Simulation-based Earthquake Insurance Risk Calculation

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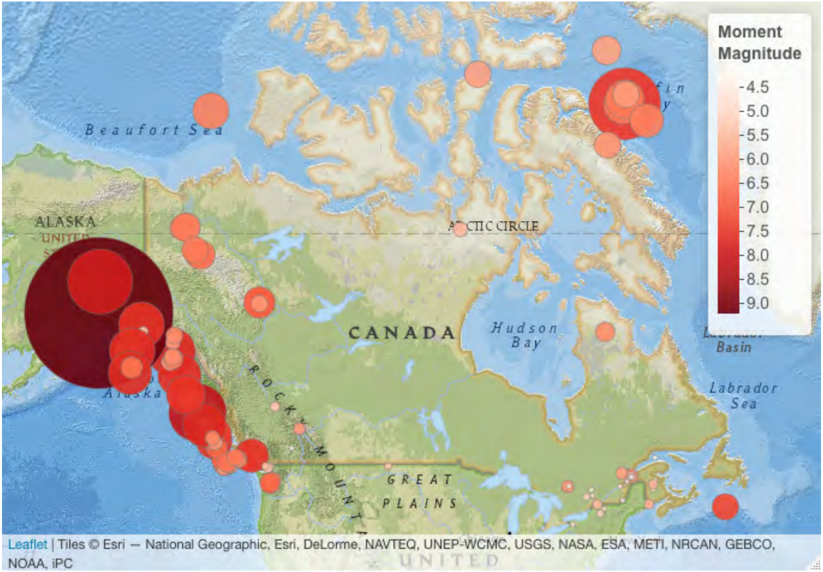
Overview

1. Motivation
   - Context
   - Goal
2. Methodology
   - Simulation algorithm
   - MCT for earthquake insurance risk
3. Results
   - Comparison with other earthquake studies
   - Simulation results
   - Earthquake risk assessment tool
4. Discussion

Context

- Catastrophic losses from earthquakes may cause a serious threat to the financial stability of P&C insurance and reinsurance companies.
- In Canada, around 600 earthquakes strike annually in the Southeast versus around 400 in the west. But how many cause damage?

Significant earthquakes in Canada



OSFI's Minimum Capital Test

The Minimum Capital Test (MCT) component for earthquake insurance risk is set by the Office of the Superintendent of Financial Institutions Canada (OSFI) in terms of the Probable Maximum Loss (PML) to be

$$\text{Canada PML}_{1/500} = \left(\text{East PML}_{1/500}^{1.5} + \text{West PML}_{1/500}^{1.5}\right)^{\frac{1}{1.5}},$$

where $\text{PML}_{1/500}$ is a 1-in-500 year event.

Goal

Earthquake models are usually complex, sold at a high price, not available for public use, and not possible to easily replicate their results.

We aim to

- Analyze earthquake insurance risk in Canada by creating a reproducible simulation-based approach, based on publicly available data.
- Provide an interactive web application that simulates a significant earthquake.
- Review OSFI's MCT formula and provide a possible alternative.

Simulation algorithm

To estimate the seismic risk, we proceed with the following steps:

(i) Collect building inventory and calculate exposure,

(ii) Simulate earthquakes in space and time,

(iii) Estimate ground shaking intensity,

(iv) Calculate damage rates, and

(v) Estimate seismic financial losses and insurance claim payments.

Simulation algorithm

(i) Collect building inventory and calculate exposure.

   a. Total square footage

   b. Building Exposure

   c. Building Content Exposure

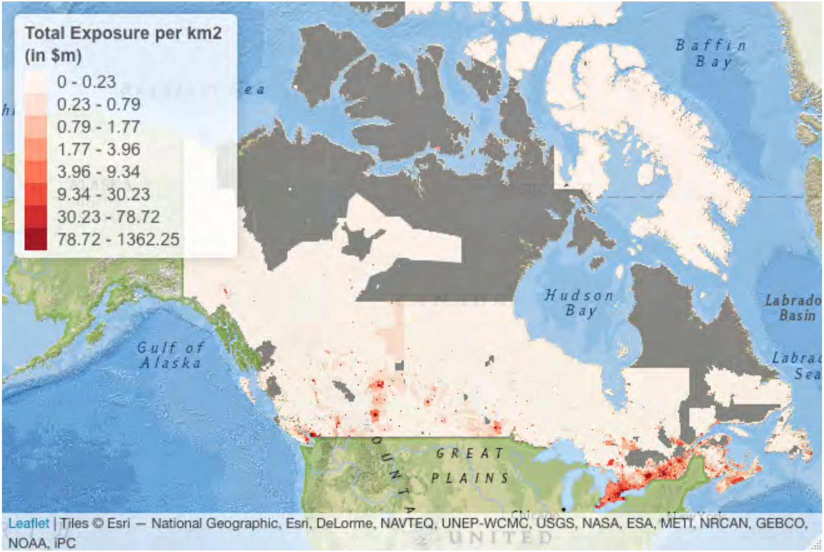
   d. Map the exposure of each building type to the building classes, i.e. wooden, steel, concrete, etc.

Single detached house

Apartment in a duplex

Apartment in a building that has 5+ storeys

Total exposure per km^2



Simulation algorithm

(ii) Simulate earthquakes in space and time.

a. Build a Spatio-Temporal Point Process (STPP) by using the data for significant earthquakes (Lamontagne et al., 2018).

   A realization of a STPP consists of geographical location $\boldsymbol{x}_i$ and a corresponding time of occurrence t_i, such that $\{(\boldsymbol{x}_i, t_i) : i = 1, \ldots, n\}$.

b. Estimate the spatio-temporal intensity function $\lambda(\boldsymbol{x}, t)$, representing the mean number of events per unit area per unit of time, by assuming separability.

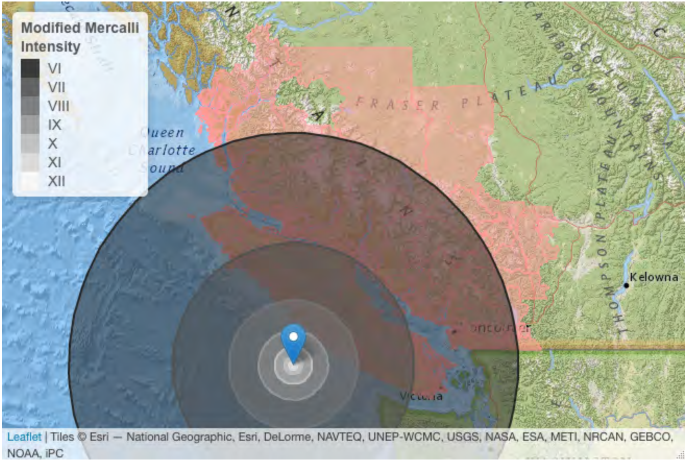
$$\lambda(\boldsymbol{x}, t) = \lambda_{\boldsymbol{x}}(\boldsymbol{x})\lambda_t(t).$$

c. Simulate a large number of years of significant earthquakes.

Simulation algorithm

(iii) Estimate ground shaking intensity.

a. Simulate significant ground motion parameters (Geological Survey of Canada, 2015) and create isoseismal maps.



Simulation Algorithm

(iv) Calculate damage rates.

a. Use damage probability matrices to calculate the mean damage factor (MDF), i.e. the ratio of dollar loss to the replacement value of the building. It is given by $\mathbb{E}[CDF|MMI = m]$).

Table: An example of a damage probability matrix (Onur et al., 2005)

Damage state	Central damage factor (CDF) (%)	Modified Mercalli intensity (MMI)						
		VI	VII	VIII	IX	X	XI	XII
None	0	12	2	0	0	0	0	0
Slight	0.5	73	30	2	0	0	0	0
Light	5	15	65	57	15	1	1	0
Moderate	20	0	3	40	66	61	28	5
Heavy	45	0	0	1	18	35	55	67
Major	80	0	0	0	1	3	16	25
Destroyed	100	0	0	0	0	0	0	3

Simulation algorithm

(v) Estimate seismic financial losses and insurance claim payments

(a) Financial losses:

$$\text{Loss} = \sum_k \left[\text{MDF}_k \times (\text{Building exposure}_k)\right],$$

where k is an index for the building class.

(b) Insurance claims:

We rely on actuarial assumptions from Insurance Bureau of Canada, 2013

MCT for earthquake insurance risk

We propose to use the correlation of the insured losses between Canadian provinces to calculate the MCT for earthquake risk.

$$\text{Canada}\,\text{PML}_{1/500} = \sqrt{\sum_{r,s} \text{CorrEQ}_{r,s} \times \text{PML}_{1/500,r} \times \text{PML}_{1/500,s}},$$

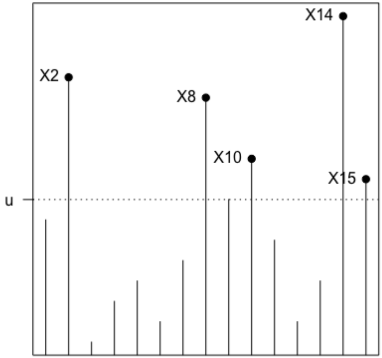
where:

1. the sum includes all combinations (r, s) of Canadian provinces.
2. $\text{CorrEQ}_{r,s}$ is the correlation of the insured losses for provinces r and s.
3. $\text{PML}_{1/500,r}$ and $\text{PML}_{1/500,s}$ are the Gross $\text{PML}_{1/500,r}$ for provinces r and s, respectively.

Estimating the Probable Maximum Loss

For a high threshold u, the number of exceedances $N \sim$ marked homogeneous Poisson process (λ) and the size of the excesses $\sim G_{\xi,\sigma}$, a Generalized Pareto Distribution.

The maximum of the N exceedances $M_N \sim H_{\xi,\mu,\psi}$, a Generalized Extreme Value distribution.



The PML is an extreme quantile of M_N such that for some small $\epsilon > 0$,

$$\mathbb{P}(M_N \leq \text{PML}_\epsilon) = 1 - \epsilon \quad \Longleftrightarrow \quad \text{PML}_\epsilon = u + \frac{\sigma}{\xi}\left[\left(-\frac{\lambda}{\ln(1-\epsilon)}\right)^{\xi} - 1\right].$$

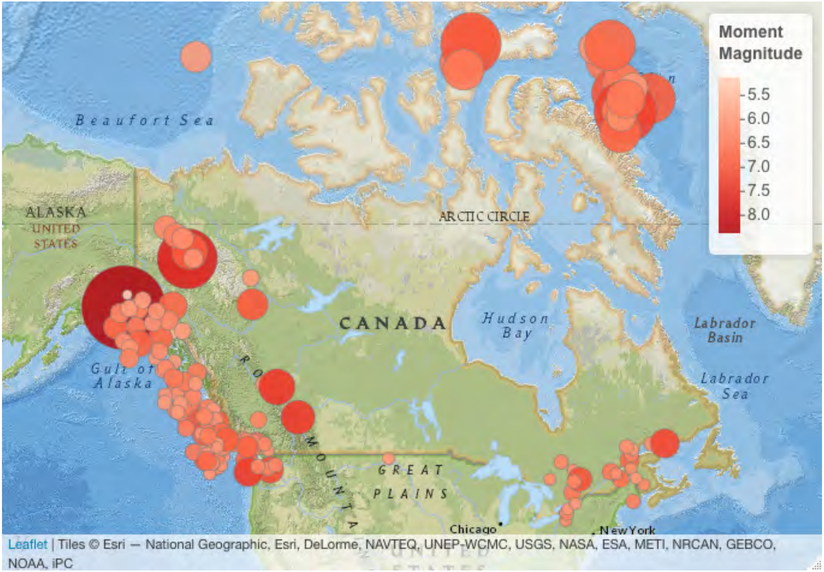
Comparison with other earthquake studies

Table: Onur et al. (2005) vs our methodology, subject to an MMI of VII.

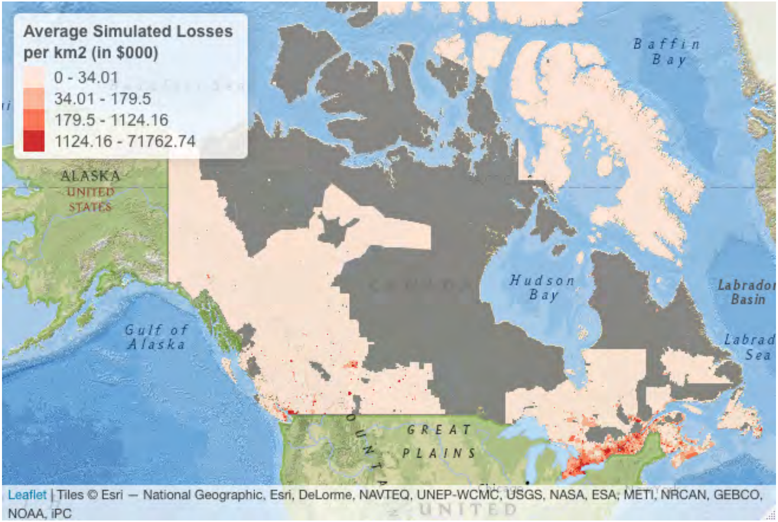
Study area	Results* by Onur et al. (2005)	Our methodology
City of Victoria	$835 million	$941 million
City of Vancouver	$6.8 billion	$5.7 billion

* Inflated to June 2021

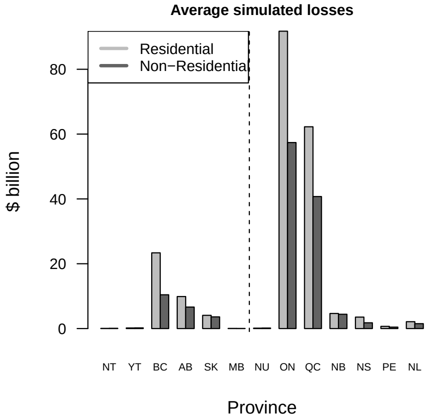
A sample of the simulated earthquakes

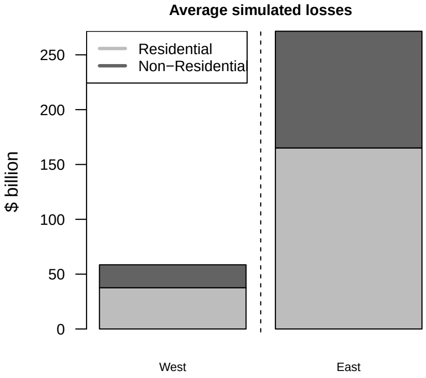


Average simulated financial losses, conditional on the occurrence of an earthquake

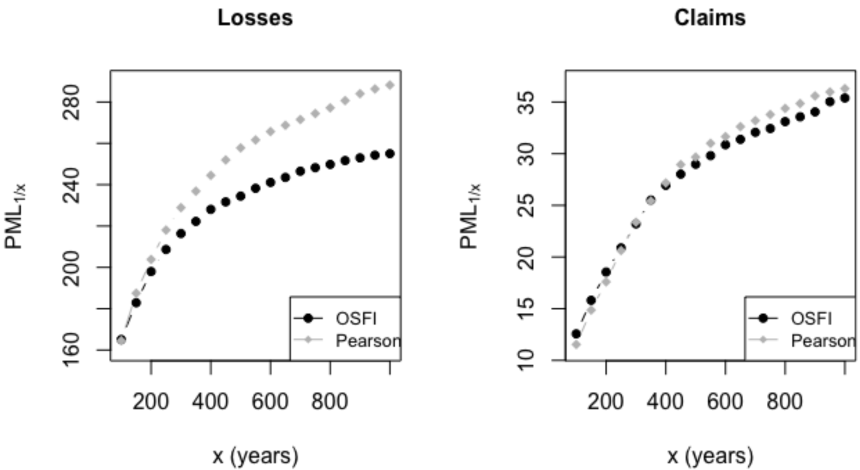


Average simulated financial losses, conditional on the occurrence of an earthquake





Comparison of results using OSFI's formula vs our proposed formula



Earthquake risk assessment tool

An open-source interactive web application is provided **here**.

Discussion

- We created a reproducible simulation-based approach to analyze earthquake insurance risk, based on publicly available data.
- We provided an alternative approach to OSFI's MCT formula for earthquake insurance risk.
- A significant earthquake event in Québec can cause financial damages of \$175 billion ($PML_{1/500}$). This is $10\times$ the budgeted COVID-19 support for the years 2020-2024.
- There is a need for further insurance market penetration.

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Thank you for your attention!