Benchmarking Scenario Performance in the First Generation Canadian Seismic Risk Assessment

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CONTEXT

The upcoming National Earthquake Risk Model for Canada will represent a great improvement in our shared understanding of risk. However, this uptake of the model relies on trust from the community.

Developed by the Global Earthquake Model (GEM) Foundation [Pinho 2012; Crowley et al. 2013], OpenQuake (OQ) is a free, open-source, community-developed code to assess seismic hazard and risk globally [see Monelli et al. 2012; Pagani et al. 2014; Silva et al. 2014]. Natural Resources Canada has been a proud public partner of GEM since 2017. In 2021, the Geological Survey of Canada will be using OQ to release a comprehensive National Seismic Risk model which includes both a probabilistic assessment and a scenario catalogue [Hobbs et al., 2020].

Model Element	Description	Source
Exposure	Inventory of buildings and occupants, including construction type, year of construction, code level, and number of occupants at different times of day. Taxonomies are consistent with HAZUS, the United States Federal Emergency Management Agency's risk software.	[Journeay et al., in prep] Based on Statistics Canada, 2016 Census. [Kircher et al., 2006]
Site Conditions	Measurement or inference of soil/rock conditions, in terms of the average shear wave velocity in the top 30 m (vs30), which can contribute to amplification of seismic shaking.	[Wald & Allen, 2007] [Allen & Wald, 2009] [Heath et al., 2020]
Ground Motion Prediction Equations	Equations and tables which relate the earthquake source characteristics to shaking at sites of interest, considering site conditions. The national model uses the same suites of GMPE's as implemented in the 6th Generation Canadian Seismic Hazard Map.	[Kolaj et al., 2020, and references therein]
Fragility and Vulnerability Functions	Discretized equations which relate the shaking at a site to the probability of damage (fragility) and economic loss (vulnerability) for a given building taxonomy.	[Rao & Silva, 2017]

The elements of the model, shown in the table above, are all independently vetted and peer reviewed. However, it is important to establish how well this approach performs, as a whole. With a paucity of significant, damaging earthquakes with which to verify, we must look for other reputable sources of risk information for Canada. In this work, we will consider a 2013 report by AIR Worldwide, commissioned by the Insurance Bureau of Canada, which evaluates the financial losses from scenario earthquakes in British Columbia and Quebec [AIR 2013]. From these results, we can determine whether the Canadian federal risk model is generally consistent with modelling performed by industry. Additionally, we consider the fidelity between this model and real earthquakes, including the 2001 Mw 6.8 Nisqually and 2012 Mw 7.8 Haida Gwaii events. While insured losses in Canada for both of these losses were relatively low, we can use United States Geological Survey (USGS) Shakemaps to confirm that our predicted losses should likewise be small. Finally, we consider how the national model compares to regional risk models using high resolution exposure data, to ensure that model results at the national level are consistent with what we expect at the urban scale.

COMPARISON WITH CAT MODELS: M 7.1 CHARLEVOIX & M 9.0 CASCADIA SCENARIOS

Scenario	GMPE	AIR Weight	Weight Used Herein
Cascadia	Atkinson and Boore, 2003	0.2	0.2
	Youngs et al., 1997	0.2	0.2
	Zhao et al., 2006	0.4	0.4
	Gregor et al., 2002	0.1	0.1
	Atkinson and Macias, 2009	0.1	0.1
Charlevoix	Atkinson, 2008	0.1	0.114
	Atkinson and Boore, 2006, modified in 2011	0.1	0.114
	Campbell, 2003	0.1	0.114
	Frankel et al., 1996*	0.1	–
	Silva et al., 2005, single corner	0.1	0.114
	Somerville, 2001	0.2	0.215
	Tavakoli and Pezeshk, 2005	0.1	0.114
	Toro et al., 2005	0.2	0.215

Fig. 1: Ground motion prediction equations used by the AIR study. Note that the Frankel model could not be used in our study given that our exposure database is partially conditioned on Spectral Accelerations at 0.6 seconds. The Frankel model does not have a value for this intensity measure, and does not support interpolation.

As AIR is a catastrophe modelling company, they use proprietary insurance industry data for their exposure model, and cannot share all elements of their approach. What can be made public, however, is the rupture geometry and ground motion prediction equations (GMPE's, Fig. 1) for their Mw 9.0 Cascadia (Western) and Mw 7.1 Charlevoix (Eastern) scenarios.

For the Charlevoix and Cascadia scenarios defined in AIR [2013], we calculated the economic losses using the same rupture geometry and GMPE's, with our publicly available exposure dataset and site model (described in 'Context'). The results are shown in Fig. 2, comparing the results from this study with that of AIR [2013]. Generally, the AIR results are higher than the GSC results, with the Charlevoix scenario costing 5.6 times as much using AIR, relative to the GSC estimate. For the Cascadia scenario the values are more similar, with the GSC model being 23% lower than the AIR model.

Scenario	Modeller	Financial Loss [CAD]
Cascadia	AIR	$43.6 Billion
	GSC	$33.7 Billion
Charlevoix	AIR	$39.5 Billion
	GSC	$7.0 Billion

Fig. 2: Comparing the economic losses from the GSC model and AIR [2013], for the Charlevoix and Cascadia scenarios.

The primary differences between the models are the site conditions, exposure, and fragility/vulnerability functions. To investigate the impact of site conditions we consider the spatial distribution of hazard intensity for the Charlevoix scenario (Figs. 3 & 4). Shaking is generally stronger in the AIR model, with Peak Ground Acceleration (PGA) of 5-7.5% g in Sorel-Tracy to the southwest and Rimouski to the northeast. PGA of 10-20% g is predicted in Saguenay, using AIR, but only 5-7.5% g using GSC. These differences suggest there is some variability in the site conditions used in the two models, being particularly evident along the banks of the St. Lawrence river to the northwest.

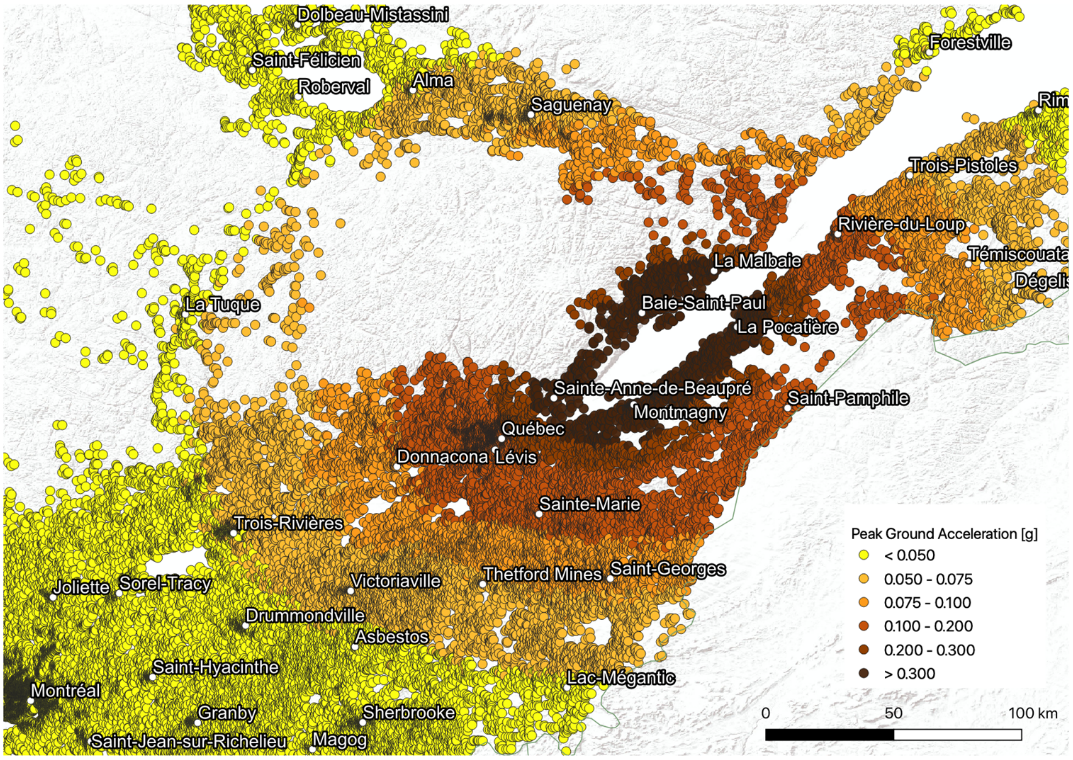

Fig. 3: Peak ground acceleration in Quebec for to the Charlevoix scenario, using the GSC model.

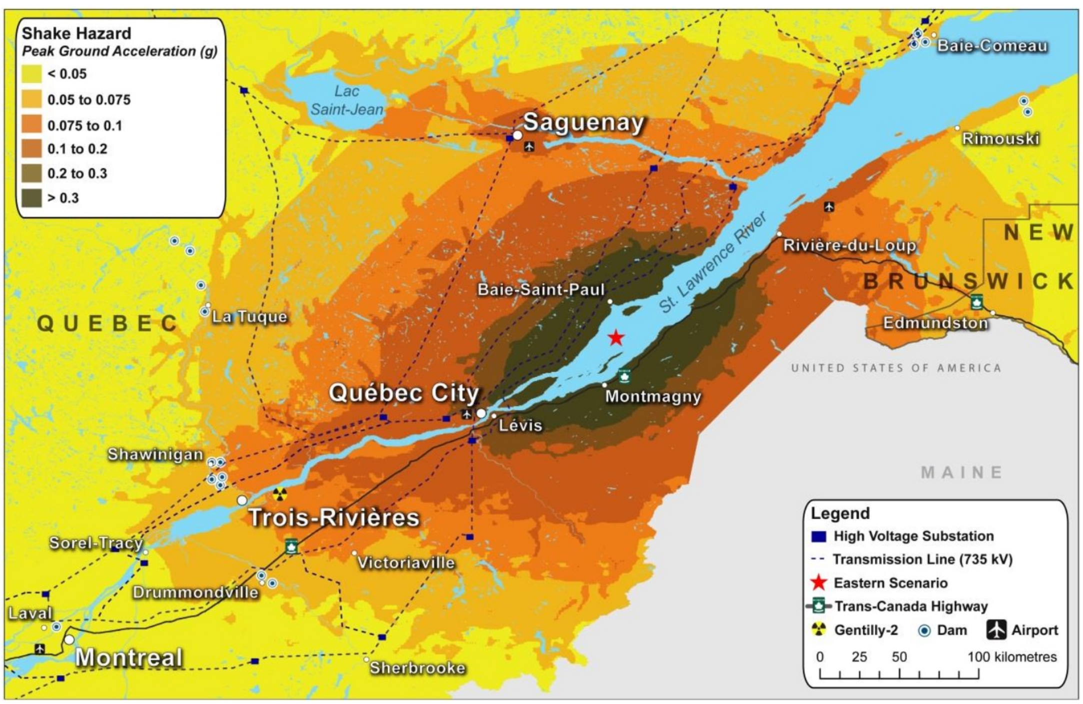

Fig. 4: Peak ground acceleration in Quebec for to the Charlevoix scenario, from the AIR [2013] model.

Work is ongoing to better constrain nuances in the differences in the exposure models, without having access to the industry data, by isolating residential and commercial losses by their spatial distribution. The large disparities between the models, for the eastern scenario in particular, may also reflect the discrepancies in vulnerability and fragility functions used for building taxonomies that are more abundant in Quebec. In the region of Quebec where shaking is damaging (Fig. 5), there is a higher proportion of Low and Pre Code buildings – those which had no seismic design considerations – than is found in BC near the Cascadia scenario (Fig. 6).

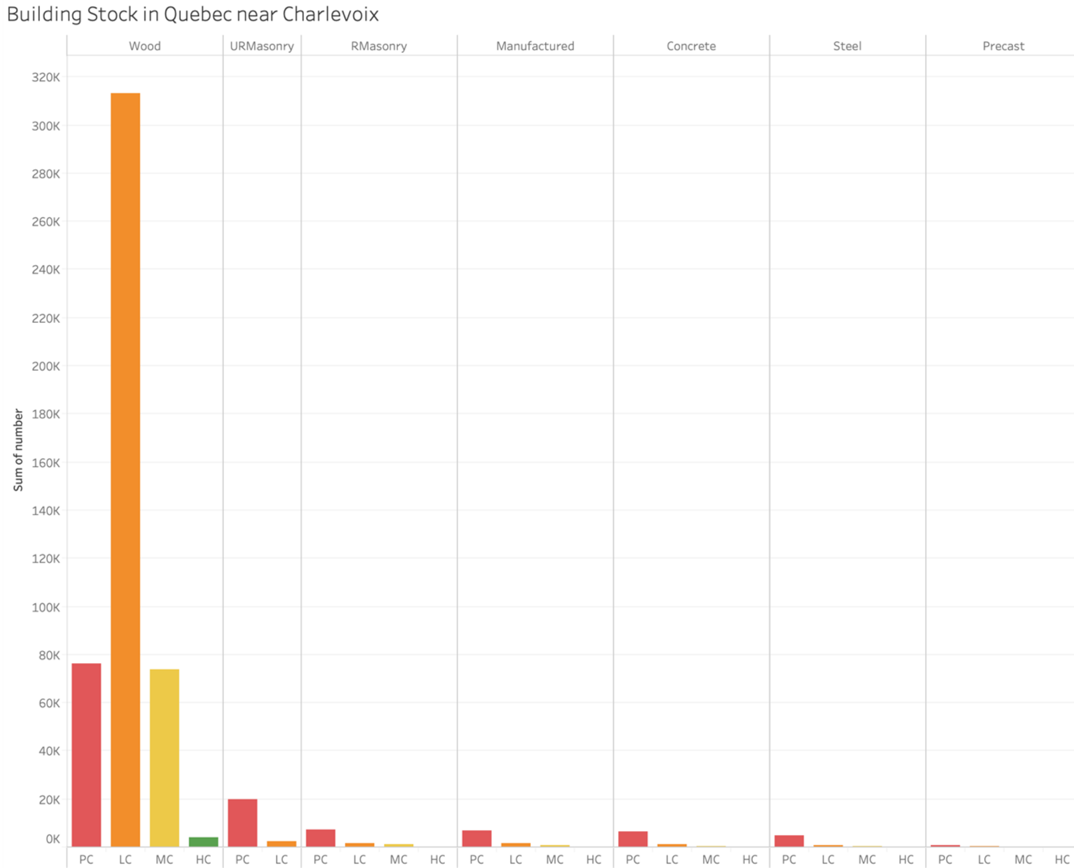

Fig. 5: Number of buildings near Charlevoix, by construction material and code: PC is pre code, LC is low code, MC is mid code, and HC is high code [Hobbs et al., 2020]. Construction types are wood, unreinforced masonry (URMasonry), reinforced masonry (RMasonry), mobile homes (Manufactured), concrete, steel, and precast concrete (Precast). 'Near Charlevoix' is defined by the following Census Economic Regions: Bas-Saint-Laurent, Capitale-Nationale, Chaudière-Appalaches, Côte-Nord, and Saguenay--Lac-Saint-Jean.

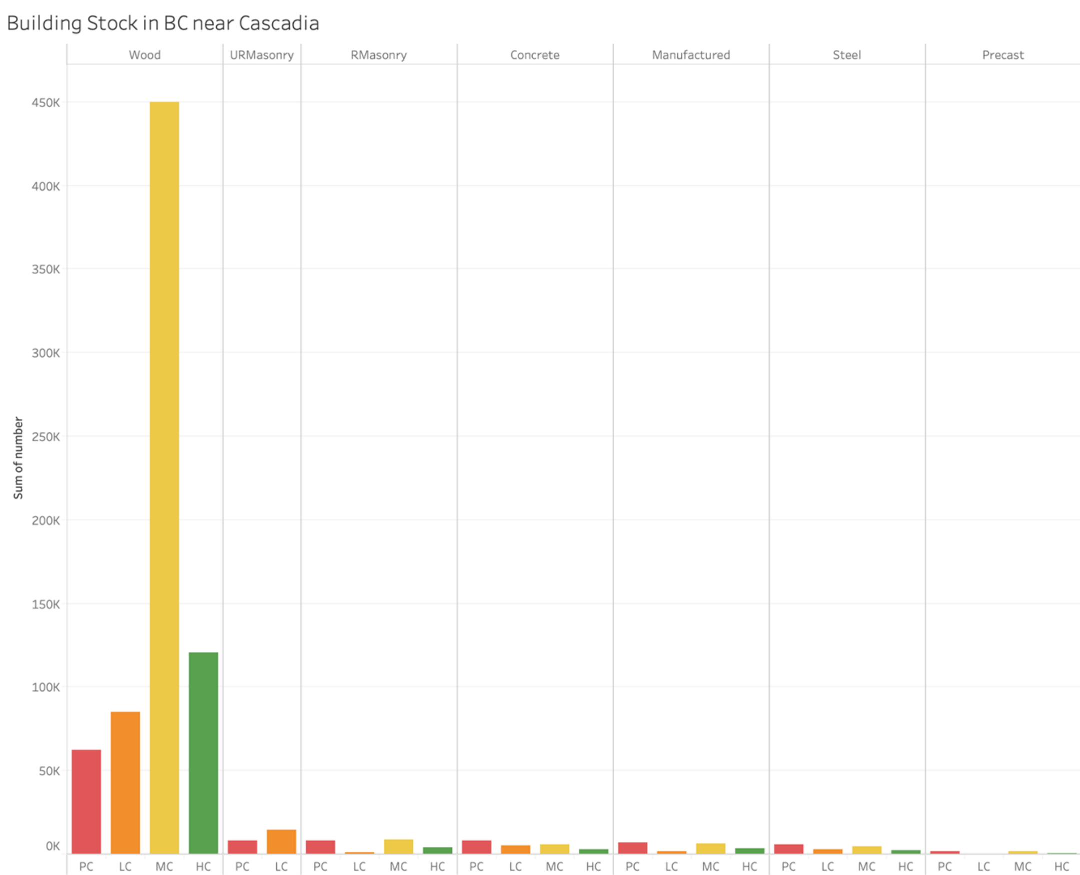

Fig. 6: Number of buildings near Cascadia, by construction material and code: PC is pre code, LC is low code, MC is mid code, and HC is high code [Hobbs et al., 2020]. Construction types are wood, unreinforced masonry (URMasonry), reinforced masonry (RMasonry), concrete, mobile homes (Manufactured), steel, and precast concrete (Precast). 'Near Cascadia' is defined by the following Census Economic Regions: Lower Mainland--Southwest / Lower Mainland--Sud-ouest and Vancouver Island and Coast / Île de Vancouver et la côte.

COMPARISON WITH REAL DATA: 2001 M 6.8 NISQUALLY & 2012 M 7.8 HAIDA GWAII EVENTS

The 2001 Mw 6.8 Nisqually and 2012 Mw 7.8 Haida Gwaii earthquakes provide a unique opportunity to test the performance of the OpenQuake Canada framework against real world observations. The Nisqually earthquake occurred on February 28th, 2001, roughly 53 km beneath Olympia, Washington. It was estimated to cause $2 billion USD in damage, kill 1 person, and injure 400 people [EM-DAT]. The Haida Gwaii earthquake occurred on October 28th, 2012. No one was killed or injured in this earthquake, and, from Bird & Lamontagne [2015]: "Thankfully, very little impact resulted from this event, in terms of damage to structures or physical injury to people" (Fig. 7).

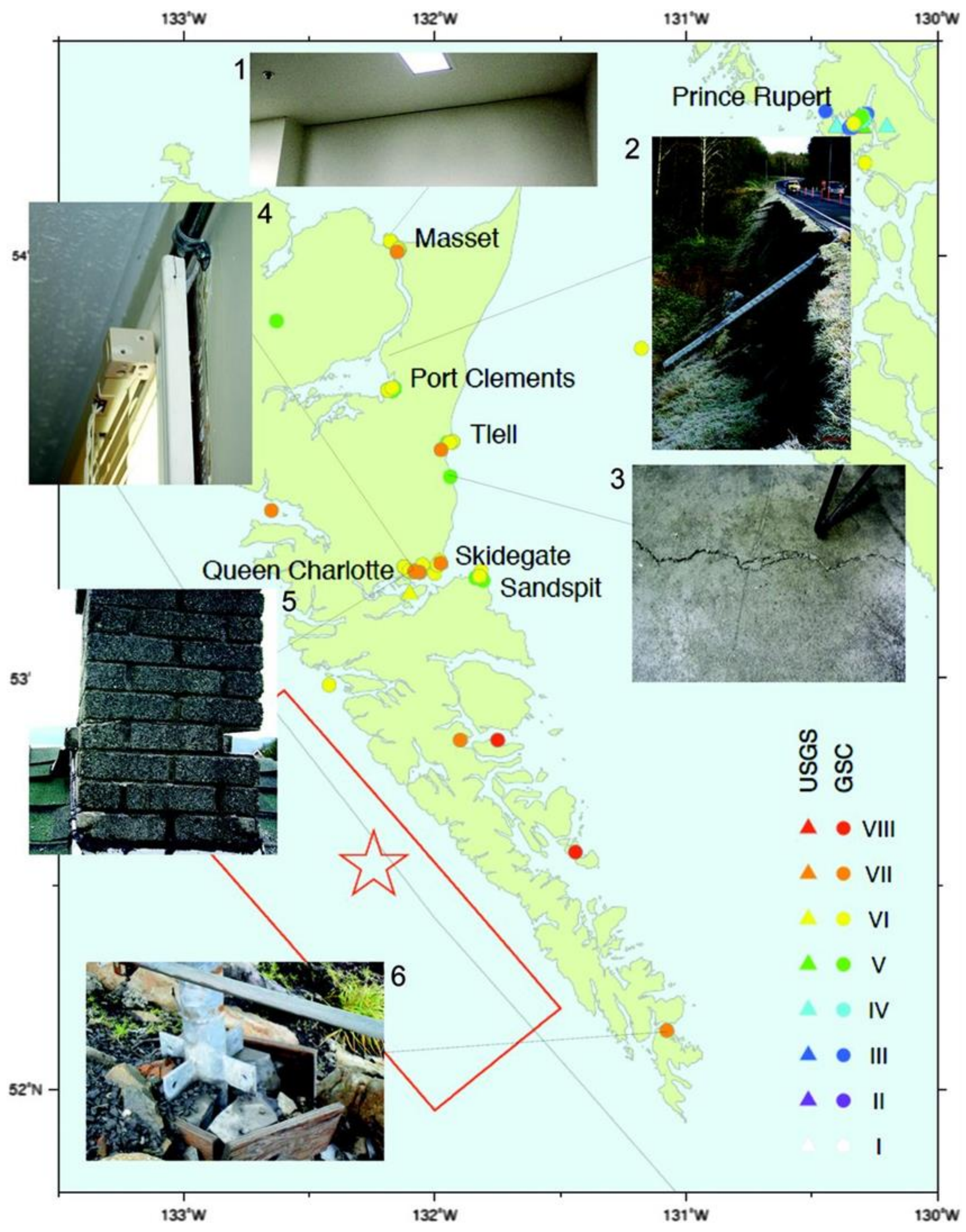

Fig. 7: Figure from Bird & Lamontagne [2015] showing slight-extensive damage to homes caused by the 2012 Haida Gwaii earthquake. Close-up map of intensities, with a selection of structural damage: wall-ceiling separation (1: A. Bird), road slump (2: A. Cober), cracked slab (3: A. Bird), trim separation (4: J. Goetzinger), chimney damage (5: J. Goetzinger), and support strut failure (6: Canadian Coast Guard).

Using the USGS Shakemaps [Wald et al., 2005] for Nisqually (uw10530748) and Haida Gwaii (usp000juhz), in the OQ Canada Framework, we find the following losses:

Earthquake	Jurisdiction	Loss
Nisqually	BC	$9.4 Million in 2001 CAD
	WA	$1,435.4 Million in 2001 USD
Haida Gwaii	BC	$8.6 Million in 2012 CAD

Conversions to 2001 and 2012 based on inflation for Canada and the United States from the Penn World Tables [see Feenstra et al., 2015]. Washington exposure data is obtained from HAZUS [Schneider & Schauer, 2006], but includes only buildings and no linear infrastructure.

Overall, the $1.4 Billion USD loss in Washington is consistent with the recorded $2 Billion loss from Nisqually. This is particularly true when considering that results presented herein do not include any damage to linear infrastructure, like roads and viaducts, or effects of secondary hazards such as landslide and liquefaction. It was estimated that at least one third of the reported losses from Nisqually came from the Alaska Way viaduct [Highland, 2003], a double-decked highway through downtown Seattle that was severely damaged from earthquake shaking and ground failure. Therefore, the OQ estimates for US Nisqually losses match with the observed losses. Likewise, the Canadian OQ estimates for Nisqually and Haida Gwaii are both under $10 Million – a relatively small amount in the world of earthquake losses. These values reflect the sum of broad, but mostly minor, damage that would be unlikely to be reported or claimed, which is why disaster databases do not list Canadian contributions for either event. Therefore, we also consider that these reported losses are consistent with observations of very minimal damage in Canada for both the Nisqually and Haida Gwaii earthquakes.

SCALING FOR URBAN RISK & CONCLUSIONS

A final way to evaluate whether our modelling approach is valid is to ensure that results are consistent for both our national exposure dataset and high resolution regional models. A machine learning approach has been used to convert BC Assessment data into a site level exposure dataset for Metro Vancouver. We ran the Cascadia scenario from AIR [2013] using this dataset, which is comprised of almost a half a million buildings. For the Metro Vancouver region, losses are predicted to be $11.8 billion using the high resolution regional model (Fig. 8) and $18.3 billion using the standard national exposure dataset (Fig. 9).

While there are some differences between the spatial extent of these inventories, such as Bowen Island to the far west of Figs. 8 & 9, both have roughly the same number of buildings (aggregated or individually). The total asset valuation of $757 billion for the national inventory and $736 billion for Metro Van, however, suggests that the national exposure inventory is slightly overvaluing assets in this region relative to BC Assessment data – an interesting result given the previous finding that the GSC model reports lower financial losses than industry (section ‘Comparison with Cat Models: M 7.1 Charlevoix & M 9.0 Cascadia Scenarios’).

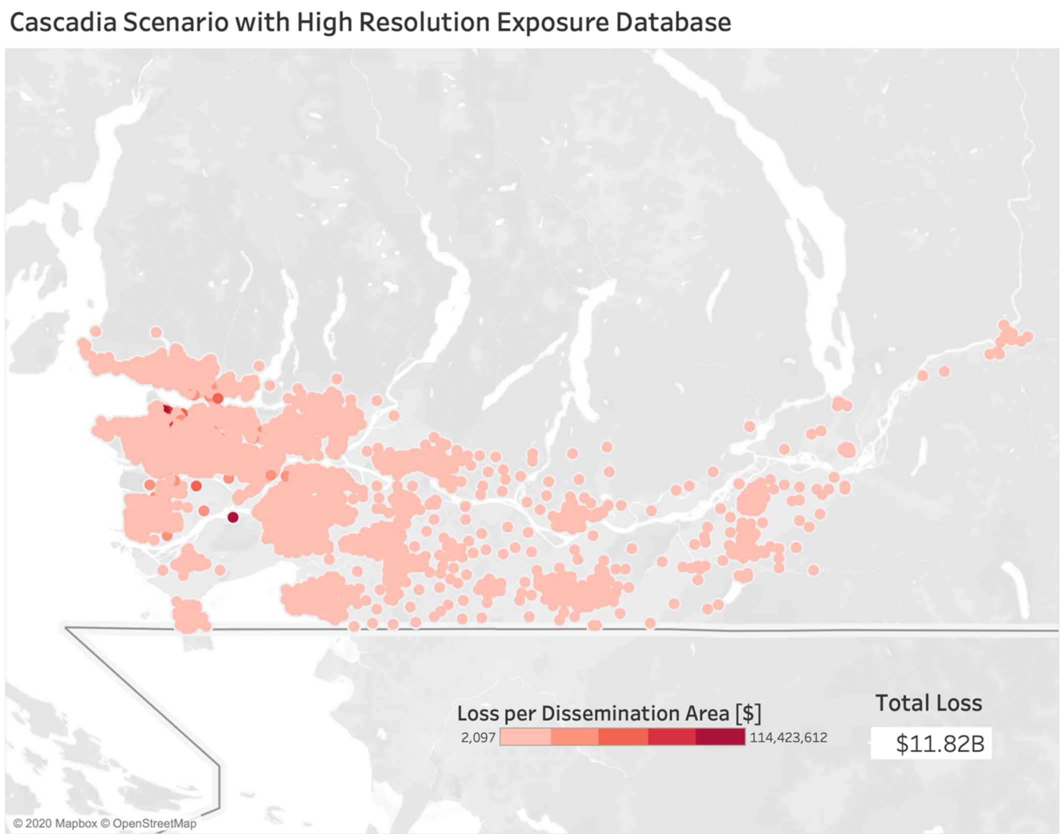

Fig. 8: Economic losses, by dissemination area, for the Cascadia scenario using a high resolution site-level building inventory.

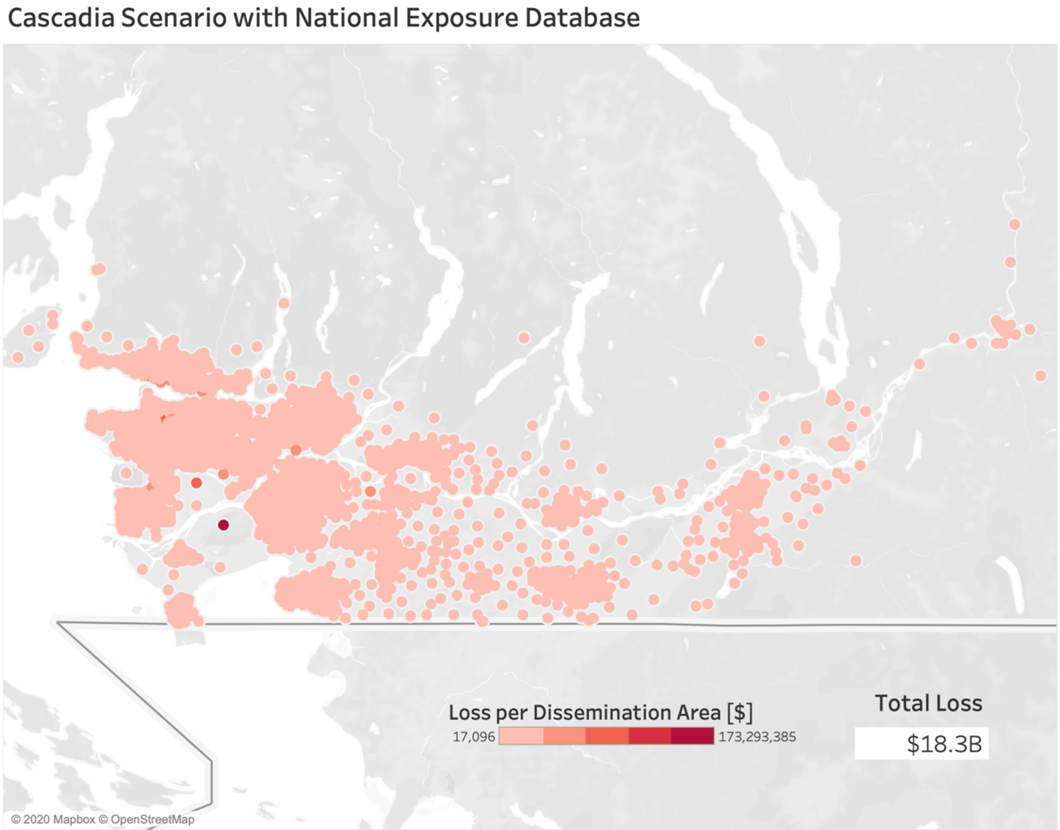

Fig. 9: Economic losses, by dissemination area, for the Cascadia scenario using the standard, national, building-level exposure inventory.

Conclusion

It is unsurprising that the national GSC seismic risk model presents somewhat different results than industry models, previous events, and regional scale models. Relative to industry, our models seem to under-predict losses, particularly for older buildings in Eastern Canada. Relative to regional scale datasets, our model slightly over-predicts losses. For observed earthquakes, this model is just right. What this primarily indicates is that there is uncertainty inherent in risk modelling. While we feel comfortable with the outputs, further work to constrain and more accurately represent this uncertainty will be critical for using and communicating these models.

AUTHOR INFORMATION

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ABSTRACT

Disaster risk reduction relies on quantitative estimates of the future impacts and consequences of known hazard threats in order to evaluate proposed mitigation and adaptation measures. Natural Resources Canada is collaborating with the Global Earthquake Model Foundation on the first ever national seismic risk assessment in Canada to inform disaster risk reduction planning by individuals, businesses and organizations working across all jurisdictional levels. The 2020 National Seismic Risk Model incorporates the 6th Generation National Seismic Hazard Map, a novel physical exposure model for the entire country, localized exposure models based on a machine learning approach to building categorization, and HAZUS-based earthquake building performance functions. Before results can be transmitted to end users, the model must be validated in a Canadian context using observations from real world disaster events or pre-existing catastrophic risk models. This study focuses on benchmarking the 2020 Canadian National Seismic Risk Model using shaking intensities and physical impacts recorded from the 2001 M_w 6.8 Nisqually and 2012 M_w 7.8 Haida Gwaii events, and the results of a 2013 catastrophic risk assessment performed by AIR Worldwide to evaluate the potential impact of major earthquakes in eastern Quebec and Cascadia.

We compute anticipated building damage, economic loss, and fatalities for these benchmark scenario earthquakes using the OpenQuake engine and the national exposure dataset. Preliminary results indicate that the model results are largely consistent with observed or predicted impacts of these earthquakes in Canada, after adjusting for economic and population growth. Subsequently, we will evaluate the impact of running the Cascadia scenario using a regional building-level exposure database versus the national level inventory. Ultimately, this work will assess the ability of the National Seismic Risk Assessment to reproduce expected results, to ensure the applicability of this model in anticipating future outcomes at the national and local level.

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