Cascadia Amphibious Array
Ocean Bottom Seismograph
Horizontal Component Orientations

2014-2015 OBS Deployments

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

Document Change History

Version	Description	Date
1.0	Report prepared by K. Aderhold and A. Frassetto	2/20/2017

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/

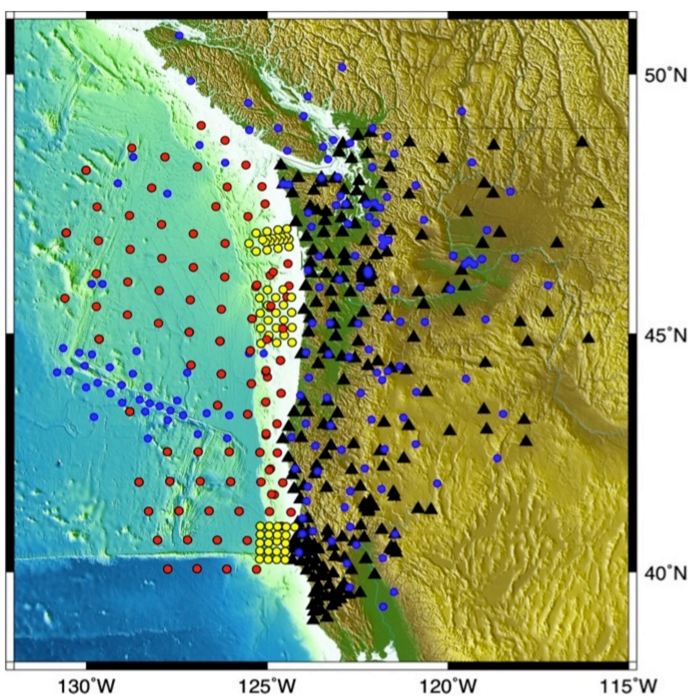


Figure 1. Planned deployments for the ocean portion of the Cascadia Amphibious Array (red and yellow circles), other complementary present/future seismometer deployments (blue circles), and real-time PBO GPS stations (black triangles).

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 (see Horizontal Orientations Reports at http://www.obsip.org/data/obs-horizontal-orientation/).

This report focuses on the fourth year of deployment, which was completed in the summer of 2015. The OBSIP Management Office also calculates the horizontal orientations of the Cascadia instruments deployed in the fourth 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 2014-2015 OBS deployment, 24/24 WHOI, 10/14 SIO, and 26/28 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 (~1.5% 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.

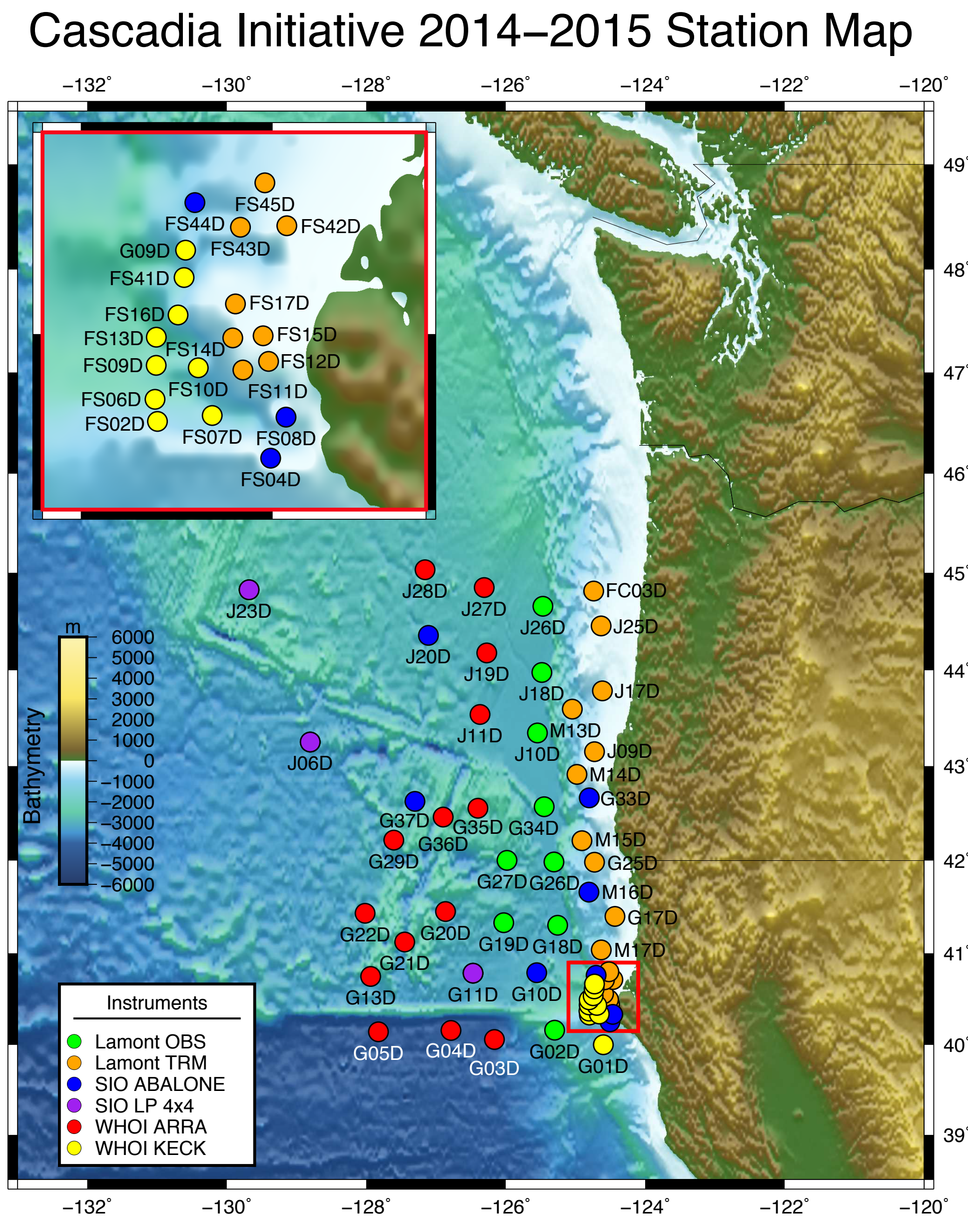


Figure 2. 2014-2015 Deployed Cascadia OBS Stations, Year 4

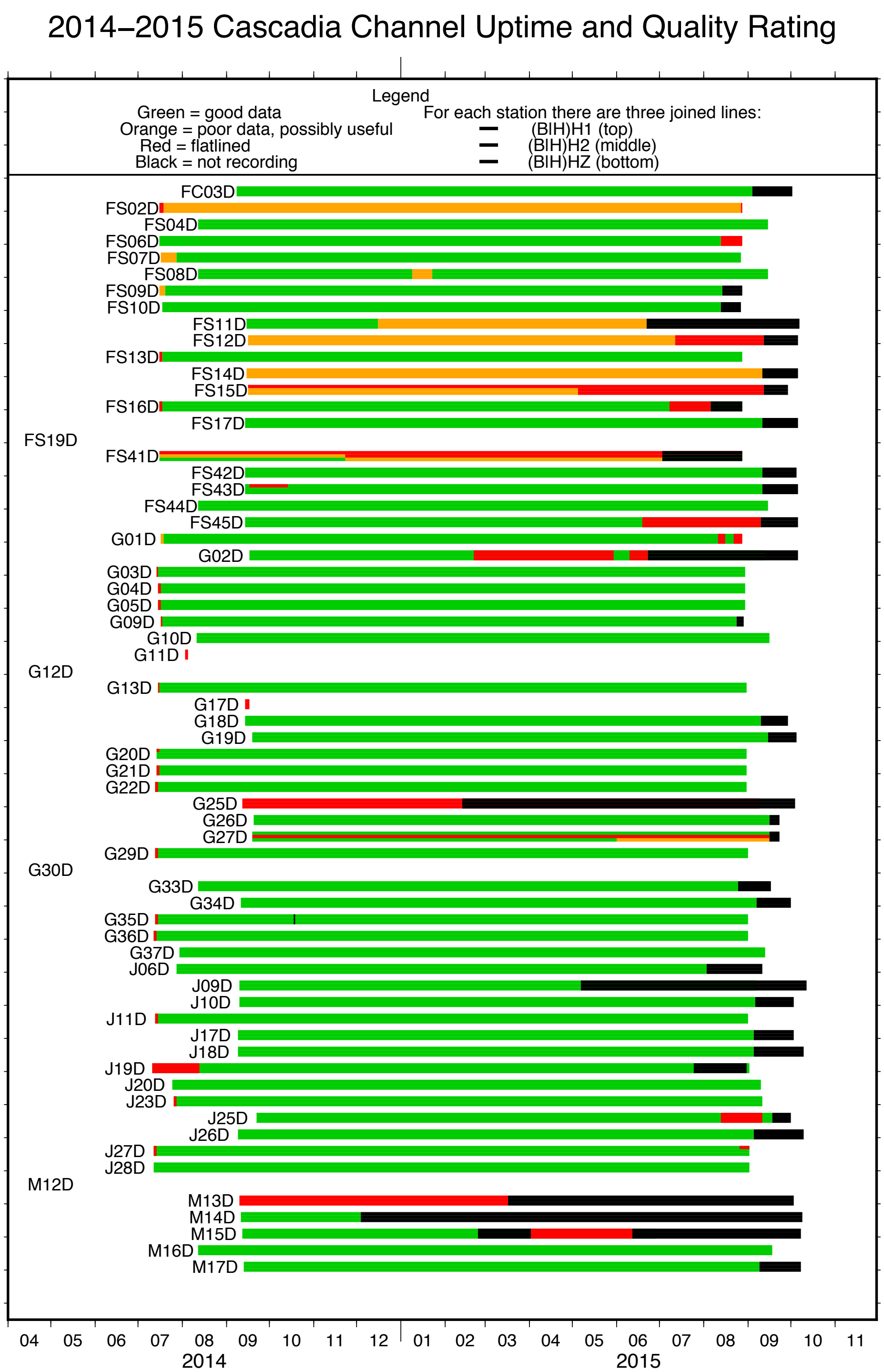


Figure 3. Cascadia station seismometer uptime and an initial quality rating. For each station there are three merged lines, corresponding to seismometer channels BH1/BH2/BHZ or HH1/HH2/HHZ from top to bottom. Color indicates usability of data: green is good data, orange is poor quality but potentially usable, red is unusable or flatlined. This quality rating was assigned based on viewed data and metrics from the IRIS DMC MUSTANG metric service: http://services.iris.edu/mustang/ (Casey et al., 2018).

2.1. Station Deployment and Performance

2.1.1. LDEO Stations

Twenty-eight seismometers were deployed in September 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 continuously on HH? channels at 125 sps. The Navy redacted data segments from all stations and produced a HX? channel (filtered above 3Hz.). Stations M12D and G17D recorded no usable data.

Table 1. Deployed Cascadia LDEO Stations, 2014-2015. (TC=Trillium Compact)

Site	Instrument Type	Sensor Type	Surveyed Position			Deployed Date	Recovered Date
			Latitude (Dec.)	Longitude (Dec.)	Depth (m)		
FC03D	TRM	Nanometrics TC	44.8133	-124.7383	-432	7-Sep-14	2-Oct-15
FS11D	Popup TRM	Nanometrics TC	40.4285	-124.5775	-150	8-Sep-14	7-Oct-15
FS12D	Popup TRM	Nanometrics TC	40.4456	-124.5105	-55	8-Sep-14	6-Oct-15
FS14D	Popup TRM	Nanometrics TC	40.4923	-124.6039	-145	9-Sep-14	6-Oct-15
FS15D	Popup TRM	Nanometrics TC	40.4964	-124.5247	-56	9-Sep-14	29-Sep-15
FS17D	Popup TRM	Nanometrics TC	40.5598	-124.5970	-145	9-Sep-14	6-Oct-15
FS42D	Popup TRM	Nanometrics TC	40.7151	-124.4631	-95	10-Sep-14	5-Oct-15
FS43D	TRM	Nanometrics TC	40.7119	-124.5839	-719	10-Sep-14	6-Oct-15
FS45D	TRM	Nanometrics TC	40.8000	-124.5203	-477	10-Sep-14	6-Oct-15
G02D	LDEO Standard	Nanometrics TC	40.1603	-125.2977	-1741	11-Sep-14	6-Oct-15
G17D*	Popup TRM	Nanometrics TC	41.3996	-124.4332	-99	12-Sep-14	8-Oct-15
G18D	LDEO Standard	Nanometrics TC	41.3047	-125.2558	-3130	12-Sep-14	29-Sep-15
G19D	LDEO Standard	Nanometrics TC	41.3316	-126.0279	-3082	13-Sep-14	5-Oct-15
G25D	TRM	Nanometrics TC	41.9811	-124.7267	-688	13-Sep-14	4-Oct-15
G26D	LDEO Standard	Nanometrics TC	41.9838	-125.3083	-3104	13-Sep-14	23-Sep-15
G27D	LDEO Standard	Nanometrics TC	42.0013	-125.9817	-2939	14-Sep-14	23-Sep-15
G34D	LDEO Standard	Nanometrics TC	42.5723	-125.4486	-3089	14-Sep-14	1-Oct-15
J09D	TRM	Nanometrics TC	43.1514	-124.7271	-252	14-Sep-14	12-Oct-15
J10D	LDEO Standard	Nanometrics TC	43.3485	-125.5451	-3085	14-Sep-14	3-Oct-15
J17D	TRM	Nanometrics TC	43.7873	-124.6134	-285	15-Sep-14	3-Oct-15
J18D	LDEO Standard	Nanometrics TC	43.9772	-125.4814	-3050	15-Sep-14	10-Oct-15
J25D	Popup TRM	Nanometrics TC	44.4567	-124.6310	-136	16-Sep-14	1-Oct-15
J26D	LDEO Standard	Nanometrics TC	44.6577	-125.4670	-2880	16-Sep-14	10-Oct-15
M12D*	TRM	Nanometrics TC	44.2270	-125.0353	-950	8-Sep-14	2-Oct-15
M13D	TRM	Nanometrics TC	43.5973	-125.0446	-990	18-Sep-14	3-Oct-15
M14D	TRM	Nanometrics TC	42.9136	-124.9779	-997	19-Sep-14	9-Oct-15
M15D	TRM	Nanometrics TC	42.2107	-124.9074	-933	19-Sep-14	8-Oct-15
M17D	TRM	Nanometrics TC	41.0370	-124.6298	-749	21-Sep-14	8-Oct-15

2.1.2. SIO Stations

Fourteen seismometers constructed by SIO were deployed between July and August 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 sps. The Navy redacted data segments from all stations and produced a BX? channel (filtered above 3Hz.). Stations FS19D, G11D, G12D, and G30D recorded no usable data.

Table 2. Deployed Cascadia SIO Stations, 2014-2015. (TC=Trillium Compact)

Site	Instrument Type	Sensor Type	Surveyed Position			Deployed Date	Recovered Date
			Latitude (Dec.)	Longitude (Dec.)	Depth (m)		
FS04D	SIO-ABALONE	Nanometrics TC	40.2528	-124.5052	-155	12-Aug-14	15-Sep-15
FS08D	SIO-ABALONE	Nanometrics TC	40.3347	-124.4653	-132	12-Aug-14	15-Sep-15
FS19D*	SIO-ABALONE	Nanometrics TC	40.6241	-124.4703	-100	12-Aug-14	15-Sep-15
FS44D	SIO-ABALONE	Nanometrics TC	40.7609	-124.7028	-837	12-Aug-14	15-Sep-15
G10D	SIO-ABALONE	Nanometrics TC	40.7888	-125.5544	-3015	11-Aug-14	15-Sep-15
G11D*	SIO-LP4x4	Nanometrics T240	40.7845	-126.4683	-3145	2-Aug-14	14-Sep-15
G12D*	SIO-LP4x4	Nanometrics T240	40.7747	-127.1364	-2884	1-Aug-14	13-Sep-15
G30D*	SIO-LP4x4	Nanometrics T240	41.9515	-128.2962	-3179	30-Jul-14	12-Sep-15
G33D	SIO-ABALONE	Nanometrics TC	42.6653	-124.8020	-686	12-Aug-14	17-Sep-15
G37D	SIO-ABALONE	Nanometrics TC	42.6285	-127.3009	-2805	30-Jul-14	12-Sep-15
J06D	SIO-LP4x4	Nanometrics T240	43.2526	-128.8041	-3245	28-Jul-14	11-Sep-15
J20D	SIO-ABALONE	Nanometrics TC	44.3604	-127.1085	-2936	25-Jul-14	9-Sep-15
J23D	SIO-LP4x4	Nanometrics T240	44.8274	-129.6805	-2687	26-Jul-14	10-Sep-15
M16D	SIO-ABALONE	Nanometrics TC	41.6618	-124.8071	-882	12-Aug-14	17-Sep-15

2.1.3. WHOI Stations

Twenty-four seismometers were deployed in July 2014. These OBS stations operated exclusively in deeper water at depths of at least 900 m. Each station recorded BH? At 50 sps and LH? at 1sps channels. The Navy redacted data segments from all stations and produced a BX? channel (filtered above 3Hz).

Table 3. Deployed Cascadia WHOI Stations, 2014-2015. (TC=Trillium Compact)

Site	Instrument Type	Sensor Type	Surveyed Position			Deployed Date	Recovered Date
			Latitude (Dec.)	Longitude (Dec.)	Depth (m)		
FS02D	WHOI-Keck	Güralp CMG-3T	40.3260	-124.8002	-948	16-Jul-14	28-Aug-15
FS06D	WHOI-Keck	Güralp CMG-3T	40.3700	-124.8067	-1947	16-Jul-14	28-Aug-15
FS07D	WHOI-Keck	Güralp CMG-3T	40.3379	-124.6577	-1274	17-Jul-14	27-Aug-15
FS09D	WHOI-Keck	Güralp CMG-3T	40.4377	-124.8037	-2122	16-Jul-14	28-Aug-15
FS10D	WHOI-Keck	Güralp CMG-3T	40.4328	-124.6940	-1154	17-Jul-14	27-Aug-15
FS13D	WHOI-Keck	Güralp CMG-3T	40.4937	-124.8034	-2291	16-Jul-14	28-Aug-15
FS16D	WHOI-Keck	Güralp CMG-3T	40.5378	-124.7468	-1080	16-Jul-14	28-Aug-15
FS41D	WHOI-Keck	Güralp CMG-3T	40.6124	-124.7310	-1079	16-Jul-14	28-Aug-15
G01D	WHOI-Keck	Güralp CMG-3T	39.9999	-124.6008	-1007	17-Jul-14	27-Aug-15
G03D	WHOI-ARRA	Nanometrics TC	40.0587	-126.1612	-4057	14-Jul-14	29-Aug-15
G04D	WHOI-ARRA	Nanometrics TC	40.1577	-126.7847	-4350	14-Jul-14	29-Aug-15
G05D	WHOI-ARRA	Nanometrics TC	40.1430	-127.8257	-4464	14-Jul-14	29-Aug-15
G09D	WHOI-Keck	Güralp CMG-3T	40.6665	-124.7269	-716	16-Jul-14	28-Aug-15
G13D	WHOI-ARRA	Nanometrics TC	40.7482	-127.9371	-3187	14-Jul-14	30-Aug-15
G20D	WHOI-ARRA	Nanometrics TC	41.4516	-126.8638	-2931	13-Jul-14	30-Aug-15
G21D	WHOI-ARRA	Nanometrics TC	41.1227	-127.4480	-3293	13-Jul-14	30-Aug-15
G22D	WHOI-ARRA	Nanometrics TC	41.4336	-128.0166	-3092	13-Jul-14	30-Aug-15
G29D	WHOI-ARRA	Nanometrics TC	42.2174	-127.6052	-2911	12-Jul-14	31-Aug-15
G35D	WHOI-ARRA	Nanometrics TC	42.5557	-126.3990	-2823	12-Jul-14	31-Aug-15
G36D	WHOI-ARRA	Nanometrics TC	42.4618	-126.8965	-3780	12-Jul-14	31-Aug-15
J11D	WHOI-ARRA	Nanometrics TC	43.5416	-126.3686	-3001	12-Jul-14	31-Aug-15
J19D	WHOI-ARRA	Nanometrics TC	44.1790	-126.2712	-2955	11-Jul-14	1-Sep-15
J27D	WHOI-ARRA	Nanometrics TC	44.8489	-126.3083	-2815	11-Jul-14	1-Sep-15
J28D	WHOI-ARRA	Nanometrics TC	45.0301	-127.1560	-2856	11-Jul-14	1-Sep-15

2.2. Station Noise Levels

2.2.1. 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 4-8).

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 4 and 5). 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 9-10), 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 B.

Figure 4. Typical PDFs for LDEO trawl-resistant OBS deployed in shallow water (285 m depth).

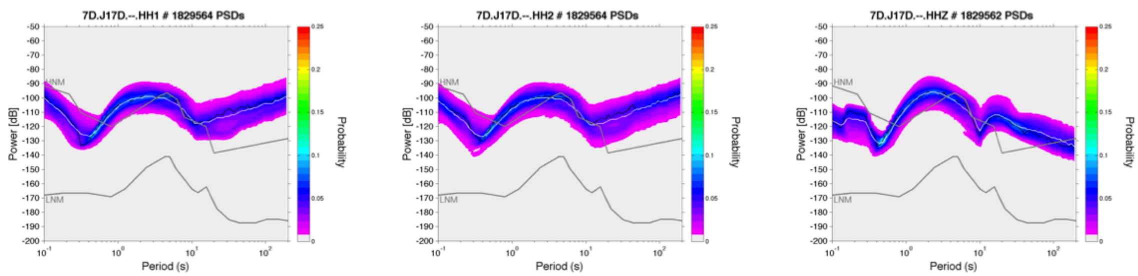


Figure 5. LDEO OBS deployed in deep water (3050 m).

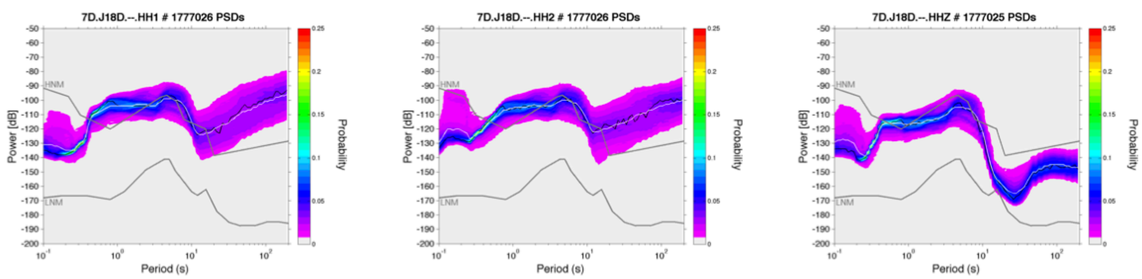


Figure 6. SIO OBS deployed in shallow water (155 m).

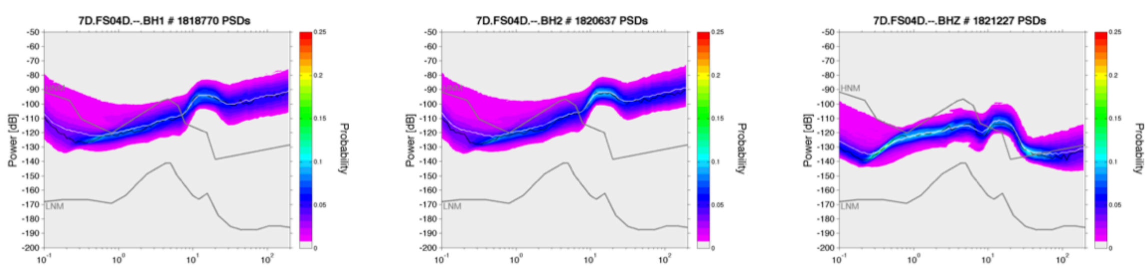


Figure 7. SIO OBS deployed in deep water (3245 m).

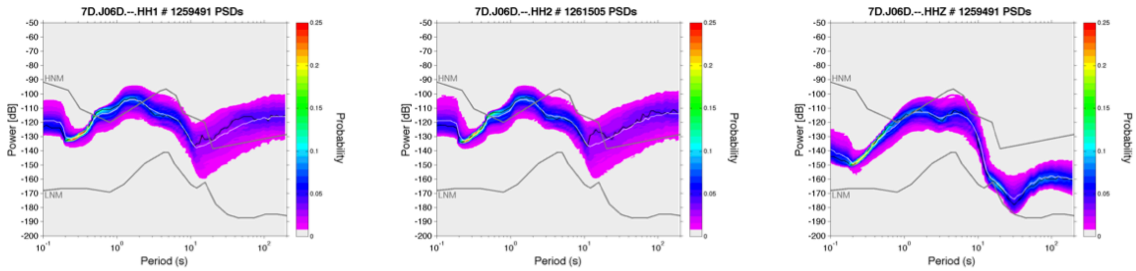


Figure 8. WHOI OBS deployed in deep water (3001 m).

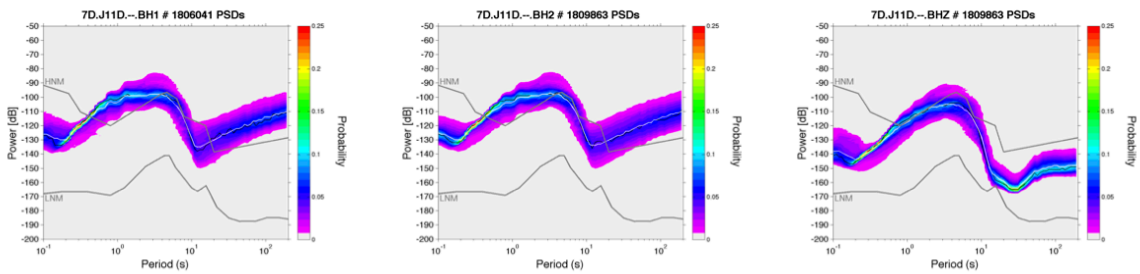


Figure 9. Cascadia TA station F04D, Columbia River for 2014.

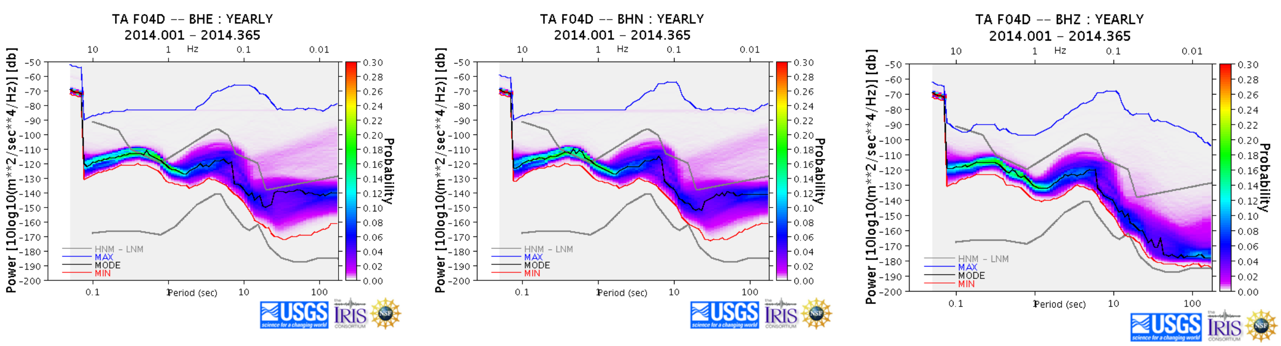
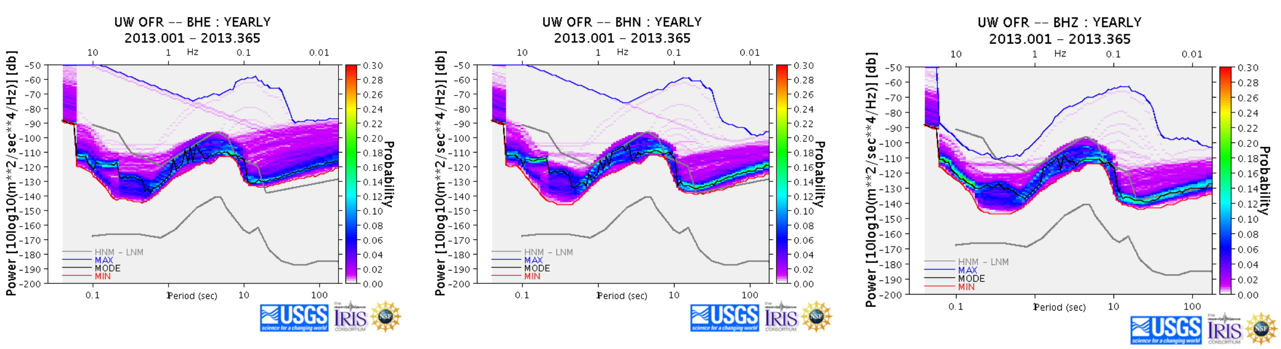


Figure 10. UW network station OFR, Olympic Peninsula for 2013



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.

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.

In the Year 4 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

Cascadia OBS stations during Year 4 yield between 0 and 62 useable measurements. Deep water stations produce more reliable estimates for orientation due to the generally lower noise levels at intermediate and long periods.

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 11). We provide all estimated orientations for each station in Appendix C.

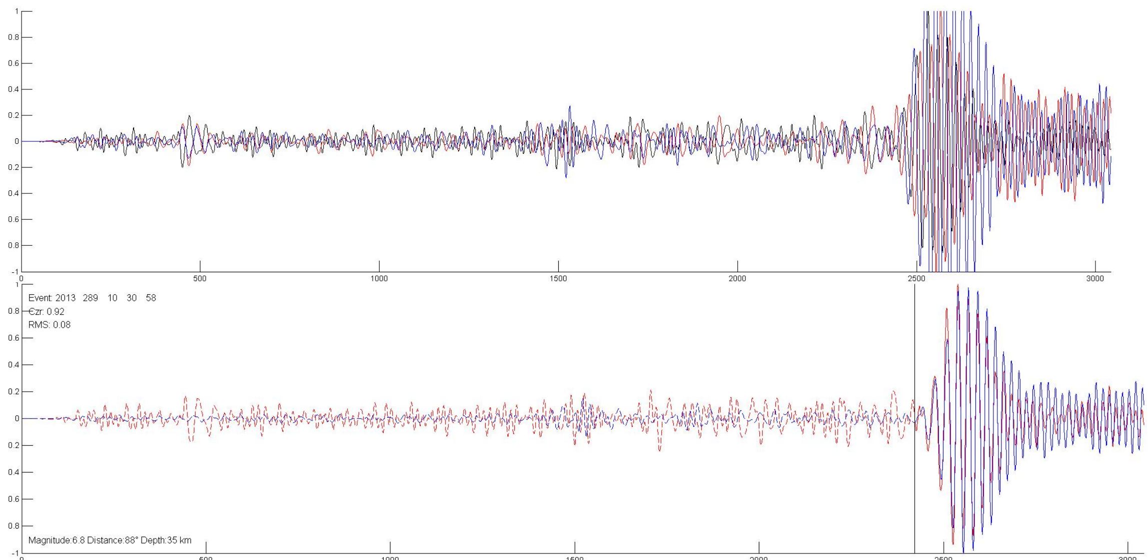


Figure 11. A "good" event with high correlation and ideal waveform appearance. The interactive viewer displays the normalized Hilbert transformed vertical channel and the calculated radial channel for the highest correlation. The top panel shows the filtered time series for HH1 (blue), HH2 (red), and 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.

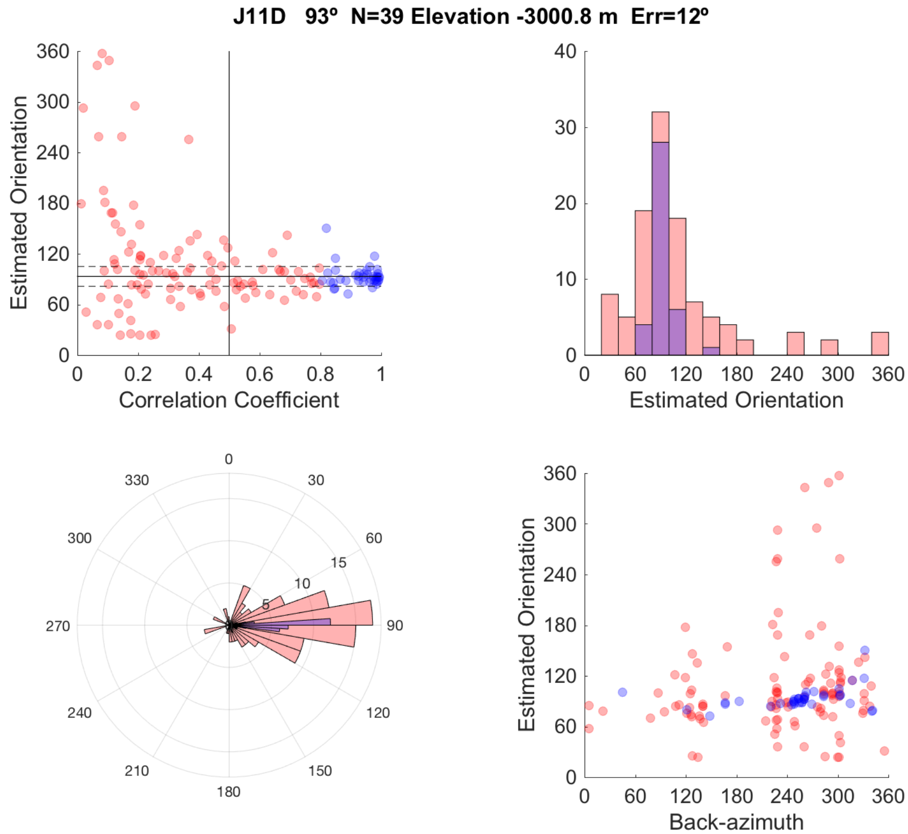


Figure 12. Orientation estimates; subplots show correlation coefficient vs. estimated orientation with mean value and uncertainty range (top-left), standard histogram of estimated orientation (top-right), polar histogram of estimated orientation (bottom-left), and earthquake back azimuth vs. estimated orientation (bottom-right).

4.1. 2014-2015 (Year 4) 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.

Site	Orientation ϕ	2σ	N
FC03D	83.0	8.5	22
FS11D	243.1	34.7	8
FS12D	169.9	24.8	16
FS14D	202.9	13.0	12
FS15D	NaN	NaN	0
FS17D	297.8	2.9	4
FS42D	87.9	20.1	2
FS43D	124.5	4.2	18
FS45D	177.0	21.7	11
G02D	70.8	8.4	12
G17D*	-	-	-
G18D	259.1	11.5	37
G19D	354.8	20.8	30
G25D	NaN	NaN	0
G26D	237.0	8.3	19
G27D	NaN	NaN	0
G34D	122.3	6.4	21
J09D	278.2	15.0	6
J10D	178.9	7.6	22
J17D	198.6	10.2	11
J18D	289.0	12.0	18
J25D	129.5	18.6	28
J26D	172.7	4.4	14
M12D*	-	-	-
M13D	NaN	NaN	0
M14D	232.0	7.0	5
M15D	240.8	9.6	7
M17D	59.0	7.8	33

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.

Site	Orientation ϕ	2 σ	N
FS04D	317.0	27.5	9
FS08D	185.4	78.7	12
FS19D*	-	-	-
FS44D	73.8	7.2	23
G10D	180.8	13.9	27
G11D*	-	-	-
G12D*	-	-	-
G30D*	-	-	-
G33D	312.7	7.1	18
G37D	135.0	7.8	62
J06D	304.7	7.8	37
J20D	186.6	10.9	53
J23D	206.5	6.8	54
M16D	315.1	5.7	23

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.

Site	Orientation ϕ	2 σ	N
FS02D	126.6	24.9	7
FS06D	66.4	4.6	7
FS07D	256.7	7.2	11
FS09D	264.0	9.1	12
FS10D	40.5	5.8	27
FS13D	274.8	9.9	21
FS16D	79.0	5.5	9
FS41D	NaN	NaN	0
G01D	7.1	12.4	19
G03D	139.5	6.2	39
G04D	260.7	12.9	37
G05D	315.5	6.6	44
G09D	283.8	2.0	7
G13D	180.6	12.8	53
G20D	310.2	8.0	44
G21D	294.9	9.4	34
G22D	169.1	10.8	46
G29D	177.5	12.5	38
G35D	52.5	9.2	51
G36D	113.5	7.9	31
J11D	93.1	11.7	39
J19D	251.7	16.0	50
J27D	24.7	13.1	39
J28D	210.6	7.6	33

5. Orientation Comparison

The orientations for the Cascadia Initiative were calculated and reported by the OMO and then later calculated and published by Doran and Laske (2017). The comparison of Year 4 orientations for stations that have orientations from each source calculated is plotted in Figure 13. Overall the two sets of orientations are in close agreement. There are several outliers. Two of these outliers are LDEO stations G02D and G19D which had the polarity of their horizontal channels reversed without the polarity of their vertical channels reversed and the horizontal data were re-archived on 9/16/16. This would result in a 180º difference between orientation results using the same method but different versions of the data.

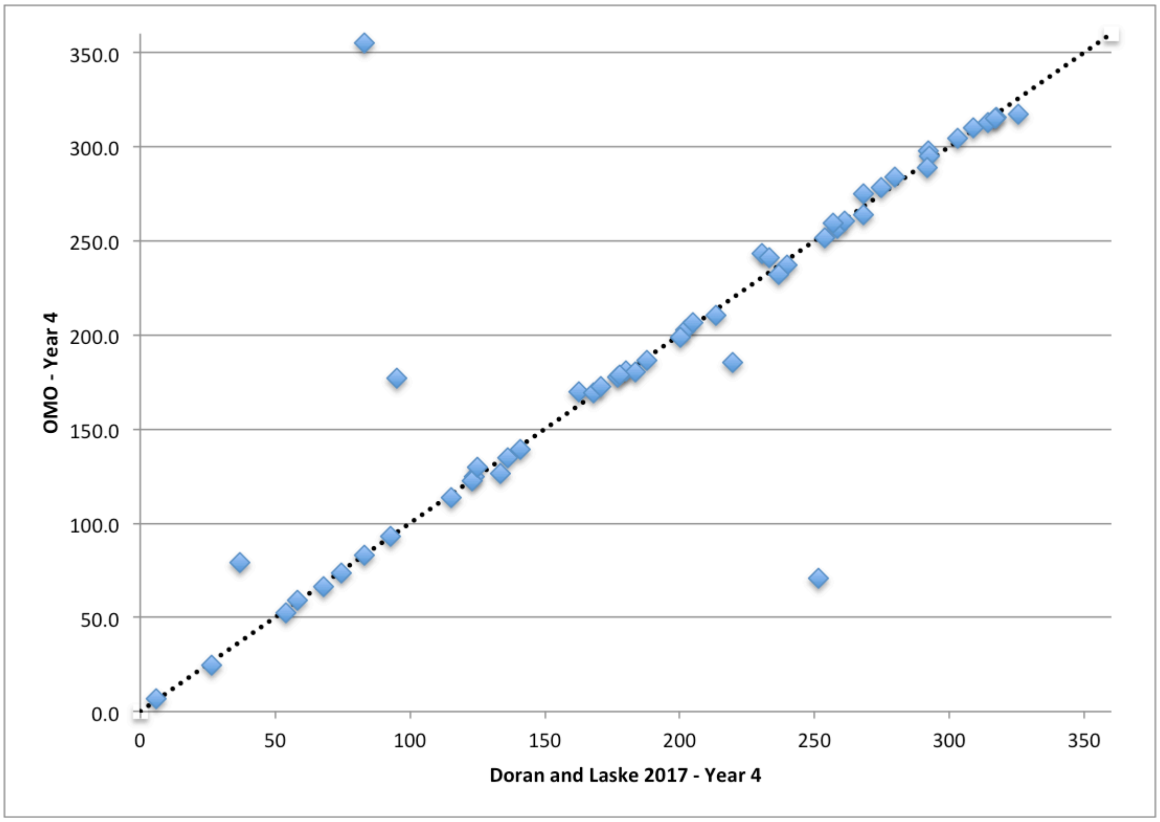


Figure 13. Comparison for Year 4 Cascadia stations between the orientations in this report and the orientations published in Doran and Laske (2017).

6. 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/).

7. References

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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

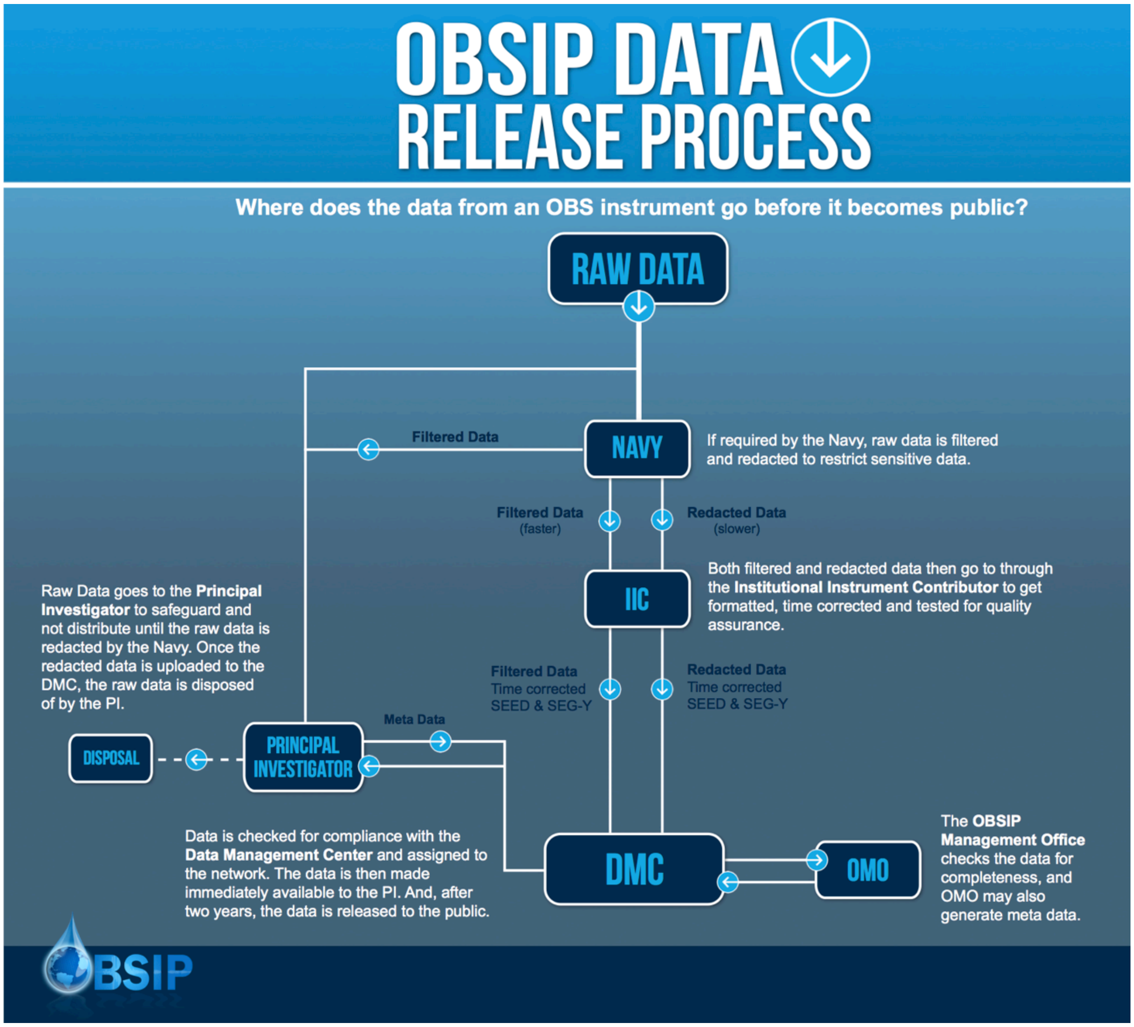
OBSIP Data Release Process

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 3 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 3 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.

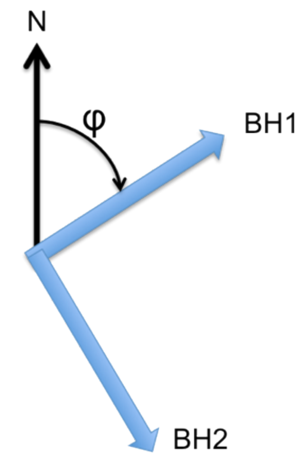


Illustration of the relative orientation of horizontal components for data collected for the Cascadia Initiative. The default header value for the BH[1,2] and HH[1,2] azimuths are 0°. The values of ϕ are determined empirically and are reported in Tables 4, 5, and 6 of this report.

Appendix B - PDF-PSD Plots

(Available in separate document)

Appendix C - Orientation Results
(Available in separate document)