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North Coast Geohazards – 2016 Seismology Update

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Abstract

Within British Columbia's north coast, specifically between Prince Rupert and Bella Bella, from the western coastline to the eastern extent of the Coast Mountains, there has been minimal research to understand earthquake hazards (Brillon, 2016). A more detailed understanding of where and how regional strain energy is being accumulated in the crust and the likelihood of damaging earthquakes in this area is necessary to estimate ground shaking and other earthquake-related hazards. To improve the understanding of seismic hazard in the area, five monitoring stations consisting of seismic and GPS instrumentation were installed in August 2014. In addition, a soft soil seismograph to measure effects of local site conditions was installed in Kitimat and improvements to older GPS and seismic stations in the region were carried out.

During the first winter of the deployment a number of the stations suffered significant weather-related damages that resulted in long periods of station downtime. By June 2015 all the stations were repaired and reinforced to minimize damages the following winter. Aside from the stations located in Kitimat, the background noise levels are within the Petersen high and low noise models (Peterson, 1993). The low seismic noise levels consistently allow earthquakes offshore Haida Gwaii with magnitudes less than *M*2.0 to be used in analysis. In addition to these events 145 earthquakes within the study area have been located. Although a number of earthquakes have been located in the north coast, the locations do not identify any new seismically active areas.

Introduction

With a growing number of on-going and planned infrastructure projects, BC's north coast is emerging as a region of high strategic importance to Canada's economy. Consequently, both the environment and the economy are vulnerable to the negative impacts of geohazards (and their secondary effects), such as earthquakes and slope failures. Within the Coast Mountains between Prince Rupert and Bella Bella, herein referred to as BCNC, there has been minimal research to understand local earthquake hazards (Brillon, 2016). A more detailed understanding of where and how regional strain energy is being accumulated in the crust and the likelihood of damaging earthquakes in this area is necessary to improve ground shaking hazard models, such as those used to develop the seismic provisions for the National Building Code of Canada.

Beginning in 2014 work began to identify what information was needed and how it could be collected (Brillon, 2016). The result of this was the installation of five temporary, near real-time, co-located seismic and GPS stations, a soft soil seismometer, and instrumentation at three GPS sites updated to the standards of other CCDS (Canadian Crustal Deformation Service) GPS stations.

Background

Existing monitoring and knowledge

Compared to the seismicity north, south and west of the BCNC, the quantity and magnitude of archived earthquakes is significantly less (Figure 1). The absence of significant earthquakes in the BCNC has resulted in a deficiency of permanent instrumentation and research in the area. Prior to 2014 there were three seismographs in the BCNC, RUBB (Prince Rupert), BCNAB (Bonilla Island) AND BBB (Bella Bella) (Figure 1). The paucity of seismic instrumentation leads to knowledge gaps that negatively affect seismic hazard models (e.g. Halchuck et. al, 2015).

Between 1971 and 2013, approximately 400 earthquakes (Figure 1) have been located in the BCNC by seismologists at Natural Resources Canada (NRCan). The largest event that has been recorded in the area was M_L 4.9 approximately 20 km southwest of Terrace on November 5, 1973. This event was felt as far as 120 km away, with some minor damage (broken windows and cracked plaster) reported near the epicentre (Rogers 1976).

The magnitude completeness level, M_C, prior to 2014 was approximately 2.1, which is considerably higher than neighbouring regions. Although earthquakes smaller than M_L 2.1 could sometimes be located, the CNSN seismic data is not consistently monitored for such small events and therefore does not guarantee that earthquakes as small as M_L 2.1 are always identified and located. This has potentially translated to the seismicity gap observed in the BCNC.

Prior to 2014 there were two permanent, provincial (BCPR-Prince Rupert, and BCTE-Terrace) GPS stations and no GSC-operated GPS (global positioning system) sites in the BCNC (Figure 1). The combination of continuous and campaign GPS data have resulted in knowledge of the general crustal deformation rates with respect to stable North America in the ITRF2000 (Altamimi et al., 2002) reference frame in the BCNC; however due to the gap of GPS studies in the BCNC, local strain vectors within the BCNC cannot be accurately resolved. Previous studies suggest that there may be some strain being transferred to the BCNC from tectonic processes to the west and southwest (Mazzotti, et al. 2003a; Leonard et al., 2007; Hippchen, 2011).

BCNC Stations

Site selection

The remoteness of the study area and the goals of the project made site selection a challenging process. The initial goal was to install six, near real-time, co-located seismic and GPS stations for a 4-year period between 2014-2018. The targets for the six sites were chosen to optimize network coverage. Other requirements that had to be taken into consideration are:

- Low background noise levels: The intention of these additional stations is to record and locate microseismicity (M_L<2) in the study area. To detect such small magnitude events, the background noise levels of the seismographs must be very low.
- Site Conditions: Both the GPS and seismograph need to be installed on solid bedrock. In addition, large snowfalls may reach depths sufficient enough to cover GPS instrumentation. Choosing a site that will have a lesser chance of having large amounts of accumulated snow is ideal.
- Accessibility: All sites will be installed on the same deployment trip. The intention was to choose sites that have the easiest access possible. In addition, if the instrumentation fails and needs to be repaired or replaced, sites accessible by road or boat are more desirable.
- Low public exposure: If the location of the site is visible to the public there is a greater risk of instruments being vandalized.
- Open horizon: 360° horizon to allow for optimal GPS coverage.
- Power: Ideally all sites would have AC power. If power is not available solar panels and/or batteries are needed.

- Communications: Utilizing existing communications, i.e., internet, cell, radio, microwave links to send data to data centers in near real-time is the most preferable option. If existing communications are not available a VSAT will be needed to transfer data. Requirements for the VSAT include a clear look angle of elevation 22° at an azimuth of 145°.
- Budget: Do all of this as inexpensively as possible.

Installation

Three reconnaissance trips proved it would be difficult to satisfy all of the requirements above. Of the six target areas, only one of them (near Kitimat townsite) is accessible by road. Similarly, the only target that has AC power is in Kitimat. The lack of accessibility compounded with the open horizon requirement limited the remaining site locations to helicopter access only. It was also realized that due to the site requirements only five stations would be installed. Of these five sites there was one with cell coverage. For the remaining four sites the only communication option is VSAT. There was not a site in Kitimat that could host both a seismometer and GPS, therefore separate locations were chosen for each of these instruments. Following noise tests at some of the sites and obtaining permissions from the appropriate persons/organizations, five near co-located stations installed in August 2014. With additional funds during 2015 a soft soil seismograph was installed in Kitimat, and three GPS stations were refurbished. Details of the sites and the instrumentation installed are in Table 1.

Performance

Data Completeness

No site chosen for these stations was ideal. The majority of the stations were mountaintop, which exposes them to high winds. High winds in late 2014 and early 2015 damaged solar panels to the extent where three of the stations (BNKB, BUTB, HWKB) were not recording data (Table 2). Maintenance trips to install guy wires to stabilized the solar panel racks and replace damaged instrumentation were completed by June 2015.

The weather-inflicted station downtime resulted in minimal data availability for the first nine months of the BCNC stations. For the months of November, 2014 through May, 2015 the overall network did not perform well. Over these months the data completeness of the five installed stations was 51-80% (Figure 2, Table 2). After station reinforcements and instrumentation replacement, data completeness increased to above 95%. Since July 2015 the five stations in the network have performed at over 99%. Thus far MBLB is also near 100% completeness.

The stations are intended to be near real-time, which is generally achieved. Data latency is on the order of hours for most stations. For the first month (December 2015) of MBLB recording, data packets were received as late as one month after the time stamp on the data packet.

Noise Levels

Fourier spectra for three hours on a typical winter day are shown in figure 3. In general, the spectral response for all stations is similar and is representative of what would be expected for remote, mountain-top stations. Power density spectral plots are also included for the five stations that have their data delivered to the Incorporated Research Institutions for Seismology (Figure 4). Each of the stations clearly shows a strong peak at the known double microseism frequency range, around 0.1-0.2 Hz. While the single microseism peak is visible around 0.06-0.07 Hz at BNKB and BUTB, low frequencies, predominantly on the horizontal channels at GRNB, HWKB, KITB and MBLB mask this peak. Longer period noise such as this can be due to ground tilt introduced by wind acting on large objects such as trees (McNamara and Buland, 2004). The 1-10 Hz frequency range is most important for locating local earthquakes, but can also be contaminated by cultural noise. In the 1-10 Hz range all stations, except MBLB show reasonably quiet spectral response. In addition to elevated levels of long period noise, HWKB also shows unusual spectral peaks at ~0.7, 20 and 30 Hz. The source of these peaks is unknown. HWKB is a very remote station with minimal vegetation, reducing the possibility of cultural noise and effects of wind on trees. The elevated response between 1-10 Hz seen at MBLB is expected, as the station is located on private property near a gravel road, running water, horses and a developing residential area, which all contribute to the elevated response in that range. MBLB is a soft soil station that will be used for site response studies, predominantly in the 0.2-5 Hz range, therefore as unfortunate as the high noise levels are, this station will be useful for its intended purpose.

Seismicity

Prior to the installation of the additional seismograph stations in the BCNC the M_C was slightly above 2.0. With this M_C it would have been difficult to locate any microseismicity that may have occurred in the area. With the additional seismographs it is possible to locate much smaller earthquakes, although it is too early to estimate a new M_C. Since the installation of these stations there has been 145 earthquakes located in the study area (Figure 1). Of these earthquakes, 77 were located with arrivals from at least the 5 seismographs (KITB, GRNB, BUTB, BNKB, HKWB) installed in 2014. The smallest earthquake located is M_L0.5, while the largest is M_L3.3. There is no clustering of seismicity that highlights a specific, previously unknown area of seismicity. The new seismographs record many earthquakes in the Haida Gwaii region, a number of earthquakes near Bella Coola (~100 likely related to volcanic activity), and some small events in the Coast Mountains (Figure 1). Seismicity located within the Coast Mountains is predominantly aligned with the eastern extent of the mountains. While seismic data recorded on these stations are not used to locate Haida Gwaii seismicity (due to different velocity models), recordings of these events will be used in ground motion analysis, which will be used to better determine how plate boundary seismic amplitudes are modified as they propagate to the BCNC. MBLB and KITB will specifically be used to improve the understanding of how much ground shaking from local and distant earthquakes is amplified within the town of Kitimat. Early results have shown that shaking is three times greater at MBLB soft soil site than at the nearby rock site of KITB (Figure 5).

Beyond 2016

These newly installed stations will remain in place until early 2018, while any refurbished stations will be a permanent improvement. The seismic data continue to be used in daily, near real-time seismic analysis. In addition to routine locations, ground motion analysis will continue as larger (M3+) earthquakes are recorded.

Due to the nature of GPS data analysis, GPS analysis is in its infancy. A minimum of 2.5 years of good quality recorded data is needed for meaningful analysis.

Conclusion

A significant effort has been made to minimize the knowledge gap with respect to earthquake hazards in British Columbia’s north coast region. Five, co-located seismic and GPS stations have been installed, as well as an additional soft-soil seismometer and improvements to select existing GPS and seismic stations. Data collection during the first nine months following station installation was significantly impacted by weather-related station damage. Since stations repairs there has been minimal station downtime; all stations have been recording data and transferring it in near real-time to NRCan data centers. Although a minimum of 2.5 years of data is required for meaningful GPS analysis, the seismic data that has been recorded has been used to locate 145 earthquakes in solely the BCNC and many more in surrounding areas such as offshore Haida Gwaii. The earthquakes that have been recorded in the BCNC have thus far not highlighted any specific areas of seismicity. Daily analysis and seismic-related research using data recorded at these stations will continue for the duration of their deployment.

Figures

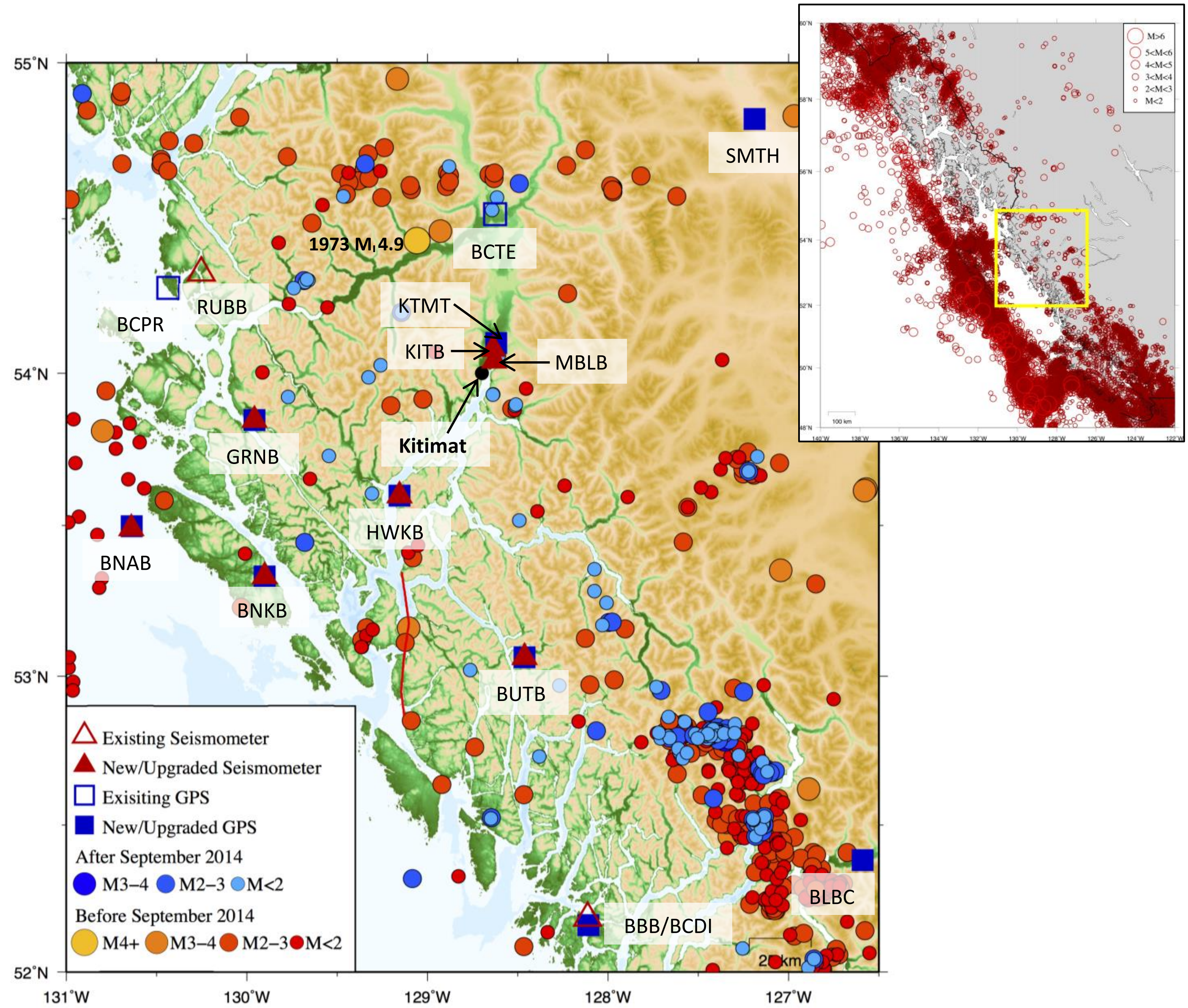


Figure 1 - Seismicity located prior to (red) and after (blue) the installation of BCNC seismographs (triangles) and GPS (squares). Permanent CNSN stations as well as those stations installed or upgraded as part of this project are shown. For details of these sites see table 1. Inset: Regional historical seismicity along BC's north coast, yellow rectangle defines study area discussed in this report.

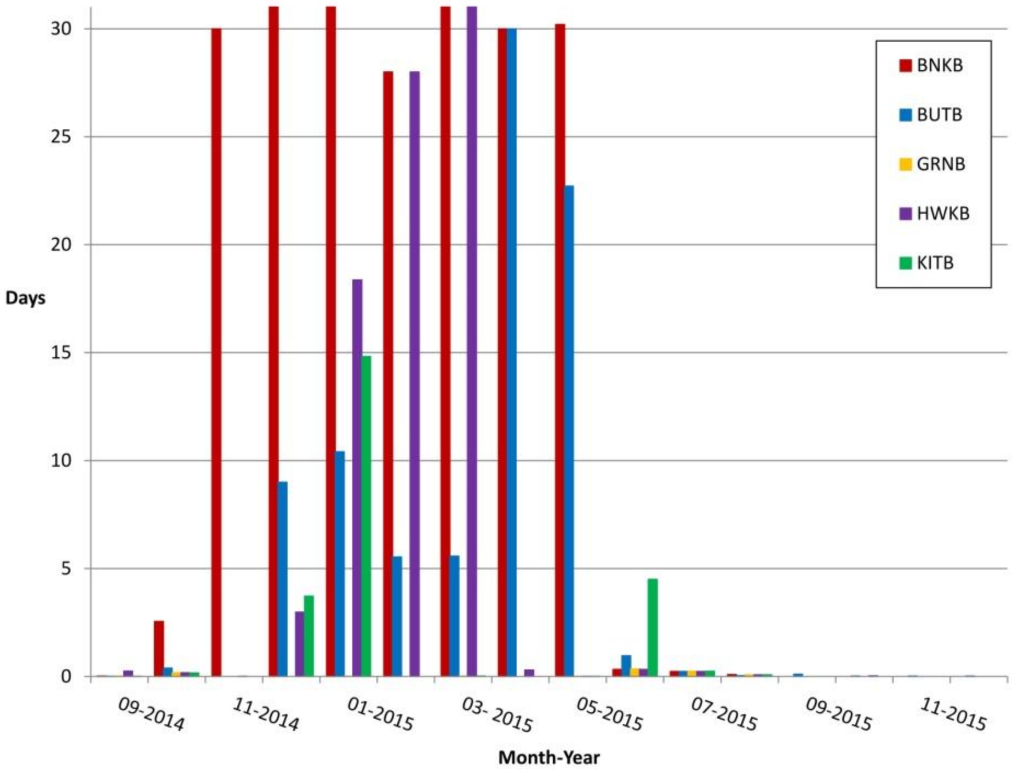
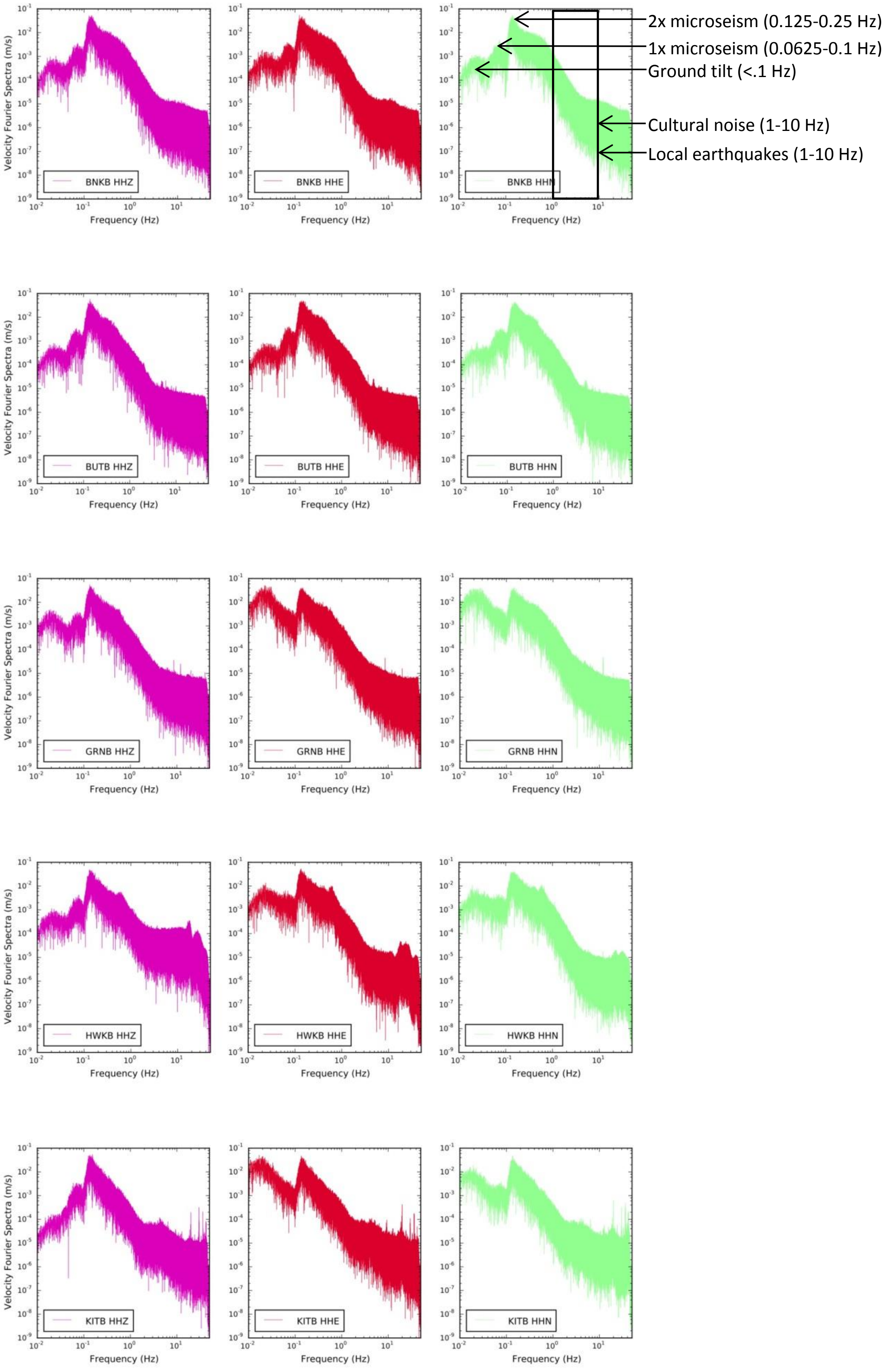


Figure 2 - Data outages for BCNC seismographs since their installation (September 2014 – December 2015). Note that MBLB is not included in this graph as it was only installed for 2 weeks in 2015.


2x microseism (0.125-0.25 Hz)
1x microseism (0.0625-0.1 Hz)
Ground tilt (<.1 Hz)
Cultural noise (1-10 Hz)
Local earthquakes (1-10 Hz)
Velocity Fourier Spectra (m/s)
Frequency (Hz)
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
BNKB HHZ
BNKB HHE
BNKB HHN
BUTB HHZ
BUTB HHE
BUTB HHN
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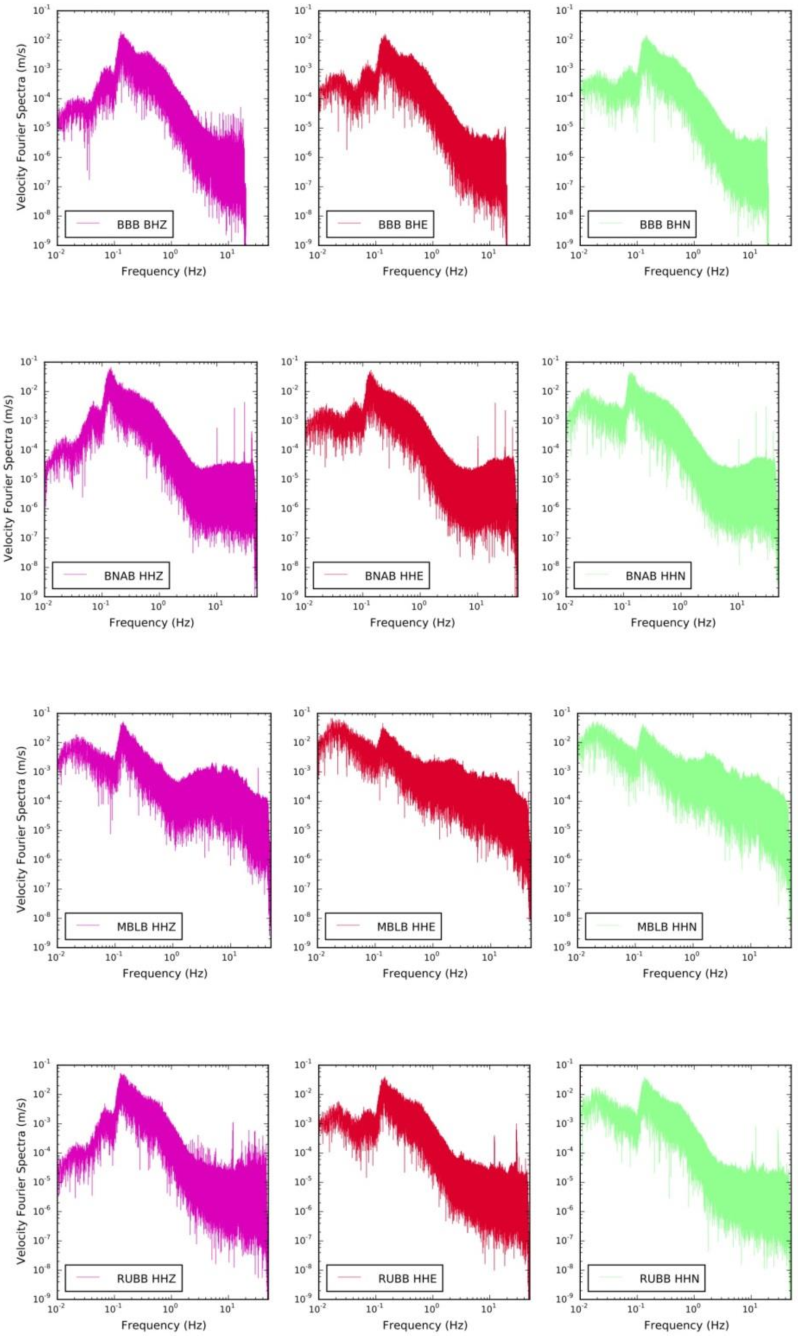


Figure 3 - Comparison of Fourier ambient noise spectra for all seismograph stations in the BCNC. Common seismic noise sources (from McNamara and Buland, 2004) are labelled on the noise spectra for BNKB.

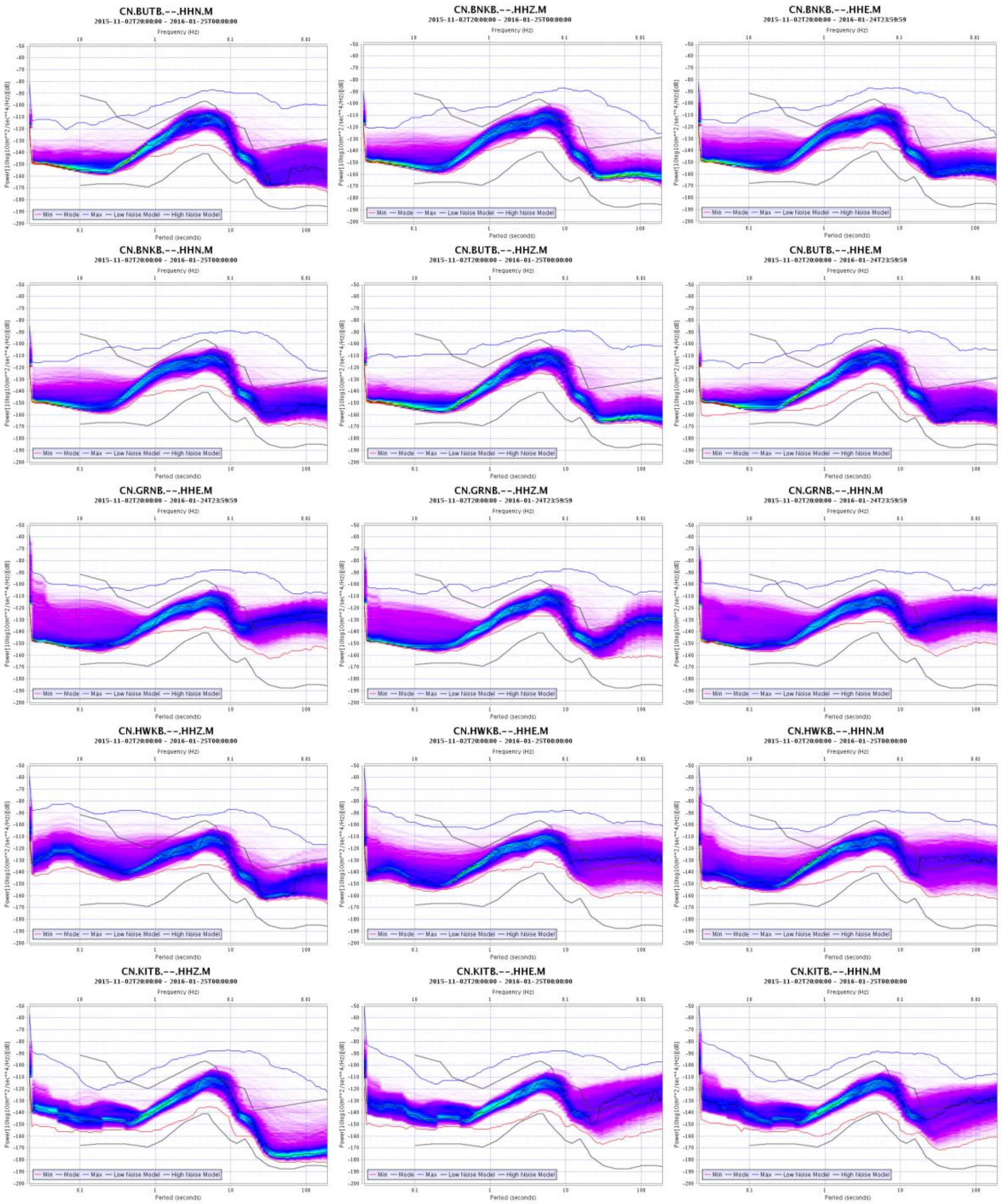
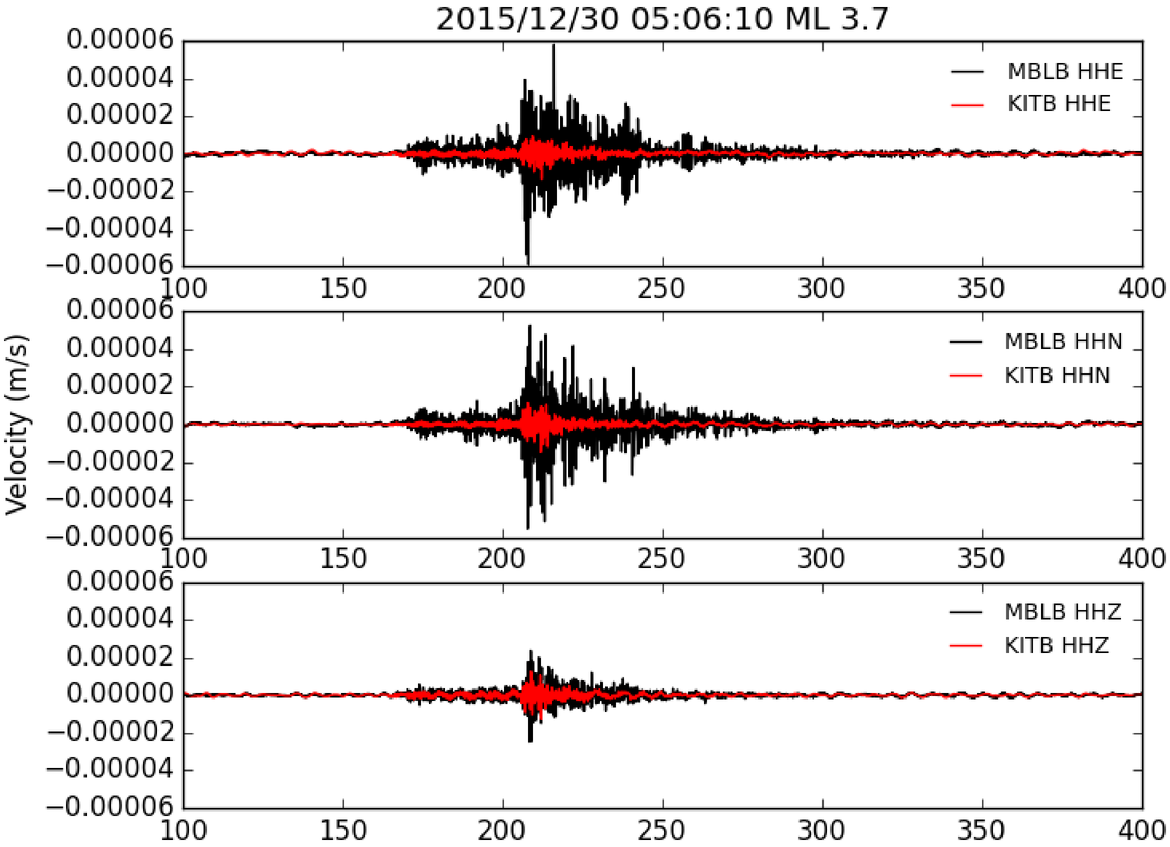


Figure 4 - Power spectral density plots for BNKB, BUTB, GRNB, HWKB, KITB (IRIS, 2016).



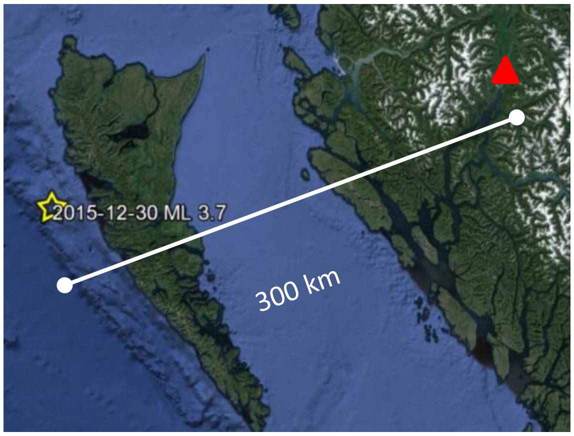


Figure 5 - Waveforms recorded on KITB (black) and MBLB (red) for a M_L3.6 (depth = 27.5 km) earthquake approximately 300 km west of Kitimat. HHE, HHN, and HHZ denote east/west, north/south and up/down channels (respectively). Filter = 0.3-60 Hz. Red triangle is the location of MBLB and KITB, yellow star is the epicenter of M_L3.6 earthquake.

Tables

Station Code	Latitude	Longitude	Location	Seismograph	GPS	Installation/ Upgrade Date	Communication	Power
KITB	54.08	-128.64	Kitimat	x		2014-03-20	cell	AC
BNAB	53.49	-130.64	Bonilla Island	x	x	2014-03-25	VSAT	AC
BNKB	53.33	-129.90	Banks Island	x	x	2014-08-20	VSAT	solar
BUTB	53.06	-128.46	near Butedale	x	x	2014-08-21	VSAT	solar
HWKB	53.60	-129.15	Hawkesbury Island	x	x	2014-08-21	VSAT	solar
GRNB	53.85	-129.96	near Grenville Channel	x	x	2014-08-24	cell	solar
BLBC	52.38	-126.59	Bella Coola		x	2015-03-19	cell	AC
BCDI	52.16	-128.11	Bella Bella		x	2015-03-27	cell	AC
KTMT	54.10	-128.62	Kitimat		x	2015-09-25	cell	AC
SMTH	54.82	-127.19	Smithers		x	2015-12-08	cell	AC
MBLB	54.04	-128.63	Kitimat	x		2015-12-09	cell	solar

Table 1 - Location and description of newly installed or upgraded seismograph and GPS sites in the BCNC (For permanent sites see Brillon, 2016).

	Station Downtimes (in days)							
Month-Year	**BNKB**	**BUTB**	**GRNB**	**HWKB**	**KITB**	**MBLB**	**Total all**	**% return**
09-2014	0.02	0.01	0.02	0.25	0.01	-	0.30	99.80
10-2014	2.55	0.38	0.17	0.17	0.16	-	3.43	97.79
11-2014	30.00	0.00	0.00	0.00	0.00	-	30.00	80.00
12-2014	31.00	9.00	0.00	2.98	3.72	-	46.70	69.87
01-2015	31.00	10.41	0.00	18.37	14.82	-	74.60	51.87
02-2015	28.00	5.54	0.00	28.00	0.00	-	61.54	56.04
03- 2015	31.00	5.57	0.02	31.00	0.02	-	67.61	56.38
04-2015	30.00	30.00	0.00	0.30	0.00	-	60.30	59.80
05-2015	30.20	22.71	0.00	0.01	0.00	-	52.92	65.86
06-2015	0.33	0.97	0.35	0.33	4.50	-	6.48	95.68
07-2015	0.23	0.24	0.24	0.23	0.24	-	1.18	99.24
08-2015	0.08	0.04	0.08	0.08	0.08	-	0.36	99.77
09-2015	0.00	0.11	0.00	0.00	0.00	-	0.11	99.93
10-2015	0.00	0.02	0.00	0.03	0.00	-	0.05	99.97
11-2015	0.00	0.02	0.00	0.00	0.00	-	0.02	99.98
12-2015	0.00	0.02	0.00	0.00	0.00	0	0.02	99.99

Table 2 - Days per month of downtime for seismograph stations from September, 2014 – December, 2015.

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