Cascadia Amphibious Array
Ocean Bottom Seismograph
Horizontal Component Orientations

2013-2014 OBS Deployments

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Table of Contents

Note: The results and methods presented here are subject to change.

Document Change History

Version	Description	Date
1.0	Report prepared by J. Lodewyk	11/14/2014
2.0	Corrected Table 1	2/20/2015
2.1	Corrected Table 5 and Table 6.	9/11/2015

1. Introduction

The Cascadia Initiative ("Cascadia") is a National Science Foundation (NSF) American Recovery and Reinvestment Act (ARRA) funded project that was started in 2010. Cascadia encompasses a community designed and administered seismic and geodetic experiment that serves to address major geologic questions specific to the Juan de Fuca plate system and the Cascadia subduction zone.

A key element of the Cascadia Initiative is an amphibious array of three-component broadband seismometers deployed throughout the region. Three Ocean Bottom Seismograph Instrument Pool (OBSIP) Institutional Instrument Contributors (IIC's):

- Woods Hole Oceanographic Institution (WHOI)
- Scripps Institution of Oceanography (SIO)
- Lamont-Doherty Earth Observatory (LDEO)

constructed 60 instruments for the ocean portion of the array. From 2011-2015, the instruments occupy a broad footprint that spans nearly the entire width of the Juan de Fuca plate and length of the Cascadia subduction zone from Vancouver Island to northern California (Figure 1). Comprehensive information about the Ocean Bottom Seismometer (OBS) portion of the Cascadia Amphibious Array is available at the Cascadia Initiative Expedition Team website: http://cascadia.uoregon.edu/CIET/

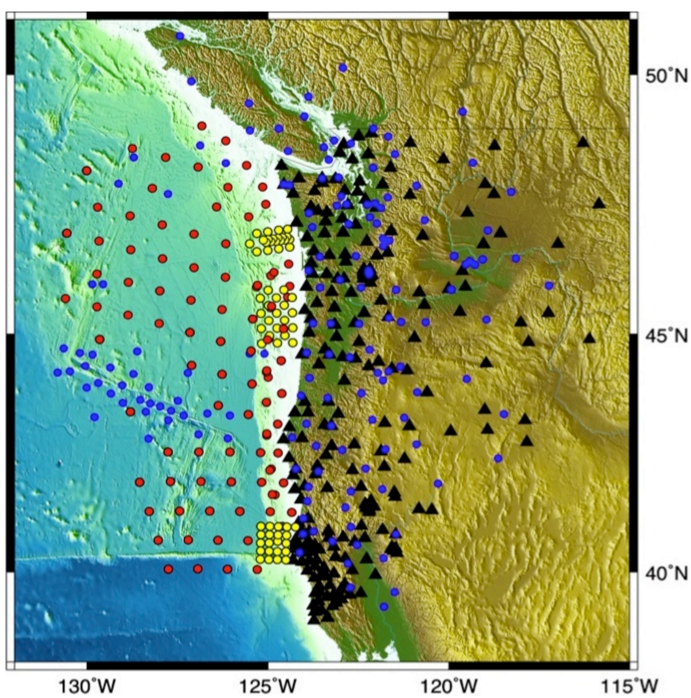


Figure 1. Planned deployments for the ocean portion of the Cascadia Amphibious Array (red and yellow circles), other complementary present/future seismometer deployments (blue circles), and real-time PBO GPS stations (black triangles).

The community design and implementation of the Cascadia project sets it apart from traditional "Principal Investigator" experiments usually funded by NSF. As a result, there is no single user of the OBS data that is initially funded to perform basic data processing.

Since Ocean Bottom Seismometers are deployed remotely and without intervention, their actual orientation on the seafloor is unknown. The Cascadia OBS stations do not carry orientation devices (e.g. magnetic compasses, gyroscopes, etc.) because accurate instruments are cost and power prohibitive, and current low cost instruments are of limited accuracy. Therefore, the horizontal orientation of an OBS must be determined empirically from the recorded data.

In an effort to make the Cascadia dataset available and useful to the widest possible number of investigators, the OBSIP Management Office calculated the horizontal orientations of the Cascadia instruments for the first and second year of deployment (see Horizontal Orientations Report: Year 1 and Year 2 at http://www.obsip.org/data/obs-horizontal-orientation/).

This report focuses on the third year of deployment, which was completed in the summer of 2014. The OBSIP Management Office also calculated the horizontal orientations of the Cascadia instruments deployed in the third year of the Cascadia Initiative (Figure 2), and the results are discussed here.

2. Data QA/QC Summary

Continuous waveform data from the OBS deployments is held in the IRIS Data Management Center, and the complete data holdings and station metadata (including these horizontal orientations upon final release of this document) can be accessed at: http://www.iris.edu/mda/7D?timewindow=2011-2017.

For the 2013-2014 OBS deployment, 24/24 WHOI, 13/15 SIO, and 24/30 LDEO stations operated as intended during the deployment period. Figure 3 illustrates the channel uptime and a qualitative quality rating of these data.

In regards to the data, the U.S. Navy redacted common segments (~7% of the data, depending on the station) of BH? and HH? channels. Appendix A contains information on this process as well as OBSIP channel naming and orientation conventions used for the Cascadia OBS instruments.

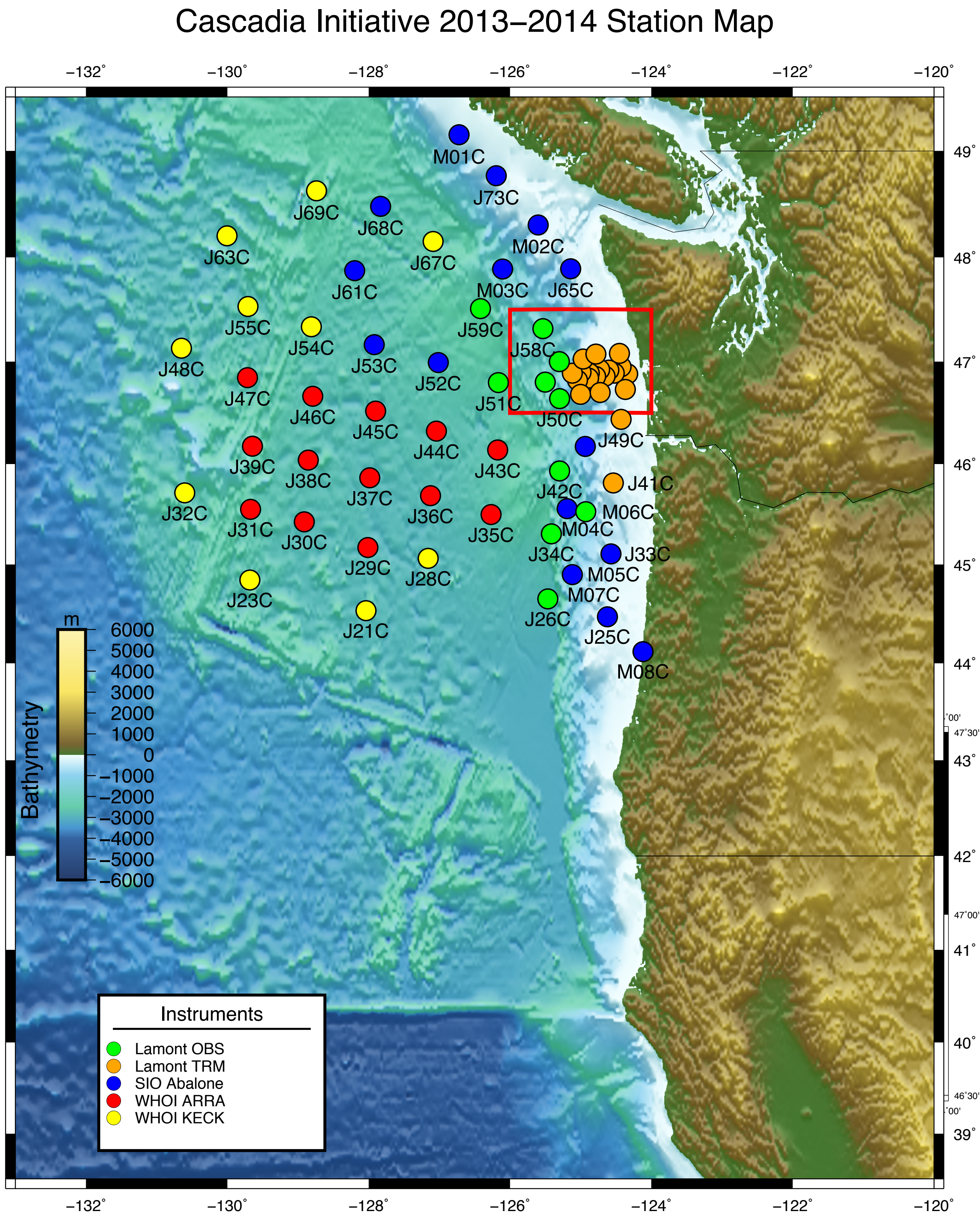


Figure 2. 2013-2014 Deployed Cascadia OBS Stations, Year 3

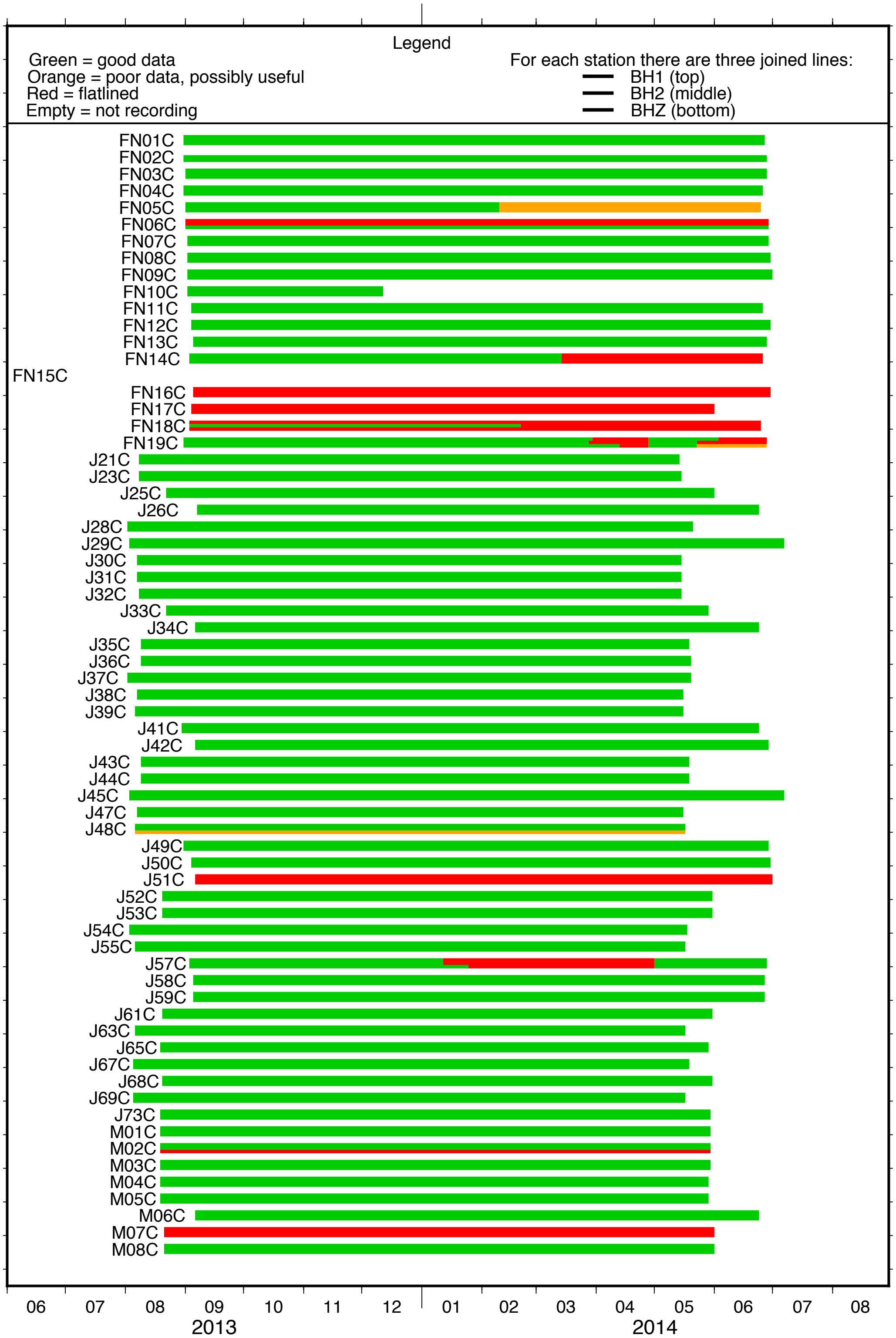


Figure 3. Cascadia station seismometer uptime and an initial quality rating. For each station there are three merged lines, corresponding to seismometer channels BH1/BH2/BHZ from top to bottom. Color indicates usability of data: green is good data, orange is poor quality but potentially usable, red is unusable or flatlined. This quality rating was assigned based on spectrogram plots generated from a PQLX database. Station FN15C was not recovered.

2.1. Station Deployment and Performance

2.1.1. LDEO Stations

Thirty seismometers were deployed between August 2013 and July 2014 (Table 1). These OBS stations operated in both shallow and deep water environments, with some stations employing a trawl-resistant design. Each station recorded HH? channels (125sps). The Navy redacted data segments from all stations and produced a HX? channel (filtered above 3Hz.). Station FN15C was not recovered. Stations FN06C, FN16C, FN17C, FN18C, and J51C experienced failure on at least one channel during deployment and the horizontal orientations were unable to be determined.

Table 1. Deployed Cascadia LDEO Stations, 2013-2014. (TC=Trilium Compact)

Station	Start	End	Lat.	Long.	Depth	Instrument	Type
FN01C	08/31/13	06/27/14	46.88	-124.3333	-56	Nanometrics TC	Popup TRM
FN02C	08/31/13	06/28/14	46.95	-124.428	-67	Nanometrics TC	Popup TRM
FN03C	09/01/13	06/28/14	46.89	-124.5251	-93	Nanometrics TC	Popup TRM
FN04C	09/01/13	06/26/14	46.92	-124.6013	-104	Nanometrics TC	Popup TRM
FN05C	09/01/13	06/25/14	46.86	-124.6556	-123	Nanometrics TC	Popup TRM
FN06C	09/01/13	06/29/14	46.92	-124.7313	-137	Nanometrics TC	Popup TRM
FN07C	09/02/13	06/29/14	46.86	-124.786	-158	Nanometrics TC	Popup TRM
FN08C	09/02/13	06/30/14	46.89	-124.876	-176	Nanometrics TC	LDEO-TRM
FN09C	09/02/13	07/01/14	46.84	-124.8872	-198	Nanometrics TC	LDEO-TRM
FN10C	09/02/13	12/12/13	46.90	-124.9935	-811	Nanometrics TC	LDEO-TRM
FN11C	09/04/13	06/26/14	46.82	-125.0454	-619	Nanometrics TC	LDEO-TRM
FN12C	09/04/13	06/30/14	46.89	-125.119	-656	Nanometrics TC	LDEO-TRM
FN13C	09/05/13	06/28/14	47.00	-125.3011	-1764	Nanometrics TC	LDEO-OBS
FN14C	09/03/13	06/26/14	47.02	-124.9642	-173	Nanometrics TC	Popup TRM
FN15C	not recovered- stuck on ship wreck						Popup TRM
FN16C	09/05/13	06/30/14	46.80	-125.5001	-1728	Nanometrics TC	LDEO-OBS
FN17C	09/04/13	06/01/14	46.68	-125.0005	-1015	Nanometrics TC	LDEO-TRM
FN18C	09/03/13	06/25/14	46.70	-124.7248	-166	Nanometrics TC	Popup TRM
FN19C	08/31/13	06/28/14	46.73	-124.3668	-72	Nanometrics TC	Popup TRM
J26C	09/07/13	06/24/14	44.65	-125.4653	-2868	Nanometrics TC	LDEO-OBS
J34C	09/06/13	06/24/14	45.31	-125.4152	-2580	Nanometrics TC	LDEO-OBS
J41C	08/30/13	06/24/14	45.81	-124.5376	-171	Nanometrics TC	Popup TRM
J42C	09/06/13	06/29/14	45.93	-125.2991	-1550	Nanometrics TC	LDEO-OBS
J49C	08/31/13	06/29/14	46.44	-124.4278	-113	Nanometrics TC	Popup TRM
J50C	09/04/13	06/30/14	46.64	-125.2987	-1931	Nanometrics TC	LDEO-OBS
J51C	09/06/13	07/01/14	46.80	-126.1631	-2626	Nanometrics TC	LDEO-OBS
J57C	09/03/13	06/28/14	47.08	-124.4506	-67	Nanometrics TC	Popup TRM
J58C	09/05/13	06/27/14	47.32	-125.5346	-1527	Nanometrics TC	LDEO-OBS
J59C	09/05/13	06/27/14	47.51	-126.4168	-2389	Nanometrics TC	LDEO-OBS
M06C	09/06/13	06/24/14	45.53	-124.9261	-1460	Nanometrics TC	LDEO-OBS

2.1.2. SIO Stations

Fifteen seismometers constructed by SIO were deployed between late August 2012 and early June 2014 (Table 2). Like the LDEO stations, the OBS stations operated across a range of depths. Each station contains BH? channels recording continuously at 50 samples/second. The Navy redacted data segments from all stations and produced a BX? channel (filtered above 3Hz.). Station M07C stopped recording early, and no orientation estimate could be calculated.

Table 2. Deployed Cascadia SIO Stations, Year 2013-2014. (TC=Trilium Compact)

Station	Start	End	Lat.	Long.	Depth	Instrument
J25C	8/22/13	6/1/14	44.47	-124.62	144.0	Nanometrics TC
J33C	8/22/13	5/29/14	45.11	-124.57	354.0	Nanometrics TC
J52C	8/20/13	5/31/14	46.99	-127.02	2640.0	Nanometrics TC
J53C	8/20/13	5/31/14	47.16	-127.92	2717.0	Nanometrics TC
J61C	8/20/13	5/31/14	47.87	-128.20	2673.0	Nanometrics TC
J65C	8/19/13	5/29/14	47.89	-125.14	169.0	Nanometrics TC
J68C	8/20/13	5/31/14	48.48	-127.83	2587.0	Nanometrics TC
J73C	8/19/13	5/30/14	48.77	-126.19	133.0	Nanometrics TC
M01C	8/19/13	5/30/14	49.15	-126.72	138.0	Nanometrics TC
M02C	8/19/13	5/30/14	48.31	-125.60	141.0	Nanometrics TC
M03C	8/19/13	5/30/14	47.89	-126.10	1839.0	Nanometrics TC
M04C	8/19/13	5/29/14	45.56	-125.19	570.0	Nanometrics TC
M05C	8/19/13	5/29/14	46.17	-124.93	837.0	Nanometrics TC
M07C	8/21/13	6/1/14	44.90	-125.12	1365.0	Nanometrics TC
M08C	8/21/13	6/1/14	44.12	-124.12	131.0	Nanometrics TC

2.1.3. WHOI Stations

Twenty-three seismometers were deployed between early August 2013 and late May 2014. These OBS stations operated exclusively in deep water, at least 2.5 km below sea-level. Each station recorded BH? (50 samples/second, redacted) and LH? (1 sample/second) channels The Navy redacted data segments from all stations and produced a BX? channel (filtered above 3Hz.).

Table 3. Deployed Cascadia WHOI Stations, Year 2013-2014. (TC=Trilium Compact)

Station	Start	End	Lat.	Long.	Depth	Instrument
J21C	8/8/13	5/14/14	44.53	-128.04	2847.0	Guralp CMG3T
J23C	8/8/13	5/15/14	44.84	-129.68	2653.0	Guralp CMG3T
J28C	8/2/13	5/21/14	45.06	-127.16	2889.0	Guralp CMG3T
J29C	8/3/13	7/7/14	45.17	-128.01	2816.0	Nanometrics TC
J30C	8/7/13	5/15/14	45.43	-128.91	2786.0	Nanometrics TC
J31C	8/7/13	5/15/14	45.55	-129.67	2624.0	Nanometrics TC
J32C	8/8/13	5/15/14	45.71	-130.60	2756.0	Guralp CMG3T
J35C	8/9/13	5/19/14	45.50	-126.27	2655.0	Nanometrics TC
J36C	8/9/13	5/20/14	45.69	-127.13	2812.0	Nanometrics TC
J37C	8/2/13	5/20/14	45.86	-127.99	2886.0	Nanometrics TC
J38C	8/7/13	5/16/14	46.04	-128.85	2731.0	Nanometrics TC
J39C	8/6/13	5/16/14	46.18	-129.64	2656.0	Nanometrics TC
J43C	8/9/13	5/19/14	46.14	-126.17	2645.0	Nanometrics TC
J44C	8/9/13	5/19/14	46.32	-127.04	2742.0	Nanometrics TC
J45C	8/3/13	7/7/14	46.52	-127.90	2742.0	Nanometrics TC
J46C	8/7/13	5/16/14	46.66	-128.79	2744.0	Nanometrics TC
J47C	8/7/13	5/16/14	46.84	-129.71	2679.0	Nanometrics TC
J48C	8/6/13	5/17/14	47.13	-130.65	2940.0	Guralp CMG3T
J54C	8/3/13	5/18/14	47.34	-128.81	2666.0	Guralp CMG3T
J55C	8/6/13	5/17/14	47.53	-129.71	2755.0	Guralp CMG3T
J63C	8/5/13	5/17/14	48.20	-130.01	2845.0	Guralp CMG3T
J67C	8/5/13	5/19/14	48.15	-127.09	2581.0	Guralp CMG3T
J69C	8/5/13	5/17/14	48.63	-128.74	2544.0	Guralp CMG3T

2.2. Station Noise Levels

2.2.1. Continuous Time Series

Helicorder plots display the continuous 1-sample/second time series recorded at each Cascadia OBS station. These are made in sets using two different bandpass filters (long period, 0.004-0.02 Hz and shorter period, 0.02-0.10 Hz). All data are normalized by the Stage 0 sensitivity of the instrument, obtained from the metadata, and the gain at horizontal channels is further reduced by an order of magnitude relative to the vertical for easier comparison. Helicorder plots generated for the long-period bandpass show strong diurnal tidal noise on some vertical and nearly all the horizontal channels. Instrument calibrations and noise can also be viewed over time. Additionally, these show the effects of signal processing related to the filter. OMO has compiled all helicorder plots for reference in Appendix B.

2.2.2. Power Spectra

Probability density functions produced from power spectral density estimates (McNamara and Buland, 2004) show the characteristic spectra of earth motion. These map the likely occurrence of signal power as a function of period for each channel, emphasizing the typical ambient noise at a station. Nearly all Cascadia OBS stations exceed the global high noise limit at intermediate and long periods for the horizontal channels and are also generally noisy, though sometimes below the high noise limit, on vertical channels (Figures 5-9).

The shallow water OBS deployments of LDEO and SIO demonstrate the highest noise levels, although there is a range of performance between traditional and trawl resistant design (Figures 5 and 6). The trawl resistant frame appears to help the station resist long-period noise imparted by tides and shallow currents, as demonstrated by the higher density of PSD measurements for lower noise levels at long periods for these stations.

Deep water stations are considerably quieter at intermediate and short periods, but also show a range of performance. The sites are considerably noisier than on-land Cascadia Transportable Array stations (Figures 10-11), and the deep-water region of Cascadia appears to have higher ambient noise levels in comparison to a recent OBS deployment around New Zealand (e.g. Zhaohui et al., 2012). OMO has compiled all PDF-PSD plots in Appendix C.

Figure 5. Typical PDFs for LDEO trawl-resistant OBS deployed in shallow water (198 m depth).

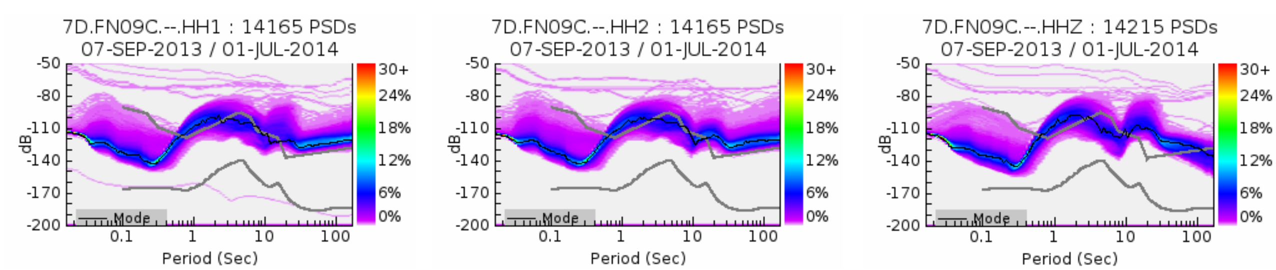


Figure 6. LDEO OBS deployed in deep water (2868 m).

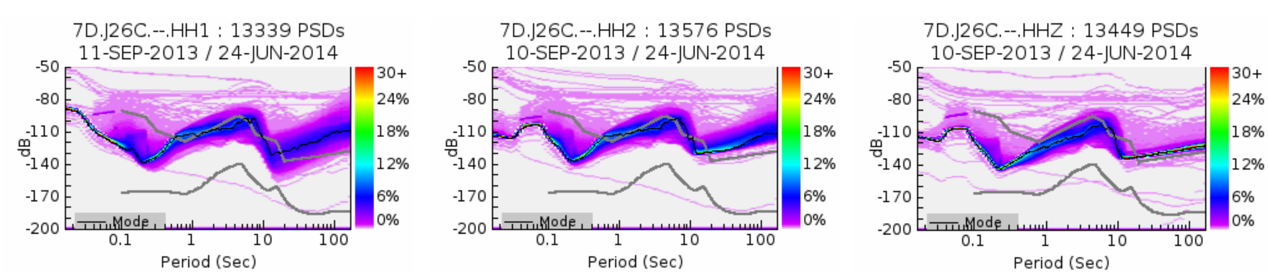


Figure 7. SIO OBS deployed in shallow water (144 m).

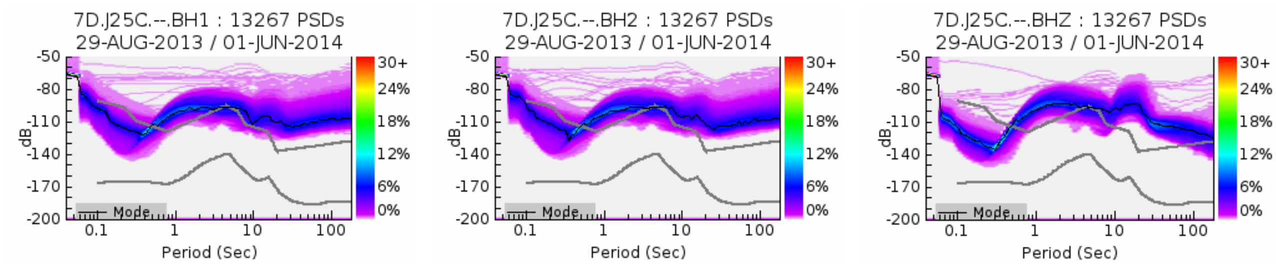


Figure 8. SIO OBS deployed in deep water (2717 m).

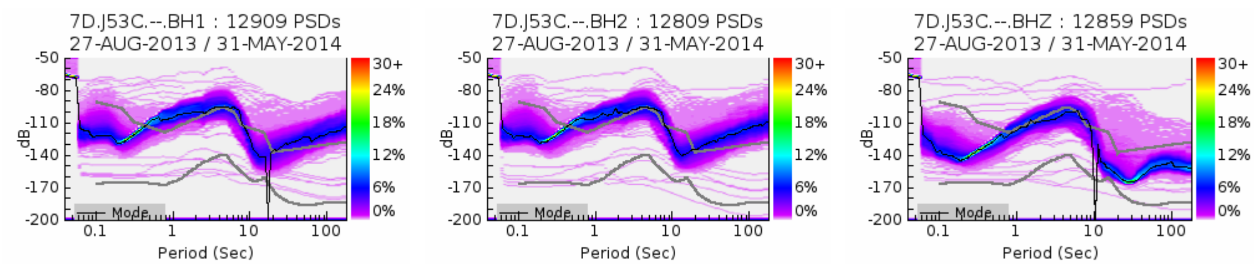


Figure 9. WHOI OBS deployed in deep water (2655 m).

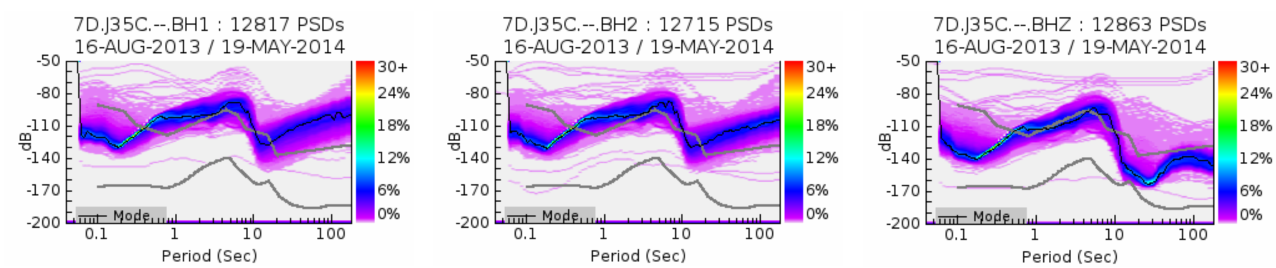


Figure 10. Cascadia TA station F04D, Columbia River for 2014.

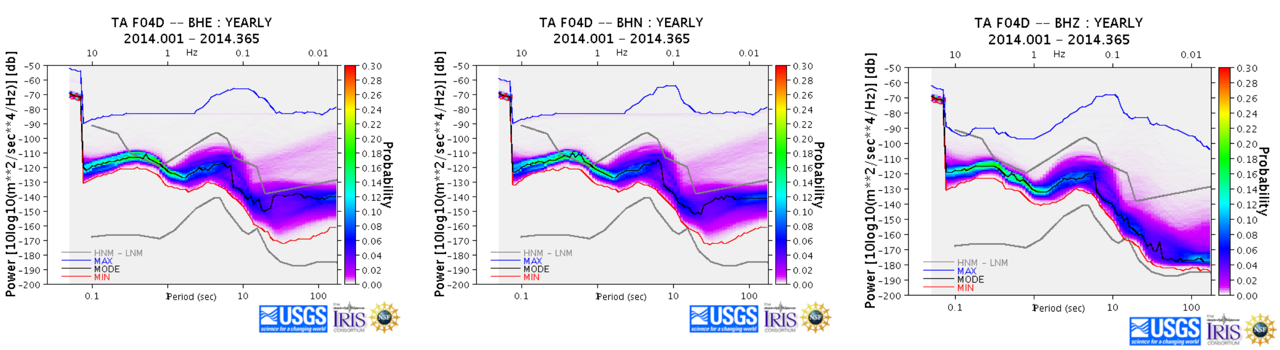
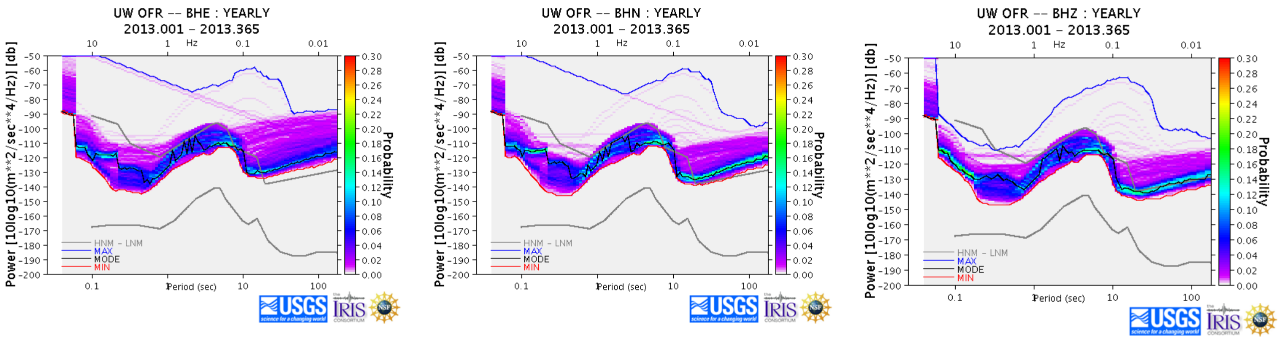


Figure 11. UW network station OFR, Olympic Peninsula for 2013



3. Horizontal Orientation Processing

We use the polarization of surface waves from large earthquakes to calculate the true horizontal orientation of Cascadia OBS stations. Our process implements an algorithm developed for orientation assessment with data from a recent OBS deployment (Stachnik et al., 2012). We select all teleseismic earthquakes with M>6. For each seismometer, the 0.02-0.04 Hz bandpass filtered 1 sample/second (LH1/LH2 or decimated HH(1/2) or BH(1/2)) horizontal channels are rotated at 2 degree increments for a 600 second envelope surrounding the predicted surface wave arrival, and the calculated arbitrary radial component is cross-correlated with the Hilbert transformed vertical component. The correlation coefficient between these two waveforms should peak at the ideal estimated orientation.

3.1. Removal of poor seismic data

Events recorded at most stations yield low correlation values due to pervasive intermediate- to long-period noise obscuring the surface wave arrivals on the horizontal channels. The low-correlation events do not influence the horizontal orientation estimate. However, the horizontal orientation estimate can be influenced by 'false estimates'. False estimates happen when the data for a time window is poor (ex: flat-lined, high noise, filtered to harmonic oscillator) but the channels have a high correlation. This does not happen often, but we have removed these 'false estimates' in the following ways:

There are instances when a station will not have a valid seismogram for all three components (BH[1,2,Z] or HH[1,2,Z]). In this situation, the code will not make a horizontal orientation estimate. Furthermore, there are time periods when a station channel may have flatlined or have zeros as the data values. This results in a correlation value that is 'not a number', which is removed from the station horizontal orientation estimate and plots.

We plot and evaluate all events with a correlation value above 0.8. If the noise level is too high to detect the event, or if filtering has caused the seismograms to become harmonic, the data is removed from the analysis.

3.3 Automated evaluation

The interactive routine developed for this report runs in MATLAB with SAC formatted data for each channel. The software can also be run in an automated mode. For stations with a low number of available events, it is possible to run the horizontal orientation code in an interactive way, where each correlation measurement is plotted and ranked as good, bad, or questionable. However, this is time intensive for researchers and introduces a researcher bias. The horizontal orientation estimates and standard deviations can be improved by running the interactive method.

In the Year 3 horizontal orientation processing, we used an automated approach to the correlation measurement analysis. We used a correlation coefficient of 0.8 as a threshold between a good and poor measurement, respectively.

4. Horizontal Orientation Results

We find there is a larger range of estimates and fewer high correlation measurements for each station than previous studies (Stachnik et al., 2012). Cascadia OBS stations yield between 0 and 38 useable measurements. Deep water stations produce more reliable estimates for orientation due to the generally lower noise levels at intermediate and long periods. The median and mean 2 σ standard deviations for WHOI stations are 22° and 22°, respectively. For LDEO stations, the median and mean are 55° and 53° and for SIO stations they are 22° and 24°.

Most deep water sites and a handful of shallow water stations yield reasonably consistent orientation estimates (Tables 4-6), with several events providing high correlation and good signal-to-noise ratio across most stations (Figure 12). We provide all estimated orientations for each station in Appendix D.

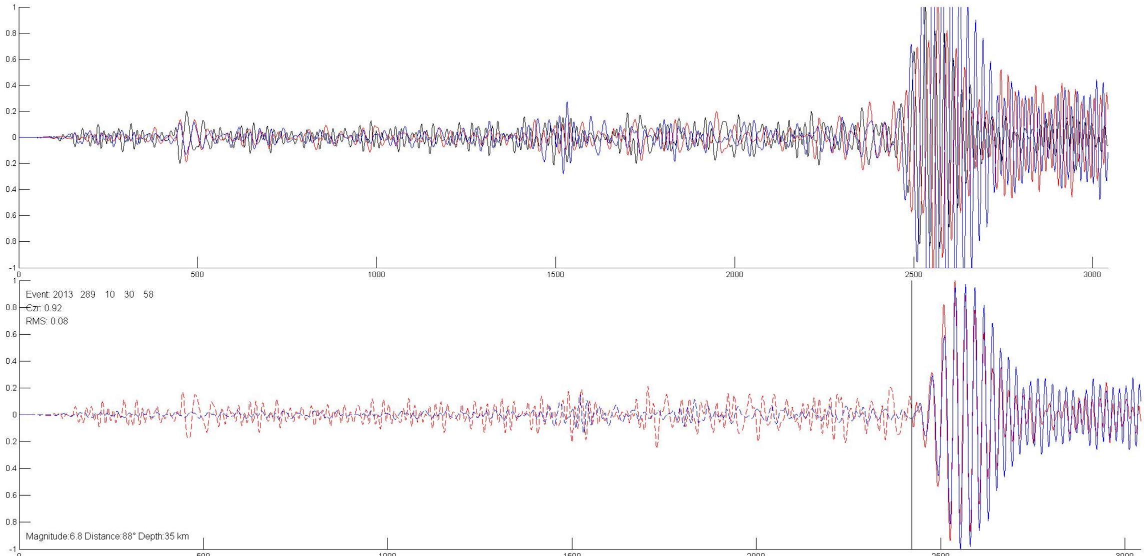


Figure 12. A "good" event with high correlation and ideal waveform appearance. The interactive viewer displays the normalized Hilbert transformed vertical channel and the calculated radial channel for the highest correlation. The top panel shows the filtered time series for HH1 (blue), HH2 (red), and HHZ (black). The bottom panel shows the normalized, rotated radial (magenta) and vertical (black) seismograms for the rotation angle that delivers the highest correlation. The portion of the time series used for the analysis is the surface wave to the right of the black vertical line.

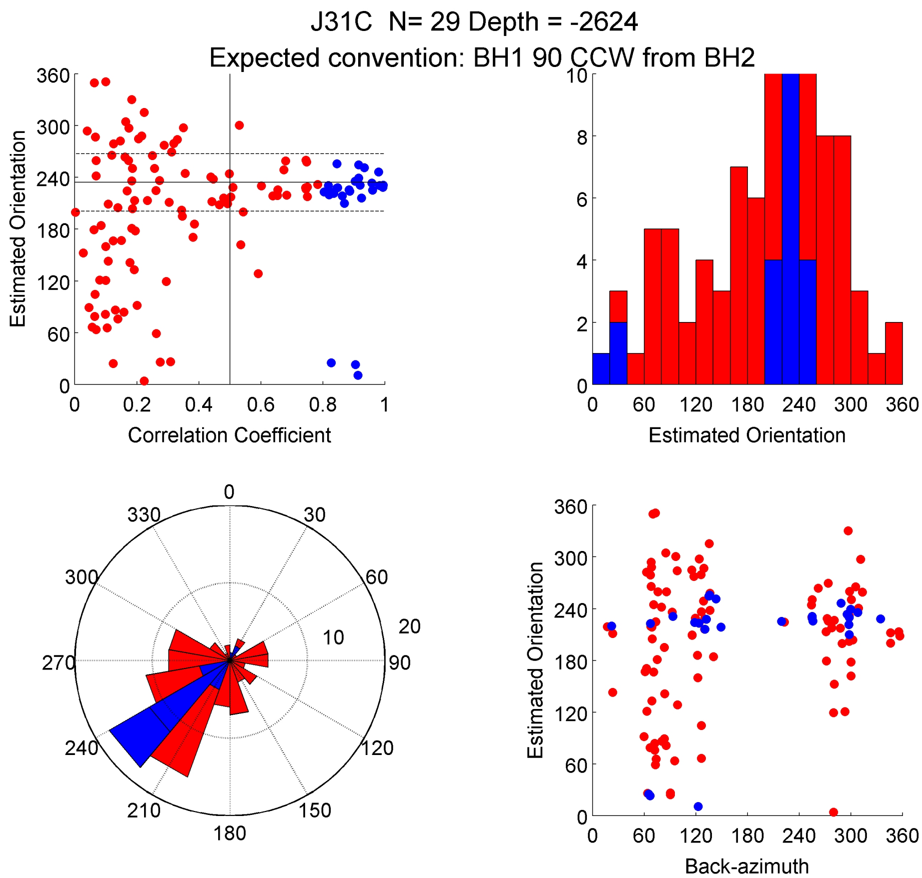


Figure 13. Orientation estimates; subplots show correlation coefficient vs. estimated orientation with mean value and uncertainty range (top-left), standard histogram of estimated orientation (top-right), polar histogram of estimated orientation (bottom-left), and earthquake back azimuth vs. estimated orientation (bottom-right).

4.1. 2013- 2014 (Year 3) Results

4.1.1. LDEO Results

Table 4. Mean true orientations (ϕ) for HH1 (assuming North=0° and positive measured clockwise), with uncertainties (2σ), and number of measurements (N) for LDEO stations. HH2 component orientation is 90° clockwise from HH1.

Station	Orientation ϕ	2σ	N
FN01C	72	65	2
FN02C	141	57	5
FN03C	26	70	38
FN04C	163	55	35
FN05C	357	43	15
FN06C	NaN	NaN	0
FN07C	171	32	7
FN08C	324	71	8
FN09C	162	25	19
FN10C	245	2	2
FN11C	252	74	4
FN12C	318	41	7
FN13C	76	48	10
FN14C	221	80	16
FN15C	NaN	NaN	0
FN16C	NaN	NaN	0
FN17C	NaN	NaN	0
FN18C	NaN	NaN	0
FN19C	182	50	20
J26C	63	64	13
J34C	325	56	10
J41C	346	78	12
J42C	225	54	17
J49C	96	59	23
J50C	339	42	12
J51C	NaN	NaN	0
J57C	103	77	3
J58C	115	39	14
J59C	333	71	8
M06C	359	29	14

4.1.2. SIO Results

Table 5. Mean true orientations (ϕ) for BH1 (assuming North=0° and positive measured clockwise), with uncertainties (2σ), and number of measurements (N) for SIO stations. BH2 component orientation is 90° clockwise from BH1. Station M07C stopped recording early, and no orientation estimate could be calculated.

Station	Orientation ϕ	2σ	N
J25C	215	36	5
J33C	215	27	11
J52C	129	26	27
J53C	301	27	31
J61C	173	17	22
J65C	109	79	9
J68C	141	5	24
J73C	329	26	8
M01C	138	6	8
M02C	88	20	2
M03C	327	24	15
M04C	103	21	10
M05C	194	15	9
M07C	NaN	NaN	0
M08C	92	9	9

4.1.3. WHOI Results

Table 6. Mean true orientations (ϕ) for BH1 (assuming North=0° and positive measured clockwise), with uncertainties (2σ), and number of measurements (N) for WHOI stations. BH2 component orientation is 90° clockwise from BH1.

Station	Orientation ϕ	2σ	N
J21C	42	32	10
J23C	147	7	10
J28C	186	12	4
J29C	59	29	37
J30C	65	26	29
J31C	234	33	29
J32C	97	3	4
J35C	333	32	18
J36C	33	20	16
J37C	228	22	18
J38C	245	36	17
J39C	268	18	22
J43C	118	28	19
J44C	303	33	19
J45C	109	18	28
J46C	175	17	25

J47C	219	39	21
J48C	290	33	11
J54C	84	14	4
J55C	127	30	11
J63C	100	15	9
J67C	178	8	6
J69C	37	6	7

5. OBS Orientation Code Package

Stachnik et al. (2012) developed software in Perl for the determination of OBS orientations and uses ASCII input. The software is currently available online at http://research.flyrok.org/software.html. The interactive routine developed for this report runs in MATLAB with SAC formatted data for each channel. The software can also be run in an automated mode. This software with an example dataset and separate mechanism for obtaining similarly formatted data are available through the OBSIP website (http://www.obsip.org/data/obs-horizontal-orientation/). Questions regarding the MATLAB software should be directed to Jessica Lodewyk (jessica@iris.edu).

6. References

McNamara, D.E., and R.P. Buland (2004), Ambient Noise Levels in the Continental United States: *Bull. Seismol. Soc. Amer.*, 94, 1517–1527.

Stachnik, J.C., A.F. Sheehan, D.W. Zietlow, Z. Yang, J. Collins, and A. Ferris (2012), Determination of New Zealand Ocean Bottom Seismometer Orientation via Rayleigh-Wave Polarization: *Seismol. Res. Lett.*, 83, 704–712, doi:10.1785/0220110128.

Zhaohui, Y., A.F. Sheehan, J.A. Collins, and G. Laske (2012), The character of seafloor ambient noise recorded offshore New Zealand: Results from the MOANA ocean bottom seismic experiment: Geochem. Geophysics. Geosys., 13, doi:10.1029/2012GC004201.

Appendix A - Understanding OBSIP Data

Ocean Bottom Seismographs (OBS) are advanced instrument systems that differ significantly from their land-based counterparts in their operation and resultant raw data. The primary differences between typical land-based and ocean bottom seismographs are summarized in the following table:

Land Seismograph	Ocean Bottom Seismograph
Easily accessible, Real-time data	Stored data (Accessed upon recovery)
Real-time corrected clocks	Post-deployment corrected clocks
Measured sensor orientation	Empirical sensor orientation
Traditional orientation code in SEED channel name	Non-traditional orientation code in SEED channel name

The deployment of Ocean Bottom Seismographs in extremely remote regions of the world precludes the ability to communicate with these instruments via radio frequency methods typically employed in land-based, remotely-monitored stations. The logistics of temporary OBS deployments further preclude the use of wired communications or power. As a result, all OBSIP ocean bottom seismographs must operate completely stand-alone.

Data Format

OBSs store their data locally for download when the instrument is retrieved. All OBS power is provided via batteries for the duration of their deployment, which limits the operational persistence of the instrument.

Data are often stored on the OBS in nonstandard formats to reduce storage space and power requirements. Each OBSIP IIC converts these data to a standardized format (SEED, SEG-Y) after data retrieval.

Timing

With no connection to the outside world, ocean bottom seismometers are not able to maintain synchronization with standard timing systems (via GPS or network connection). Precision time stamping of the seismometer data must be performed onboard the instrument system and then corrected when the instrument is recovered and compared to standardized timing systems. Each OBSIP IIC will perform this step upon recovery of the instrument and in data post-processing.

Orientation

Because OBS's are deployed remotely and without intervention, their actual orientation on the seafloor is unknown. The Cascadia OBS stations do not carry orientation devices (magnetic compasses, gyroscopes, etc.) because accurate instruments are cost and power prohibitive, and current low cost instruments are of limited accuracy. Therefore, the user must determine the horizontal orientation of the OBS from recorded data.

The process of determining the horizontal orientation of the OBS can be subjective depending on the impact of ambient noise and the quality and distribution of seismic events that have been recorded. As a result, the OBSIP IIC's do not generally perform horizontal orientation of the data - this is a responsibility of the Principal Investigator.

The community design and implementation of the Cascadia project sets it apart from traditional NSF-funded projects. With no "Principal Investigator" there is no single user of the OBS data that is initially funded to perform basic data processing. In an effort to make the Cascadia dataset available and useful to the widest possible number of investigators, the OBSIP Management Office is calculating the horizontal orientations of the Cascadia instruments for each year of deployment

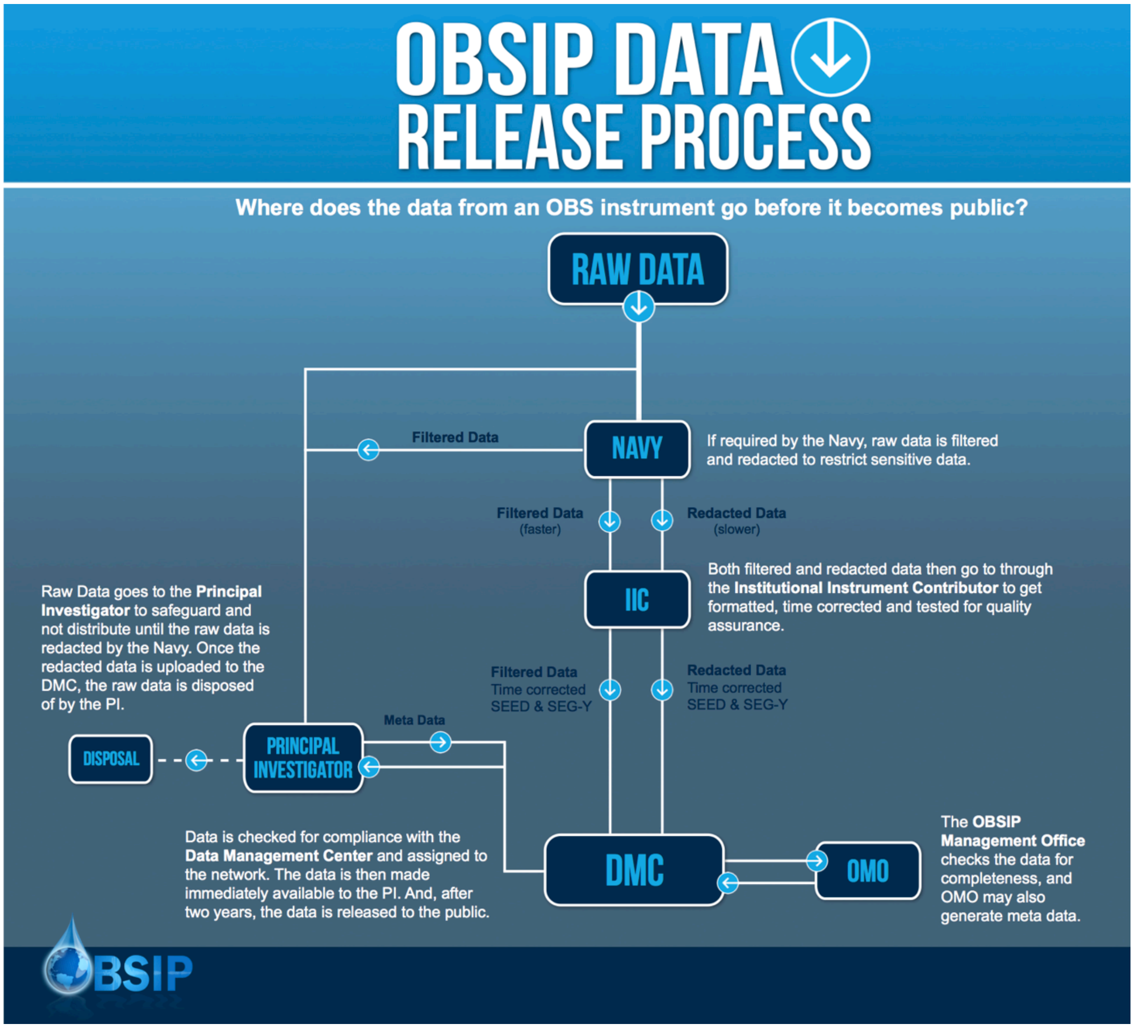
OBSIP Data Release Process

The release of OBSIP data is a multi-step process that has several variables, depending on when and where the data were collected. Low frequency acoustic data recorded in the oceans can be of interest to national security concerns and as a result, may be subject to review and redaction by the US Navy (this is often the case with Cascadia OBS data).

If the Navy determines that the data are of interest, it will process the data in two parallel steps prior to public release. Upon collection, the Navy will immediately filter the data below 4 Hz - this step generally takes little additional time.

In addition, the Navy will redact certain portions of the full bandwidth dataset to remove signals of interest. This step generally takes more time and may result in a delay in the public release of full bandwidth data for up to three months.

The OBSIP IIC's then post-process each of these data sets to put the data in the correct format (SEED or SEG-Y) and to correct the timing of the data samples. Upon completion of this step, the data are uploaded to the IRIS Data Management Center for public use. Note that additional post-processing and metadata generation (including horizontal orientation) may take place at this point. The OBSIP data release process is summarized in the following figure.



Channel Naming Conventions

OBSIP data at the DMC use standard SEED channel names. The possible redaction of time segments and/or low-pass filtering of the data, as discussed in the previous section, makes channel naming somewhat more complicated. Table 1 provides a summary of channel names used for the Cascadia OBSIP broadband data streams.

Table 1. Channel names used for broadband data in the Cascadia OBS instruments.

SEED Channel Name	Description
LH?	Raw broadband data, 1 sps
BH?, HH?	Raw broadband data, but with possible redacted time windows
BX?	Broadband data, low-pass filtered with 4 Hz corner

Relative Sensor Orientations for Horizontal Components

As noted above, typical OBSIP instruments are not oriented at installation, though the mechanical structure of the broadband seismometer ensures that the three components are orthogonal. Assuming the instrument package lands on the seafloor in a near vertical orientation, the remaining ambiguity is the absolute orientation of the horizontal components, relative to north. The orientation of the horizontals is determined empirically, after recovery of the instruments from the seafloor. However, at the time the data are delivered to the IRIS DMC the empirical orientation analysis for the horizontal components is not complete. This situation requires that default values be assigned to the SEED format fields that indicate the azimuth of the horizontal components.

All Cascadia instruments now have a “left handed” orientation where the BH2/HH2 channel is oriented 90° clockwise of BH1/HH1.

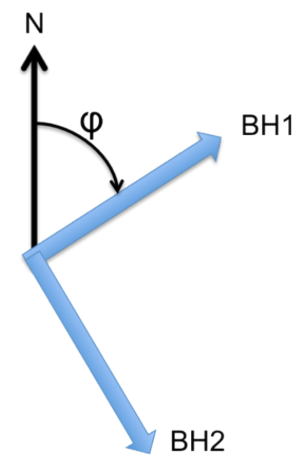


Illustration of the relative orientation of horizontal components for data collected for the Cascadia Initiative. The default header value for the BH[1,2] and HH[1,2] azimuths are 0°. The values of ϕ are determined empirically and are reported in Tables 4, 5, and 6 of this report.

Appendix B - Helicorder Plots

(Available in separate document)

Appendix C - PDF-PSD Plots

(Available in separate document)

Appendix D - Orientation Results
(Available in separate document)