NATIONAL REPORT – ICG/PTWS-XXXI
Submitted by CANADA

BASIC INFORMATION

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4. Local Tsunami Procedures. (If a local tsunami exists)
The United States' National Tsunami Warning Centre (NTWC) provides tsunami monitoring, assessment, and alerting for North American ocean coasts. Federal, provincial, and municipal organizations, however, are responsible for tsunami emergency management in Canada. The Province of British Columbia maintains tsunami alert procedures for Canada's Pacific Coast in the Tsunami Notification Process Plan (2023 Edition) available on the web: https://www2.gov.bc.ca/gov/content/safety/emergency-management/emergency-management/provincial-emergency-planning

The NTWC continuously monitors seismic data provided in near real-time by Natural Resources Canada's (NRCan) Canadian Hazards Information Service (Hazards Service) and other organizations operating seismograph networks. NRCan streams data from select Canadian National Seismograph Network (CNSN) stations directly to NTWC by radio, satellite, cellular, and landline telecommunications.

If NTWC automated systems and human analysts determine an offshore or near-ocean earthquake is large enough and shallow enough to disturb the ocean floor, NTWC issues Tsunami Warnings, Advisories, or Watches. Tsunami Information Statements are issued for locations where there is an earthquake or tsunami of interest but no threat to coastal residents.

Environment and Climate Change Canada's (ECCC) Pacific Storm Prediction Centre (PSPC) receives, re-formats, and re-distributes NTWC tsunami messages to Canadian federal and provincial agencies with tsunami emergency responsibilities. The PSPC delivers the alerts through the ECCC alert dissemination system, such as the weather office website and WeatherCan app (which also includes other alert types, for example, rainfall or storm surge). EMCR rebroadcasts NTWC messages and issues British Columbia-specific tsunami messages through the Provincial Emergency Notification System.

EMCR is responsible for acting upon the above information in accordance with the British Columbia Tsunami Notification Process Plan and will be in contact with one of two NRCan Seismologists On Call and the Tsunami Duty Officer of the Canadian Hydrographic Service of the Ministry of Fisheries and Oceans (DFO). EMCR, NRCan, DFO, and ECCC on-call subject matter experts may attend NTWC tsunami threat conferences and provide scientific and technical advice to provinces and territories and to Public Safety Canada (PS) or its Government Operations Centre (GOC). Canadian Coast Guard (CCG) will issue radio navigation warnings to advise vessels at sea.

After the initial tsunami messages, NTWC issues additional messages based on their continued analyses of seismic data and analyses of information from sea-level sensor networks, other tsunami warning centers, coastal observations, and scenario models. The NTWC continuously monitors sea-level data provided in near real-time by the Department of Fisheries and Oceans Canada's (DFO) Canadian Hydrographic Service (CHS) and other water-level network operators. DFO streams sea-level data to NTWC from coastal tide gauges by radio, satellite, cellular, and landline telecommunications.

DART (Deep-ocean Assessment and Reporting of Tsunamis) buoys monitored and installed by NOAA and tide gauges are generally too close to shore to provide early warning to nearby coasts. However, the relative wave amplitude measurements can be used in combination with wave propagation modelling to estimate wave heights at other sites. The West Coast of Canada does not have DART buoy coverage and therefore a subduction earthquake off the coast that generates a tsunami would not be detected by this system by the time the initial waves reach the Canadian Coast.

5. Distant Tsunami Procedures. (When a distant tsunami hazard exists)

Tsunamigenic events from distant source areas are identified by the NTWC and this information (Tsunami Warning, Tsunami Advisory, Tsunami Watch, Information Statement) is transmitted via the NOAA Weather Wire system to Canada.

The Pacific Storm Prediction Centre (PSPC) in Vancouver of Meteorological Service of Canada (MSC), ECCC issues Tsunami Alerts (Warning, Advisory or Watch) which are created directly from these NTWC tsunami alerts or as directed by EMCR. The PSPC delivers the alerts through the ECCC alert dissemination system, such as the weather office website and WeatherCan app (which also includes other alert types, for example, rainfall or storm surge).

EMCR also disseminates these tsunami alerts and issues British Columbia-specific tsunami alerts through the Provincial Emergency Notification System and procedures are outlined in the British Columbia Tsunami Notification Process Plan. NRCan and DFO provide observational data and advice to EMCR to support EMCR's decision making.

After the initial tsunami messages, NTWC issues additional messages based on their continued analyses of seismic data and analyses of information from sea-level sensor networks, other tsunami warning centers, coastal observations, and scenario models. The NTWC continuously monitors sea-level data provided in near real-time by Fisheries and Oceans Canada's (DFO) Canadian Hydrographic Service (CHS) and other water-level network operators. DFO streams sea-level data to NTWC from coastal tide gauges by radio, satellite, cellular, and landline telecommunications.

DART (Deep-ocean Assessment and Reporting of Tsunamis) buoys monitored and installed by NOAA and tide gauges are generally too close to shore to provide early warning to nearby coasts. However, the relative wave amplitude measurements can be used in combination with wave propagation modelling to estimate wave heights at other sites. The West Coast of Canada does not have DART buoy coverage and therefore a subduction earthquake off the coast that generates a tsunami would not be detected by this system by the time the initial waves reach the Canadian Coast.

A final tsunami bulletin is issued when it has been determined that the threat has ended. The circumstances may be such that a wave exists but has been observed to be too small to be damaging, or that previous bulletins were based on erroneous information (i.e., no tsunami waves exist.)

6.1. Canada's National Sea Level Network - Permanent Water Level Network (PWLN) and Tsunami Warning System (TWS)

The Department of Fisheries and Oceans (DFO)'s Canadian Hydrographic Service (CHS) collects, generates and disseminates water level and current data (observations, predictions and forecasts). These data are broadly used to support safe and accessible waterways for navigation, particularly for critical areas such as harbours, dredged areas and shipping routes; to support ocean monitoring, prediction and forecasting programs and services; for scientific research; to support international Tsunami and Storm Surge Warning systems operated by Emergency Management Organizations (EMOs) and to support other usages. The delivery of water levels to users remains a very important responsibility for DFO. Information provided to stakeholders must be accurate, comprehensive and delivered in a timely manner.

Water level observations are collected through a national network of 135 water level and current monitoring gauges which includes the Permanent Water Level Network (PWLN) and the Tsunami Warning System (TWS), as well as seasonal and temporary gauges (Figure 1). Data from these gauges are automatically uploaded to the Integrated Water Level System (IWLS) national database and are made available through a range of data services to EMOs, navigational services, the marine industry, the scientific community and the public. The data are also used by the CHS and international hydrographic organizations to maintain and create both Canadian and international navigational products.

The management of this data is the joint responsibility of a Tides, Current and Water Level (TCWL) working group consisting of the regional experts responsible for the program and the Ocean Science Branch (OSB) in Ottawa. OSB's mandate is to manage and archive ocean data collected by DFO, or acquired through national and international programs conducted in ocean areas adjacent to Canada. In addition, OSB disseminates data, data products, and services to the marine community in accordance with the policies of the Department, including provision of the official daily means and hourly heights to Environment and Climate Change Canada (ECCC), U.S. Army Corps of Engineers (USACE) and the International Lake Ontario –St. Lawrence River Board (ILO-SLRB).

In the Pacific Region CHS operates a network of 42 real-time water level and 6 real-time current stations along the British Columbia Coast. Seventeen of these stations serve the Permanent Water Level Network (PWLN) and Tsunami Warning System (TWS).

All stations utilize a combination of Sutron data loggers coupled to multiple types of sensors which include dual encoder/float/dry counterweight systems, radars, bubbler sensors and HADCP's. Sixteen of the stations have dual data loggers for redundancy.

One-second water levels are collected and averaged to provide 1-minute data. At all PWLN and TWS stations data loggers, sensors and ancillary equipment are backed up with dual batteries. The tide gauge clocks are automatically GPS time synced daily and data downloads are quality controlled automatically. All acquired data are further processed (monthly and yearly) to compensate for hardware and site-specific limitations.

Eleven of the Pacific Coast stations also have stations also have GOES satellite transmission to NOAA's Wallups Island download site for access by the National Tsunami Warning Center (Palmer, Alaska). The GOES data, for redundancy purposes, can be downloaded from multiple websites (NOAA, USGS, Sutron) using custom CHS software, enabling access to the data from anywhere there is internet connection. The GOES data are also ingested into the Integrated Water Level System (IWLS) database as a backup to IP or landline interruption.

Ten of the stations - Henslung Cove, Prince Rupert, Winter Harbour, Tofino, Port Alberni, Seal Cove, Port Hardy, Nanaimo, Daajing Giids (Queen Charlotte City) and Patricia Bay, also have barometric pressure sensors providing 1-minute data. Data from these sensors have been valuable in detecting air pressure related 'meteotsunami' events.

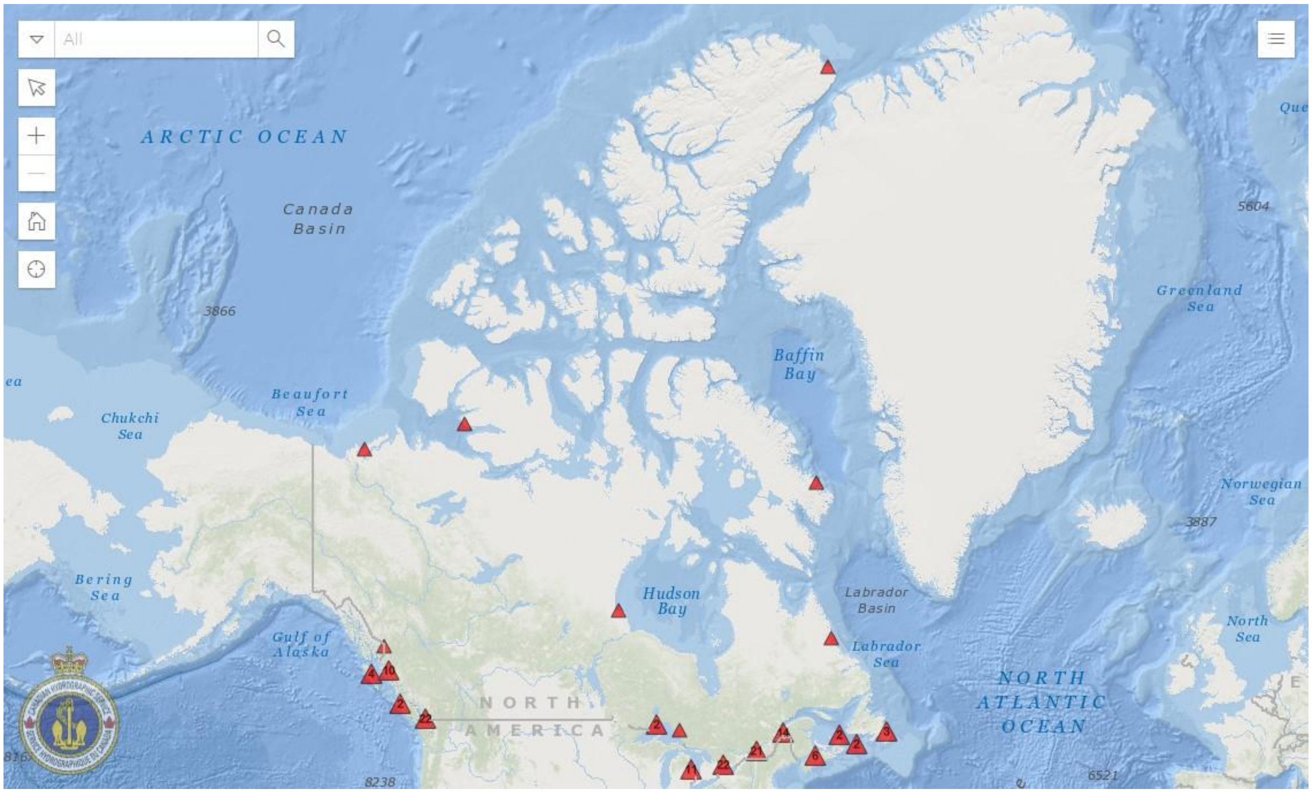

Figure 1. Canada's National Sea Level Network

6.2. Natural Resources Canada - Canadian National Seismograph Network (CNSN)
NRCan's Canadian Hazards Information Service operates the CNSN, a Canada-wide network of over 100 high-gain seismographs and 60 low gain accelerographs (Figure 2). The seismographs provide greater detail of weaker ground motions from lower-magnitude or distant earthquakes. The accelerographs provide greater detail of stronger ground motions from higher-magnitude or nearby earthquakes.

The CNSN streams data in near real-time to parallel and geographically redundant data centres for automated earthquake analyses and rapid notification. Two Seismologists On Call are available 24 hours per day seven days per week to prepare earthquake reports that quickly follow the automated preliminary earthquake notifications. NRCan also streams data from select CNSN stations to NTWC for inclusion in North American tsunami monitoring, assessment, and alerting.

NRCan's Earthquake Early Warning System became operational in 2024 with hundreds of additional seismic sensors and alerting protocols in British Columbia providing seconds to tens of seconds of early warning of imminent dangerous shaking. NRCan will use the nearly operational system to integrate Global Navigation Satellite System (GNSS) geodetic data with earthquake and tsunami alert.

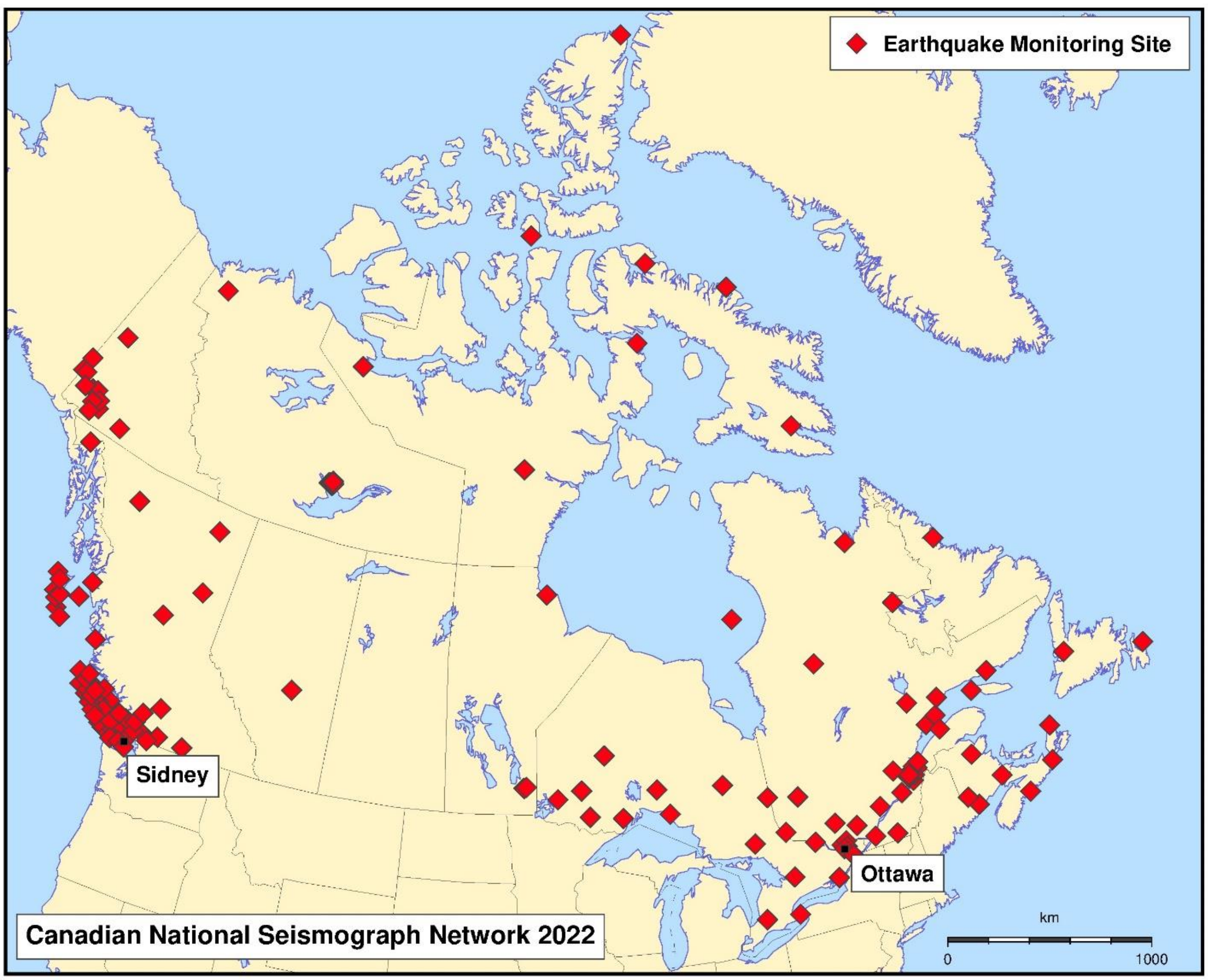

Figure 2. Canadian National Seismograph Network (CNSN)

7. Information on Tsunami occurrences

There were no seismically generated tsunamis during the period of 2023-2025 that were observed on the coast of Canada. However, the South Sandwich tsunami of 12 August 2021 (Figure 4) was not described in the 2023 National report of Canada and it was recently found that this tsunami event was clearly recorded on the coast of British Columbia; the corresponding records were thoroughly examined, and the results are presented in the present report. In addition, a significant local meteorological tsunami was recorded on 29 August 2023 in the southern part of Vancouver Island, mostly in the area of the Saanich Peninsula ("Saanich meteotsunami"). This event is also described in the report.

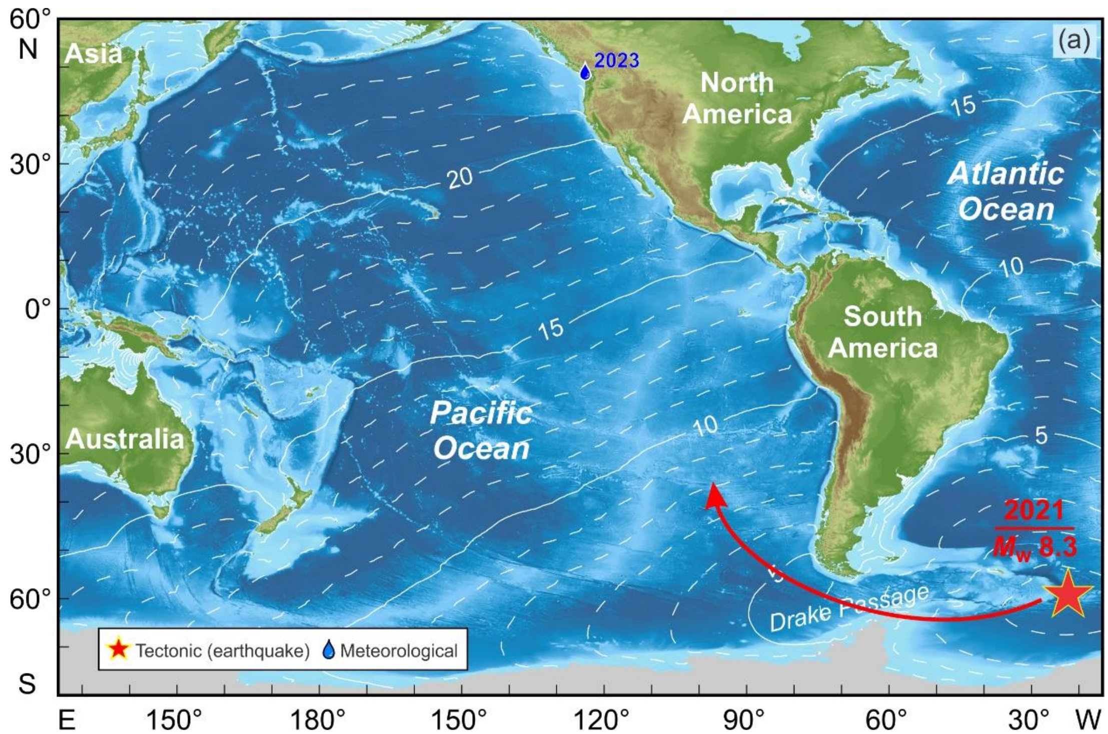

Figure 3. The epicenter (red star) of the South Sandwich Islands earthquake (Mw 8.1-8.3) of 12 August 2021 and the travel times (white lines) of the generated tsunami from the source area to the North Pacific Ocean. The location of the Saanich meteotsunami of 29 August 2023 is indicated by the blue raindrop.

8. Tsunami measurements

To examine the character of the 2021 tsunami and 2023 meteotsunami events on the coast of British Columbia we used the Canadian Hydrographic Service (CHS) network of coastal tide gauges and other sources from the research network when available. The primary stations used in our analyses are shown in Figure 4; for some events we also used certain additional stations that are described in the subsections related to the respective events.

The preliminary analysis of the records included data verification and correction, then based on tidal harmonic analysis, these records were de-tided and an additional high pass filter with 3-4 hour Kaiser Bessel window was applied to the residual time series.

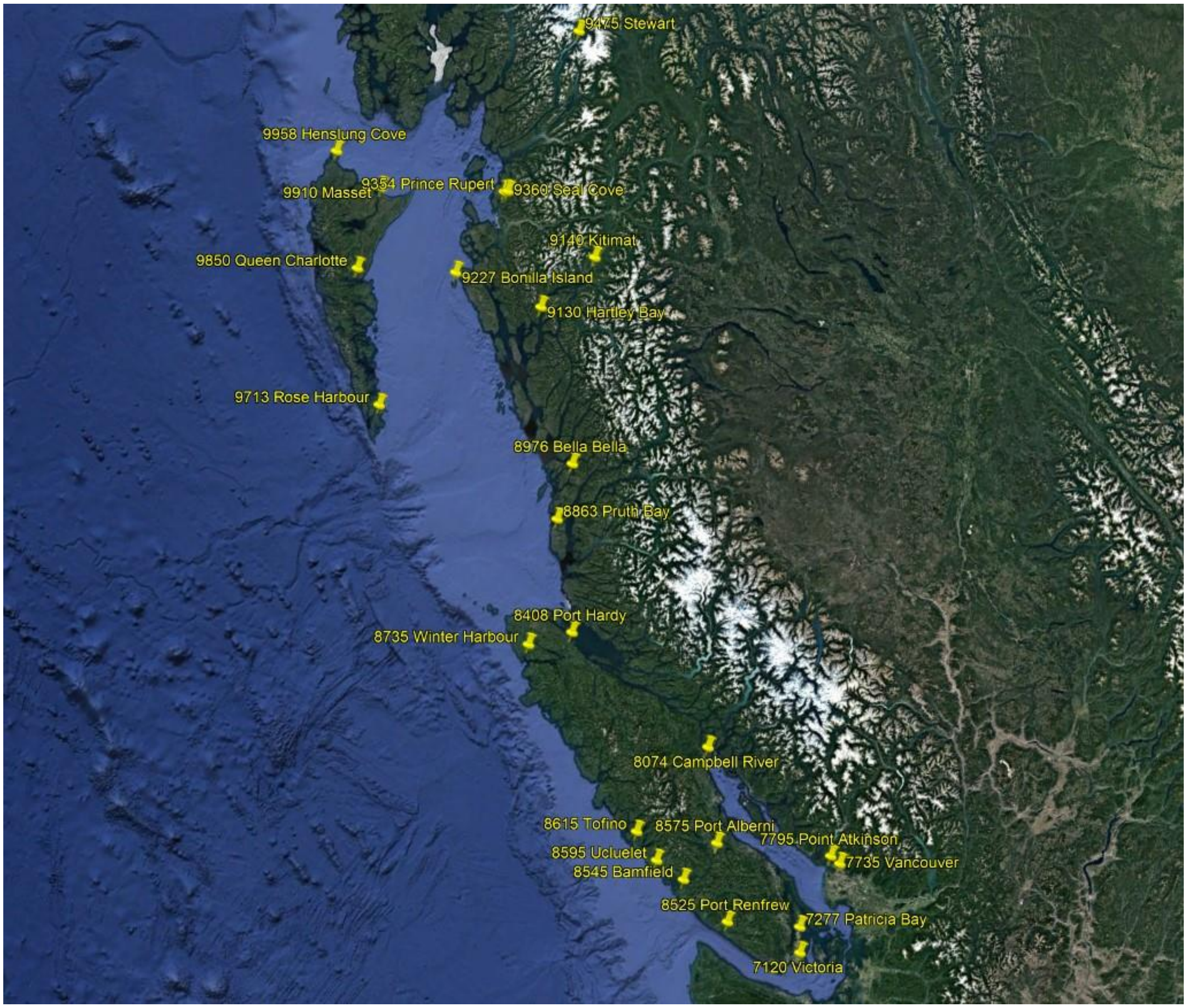

Figure 4. Map of coastal British Columbia showing the location of the Canadian Hydrographic Service Pacific Region coastal tide stations.

8.1. South Sandwich Islands tsunami of 12 August 2021

On 12 August 2021, a major earthquake struck the South Sandwich Islands region. The initial earthquake measured magnitude Mw 7.5, but just three minutes later, an Mw > 8 quake followed, rupturing the shallow subduction zone. The US Geological Survey (USGS) initially evaluated the 2021 event as Mw 8.1, while the Global Centroid Moment Tensor Catalog (GCMT) estimate was Mw 8.3. Because the Mw 8.1 earthquake occurred so closely after the Mw 7.5 event, the first quake had initially masked the second quake's seismic signature. It was the unpredicted, global-spreading tsunami that gave scientists insight into the nature of the earthquake. The tsunami waves propagated throughout the entire World Ocean and affected far remote areas of the Indian, Atlantic and Pacific oceans, including Kamchatka, the Aleutian Islands, Alaska and British Columbia, where tide gauges measured peak amplitudes of ~20 cm at over 10,000km distance from the source.

Figure 5. Map of Vancouver Island with the locations of the Canadian Hydrographic Service (CHS) coastal tide gauges indicated by circles open-ocean DART stations indicated by red squares. Yellow circles with blue contours (CHS S) are CHS stations of the southern group of tide gauges that recorded the 2021 South Sandwich tsunami, the yellow circles with red contours (CHS N) are the same but for CHS tide gauges from the northern group, the white circle with the red contour (CHS empty) indicates Bonilla station that did not record this tsunami.

For the analysis we selected 17 stations separated into two groups (Figure 5): All stations located at the coast of Vancouver Island, except Port Hardy, were called "the southern group" (eight tide gauges altogether), while Port Hardy and the other eight gauges were identified as "the northern group". No tsunami signal was found at Bonilla, located in Hecate Strait. These stations are all tide gauges belonging to the Canadian Hydrographic Service (CHS), and are mostly located on the outer (oceanic) coast of British Columbia.

The data were verified and corrected, predicted tides were subtracted from the original records and then high-pass filtered using a 3-h Kaiser-Bessel (KB) window to suppress low-frequency sea level fluctuations, which are mainly associated with atmospheric processes. These filtered sea level time series were then used to construct plots of tsunami records (Figures 6-7) and to estimate statistical characteristics of the recorded tsunami waves (Table 1). As a result, the 2021 South Sandwich tsunami waves were identified in all examined records apart from Bonilla; the latter record was too noisy and had some definite instrumental problems that lead to regular spikes in the data.

The 2021 South Sandwich tsunami waves first arrived at Tofino on 13 August at 17:46 UTC - 23 h and 13 min after the main earthquake shock, which agrees with the numerically computed travel time presented in Figure 3. Then, about 40 min later, these waves were observed in Ucluelet, Rose Harbour and Bamfield. At two important, Tsunami Warning stations, Winter Harbour and Henslung Cove (Langara Island) the tsunami waves arrived 24 h 16 min and 24 h 39 min after the earthquake respectively. The two most remote stations, Prince Rupert and Queen Charlotte City (Daajing Giids), observed the tsunami waves about 3 h and 20-25 min later than at Tofino (Table 1). The arrival times at all stations were consistent and in good agreement with the calculated arrival times. The recorded waves were small but evident (Figures 6-7). The maximum wave heights were measured at Ucluelet (13.7 cm), Pruth Bay (11.9 cm), Rose Harbour (11.4 cm) and Port Alberni (11.0 cm). At all other stations the observed maximum wave height was below 9 cm. The tsunami wave periods strongly varied from one site to another, but mostly were in the range of 12-55 min. The only two exceptions were Port Alberni and Prince Rupert, both with an observed wave period of 110 min, however it is well known that both Alberni Inlet and Dixon Entrance play the role of low-pass filters passing through low frequencies and suppressing high frequencies. Periods of 110 min are typical for recorded tsunami waves at these stations.

Table 1. Parameters of the South Sandwich tsunami of 12 August 2021 recorded on the coast of British Columbia All arrival times and times of the maximum waves (in UTC hours) are related to 13 August 2021, except those indicated by *.

Station	First wave			Max waves			Visible period (min)
	Arrival time (UTC)	Travel time (hh:mm)	Amplitude (cm)	Max amplitude (cm)	Time (UTC) of max amplitude	Max wave height (cm)	
Prince Rupert	21:06	26:33	2.6	3.2	01:39*	5.6	110
Masset	19:36	25:03	1.5	1.8	21:05	4.0	60
Henslung Cove	19:12	24:39	1.6	3.7	21:01	8.6	12, 30
Queen Charlotte C.	21:11	26:38	0.4	3.2	14:40*	7.6	15, 40
Rose Harbour	18:25	23:52	2.2	5.3	00:34*	11.4	20
Bella Bella	19:18	24:45	1.6	4.0	14:56*	7.2	30, 55
Pruth Bay	19:21	24:48	2.0	7.1	15:23*	11.9	25
Port Hardy	19:48	25:13	1.4	2.2	21:08	4.3	12, 20
Port Alice	19:08	24:35	0.8	3.3	20:47	6.1	50, 110
Winter Harbour	18:49	24:16	1.7	2.7	19:49	7.7	30, 50
Tofino	17:46	23:13	2.3	3.6	02:10*	6.6	20, 55
Ucluelet	18:24	23:51	1.5	5.8	19:26	13.7	15, 22
Port Alberni	19:34	25:01	3.5	3.6	23:40	11.0	110
Bamfield	18:27	23:54	0.6	2.5	20:20	5.0	18, 140
Port Renfrew	19:11	24:38	1.7	3.1	01:18*	6.3	35, 60
Victoria	?	?	?	2.0	02:47*	4.5	20, 60

* 14 August 2021.

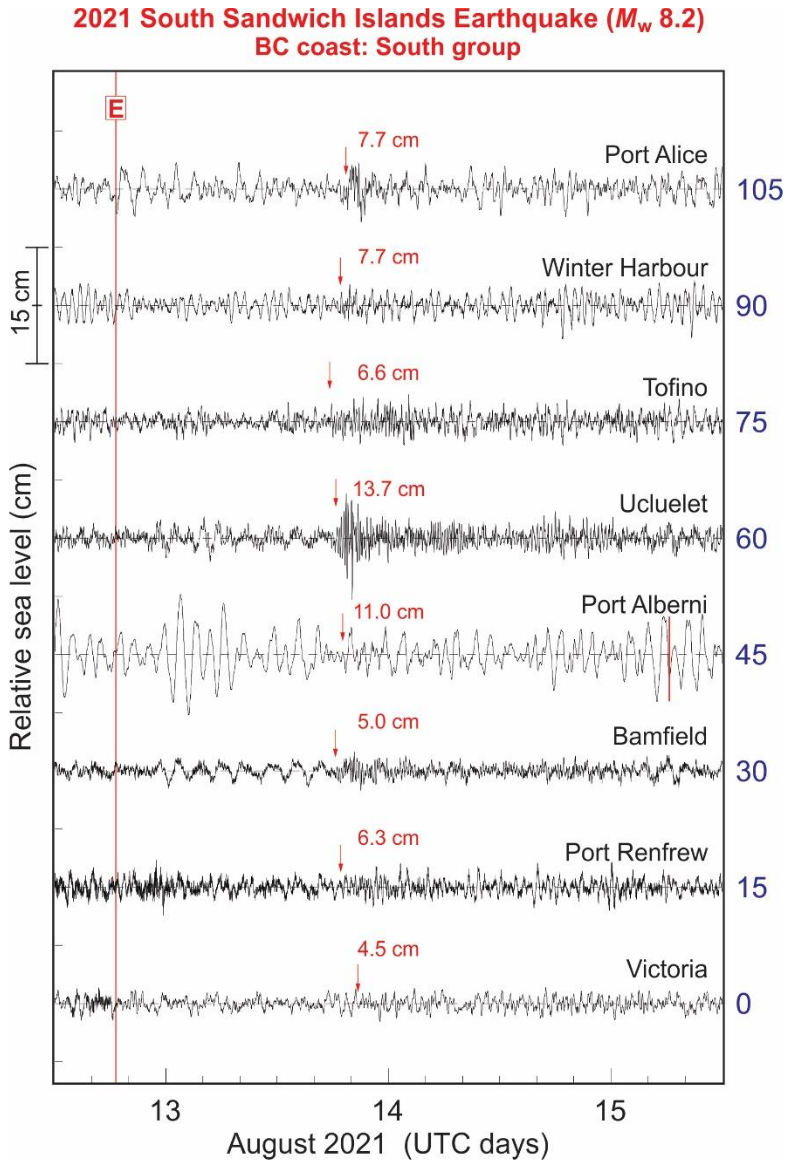

Figure 6. De-tided and high-pass filtered (3-hour Kaiser-Bessel window) 3-day records of the 2021 South Sandwich tsunami at the CHS stations of the southern group. The solid vertical red line labelled "E" indicates the time of the earthquake, the small red arrows denote the tsunami arrival times at the corresponding stations, and red numbers are maximum recorded tsunami wave heights at these stations. The individual records are shifted in vertical relative to each other; the shift values (in cm) are listed along the right axis.

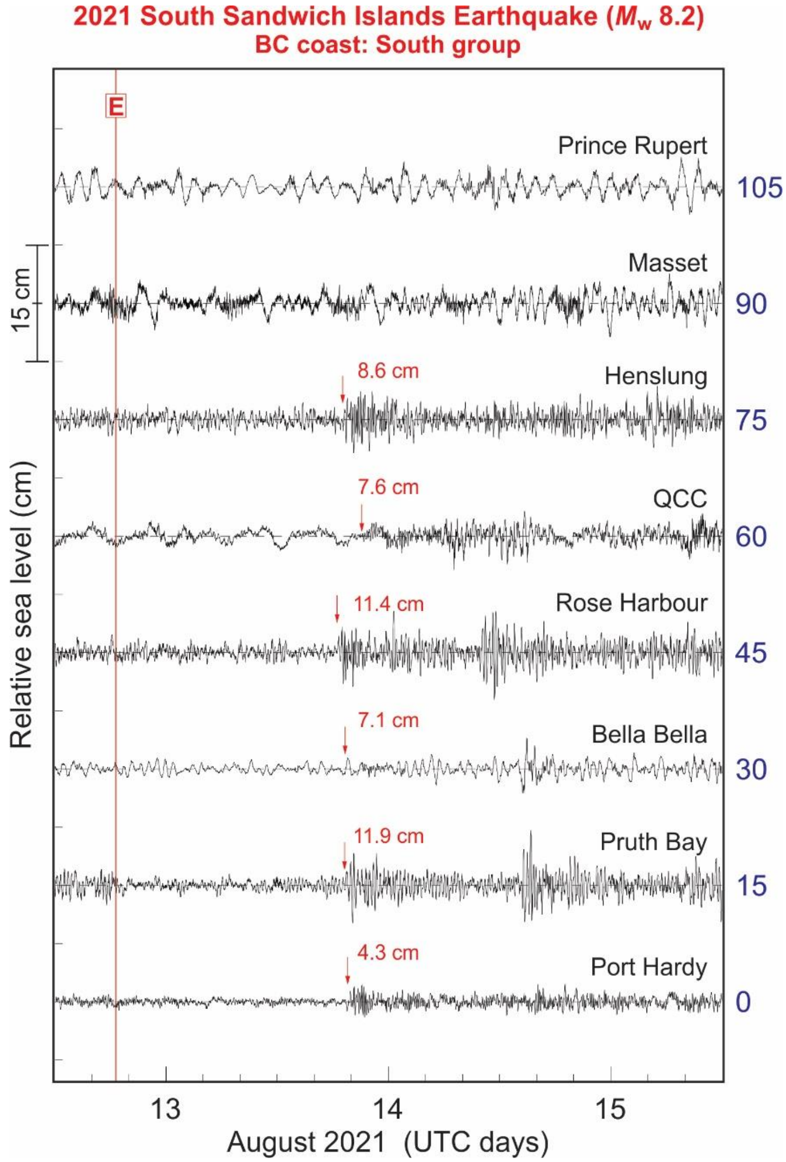

Figure 7. De-tided and high-pass filtered (3-hour Kaiser-Bessel window) 3-day records of the 2021 South Sandwich tsunami at the CHS stations of the southern group. The solid vertical red line labelled "E" indicates the time of the earthquake, the small red arrows denote the tsunami arrival times at the corresponding stations, and red numbers are maximum recorded tsunami wave heights at these stations. The individual records are shifted in vertical relative to each other; the shift values (in cm) are listed along the right axis.

8.2. Meteorological tsunami in the Southern Coast of Vancouver Island region on 29 August 2023

A prominent seiche event was found to occur on 29 August 2023 on the southern coast of Vancouver Island in the area of the Saanich Peninsula. This seiche event was evident in the records of permanent Canadian Hydrographic Service (CHS) tide gauges: Patricia Bay, Victoria, Port Renfrew and (weakly) Point Atkinson. No corresponding event was measured at CHS stations at Bamfield, Ucluelet, Port Alberni, Tofino and Winter Harbour on the west coast of Vancouver Island. Following inspection of tide gauge records from three temporary CHS stations (Sidney, Bamberton, and Nitinat), and several NOAA stations (see Figure 8 for station locations) it was confirmed that this event was observed along the Strait of Juan de Fuca and in the southernmost part of the Strait of Georgia, but not along the western coasts of Vancouver Island and Washington State. Thus, the event was very localized. Preliminary investigation of the CHS air pressure records at Patricia Bay, Port Alberni and Tofino revealed that the extreme seiches detected in a few southern stations were produced by a train of extreme atmospheric high-frequency waves propagating over the Saanich Peninsula and adjacent areas of the Strait of Juan e Fuca and the Strait of Georgia. The generated sea level oscillations had characteristics typical of tsunami waves and are referred to as a meteotsunami.

For our analysis of this event we selected only five permanent CHS stations, all located in southern British Columbia. In four of them – Patricia Bay, Victoria, Port Renfrew and Point Atkinson – the meteotsunami of 29 August 2023 had been detected. Bamfield was used as a control. Additionally, we downloaded the records from three temporary CHS stations located in this region – Sidney, Bamberton and Nitinat. We also used the data from five NOAA stations located in Juan de Fuca Strait and the southern Strait of Georgia. The locations of these 13 stations are presented in Figure 8. The sampling interval for Port Angeles was 6 min while all other records had 1-minute sampling intervals. The sea level records have been examined using data analysis procedures the same as for the South Sandwich Islands event.

Figure 8. (a) Map of southern British Columbia (BC) and northern Washington State (WA) with shown locations of CHS (yellow circles) and NOAA (white circles) tide gauges, CHS microbarographs (brown squares) and Ocean Network Canada (ONC) bottom pressure recorders, BPRs (light green rhombs). (b) The Saanich Peninsula region indicated by the light blue box in (a). Abbreviated names of the ONC BPRs: SoG = Strait of Georgia, SI = Saanich Inlet.

Figure 9 shows 3-day records for the period of 28-30 August 2023 from the eight CHS tide gauges shown in Figure 8. The meteotsunami event is obvious in six of them but totally absent in the records of two stations – Nitimat and Bamfield – located on the oceanic coast of Vancouver Island. A zoomed version of six meteotsunami records is shown in Figure 10. The strongest oscillations, with a trough-to-crest height more than 30 cm, were recorded at Victoria, the weakest, of less than 10 cm, at Point Atkinson; wave heights at the four other stations were similar: 15-20 cm. The meteotsunami signal was also found in two bottom pressure records: 4 cm at SoG and 12 cm Si (see Figure 8 for station locations).

The observational data were used to estimate various parameters of the meteotsunami: beginning time, duration, maximum amplitude and its time, and maximum min/max range. These parameters are presented in Table 2. The event began at Victoria at 09:27 UTC, then 15-30 min later in the area of the northern Saanich Peninsula and finally, at 10:48 UTC, at Point Atkinson. Such beginning times indicate that the tsunamigenic atmospheric disturbance moved in a northward direction.

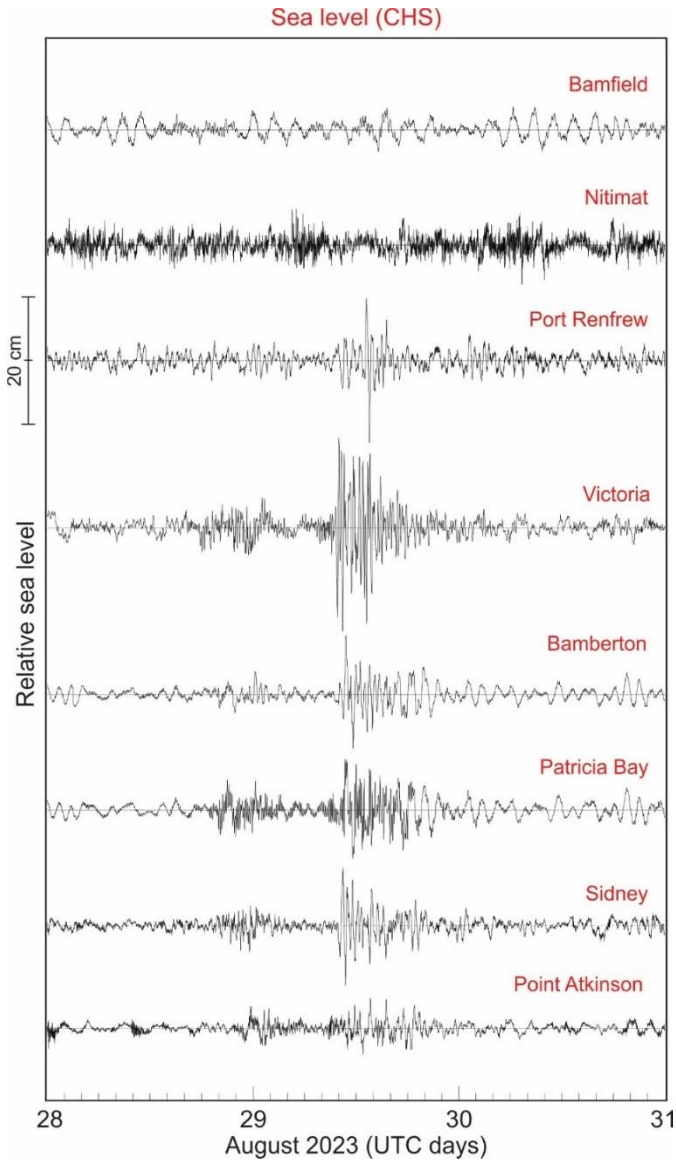

Figure 9. Residual (de-tided) and high-pass filtered with 3-hour Kaiser-Bessel (KB) window 3-day tide gauge records (28-30 August 2023) at 8 CHS stations on the southern coast of British Columbia (See Figure 8 for station locations).

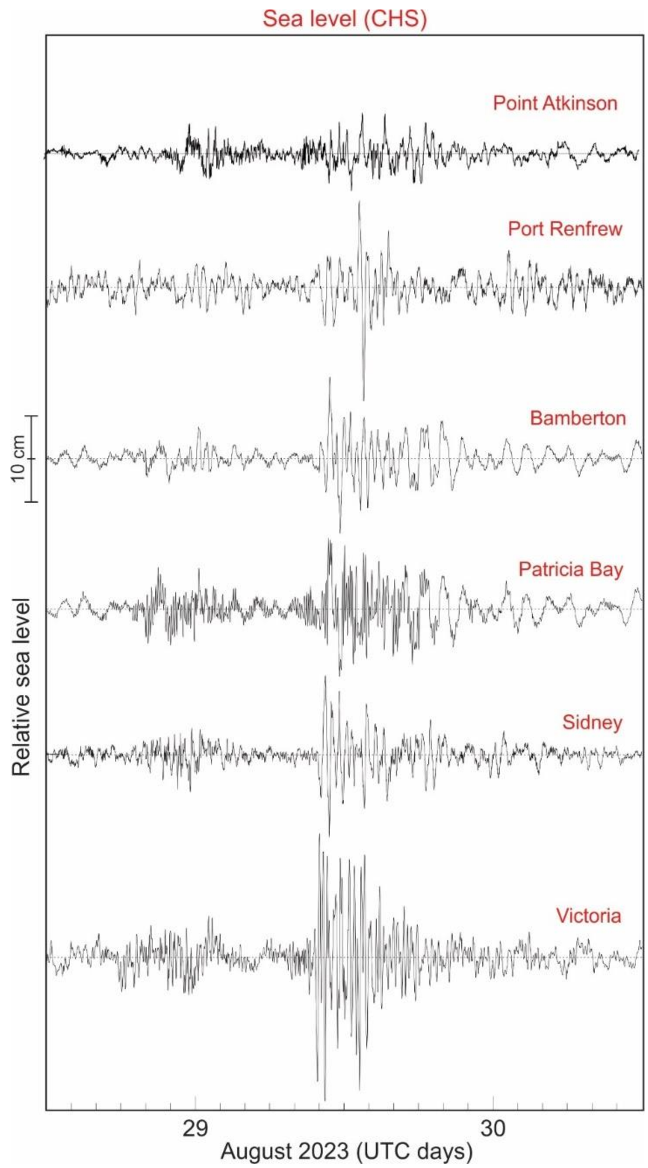

Figure 10. Residual (de-tided) and high-pass filtered with 3-hour Kaiser-Bessel (KB) window 3-day tide gauge records (28-30 August 2023) at 8 CHS stations on the southern coast of British Columbia (See Figure 8 for station locations).

The durations of the event ranged from 8.7-9.5 hours at Point Atkinson, Port Renfrew and Victoria, to 12-12.5 hours at Station SoG and stations located within Saanich Inlet. It appears that this is determined by higher radiation conditions in the former regions and energy being trapped in Saanich Inlet and nearby in the Strait of Georgia.

Amplified meteotsunami amplitudes in the area of Victoria, Patricia Bay and Bamberton are indicative of intense atmospheric activity in this region. To verify this we used the data from three CHS microbarographs: Patricia Bay, Port Alberni and Tofino (the locations of the instruments are shown in Figure 8).

Table 2. Parameters of the meteotsunami of 29 August 2023 in the area of the Saanich Peninsula, Juan de Fuca Strait and the Strait of Georgia estimated from CHS tide gauges and ONC bottom pressure stations. Also given are the parameters of the atmospheric disturbance recorded at Port Alberni. All times are related to the 29th August.

Station	Beginning (UTC hh:mm)	Max amplitude*	Time of max (hh:mm)	Max range*	Duration (hour)	Period (min)
	Sea level (cm)					
Point Atkinson	10:48	4.5	13:41	8.4	8.7	35
Port Renfrew	10:09	9.8	13:12	22.8	9.0	36
Bamberton	10:00	9.4	10:49	18.0	12.0	35, 80
Patricia Bay	09:57	7.4	10:43	14.7	12.0	9, 34, 85
Sidney	09:54	9.2	10:29	18.7	10.8	34, 85
Victoria	09:27	14.0	10:00	30.9	9.5	17, 34
BPR Strait of Georgia (SoG)	09:45	1.6	15:35	4.1	12.5	38, 64
BPR Saanich Inlet (SI)	09:40	6.7	10:54	12.7	12.5	34, 80
	Atmospheric pressure (hPa)					
AP Patricia Bay	09:37	2.4	09:57	4.8	9.7	38, 70

*Sea level values are in cm; the atmospheric pressure value is in hPa.

The most distinctive feature of the air pressure records, shown in Figure 11, is the highly intense atmospheric disturbance that was observed at Patricia Bay on the 29 August. This disturbance has the evident character of a train of strong atmospheric gravity waves (AGW), with the maximum wave height of more than 4.5 hPa, passing over this station. No such atmospheric phenomena were observed at Port Alberni (located in only ~120 km from Patricia Bay) or Tofino (~190 km). This was not related to a cyclone or other "bad weather activity", but to a broad high-pressure "good-weather" system; the mean air pressure at Patricia Bay at the time of the train arrival was 1017.5 hPa and it was increasing (Figure 11). It is obvious that this AGW train was responsible for the extreme seiche oscillations observed at Patricia Bay and other southern stations.

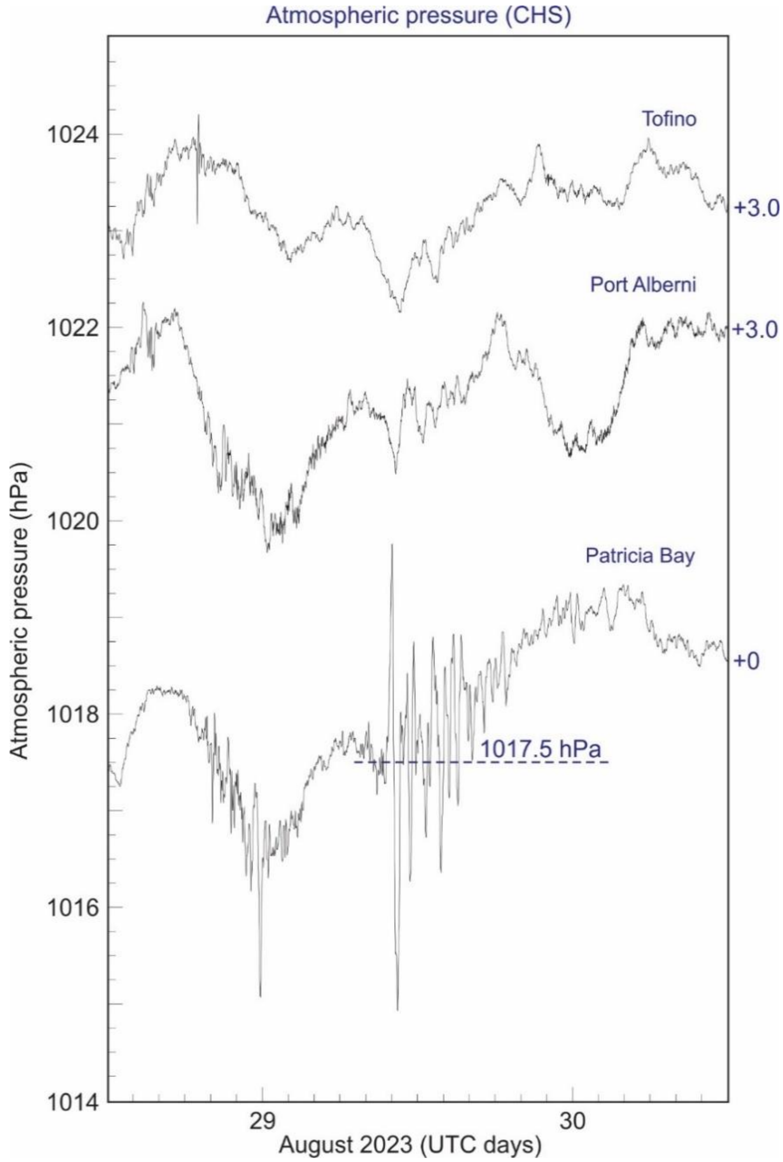

Figure 11. Atmospheric pressure records at three CHS stations – Tofino, Port Alberni and Patricia Bay – for the period of 28-30 August 2023 (see Figure 8 for station locations). For display purposes the records at Tofino and Port Alberni are offset +3.0 hPa relative to the record at Patricia Bay. The strong meteotsunami disturbance on 29/08, as well as a weaker disturbance 10 hours earlier, are evidently seen in the record of Patricia Bay but absent in the two other records. The dashed horizontal line labelled 1017.5 hPa indicates the atmospheric pressure at Patricia Bay at the time of the main disturbance arrival.

It is interesting that approximately ten hours earlier another atmospheric disturbance (Figure 11) propagated over Patricia Bay (but not over Port Alberni or Tofino). This disturbance was weaker (maximum height = 2.2 hPa) but was still deemed as significant and produced noticeable sea level/bottom pressure oscillations (see Figure 10). It appears that the two disturbances following each other were the result of anomalous atmospheric conditions over the region. The character of these two mesoscale disturbances is better seen in high-pass filtered records of the atmospheric pressure (Figure 12). These disturbances at Patricia Bay significantly exceed the background noise level. They are unnoticeable in the records of Port Alberni and Tofino, but in general their records demonstrate high atmospheric wave activity.

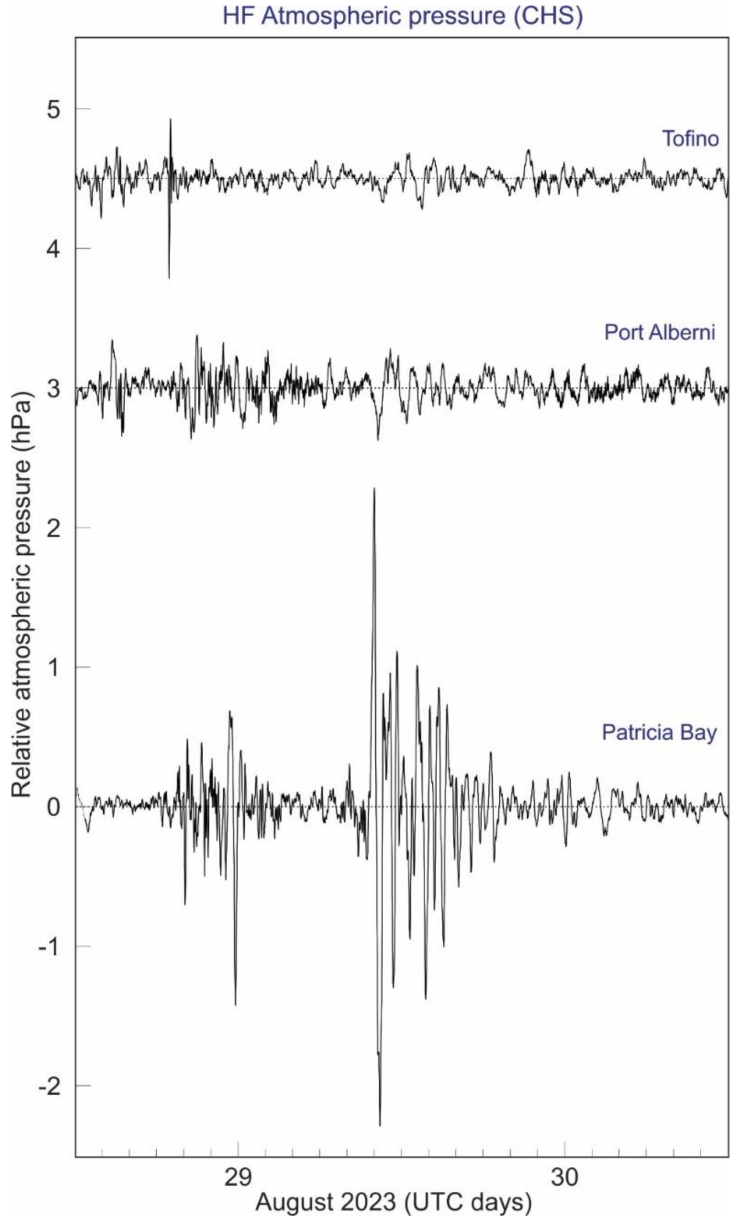

Figure 12. High-pass filtered (with 3-hour KB window) atmospheric pressure records at three CHS stations – Tofino, Port Alberni and Patricia Bay – for the period of 28-30 August 2023. (See Figure 8 for station locations). Two disturbances are evident at the atmospheric pressure record at Patricia Bay but absent at Tofino and Port Alberni.

9. Tsunami websites

Tsunami related websites are operated by:

1) BC Ministry of Emergency Management and Climate Readiness (EMCR) – Prepared BC
preparedbc.ca.

2) BC Ministry of Emergency Management and Climate Readiness (EMCR) – EmergencyInfo BC
https://www.emergencyinfobc.gov.bc.ca/

3) BC Ministry of Emergency Management and Climate Readiness – ClimateReadyBC
https://climatereadybc.gov.bc.ca/

4) Canadian Hydrographic Service of Fisheries and Oceans Canada (DFO)
https://tides.gc.ca/en

5) Canadian Hazards Information Service of Natural Resources Canada (NRCan)
https://earthquakescanada.nrcan.gc.ca/info-gen/tsunami-en.php

10. Summary plans of future tsunami warning and mitigation system improvements

The Canadian Hazards Information Service of NRCan's Earthquake Early Warning System (EEW) became operational in 2024 with hundreds of additional seismographs and alerting protocols providing early warning of imminent dangerous shaking in parts of British Columbia. NRCan will use EEW to integrate Global Navigation Satellite System (GNSS) geodetic data with earthquake and tsunami alerts.

NATIONAL PROGRAMMES AND ACTIVITIES INFORMATION

11. EXECUTIVE SUMMARY

The Ministry of Emergency Management and Climate Readiness (EMCR) is the provincial agency for distributing tsunami warnings to coastal areas of BC and takes the lead in tsunami public education. Environment and Climate Change Canada (ECCC) works on behalf of the EMCR to issue and carry BC-specific Tsunami alerts on ECCC dissemination networks.

The Department of Fisheries and Oceans (DFO)'s Canadian Hydrographic Service (CHS) collects, generates and disseminates water level and current data: observations, predictions and forecasts. These data are broadly used to support safe and accessible waterways for navigation, particularly for critical areas such as harbors, dredged areas and shipping routes; to support ocean monitoring, prediction and forecasting programs and services; for scientific research; to support international Tsunami and Storm Surge Warning systems operated by Emergency Management Organizations (EMOs).

NRCan's Canadian Hazards Information Service operates the CNSN, a Canada-wide network of over 100 high-gain seismographs and 60 low gain accelerographs. NRCan streams data from select CNSN stations to NTWC for inclusion in North American tsunami monitoring, assessment, and alerting. NRCan's Earthquake Early Warning System became operational in 2024 with hundreds of additional seismic sensors and alerting protocols in British Columbia providing seconds to tens of seconds of early warning of imminent dangerous shaking. NRCan will use the nearly operational system to integrate Global Navigation Satellite System (GNSS) geodetic data with earthquake and tsunami alert.

12. NARRATIVE

Province of British Columbia – Ministry of Emergency Management and Climate Readiness (EMCR)

EMCR is British Columbia's lead coordinating agency for all emergency management activities and works with federal departments, First Nations, local governments and other organizations in BC to prepare for future tsunami events. In 2023, the new *Emergency and Disaster Management Act (EDMA)* came into effect to replace the *Emergency Program Act*. Under *EDMA* regulations, EMCR is responsible for developing risk assessments and emergency management plans for the geologic hazards of earthquakes, tsunami, and volcanic eruptions. Work is underway to meet these requirements. Hazard specific emergency management plans will consider all phases of emergency management (preparedness, mitigation, response, and recovery). It is anticipated that further regulations under EDMA will be developed for regulated entities such as local governments and critical infrastructure operators and that they will also be responsible for developing risk assessments for any hazards that may impact their jurisdiction and to develop emergency management plans that address those risks.

EMCR maintains Provincial response plans and is responsible for coordinating the dissemination of Provincial tsunami messages to local governments, media, and other emergency management partners. Many other agencies, however, collaborate to further disseminate tsunami messages to as many people as possible in as short of time as possible. EMCR rebroadcasts NTWC messages and issues BC-specific tsunami messages through the Provincial Emergency Notification System (PENS). PENS consists of multiple methods and partner agencies to ensure timely and accurate tsunami messaging which include social media, phone calls, email, fax, public broadcast intrusive alerts, and emergency radio amongst other methods. EMCR holds regular tests of the Alert Ready system which is used as part of PENS to issue public broadcast intrusive alerts to radio, television and compatible mobile phone devices. Alert Ready is only used in the event of a tsunami warning. PENS is capable of disseminating a large number of messages in a short period of time and local emergency officials use this information to activate their community emergency plans to take the necessary life-saving actions to ensure public safety. Further details of EMCR's role in tsunami notification and PENS is found within the BC Tsunami Notification Process Plan.

EMCR participates in the Warning Coordination Subcommittee of the US National Tsunami Hazard Mitigation Program to provide feedback to the NTWC, maintain awareness of tsunami warning system developments and products, and to coordinate with the NTWC as well as neighbouring jurisdictions.

To strengthen public education, EMCR has implemented PreparedBC which is British Columbia's emergency preparedness education program. PreparedBC serves the general public, schools, local governments, and First Nations, providing tsunami preparedness information that is easy to access and share. Tsunami preparedness resources include the PreparedBC Earthquake and Tsunami Preparedness Guide (updated in 2024) and the earthquake and tsunami preparedness social media package. All information and resources from PreparedBC can be accessed at preparedbc.ca.

In addition, PreparedBC also leads Tsunami Preparedness Week (the second full week of April each year) to raise awareness of tsunami risk in B.C. Communities are encouraged to mark the week by hosting a High Ground Hike. High Ground Hikes are community-led events that give people along the coast an opportunity to practice reaching a tsunami-safe location. PreparedBC also leads a tsunami preparedness social media campaign during this week. More information about Tsunami Preparedness Week and High Ground Hike can be found at PreparedBC.ca/HighGroundHike.

EMCR has developed the Master of Disaster Program which is a free classroom program designed to help young people learn about emergency preparedness. The program teaches youth in grades 4 to 8 about hazards in BC including floods, wildfires earthquakes, and tsunamis, and shows them how to get prepared. Information about the program can be accessed at: PreparedBC.ca/MasterOfDisaster

In 2023, EMCR launched ClimateReadyBC, a one-stop disaster and climate risk reduction online platform, for First Nations, local governments, critical infrastructure operators, public sector organizations and practitioners. The site provides hazard specific information and includes searchable resources to support community resilience. The site includes hazard specific information and resources relating to better understanding and reducing risks associated with tsunamis. Further information can be found at ClimateReadyBC website at: https://climatereadybc.gov.bc.ca/

EMCR also maintains and supports various disaster mitigation funding programs. The funding programs offer support to First Nations and local governments to better understand and mitigate the risks posed by natural hazards and climate change. Tsunami specific projects are eligible to receive funding. Funding streams have supported projects involving modelling, hazard mapping, and risk assessment. Further information on funding can be found at ClimateReadyBC website at: https://climatereadybc.gov.bc.ca/ or EMCR's website at: https://www2.gov.bc.ca/gov/content/safety/emergency-management/local-emergency-programs/financial

Fisheries and Oceans Canada/Canadian Hydrographic Service (DFO/CHS)

The Department of Fisheries and Oceans (DFO)'s Canadian Hydrographic Service (CHS) collects, generates and disseminates water level and current data (observations, predictions and forecasts). These data are broadly used to support safe and accessible waterways for navigation, particularly for critical areas such as harbors, dredged areas and shipping routes; to support ocean monitoring, prediction and forecasting programs and services; for scientific research; to support international Tsunami and Storm Surge Warning systems operated by Emergency Management Organizations(EMOs).

In the Pacific Region CHS operates a network of 42 real-time water level and 6 real-time current stations along the British Columbia Coast (Figure 1). Seventeen of these stations serve the Permanent Water Level Network (PWLN) and Tsunami Warning System (TWS).

Primary data acquisition is achieved using cellular IP modems (with landline, radio, satellite IP and GOES as backup). The IP data is 'pushed' from the remote station automatically in real-time via the Integrated Water Level System (IWLS). The IWLS is a centralized, national data management system for Canadian coastal water level, current speed and direction time series and metadata.

Data from all CHS water level stations is made available on a number of platforms: standardized Web services (Rest-API) to users both internal and external to DFO; CHS National Water Level Website (https://tides.gc.ca) which provides observations at all real-time, active stations as well as predicted time interval (1 minute for Pacific) times and heights of high and low waters for over seven hundred stations in Canada; Water Level Mobile App: a Progressive Web App which connects to the IWLS through the restful API and provides water level information through any web-service connected device (mobile phones, tablets, laptop, desktop, etc.) and eleven of the stations in the network stations also have GOES satellite transmission to NOAA's Wallups Island download site for access by the National Tsunami Warning Center (NTWC) in Palmer, Alaska.

Natural Resources Canada (NRCan)

NRCan's Canadian Hazards Information Service (CHIS) operates the CNSN, a Canada-wide network of over 100 high-gain seismographs and 60 low gain accelerographs. The seismographs provide greater detail of weaker ground motions from lower-magnitude or distant earthquakes. The accelerographs provide greater detail of stronger ground motions from higher-magnitude or nearby earthquakes.

The CNSN streams data in near real-time to parallel and geographically redundant data centres for automated earthquake analyses and rapid notification. Two Seismologists On Call are available 24 hours per day seven days per week to prepare earthquake reports that quickly follow the automated preliminary earthquake notifications. NRCan also streams data from select CNSN stations to NTWC for inclusion in North American tsunami monitoring, assessment, and alerting. The CNSN's high quality digital data are used to conduct research on the properties of earthquakes including seismic hazard assessments and contributions to the earthquake resistance provisions of the National Building Code of Canada.

NRCan's Earthquake Early Warning System became operational in 2024 with hundreds of additional seismic sensors and alerting protocols in British Columbia providing seconds to tens of seconds of early warning of imminent dangerous shaking. NRCan will use the nearly operational system to integrate Global Navigation Satellite System (GNSS) geodetic data with earthquake and tsunami alert.

The discovery of Episodic Tremor and Slip (ETS) in the Cascadia Subduction zone by NRCan scientists in the Geological Survey of Canada (GSC) and the Canadian Hazards Information Service (CHIS) and subsequent observation and modelling research have led to much improved understanding of the slip behaviour of the megathrust and downward extent and along-strike segmentation of rupture during subduction earthquakes. Observation and modelling of contemporary crustal deformation and background seismicity have improved the delineation of the locking state of the megathrust and rupture potential.

These NRCan research results help to define the magnitude of future subduction earthquakes, the proximity of shaking to inland population centers – valuable information that has been incorporated into Canada's building code. NRCan sea floor displacement results also provide the key input for tsunami generation estimates. There is also significant advancement in modelling megathrust rupture as tsunami sources which integrates geophysically-constrained fault geometry, paleoseismic studies, the theory of rupture mechanics, and knowledge learned from tsunami-genic earthquakes in other subduction zones. NRCan source models provide the basis for tsunami modelling for the purpose of early warning, design of evacuation strategy, and probabilistic hazard analyses.

The only deaths due to tsunamis in Canada since written records have begun are from tsunamis caused by landslides or landslides triggered by earthquakes. In 1908 a landslide on the Liève River in western Québec produced a wave that inundated the village of Notre-Dame-de-la Salette and killed 27 people. In Newfoundland, a magnitude 7.2 earthquake created an offshore, underwater slump on the Atlantic Ocean's Grand Banks, generating a tsunami of up to 7 m in height, which killed 29 people. The 1946 Vancouver Island M7.2 earthquake caused underwater landslides within the Strait of Georgia, one of which is known to have caused a water wave that reportedly overturned a boat and resulted in one drowning. In Knight Inlet BC, First Nations histories tell of the destruction of a village and over 100 deaths when a rock avalanche descended into the water on the opposite side of the fjord (Bornhold et al., 2010).

Landslide tsunamis occur on a more frequent basis than earthquake generated tsunamis, particular in the steep sided fjords of Canada west coast. The GSC is investigating the magnitude and frequency of these submarine failures around the country (Lintern et al., 2020). Canada has wrapped up a 5-year project aimed to understand the threat of landslide generated tsunami in Douglas Channel BC where there is a recent history of destructive landslide-generated tsunamis (Lintern et al., 2019). The project identified over 200 mass movements throughout the channel system (Stacey et al., 2020). Through collaboration between the GSC, DFO, and the University of Victoria, the work has evolved now in Douglas Channel and elsewhere to modelling of potential failure based on geologies which are indicative of possible failure (eg. Orcas Island USA, Nemati et al, 2023a), and also conducting scientific investigations to determine what technologies can be used to detect and warn of landslide generated tsunamis (Nemati et al, 2023b).

In addition, EMCR, NRCan and DFO all provide tsunami and earthquake information on their web sites. The present DFO modeling studies and tsunami catalogue provide valuable information for public education and mitigation planning. All telephone directories for communities in B.C. coastal areas contain information on earthquake and tsunami response.

Environment and Climate Change Canada (ECCC)
The Meteorological Service of Canada (MSC) of ECCC involves in the Canadian Tsunami Program on both coasts.

On the Pacific Coast of Canada, MSC's Pacific Storm Prediction Centre (PSPC) in Vancouver works on behalf of the British Columbia Ministry of Emergency Management and Climate Readiness (EMCR) who is the Tsunami Warning Focal Point (TWFP). The PSPC issues Tsunami Alerts (Warning, Advisory or Watch) created directly from the US National Tsunami Warning Centre (NTWC) tsunami alerts or as directed by EMCR. The PSPC delivers the alerts through the ECCC alert dissemination system.

On the Atlantic Coast of Canada, MSC's Atlantic Storm Prediction Centre (ASPC) in Dartmouth, Nova Scotia, serves as the TWFP for the NTWC and for the Canadian Atlantic Tsunami Warning System (CATWS). The ASPC receives the relevant tsunami bulletins from the NTWC, reformats the messages to create Canadian-specific tsunami bulletins, and then transmits the Canadian-specific bulletins to a pre-defined list of stakeholders. These bulletins are also disseminated to the Canadian public through a variety of dissemination systems of ECCC. The purpose of reformatting the NTWC tsunami messages into Canadian-specific products is to simplify and clarify the messages for a Canadian audience by providing provincial Emergency Management Organizations (EMOs) and other Canadian recipients with the specific information they need to make decisions and take actions.

The ASPC serves as the back-up office of the PSPC. Its sister office, Newfoundland and Labrador Weather Office (NLWO) situated in Gander, Newfoundland, is designated as the contingency office for the ASPC.

Public Safety Canada (PS) – Atlantic Region

On Canada's Atlantic Coast, multiple Canadian provinces have jurisdiction for public alerting. PS – Atlantic has coordinated development of a Federal Atlantic Tsunami Protocol to establish federal agency roles, responsibilities, and procedures. The draft has been introduced to some provinces and will, hopefully, form the core of a joint provincial and federal protocol for response to Canadian Atlantic coast tsunamis.

12.1. Selected tsunami and subduction zone related publications from or about Canada 2019-2023

2019

Itoh, Y., K. Wang, T. Nishimura, and J. He (2019), Compliant volcanic arc and back-arc crust in southern Kurile suggested by interseismic geodetic deformation, *Geophysical Research Letters*, 46, 11790–11798. doi:10.1029/2019GL084656

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Lintern, G., Blais-Stevens, A., Stacey, C., Shaw, J., Bobrowsky, P., Conway, K., et al. (2019). Providing multidisciplinary scientific advice for coastal planning in Kitimat Arm, British Columbia. *Geol. Soc. Lond. Spec. Publ.* 477, 567–581. doi: 10.1144/SP477.40

Rabinovich, A.B., Thomson, R.E., Krassovski, M.V., Stephenson, F.E., and Sinnott, D.C. (2019), Five great tsunamis of the 20th century as recorded on the coast of British Columbia, *Pure and Applied Geophysics*, 176, 2887–2924; doi: 10.1007/s00024-019-02133-3.

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2020

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Luo, H., Ambrosius, B., Russo, R. M., Mocanu, V., Wang, K., Bevis, M., and Fernandes, R. (2020). A recent increase in megathrust locking in the southernmost rupture area of the giant 1960 Chile earthquake. *Earth and Planetary Science Letters,* 537, 116200. https://doi.org/10.1016/j.epsl.2020.116200

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Peacock, S. M., and Wang, K. (2021). On the stability of talc in subduction zones: A possible control on the maximum depth of decoupling between the subducting plate and mantle wedge. *Geophysical Research Letters*, 48, e2021GL094889; https://doi.org/10.1029/2021GL094889

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