



# **Cascadia Amphibious Array Ocean Bottom Seismograph Horizontal Component Orientations**

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**2012-2013 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 J. Lodewyk	5/2/2014

## 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. The 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/>

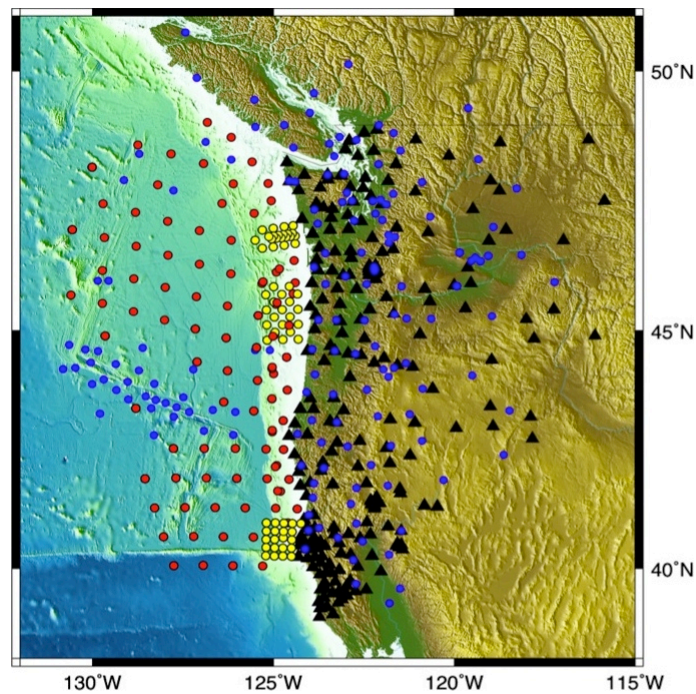


Figure 1. Planned deployments for the ocean portion of the Cascadia Amphibious Array (red and yellow circles), other complementary present/future seismometer deployments (blue circles), and real-time PBO GPS stations (black triangles).

The community design and implementation of the Cascadia project sets it apart from "Principle 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 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 (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 year of deployment (see Horizontal Orientations Report: Year 1 at <http://www.obsip.org/data/obs-horizontal-orientation/>) This report also provides corrected results from Year 1 report as well as providing results from an automated method.

The second year of deployment was completed in the summer of 2013. The OBSIP Management Office also calculated the horizontal orientations of the Cascadia instruments for the second year of deployment (Figure 2).

## 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>.

The 2012-2013 OBS deployments were successful, 24/24 WHOI and 15/15 SIO stations operated as intended during the deployment period. The LDEO stations had a systematic battery problem (due to a switched diode) that led to the LDEO stations running on a backup battery for around the last one-third of their deployment. Data was recorded during this time, but will only be useful for some research purposes. 24/30 of the LDEO stations operated as intended until the battery failure. The channel uptime and a qualitative quality rating of the data is shown in Figure 3.

Of note to land-users, 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.

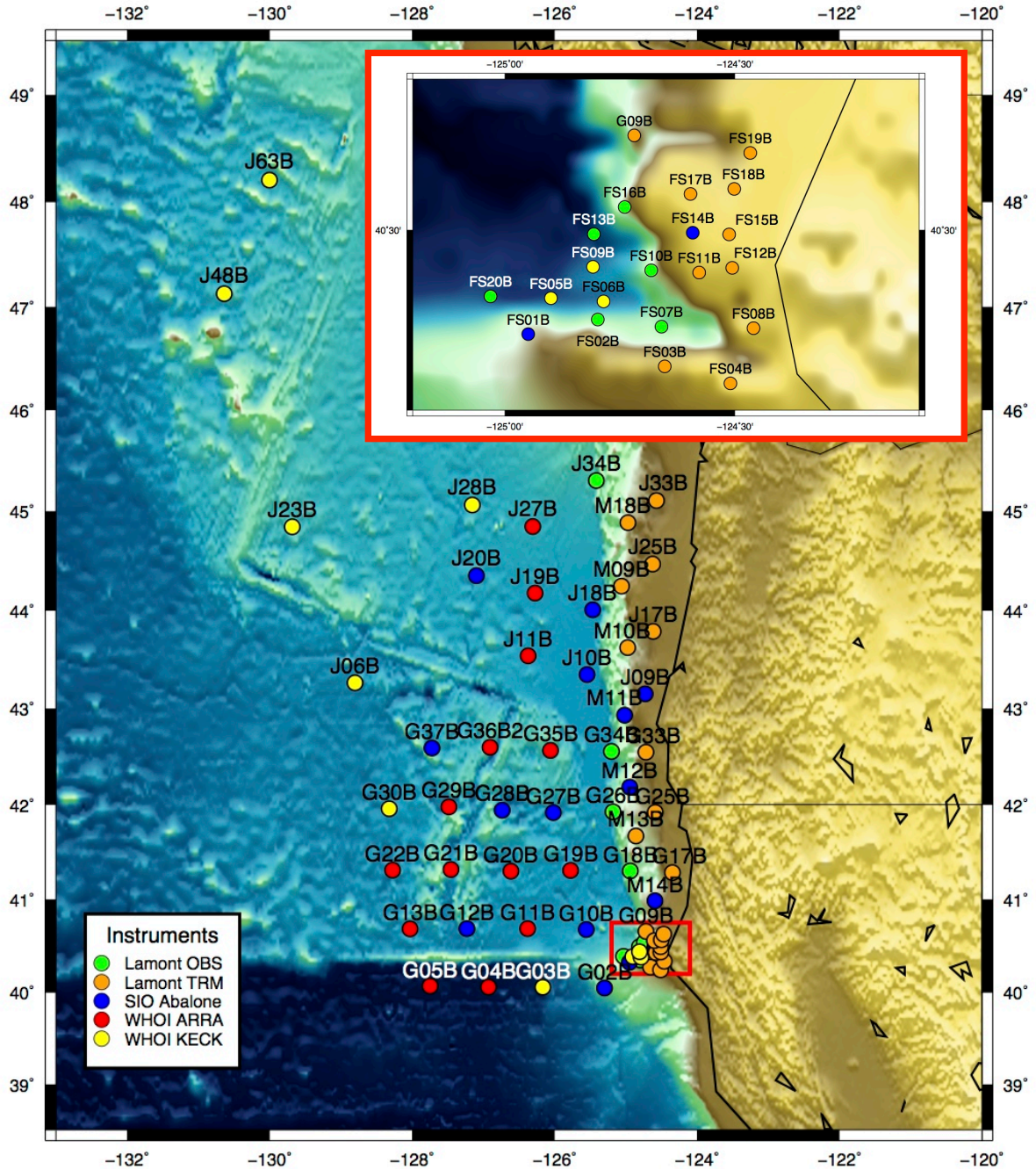


Figure 2. 2012-2013 Deployed Cascadia OBS Stations, Year 2

## 2.1. Station Deployment and Performance

### 2.1.1. LDEO Stations

Thirty seismometers were deployed between mid July 2012 and early July 2013 (Table 1). 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). No LDEO stations were of interest to the Navy. There

was significant loss of data at the end of the deployment when the battery power failed. There were also several stations that experienced general problems. FS08B, G33B, J17B, M10B, M13B, and M18B experienced failure on all channels during deployment and the horizontal orientations were unable to be determined.

**Table 1. Deployed Cascadia LDEO Stations, 2012-2013. (TC=Trilium Compact)**

<b>Station</b>	<b>Start</b>	<b>End</b>	<b>Lat.</b>	<b>Long.</b>	<b>Depth</b>	<b>Instrument</b>	<b>Note</b>
FS02B	9/14/12	7/1/13	40.35	-124.80	1402.8	Nanometrics TC	
FS03B	9/14/12	7/1/13	40.27	-124.65	345.0	Nanometrics TC	Trawl Resistant
FS04B	9/14/12	7/1/13	40.24	-124.51	159.0	Nanometrics TC	Trawl Resistant
FS07B	9/13/12	7/3/13	40.34	-124.66	1297.2	Nanometrics TC	
FS08B	9/14/12	7/2/13	40.34	-124.46	120.0	Nanometrics TC	Trawl Resistant
FS10B	9/13/12	7/2/13	40.43	-124.68	1075.7	Nanometrics TC	
FS11B	9/15/12	7/2/13	40.43	-124.58	132.0	Nanometrics TC	Trawl Resistant
FS12B	9/15/12	7/2/13	40.44	-124.51	60.0	Nanometrics TC	Trawl Resistant
FS13B	9/13/12	7/3/13	40.49	-124.81	2332.2	Nanometrics TC	
FS15B	9/13/12	7/2/13	40.49	-124.51	52.0	Nanometrics TC	Trawl Resistant
FS16B	9/13/12	7/3/13	40.54	-124.74	1073.2	Nanometrics TC	
FS17B	9/16/12	7/2/13	40.56	-124.60	146.0	Nanometrics TC	Trawl Resistant
FS18B	9/16/12	7/1/13	40.57	-124.50	107.0	Nanometrics TC	Trawl Resistant
FS19B	9/17/12	7/1/13	40.63	-124.47	87.0	Nanometrics TC	Trawl Resistant
FS20B	9/12/12	7/3/13	40.39	-125.03	2377.9	Nanometrics TC	
G09B	9/17/12	6/30/13	40.66	-124.72	842.0	Nanometrics TC	Trawl Resistant
G17B	9/17/12	6/30/13	41.28	-124.34	123.0	Nanometrics TC	
G18B	9/18/12	7/5/13	41.30	-124.94	1463.6	Nanometrics TC	
G25B	9/18/12	6/29/13	41.92	-124.59	430.4	Nanometrics TC	Trawl Resistant
G26B	9/18/12	7/5/13	41.92	-125.18	2356.8	Nanometrics TC	
G33B	9/19/12	6/29/13	42.55	-124.72	213.0	Nanometrics TC	Trawl Resistant
G34B	9/12/12	7/5/13	42.56	-125.20	2953.5	Nanometrics TC	
J17B	7/16/12	6/28/13	43.79	-124.61	286.0	Nanometrics TC	Trawl Resistant
J25B	7/15/12	6/27/13	44.47	-124.62	147.0	Nanometrics TC	Trawl Resistant
J33B	7/15/12	6/26/13	45.11	-124.57	350.0	Nanometrics TC	Trawl Resistant
J34B	9/19/12	6/26/13	45.31	-125.41	2583.1	Nanometrics TC	
M09B	7/17/12	6/28/13	44.25	-125.06	914.0	Nanometrics TC	Trawl Resistant
M10B	7/16/12	6/29/13	43.62	-124.97	675.0	Nanometrics TC	Trawl Resistant
M13B	9/18/12	6/30/13	41.67	-124.86	908.9	Nanometrics TC	Trawl Resistant
M18B	7/14/12	6/27/13	44.89	-124.97	720.0	Nanometrics TC	Trawl Resistant

### 2.1.2. SIO Stations

Fifteen seismometers constructed by SIO were deployed between early September 2012 and mid June 2013 (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. For stations with Naval redactions a BX (filtered above 3 Hz) channel was generated.

**Table 2. Deployed Cascadia SIO Stations, Year 2012-2013. (TC=Trilium Compact)**

<b>Station</b>	<b>Start</b>	<b>End</b>	<b>Lat.</b>	<b>Long.</b>	<b>Depth</b>	<b>Instrument</b>
FS01B	9/2/12	6/19/13	40.33	-124.95	940.0	Nanometrics TC
FS14B	9/2/12	6/19/13	40.50	-124.59	107.0	Nanometrics TC
G02B	9/2/12	6/19/13	40.05	-125.30	1920.0	Nanometrics TC
G10B	9/2/12	6/19/13	40.68	-125.55	2936.0	Nanometrics TC
G12B	9/3/12	6/20/13	40.69	-127.23	3080.0	Nanometrics TC
G27B	9/4/12	6/20/13	41.92	-126.02	3480.0	Nanometrics TC
G28B	9/4/12	6/20/13	41.94	-126.73	3327.0	Nanometrics TC
G37B	9/4/12	6/20/13	42.59	-127.72	3004.0	Nanometrics TC
J09B	9/1/12	6/21/13	43.15	-124.73	252.0	Nanometrics TC
J10B	9/1/12	6/18/13	43.35	-125.54	3093.0	Nanometrics TC
J18B	9/1/12	6/18/13	44.01	-125.47	3047.0	Nanometrics TC
J20B	9/5/12	6/21/13	44.35	-127.10	2934.0	Nanometrics TC
M11B	9/1/12	6/18/13	42.93	-125.02	1109.0	Nanometrics TC
M12B	9/1/12	6/18/13	42.18	-124.95	1045.0	Nanometrics TC
M14B	9/2/12	6/19/13	40.99	-124.59	638.0	Nanometrics TC

### **2.1.3. WHOI Stations**

Twenty-four seismometers were deployed between late August 2012 and mid June 2013. 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. For stations with Naval redactions a BX (filtered above 3 Hz) channel was generated.

**Table 3. Deployed Cascadia WHOI Stations, Year 2012-2013. (TC=Trilium Compact)**

<b>Station</b>	<b>Start</b>	<b>End</b>	<b>Lat.</b>	<b>Long.</b>	<b>Depth</b>	<b>Instrument</b>
FS05B	8/27/12	6/12/13	40.39	-124.8996	-2316.0	Guralp CMG3T
FS06B	8/27/12	6/12/13	40.38	-124.7853	-2198.0	Guralp CMG3T
FS09B	8/28/12	6/12/13	40.44	-124.8085	-2161.0	Guralp CMG3T
G03B	8/27/12	6/11/13	40.06	-126.1634	-4051.0	Guralp CMG3T
G04B	8/27/12	6/8/13	40.06	-126.9285	-4368.0	Nanometrics TC
G05B	8/27/12	6/8/13	40.07	-127.7478	-4462.0	Nanometrics TC
G11B	8/28/12	6/9/13	40.69	-126.3764	-3123.0	Nanometrics TC
G13B	8/26/12	6/7/13	40.68	-128.0283	-3215.0	Nanometrics TC
G19B	8/28/12	6/13/13	41.31	-125.7736	-3071.0	Nanometrics TC
G20B	8/28/12	6/11/13	41.30	-126.6133	-3141.0	Nanometrics TC
G21B	8/28/12	6/11/13	41.32	-127.4537	-3156.0	Nanometrics TC
G22B	8/26/12	6/7/13	41.31	-128.2740	-3038.0	Nanometrics TC
G29B	8/29/12	6/11/13	41.98	-127.4834	-3197.0	Nanometrics TC
G30B	8/26/12	6/7/13	41.96	-128.3198	-3119.0	Guralp CMG3T
G35B	8/29/12	6/10/13	42.57	-126.0558	-2367.0	Nanometrics TC
G36B2	8/29/12	6/10/13	42.60	-126.9038	-2423.0	Nanometrics TC
J06B	8/26/12	6/7/13	43.27	-128.7997	-3220.0	Guralp CMG3T
J11B	8/30/12	8/10/13	43.54	-126.3700	-3030.0	Nanometrics TC
J19B	8/30/12	6/10/13	44.18	-126.2717	-2968.0	Nanometrics TC
J23B	8/24/12	6/6/13	44.85	-129.6821	-2650.0	Guralp CMG3T
J27B	8/24/12	6/4/13	44.85	-126.3069	-2824.0	Nanometrics TC
J28B	8/24/12	6/4/13	45.06	-127.1552	-2866.0	Guralp CMG3T
J48B	8/25/12	6/6/13	47.13	-130.6385	-2877.0	Guralp CMG3T
J63B	8/25/12	6/5/13	48.21	-130.0019	-2857.0	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. Helicorders 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 the filter. All helicorder plots are compiled 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. WHOI stations demonstrate an average higher (10-20 dB) noise floor than their LDEO and SIO counterparts (Figures 7-9). This may be explained by the design of a glass ball on the instrument. WHOI is currently purchasing feet to install on the instrument package in the hopes of reducing long period horizontal noise.

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 PDFs for LDEO trawl-resistant OBS deployed in shallow water (146 m depth). This station experienced battery failure after 2/12/13. The data from after the battery failure was removed.**

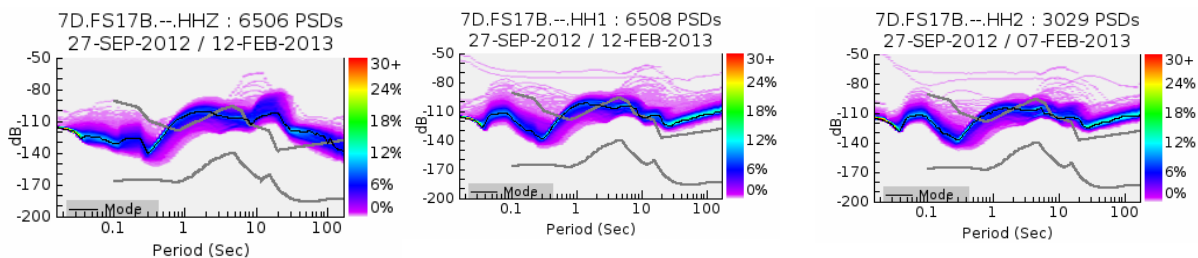


Figure 6. SIO OBS deployed in shallow water (252 m).

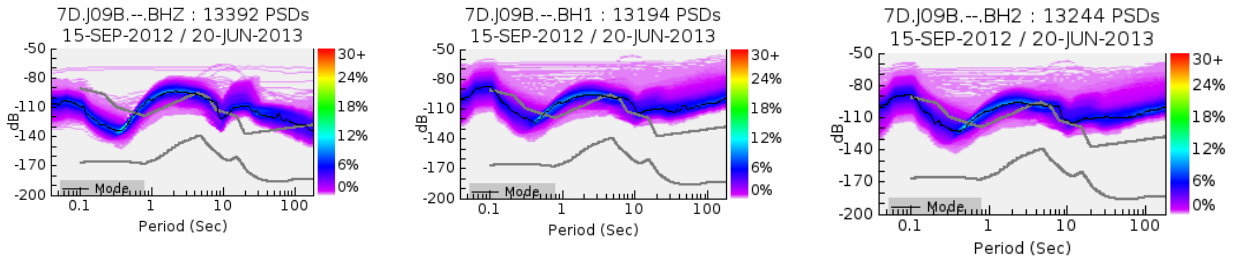


Figure 7. SIO OBS deployed in deep water (3004 m).

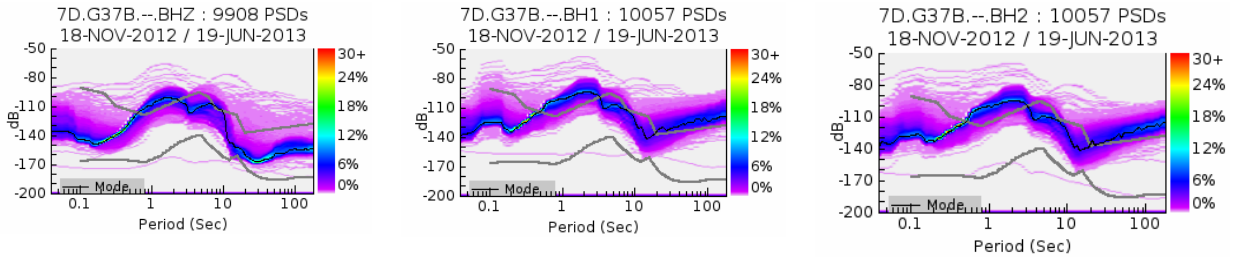


Figure 8. LDEO OBS deployed in deep water (2953 m). This station experienced battery failure after 2/16/13. The data from after the battery failure was removed.

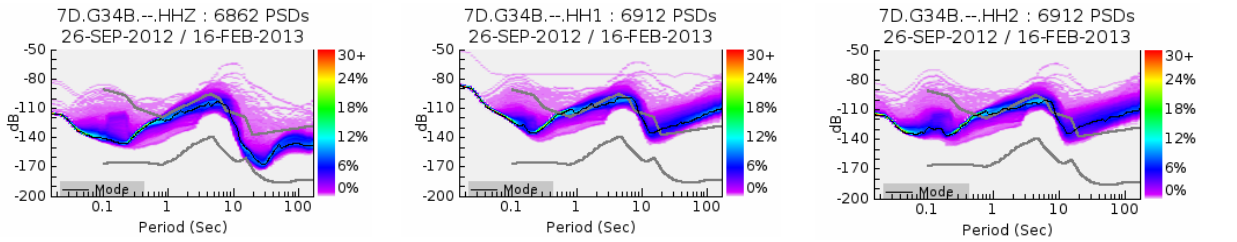


Figure 9. WHOI OBS deployed in deep water (3071 m).

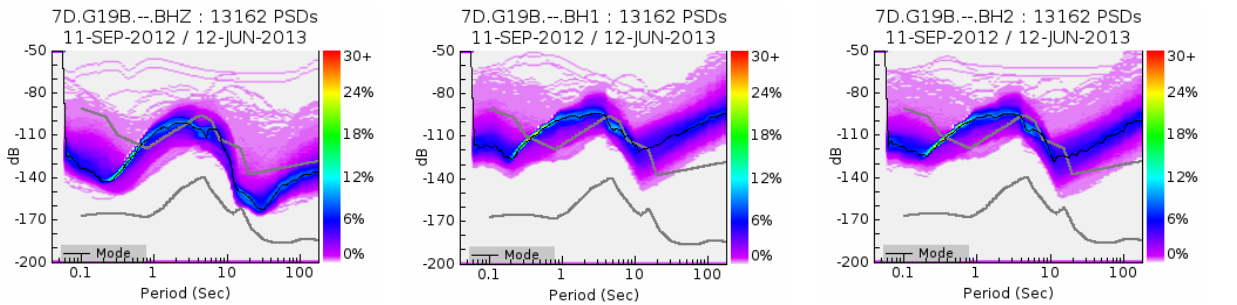


Figure 10. Cascadia TA station F04D, Columbia River for 2012.

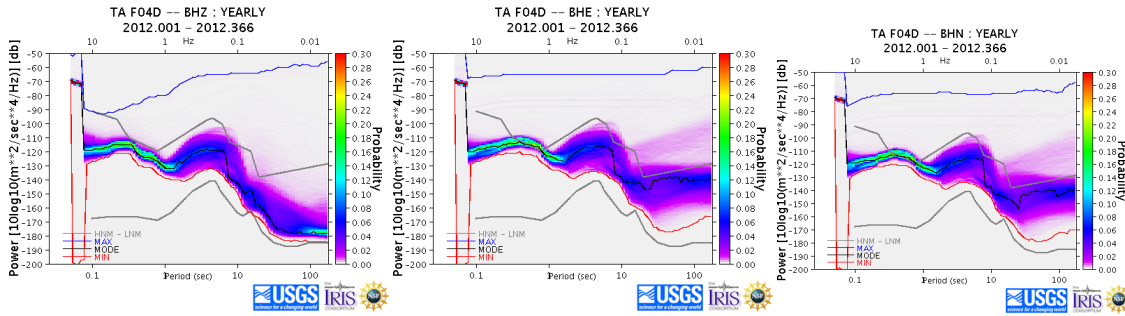
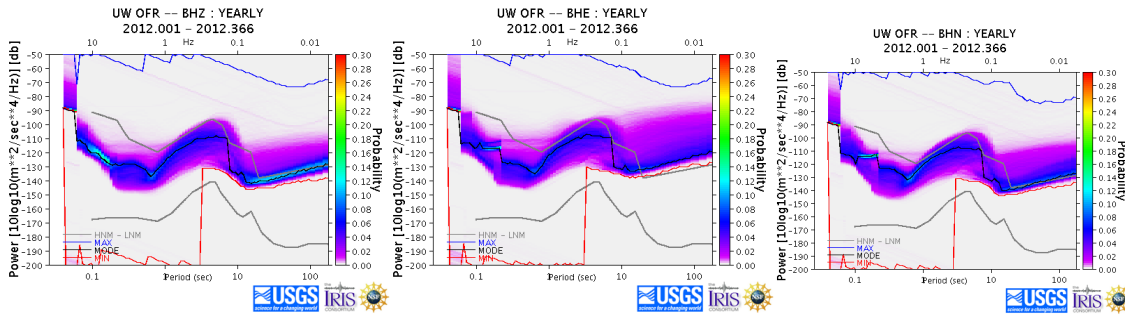


Figure 11. UW network station OFR, Olympic Peninsula for 2012



### 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 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.

#### 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 (BH1/HH1, BH2/HH2, and BHZ/HHZ). In this situation the horizontal orientation code will not make a horizontal orientation estimate.

There are time periods when a station may have a flatlined channel or zeros as the data values on a channel. This results in a correlation value that is 'Not a number'. The 'Not a number' correlations are removed from the station horizontal orientation estimate and plots.

All events with a correlation value over 0.8 are plotted and evaluated. 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**

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.

In the Year 2 horizontal orientation processing, we used an automated approach to the correlation measurement analysis. If the correlation coefficient was lower than 0.8, then it was ranked as a bad measurement. If the correlation coefficient was higher than 0.8, then it was ranked as a good measurement.

## **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 1 and 40 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  $2\sigma$  standard deviations for WHOI stations are  $11^\circ$  and  $14^\circ$  respectively. For LDEO stations the median and mean are  $30^\circ$  and  $35^\circ$  and for SIO stations they are  $15^\circ$  and  $16^\circ$ .

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). All estimated orientations for each station for are provided in Appendix D.

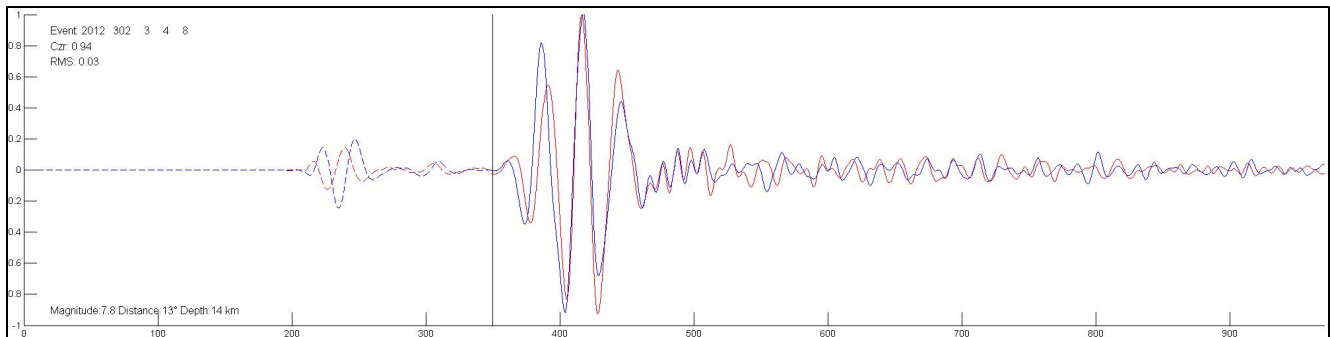
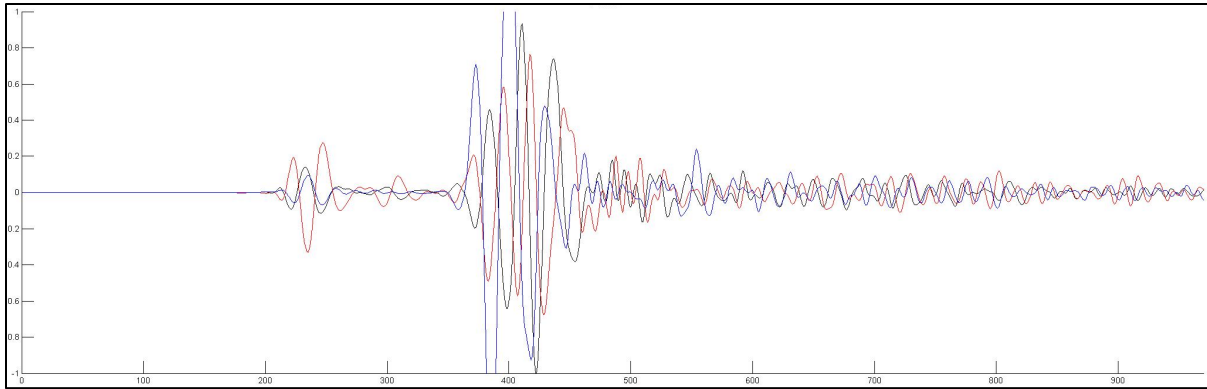


Figure 12. A "good" event with high correlation and ideal waveform appearance. The interactive viewer displays the normalized Hilbert transformed vertical channel and the calculated radial channel for the highest correlation. The top panel shows the filtered time series for HH1 (blue), HH2 (red), and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

## 4.1. 2012- 2013 (Year 2) Results

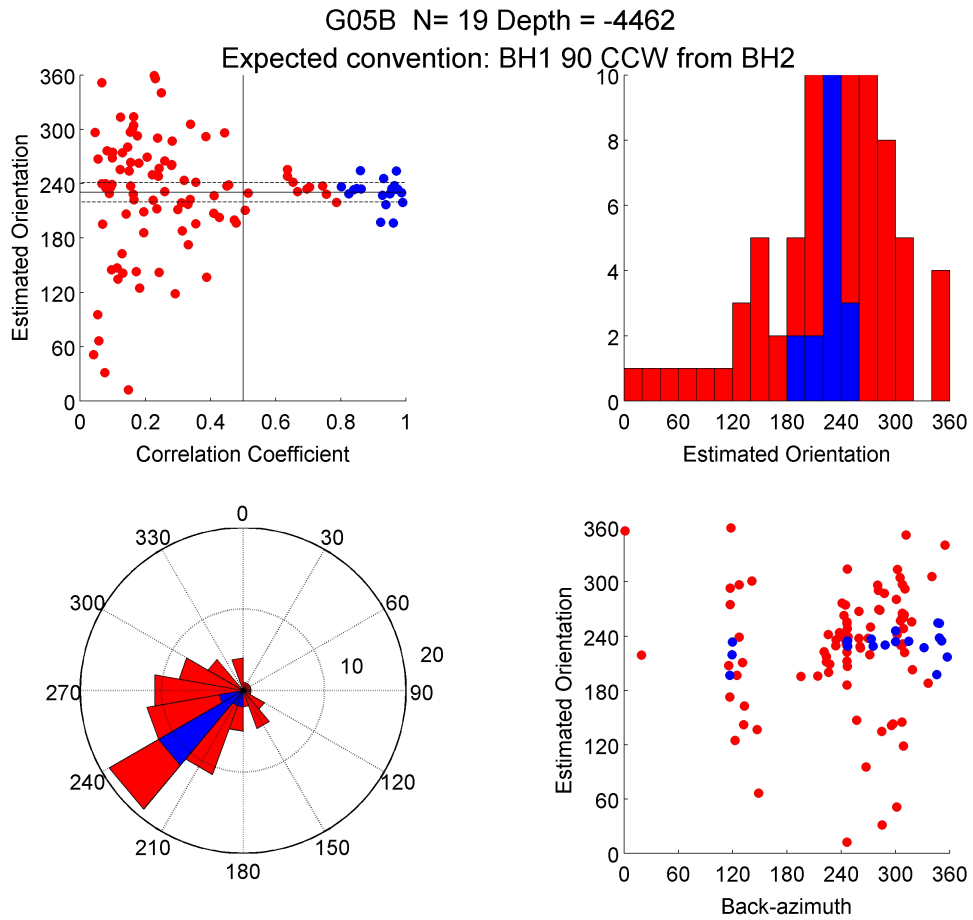
### 4.1.1. LDEO Results

Table 4. Mean true orientations ( $\phi$ ) for HH1 (assuming North= $0^\circ$  and positive measured clockwise), with uncertainties ( $2\sigma$ ), and number of measurements (N) for LDEO stations. HH2 component orientation is  $90^\circ$  clockwise from HH1.

Station	$\phi$ ( $^\circ$ )	$2\sigma$ ( $\pm$ )	N
FS02B	78	60	6
FS03B	N/A	N/A	N/A
FS04B	151	12	12
FS07B	30	N/A	1
FS08B	N/A	N/A	N/A
FS10B	N/A	N/A	N/A
FS11B	202	29	3
FS12B	25	29	16
FS13B	341	30	5
FS15B	141	37	4
FS16B	N/A	N/A	N/A
FS17B	N/A	N/A	N/A
FS18B	47	67	4
FS19B	31	N/A	1
FS20B	0	19	9
G09B	220	12	5

G17B	324	60	10
G18B	221	N/A	1
G25B	334	3	5
G26B	316	50	2
G33B	N/A	N/A	N/A
G34B	151	17	13
J17B	87	N/A	1
J25B	99	81	7
J33B	10	37	10
M09B	98	4	13
M10B	N/A	N/A	N/A
M13B	N/A	N/A	N/A
M18B	N/A	N/A	N/A

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).



#### 4.1.2. SIO Results

Table 5. Mean true orientations ( $\phi$ ) for BH1 (assuming North=0° and positive measured clockwise), with uncertainties ( $2\sigma$ ), and number of measurements (N) for SIO stations. BH2 component orientation is 90° clockwise from BH1.

Station	$\phi$ (°)	$2\sigma$ (±°)	N
FS01B	346	15	23
FS14B	164	51	2
G02B	200	18	33
G10B	133	16	24
G12B	209	21	8
G27B	212	17	27
G28B	161	15	21
G37B	102	13	40
J09B	163	6	3
J10B	89	10	34
J18B	80	1	2
J20B	331	9	35
M11B	201	19	13
M12B	235	15	6
M14B	266	13	7

#### 4.1.3. WHOI Results

Table 6. Mean true orientations ( $\phi$ ) for BH1 (assuming North=0° and positive measured clockwise), with uncertainties ( $2\sigma$ ), and number of measurements (N) for WHOI stations. BH2 component orientation is 90° clockwise from BH1. Failure of the vertical channel at G04B prevented an orientation estimate for that station.

Station	$\phi$ (°)	$2\sigma$ (±°)	N
FS05B	307	11	3
FS06B	331	76	4
FS09B	349	25	3
G03B	29	8	4
G04B	N/A	N/A	N/A
G05B	231	11	19
G11B	39	15	19
G13B	225	13	17
G19B	79	14	12
G20B	3	15	28
G21B	250	11	13
G22B	260	9	29
G29B	329	8	15
G30B	230	7	11
G35B	333	13	15
G36B2	195	14	8
J06B	240	13	12
J11B	321	10	19
J19B	125	7	24
J23B	315	9	19
J27B	292	13	18
J28B	23	9	16
J48B	201	8	17
J63B	145	7	11

## 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. 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](mailto:jessica@iris.edu)).

## 6. References

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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, 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:

<b>Land Seismograph</b>	<b>Ocean Bottom Seismograph</b>
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.

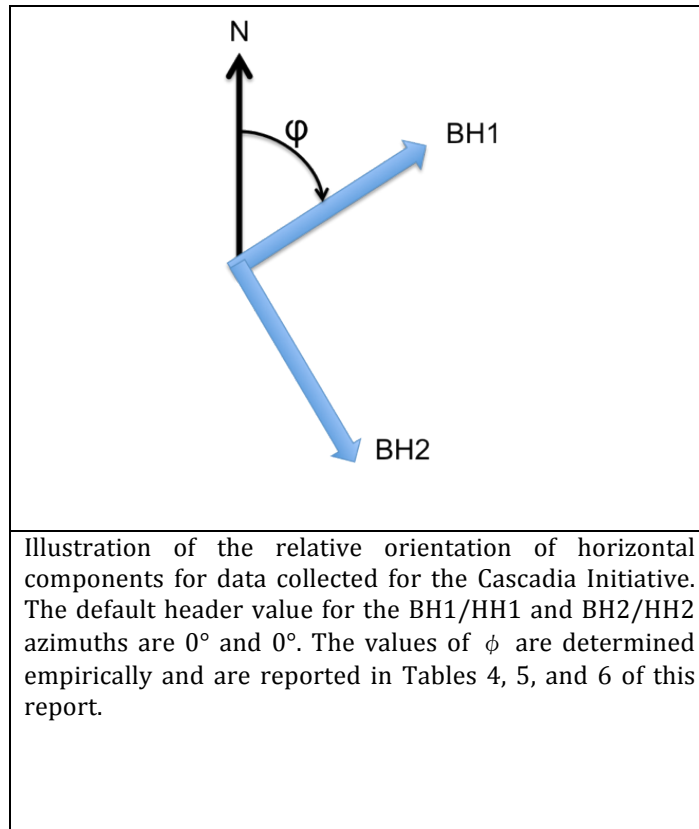
The OBSIP IIC's then post-process each of these data sets to put the data in the correct format (SEED or SEG-Y) and to correct the timing of the data samples. Upon completion of this step, the data are uploaded to the IRIS Data Management Center for public use. Note that additional post-processing and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



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.



## Appendix B - Helicorder Plots

## Appendix C - PDF-PSD Plots

## Appendix D - Orientation Results

## **Appendix E – Information about Data Re-upload and Horizontal Convention Change**



## **Appendix F – Determining Possible Errors in Channel Orientations**