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Updates on Canadian Strong Motion Monitoring and Data Access

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ABSTRACT

Strong motion monitoring continues to evolve rapidly in Canada, with hundreds of new instruments deployed and many organisations contributing data. This article summarises the current state (and near-future plans) of strong motion monitoring across Canada and provides information on how to access these data. As of March 2023, the Canadian National Seismograph Network (CNSN) upgrade has been completed, resulting in one of the most significant changes in strong motion monitoring in Canada since the first deployment of accelerometers in 1963. As a part of this upgrade, more than 100 new strong motion instruments (Nanometrics Titans) were deployed at mostly bedrock sites in high seismic hazard regions of Canada. A major initiative that will contribute to strong motion monitoring across the country is the deployment of the national Earthquake Early Warning network (led by Natural Resources Canada (NRCan)). As of March, 2023, 148 strong motion EEW instruments have been deployed with an additional 200+ strong motion instruments to be deployed across Canada over the coming year. These instruments are concentrated in the seismically active regions of southwest British Columbia and southern Quebec/eastern Ontario. Other organisations collecting strong motion data include BC Hydro (with ~100 strong motion instruments across BC), the BC Ministry of Transportation and Infrastructure (BC MoTI) operates the British Columbia Smart Infrastructure Monitoring System (BCSIMS) which includes ~180 strong motion sensors and over 400 earthquake sensors installed on 14 BC MoTI owned key bridges. In addition, Ocean Networks Canada has 41 strong motion instruments on the seafloor west of Vancouver Island and onshore Vancouver Island, and UBC operates 67 instruments in southwest BC. In eastern Canada, organisations operating strong motion instruments include: Hydro-Quebec at dams and substations; Ontario Power Generation and New Brunswick at their nuclear power stations and Gaz Metropolitain at its Montreal LNG plant. Data access is becoming easier, CNSN data are available via NRCan's FDSN server at https://earthquakescanada.nrcan.gc.ca/fdsnws/ BCSIMS network data (including BC MoTI and some UBC data) are available via www.bcsims.ca and most ONC strong motion data (OW/NV networks) can be accessed via http://ds.iris.edu/ds/.

Keywords: Strong motion data, seismic hazard, seismic monitoring.

INTRODUCTION

The purpose of this paper is to provide: 1) a brief overview of the strong motion networks in Canada as of March, 2023 and some notable upcoming changes; and 2) a summary of how to access Canadian strong motion datasets. For details of the history of strong motion instrument deployments in Canada, see [1-9]. As in the previous summaries, there is an emphasis on free-field instruments, and the survey does not cover most structural monitoring instruments. Since the last review [9] in 2019, the number of instruments deployed has increased by nearly 40%, to nearly 700 strong motion instruments (all digital and most with real-time data availability).

CNSN network renewal with a major deployment of 123 strong motion (Titan) instruments at CNSN sites (mostly bedrock) across Canada has been completed [10]. One of the most significant changes in the history of strong motion monitoring in Canada is currently underway – the deployment of hundreds of strong motion instruments as a part of Canada's National

Earthquake Early Warning (EEW) System. This network will (by ~March 2024) include more than 400 strong motion instruments. Details are provided below.

Currently, the largest strong motion networks in Canada are those operated by NRCan as a part of the CNSN (123 instruments), NRCan's EEW system (currently 148 instruments across Canada), British Columbia Ministry of Transportation and Infrastructure (BC MoTI) with ~180 free-field and down-hole instruments and more than 50 additional structural monitoring instruments, BC Hydro, including dams and transmission facilities (101 instruments), UBC (67 instruments), Hydro-Québec (10 instruments), and Ocean Networks Canada (ONC) (41 instruments). Most of the strong motion sensors are deployed in the earthquake-prone areas of British Columbia, Quebec, and the Yukon (Figures 1 – 5). A summary of instruments and owners is provided in Table 1 and described in more detail below.

STRONG MOTION NETWORKS – WESTERN CANADA

As of March, 2023, more than 500 strong motion instruments were operating across British Columbia (Figures 1-4). A brief description of the instruments operated by various organisations is provided below. Many of these instruments are interconnected through the BC Smart Infrastructure Monitoring System – BC SIMS. NRCan has 50 Titan strong motion instruments deployed at bedrock sites across the province as a part of the CNSN and an additional 58 sites (mainly on soil) deployed as a part of the EEW network. Many of the strong motion instruments operate through partnerships – as one example the 15 strong motion instruments in northeast BC operated by the British Columbia Seismic Monitoring Consortium (BCSMC: NRCan, British Columbia Oil and Gas Commission (BCOGC), Geoscience BC and the Canadian Association of Petroleum Producers (CAPP)). Partnerships are also important for the national EEW network.

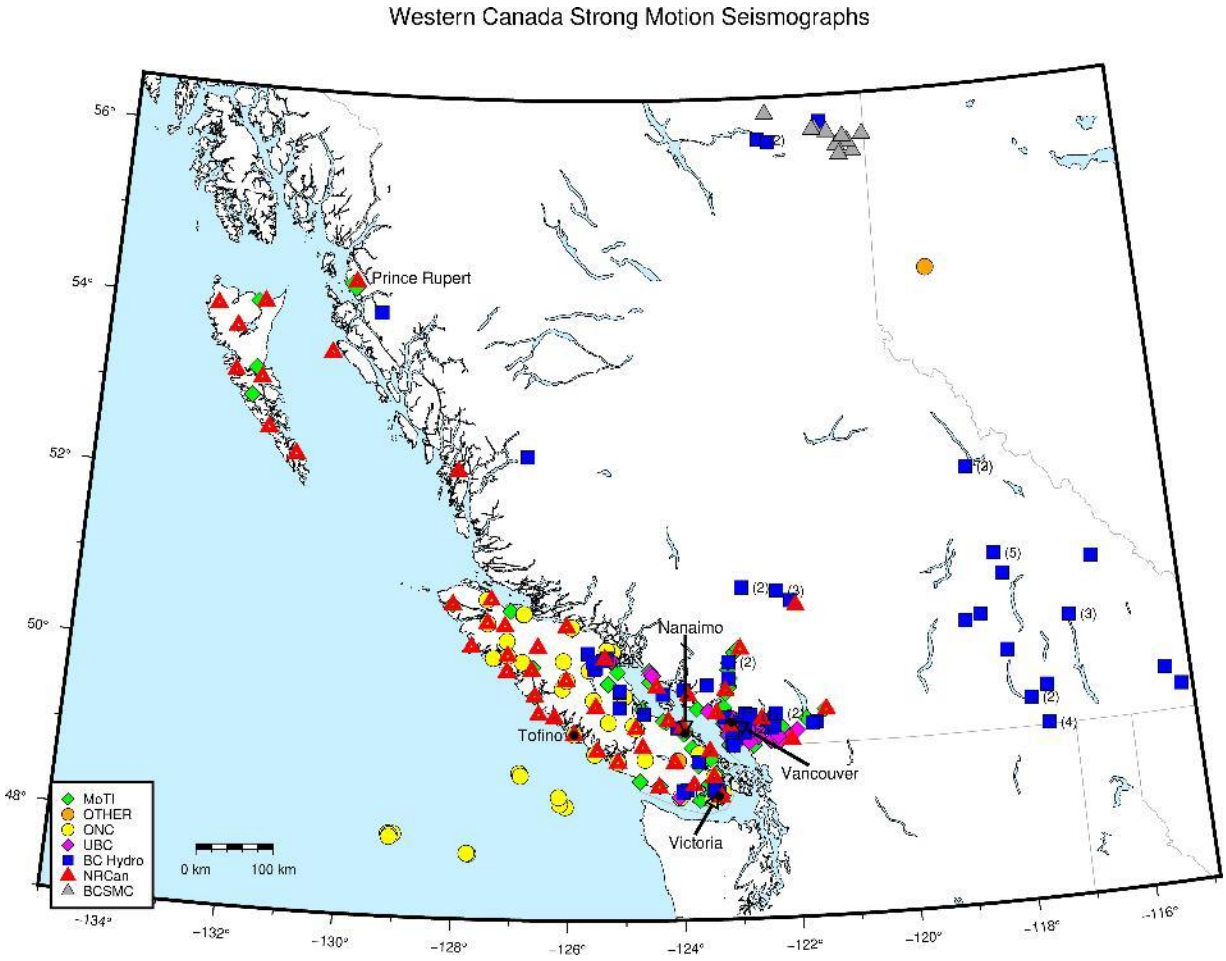

Figure 1. Strong motion seismographs in British Columbia as of March, 2023. Numbers in parenthesis indicate the total number of instruments at that site.

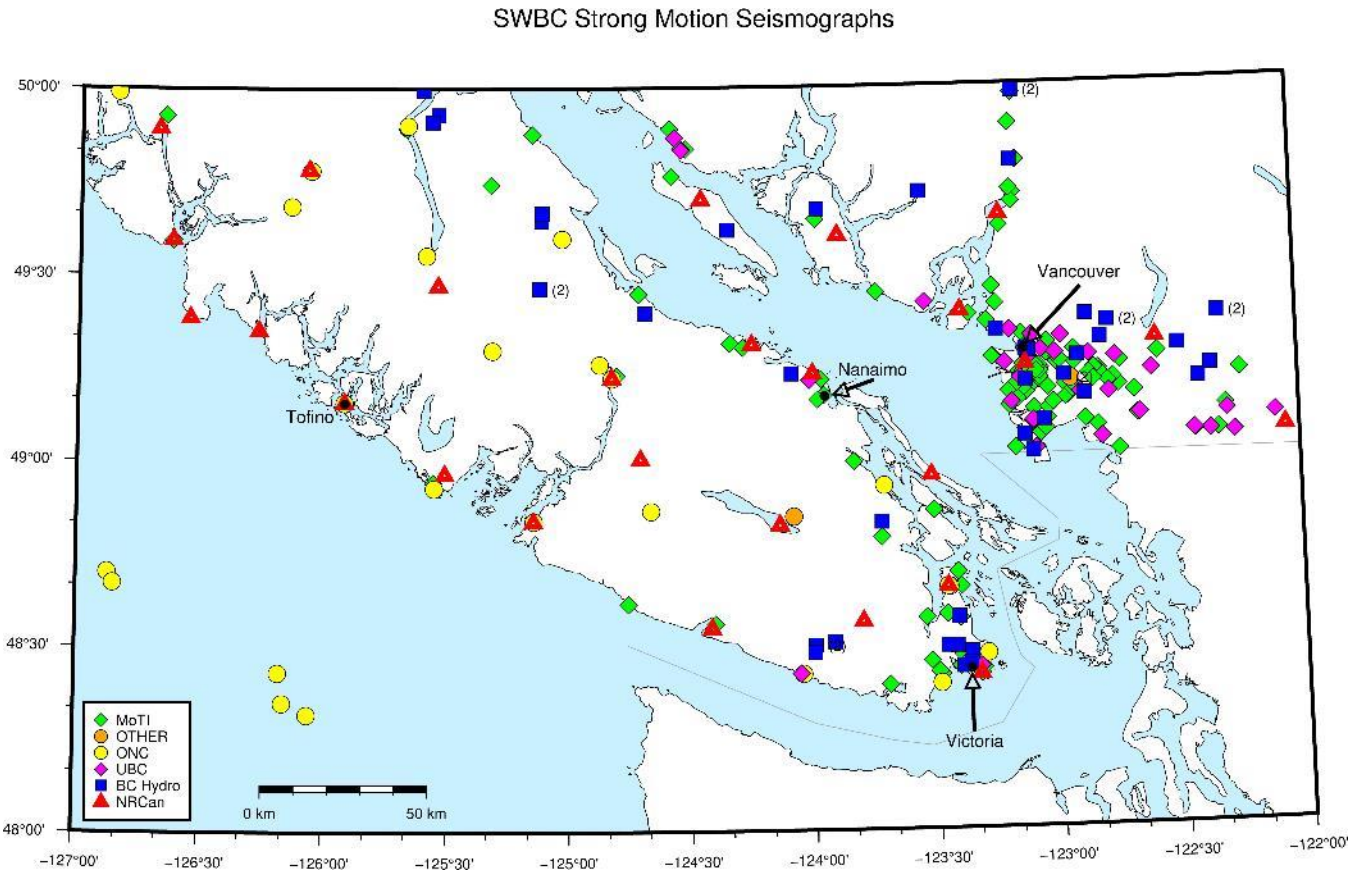

Figure 2. Strong motion seismographs in southwest British Columbia. Numbers in parenthesis indicate the total number of instruments at that site. Status as of March, 2023.

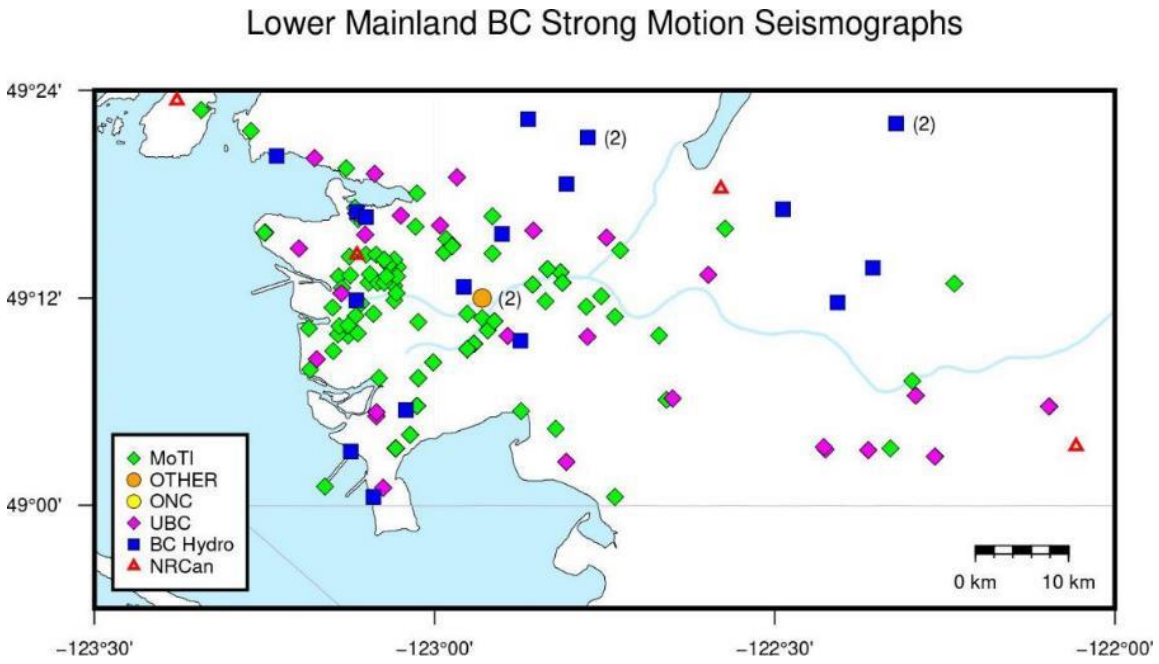

Figure 3. Strong motion seismographs in greater Vancouver and the Lower Mainland. Status as of March, 2023.

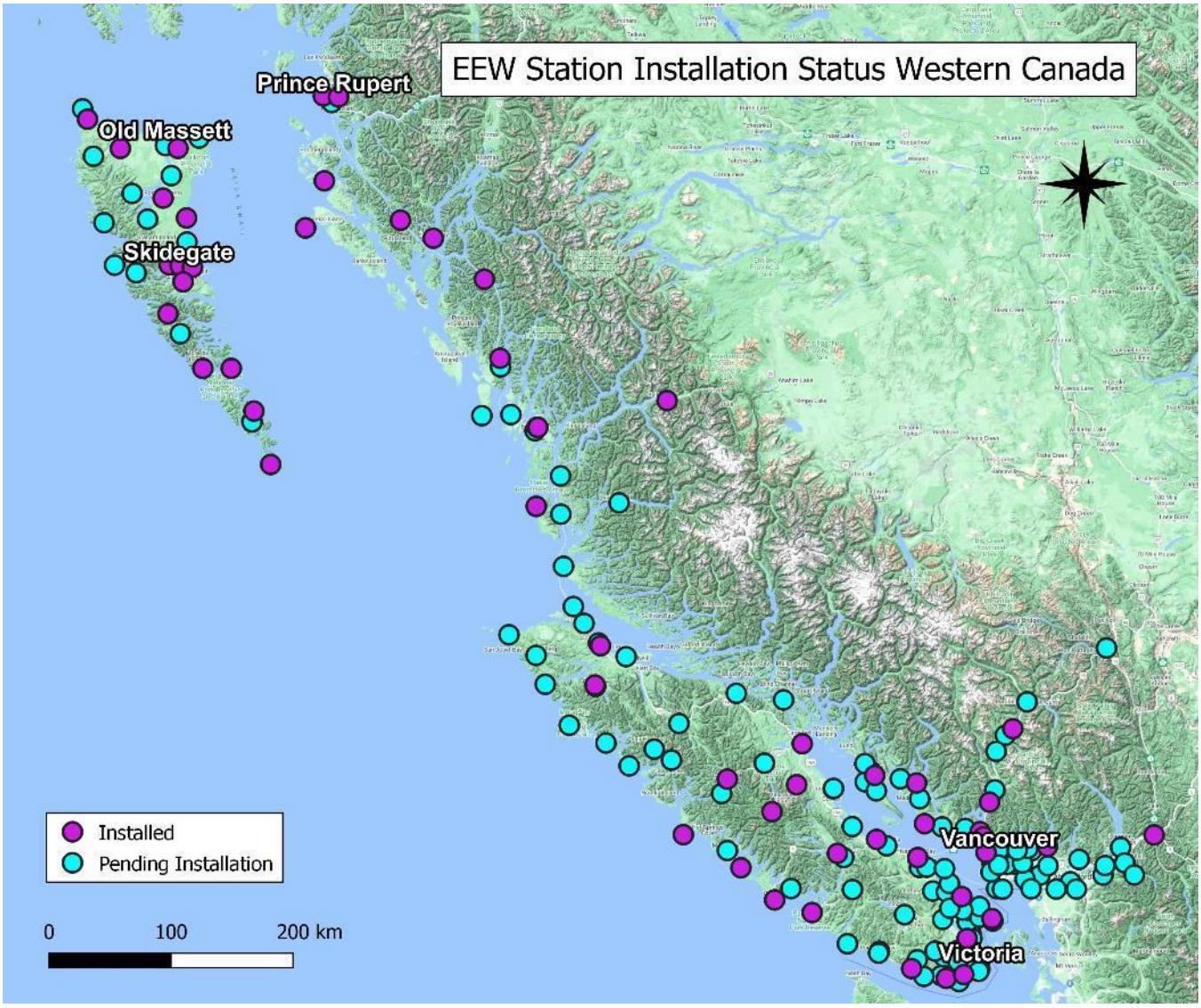

Figure 4. Status of the National EEW Network Deployment (NRCan and partners) as of March, 2023.

Natural Resources Canada

Significant improvements in strong motion monitoring are underway by NRCan across Canada. Since the last update [9], the Internet Accelerometer (IA) network [11] is being replaced (in some cases) by EEW stations or taken over by other organisations (e.g., BC MoTI). The CNSN modernization was completed, providing a total of 101 strong motion instruments (Titans) and 23 stand-alone strong motion instruments (now being transitioned to the EEW network). They are currently streaming data at 100 s/s and are set for the maximum 4 g recording level. The continuous records from the Titan sensors are available by request to the NRCan's National Waveform Archive. It is intended that higher sample rate streams be implemented, with the understanding that the data will be stored in the digitizer for later request, and not streamed because of bandwidth limitations. The availability of 100 s/s data is very important for developing GMMs at short periods, and it may be possible to extend acquisition of the data to 200 or 250 s/s in order to acquire data for future studies. Most of the NRCan CNSN Titans are deployed on bedrock (co-located with broadband instruments). The goal is to record the pattern of shaking on rock, but some Titans are deployed on soil to help determine the non-linear behaviour of the soil under strong shaking [12, 13]. The latter is very important for the thick Leda clay deposits of the St. Lawrence valley, as we know that they provide very strong linear amplification of weak shaking (up to ~50 times stronger than on rock) with basin effects, but currently we have no records of their behaviour in the non-linear domain (i.e. for the strong shaking that is important for damage).

The other significant development (to be completed by March, 2024) is the deployment of strong motion instruments for the National Earthquake Early Warning (EEW) network. This system utilizes both Nanometrics Titan and Güralp Fortimus accelerometers. The EEW network, to be operational by Spring, 2024 is comprised of a "core network" maintained by NRCan

– this will have ~315 stations across Canada, and a partner network of ~150 instruments across Canada. Partners include local governments, Indigenous governments and provincial agencies. Partner groups will maintain instruments, NRCan will collect and utilise the data for EEW applications and archive select data. These EEW instruments are/will be concentrated in areas of highest seismic risk and will include deployments on soil sites and rock sites. They have a dynamic range of 2g and use two data streams, one continuous (low-latency) with a 100 Hz sample rate and a minimum phase/causal filter and the other a triggered stream with a sample rate of 250 Hz using a linear phase/acausal filter. The bulk of these stations use GNSS timing and a limited number will use PTP/NTP. As of March, 2023 the EEW network (both core and partner) includes 147 instruments across Canada (58 in the west and 89 in the east). This relatively dense network of instruments will provide data that are useful for not only EEW applications, but also for rapid estimation of shakemaps for emergency response applications (e.g., [14]) and for seismic site response evaluation (e.g., [12, 13]).

British Columbia Hydro

The BC Hydro strong motion network in British Columbia has expanded since 2013. BC Hydro maintains 101 strong motion instruments at most hydroelectric dams and transmission facilities across the province (Figures 1-3). These instruments provide data for both the dam safety program (e.g., for post-earthquake dam performance) and the transmission program (e.g., post-earthquake analysis of transmission facility performance). A total of 67 instruments operate at 26 dam facilities (labelled "BC Hydro" in Figures 1-3), with multiple instruments often installed at a dam site in locations such as the crest, abutment or toe (in a few cases on foundation bedrock). In addition, there are 15 seismic triggers that provide notification of shakings exceeding target threshold levels. Of the 67 instruments, most are digital SYSCOM MR202 units, with 2-g full scale, and trigger thresholds of about 0.5%g, 5 are Altus-ETNA's and 6 are EpiSensors (2g). A further 24 instruments are deployed at transmission facilities (major substations and terminal stations – most are in urban settings and deployed on soil). These are all SSA-2's or ETNA's, 2-g full scale with trigger thresholds of either 0.4%g or 0.6%g.

Ten new instruments have been deployed to collect site-specific recordings to better assess site-response at select facilities. These are side-by-side three-component force-balance broadband seismometer (Trillium Horizon broadband) and strong motion accelerometer (Titan strong motion accelerometer) sensors installed within a surface metal vault anchored to a concrete pad, which was cast directly on and anchored to clean, exposed bedrock.

None of the BC Hydro and Transmission instruments currently provide waveform data in real-time. There are plans to upgrade this monitoring network over the next several years.

British Columbia Ministry of Transportation and Critical Infrastructure (BC MoTI)

The BC Ministry of Transportation and Infrastructure (BC MoTI) currently maintains a dense seismic monitoring network called the British Columbia Smart Infrastructure Monitoring System (BCSIMS) which includes ~180 strong motion sensors and over 400 earthquake sensors installed on 14 BC MoTI owned key bridges in BC (e.g., the new Port Mann Bridge has a total of 350 channels, and the Second Narrows Bridge has 122 channels). The BCSIMS network [15] contributes to situational awareness at the time of an earthquake (providing shake-maps and ground shaking parameters for BC MoTI and emergency responders), and much like ShakeCast (e.g., [14]), to priorities infrastructure inspections and aftershock response, and to provide data in real-time that may be useful for other applications such as earthquake early warning. Strong motion instruments are mainly installed at schools, firehalls, BC Ambulance stations, BC housing, and DriveBC camera locations, etc. Most of the free-field strong motion sensors are legacy Internet Accelerometer (IA) sensors [11]. However, BC MoTI is in the process of procuring new earthquake sensors to replace at least 50 of these legacy IA sensors in 2023/24 as a partner in the NRCan National EEW network. These new earthquake sensors will provide data to BCSIM and NRCan's national earthquake early warning network, simultaneously. Some of the strong motion sensors are operating as downhole arrays on the Fraser River delta just south of Vancouver (two arrays on the South Fraser Perimeter Road project, and three downhole arrays near the Port Mann Bridge). Data for events that record ground motions >.1g at BC MoTI stations are available via public website www.bcsims.ca.

Ocean Networks Canada (ONC)

As of March, 2023, Ocean Networks Canada operates 41 strong motion instruments in southwest BC, including 13 seafloor strong motion instruments (Guralp accelerometers and Titans) at 5 sites offshore Vancouver Island, and 28 Titans onshore (mostly on Vancouver Island). A number of the ONC onshore instruments are co-located with NRCan instruments (broadband seismic and GNSS) in order to share resources and communications where possible. ONC strong motion instruments have sample rates between 100 and 500 Hz. Data from ONC instruments are used for a regional EEW network designed for offshore earthquakes [16] and are available via IRIS.

University of British Columbia (UBC)

The Department of Civil Engineering – Earthquake Engineering at the University of British Columbia (UBC) has deployed P-wave detectors at ~30 schools across southwestern BC as part of a local earthquake early warning system. Currently 67 instruments (not linked with BCSIMS at this time) are deployed at 33 sites (Figures 2 and 3), most located in greater Vancouver.

British Columbia Seismic Monitoring Consortium (BCSMC)

The British Columbia Seismic Monitoring Consortium (BCSMC) is a partnership between the British Columbia Oil and Gas Commission, Geoscience BC, the Canadian Association of Petroleum Producers and NRCan. As of March, 2023, 15 strong motion instruments (Titan PH sensors) are maintained in northeast BC (especially the Dawson Creek and Fort St. John areas) to help monitor and assess local induced seismicity (Figure 1).

Other

FortisBC Gas operates two strong motion instruments at the Tillbury Island LNG plant, just south of Vancouver and Tata Communications Canada (formerly known as Teleglobe Canada) operates an instrument at Cowichan Lake on Vancouver Island. The Raven seismic network of the Alberta Geological Survey has a strong motion instrument in northwest Alberta (Figure 1).

STRONG MOTION NETWORKS – EASTERN CANADA

As of March, 2023, nearly 180 strong motion instruments were operating across eastern Canada (Figures 5-6). A brief description of the instruments operated by various organisations is provided below. The most substantive changes since the last review [9] have been the completion of the CNSN upgrade and the deployment of NRCan strong motion instruments as a part of the national EEW network (Figure 6).

NRCan operates the vast majority (150) of the strong motion instruments in eastern Canada. This includes 61 CNSN strong motion instruments (mainly bedrock sites – see Figure 5) and 89 instruments (with partner organisations) for earthquake early warning (Figure 6). Internet accelerometers and Etna's that were previously operated by NRCan have been removed and replaced with Titan's for EEW. These data will provide near-field strong-motion data for the seismically active regions of eastern Canada, better assessments of ground attenuation relationships and low-latency data for earthquake early warning and shakemap applications.

Strong motion instruments are also operated by Hydro-Québec Production and Trans-Energie units of Hydro-Québec. Their instruments are installed at key hydroelectric dams and transformer sub-stations (Figure 5) as a part of their overall permanent seismic monitoring program. Most of the 10 instruments are Kinemetrics SSA-1's (1 or 2g) or 2g ETNA's. Ontario Power Generation and New Brunswick Power operate triggered strong motion instruments in and (for free-field motions) near their nuclear power plants in Ontario and New Brunswick, respectively, and Gaz Metropolitian Inc. has a free field digital accelerograph installed at their LNG plant in Montreal.

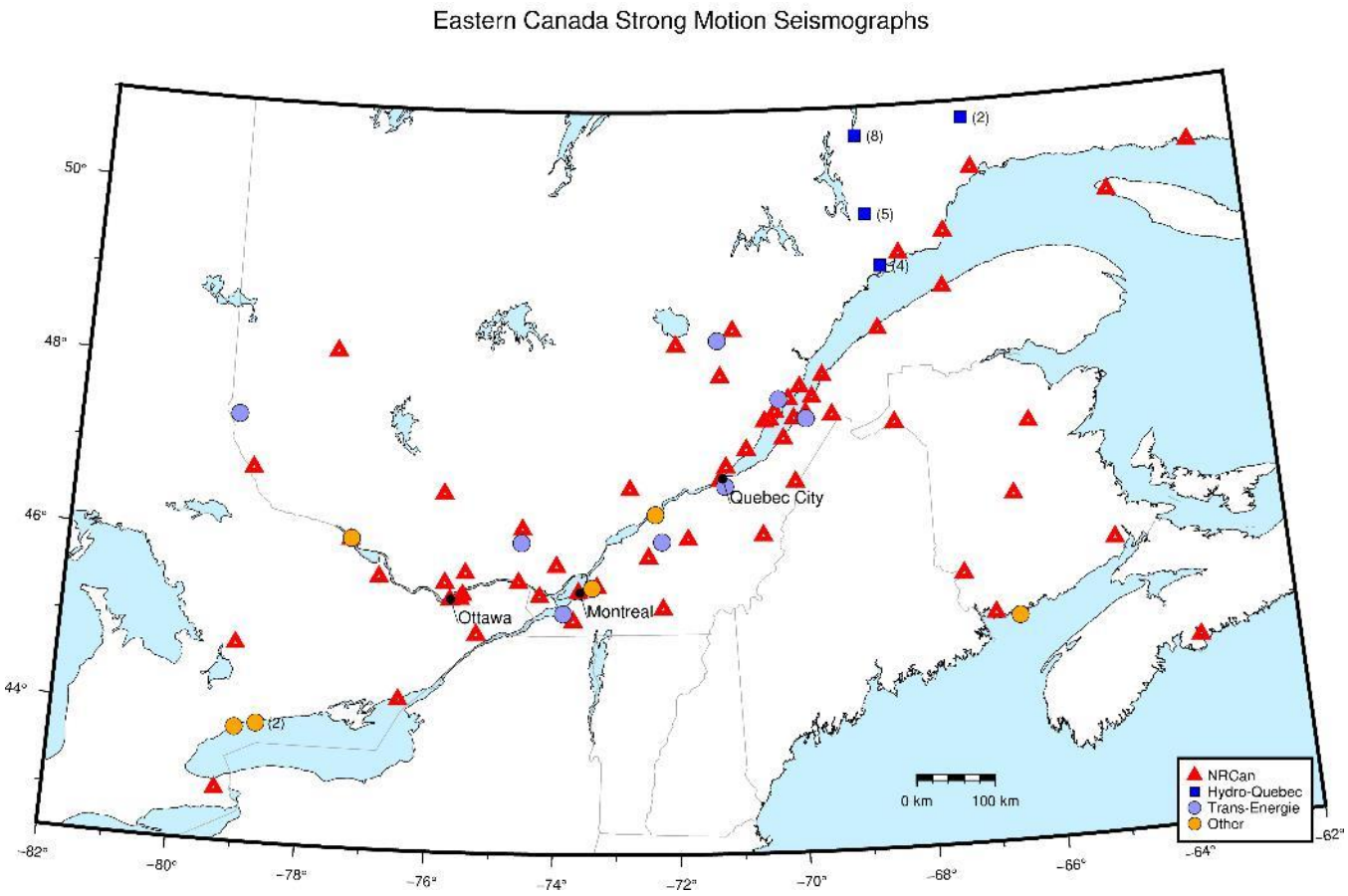

Figure 5. Strong motion seismographs in eastern Canada Numbers in parenthesis indicate the total number of instruments at that site. Status as of March, 2023.

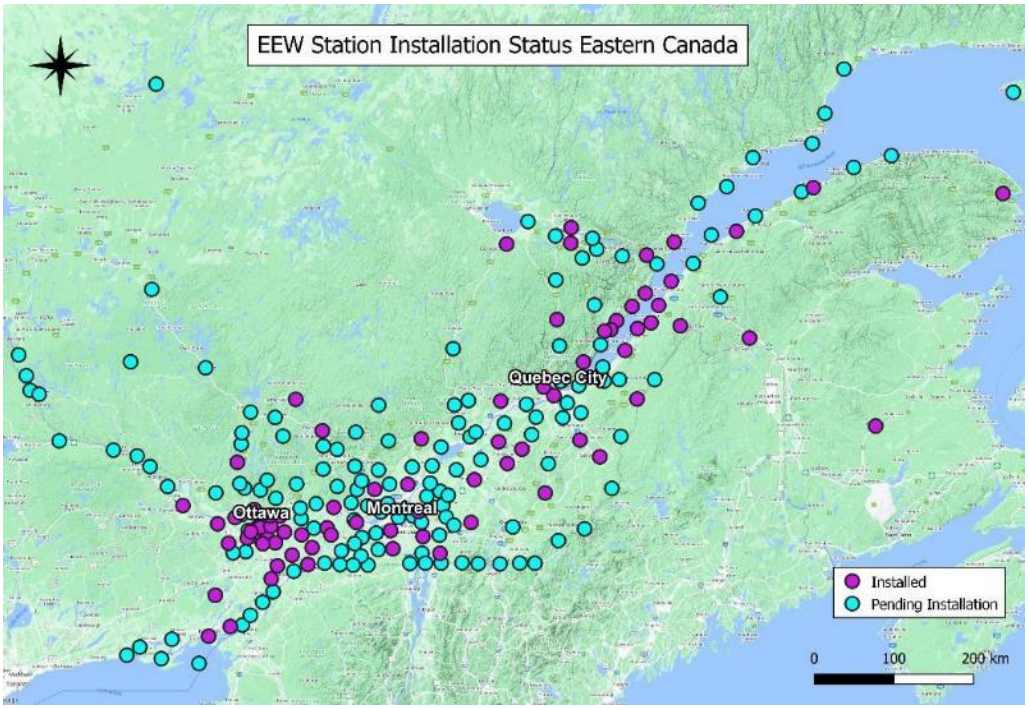

Figure 6. Status of the National EEW Network Deployment (NRCan and partners) as of March, 2023.

STRONG MOTION NETWORKS – NORTHERN CANADA

In addition to the BCSMC and BCH strong motion instruments operating in northeastern BC (described previously), NRCan operates an additional 13 strong motion instruments (Titans) in northern Canada (north of 55º latitude). These instruments (Figure 7) provide coverage in some of the most seismically active regions of the north, from Baffin Island through the Arctic islands to the southwest Yukon.

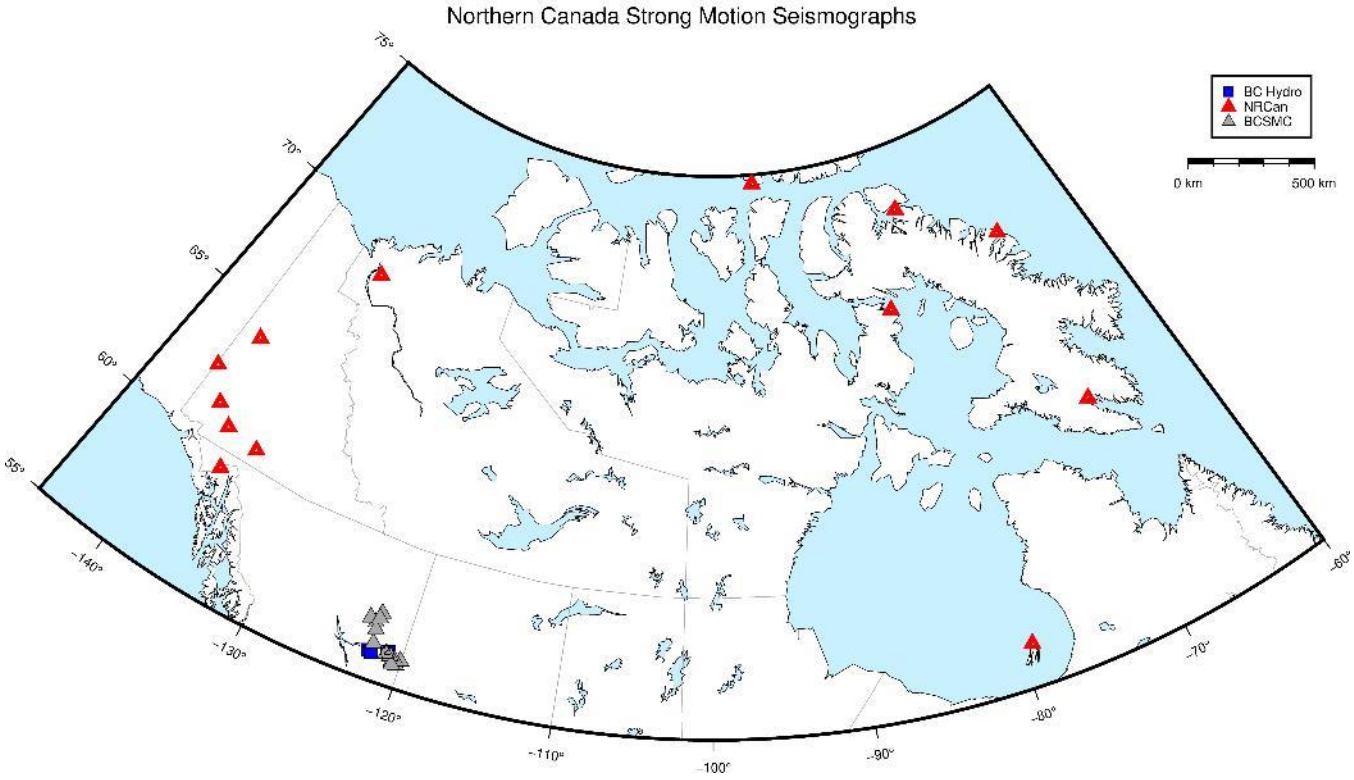

Figure 7. Strong motion seismographs in northern. Status as of March, 2023.

Table 1. Strong motion instruments deployed in Canada (as of March 2023).

Owner	**#Sites**	**#Instruments**
NRCan West CNSN	50	50
EEW NRCan/partners West	58	58
BC Hydro/Transmission	56	101
BC MoTI	160	160
UBC	33	67
ONC	32	41
BCSMC	15	15
Other West*	3	4
NRCan East CNSN	61	61
EEW NRCan/Partners East	89	89
Hydro-Québec	9	10
Other East*	5	6
NRCan North Titan	13	13
Total – All of Canada	**584**	**675**

*these numbers may not be complete as we have not surveyed all potential owners.

CANADIAN STRONG MOTION DATA AVAILABILITY

Since the last review of strong motion networks in Canada [9], seismic waveforms from NRCan strong motion instruments have been archived at the National Waveform Database, accessible through the website: https://earthquakescanada.nrcan.gc.ca/stndon/index-en.php. Although there is currently no single repository for all Canadian strong motion data, there are a few locations where the majority of the data can be collected at this time.

These sites are:

1. CNSN strong motion data are available as described in the "waveform data section" of the EarthquakesCanada website: https://earthquakescanada.nrcan.gc.ca/stndon/index-en.php. Access to EEW strong motion data will be described on this site when available.
2. Data for triggered stations in the BCSIMS network are available via public website www.bcsims.ca.
3. Strong motion data from Ocean Networks Canada, the BSSMC and many stations from NRCan and BC MoTI are available from the IRIS data center: as one example, for ONC data: http://ds.iris.edu/gmap/#network=NV&channel=?NZ&starttime=2009-01-01&endtime=2599-12-31T23:59:59&planet=earth

CONCLUSIONS

Strong motion monitoring continues to evolve rapidly across Canada, with additional organisations now contributing data, and increasing and varied applications for these data. As of March, 2023, more than 670 (near free-field) strong motion instruments are deployed across the country.

One significant advancement is the completion of the CNSN renewal, specifically the deployment of new Titan strong motion instruments (co-located with broadband seismometers) at ~100 bedrock sites across Canada. These data will be used to better understand ground motions and improve situational awareness following major earthquakes (e.g., more accurate shakemaps), and will contribute to the development of earthquake early warning systems in some areas. Another key development is the deployment of a national EEW network, that, when completed in Spring, 2024, will provide (between NRCan and partners such as BC MoTI) more than 400 strong motion sensors across Canada.

All Canadian strong motion data are not (yet) available at a single portal, however, the vast majority are readily available from the CNSN data centre, the IRIS data center or via BCSIMS, as described in this article.

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