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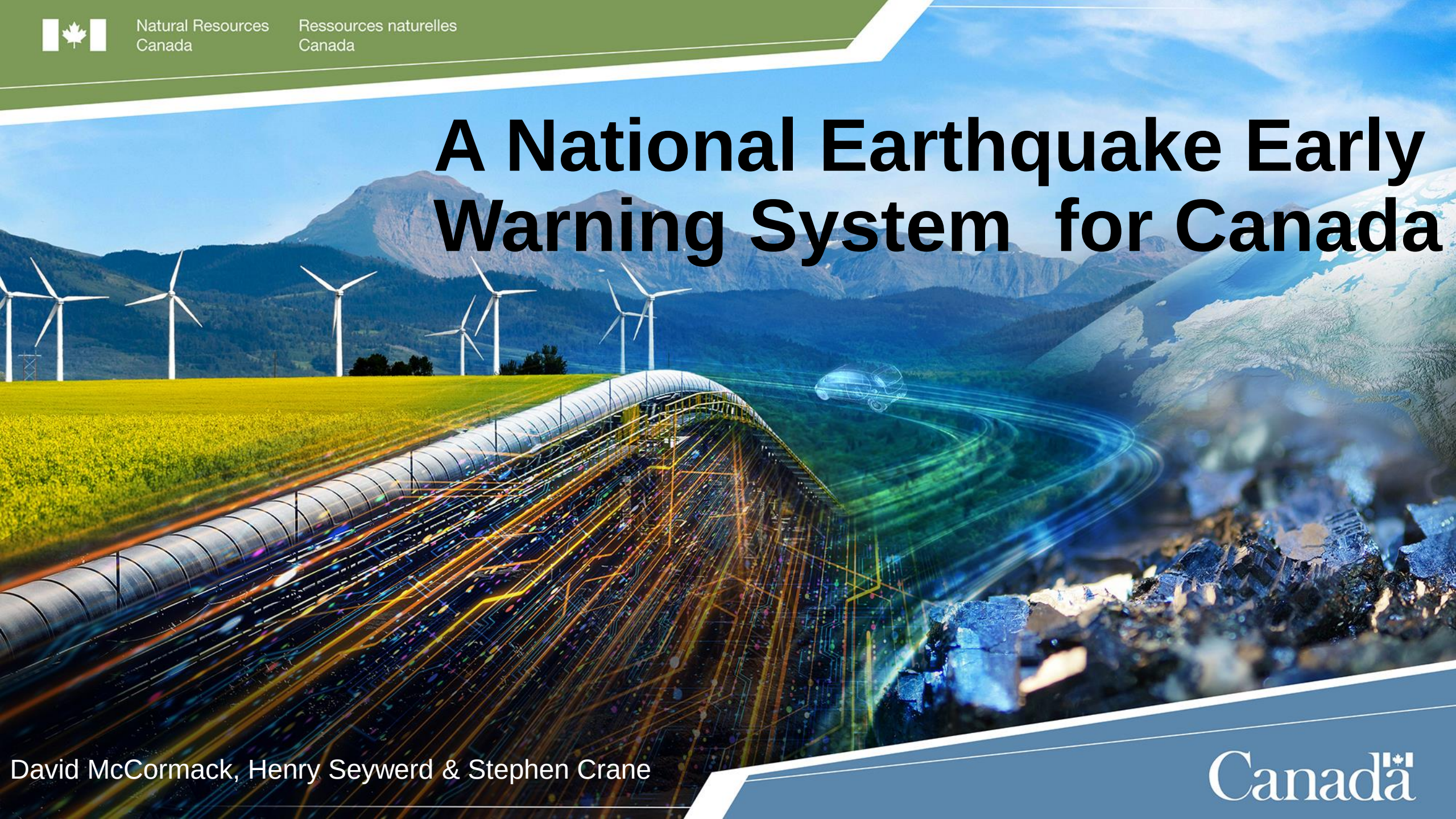
A National Earthquake Early Warning System for Canada



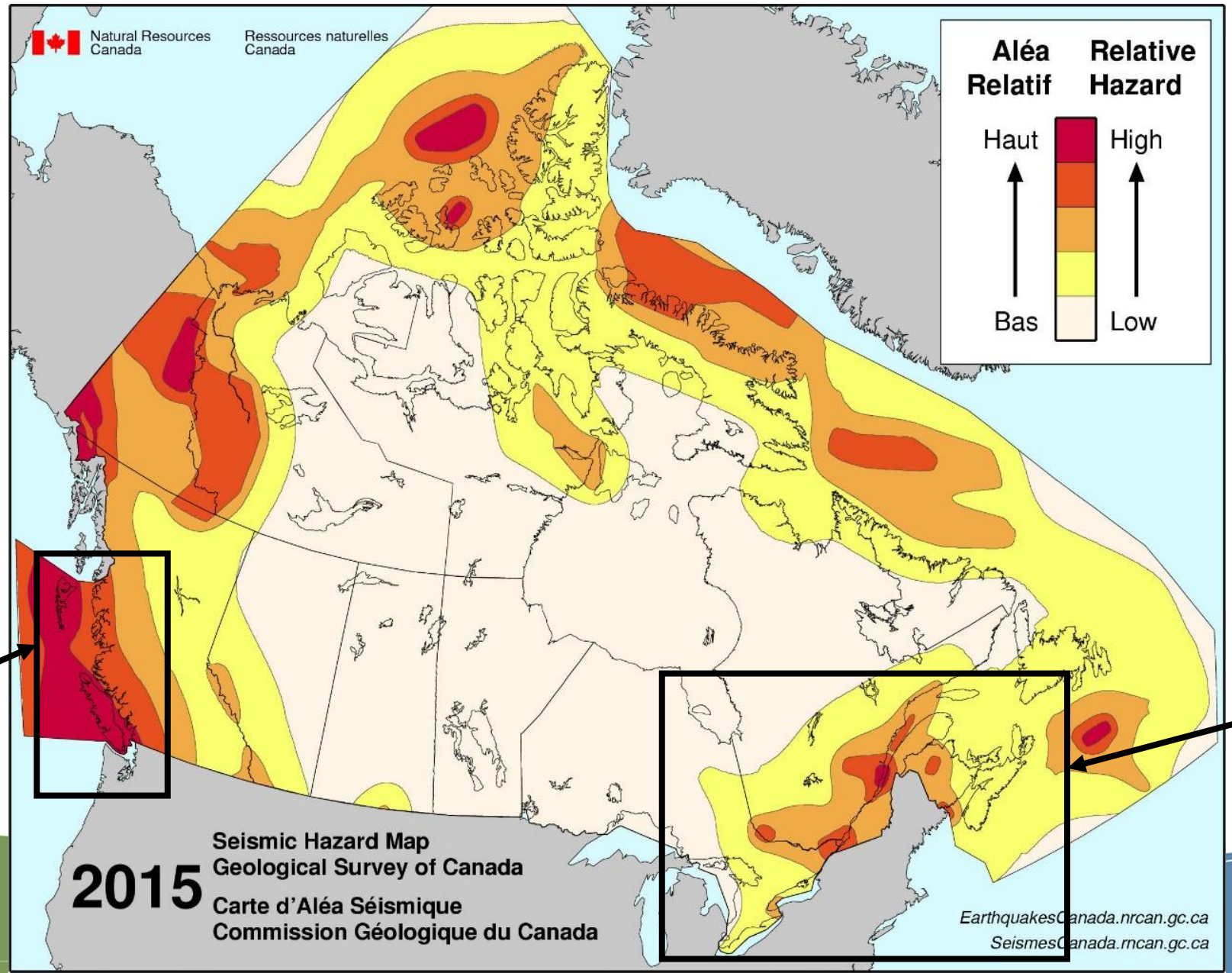
David McCormack, Henry Seywerd & Stephen Crane

Canada

Outline

- Quick recap: seismic hazard/risk in Canada
- Why EEW?
- Sensors & locations
- Modelling warning times
- Processing
- Alert dissemination
- Opportunities

Seismic hazard

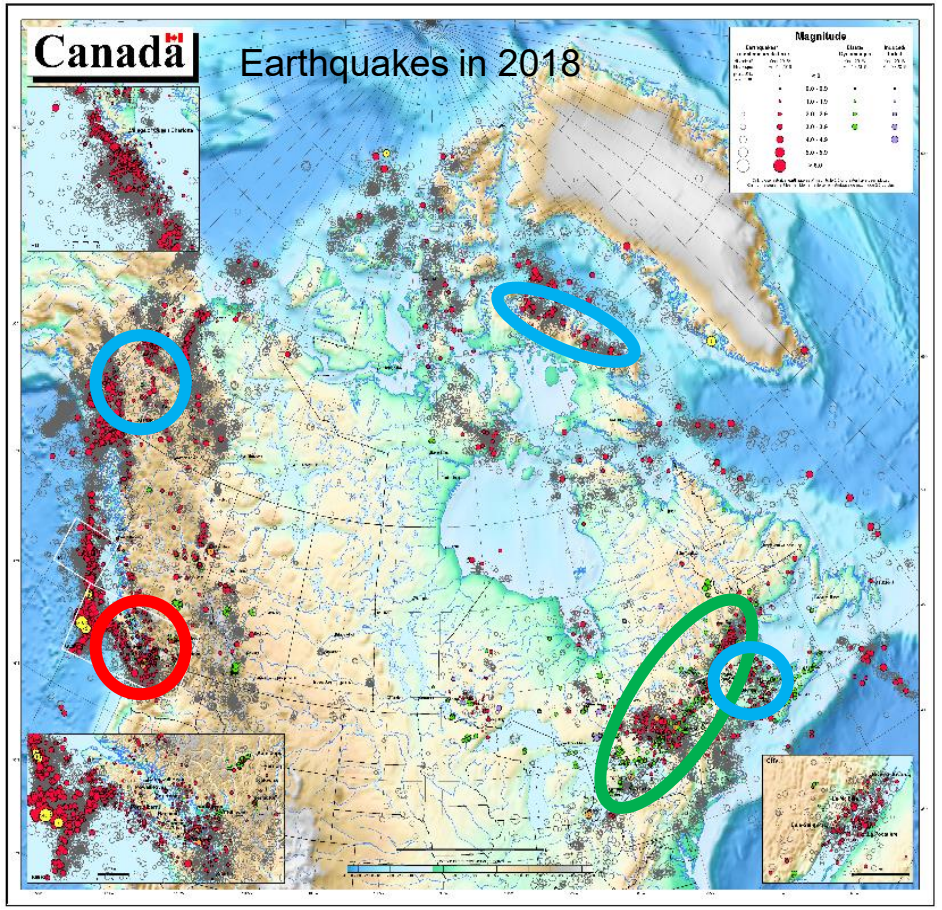


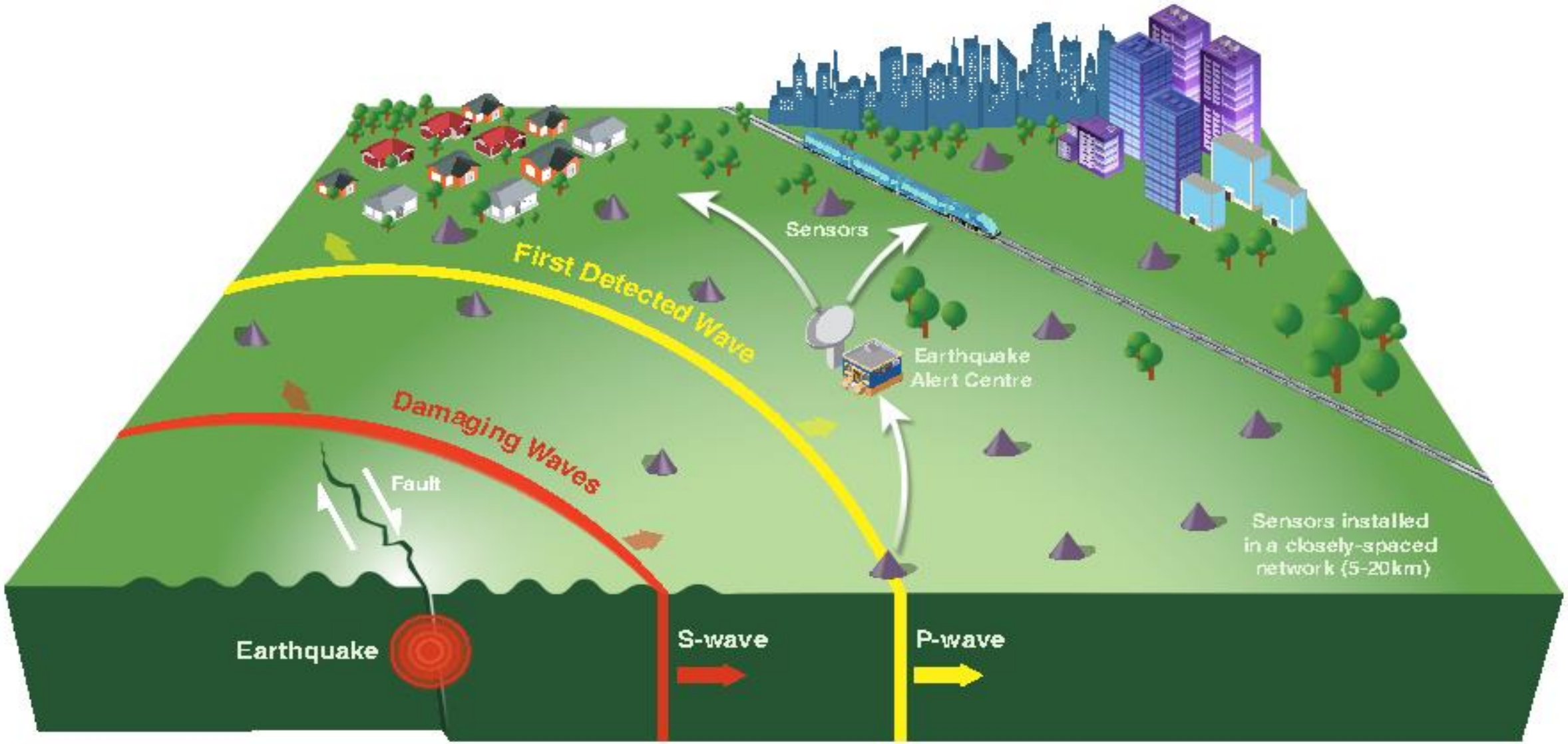
Western Canada

Eastern Canada

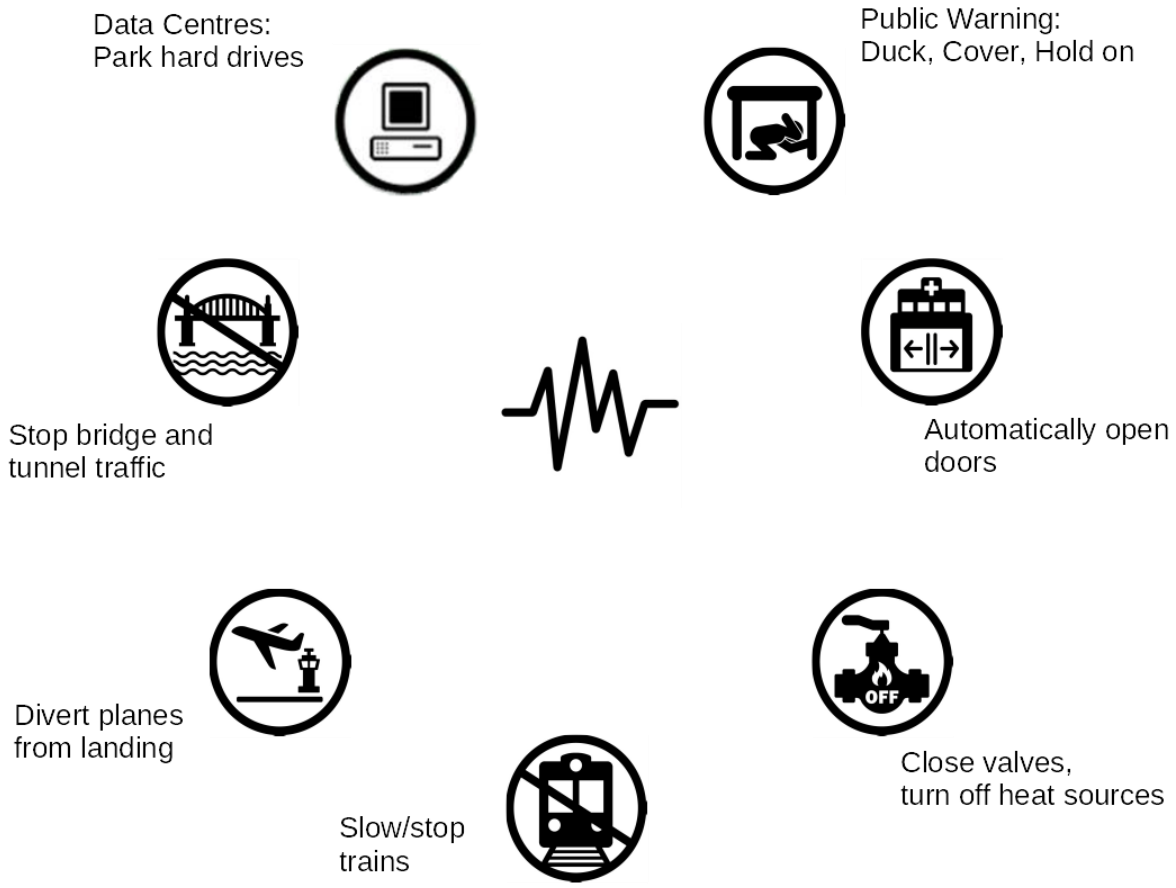
Why EEW?

- Hazard models and the National Building Code are mature, and codes are well-implemented.
- Nevertheless, parts of Canada with significant populations remain exposed to substantial earthquake risk:
  - AIR scenario study: $75 billion in the West and $60 billion in the East
- EEW can provide seconds to tens of seconds of warning before the arrival of strong shaking to allow protective measures and reduce the impact of an event
- EEW projects in other countries with high earthquake risk: Japan, Taiwan, China, USA…
- Canada currently has earthquake monitoring, but not warning




Sensors
First Detected Wave
Damaging Waves
Earthquake Alert Centre
Fault
Sensors installed in a closely-spaced network (5-20km)
Earthquake
S-wave
P-wave

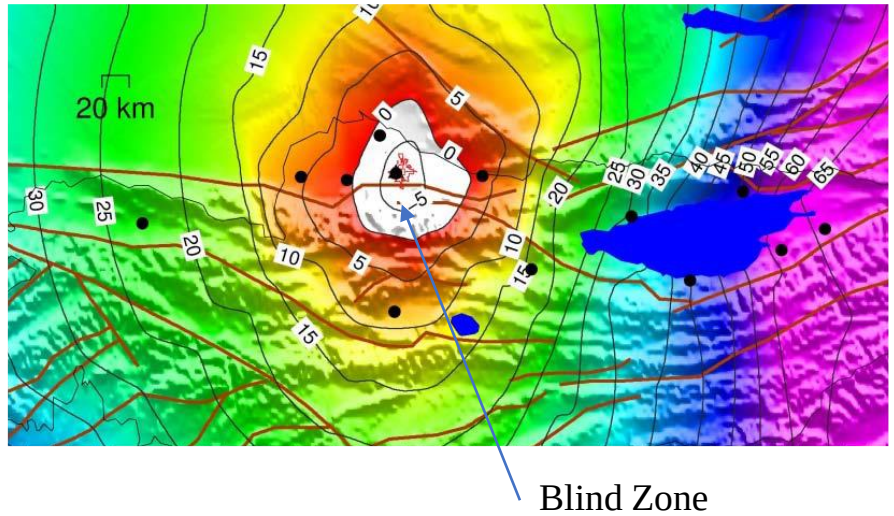
Automated Responses



- EEW connected systems can **automatically** take protective actions
- EEW connected systems - opportunity for value-added services
- Damage assessment, business resumption

EEW Constraints

- System cannot predict an earthquake
- Warning time is short
- Blind zone: very little/no warning time close to the epicentre
- Alerts to be provided only for strong damaging earthquakes – user fatigue vs system confidence
- Much of the at risk areas may be affected by an earthquake in USA – transborder interoperability critical
- System does not protect by itself, but requires that recipients of an EEW message must act



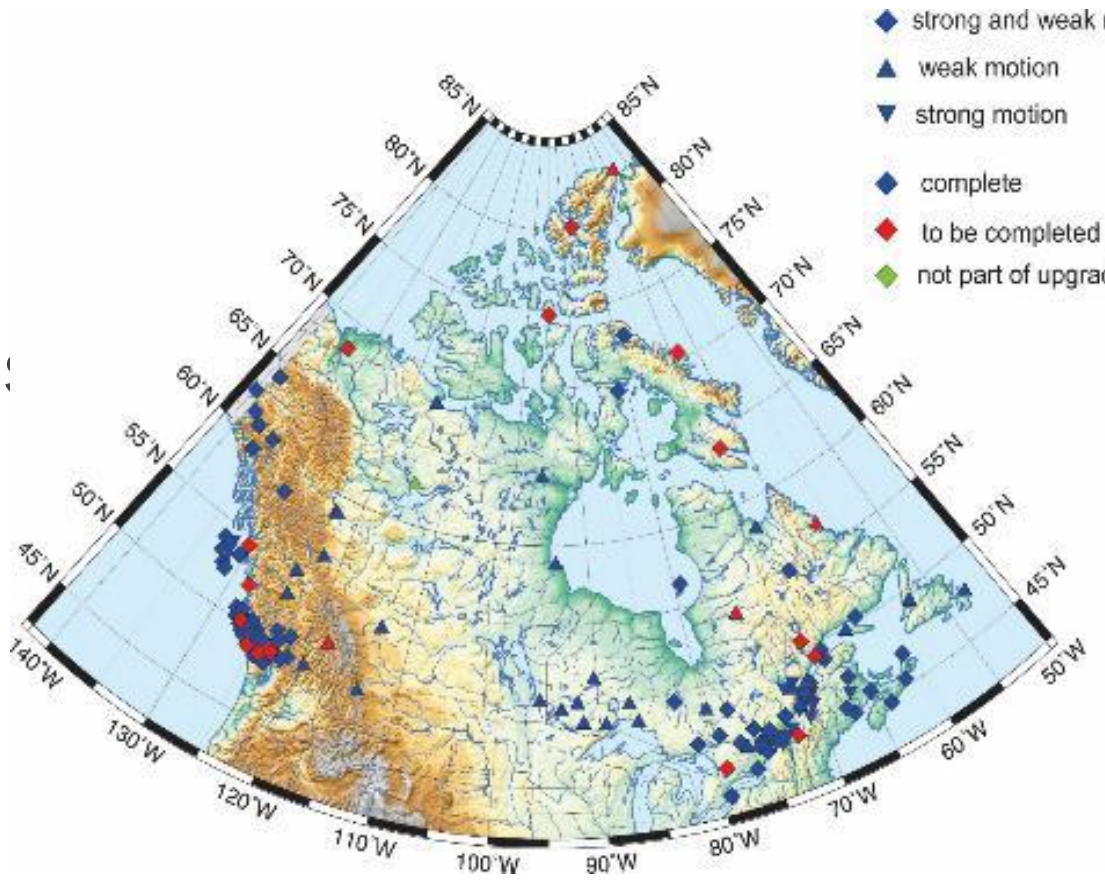
S. Parolai et al. Frontiers in Earth Science, 5, 74. (2017)

Canada's EEW Program

- 2019 Federal Budget included funding for 'Ensuring Better Disaster Management Preparation and Response', including Earthquake Early Warning
- Implementation phase of the EEW program 2019-2024
- Operation and sustainment thereafter
- Principal components:
  - Sensor Networks
  - Processing –cross-border interoperability and data sharing with US through use of USGS EEW software
  - Alert distribution
    - Public
    - Technical users (CI operators) for automated response

Sensors – Current Seismic Monitoring in Canada

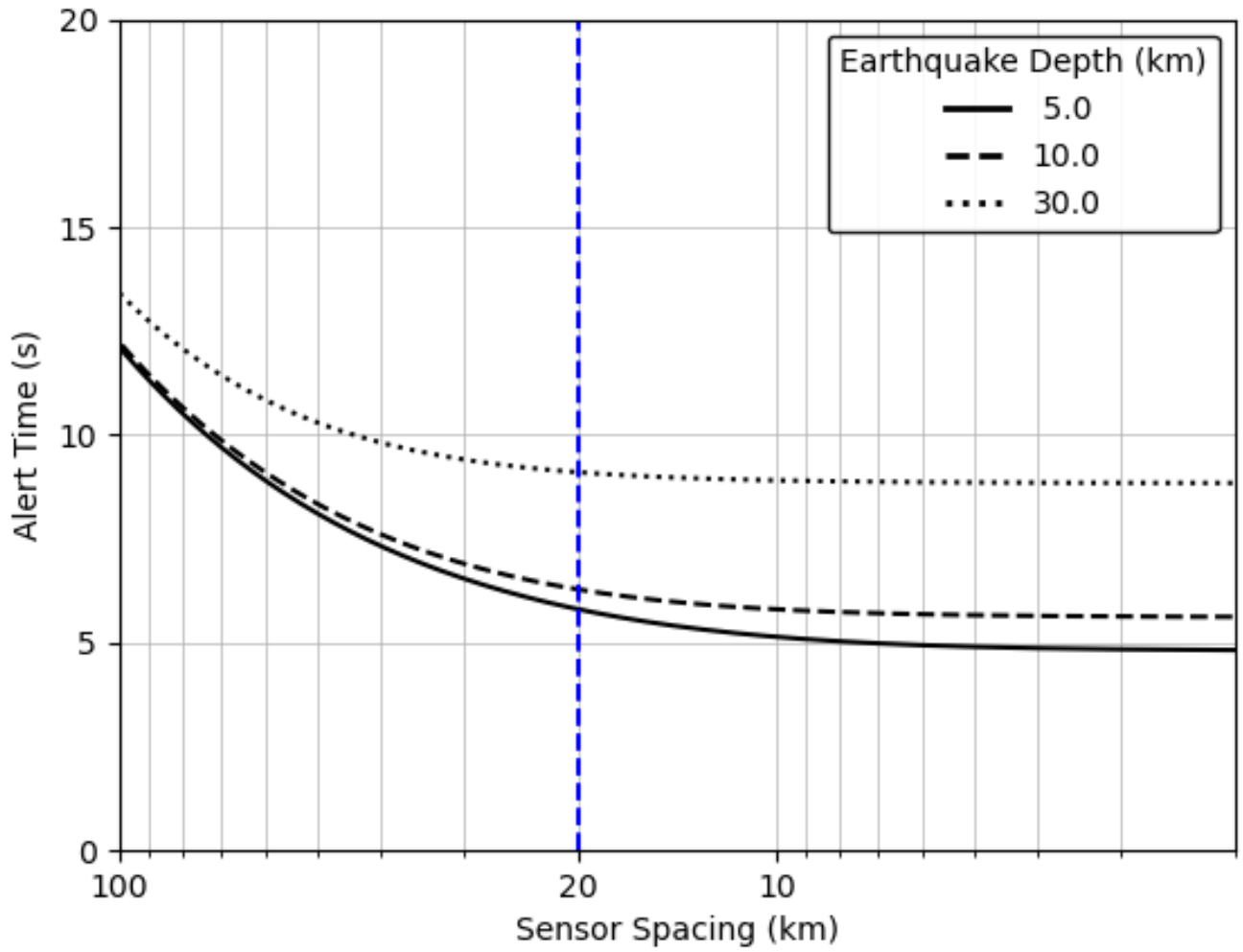
- Natural Resources Canada through the Canadian Hazard Information Service (CHIS) operates Canadian National Seismographic Network (CNSN)
- Existing network of over 150 stations
- Not designed for early warning
  - Insufficient station density
  - Not optimized for latency
  - Instrumentation quality (and cost) greater than required for EEW



Sensor Networks: General Station Layout

- Require space in basement/ on grade room
- Area requirement ~ 1 m^2
- Station enclosures locked to prevent tampering
- Sensor, digitizer (one unit)
- Power manager
  - Requires 120VAC, <20W - $30/year
- System generates no nuisance, noise, minimal heat
- Service visits less than once/year

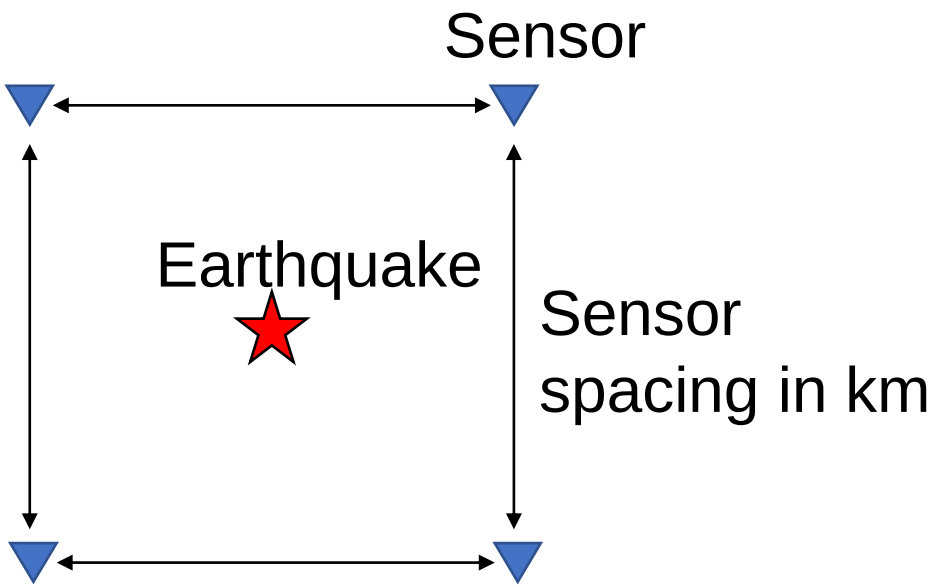
Alert Time based on sensor spacing



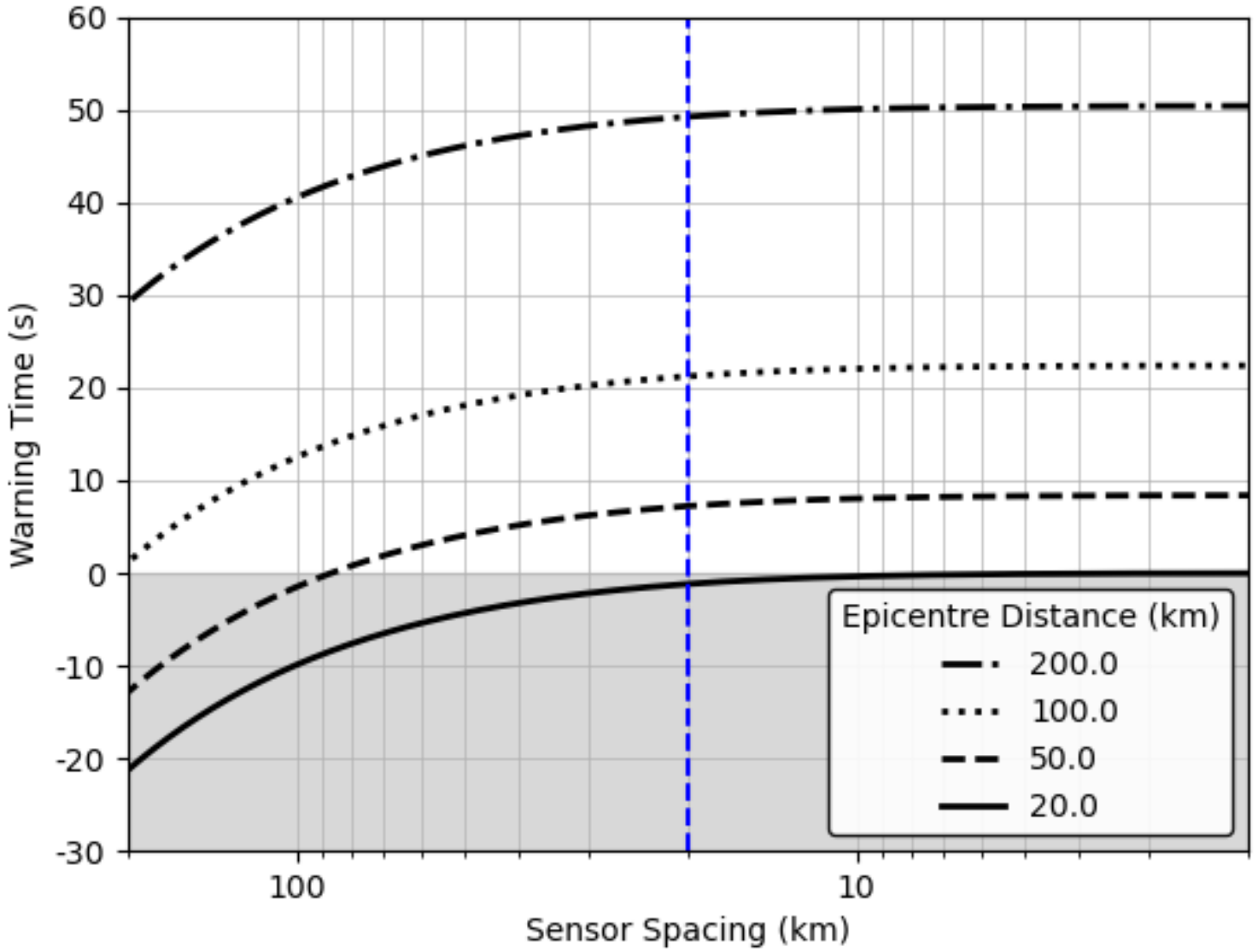
The alert time is the time it takes to issue an alert:

$$t_a = \max(t_{loc}, t_{mag})$$

Modelled using a square grid of sensors

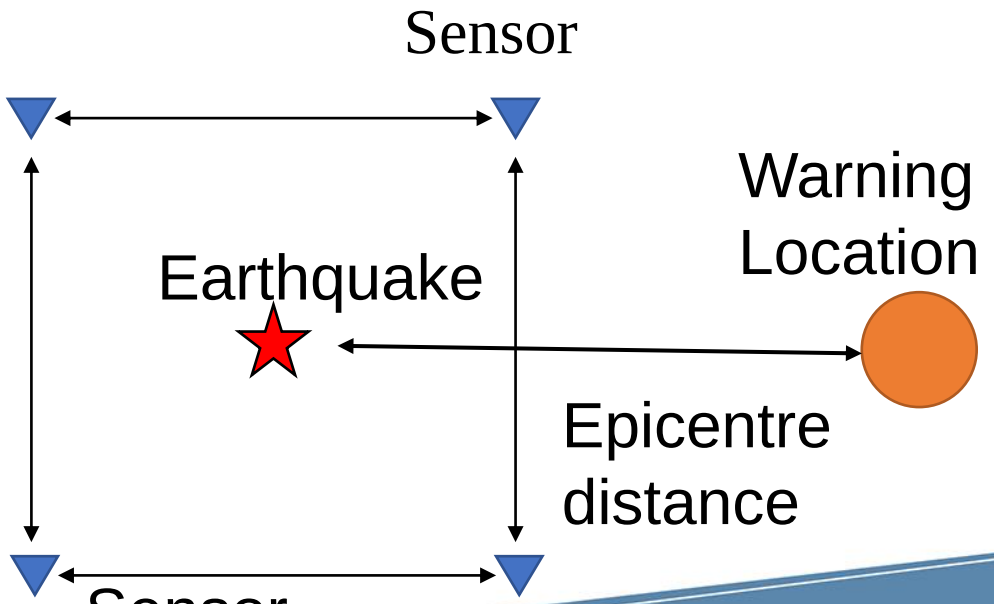


Warning time based on sensor spacing



The warning time is the time it takes for strong shaking to arrive less the time it takes to issue an alert

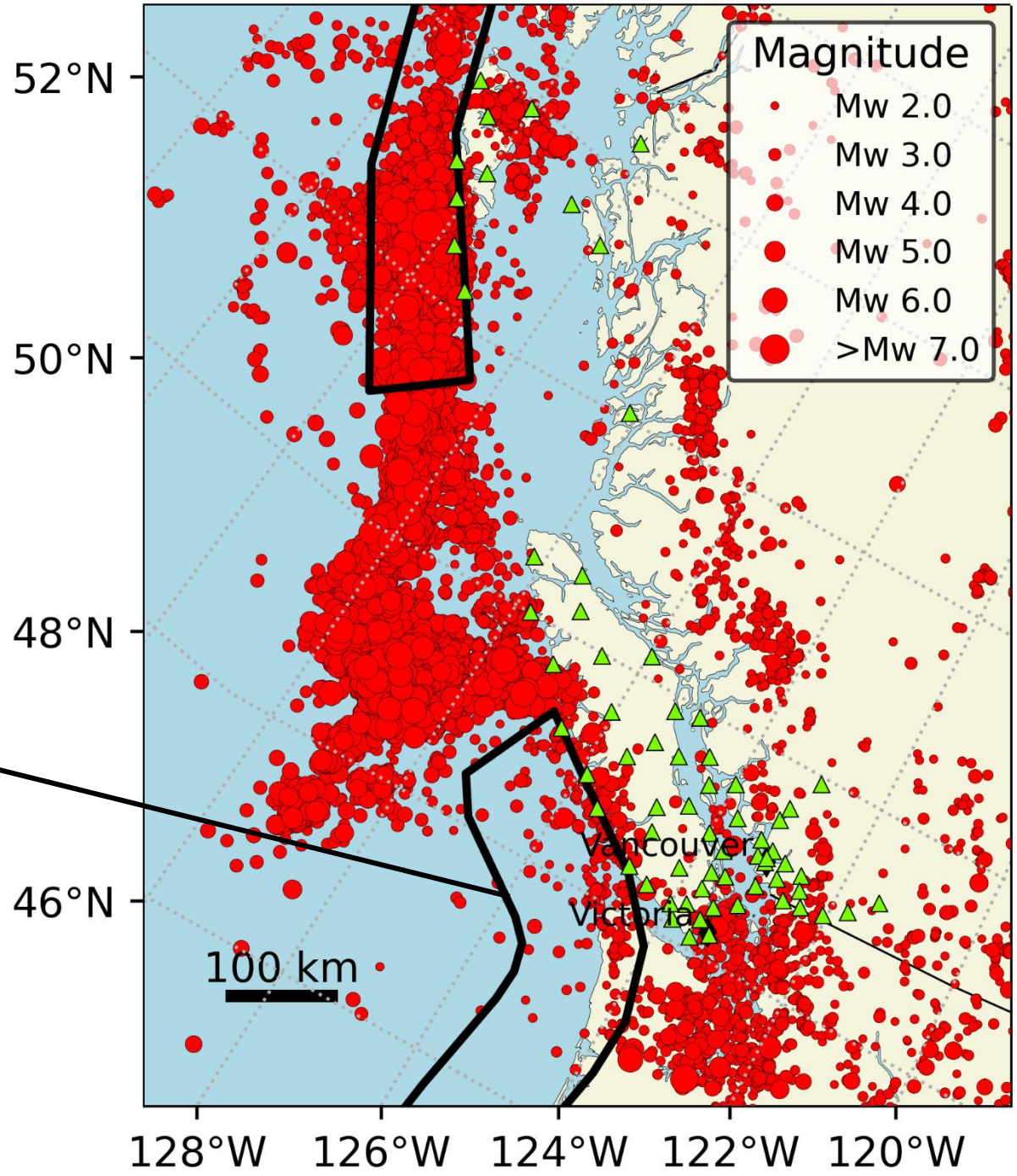
$$t_w = t_S - t_a$$



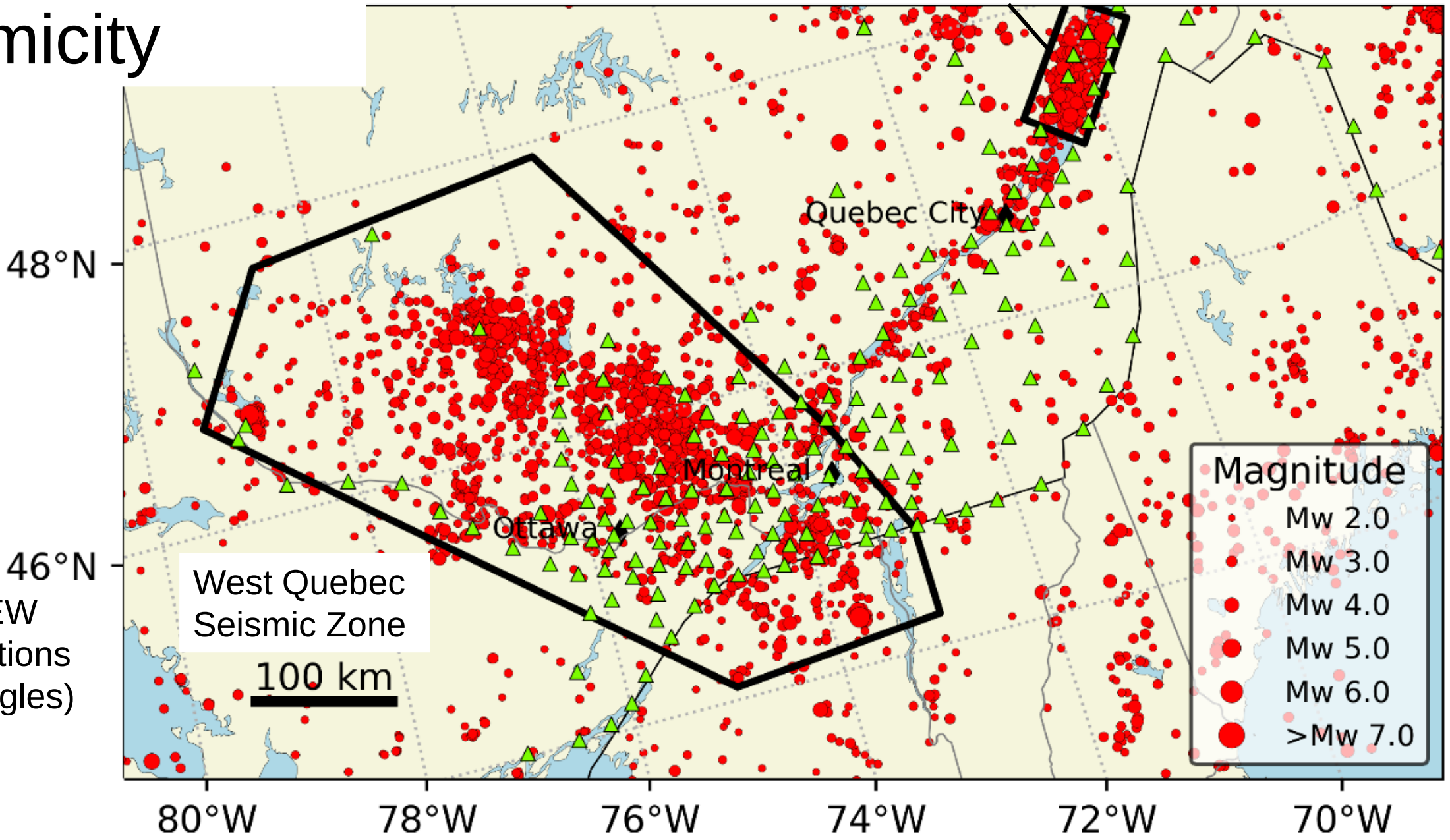
Western Canada Seismicity

Cascadia Subduction Zone: possible M9 earthquake source

Nominal EEW station locations (green triangles)



Eastern Canada Seismicity

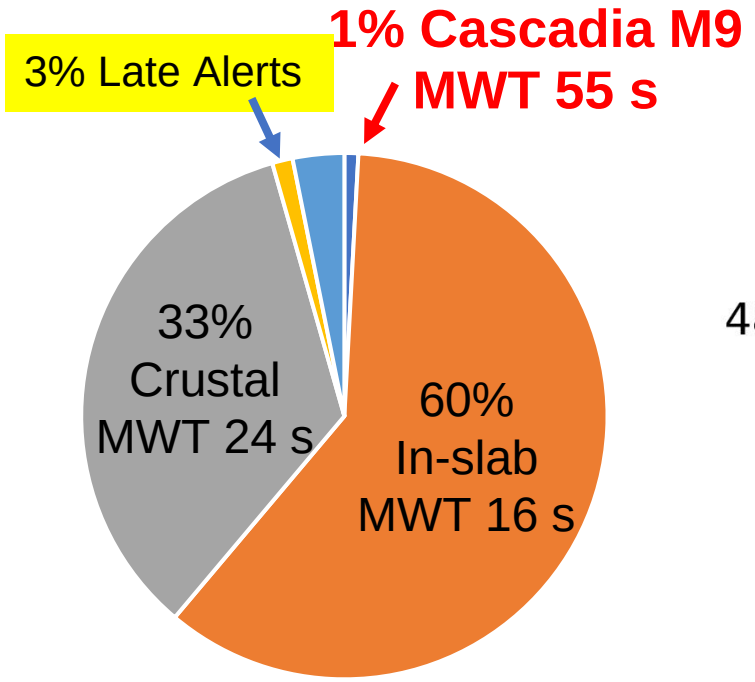


Nominal EEW station locations (green triangles)

Modelling System Performance

- Our historical record is incomplete
- We use a synthetic earthquake catalog to represent 10,000 years of seismicity
- The synthetic earthquake catalog represents the possible seismic events, not just the ones that have occurred in the last ~100 years

Predicted Vancouver Warnings



in 10,000 years
~2000 warnings → 1 per 5 years
63 missed → 1 per 160 years
(31 warnings per missed event)

*MWT = Mean warning time

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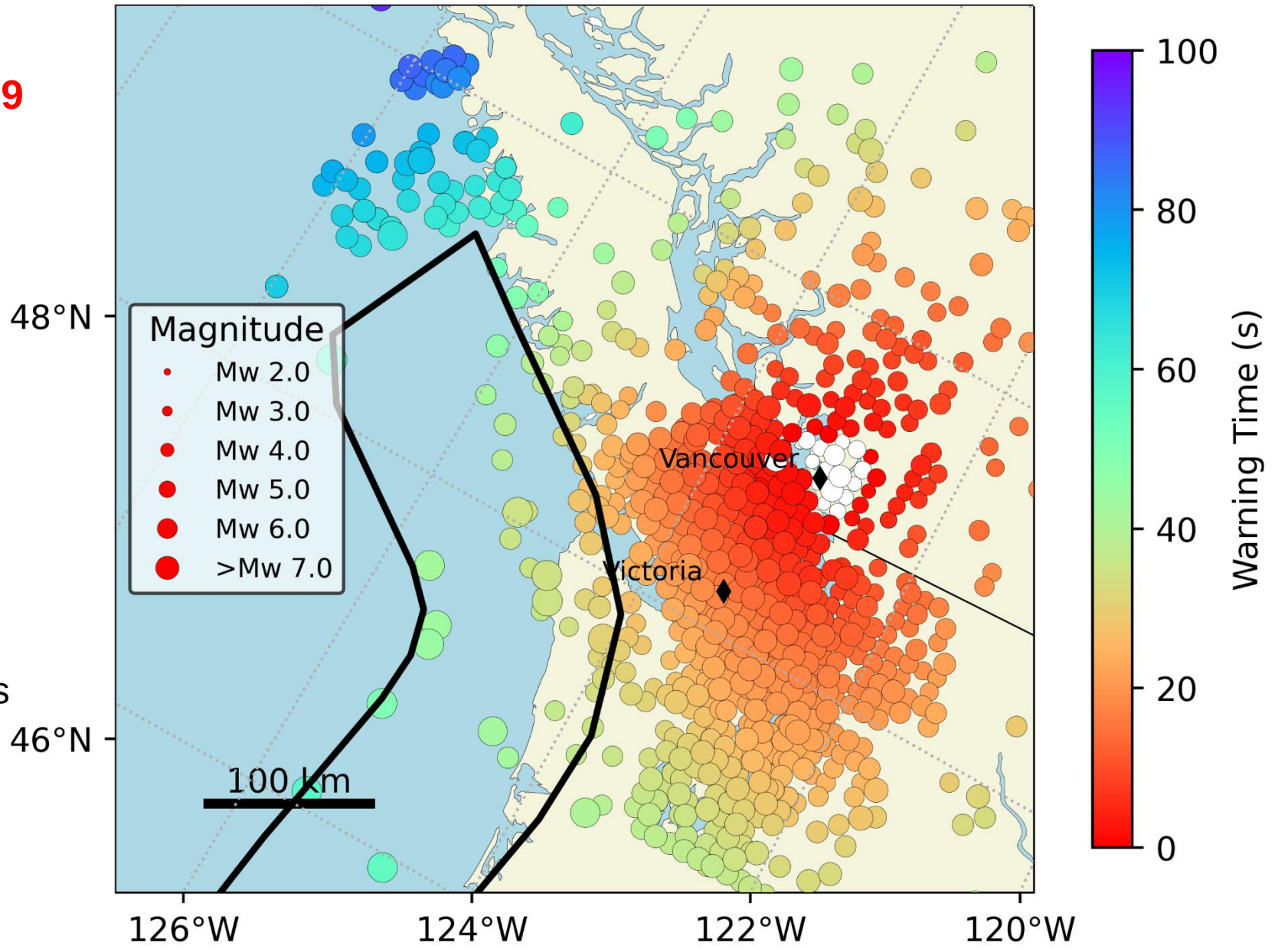
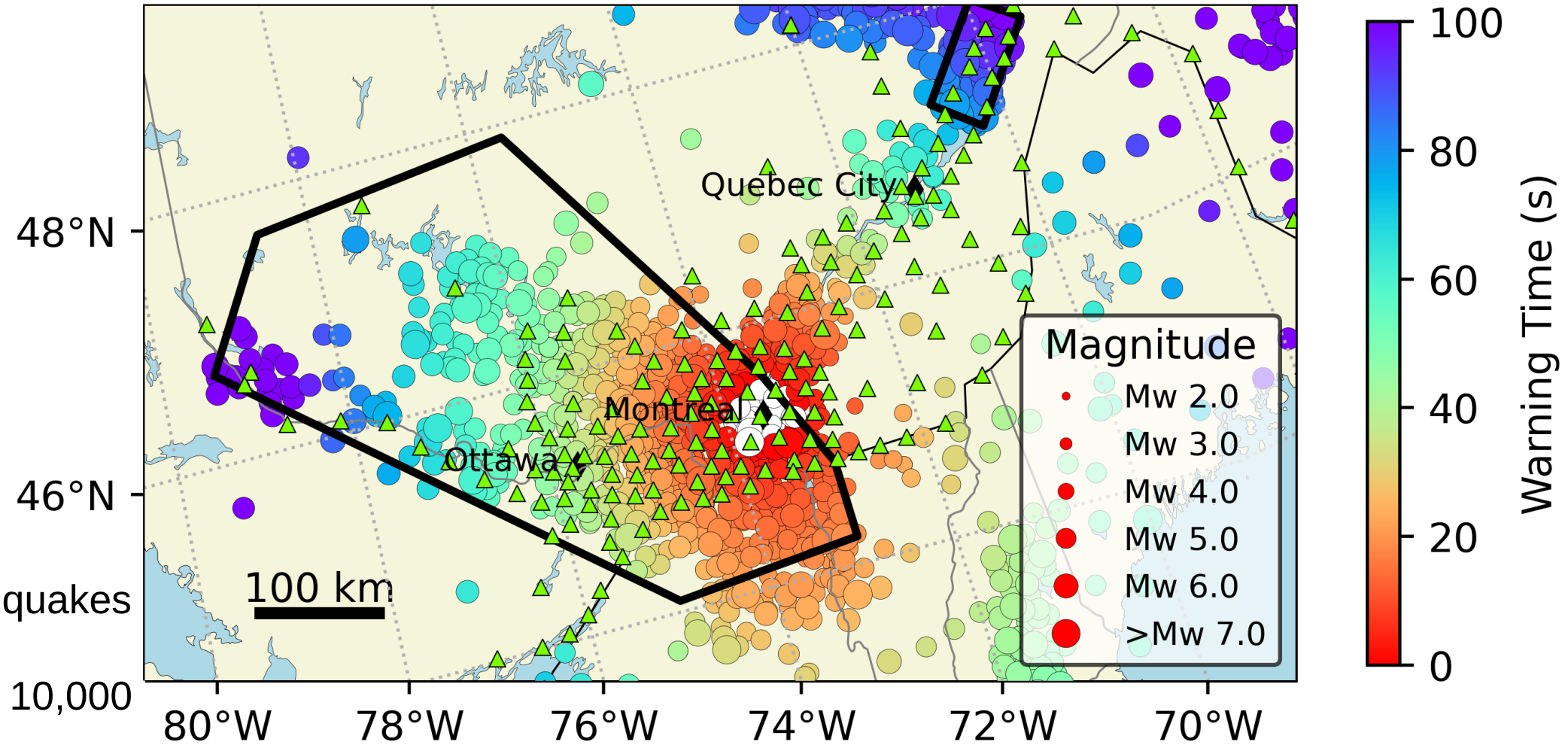
Warnings in Vancouver for potential widely felt earthquakes (predicted MMI IV+)

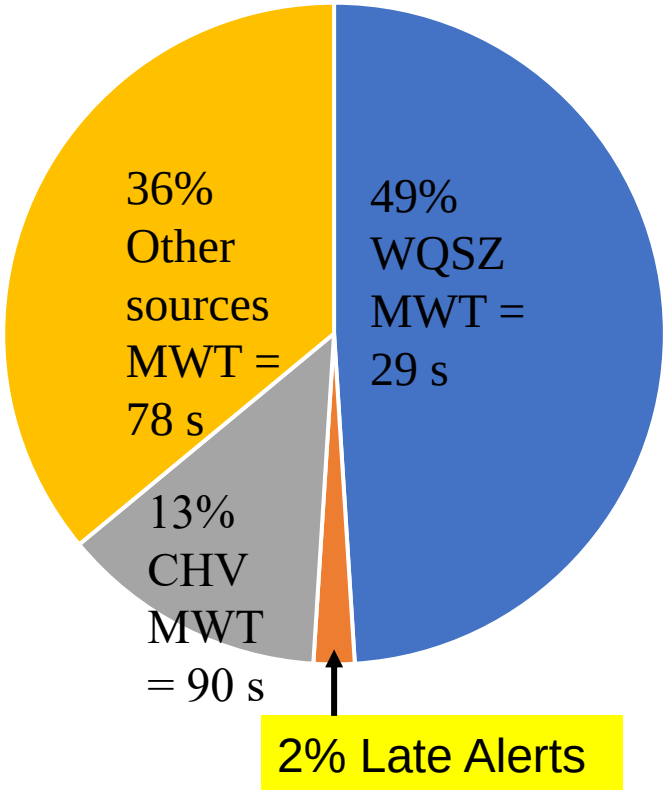


Warnings in Montreal for potential widely felt earthquakes (predicted MMI IV+)



Total: ~2200 earthquakes
Late Alert Zone
69 earthquakes in 10,000 years

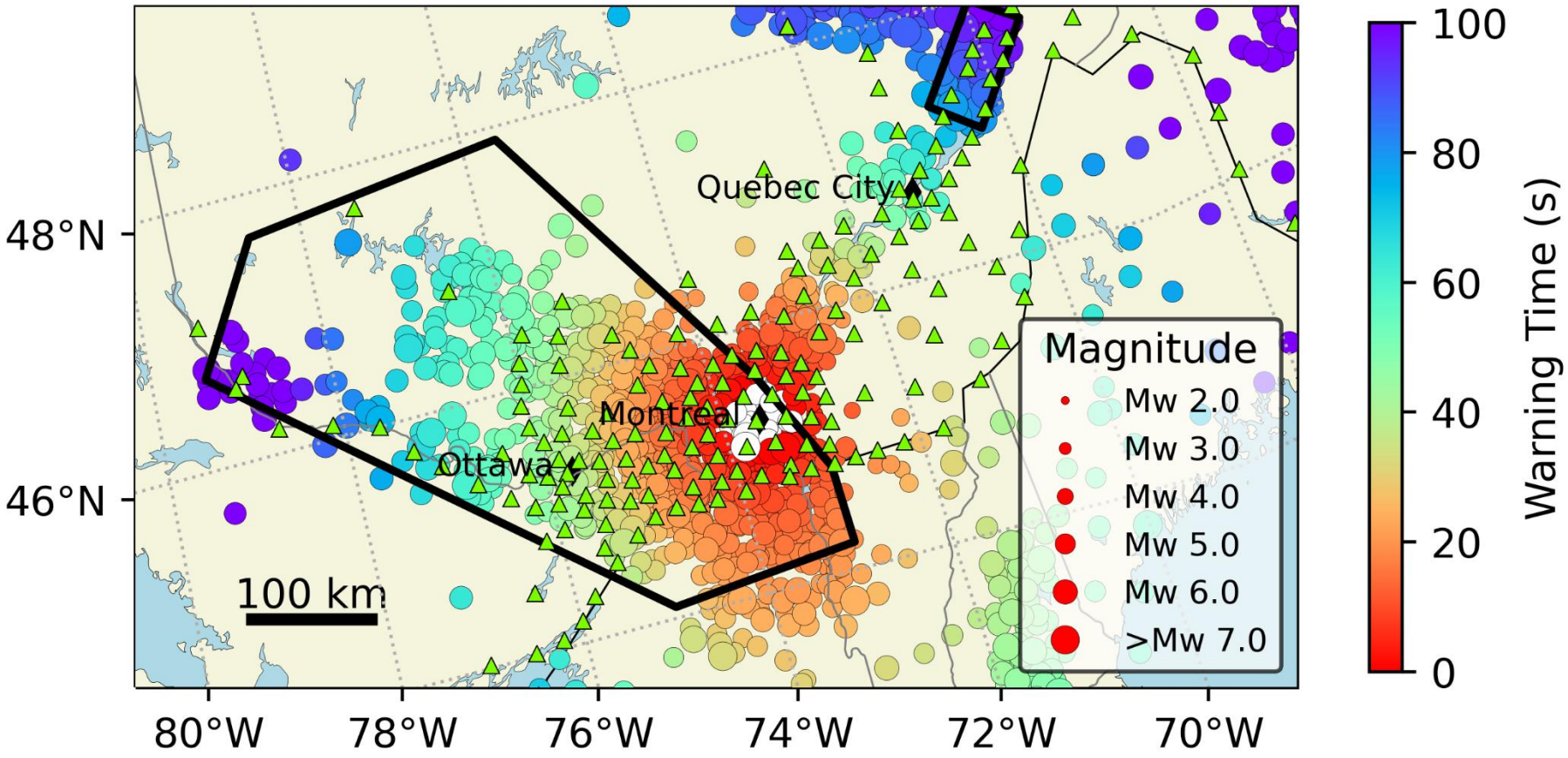
Predicted Montreal Warnings



in 10,000 years
~2200 warnings → 1 per 5 years
49 missed → 1 per 200 years
(44 warnings per missed event)

*MWT = Mean warning time

Warnings in Vancouver for potential widely felt earthquakes (predicted MMI IV+)



Canada

Sensor Layout: Victoria-Vancouver

Goal: warnings for Vancouver, Victoria and lower island communities

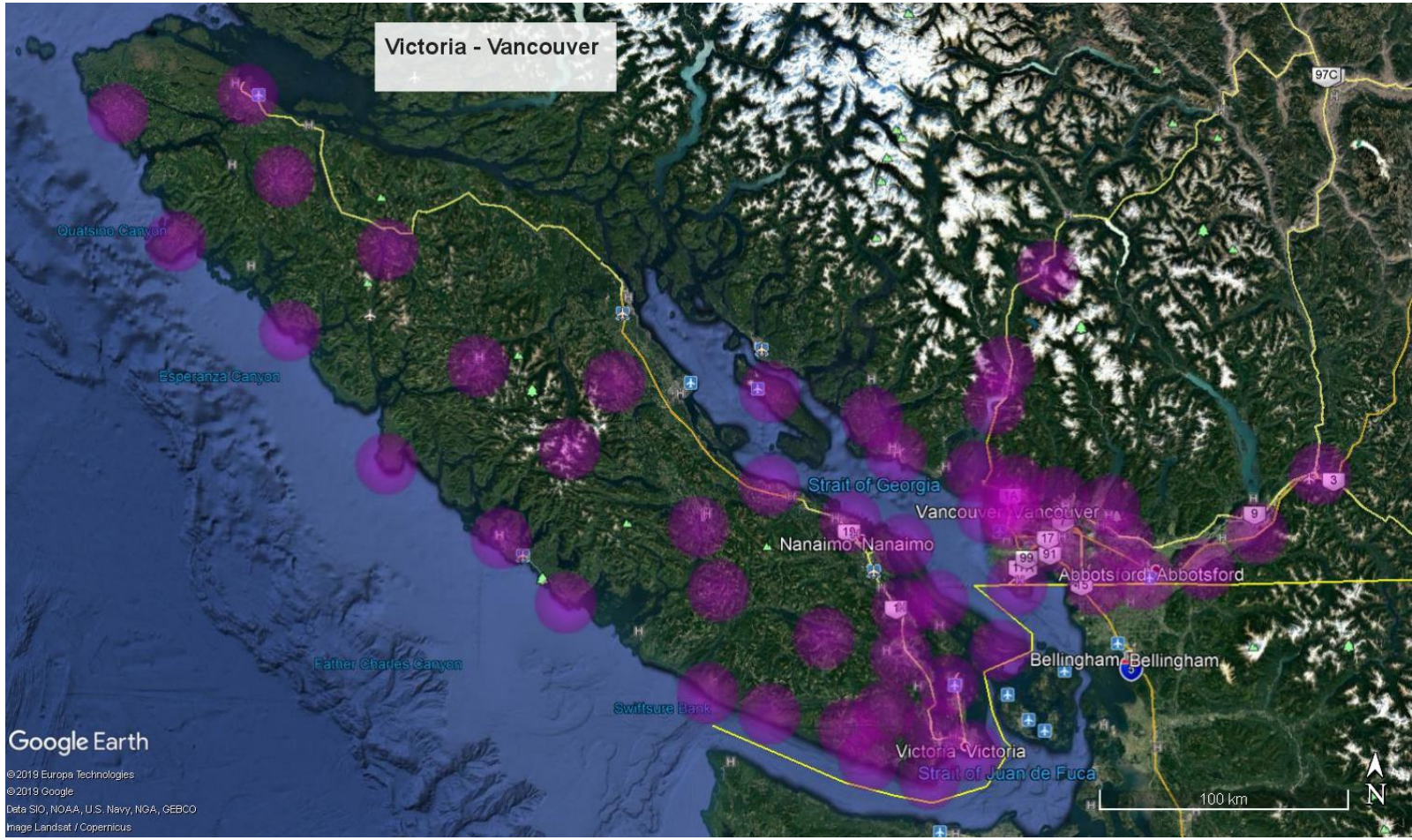
Threat: Cascadia subduction earthquakes; BUT ALSO deep inslab earthquakes; crustal earthquakes; earthquakes in Washington state

35 sensors on southern Vancouver Island and adjacent mainland at ~20 km spacing

+15 sensors on N Vancouver Island

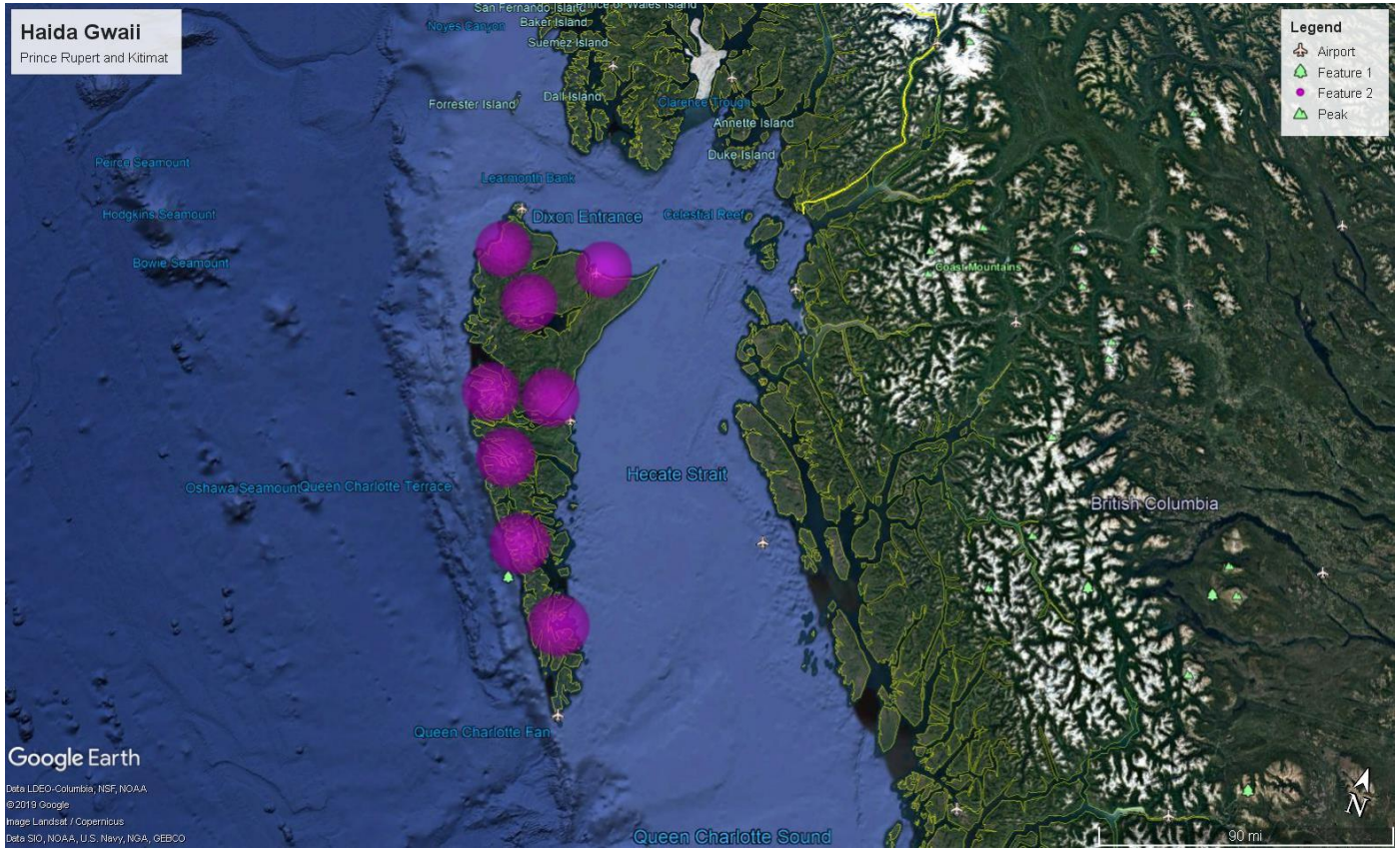
Additional stations required to provide redundancy

Cross-border networks will share station data



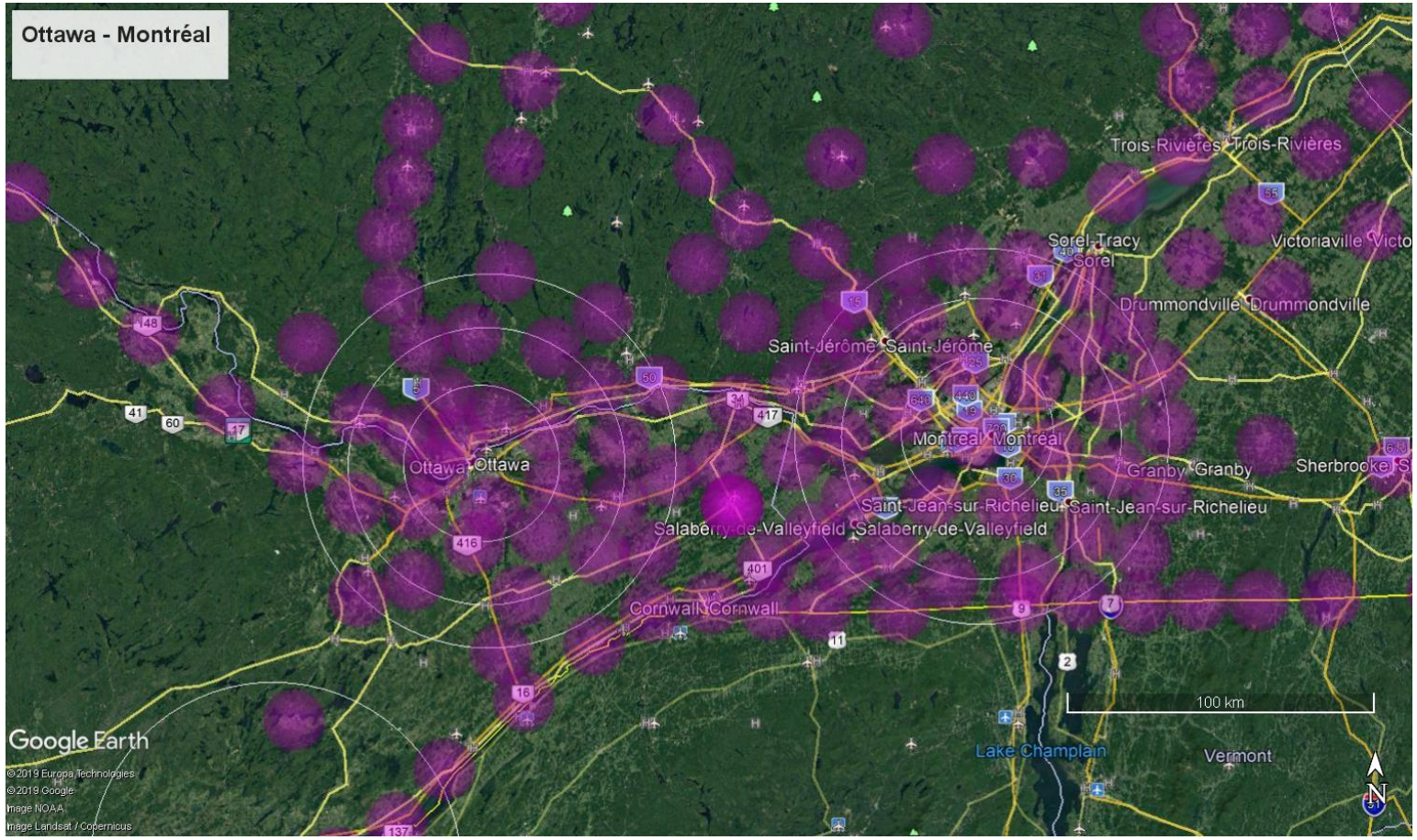
Sensor Layout: Haida Gwaii, Prince Rupert

- Goal: warnings for Prince Rupert and Kitimat
- Threat: Haida Gwaii earthquakes
- 8 sensors on the islands to detect offshore Queen Charlotte plate boundary earthquakes, leverage existing installations – add EEW instruments
- May provide some warning for island residents
- Sites very constrained by physical geography



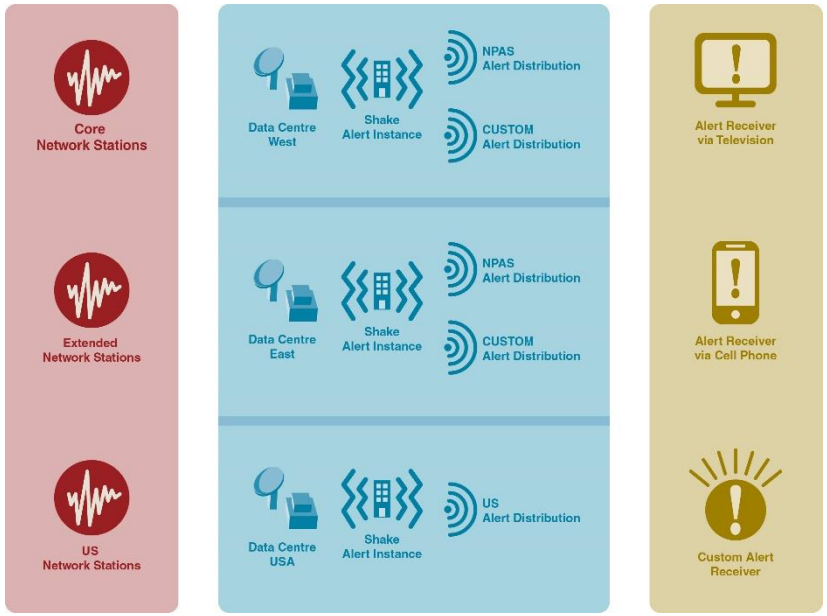
Sensor Layout: Ottawa - Montreal

- Goal: warnings for Ottawa and Montreal
- Threat: Crustal earthquakes from western Quebec source and from the US
- ~100 sensors
  - Mostly ~20 km spacing
  - Plus sensors extending towards more distant sources
  - Constrained by geography
  - sensors along US border (currently no EEW sensors in eastern USA)
  - Additional stations required to provide redundancy



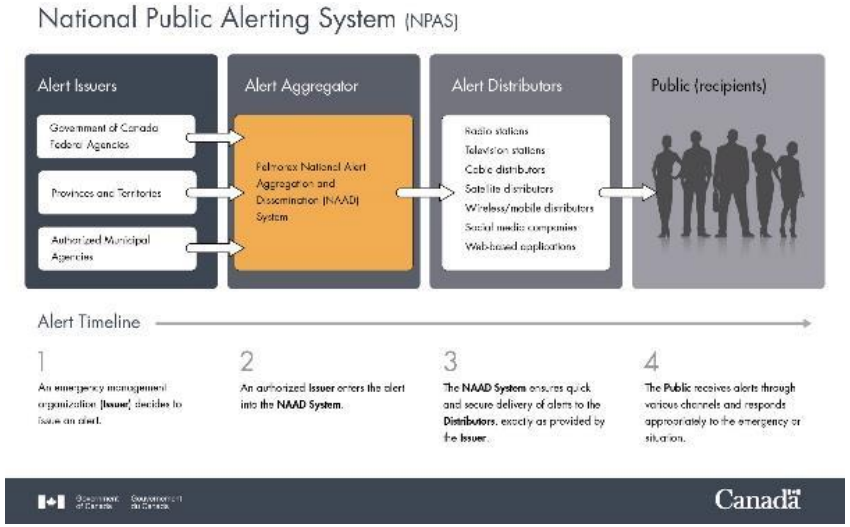
Processing

- USGS EEW software - $50M investment
- Instances in at least two redundant data centres, likely one West one East for latency
  - Exploring options for ‘cloud’ solution
  - Security vs latency
- Connected to US instances, but only Canadian instances could trigger Canadian systems
- Cybersecurity & supply chain integrity



Alert Dissemination - Public

- National Public Alerting System (NPAS) – already used for eg extreme weather
  - Distribution through radio/TV/web/social media/cell
  - EEW places requires much lower latency than current use cases
- Challenge – threshold & frequency of alerting
  - Threshold too low annoys people
  - Threshold too high – is it working?
  - Frequency – how to train people?



Alert Dissemination - CI

- To critical infrastructure operators
  - Tailored alerts for specific users
  - Potential for third party value added services
  - Alert data issued in xml format for automatic/machine-to-machine mitigatory actions
- To FPT operations centres

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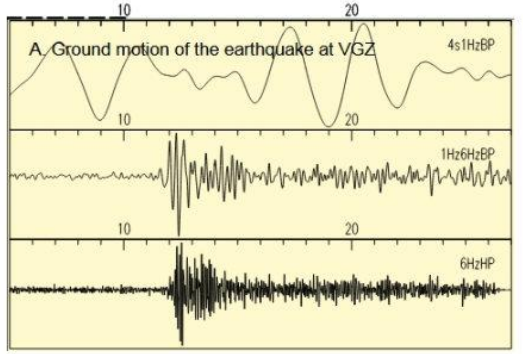
Issued 20yy/mm/dd 99:99 UT

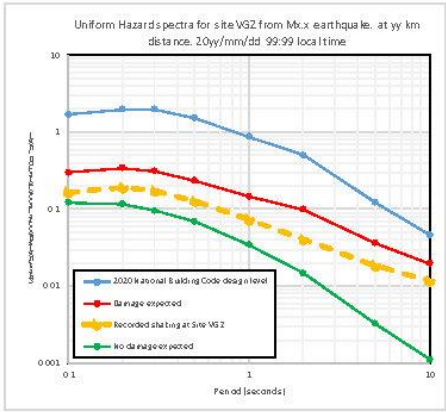
Shaking Alert Report for Station VGZ

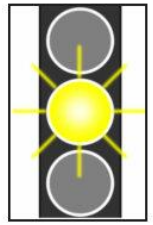
Earthquake with an estimated magnitude of x.x
Located 31 km WSW of station VGZ
Epicentre 48.26N 123.66W, 31 km WSW of VGZ
Origin Time 20yy/mm/dd 88:88 local time (20yy/mm/dd 77:77 UT)



Uniform Hazard Spectra - shaking levels recorded at VGZ from earthquake on 20yy/mm/dd at 88:88 local time

Sa(0.1)	Sa(0.2)	Sa(0.3)	Sa(0.5)	Sa(1.0)	Sa(2.0)	Sa(5.0)	Sa(10.0)	PGA
0.16	0.19	0.17	0.13	0.07	0.04	0.02	0.01	0.09





Client should exercise caution, perform necessary checks, etc.

Canada

Program Timeline

Year	Activities
2019-20	Specification development, procurement, network design, software development, stakeholder engagement
2020-21	Equipment Delivery, core network installation, RFP for network partners, complementary network installation, software development, alert dissemination development
2021-22	Equipment Delivery, core and complementary network installation, software development, alert dissemination development, testing
2022-23	Core and complementary network installation, software development, alert dissemination development, testing
2023-24	Core and complementary network installation, software development, alert dissemination development, testing, provisional alerts issued
Beyond	Provisional operation, alerts ready

Where are we now?

- Project
  - Team staffed up
  - Project board for BC component with provincial participation
  - Standing up science advisory board

- Sensors
  - Instrument & network design complete
  - RFI complete
  - RFP posted

- Processing
  - USGS EEW software running on NRCan servers
  - Consultations on datacenter configurations & cybersecurity

- Alerting
  - Briefs to SOREM
  - Workshops for OGDs
  - Initial testing with Pelmorex
  - Discussions with telcos
  - Ongoing engagement with CI community

Opportunities!!!

- Extension of network coverage beyond core
- Improvements to EEW techniques
  - Must be interoperable
- Other sensors on EEW infrastructure

Summary

- Earthquake Early Warning has the potential to further mitigate the impact of major earthquakes in Canada
- Complements the existing national monitoring network
- 5 year NRCan program to construct system with initial operation to begin in ~2024
- Close cross border integration with systems in the United States

2020