Cascadia Amphibious Array
Ocean Bottom Seismograph
Horizontal Component Orientations

2011-2012 OBS Deployments

Version 3.0
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Note: The results and methods presented here are subject to change.

Document Change History

Version	Description	Date
1.0	Initial draft, only WHOI data.	1/17/2013
2.0	Added results of LDEO and SIO analyses, reorganized sections.	2/26/2014
3.0	Re-published report after data was re-uploaded and convention of WHOI and LDEO stations had changed (see Appendix E)	3/20/2014

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 seismologic 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. Deployed in 2011, these instruments will occupy a broad footprint spanning 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). Complete 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/

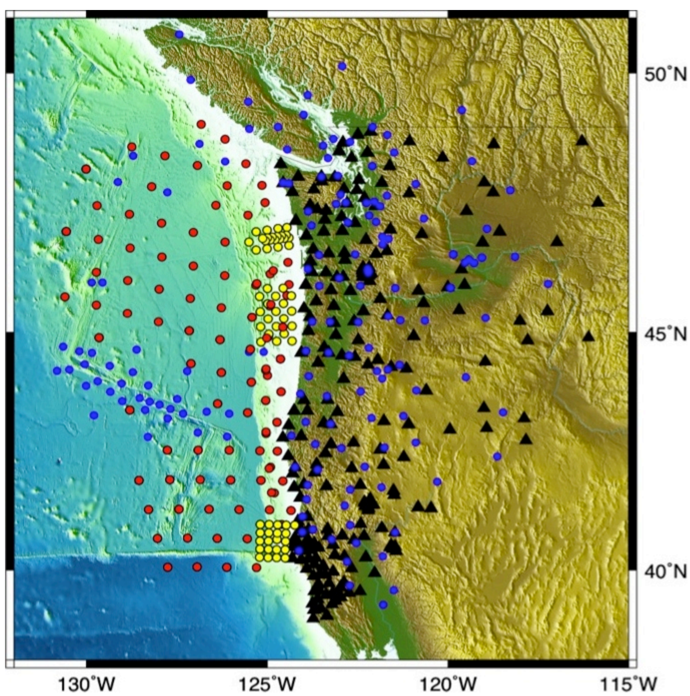


Figure 1. Planned deployments for the ocean portion of the Cascadia Amphibious Array (red and yellow circles), other complementary present/future seismometer deployments (blue circles), and real-time PBO GPS stations (black triangles).

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

Because OBS instruments 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, horizontal orientation of each 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 is calculating the horizontal orientations of the Cascadia instruments for the first year of deployment (Figure 2).

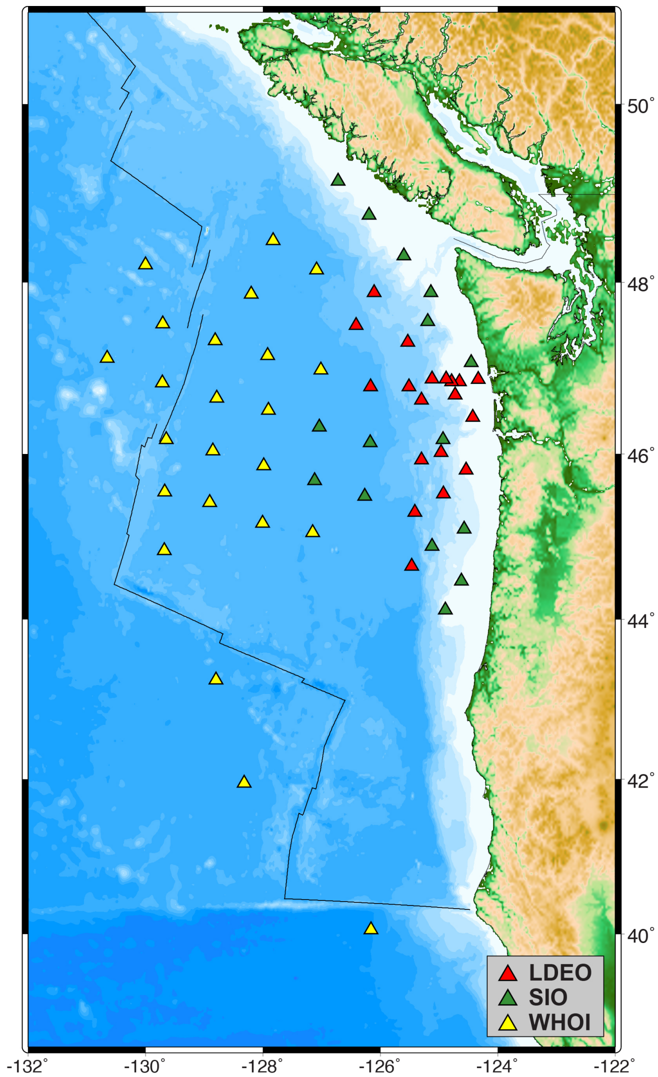


Figure 2. Deployed Cascadia OBS Stations, Year 1

2. Data QA/QC Summary

Continuous waveform data from the OBS deployments are 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.

The 2011-2012 OBS deployments were successful; 22 of 23 WHOI, 10 of 19 LDEO, and 12 of 15 SIO stations operated normally during the deployment period. Of note, BH and HH data channels are missing common segments (~10% of the data, depending on the station) that are redacted by the U.S. Navy. Information on this process as well as OBSIP channel naming and orientation conventions used in the Cascadia OBS instruments can be found in Appendix A.

2.1. Station Deployment and Performance

2.1.1. WHOI Stations

Twenty-three seismometers were deployed between late November 2011 and mid-May 2012 (Table 1). These OBS stations operated exclusively in deep water, at least 2.5 km below sea-level. Each station recorded BH (50 samples/second, redacted), BX (filtered above 4 Hz), and LH (1 sample/second) channels. The vertical component of station J48A failed following deployment, but its horizontal channels appear to have behaved normally. As such, the seismometer is unable to be oriented using the methods applied here.

Table 1. Deployed Cascadia WHOI Stations, Year 1. (TC=Trilium Compact)

Station	Start	End	Lat.	Lon.	Depth	Instrument
G03A	11/17/11	5/13/12	40.06	-126.16	-4113	Guralp CMG3T
G30A	11/18/11	5/14/12	41.96	-128.32	-3124	Guralp CMG3T
J06A	11/19/11	5/14/12	43.25	-128.80	-3224	Guralp CMG3T
J23A	11/21/11	5/15/12	44.84	-129.68	-2655	Guralp CMG3T
J28A	11/16/11	5/16/12	45.06	-127.16	-2867	Guralp CMG3T
J29A	11/20/11	5/16/12	45.18	-128.01	-2849	Nanometrics TC
J30A	11/20/11	5/15/12	45.42	-128.91	-2824	Nanometrics TC
J31A	11/21/11	5/16/12	45.55	-129.67	-2657	Nanometrics TC
J37A	11/28/11	5/16/12	45.86	-127.99	-2862	Nanometrics TC
J38A	11/23/11	5/17/12	46.04	-128.85	-2734	Nanometrics TC
J39A	11/22/11	5/17/12	46.18	-129.64	-2659	Nanometrics TC
J45A	11/28/11	5/18/12	46.52	-127.90	-2757	Nanometrics TC
J46A	11/23/11	5/18/12	46.66	-128.79	-2744	Guralp CMG3T
J47A	11/23/11	5/17/12	46.84	-129.71	-2685	Nanometrics TC
J48A	11/23/11	5/17/12	47.13	-130.65	-2973	Guralp CMG3T
J52A	11/28/11	5/18/12	46.99	-127.02	-2613	Nanometrics TC
J53A	11/28/11	5/18/12	47.16	-127.92	-2686	Guralp CMG3T
J54A	11/27/11	5/18/12	47.34	-128.81	-2662	Nanometrics TC
J55A	11/24/11	5/19/12	47.53	-129.71	-2800	Nanometrics TC
J61A	11/27/11	5/20/12	47.87	-128.20	-2644	Nanometrics TC
J63A	11/25/11	5/19/12	48.21	-130.00	-2882	Guralp CMG3T
J67A	11/26/11	5/19/12	48.15	-127.08	-2612	Nanometrics TC
J68A	11/25/11	5/19/12	48.48	-127.83	-2590	Guralp CMG3T

2.1.2. LDEO Stations

Nineteen seismometers were deployed in late July and mid-October 2011 and recovered in July and August 2012 (Table 2). These OBS stations operated in both shallow and deep-water environments, with some stations employing a trawl-resistant design and residing at less than 200 meters depth. Each station recorded HH channels (125 samples/second, redacted). Several stations experienced significant difficulties during the deployment, including several of the shallow water stations. The HH2 component of station M06A failed, and thus that station is unable to be oriented.

Table 2. LDEO Stations, Year 1.

Station	Start	End	Lat.	Lon.	Depth	Instrument	Note
FN01A	7/27/11	7/21/12	46.88	-124.33	-54	Nanometrics TC	Trawl-Resistant
FN05A	7/29/11	1/10/12	46.86	-124.66	-124	Nanometrics TC	Trawl-Resistant
FN07A	7/28/11	7/20/12	46.86	-124.79	-154	Nanometrics TC	Trawl-Resistant
FN08A	7/29/11	7/22/12	46.89	-124.88	-177	Nanometrics TC	Trawl-Resistant
FN12A	7/27/11	7/20/12	46.89	-125.12	-650	Nanometrics TC	Trawl-Resistant
FN14A	7/31/11	7/20/12	46.02	-124.96	-173	Nanometrics TC	Trawl-Resistant
FN16A	10/17/11	7/21/12	46.80	-125.52	-1907	Nanometrics TC	
FN18A	7/30/11	7/18/12	46.70	-124.72	-163	Nanometrics TC	Trawl-Resistant
J26A	10/21/11	7/15/12	44.65	-125.47	-2864	Nanometrics TC	
J34A	10/16/11	7/17/12	45.31	-125.41	-2574	Nanometrics TC	
J41A	7/25/11	7/13/12	45.81	-124.54	-175	Nanometrics TC	Trawl-Resistant
J42A	10/16/11	7/17/12	45.93	-125.30	-1540	Nanometrics TC	
J49A	7/26/11	7/13/12	46.44	-124.43	-120	Nanometrics TC	Trawl-Resistant
J50A	10/17/11	7/20/12	46.64	-125.30	-1909	Nanometrics TC	
J51A	10/20/11	8/7/12	46.80	-126.16	-2610	Nanometrics TC	
J58A	10/18/11	7/11/12	47.32	-125.53	-1511	Nanometrics TC	
J59A	10/20/11	7/11/12	47.51	-126.42	-2371	Nanometrics TC	
M03A	10/19/11	7/11/12	47.89	-126.10	-1818	Nanometrics TC	
M06A	10/16/11	7/17/12	45.53	-124.93	-1439	Nanometrics TC	

2.1.3. SIO Stations

Fifteen seismometers constructed by SIO were deployed between mid-October 2011 and mid-July 2012 (Table 3). Like the LDEO stations, the OBS stations operated across a range of depths. Each station contains BH channels recording continuously at 50 samples/second (redacted). Stations M04A and M05A did not record any data during the deployment. Additionally, station M02A appears to have experienced failure on all 3 channels, and thus cannot be oriented.

Table 3. SIO Stations, Year 1.

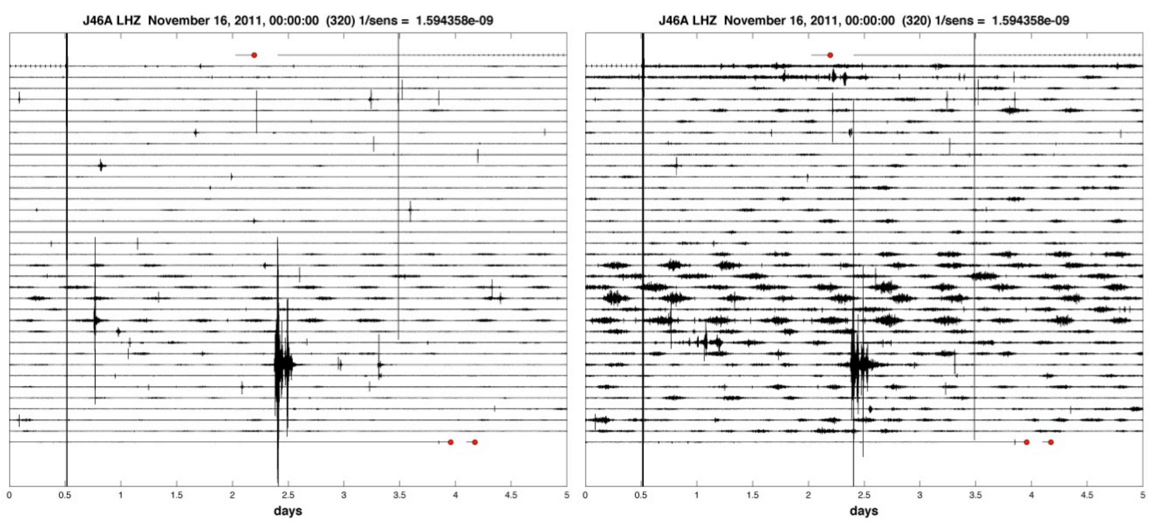
Station	Start	End	Lat.	Lon.	Depth	Instrument
J25A	10/21/11	7/18/12	44.47	-124.62	-143	Nanometrics TC
J33A	10/16/11	7/19/12	45.11	-124.57	-349	Nanometrics TC
J35A	10/19/11	7/18/12	45.50	-126.27	-2662	Nanometrics TC
J36A	10/19/11	7/18/12	45.69	-127.12	-2821	Nanometrics TC
J43A	10/19/11	7/17/12	46.14	-126.17	-2654	Nanometrics TC
J44A	10/19/11	7/18/12	46.32	-127.04	-2724	Nanometrics TC
J57A	10/17/11	7/15/12	47.08	-124.45	-56	Nanometrics TC

J65A	10/17/11	7/16/12	47.89	-125.14	-165	Nanometrics TC
J73A	10/18/11	7/17/12	48.77	-126.19	-143	Nanometrics TC
M01A	10/18/11	7/16/12	49.15	-126.72	-133	Nanometrics TC
M02A	10/18/11	7/16/12	48.31	-125.60	-139	Nanometrics TC
M04A	10/17/11	7/16/12	47.56	-125.19	-563	Nanometrics TC
M05A	10/17/11	7/15/12	46.17	-124.93	-828	Nanometrics TC
M07A	10/15/11	7/15/12	44.90	-125.12	-1357	Nanometrics TC
M08A	10/20/11	7/18/12	44.12	-124.90	-126	Nanometrics TC

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 sensitivity of the instrument, obtained from the metadata ("Stage 0" in SEED nomenclature), and the gain at horizontal channels is further reduced by an order of magnitude relative to the vertical for easier comparison. Arrivals from teleseismic earthquakes are regularly seen on the vertical channel, the April 11, 2012 M8.6 Indian Ocean earthquake and its M8.2 aftershock being most prominent (Figures 3 and 4). 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. Helicorder plots from LDEO and SIO stations utilize data from the redacted channels, demonstrating the gaps in coverage consistent with this process. Additionally, these show the effects of signal processing related to using noncontinuous data. All helicorder plots are compiled for reference in Appendix B.



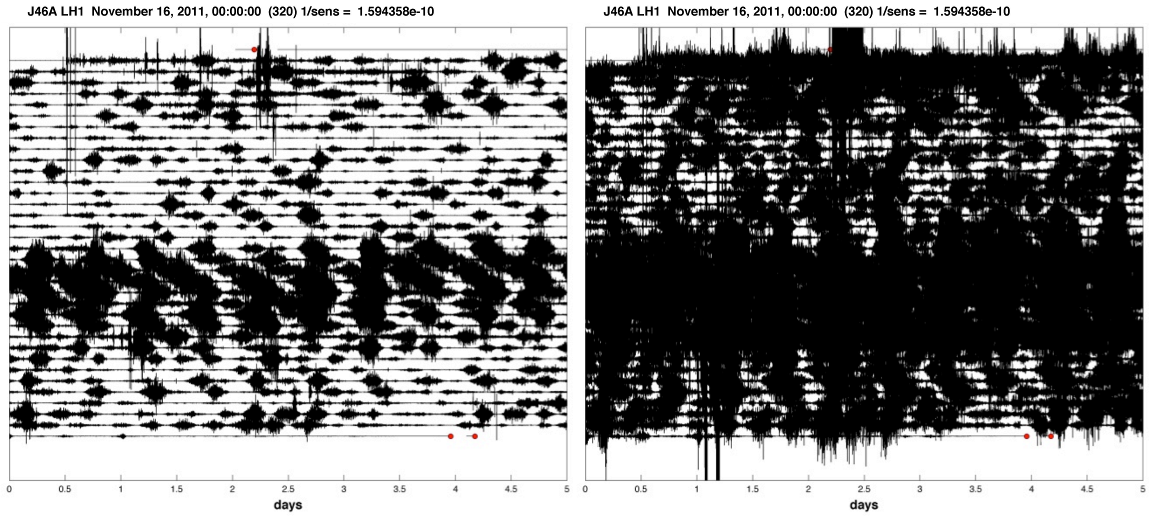
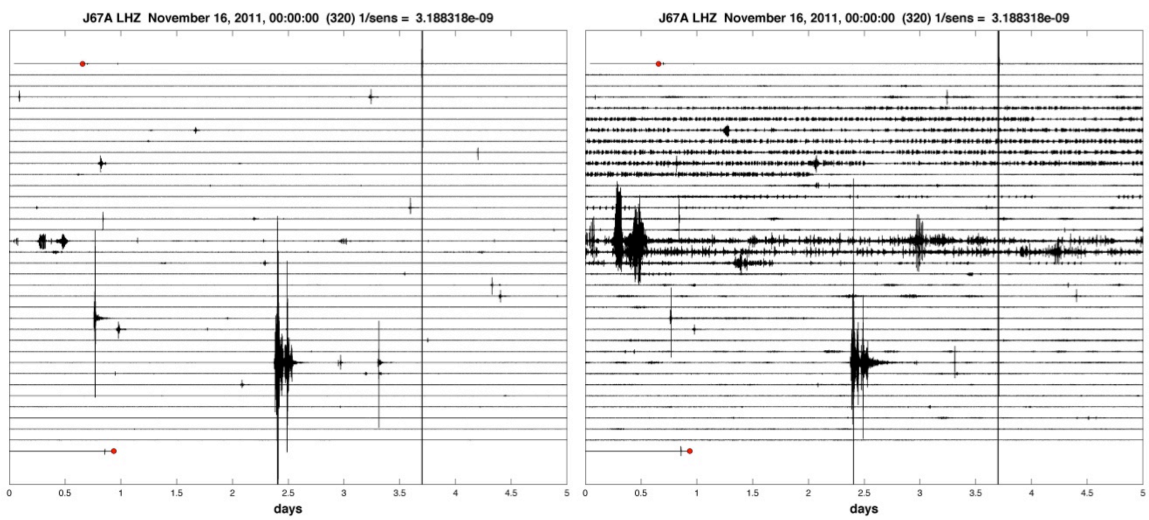


Figure 3. Helicorder plots for low (left) and high (right) bands for a WHOI station. Long period diurnal noise is constant but grows in intensity during the winter, possibly amplified by storm activity. The Indian Ocean earthquake appears prominently on the LHZ channel (top).



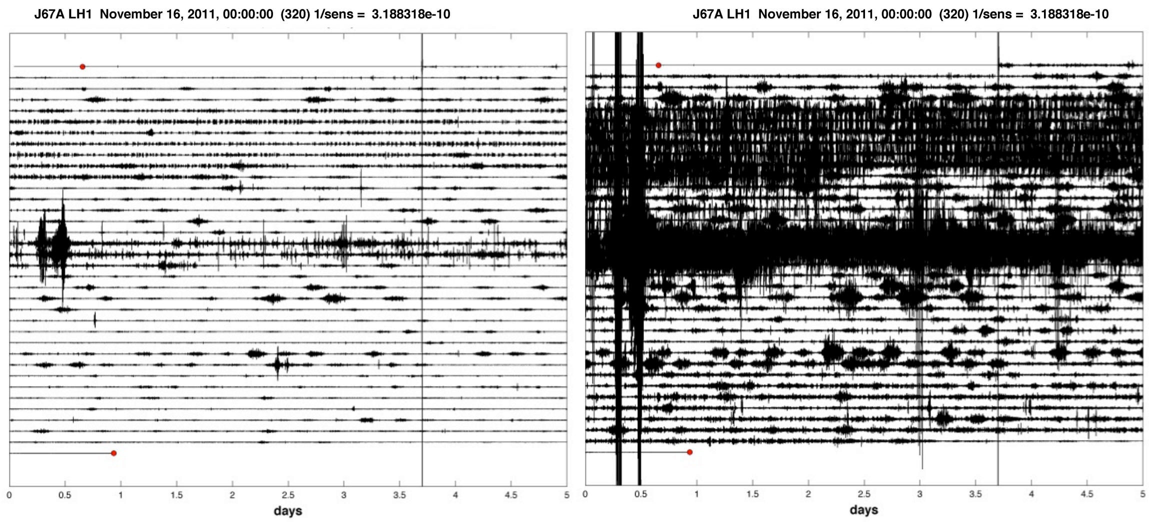


Figure 4. Some stations (units built for the Cascadia deployment) show bursts of possibly instrument-related noise on all channels for durations of days to weeks.

2.2.2. Power Spectra

Probability density functions (PDFs) produced from power spectral density (PSD) 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 model (Peterson, 1993) at intermediate and long periods for the horizontal channels and are also generally noisy, though sometimes below the high noise model, 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. WHOI stations demonstrate an average higher (10-20 dB) noise floor than their LDEO and SIO counterparts (Figures 7-9). This is explained by the seasonal bias of the WHOI deployment, in which all stations were operated during the winter and spring only while the other deployments extended into the summer.

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). All PDF-PSD plots are compiled in Appendix C.

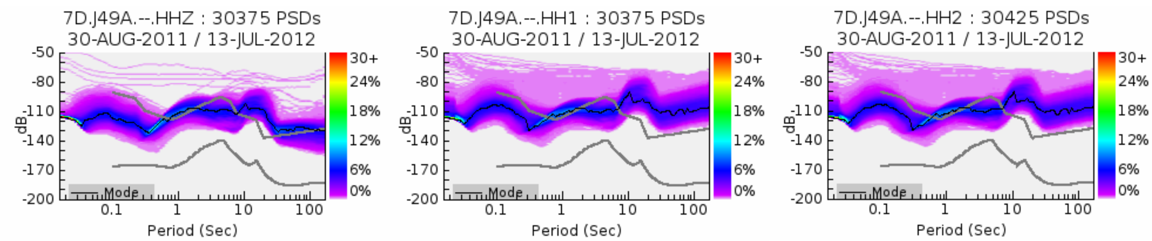


Figure 5. Typical PDF-PSD plots for LDEO trawl-resistant OBS deployed in shallow water (-120 m depth).

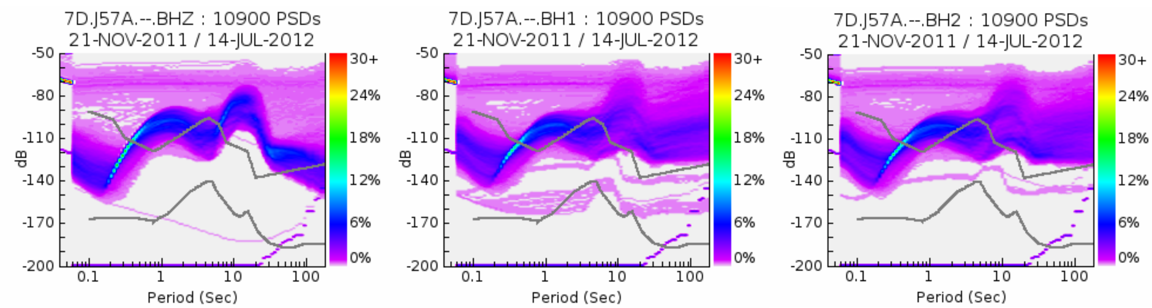


Figure 6. SIO OBS deployed in shallow water (-55 m).

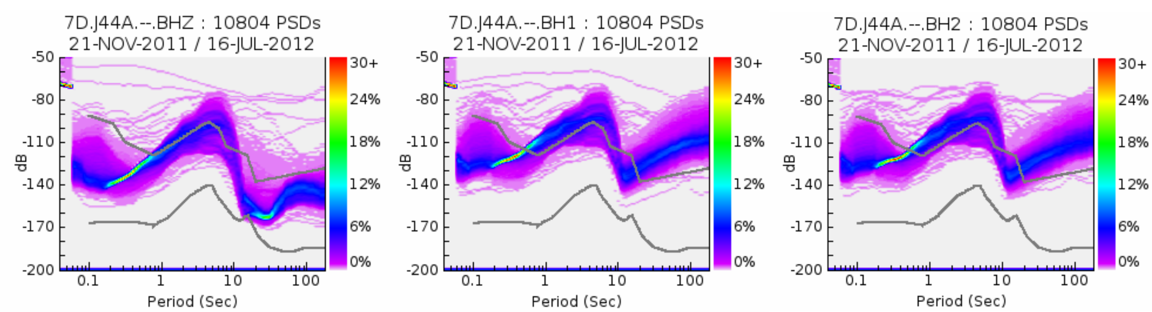


Figure 7. SIO OBS deployed in deep water (-2724 m).

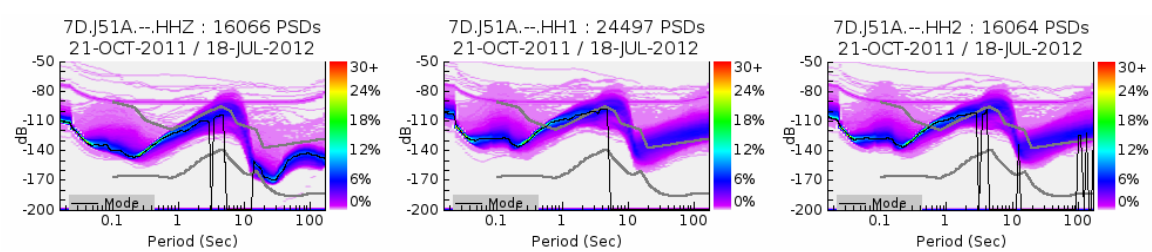


Figure 8. LDEO OBS deployed in deep water (-2610 m).

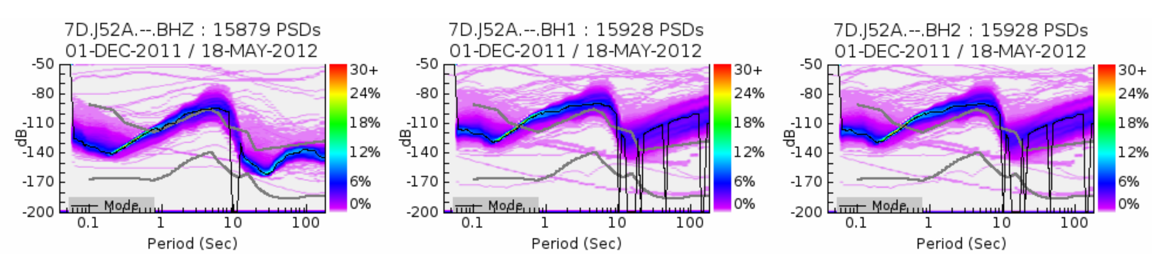


Figure 9. WHOI OBS deployed in deep water (-2613 m).

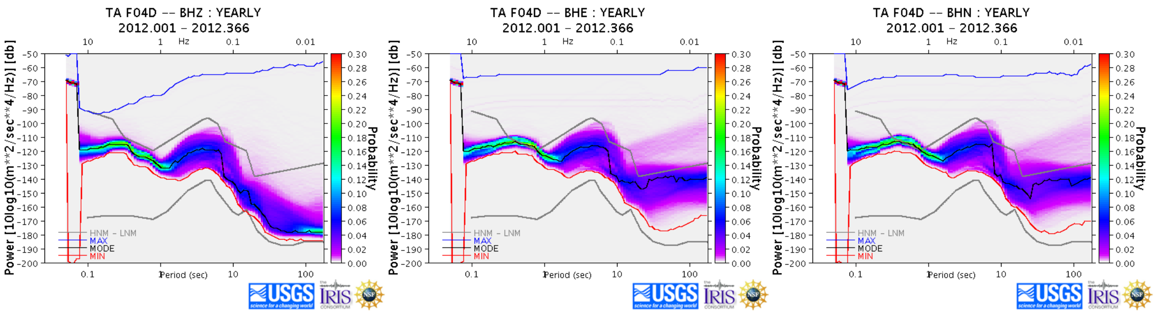


Figure 10. Cascadia TA station F04D, Columbia River.

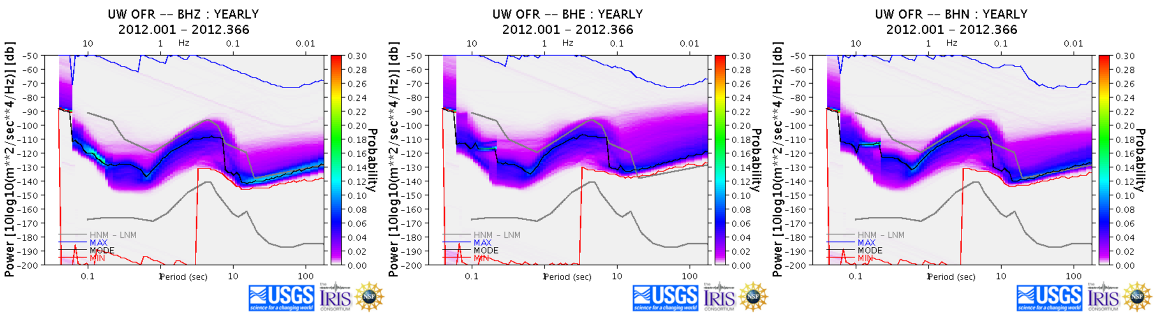


Figure 11. UW network station OFR, Olympic Peninsula.

3. Horizontal Orientation Processing

3.1. General Method

We use the polarization of surface waves from large teleseismic earthquakes to calculate the true horizontal orientation of Cascadia OBS stations. Our process implements the algorithm developed for an assessment of orientations for a recent OBS deployment (Stachnik, et al., 2012). We select all 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 (Figure 12).

Many 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. Because of this and an overall lower number of available events compared to the dataset of Stachnik et al. (2012), we choose a simpler and more interactive statistical analysis. In the first version of this report, we qualitatively evaluated each waveform during processing to flag events. Individual measurements are ranked as bad (low correlation, noisy waveform), questionable (high correlation, clear waveform, but unequal component amplitudes after rotation), and good (high correlation, clear waveform and approximately equal amplitudes). In the second version of the report, we have moved to an automated quality rating for seismograms.

3.2. Automatic Quality Rating of Seismograms

After running the horizontal orientation code in an interactive mode, an option to automate the quality rating of seismograms was added to the code to reduce the amount of time needed to generate horizontal orientations. For each event, the correlation coefficient is plotted as a function of the ideal estimated orientation. If the correlation coefficient was lower than 0.8, it was ranked as a bad measurement. If the correlation coefficient was higher than 0.8, it was ranked as a good measurement.

The automated method should only be used when there are a large number of events for a station. For stations with a small number of events recorded, the interactive method should still be used.

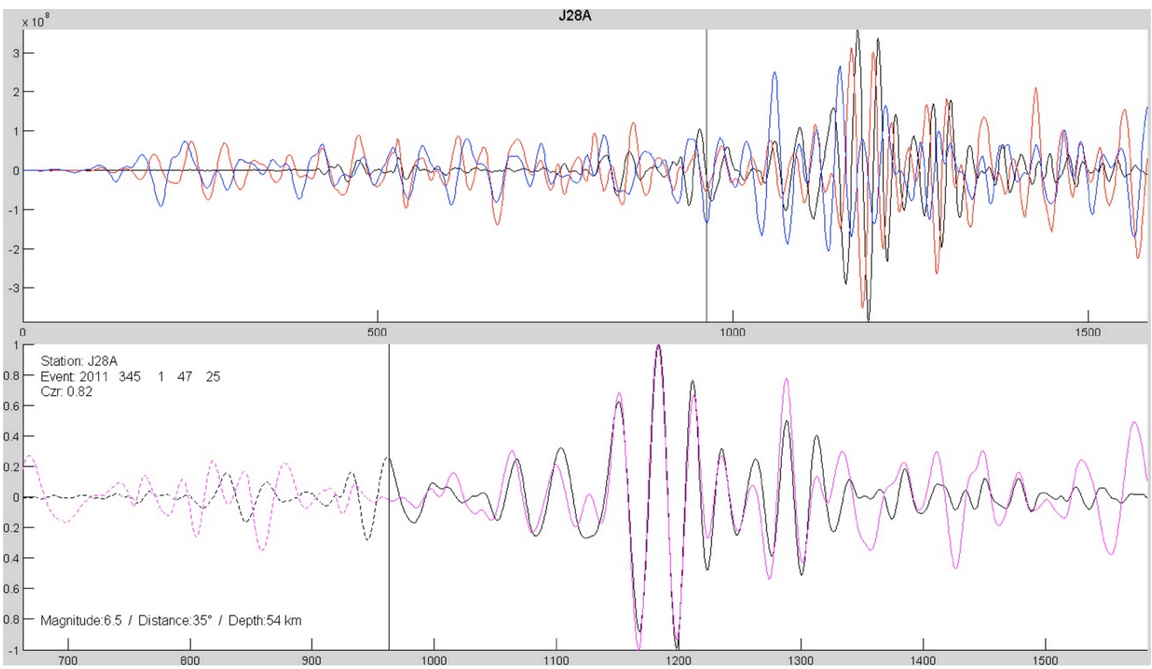


Figure 12. A "good" event with high correlation and ideal waveform appearance. The interactive viewer displays the normalized Hilbert transformed vertical channel and the calculated radial channel for the highest correlation. The top panel shows the filtered time series for BH1 (blue), BH2 (red), and BHZ (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 to the right of the black vertical line encompasses the surface wave arrival and is used for the analysis.

4. Horizontal Orientation Results

We see a larger range of orientation estimates and fewer high correlation measurements compared to the reference OBS study (Stachnik, et al., 2012). Cascadia OBS stations yield between 1 and 24 useable measurements. Deep-water stations produce more reliable estimates due to the generally lower noise levels at intermediate and long periods (Figure 13). The median and mean 2σ standard deviations for WHOI stations are 11° and 10° respectively. For LDEO stations the median and mean are 22° and 26° and for SIO stations they are 13° and 25°.

Most deep-water 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. All estimated orientations for each station for are provided in Appendix D.

4.1. Corrected 2011-2012 (Year 1) Results

The CI data was re-uploaded to the IRIS DMC on 3/20/14 to make all the relative orientation of the horizontal components consistent. The horizontal orientations of the stations were re-calculated after the data was re-uploaded. For more details about the relative orientations before and after the data was re-uploaded, see Appendix E.

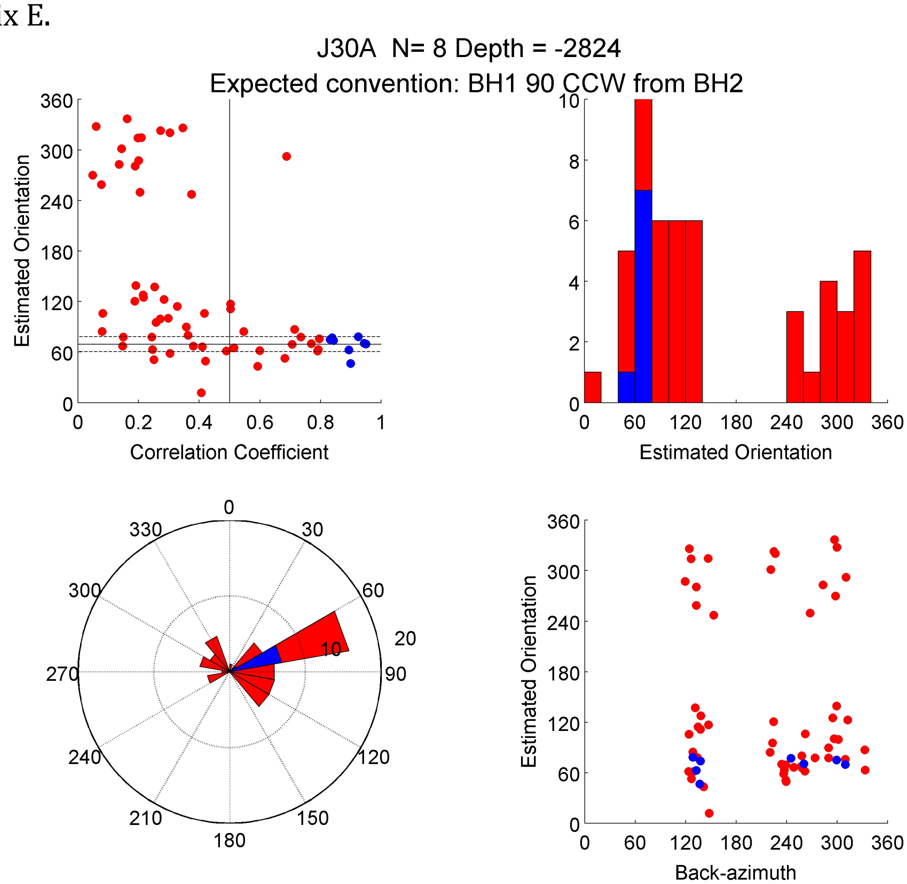


Figure 13. Orientation estimates; subplots show correlation coefficient vs. estimated orientation with mean value and uncertainty range (top-left), standard histogram of estimated orientation (top-right), polar histogram of estimated orientation (bottom-left), and earthquake back azimuth vs. estimated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

4.1.1. 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. Several stations had data of insufficient quality to calculate an orientation.

Station	ϕ (°)	2σ (±°)	N
FN01A	N/A	N/A	N/A
FN05A	6	N/A	1
FN07A	118	N/A	12
FN08A	128	55	4
FN12A	312	N/A	1
FN14A	347	44	17
FN16A	201	22	15
FN18A	296	56	8
J26A	N/A	N/A	N/A
J34A	N/A	N/A	N/A
J41A	60	33	11
J42A	83	5	5
J49A	291	13	14
J50A	93	23	65
J51A	133	27	26
J58A	190	13	6
J59A	109	11	15
M03A	161	13	11
M06A	N/A	N/A	N/A

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. Failure of M02A prevented an orientation estimate for that station.

Station	ϕ (°)	2σ (±°)	N
J25A	145	82	2
J33A	12	24	5
J35A	202	8	23
J36A	37	7	15
J43A	82	8	28
J44A	207	8	12
J57A	157	79	2
J65A	51	12	2
J73A	16	32	2
M01A	100	25	5
M02A	N/A	N/A	N/A
M07A	91	14	18
M08A	8	7	3

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. Failure of the vertical channel at J48A prevented an orientation estimate for that station.

Station	ϕ (°)	2σ (±°)	N
G03A	154	5	4
G30A	140	2	5
J06A	225	6	5
J23A	114	11	5
J28A	206	12	4
J29A	74	13	7
J30A	69	9	8
J31A	5	11	7
J37A	264	9	11
J38A	101	14	7
J39A	323	13	9
J45A	12	10	13
J46A	254	14	4
J47A	247	14	9
J48A	N/A	N/A	N/A
J52A	253	11	11
J53A	149	13	2
J54A	27	9	6
J55A	211	12	4
J61A	257	6	6
J63A	165	8	3
J67A	138	5	5
J68A	158	20	4

5. OBS Orientation Code Package

The software developed by Stachnik et al. (2012) for determining OBS orientations is written in Perl to use ASCII input and currently available online (http://research.flyrok.org/software.html). The interactive routine developed for this report runs in MATLAB with SAC formatted data for each channel. 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

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Appendix A - Understanding OBSIP Data

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

Land Seismograph	Ocean Bottom Seismograph
Real-time data	Stored data
Real-time corrected clocks	Post-deployment corrected clocks
Measured sensor orientation	Empirical sensor orientation
Typically uses traditional orientation code in SEED channel name	Uses non-traditional orientation code in SEED channel name

Ocean Bottom Seismographs are deployed in extremely remote regions of the world. The subsea environment 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

OBS's 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, horizontal orientation of the OBS must be determined from the 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 Principle Investigator.

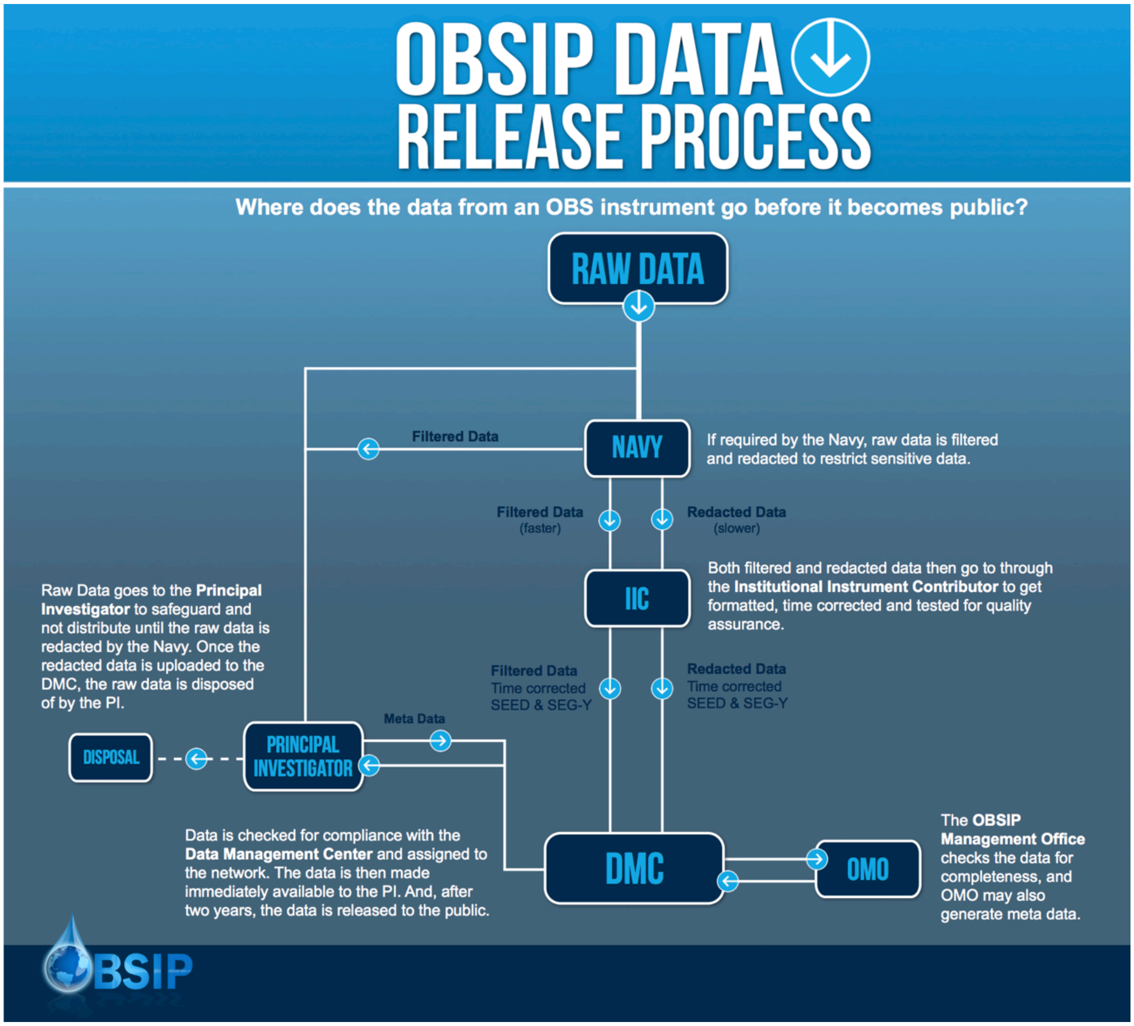
The community design and implementation of the Cascadia project sets it apart from traditional NSF-funded projects. With no "Principal Investigator" there is no single user of the OBS data that is initially funded to perform basic data processing. In an effort to make the Cascadia dataset available and useful to the widest possible number of investigators, the OBSIP Management Office is calculating the horizontal orientations of the Cascadia instruments for the first 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 4Hz - 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.

When the Cascadia Initiative data was first uploaded, the relative orientation of the horizontal components varied between the three IICs. The CI data was re-uploaded to the IRIS DMC on 5/2/14 to make all of the relative orientation of the horizontal components consistent. All Cascadia instruments now have a "left handed" orientation where the BH2/HH2 channel is oriented 90° clockwise of BH1/HH1.

For more details about the relative orientations before and after the data was re-uploaded, see Appendix E.

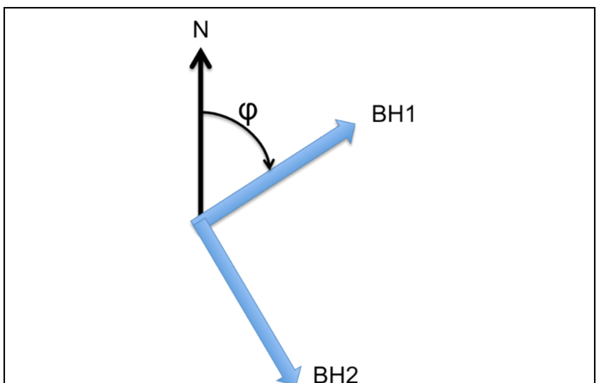


Illustration of the relative orientation of horizontal components for data collected for the Cascadia Initiative. The default header value for the BH1/HH1 and BH2/HH2 azimuths are 0° and 0°. The values of ϕ are determined empirically and are reported in Tables 4, 5, and 6 of this report.

Appendix B - Helicorder Plots

Appendix C - PDF-PSD Plots

Appendix D - Orientation Results

Appendix E – Data Re-upload and Horizontal Convention Change