Pragmatic choices and wrinkles for implementing PSHA into the National Building Code for Canada

John Adams[1]

john.adams@canada.ca

With major input from Trevor Allen[2] and Stephen Halchuk[1]

1) Geological Survey of Canada, Ottawa, Canada,
2) Formerly Geological Survey of Canada, Sidney, Canada, now Geoscience Australia, Canberra, Australia

PSHA Workshop Lenzburg Switzerland 2017 September 5-7

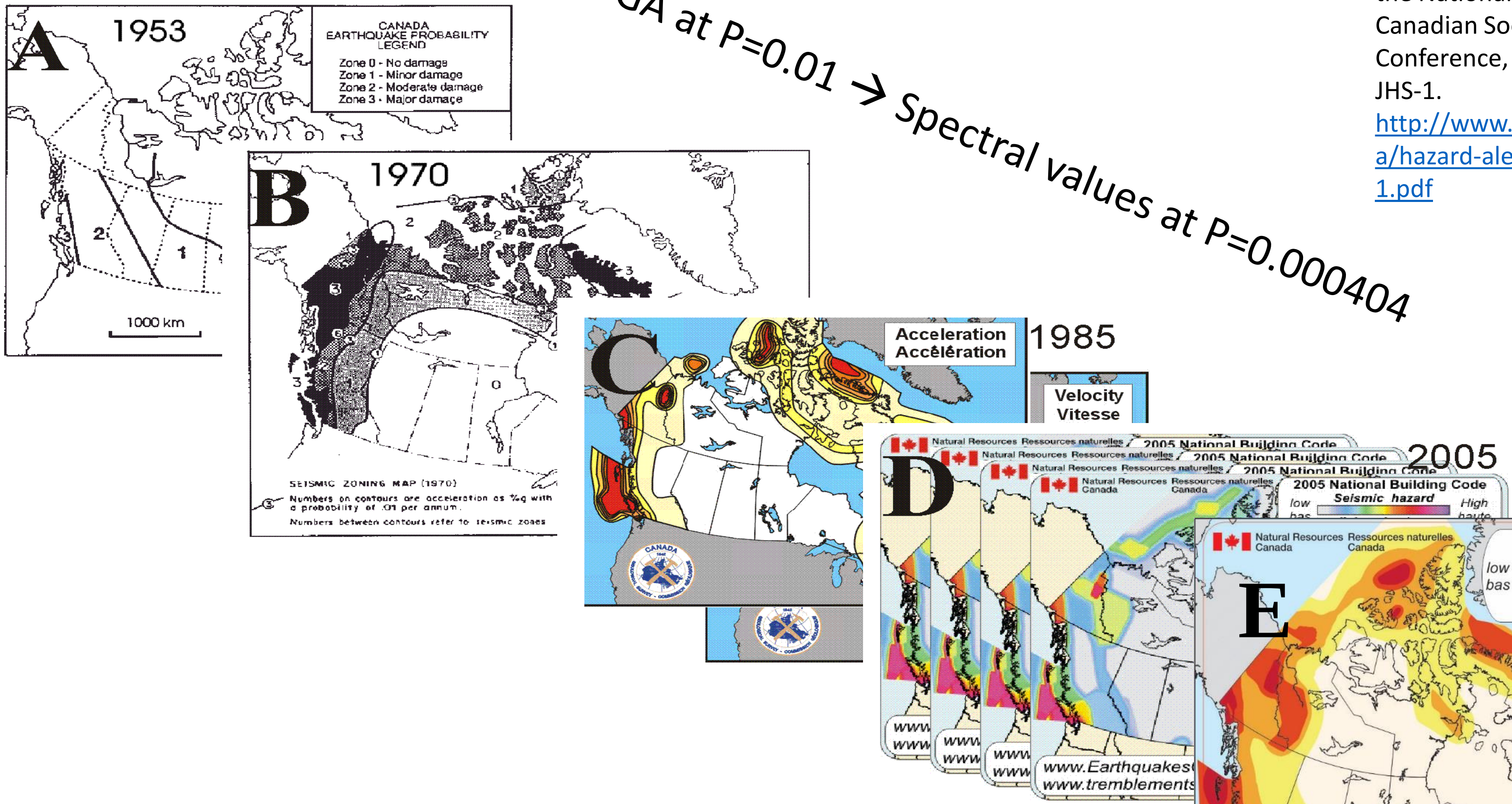
Natural Resources Canada
Ressources naturelles Canada

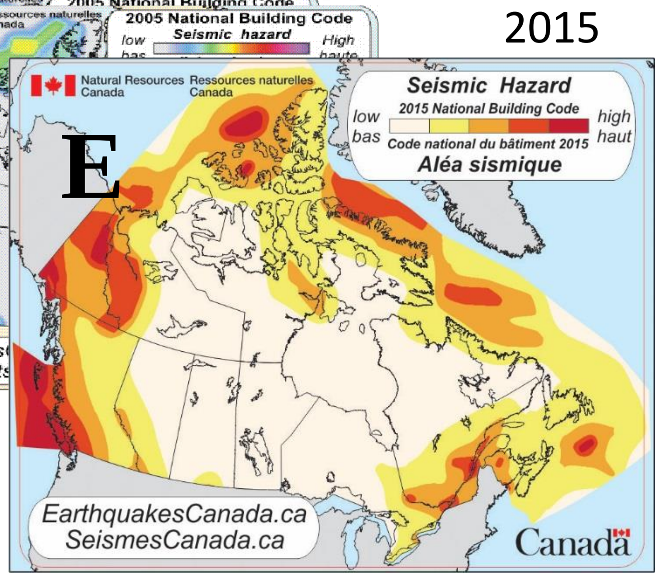
CANADA 1842 GEOLOGICAL SURVEY - COMMISSION GEOLOGIQUE

There are already 5 generations of seismic hazard maps for the National Building Code of Canada*

PGA at P=0.01 → Spectral values at P=0.000404

Adams, J. 2011. Seismic Hazard Maps for the National Building Code of Canada. Canadian Society for Civil Engineering Conference, Ottawa 14-17 July 2011, paper JHS-1. http://www.earthquakescanada.nrcan.gc.ca/hazard-alea/2011CSCE/2011CSCE_JHS-1.pdf





***National Building Code is th**e minimum standard to protect the life and safety of building occupants and the general public as the building responds to strong ground shaking

Successive improvements: for the 5th Generation 2015 model

1. Revised earthquake catalogue in Mw
2. Revised seismic source models
3. Probabilistic treatment of Cascadia and other faults

   Including fault slip rate information & GPS deformation

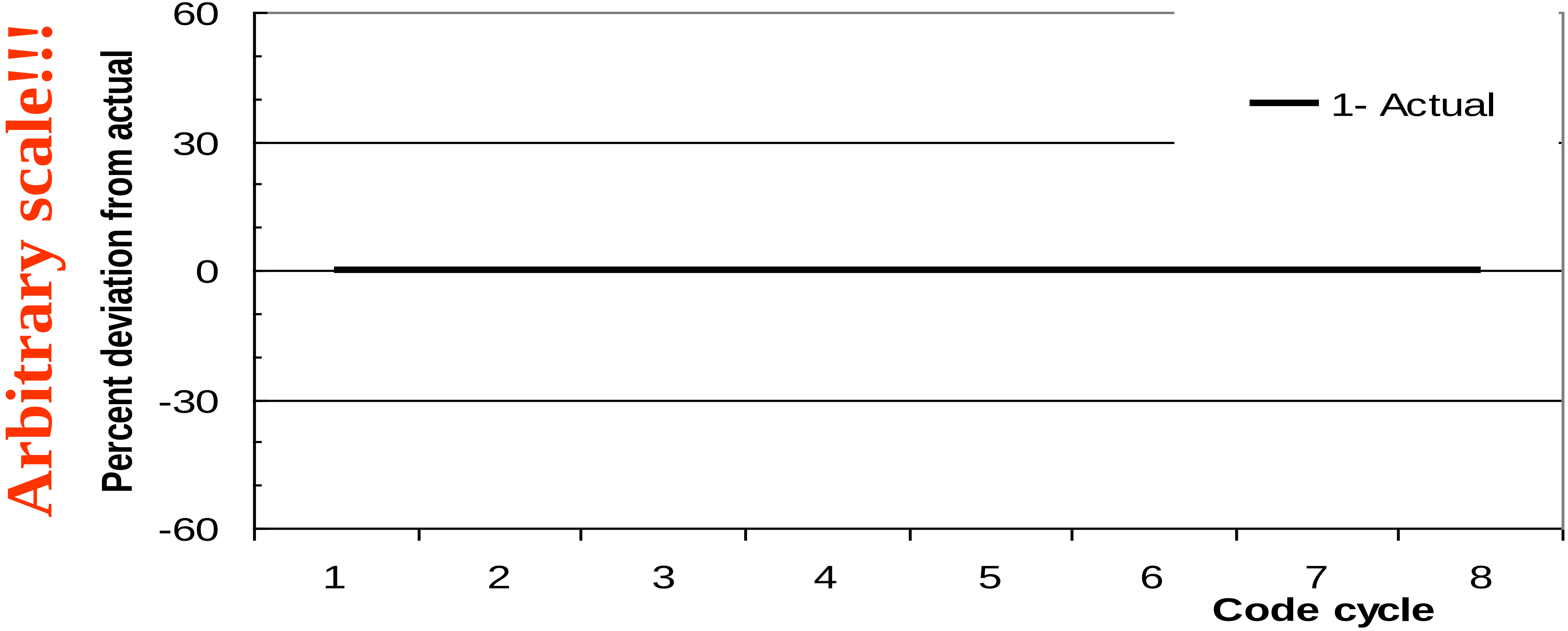
4. New Ground Motion Prediction Equations (GMPEs)
5. New spectral values provided (for longer & shorter periods)
6. Specified reference ground condition (Vs30=450 m/s)
7. F(T) soil factors replacing Fa and Fv

What do engineers need/want*?

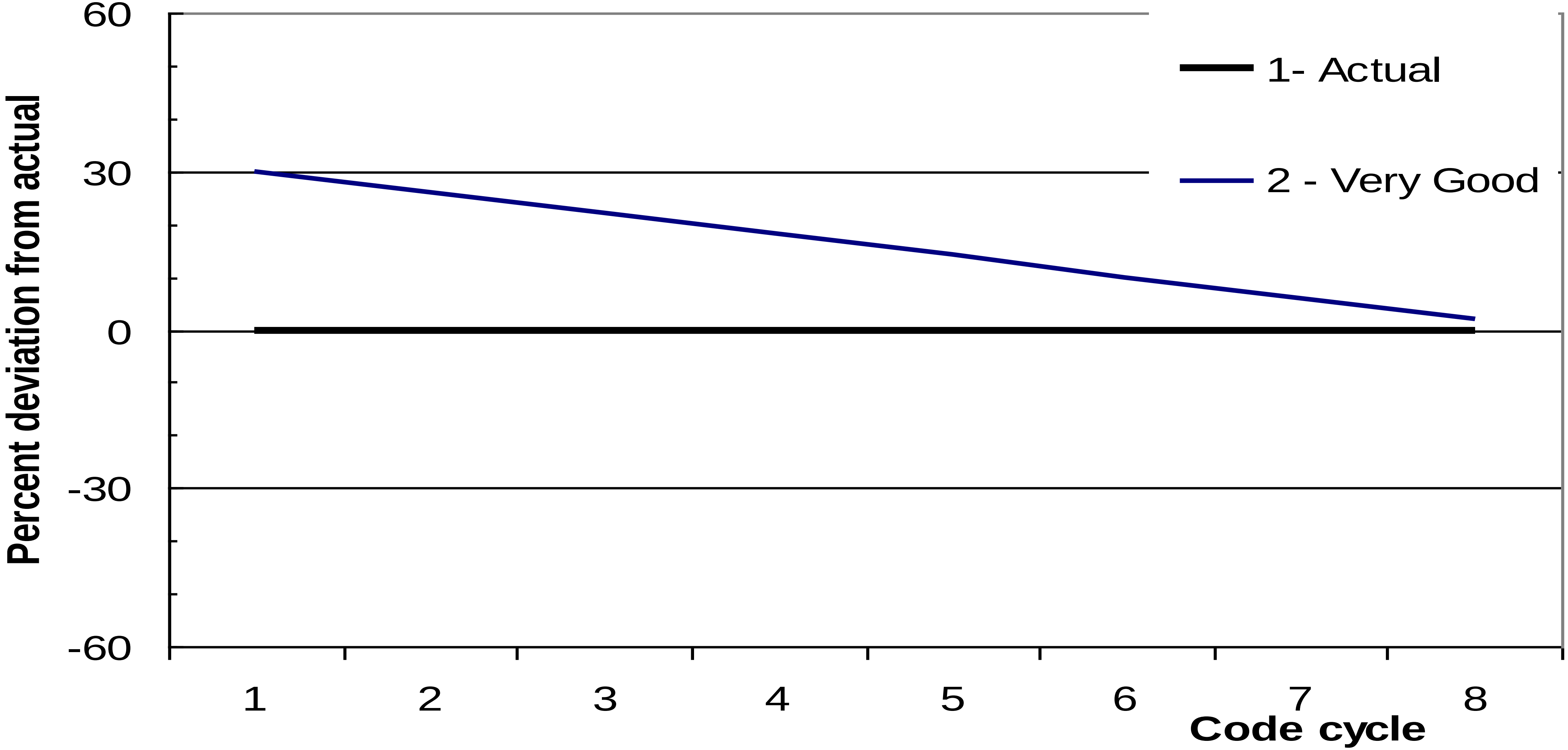
- Simple — "as simple as possible, as complicated as necessary"
- Fair — distributes consequences appropriately
- Stable — monotonic changes, once a decade

*a seismologist's view

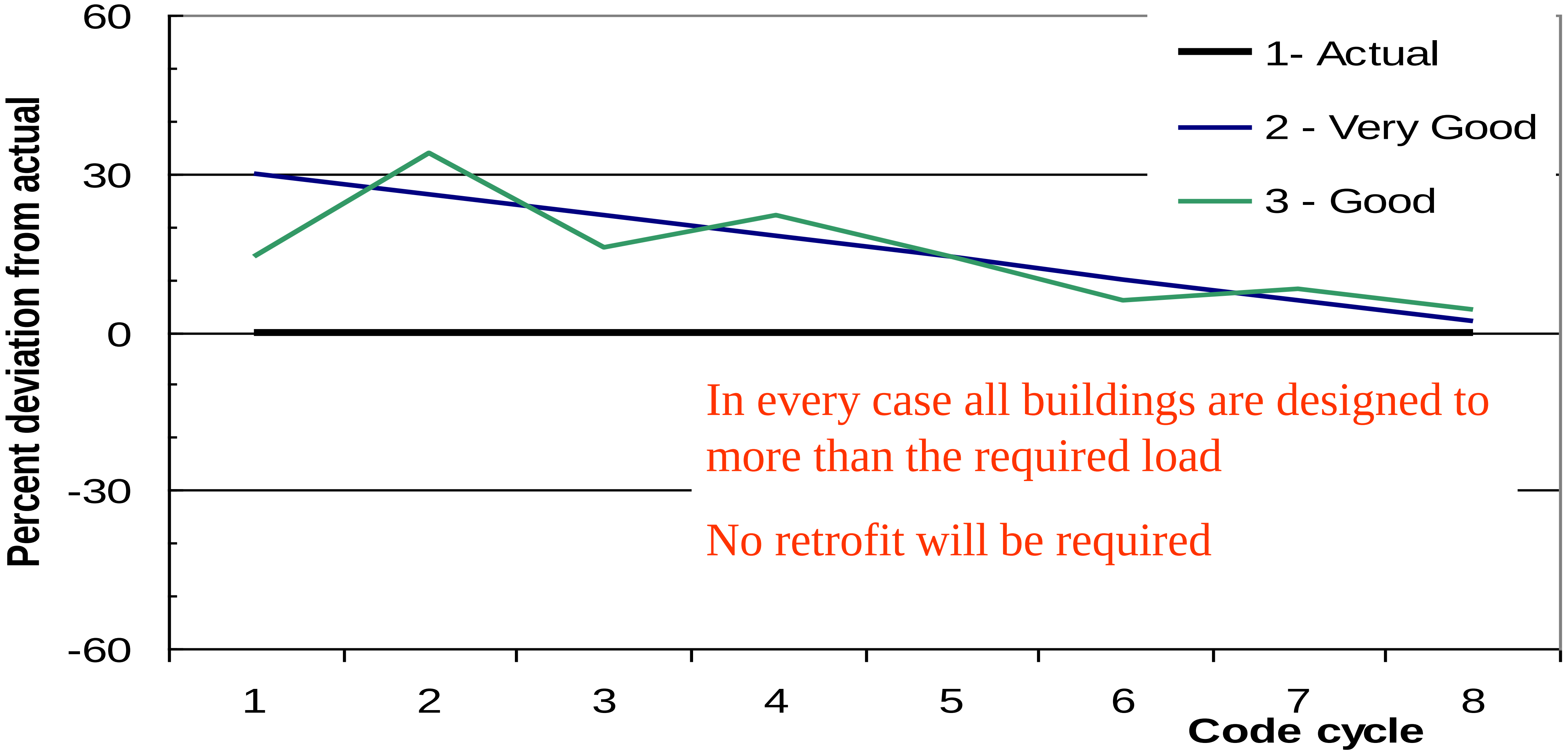
Evolution of Seismic design levels (cartoon)



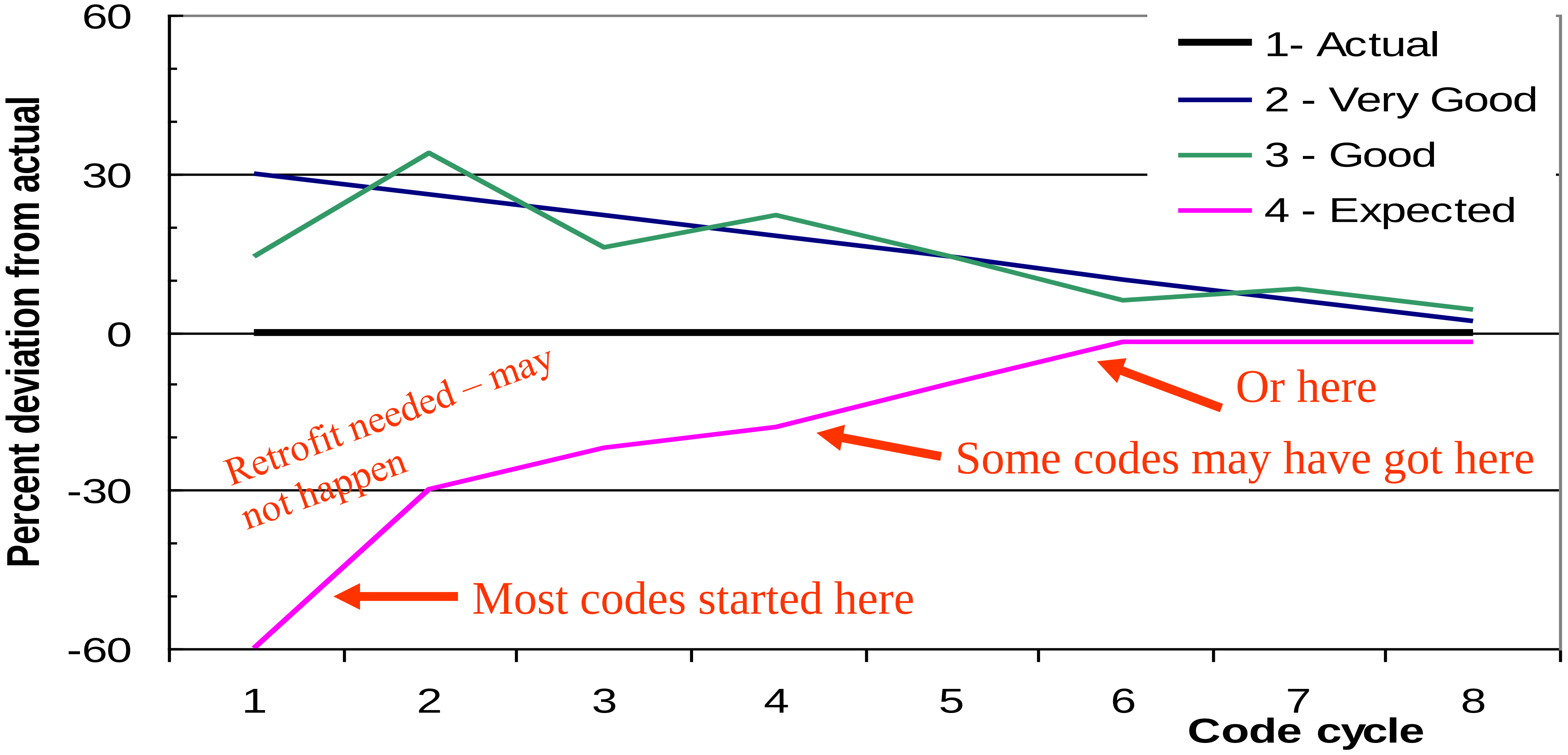
Adams, J. 2011. **Seismic Hazard Estimation in Canada and its Contribution to the Canadian Building Code - Implications for Code Development in Countries such as Australia** Australian Journal of Structural Engineering Vol. 11(3) p. 267-281



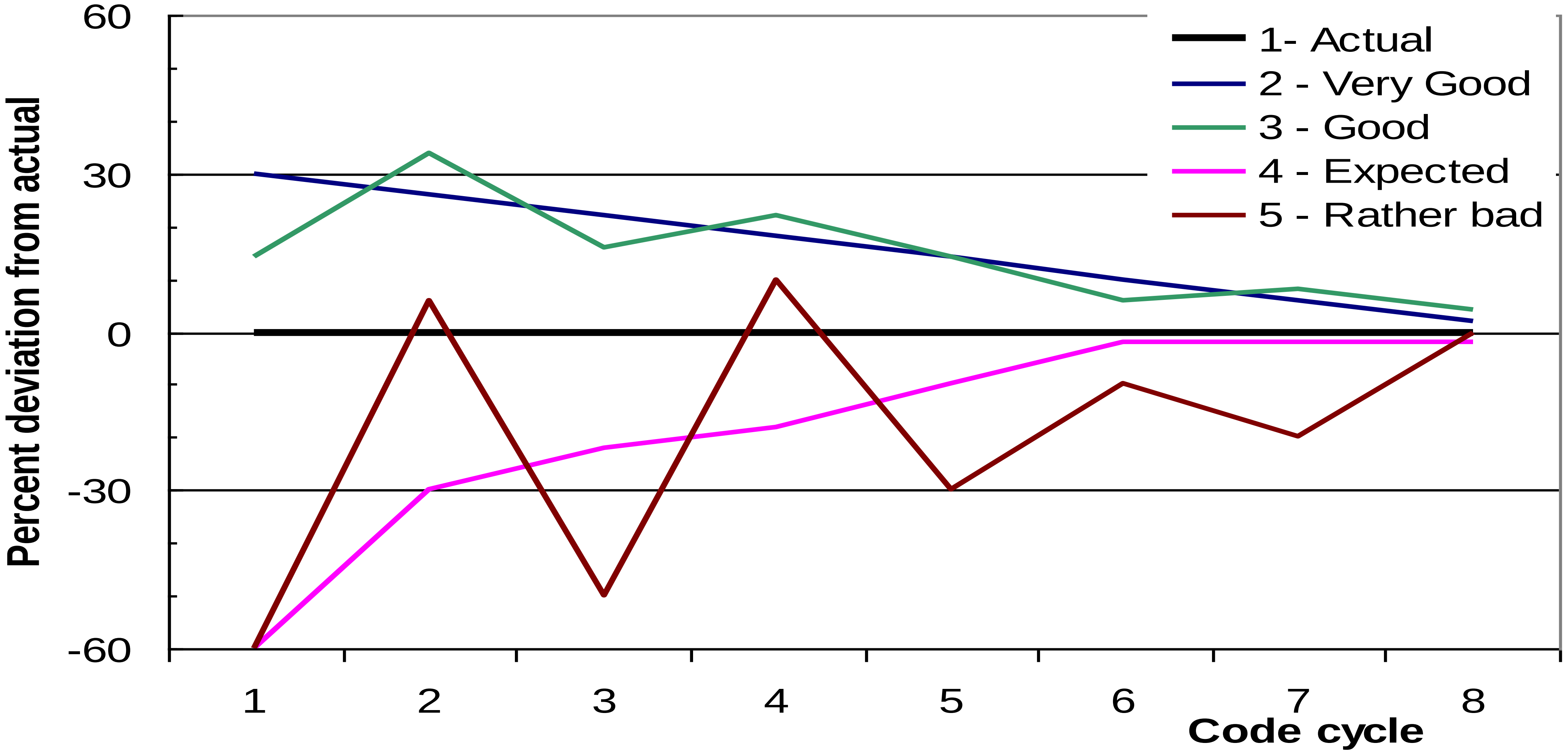
Percent deviation from actual
60
30
0
-30
-60
1
2
3
4
5
6
7
8
Code cycle
1- Actual
2 - Very Good



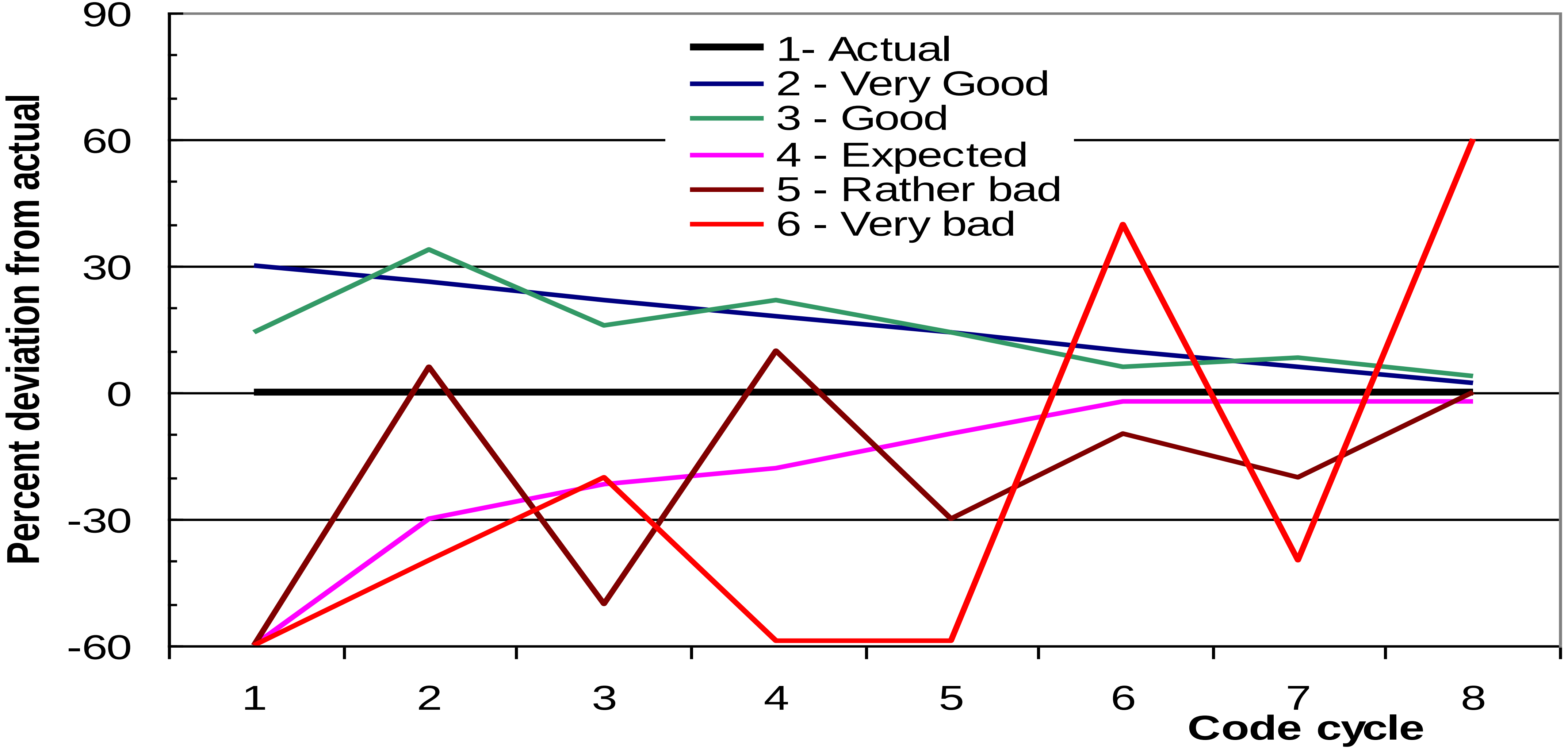
60
30
0
-30
-60
Percent deviation from actual
1
2
3
4
5
6
7
8
Code cycle
1- Actual
2 - Very Good
3 - Good
In every case all buildings are designed to more than the required load
No retrofit will be required



60
30
0
-30
-60
Percent deviation from actual
1- Actual
2 - Very Good
3 - Good
4 - Expected
Retrofit needed – may not happen
Or here
Some codes may have got here
Most codes started here
1
2
3
4
5
6
7
8
Code cycle



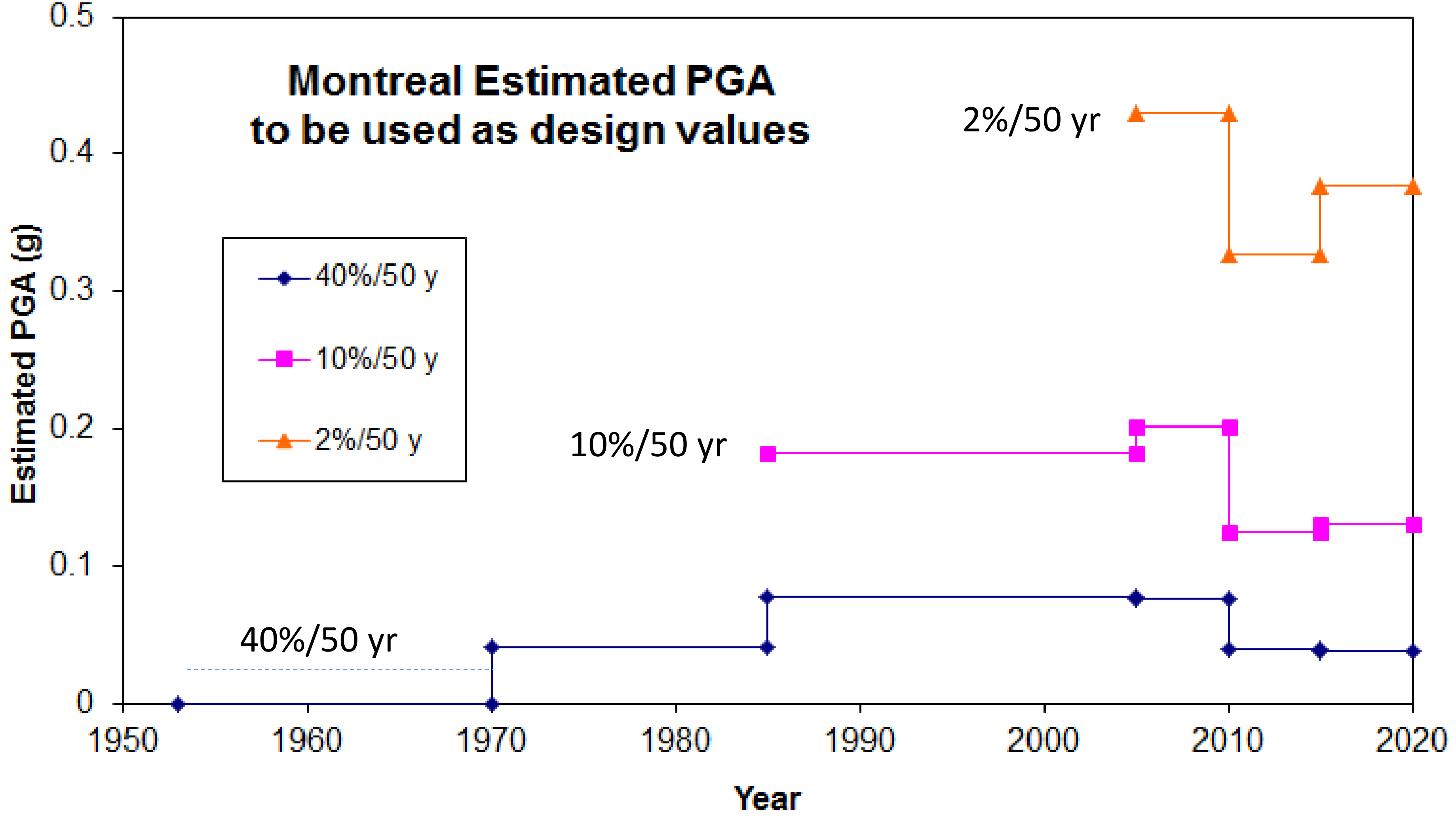
Percent deviation from actual
60
30
0
-30
-60
1
2
3
4
5
6
7
8
Code cycle
1- Actual
2 - Very Good
3 - Good
4 - Expected
5 - Rather bad



1- Actual
2 - Very Good
3 - Good
4 - Expected
5 - Rather bad
6 - Very bad
Percent deviation from actual
90
60
30
0
-30
-60
1
2
3
4
5
6
7
8
Code cycle

Are Canada's seismic hazard results stable?

Can only compare PGA for several cycles



What do engineers need/want*?

- Simple — “as simple as possible, as complicated as necessary”
- Fair — distributes consequences appropriately
- Stable — monotonic changes, once a decade
- Reliable — an accurate estimate*

*We’re really not sure,
but “we think it’s getting better all the time”

Mostly increases!

What contributed to changes in estimated hazard <u>in the past</u>?

- Mis-understanding sigma in the GMPEs
- GMPEs: poor, scant data → better now
- Treatment of uncertainty (not best-estimate)
- Increases in Mmax
- Changes in estimation of earthquake rates
  - Better knowledge
  - Better estimation of old magnitudes
  - Incorporation of uncertainty in magnitudes
  - GPS and paleoseismic constraints
- Inclusion of newly-recognized hazard sources
- Improvements in computation/methodology
  - Increasingly complex models
- [drops in provided probability level]

What we don't do (yet) in the Canada model

- Consider induced eq hazard
- Declustering
- Magnitude uncertainty….
- Smoothed seismicity
- Time-dependent hazard
- Fuzzy source boundaries
- ………

What is likely to contribute to changes in estimated hazard in the future?

- GMPEs - because the earthquake dataset is still mostly too sparse
  - few M8+ earthquakes – are the ones we have typical?
  - few M6+ stable craton earthquakes
- Spatial earthquake distribution models (smoothed seismicity vs others)
- Declustering choices, especially in low-seismicity regions
  - Do we have the right goal?
  - Do we have the right parameters?
- Better estimation of all magnitudes
- Inclusion of newly-recognized hazard sources
  - If we add a fault source, how do we change rates in the surrounding areal source?
  - Do we know what we don't know, yet?

Good News!

The computation of seismic hazard from specified model inputs can be replicated!

Reconciliation of Canada's 5th Generation Seismic Hazard Model results with those from the OpenQuake-engine

John Adams[1], Trevor Allen[2] and Stephen Halchuk[1]

1) Geological Survey of Canada, Ottawa, Canada,
2) Formerly Geological Survey of Canada, Sidney, Canada, now Geoscience Australia, Canberra, Australia

Presentation slides abstracted from IASPEI Meeting, Kobe Japan, 2017 August 01

Why does this matter?

- Seismic hazard should be a determinable quantity

- Choices on inputs to a model imply different estimates of seismic hazard for the same site and probability – that’s OK!

- However given the same input choices, the computed seismic hazard should be the same irrespective of the computational engine

- 2 main seismic hazard algorithms: Direct Integration (DI) and Monte Carlo simulation (MC)
- Their hazard estimates converge
  - but may need ~1-million-year synthetic history for MC
- We used the DI algorithm in OpenQuake (OQ), not the MC one

Why validate between codes?

Canada wants to adopt OQ for the 2020 National Building Code

- The GSC has modified and maintained a commercial version of FRISK88 (GSCFRISK) since the late 1980s
- Used for Canada's 5th Generation hazard maps (2015)
- Software has become difficult to maintain/enhance over time as the science underpinning PSHA rapidly advances.

Need to demonstrate that:

1) the OpenQuake-engine (OQ) is able to generate seismic hazard values consistent with those generated by GSCFRISK
2) future changes in the hazard are due to scientific advances and differences in modelling assumptions rather than the software

For validation tests we used Canada's 5th Generation model

How close is close enough?

Impossible to achieve exact convergence

Pragmatically engineers should probably happy with +/-10%, but they get nervous at this level; they are more use to working with uncertainties of a few %.

We chose to aim for **2% tolerance**. We are talking about mathematical precision here, so it should be possible to get "very" close.

From our prior experience comparing GSCFRISK values to

EZ-FRISK (collaborator=Carlos Ventura)
EQHAZ (Gail Atkinson & Karen Assatourians)
OpenSHA (Ken Campbell), and now
OQ (Marco Pagani and Graeme Weatherill)

- **for most sites** getting within 5% is achievable without much work
- if there are differences in the 2-5% range, the sources of the discrepancy can be identified **most** of the time

Through this process we learn a lot about how the codes (and our model input assumptions) are working

Implementation of the 2015 Model in the OpenQuake-Engine

- Required the development of Canada-specific modules for OpenQuake v2.1:
  - Ground-motion table interpolator (to use ground-motion look-up tables rather than parametric ground-motion models)
  - Fault-scaling modules
- Additional modules developed:
  - Yenier & Atkinson (2015) GMM implemented
  - Implemented Japan-Cascadia adjustment factors for Zhao et al (2006) interface and intraslab GMM
- Translation of some GSCFRISK inputs before porting them to OQ

- All code and model inputs are open source
- Input source files for the 2015 NBC can be "cloned" from github: https://github.com/treviallen/2015_gsc_nshm

Final outcome was satisfactory,

but found 4 issues:

Issue #1 Magnitude-Frequency relation

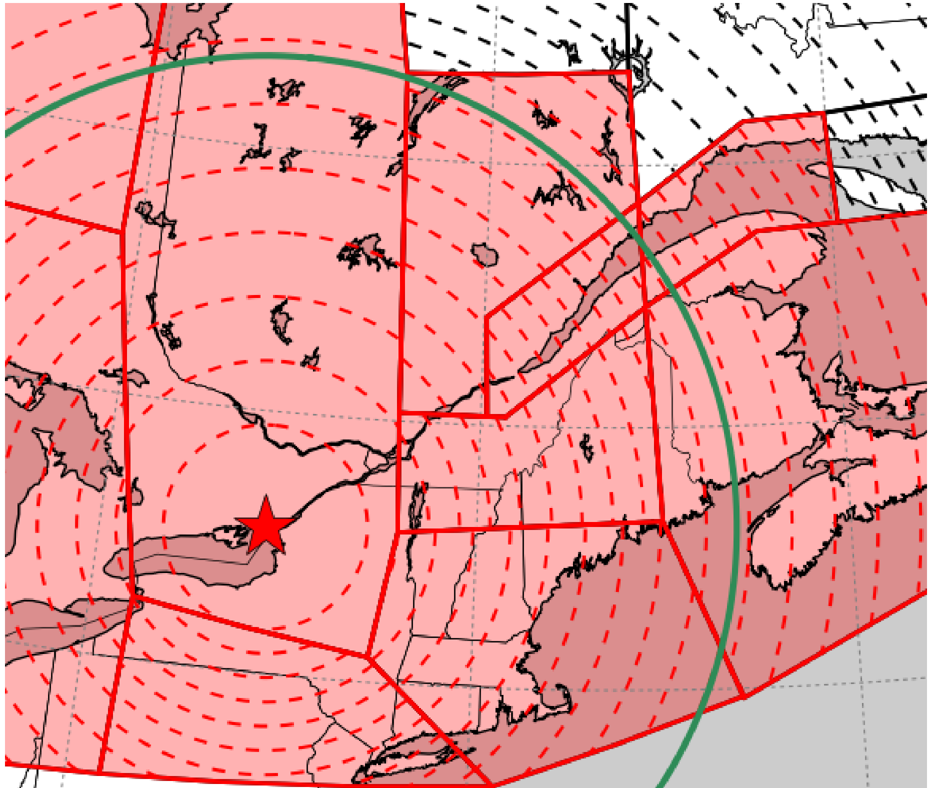
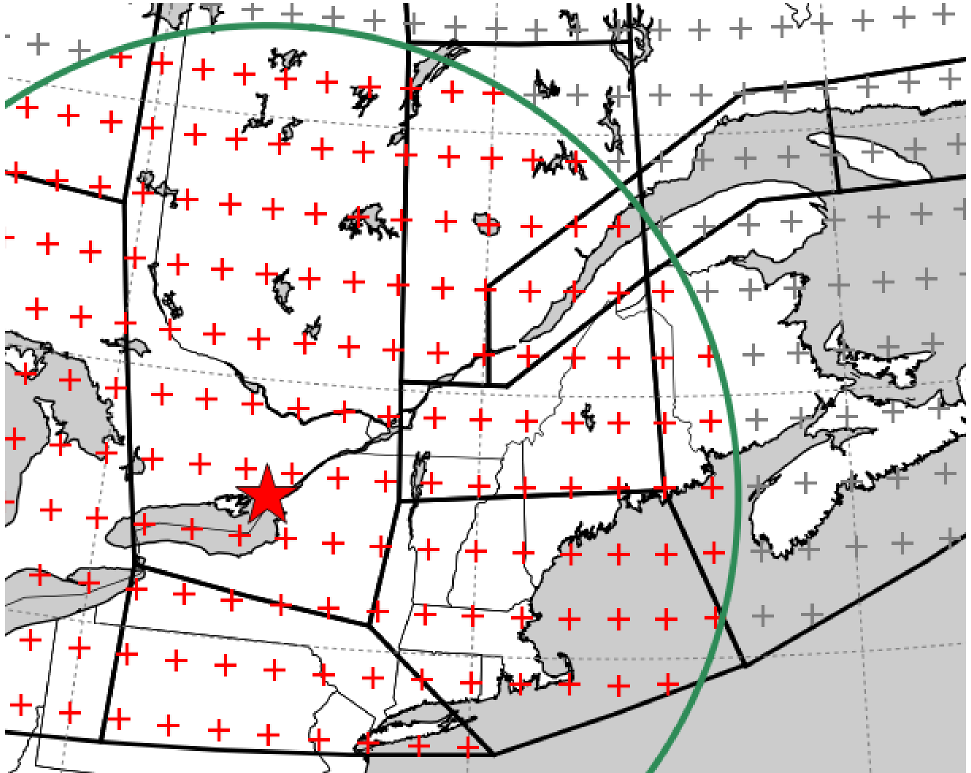
Earthquake rate difference in the Magnitude-Frequency relations for the same a, b, Mmax values

- Solved by computing incremental 5^{th} Generation rates for each magnitude and importing these into OQ
- Still need to resolve why the same **a** and **b** values gave different rates
  - Due to bin size and where the magnitude for the bin is applied? – mote that discrepancy reduces with 0.01 mag. bin sizes
  - Due to the different shape of the asymptotic truncation at Mmax?

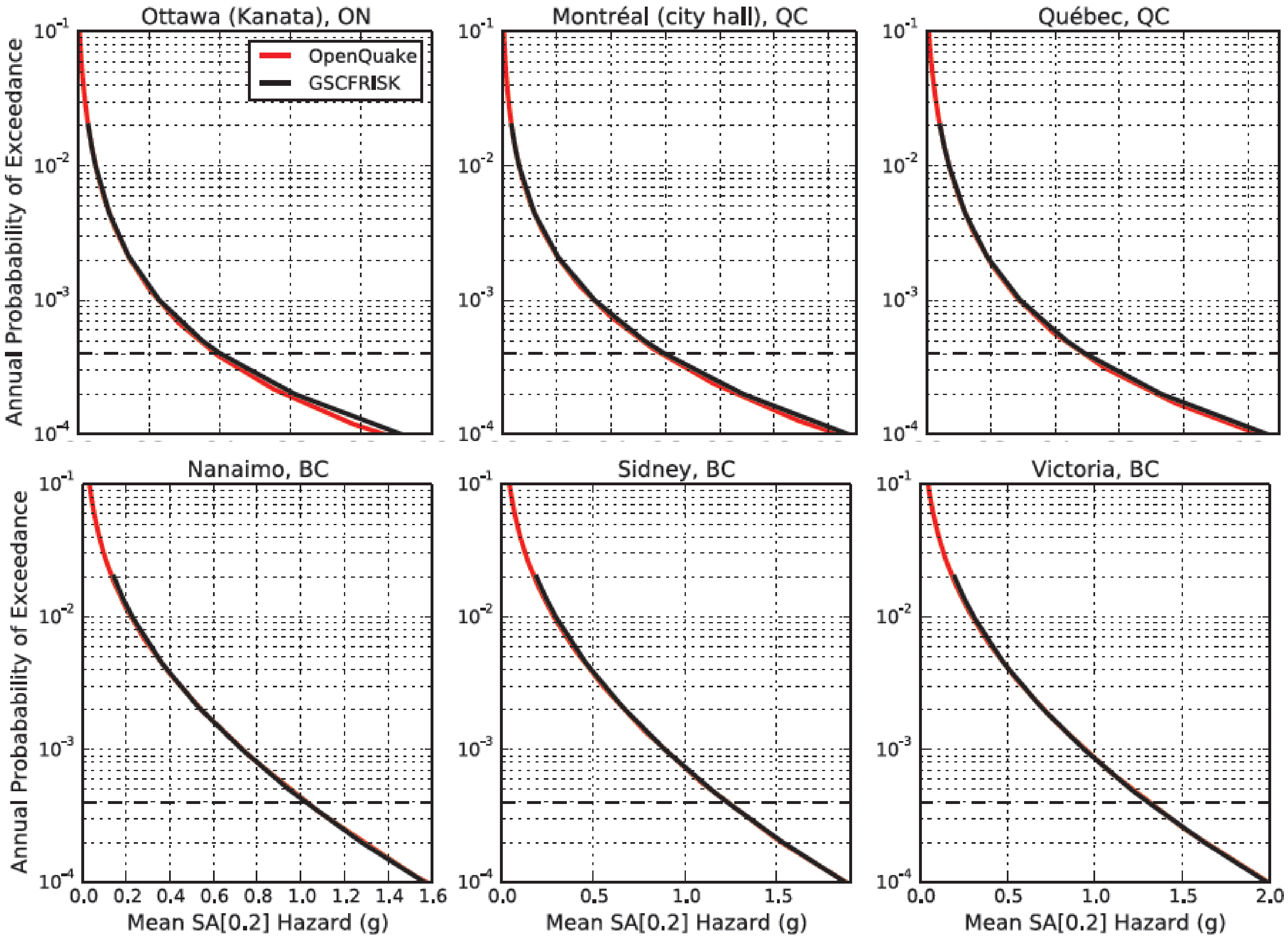
Issue #2 Integration step size

- Fixed number of slices in FRISK88
- Oversamples small zones; undersamples large ones
- Compares to even grid used by OQ
- <u>Solved</u> by increasing slice number in GSCFRISK

Brute force, not elegant

Interim Runs – not too bad for many sites……



Comparison of Sa(0.2s) hazard curves for eastern (top) and western (bottom) sites

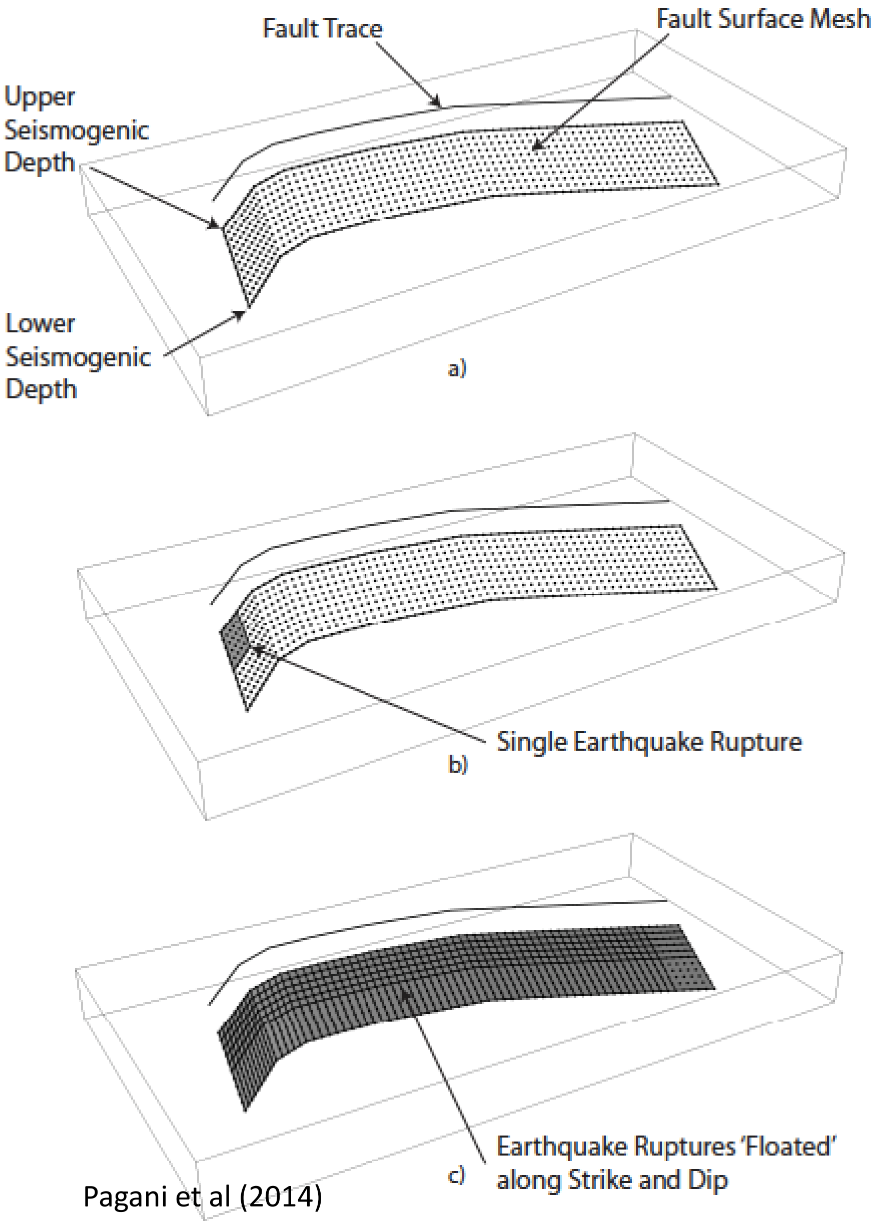
Interim Runs – but note remaining % discrepancies

Table 1 – Comparison of 2% in 50-year seismic hazard values (on Site Class C) for selected Canadian localities as calculated by GSCFRISK and the OpenQuake-engine.

Locality	Sa (0.2 s) g			Sa (1.0 s) g		
	GSCFRISK	OpenQuake	% Difference	GSCFRISK	OpenQuake	% Difference
Tofino, BC	1.46	1.53	4.8	0.883	0.921	4.1
Victoria, BC	1.30	1.30	0.68	0.677	0.681	0.53
Vancouver, BC	0.846	0.848	0.19	0.425	0.428	0.67
Sandspit, BC *	1.31	1.48	12.0	0.727	0.815	11.4
Penticton, BC	0.158	0.160	1.2	0.102	0.104	2.7
Toronto, ON	0.249	0.247	0.83	0.063	0.062	1.7
Ottawa, ON	0.401	0.387	3.6	0.110	0.107	2.4
Montréal, QC	0.595	0.580	2.7	0.148	0.144	2.5
Québec City, QC	0.492	0.482	2.14	0.133	0.130	2.1
Halifax, NS †	0.110	0.108	1.5	0.053	0.050	6.3

Issue #3: Differences due to “floating ruptures”

- Earthquakes are uniformly distributed over a fault surface
- An earthquake of a given magnitude is defined as a portion of the fault surface
- To simulate all possible rupture locations, an earthquake rupture is moved, or floated, over the entire fault surface



Pagani et al (2014)

Issue #3: Differences due to "floating ruptures"

- Detailed analysis & correspondence with the FRISK developers suggests the 5th Generation model may have incorrectly included rupture-length uncertainty for "floating ruptures"
- Confirmed by changing value of NRL in GSCFRISK from default value of 4 → 1
- Hazard near the Haida Gwaii and Queen Charlotte faults is underestimated by about 10-15% if using NRL=4
- If nothing else is changed, OQ will result in higher* hazard for near-fault sites in 2020 maps.
  - This effect is exacerbated for fast-moving active faults

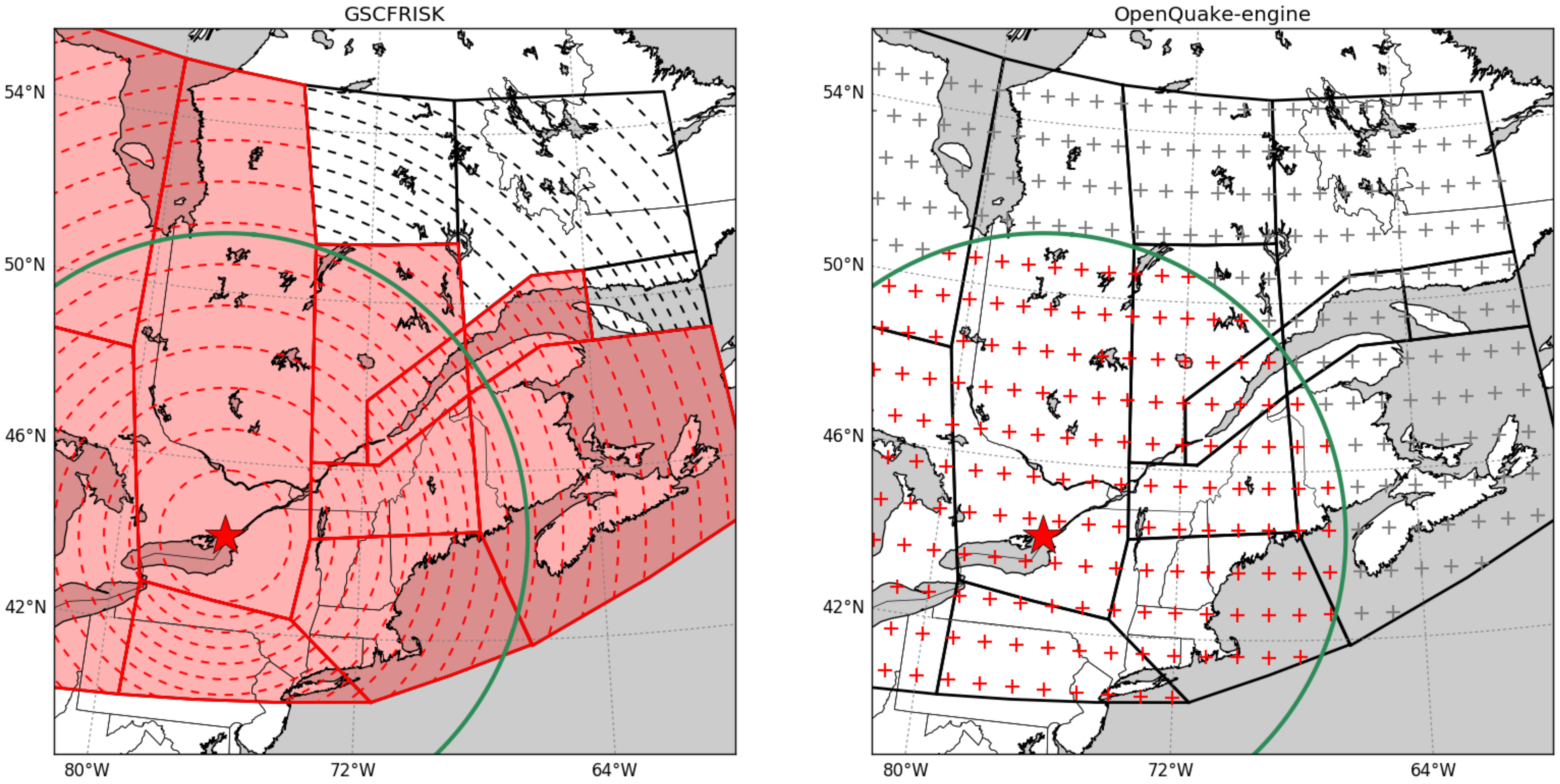
* counter-intuitive – adding uncertainty reduced the hazard!

Perhaps rupture-length uncertainty is already included via stress drop variations in the GMPEs?

"… I am wondering if what you are seeing is a censoring effect. If the rupture areas cannot exceed the total size of the fault, and if we imagine that the total fault size would correspond to some value epsilon standard deviations from the median expected area from the MSR (where epsilon is positive or zero), then the probability distribution becomes bounded at epsilon above the median but remains unbounded below. This would mean that the probability of smaller ruptures (and therefore larger source to site distances) is higher than in the case when uncertainty is neglected and the pdf becomes a Dirac function at the median value." (Graeme Weatherill, email to Trevor Allen, 20161024)

Issue #4:   Differences in Cutoff Distances

GSCFRISK
Entire zone contributes even if only a corner is within the distance



Red slices = in
Black slices = out
Green circle = GMM cut-off distance

Red crosses = in
Grey crosses = out
Green circle = GMM cut-off distance

OpenQuake
Only grid points within the distance contribute

<u>Confirmed</u> by increasing cutoff distance in both codes
→ OQ’s implementation is better

Hazard from final implementation of the 2015 model in the OpenQuake-Engine

Locality	*Sa*(0.2 s) g			*Sa*(1.0 s) g		
	GSCFRISK	OpenQuake	% Difference	GSCFRISK	OpenQuake	% Difference
Tofino, BC	1.46	1.53	4.8	0.883	0.921	4.1
Victoria, BC	1.30	1.30	0.68	0.677	0.681	0.53
Vancouver, BC	0.846	0.848	0.19	0.425	0.428	0.67
Sandspit, BC*	1.47	1.50	2.0	0.809	0.830	2.5
Penticton, BC	0.158	0.160	1.2	0.102	0.104	2.7
Toronto, ON	0.249	0.247	0.83	0.063	0.062	1.7
Ottawa, ON	0.401	0.387	3.6	0.110	0.107	2.4
Montréal, QC	0.595	0.580	2.7	0.148	0.144	2.5
Québec City, QC	0.492	0.482	2.14	0.133	0.130	2.1
Halifax, NS†	0.110	0.108	1.5	0.0531	0.0526	1.0

Final tweaks: NRL changed for Sandspit, Maximum cutoff distance changed for Halifax

Summary

	GSCFRISK	OpenQuake	Consequences for 2020 hazard
Magnitude-frequency distribution	Weichert equation	Other equation	Major discrepancy ***Needs more thought***
Integration step	Same number of slices for each source zone	Equi-spaced grid over entire area	Under- and over-sampling ***OQ is better***
Floating rupture on faults	Uncertainty in mag-length was included	No explicit uncertainty in mag-length	Reduces hazard in some cases ***Still thinking, OQ likely better***
Cutoff distance	Entire zone contributes even if only a corner is within the distance	Only grid points within the distance contribute	Appropriate reduced contribution from distant sources ***OQ is better***

Conclusions from validation

- Validation of hazard codes to within 2-3% is possible, at least at the 2%/50yr probability level.
- Differences >5% suggest an underlying cause should be identifiable.
- In our experience, “unexpected” causes may be discovered by diligently looking into the differences
- We identified 4 issues due to different treatment of model inputs; there are probably others!
- NRCan will adopt OQ-engine for future Canadian national hazard models
- But cannot use the OQ software to re-compute 2015 Building Code values
  - Too much tweaking would be needed
  - Instead values will be archived from GSCFRISK code

Reconciliation to 5% (or even 10%) precision may be unnecessary given the (low) accuracy of the hazard estimates, but it

- reassures the engineers
- gives us confidence that no significant input discrepancy (or blunder) has been over-looked

See also: Allen, Halchuk, Adams and Rogers (2017) CANADA’S 5TH GENERATION SEISMIC HAZARD MODEL: 2015 HAZARD VALUES AND FUTURE MODEL UPDATES. *16th World Conference on Earthquake, Santiago Chile, January 9th to 13th 2017, Paper N° 3494*

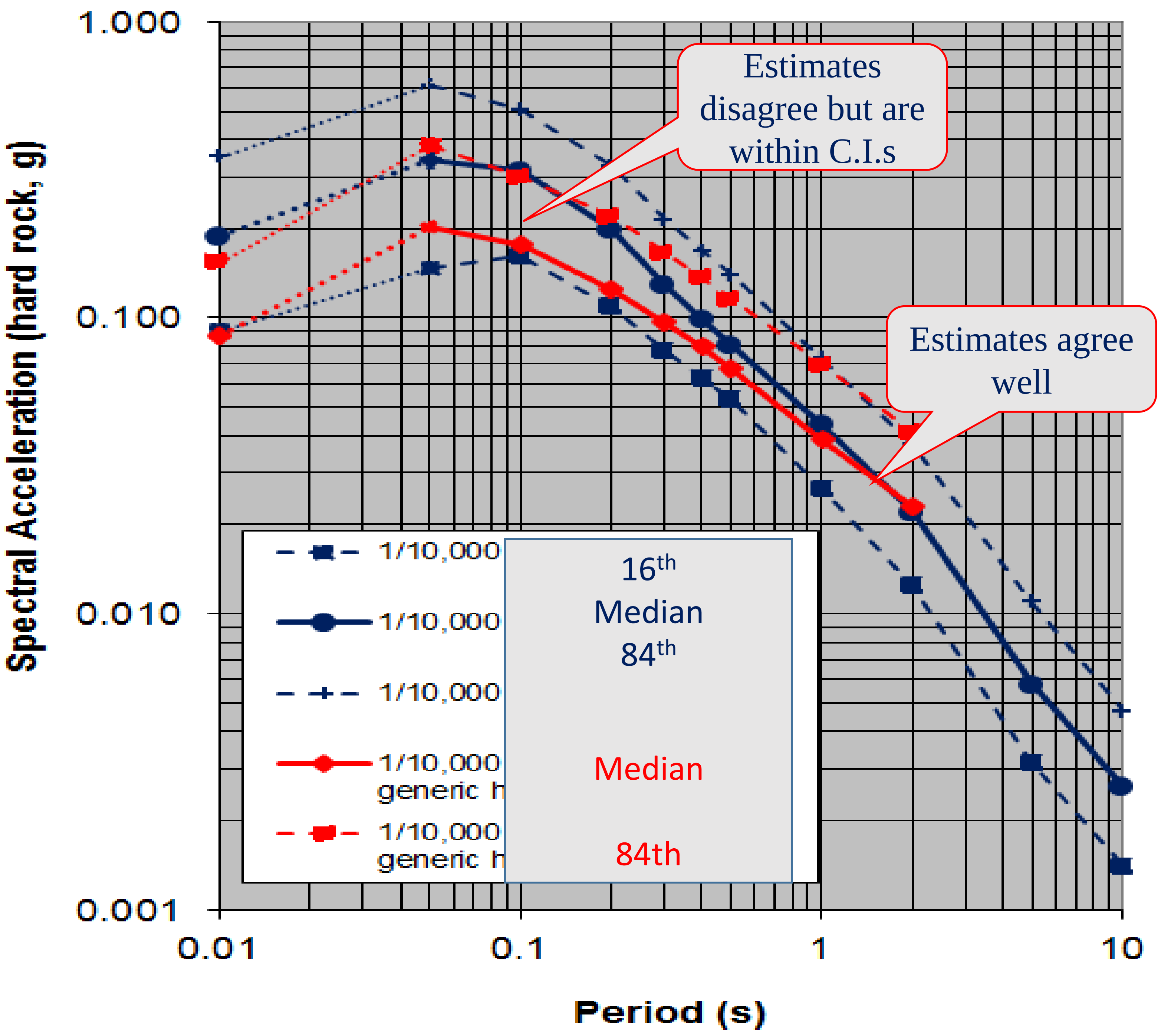
Not so Good News

Equivalently-valid models with different inputs can differ by 50-100% or more

- “valid” = scientifically justified
- differences this big may still be within each other’s confidence interval

→ Uncertainties are large

- Is this really the best we can do?



The uncertainties on PSHA are very large

This minimizes the chance that we will be flat-out wrong

Guidance for smart model choices has received less attention than testing of uniformly-performed seismic hazard estimates

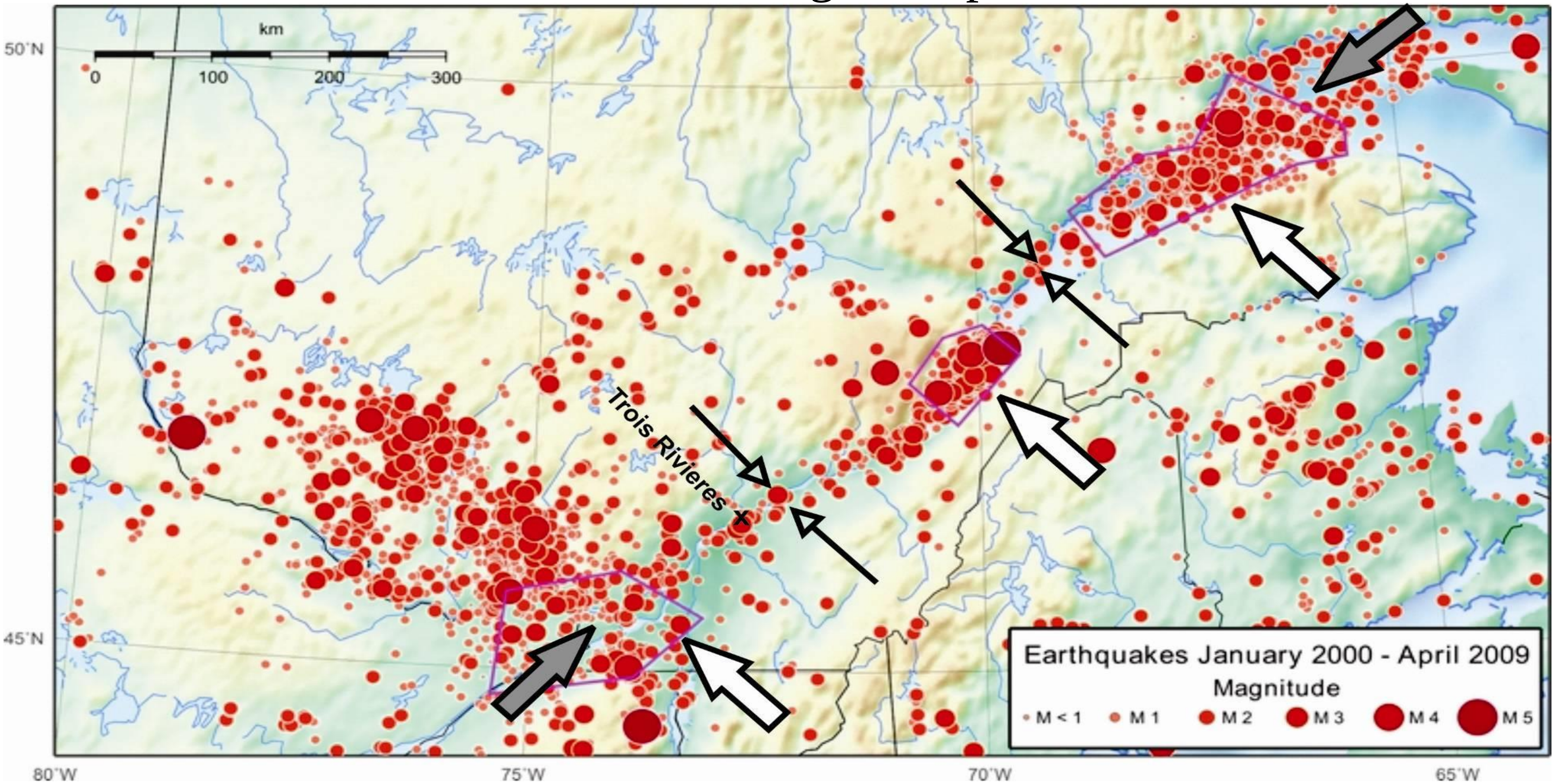
Example: smoothed seismicity or regionally-uniform earthquake density?

- In the long-term, smoothed-seismicity models can't possibly be right (or we would have spiky mountains where the last few hundred years' earthquakes have happened) …. so …..

A. Over what future time period are smoothed-seismicity models more valid than the alternatives?

B. Are we missing information when we consider spatial distribution of only "moderate" M>3, M>4, M>5 earthquakes? - *should we take the (declustered!) distribution of M~1 earthquakes as the likely distribution of future M~6 earthquakes (in low-seismicity regions)?*

Eastern source zones: small magnitude earthquakes outline potential sources between current active clusters along the Iapetan rift fault structure



Adams, J. 2011. **Seismic Hazard Maps for the National Building Code of Canada. Canadian Society for Civil Engineering Conference, Ottawa 14-17July 2011 paper JHS-1**
http://www.earthquakescanada.nrcan.gc.ca/hazard-alea/2011CSCE/2011CSCE_JHS-1.pdf

Thank You!

Permanent jobs, closing Sept 28th

3 new permanent positions with CHIS/GSC NRCan in Ottawa and Sidney

English- https://emploisfp-psjobs.cfp-psc.gc.ca/psrs-srfp/applicant/page1800?poster=1060247

French- https://emploisfp-psjobs.cfp-psc.gc.ca/psrs-srfp/applicant/page1800?poster=1060247&toggleLanguage=fr

Although preference must be given to qualified Canadians, for the specialist positions we think it likely that applicants from the rest of the world could be successful.

The two CHIS jobs will complement two permanent seismologist analysts hired last year, and two 2-year term seismologists just hired. This will be quite a renaissance for CHIS in Ottawa, and I find it a very exciting time.

john.adams@canada.ca