Canada’s new earthquake science
Learning from loss models

January 26, 2021
Learning from loss models

The program

- Welcome – why the new earthquake science is important
- Tail risk – how models support management of extreme earthquake hazards
- Increased shaking – Canada’s 6th generation seismic hazard model
- Fire – why it is important to anticipate fire following large earthquakes
- Public interest – how catastrophe models serve the public
Institute for Catastrophic Loss Reduction

Canada’s leading disaster research institute

- working to promote resilience to earthquakes and climate-related risks
- International Council of Science Centre of Excellence
- funded by gov’ts and 120 private and public member insurers
- established in 1997 / based at the University of Western Ontario
Welcome

How models inform decisions

✓ changing knowledge about hazards
✓ changing knowledge about the risk that hazards result in loss
✓ special case for low probability / high consequence risks
✓ Canadian focus on catastrophic earthquakes
Tail risk

How models support management of extreme earthquake hazards

✓ Alister Campbell, PACICC
✓ Tiegan Hobbs, NRCan
✓ Arash Nasseri, AIR
✓ Bryant Reyes, RMS
✓ David Gregory, CoreLogic
Tiegan Hobbs
Natural Resources Canada

How models support management of extreme earthquake hazards
A National Seismic Risk Profile for Canada from NRCan

Risk: M. Journeay, T. Hobbs, A. Rao, V. Silva, L. Martins, M. Simionato,
Hazard: M. Kolaj, T. Hobbs, M. Pagani, K. Johnson,
Physical Exposure: M. Journeay, W. Chow
Social Vulnerability: M. Journeay, J. Yip, C. Wagner
OpenDRR Platform: J. van Ulden, D. Rotheram-Clark, W. Chow
A National Seismic Risk Profile for Canada

2015
2019
2020
2021

Risk Profile
6th Generation PSHA Model
National Seismic Hazard
National Seismic Risk
Regional Scenario Hazard
Regional Scenario Impacts
2nd Generation National Seismic Risk Model

Public Release
GEM Global Fabric
National
Regional
Municipal

R&D on Seismic Hazards in Canada
OpenData Platform
A National Seismic Risk Profile for Canada

- Risk Profile
- Probabilistic Seismic Risk Model
- National Seismic Hazard
- National Seismic Risk
- Regional Scenario Hazard
- Regional Scenario Impacts

Physical Risk

- Building Performance: Damage, Recovery Time, Disaster Debris
- Public Safety: Critical Injuries, Entrapment, Emergency Services, Shelter Needs
- Economic Security: Direct Impact Losses, Cascading Indirect Losses
- Social Disruption: Household Displacement, Business Interruption

Strain on Social Fabric

- Shelter: Tenancy, Quality and Suitability of Housing, Capacity to Maintain
- Individual Autonomy: Age, Social Marginalization, Race and Linguistic Barriers
- Family Structure: Social Connections, Dependency, Living Alone, Mobility

GEM
GLOBAL EARTHQUAKE MODEL

Canada
Rapid Disaster Modelling

- Uses Shakemap from provincial network in OQ Canada framework
- Raw outputs are validated, indexed, entered into database
- Results are pulled via API, displayed in a user-friendly dashboard
How models support management of extreme earthquake hazards
Extreme Event / Catastrophe Modeling

What does your company do?
What does it produce?
AIR Worldwide provides catastrophe risk modeling software and consulting services that make organizations and society more resilient.

- A subsidiary of Verisk Analytics
- Founded in 1987
- 400+ Clients
- Offices in 8 countries
- Our models cover extreme events across the globe
What Questions Are Catastrophe Models Designed to Answer?

- What is the probability of a given level of loss for my book in a wide range of catastrophe scenarios?
- Where are future events likely to occur?
- How frequently are they likely to occur?
- How intense are they likely to be?
- For each potential event, what is the estimated range of damage and insured loss?
Providing a Wide Range of Analytics for Managing Risk

TOUCHSTONE®

Access to Multiple Models

Underwriting

Data Quality Analytics

Loss Grouping

Hazard Analytics

Geospatial Analytics

Non-Cat Analytics

Comparative Analytics

Touchstone Re™

Analyze Re

Loss Analytics w/ Uncertainty
How models support management of extreme earthquake hazards
Make every risk known
With 30 years of experience in the risk modeling industry, we have developed some of the most widely used models in the world. Building and using these models has given us a wholly unique view of the physics of risk – one that allows us to lead the charge in building a more resilient world.

- **Hundreds of catastrophe models including:**
  - Canada Wildfire
  - Canada Windstorm
  - Canada SCS
  - Global Terrorism

- **Over 1,000 products in total including:**
  - Data Products (hazard data, risk scores, etc.)
  - Integrated software solutions for the industry
  - Analytical Services
RMS CAEQ Model: themes that make a difference

• 100-person years to develop
• 30+ EQ conference and peer-reviewed journal publications by RMS authors in a given year
• USGS and NGA-West 2 project involvement
  • External model reviewers
• 1,700+ pages of documentation
Canada EQ Model: Scope

- **Country-wide Probabilistic Model**
  - Shake
  - Fire following EQ
  - EQ Sprinkler Leakage
  - Industrial Facilities Model
  - Builders Risk
  - Accumulation scenarios
    - Tsunami (west coast)
How models support management of extreme earthquake hazards
Tail Risk
Definitions

• OEP: The probability of loss from an event exceeding a loss in a given year, such as a 0.2% annual exceedance.

• Return Period: The probability of a loss specified as a 1-in-xx chance, e.g. 1-in-500 year.

• T-VaR Tail Value at Risk: The average value of a loss above a selected EP return period
Tail Risk
Issues in modelling

- Handled by the financial model, but relies on a robust Hazard & Vulnerability model
  - 2011 M9.0 Tohoku, Japan
  - Appropriate uncertainty captured in the vulnerability
  - Correlation is important
  - Infrequent events
  - Commercial Vendors face ‘run time issues’

Source: NRCan
Tail Risk
CoreLogic method

- CoreLogic employs a 300,000 year simulation period – pushes the uncertainty as far as possible into the tail
- Allows for robust capture of large events
- Include uncertainty on upper-bound magnitude
- Correlation
Discussion
Extra slides follow
Seismic Sources

**Objective** – Small rates (long return periods) matter (especially in Canada). Taking shortcuts can compromise accuracy in hazard, correlation, and risk.

- GSC Seismic Hazard
- 2014 USGS NSHMP
  - Cascadia Subduction Zone
  - California: UCERF3
- Updated historical catalogs and improved background methodology

**WHY IT MATTERS:** Low probability scenarios comprise most of the tail in Canada. Realistic representation of the range of events is important.
Ground Motions

**Objective** – Incorporate ground motion modeling consistent with the latest scientific understanding

- New ground motion prediction equations (GMPEs) and weighting schemes for all tectonic regions
  - NGA-West2 for active crustal regions
  - Custom relationships for Hawaii
  - BC Hydro for the Cascadia Subduction Zone
  - Global and local ground motion models for the Mexico Subduction Zone

**WHY IT MATTERS:** GMPEs determine relative distribution of shaking in an event. Updated relationships consider 1000s more recordings than previous studies.
## SECONDARY PERILS

<table>
<thead>
<tr>
<th><strong>Fire Following EQ</strong></th>
<th><strong>Sprinkler Leakage</strong></th>
<th><strong>Tsunami</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved high-resolution simulation methodology for 18 major US metro areas and 6 Canada metro areas used to determine fire vulnerability</td>
<td>Re-evaluation of earthquake sprinkler curves</td>
<td>• New accumulation footprints available for 15 Cascadia Subduction Zone scenarios (instead of one), M9.3-M8.3</td>
</tr>
<tr>
<td>Updated building density, fire fighting capacity, wind speed and other input data</td>
<td>Vulnerability linked to peak ground acceleration (PGA)</td>
<td>• Covering coastal areas of western US (California, Oregon, Washington) and western Canada (British Columbia)</td>
</tr>
<tr>
<td>Improved vulnerability extrapolation methodology for areas outside simulation areas</td>
<td>New for Canada</td>
<td>• Damage ratios vary by line of business and inundation depths</td>
</tr>
</tbody>
</table>
Contribution to AAL by Magnitude and Event Return Period

Ontario

Quebec

- >100k
- 50k-100k
- 25k-50k
- 10k-25k
- 5k-10k
- 1k-5k
- 0-1k
Increased shaking

Canada’s 6th generation seismic hazard model

✓ Michal Kolaj, NRCan
✓ Tiegan Hobbs, NRCan
✓ Emel Seyhan, RMS
✓ Arash Nasseri, AIR
✓ David Gregory, CoreLogic
The 6th Generation Seismic Hazard Model of Canada (CanadaSHM6) was released in 2020.

It is currently proposed for inclusion within the 2020 edition of the National Building Code of Canada.

Map shows the change in estimates for select cities between CSHM6 (2020) and CSHM5 (2015) for short period hazard on firm ground.

For more information see:

The 6th Generation seismic hazard model of Canada
Michal Kolaj, John Adams, and Stephen Halchuk
Paper 1c-0028, 17th World Conference on Earthquake Engineering
Approach to estimating hazard and risk in Canada
Tiegan Hobbs
Natural Resources Canada
NRCan Seismic Risk Modelling

[Adams et al., 2019, 12th CCEE]
Risk Inputs – Hazard & Fragility

<table>
<thead>
<tr>
<th>Tectonic Environment</th>
<th>GMPE</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stable Shallow Crust</td>
<td>Goulet et al. (2017)</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>Atkinson and Adams (2013)</td>
<td>0.50</td>
</tr>
<tr>
<td>Active Shallow Crust</td>
<td>Abrahamson et al. (2014)</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Boore et al. (2014)</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Campbell and Bozorgnia (2014)</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Chiou and Young (2014)</td>
<td>0.25</td>
</tr>
<tr>
<td>Subduction Interface</td>
<td>Abrahamson et al. (2016)</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Atkinson and Macias (2009)</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Ghofrani and Atkinson (2014)</td>
<td>0.25</td>
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<tr>
<td></td>
<td>Zhao et al. (2006)</td>
<td>0.25</td>
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<tr>
<td>Subduction Intraslab</td>
<td>Abrahamson et al. (2016)</td>
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<td>Atkinson and Boore (2003)</td>
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<td></td>
<td>García et al. (2005)</td>
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<tr>
<td></td>
<td>Zhao et al. (2006)</td>
<td>0.25</td>
</tr>
</tbody>
</table>

All GMPE's Modified for CanSHM6 per Kolaj et al. (2019)

[USGS; Allen & Wald, 2009]
Risk Inputs - Exposure

Earth Observation
Settled Areas
Land Use Type
Building Portfolio
Social Fabric

Seismic Zones
- Zone 4: > 0.6g
- Zone 3: 0.30-0.6g
- Zone 2B: 0.24-0.32g
- Zone 2A: 0.16-0.24g
- Zone 1: 0.075-0.19g
- Zone 0: < 0.075g

Proposed Seismic Design Levels for Existing Buildings in Canada

<table>
<thead>
<tr>
<th>NBC Site Seismic Category (SNC)</th>
<th>PGA (2%50yr)</th>
<th>Sa(2) (2%50yr)</th>
<th>Sa(1.0) (2%50yr)</th>
<th>2005-present</th>
<th>1990-2004</th>
<th>1973-1989</th>
<th>Pre-1972</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNC-6</td>
<td>&gt;0.4</td>
<td>&gt;1.15</td>
<td>&gt;0.15</td>
<td>High-Code</td>
<td>High-Code</td>
<td>Moderate Codes</td>
<td>Pre-Code¹</td>
</tr>
<tr>
<td>SNC-4</td>
<td>0.32-0.4</td>
<td>0.15-1.15</td>
<td>0.05-0.15</td>
<td>High-Code</td>
<td>Moderate Codes</td>
<td>Low-Code</td>
<td>Pre-Code²</td>
</tr>
<tr>
<td>SNC-3</td>
<td>0.24-0.32</td>
<td>0.05-0.75</td>
<td>0.15-0.30</td>
<td>Moderate-Code</td>
<td>Moderate-Code</td>
<td>Low-Code</td>
<td>Pre-Code²</td>
</tr>
<tr>
<td>SNC-2</td>
<td>0.10-0.24</td>
<td>0.05-0.35</td>
<td>0.10-0.15</td>
<td>Moderate-Code</td>
<td>Low-Code</td>
<td>Low-Code</td>
<td>Pre-Code²</td>
</tr>
<tr>
<td>SNC-1</td>
<td>0.075-0.18</td>
<td>0.10-0.20</td>
<td>0.05-0.10</td>
<td>Low-Code</td>
<td>Low-Code</td>
<td>Pre-Code³</td>
<td>Pre-Code³</td>
</tr>
<tr>
<td>SNC-0</td>
<td>0.05-0.75</td>
<td>&lt;=0.10</td>
<td>&lt;=0.06</td>
<td>Low-Code</td>
<td>Low-Code</td>
<td>Pre-Code³</td>
<td>Pre-Code³</td>
</tr>
</tbody>
</table>

1. Assume Moderate-Code design for residential wood-frame buildings (WF).
Economic Security – expected ground up losses
minimum expected future loss from known seismic events of varying magnitude (return period)

Return Period (years)

Ground-up Building Loss – $Billion CAD

B C Q C O N

~$40B

BC

18 3%

78 %
Arash Nasseri
AIR
AIR Earthquake Model for Canada - Overview

Last Updated in 2017

Covers all line of business, and coverage

Supports regular buildings, industrial facilitates, infrastructure, automobiles and builder's risk

Uses high resolution Industry Exposure Database

- Shake
- Liquefaction
- Fire Following
- Landslide
- Tsunami
AIR Earthquake Model for Canada – Hazard Component

- Unified US/Canada seismicity model
- Informed by data from NRCan, USGS and in-house studies
- Peer reviewed
- 10K TD/TID catalogs optimized from 100K
- Historical and EDS/RDS scenarios
- Utilizes ensemble of ground motion models with logic tree
- Explicit inclusion of site conditions and deep basin impacts
AIR Earthquake Model for Canada – Vulnerability Component

- Utilizes a hybrid approach by blending engineering analysis with data
- Use different intensity measure for building of different heights
- Informed by evolution of NBCC codes
- Collaborated with local experts
- Peer reviewed
RMS Canada Earthquake Model
Seismic Hazard and Risk

- Complete Seismic Model Across all Canadian Provinces and Territories
- A Forward Looking Seismic Hazard and Risk Model
- Increased Definition of Regional Variations Provides Greater Clarity
- Accurate Risk Pricing Differentiation
- Robust Model Validation
- Improved Science: Journal Publications by RMS Modelers

Source: RMS North America Earthquake Models Methodology Version 17.0

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RMS Canada Earthquake Model
Seismic Hazard and Risk

Seismic Source
- Extended Cascadia Subduction zone
- SHEEF2010 catalog
- Careful treatment of Charlevoix seismic zone

Ground Motions and Site Response
- 2014 NGA-West 2 and 2016 BC Hydro in West; Prelim. NGA-East in East
- Modeled epistemic unc.
- High res. nonlinear site amplification models
- Vancouver basin

Geotechnical Data and Models
- High resolution geology based site characterization ($V_{S30}$)
- Probabilistic liquefaction model
- High res. groundwater depth

Vulnerability
- Seismic performance of building stock based on seismic design code and standards
- Building inventory distribution by location and line of business

Secondary Perils
- Tsunami in West
- Fire following
- Sprinkler leakage
David Gregory
CoreLogic
Seismic Risk

Seismic Hazard

- How big?
- How frequent?
- Where?

- Ground Motion Models
- Site Adjustments
- Severity of shaking
- Soil Maps
Considerations and impact of 6th Generation model for earthquake hazard and risk in western Canada
321st Anniversary of the Cascadia 1700 January 26 ~M9 earthquake

1. Crustal (e.g., 1946 M7 on Vancouver Island)
2. Inslab (e.g., 2001 M6.8 Nisqually)
3. Megathrust (e.g., 1700 ~M9)

Images: NRCan GeoFact Sheets on earthquakes in southwestern British Columbia
Shakemap – USGS: https://earthquake.usgs.gov/scenarios/eventpage/bssc2014cascadia_sub0_m9p34_se#shakemap
David Gregory
CoreLogic
Western Canada

Recap of changes in CanadaSHM6:
• Updated recurrence of Cascadia Subduction Zone – The Big One
• Inclusion of more active shallow fault sources (Leach River Valley / Devils Mountain fault system), expect a local impact on Victoria.
• Updates to GMMs (NGA-West2)
• Site specific soil adjustment factors

**BUT:** Some overlap with USGS hazard model

Cascadia event - The Big One

*Typically assumed to drive majority of WC risk, but by how much?*
What seismic sources drive Western Canada hazard?
Western Canada: Key Differentiators
Cascadia Subduction Zone

RMS ground shaking logic trees include (more similar to NRCan6 than NRCan5):
- BC Hydro 2015 in subduction zones
- NGA-West 2 in active crustal regions

- Largely following Goldfinger et al. (2012)
- Cascadia subduction zone extended farther northward
- Time-dependence on interface
- SHEEF2010 earthquake catalog

RMS

90% of earthquakes occur along active plate boundaries. 60% of Canada's earthquakes occur along BC's coast.

British Columbia
500-year contribution

Source: Earthquakes Canada

Natural Resources Canada
Western Canada: **Key Differentiators**
The Fraser River Delta in British Columbia

**RMS Probabilistic Liquefaction Model**

- Unique RMS prediction of groundwater using well database
- Separation of vertical and lateral displacement

**RMS Vancouver Basin**
Published as Kim and Seyhan, 2016

1. Basin effects on tall buildings around deep, soft soil sites
2. Shallow sediment thickness impact

Source: RMS North America Earthquake Models Methodology Version 17.0
AIR Hazard Model for Western Canada Assimilate Various Data Sources

Cascadia Subduction Interface Earthquakes

- Uses rupture model from Goldfinger et al. 2012
  - Considers full rupture with larger maximum magnitude (9.3)
  - Considers partial ruptures in southern Cascadia zone
- Account for time dependency

In-slab Deep Earthquakes

- AIR model considers varying depth following slab geometry and depth model from USGS
AIR Hazard Model for Western Canada Assimilate Various Data Sources

Crustal Events

- Explicitly model faults and areal seismic zones
  - Includes Devil Mountain Fault and also Tacoma and Seattle faults from USGS
  - Includes background seismicity with magnitudes up to 8
- Seismicity rate is constrained by historical data, fault data, and strain rates calculated from Kinematic modeling using GPS data
Shaking Intensity is Calculated Using An Ensemble of Ground Motion Models

- For each tectonic region, AIR model uses a number of appropriate ground motion models in a logic tree approach.
- Directly uses Vs30 in GMMs to account for site amplification.
  - Detailed soil maps are used to define site conditions.
- Explicitly accounts for the deep Georgia Basin.

AIR hazard model is comprehensive and incorporates data beyond SHM5. The updates in SHM6 methodology and data bring it closer to AIR’s modeling approach.
Tiegan Hobbs
Natural Resources Canada
Cascadia Event in our Scenario Catalogue

Impacts of CanSHM6:
- Cascadia scenario losses increase from ~$27 Billion to ~$39 Billion
- Likelihood of MMI 7 event in 50 years ~doubles for Vancouver and Victoria
Discussion and Q&A
Considerations and impact of 6th Generation model for earthquake hazard and risk in eastern Canada
Earthquakes in eastern Canada

Large urban cities in or near zones of large historical / pre-historical earthquakes.

Lack of data results in high uncertainty in the characteristics of future earthquakes.

Recent developments:

NGA-East:
- new “next-generation” ground motion models (GMMs)
- GMMs provide predictions for the level of ground shaking based on earthquake and site characteristics
Emel Seyhan
RMS
Eastern Canada: **Key Differentiators**

**Ground Motion Variability**

RMS ground shaking logic trees include (more similar to NRCan6 than NRCan5):
- Prelim. NGA-East models
- 2014 Central and Eastern North America models

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**Eastern Canada**

*MW 7.0 Class C*

**Western Canada**

*MW 8.5 Class C*

Source: *NGA-West 2 and NGA-East published papers*

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Find out more

RMS blog on this topic

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Recognizing 2020 GSC Updates Within the RMS Canada Earthquake Model

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Eastern Canada: **Key Differentiators**

Saint Lawrence River and Charlevoix Seismic Zone

- Separate catalog treatment
- Separate “Recurring Large Magnitude Earthquake” zone

High seismicity, high exposure and more historical data

Source: RMS North America Earthquake Models Methodology Version 17.0
Seismicity in Eastern Canada is Characterized by Activities on Stable Continental Region

- Lack of data poses challenges in understanding and formulating hazard
- Relies on global data to fill in the gap
- Subject to large uncertainty

Uncertainty in all components of hazard models

Seismic Source Model  
Magnitude-Rate models  
Ground Motion Models
AIR Model in Eastern Canada Follows a Logic Tree Approach to Account for Variability and Uncertainty

- GSC $H$ and $R$ source models are used along with the smooth seismicity concept from USGS models

- On ground motion models we use a weighted average of multiple GMMs for stable continental regions
  - Accounts for both aleatory and epistemic uncertainty
  - Explicitly uses Vs30 to reflect site amplification in GMMs
In SHM6, Ground Motion Models and Treatment of Uncertainty Drive the Hazard Change in Eastern Canada

- Incorporation of NGA-East results, along with a switch to a classic logic-tree combination of GMPE to account for epistemic uncertainty, drove a large increase in hazard from SHM5 to SHM6.

- The uncertainty model in the AIR’s 2017 U.S.-Canada models is similar to SHM6.

- Incorporation of NGA-East will have an impact on the AIR model.
  - Impact on hazard depends on magnitude and distance.
  - Quantifying the impact on loss is complicated and depends on exposure type and location.
David Gregory
CoreLogic
What seismic sources drive Eastern Canada hazard?
*Trends shown here for example only; population density is at FSA, hazard and soils are often much higher resolution, hazard/risk can vary dramatically within an FSA.
Tiegan Hobbs
Natural Resources Canada
Charlevoix Scenario & Eastern Considerations

**Shake Hazard**
- Peak Ground Acceleration (g) & Eastern Scenario
- Legend:
  - High Voltage Substation
  - Transmission Line (735 kV)
  - Truss-Canada Highway
  - Gently-2 Dam
  - Airport
- Map showing areas with different levels of ground acceleration.

**Financial Loss Table**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Modeller</th>
<th>Financial Loss [CAD]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cascadia</td>
<td>AIR GSC</td>
<td>$43.6 Billion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$33.7 Billion</td>
</tr>
<tr>
<td>Charlevoix</td>
<td>AIR GSC</td>
<td>$39.5 Billion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$7.0 Billion</td>
</tr>
</tbody>
</table>
Discussion and Q&A
Why it is important to anticipate fire following large earthquakes

✓ Charles Scawthorn, SPA Risk
✓ Arash Nasseri, AIR
✓ Tom Larsen, CoreLogic
✓ Bryant Reyes, RMS
Fire following earthquake session outline

- Moderator
  - Introductions of speakers
  - Fire following earthquake – summary recent modeling for Lower Mainland

- Approaches to Fire following earthquake modeling
  - AIR Worldwide
  - CoreLogic
  - RMS

- Discussion / Q&A
Arash Nasseri Ph.D. is a Principal Engineer and Senior Manager, Research and Modeling. AIR Worldwide is a risk modeling and data analytics company serving the insurance, reinsurance, financial services, and government markets. [www.air-worldwide.com](http://www.air-worldwide.com)

Tom Larsen is responsible for subject matter expertise and thought leadership focused on natural catastrophes and data analytics at CoreLogic. CoreLogic provides information intelligence to identify and manage growth opportunities, improve business performance and manage risk. [www.corelogic.com](http://www.corelogic.com)

Bryant Reyes, PhD is a Product Manager for the Americas Earthquake Models at RMS with user-focused experience in the cat modeling industry and physical modeling in academia. RMS helps insurers, financial markets, corporations, and public agencies evaluate and manage global risk from natural and man-made catastrophes. [www.rms.com](http://www.rms.com)

Charles Scawthorn, S.E., D.Eng. has contributed for 35+ year to the fields of earthquake engineering and fire following earthquake mitigation. SPA Risk LLC develops integrated mitigation programs for natural and technological hazards worldwide. [www.sparisk.com](http://www.sparisk.com)
EQ4 Mw 7.3 Georgia Strait (GS) shallow crustal event

Distribution of mean losses (C$ billions)
Summary Results

<table>
<thead>
<tr>
<th>Scenario</th>
<th>EQ1 Mw 9.0 CSZ</th>
<th>EQ2 Mw 6.8 JDF</th>
<th>EQ3 Mw 7.3 LRDM</th>
<th>EQ4 Mw 7.3 GS</th>
<th>EQ5 Mw 6.5 NWM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Ignitions</td>
<td>16</td>
<td>106</td>
<td>4</td>
<td>216</td>
<td>93</td>
</tr>
<tr>
<td>Mean no. Large Fires</td>
<td>0.6</td>
<td>31</td>
<td>0.02</td>
<td>47</td>
<td>29</td>
</tr>
<tr>
<td>Mean Losses CS billions</td>
<td>$0.16</td>
<td>$7.4</td>
<td>$0.01</td>
<td>$10.7</td>
<td>$7.2</td>
</tr>
</tbody>
</table>

Insurance aspect
- Almost entirely insured.
- *Consensus*: Swiss Re (2017): potential for **financial contagion**
- Being addressed by **industry and government**
Reducing the risk

Create regional Portable Water Supply System

High-rise Secondary Water Supplies (like California)

Gas meter seismic shutoff device
Canada’s insurers rely on three modeling companies: AIR, CoreLogic, RMS

→ Fire following earthquake modeling?

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**Triangle of Knowledge**

**Essentials**
- Hazard
- Building inventory
  → 1 Ignition model
- Fire resources
  → 2 Water resources
  → 3 Fire service response
- Firespread model
  → 4 Fire response modeled
  → 5 Example Results

**Simple:** Buildings all same or few types, assumed fire spread, simplistic analysis of water supply, fire response modeled

**Intermed:** More building types, fire spread function of spacing, materials, damage to water supply network, fire response modeled

**Detailed:** Individual building properties, spacing; fire spread equations, analysis of water supply network, fire response engine-by-engine

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90
Fire following earthquake analyses of Montreal and Vancouver

Basis: Field surveys, meetings with fire, water, building and other agencies/departments, GIS... data collection...

Ignition model: Empirical, based on each building's attributes, size, occupancy, random time of day and season

Water: Serviceability on each segment of water distribution pipe: size, material, age, type of soil etc

Fire response: all engines accounted for, assumed to be in stations at time of EQ, each engine tracked to first and succeeding fires

Firespread: hybrid (combined empirical-heat transfer) model based on each building's size, materials of construction, age, spacing, partial sprinkler information, etc.

Areas for Improvement

Hybrid (empirical-mechanistic) based on contents

Hydraulic analysis (done elsewhere)

Assumptions → AI decision-making model

Account for fenestraton, specific roofing and cladding materials
Arash Nasseri Ph.D. is a Principal Engineer and Senior Manager, Research and Modeling. AIR Worldwide is a risk modeling and data analytics company serving the insurance, reinsurance, financial services, and government markets. www.air-worldwide.com
AIR Catastrophe Modeling Framework

Hazard
- Event Generation
- Local Intensity Calculation
- Exposure Data

Engineering
- Damage Estimation
- Policy Conditions

Financial
- Insured Loss Calculation
Advanced Modeling Technique and Data Are Implemented to Capture the Uncertainty in Fire Following Risk
Understanding the Exposure and Built Environment is Critical in Modeling Fire Following Earthquakes

- Ignition and spread occurs where there is exposure
- 40 Characteristic Blocks represent the built environment
  - Density
  - Combustibility
  - Size and spacing of buildings

1 km grid
Ignition Generation Component Uses Ground Motion and Total Building Floor Areas in a City Block

<table>
<thead>
<tr>
<th>Event</th>
<th>Observed*</th>
<th>Modeled</th>
</tr>
</thead>
<tbody>
<tr>
<td>M6.0 Whittier-Narrows (1987)</td>
<td>36</td>
<td>43 (23-73)</td>
</tr>
<tr>
<td>M6.9 Loma Prieta (1989)</td>
<td>72</td>
<td>58 (30-83)</td>
</tr>
<tr>
<td>M6.7 Northridge (1994)</td>
<td>123</td>
<td>150 (110-192)</td>
</tr>
</tbody>
</table>

*adjusted to 2015
Detailed Fire Spread Model from Block Level to Regional Level

- Fire spread in characteristic blocks
- Blocks in 1km grid cell
- Grid cells in the entire region

>Vancouver

~ 1 km x 1 km grid cells
Uncertainty in Ignition Location, Method of Spread, Wind Speed and Direction and Fire Break Size is Taken into Account

10,000 simulations for each block, accounting for uncertainties in wind speed/direction, and ignition location and

Probability of fire crossing across blocks depends on firebreak width, wind condition, and fire suppression

Figures adapted from Scawthorn et al. (2005)
Fire Suppression Effectiveness Depends on Engines, Water Supply, and Fire Size

- Engine data
- Fire hydrant data
- Alternative Water sources
- Vancouver Dedicated Fire Protection System
- Serviceability and possibility of pipe damage
Model Results Demonstrate Potential for Large Losses from Fire Following Earthquakes

1732 M5.8 Earthquake new Montreal (uncertainty in location and magnitude)

2 scenarios for the earthquake source

Mean fire following losses considering variation in ignition location, wind speed and direction, etc.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Magnitude</th>
<th>FFE Loss (CAD bil)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.8</td>
<td>8.9</td>
</tr>
<tr>
<td>2</td>
<td>6.05</td>
<td>17.8</td>
</tr>
</tbody>
</table>

* In 2017 value
Tom Larsen is responsible for subject matter expertise and thought leadership focused on natural catastrophes and data analytics at CoreLogic. CoreLogic provides information intelligence to identify and manage growth opportunities, improve business performance and manage risk. www.corelogic.com
CoreLogic Earthquake Risk Modeling - Canada

Fire Following Earthquake

This discussion is relevant for evaluating urban conflagration risk.

Many process industries (refineries, paper/pulp, chemical) have distinct risk characteristics and analytic methodologies.
Fire Following Earthquake

Ignition Model

- Ignitions are modeled as the number of fires per one million square feet of building area.

- Ignition rates vary by
  - Shaking intensity
  - Predominant occupancy
  - Building code enforcement
Fire Following Earthquake

Suppression: Water Resources and Fire Service Response

- The fire suppression module incorporates variables whose values vary by geography including:
  - fire-fighting capability (number of engines)
  - water system performance (accounts for failed pipelines, due to soil liquefaction)
  - availability of mutual aid in firefighting

For firefighters:
The three main incident priorities: Life Safety (both the occupants and the responders), Incident Stabilization and Property Conservation

Property Conservation is 3rd of 3

For every simulation – the number of ignitions is evaluated against the net availability of resources to combat the ignition
Fire Following Earthquake

Fire Spread Model

• The fire spread module incorporates variables whose values vary by geography including:

  • density of construction

  • amount of fuel (proportion of buildings constructed of wood)

  • distribution of occupancy types

  • weather conditions such as prevailing wind speed

90%-ile Hourly winds, Vancouver
April: 7.5 miles per hour
August: 5 miles per hour
Vancouver, BC
Risk from Fire Following Earthquake

Analysis:
Evaluate EQ ruptures surrounding Vancouver Portfolio:
CoreLogic Industry (IED)

Results:
Loss potential to $20 Billion
Fire only
Insights:
High dependence on EQ location, season, weather
Using Modeling Analytics for Decision-making

Should Fire-following EQ be treated differently than shake damage

• Earthquake risk is often assessed as a point on the probability distribution

  • E.g., the 500-year loss, or loss with an annual probability of exceedance of 0.2%

• The largest fire-following losses are conditional on additional factors such as weather, time of day

  • This lowers the frequency of the worst events

• The Tail-Value-at-Risk statistic is the average loss beyond a threshold

  • For earthquake, often 1.5 to 2 times the peak loss.

  • For fire-following, can be 5 to 10 times
Bryant Reyes, PhD is a Product Manager for the Americas Earthquake Models at RMS with user-focused experience in the cat modeling industry and physical modeling in academia. RMS helps insurers, financial markets, corporations, and public agencies evaluate and manage global risk from natural and man-made catastrophes. www.rms.com
**Simulation Approach**

- Performed **over 24-million simulations** for 24 metro areas to develop high-res fire loss indices (FLIs)
Simulation Approach

- Performed over 24-million simulations for 24 metro areas to develop high-res fire loss indices (FLIs)

- Fire simulation methodology:
  - **high resolution data** for building footprints, building separation distance, city-block size, etc.
  - precise location and count of fire engines

![Map and diagrams illustrating simulation approach](image)
Ignition

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  - advanced fire ignition model (proprietary based on seasonality, construction, and occupancy)
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Fire Spread and Suppression

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  - wind speed/direction and humidity statistics for all grids in simulation
  - combination of recalibrated fire spread models via logic tree approach
  - dynamic approach to assign fire engines to active fires in the simulations
  - potential damage to fire stations and road network is accounted for in the simulations
FEEQ Model validation in California (number of ignitions)

- Modeled fire ignitions are in good agreement with the Hazus 2009 fire ignition function.

- Modeled mean values for the fire ignitions are also in good agreement with either observed values or recent studies:
  - Note that, according to some reports, a Today’s replica of the 1906 SF earthquake is believed to cause more than 500 ignitions (we estimate on average 720)

Statistics of fire ignitions for a set of selected historical events and scenarios. P5 and P95 are the 5th and 95th percentiles of the fire ignitions PDF, respectively.

<table>
<thead>
<tr>
<th>Earthquake event</th>
<th>PGA (g) average and (max)</th>
<th>Number of shake-induced fire ignitions on structures modeled within sim. area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Observed</td>
</tr>
<tr>
<td>M 7.8 1906 San Francisco</td>
<td>0.38 (1.24)</td>
<td>50 to 59</td>
</tr>
<tr>
<td>M 6.7 1971 San Fernando</td>
<td>0.10 (1.10)</td>
<td>91 to 109</td>
</tr>
<tr>
<td>M 6.9 1989 Loma Prieta</td>
<td>0.17 (0.62)</td>
<td>58 to 67</td>
</tr>
<tr>
<td>M 6.7 1994 Northridge</td>
<td>0.15 (0.86)</td>
<td>92 to 95</td>
</tr>
<tr>
<td>M 7.0 Haywired scenario</td>
<td>0.36 (1.45)</td>
<td>--</td>
</tr>
<tr>
<td>M 7.8 Shakeout scenario</td>
<td>0.25 (1.58)</td>
<td>--</td>
</tr>
</tbody>
</table>
Montreal 6.5 Mw

Loss Cost at Post Code

- Scenario centered near city hall
- RMS Industry Exposure Database
- Ground Up Loss

Montreal 6.5 Mw

Fire Following as Percentage of Shake Loss

- As a percentage of total loss, fire following is between 0-7% of total loss in a given post code
Discussion

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# Loss Comparison(s)

<table>
<thead>
<tr>
<th>Modeler</th>
<th>Lower Mainland</th>
<th>Montreal</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIR-Worldwide</td>
<td></td>
<td>M5.8 C$ 8.9 billion M6.0 C$ 17.8 billion</td>
</tr>
<tr>
<td>CoreLogic</td>
<td>range in C$ billions (see below)</td>
<td></td>
</tr>
<tr>
<td>RMS</td>
<td>M 6.8 JDF C$ 7.4 bns.</td>
<td>M 6.3 G S C$ 10.7 bns.</td>
</tr>
<tr>
<td>ICLR / SPA Risk</td>
<td>M6.5 C$ 12 bns.</td>
<td>M7 C$ 28 bns.</td>
</tr>
</tbody>
</table>

![Graph showing losses](Image)
Thank You

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bryant.reyes@rms.com

cscawthorn@sparisk.com
How catastrophe models can serve the public interest

- Paul Kovacs, ICLR
- Lori Medders, Appalachian State University
- John Schneider, Global Earthquake Model Foundation
Public interest discussion

Lori Medders
Joseph F. Freeman Distinguished Professor of Insurance, Appalachian State University
Past Chair, Florida Commission on Hurricane Loss Projection Methodology

John Schnieder
Secretary General, Global Earthquake Model Foundation

Paul Kovacs
Founder and Executive Director, Institute for Catastrophic Loss Reduction
Canada’s new earthquake science
Learning from loss models