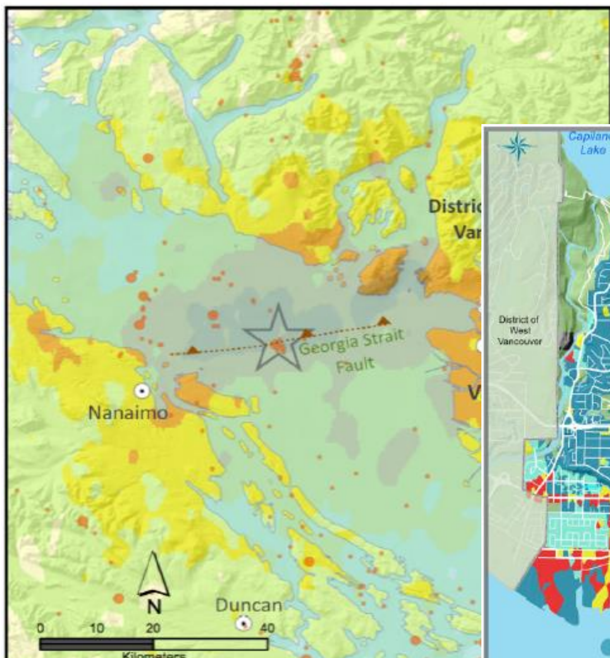
Barrie & Greene (2015)

Induced Seismicity

- Several cases of earthquakes potentially triggered by hydro-fracturing **(not wastewater injection)**:
  - M_W 4.6 Fox Creek, Alberta (June 2015)
  - M_W 4.6 northern British Columbia (August 2015)
- Several philosophical issues:
  - the appropriateness of the Poisson earthquake process
  - catalogue declustering, earthquake rates, and *b*-value
  - the maximum magnitude of induced events
  - ground motions from shallow induced events
  - the frequency of hazard model updates

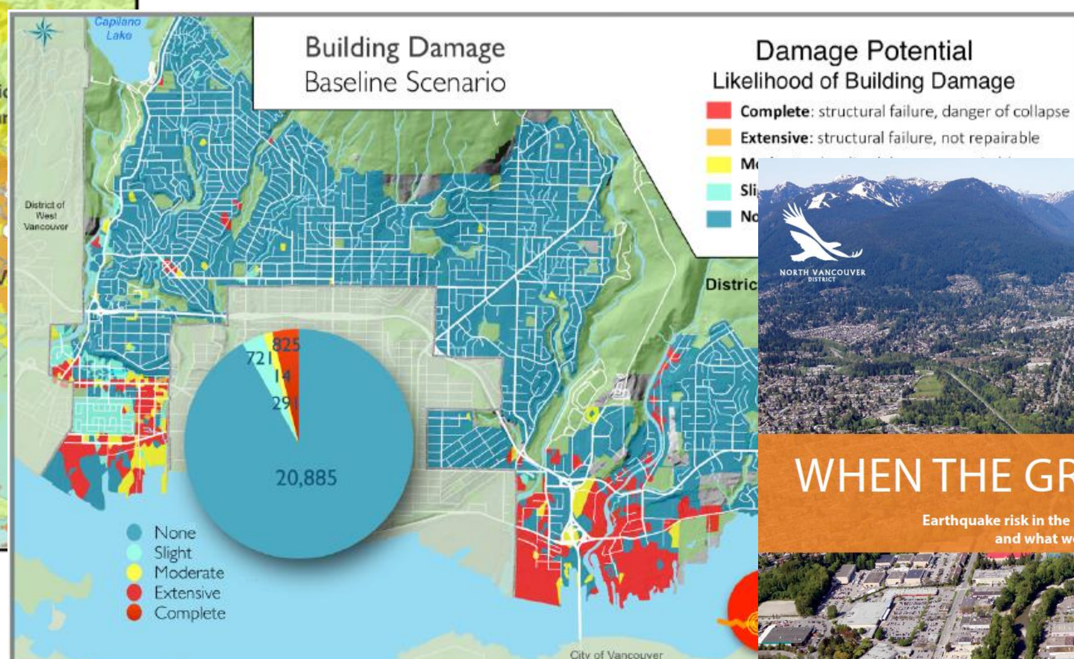
Community Resilience Planning – How Can VGS Help?

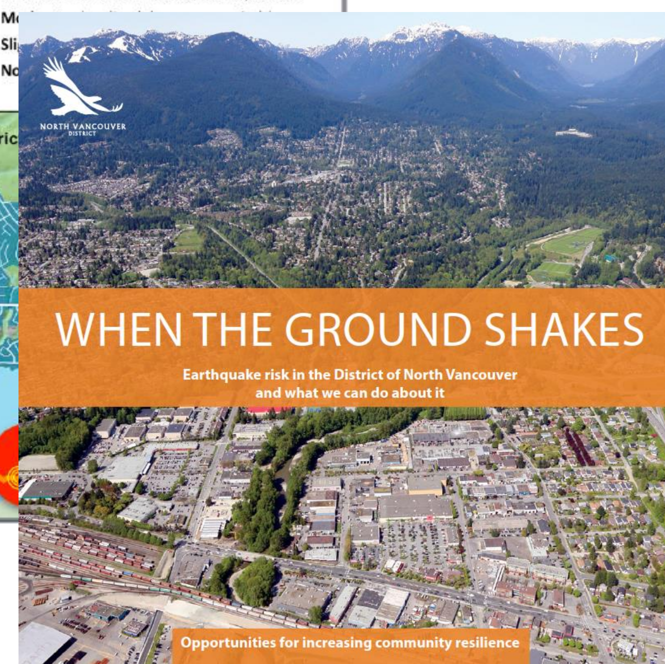
- Canadian adaptation of Hazus used to assess losses for an earthquake scenario in the Strait of Georgia
- Mainstreaming disaster risk planning for the District of North Vancouver



Journeay & Dercole (2015)

- Geotechnical records are critical for reliable risk assessments





QUESTIONS?