CRUISE REPORT
PS1306

R/V Point Sur
Valparaiso - Valparaiso, Chile
March 15-21, 2013

The 2010 Maule, Chile Earthquake: Project Evaluating Prism Post-Earthquake Response (Chile-PEPPER) OBS recovery cruise

Chief Scientist - Anne Tréhu, Oregon State University

Cruise Report
PS1306

Scientific Party:
Anne Trehu (Oregon State Un.; professor/chief scientist)
Bridget Hass (Oregon State Un.; graduate student/watchstander)
Javier Ruiz (Un. of Santiago Chile; professor/watchstander)
Sebastian Obando (Un. of Santiago Chile; graduate student/watchstander)
Ted Kozinski (Lamont-Doherty Earth Observatory/OBS engineer)
David Gassier (Lamont-Doherty Earth Observatory/OBS engineer)
Tina Marie Thomas (Marine technician)
Begonia Paraguez (Chilean observer)

Crew:
Anthony Diego Mello (Captain)
Matt Curtis Davis (First mate)
Amy Robbins Biddle (Second mate)
Thomas Barrett Carpenter (Chief engineer)
Kimberley Marie Gardner (Assistant engineer)
Steve Lamb (Steward, Cook)
Scott Allen Hansen (AB)
Christian (Dutch) Meyer (AB)

note: Chile-PEPPER co-PI Mike Tryon (Scripps Institution of Oceanography) did not participate in the cruise.

Abstract: The objective of cruise PS1306 on the R/V Point Sur was to recover ocean bottom seismometers deployed in May 2012 from the R/V Melville. The scientific background for the project has been given in the cruise report for the OBS deployment cruise on the R/V Melville in 2012 and will not be repeated here. See http://www.rvdata.us/catalog/MV1206. In addition to recovering the OBSs, we acquired several sub-bottom profiling surveys using the R/V Point Sur's Knudsen 320BR 3.5 and 12 kHz echosounder while preparing to dredge for one OBS that did not release on command (although it was "alive" and responding acoustically).

Acknowledgements: This project is funded by the Marine Geology and Geophysics Program of the U.S. National Science Foundation through grants OCE1130013 to Oregon State University and OCE1129574 to the Scripps Institution of Oceanography.

Cruise narrative (Times are given UTM; local time is 3 hours earlier):

March 15: Left the dock at 1600 and began the transit to the study area.

March 16: We arrived at the first recovery site (S05) at 0640. OBS S05 at site 01 responded but did not release from the seafloor. After several attempts, at 0832 we decided to proceed to site 3 (S08) and retrieve it and site 2 (S01) before returning to site 1 for another attempt. We arrived at site 3 at 0923. By 0830, the OBS was on board, gear was secured and we were on our way to site 2. We arrived at site 2 at 1159. S01 was on board and we were on our way back to site 1 by 1035. OBS S05 at site 1 still did not release, so we proceeded to site 4. OBSs at sites 4, 5, 6 and 7 were retrieved without incident by 2128. Six recoveries in one day! It was time for a rest. We conducted a 3.5 kHz survey for the night, with plans to continue OBS recoveries the next day.

March 17: We were in position at site 8 at 0800 and the transducer was in the water at 0521. The OBS at site 8 was on board at 1006. Sites 9 and 10 were also recovered smoothly, with all recoveries except for site 1 completed by 1900. We then returned to site 1 for another attempt. The OBS continued to recognize the release command but did not budge from its place on the seafloor. From 1849-1906, the underway seawater system was stopped for maintenance. We then began a transit to the start of a 3.5 kHz profile along the existing seismic line down the axis of the trench. The plan was to survey while the crew and OBS team rested and then start dragging for the instrument at first light on March 18. The 3.5 kHz survey began at 2243.

March 18: The 3.5 kHz survey was completed at 0650, and we headed back to site 1 to start dragging operations to try to recover OBS S05 at site 1. We arrived at the site at 1040 and made yet another unsuccessful attempt to release the OBS. The day was spent laying out wire on the seafloor and dragging it over the OBS in an attempt to dislodge it. A 3.5 kHz survey of an apparently active fault overlying the landward edge of the recent accretionary prism was conducted at night.

March 19: Dragging operations resumed at 0800 (local). A different approach was tried. Two passes around the instrument were attempted. Both were unsuccessful. The 3.5 survey of the active fault was continued during the night.

March 20. Dragging operations to try a 3rd strategy were begun around 0800 (local). Operation continued to ~1700 (local) but was not successful. A 3.5 kHz survey was conducted during the night.

March 21: The 3.5 kHz survey track was aborted at ~0330 (local) because it was time to start heading directly to Valparaiso to be there in time to meet the pilot at 1500 (local). Acquisition of 3.5 kHz data continued during the transit.

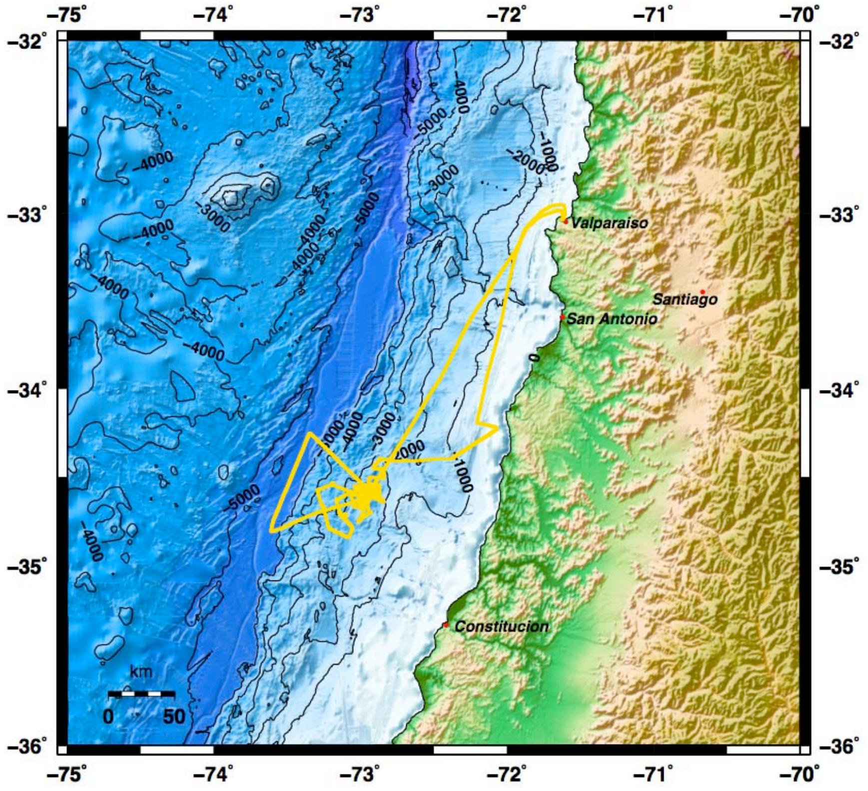


Figure 1a. Trackline for cruise PS1306.

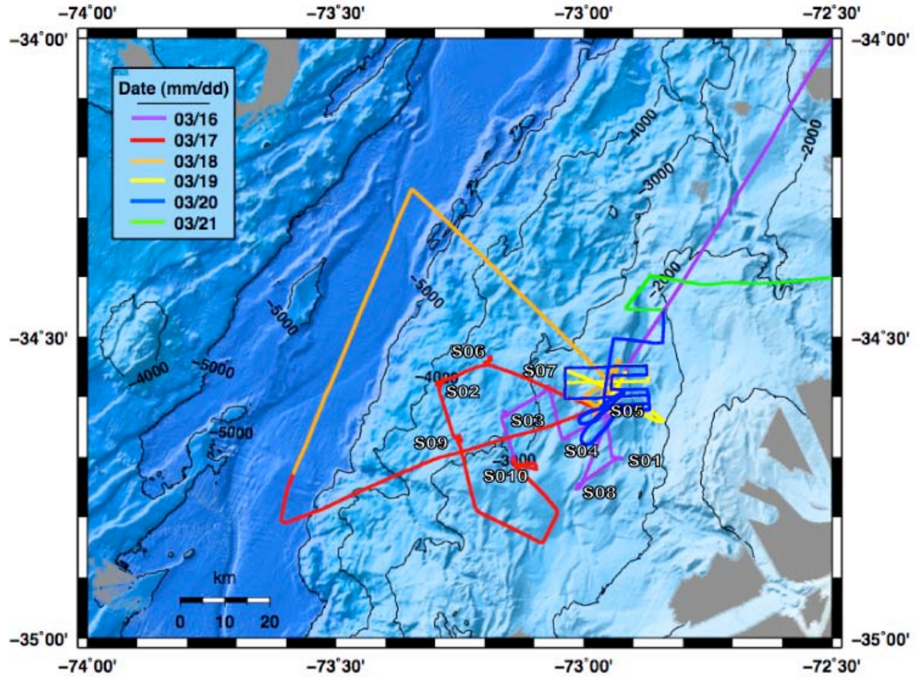


Figure 1b. Trackline for cruise PS1306 within the primary study area. Each day is shown in a different color. Site locations are labeled.

OBS data report:

Two different types of OBS were recovered: the "Standard" LDEO broadband OBS (SL-OBS) with L4C seismometers with a low-noise amplifier to boost the low-frequency response and a differential pressure gauge (DPG) and the "Cascadia Initiative" LDEO broadband OBS (CI-OBS), with Trillium Compact seismometers and absolute pressure gauges (APG). Specifications of the instruments are given in Appendix 1. Instrument positions in Table 1A were determined by ranging to them after deployment. More details about deployment procedures are given in the MV1206 cruise report. Ranging to the instruments as part of the recovery procedure indicates that these positions are accurate. Appendix 2 presents a more detailed discussion of data quality.

Clock drifts relative to GPS time were measured for all instruments on recovery and were <1.2 s (Table 1B). The data have been corrected for clock drift and for a leap second that occurred on June 30, 2012. This correction was evaluated by comparing data before and after application of the clock drift and leap second corrections. Timing was also evaluated by examining data across the array from two deep, subduction zone earthquakes beneath Bolivia that generated impulsive P-waves that should approximate a plane wave impinging nearly vertically on the array. The direct P-wave from these events was impulsive and could be picked precisely on all the OBSs. This analysis revealed a problem with the software used on board to convert raw APG data to miniseed format. In addition, preliminary locations for an earthquake that occurred within the array indicated an ~2 s mismatch in the timing between the two OBSs types. This problem was also tracked down to a software error in the software used on board to reformat the SL-OBS data. The raw data for the APGs and SL-OBSs have been reprocesses and these timing errors have been corrected. This experience emphasizes the need to use an empirical, data-based approach to test timing consistency between different types of OBSs (and relative to land-based instruments when possible) and for close collaboration between PIs and the OBSIP before conducting automated analysis of the data. Several months and many hours of work both by the PIs and personnel at the LDEO OBSIP instrument center elapsed between data recovery and identification and correction of the timing errors.

The SL-OBS generally performed well, with data recorded most of the time on all 4 channels of all 4 instruments that were recovered for the entire deployment. The glass ball containing the sensor for S08 was partially flooded. A deterioration of the signal quality with time is observed and may be related to intrusion of salt water into the sensor sphere. S07 also had numerous data faults that affect 50-75% of the data. Less severe data faults (spikes and occasional step-like offsets) were observed intermittently on S06 and S09. See Appendix 2 for examples.

The CI-OBS performed less well. No useful data were recorded from the Trillium Compact seismometers. This has been attributed to the instrument attempting to level the seismometer while it was still in the water column. Similar problems were observed during the first year of the Cascadia Initiative (see http://cascadia.uoregon.edu/CIET), although they only affected a subset of the instruments during that experiment. The problem seems to have been solved for the second Cascadia Initiative deployment. A decrease in the delay time before starting the leveling processes for the ChilePEPPER experiment aggravated this problem, leading to a failure to record useful data on the broadband seismometers. This experience underlines the need to fully test any parameter changes before implementing them, especially when there is no opportunity to test the effect of such changes prior to a year-long deployment.

Data were recorded from all 5 APGs. Examination of the data revealed increasing instrument noise at frequencies above 2 Hz, in contrast to the published instrument specifications. Consequently only the largest local and regional events generated signal above the noise level in this frequency band. This feature of the APG instrument response also precludes use of the APG data for obtaining a velocity model from GI-gun shots fired during MV1206. In addition, two of the APGs (stations S02 and S03) show a loss of sensitivity to frequencies <0.001 Hz that occurred over a period of a few days. For S02, this occurred ~10 days into the experiment; for S03, this occurred ~100 days into the experiment. This problem has been attributed to corrosion of tubing in the APG. Such corrosion does not appear to be a problem with the CI data, which used a slightly different design. This experience illustrates the danger of implementing untested design changes, even when they appear to be quite minor.

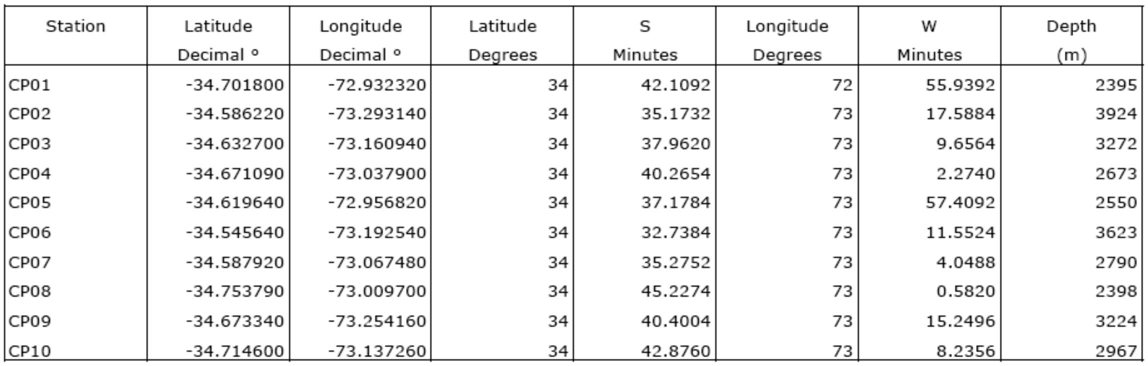
Table 2 is a summary of data return. We have estimated the percentage of useful data on each channel. This exercise is somewhat subjective given that certain data issues affect some scientific studies more than others. With assumptions and qualifications discussed below, the overall data return for this deployment is estimated to be ~35% for acheiving ChilePEPPER objectives and 40% for frequencies below 1-2 Hz.

The percentage data return for the SL-OBS seismometer and DPG data depends on the severity of data faults. In some cases, dropouts, offsets and other data faults were minor and a data return rate of 100% was assigned. In other cases, waveform quality problems are more severe, leading to estimates of 50-80% useful data return. Overall data return for the 4 SL-OBSs that were recovered is ~74%.

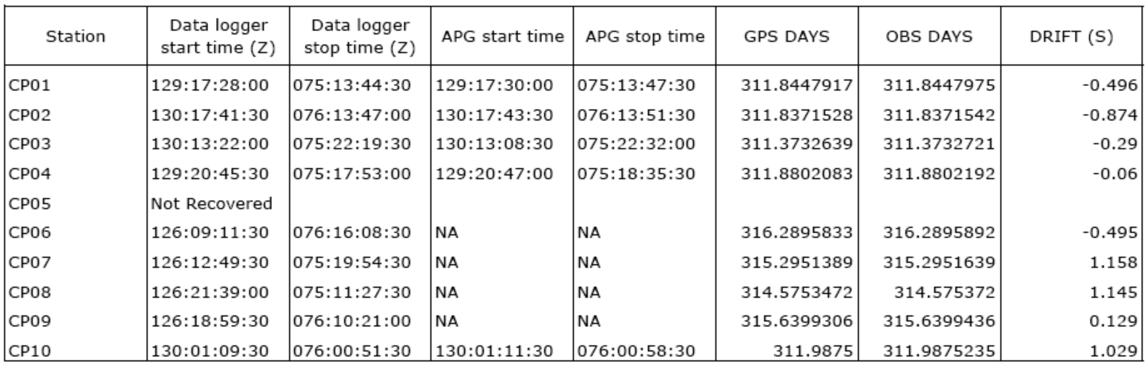
APGs at sites CP01, CP04 and CP10 were assigned a useful data percentage of 50% because data from these instruments should be useful for studies of teleseismic and larger regional earthquakes. However, these instruments will be of limited use for achieving the primary objectives of ChilePEPPER because of the increasing instrument noise on the APGs above 2 Hz. APGs at CP02 and CP03 are given a useful data percentage of 10% and 30% because the data may be useful for oceanographic and geodetic studies even though these instruments lost sensitivity to seismic frequencies due to corrosion. The overall data recovery for the CI-OBSs is estimated at 10% for adressing ChilePEPPER objectives and 20% for teleseismic studies.

All OBS data are being archived at the IRIS DMC and will be available to the public after a 2-yr post-cruise period. For access to the data prior to August 2015, please contact the PI at trehu@coas.oregonstate.edu. Network code is Z4.

Table 1: A. OBS positions obtained from acoustic ranging to the instruments after deployment (see MV1206 cruise report). B. clock drifts determined from comparison of the data logger time at deployment and recovery and comparing the time to the time recorded by a satellite clock. This table lists station IDs as CPxx, consistent with the station IDs in the IRIS DMC database. The corresponding station IDs elsewhere in this report and in the MV1206 cruise report are listed as Sxx.



Station	Latitude Decimal °	Longitude Decimal °	Latitude Degrees	S Minutes	Longitude Degrees	W Minutes	Depth (m)
CP01	-34.701800	-72.932320	34	42.1092	72	55.9392	2395
CP02	-34.586220	-73.293140	34	35.1732	73	17.5884	3924
CP03	-34.632700	-73.160940	34	37.9620	73	9.6564	3272
CP04	-34.671090	-73.037900	34	40.2654	73	2.2740	2673
CP05	-34.619640	-72.956820	34	37.1784	73	57.4092	2550
CP06	-34.545640	-73.192540	34	32.7384	73	11.5524	3623
CP07	-34.587920	-73.067480	34	35.2752	73	4.0488	2790
CP08	-34.753790	-73.009700	34	45.2274	73	0.5820	2398
CP09	-34.673340	-73.254160	34	40.4004	73	15.2496	3224
CP10	-34.714600	-73.137260	34	42.8760	73	8.2356	2967



Station	Data logger start time (Z)	Data logger stop time (Z)	APG start time	APG stop time	GPS DAYS	OBS DAYS	DRIFT (S)
CP01	129:17:28:00	075:13:44:30	129:17:30:00	075:13:47:30	311.8447917	311.8447975	-0.496
CP02	130:17:41:30	076:13:47:00	130:17:43:30	076:13:51:30	311.8371528	311.8371542	-0.874
CP03	130:13:22:00	075:22:19:30	130:13:08:30	075:22:32:00	311.3732639	311.3732721	-0.29
CP04	129:20:45:30	075:17:53:00	129:20:47:00	075:18:35:30	311.8802083	311.8802192	-0.06
CP05	Not Recovered						
CP06	126:09:11:30	076:16:08:30	NA	NA	316.2895833	316.2895892	-0.495
CP07	126:12:49:30	075:19:54:30	NA	NA	315.2951389	315.2951639	1.158
CP08	126:21:39:00	075:11:27:30	NA	NA	314.5753472	314.575372	1.145
CP09	126:18:59:30	076:10:21:00	NA	NA	315.6399306	315.6399436	0.129
CP10	130:01:09:30	076:00:51:30	130:01:11:30	076:00:58:30	311.9875	311.9875235	1.029

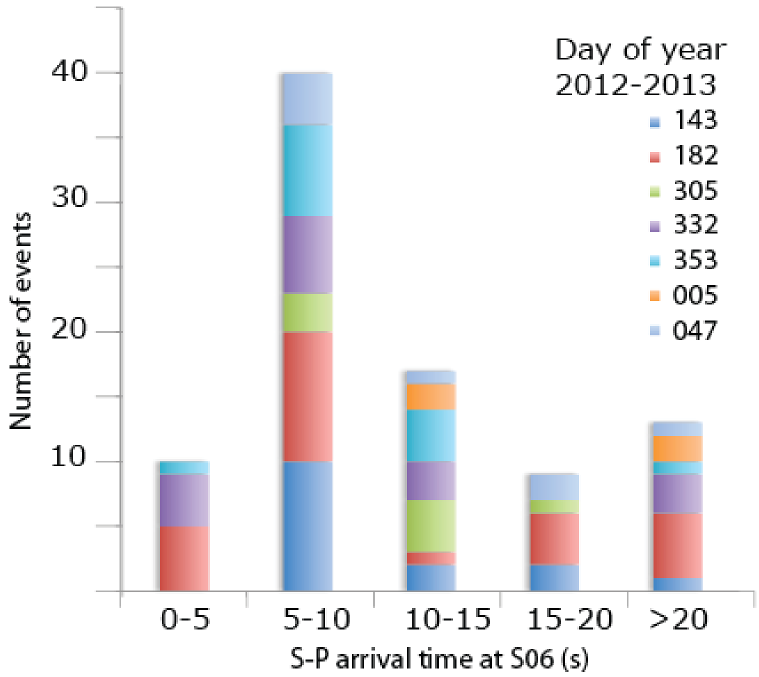
Table 2. Summary of data return. CI are OBSs of the new Cascadia Initiative design, with Trillium Compact seismometers and Absolute Pressure Gauges (APG). SL are the Standard LDEO design, with L4C seismometers and Differential Pressure Gauges (DPG). na - not applicable. nd - no data. See text for the reasoning used to attribute percentages for this admittedly somewhat subjective exercise.

Site	Type	Z	H1	H2	APG	DPG	Comment
S01	CI	nd	nd	nd	50%	na	No seismometer data. APG data good for frequencies below 2 Hz.
S02	CI	nd	nd	nd	30%	na	No seismometer data. APG data not sensitive to seismic frequencies because of blocked tubing after day 230, 2012.
S03	CI	nd	nd	nd	10%	na	No seismometer data. APG data not sensitive to seismic frequencies because of blocked tubing after day 150, 2012
S04	CI	nd	nd	nd	50%	na	No seismometer data. AGP data good for frequencies below 2 Hz.
S05	SL	nd	nd	nd	na	nd	Instrument not recovered.
S06	SL	100%	100%	100%	na	80%	Seismometer data quality is good. Quality of DPG signal deteriorates by day 048 2013.
S07	SL	50%	50%	50%	na	50%	Signal has intermittent offsets, drop outs and zeros on Z and DPG. Data quality deteriorates with time. Roughly 50% of the data are useful.
S08	SL	50%	50%	50%	na	80%	Sensor ball was partially flooded. Seismometer and DPG signal quality deteriorates with time.
S09	SL	100%	100%	100%	na	75%	Many data dropouts and offsets on the DPG data. Roughly 75% of the data are useful.
S10	CI	nd	nd	nd	50%	na	No seismometer data. AGP data good for frequencies below 2 Hz.

Preliminary results:

During the cruise we scanned 7 days of data, chosen to corresponded to the birthdays of science party members. The data contain many local and regional earthquakes with S-P times <25 s (Figure 2). Many teleseismic events are also observed. Most of the events in this histogram were not reported by shore-based networks. Assuming that this level of activity is typical, we expect to detect ~7 events/day with S-P time <10s. Interestingly, some events have strong T-phases whereas others have no observable T-phase. Impulsive signals followed by a narrow-band resonance that are seen on only 1 instrument are relatively rare compared to some other deployments on continental margins. These are usually attributed to biological activity around the instrument.

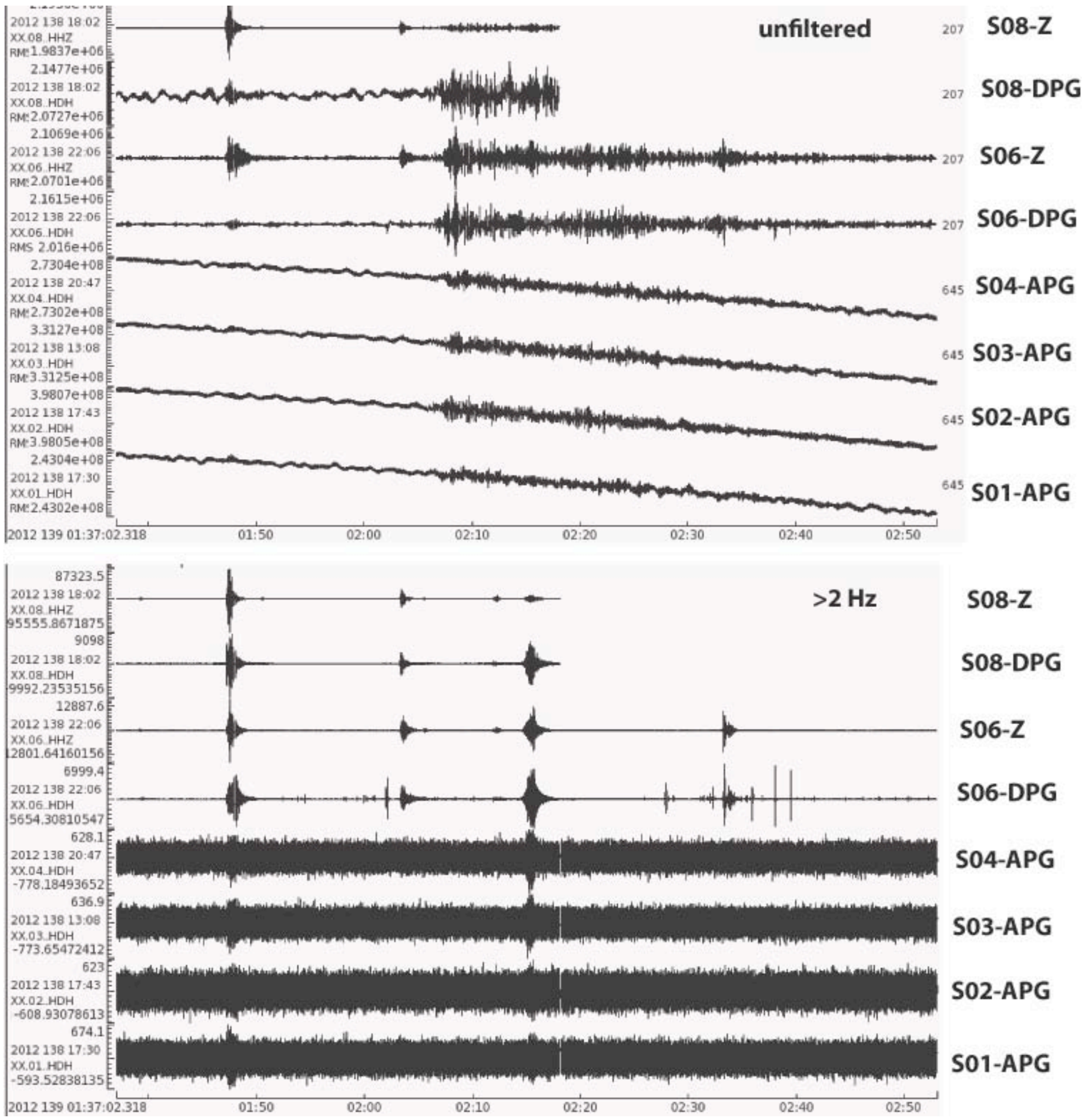
Figure 2. Histogram of the number of earthquakes with S-P times <30s observed on 7 randomly selected days.



S-P of 5 s is approximately a distance of 37 km for the P/S velocity ratio expected for accretionary complex sediments.

Figure 3 shows a 1.25 hr-long window of data containing several different events with energy in different frequency bands. Top panel shows unfiltered data. All traces are scaled to the maximum amplitude in that trace. The number on the right is the decimation factor for plotting. The short period energy is best seen on the 1 Hz vertical geophone (Z) and differential pressure gauge (DPG). The absolute pressure gauge (APG) data are dominated by instrument noise at frequencies above 2 hz for all but very strong signals. At long periods they measure tidal changes in pressure and have potential to provide information on geodetic uplift. None of the events in this time window are listed in the ANSS or local Chile network catalogs.

Figure 3. Example of data in different frequency bands.



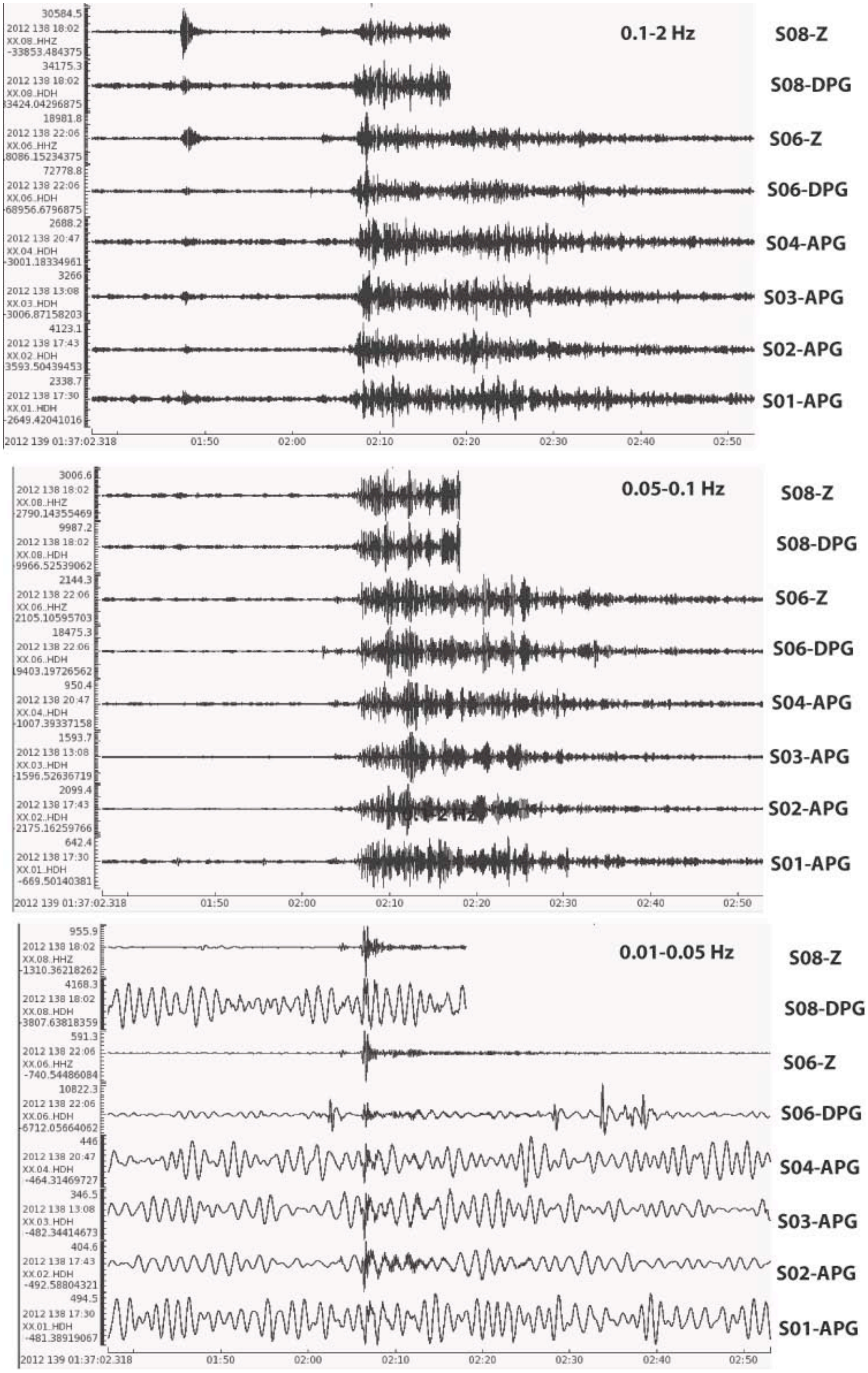
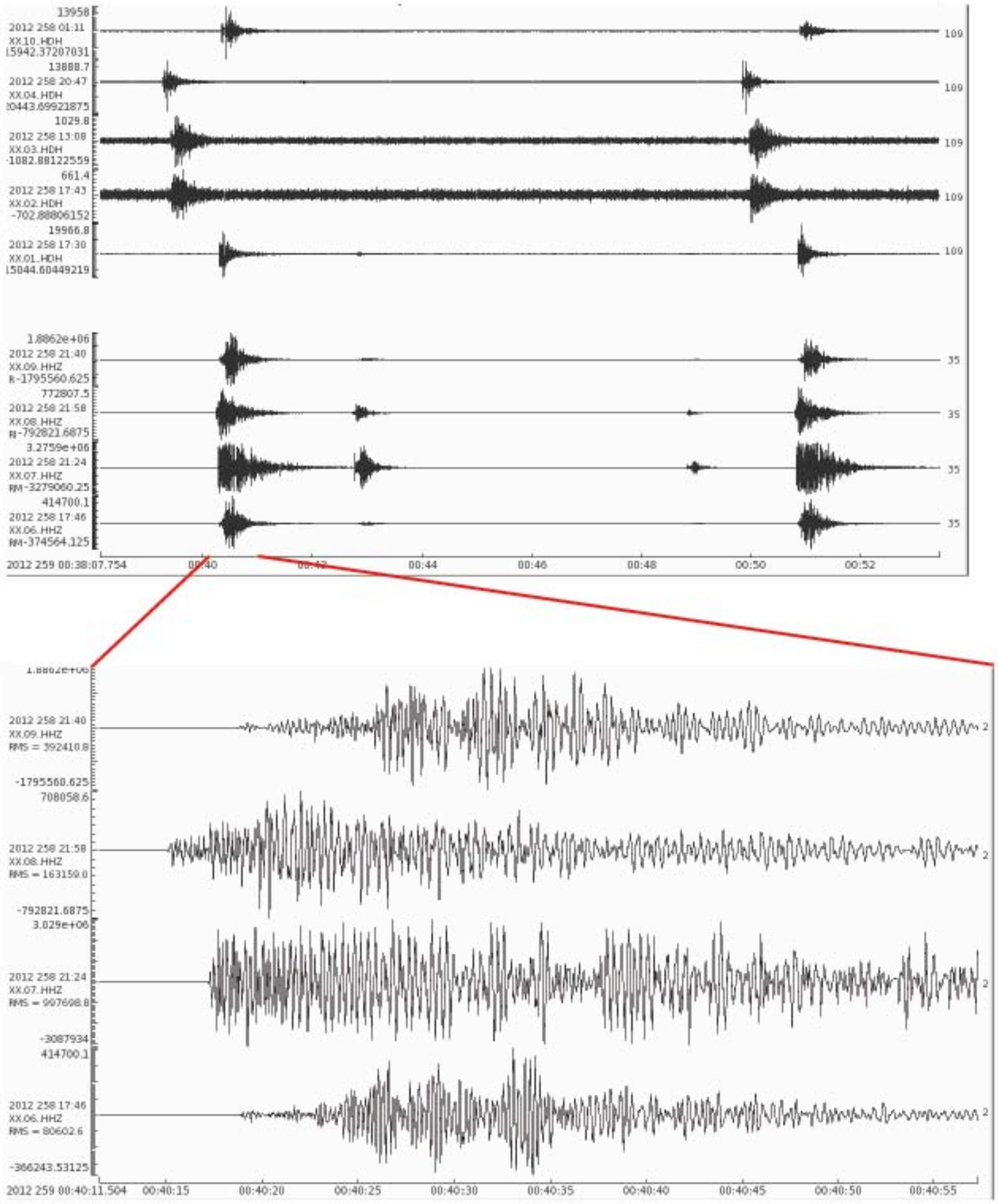

0.1-2 Hz
S08-Z
S08-DPG
S06-Z
S06-DPG
S04-APG
S03-APG
S02-APG
S01-APG
30584.5
2012 138 18:02
XX.08..HHZ
-33853.484375
34175.3
2012 138 18:02
XX.08..HDH
2012 138 22:06
XX.06..HHZ
2012 138 22:06
XX.06..HDH
2012 138 20:47
XX.04..HDH
2012 138 13:08
XX.03..HDH
2012 138 17:43
XX.02..HDH
2012 138 17:30
XX.01..HDH
2012 139 01:37:02.318
01:50
02:00
02:10
02:20
02:30
02:40
02:50
0.05-0.1 Hz
0.01-0.05 Hz

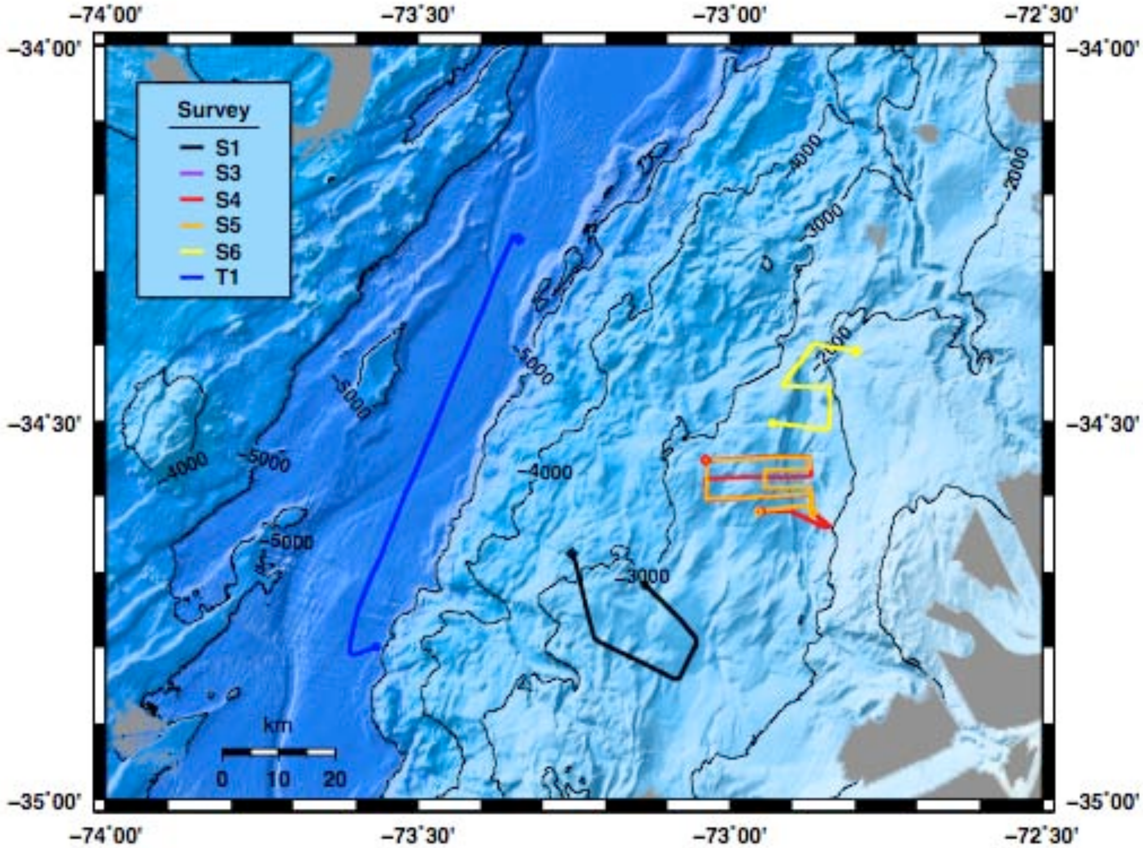
Figure 4 shows data from an earthquake that was reported by the Chilean network with an epicenter close to S05. At least 12 earthquakes with similar waveforms were recorded on the day during which 3 events were reported in the network. Three of these events have been relocated. Relocations using only OBS data indicate that events were indeed located within the array. Epicenters are ~10 km from those reported by the Chilean seismic network and ~40 km for the largest event (M4.7) as reported by NEIC. Preliminary depths for the three events located to date are 7.5-8.5 km beneath the sea surface, which places them near the top of the subducting oceanic crust in the model of Moscoso et al. (2011). Consistency of residuals between CI-OBSs and SL-OBSs also provides empirical confirmation of consistency between the corrrected timing for both types of instruments.



3.5 khz subseafloor imaging:

Several short surveys of features identified on the bathymetric data were surveyed using the Knudsen 320BR 3.5 kHz system on the R/V Pt. Sur. These included: (1) a line along the trench to determine whether there were changes in seafloor reflectivity associated with changes in sedimentary patterns in the trench imaged with bathymetric and high resolution MCS data during the 2012 cruise on the R/V Melville, (2) a survey of a strike-slip fault within a N-S-trending topographic channel on the slope that was imaged with MCS data in 2012, and (3) a survey in the region of the Pichilemu aftershock sequence, which extends offshore. Data are available from the Rolling Deck to Repository cruise catalog
(www. rvdata.us/catalog/PS1306).

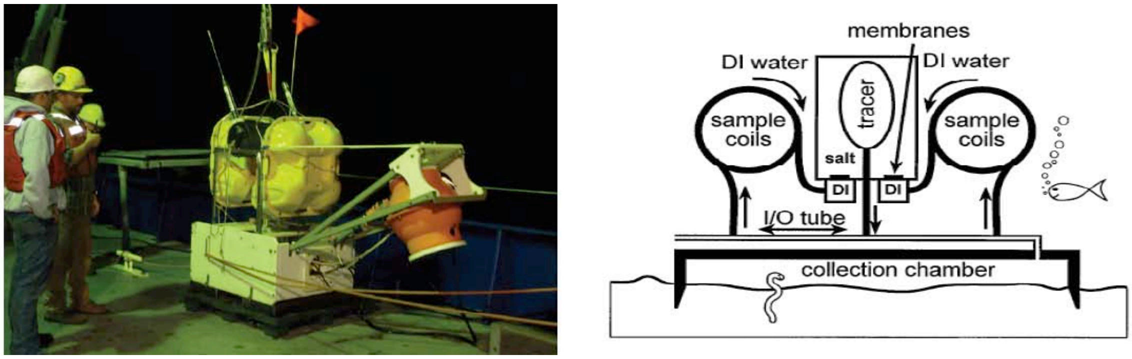
Figure 5. Map showing location of 3.5 kHz surveys. Survey S3 was near -34.3, -



Fluid flow data:

Fluid flow data were acquired from all 9 sites that were recovered. Data are currently being processed. Figure 5 shows a schematic of the fluid flow instrumentation. The collection chamber for flow was built into the base of the main instrument package. The sample coils were mounted in a box on the side of the OBS (on the far side in the photograph below). This was the first time these flow meters had been integrated with this model OBS.

Figure 6. Schematic of the flow meter. See Tryon et al. (2001). The collection chamber was installed beneath the rectangular instrument frame with cut-out for the drop weights that release the instrument. The sample coils and tracer injector where in a box mounted on the side of the frame (out of view in this photo).



Appendix 1: Specifications of the OBSs deployed for ChilePEPPER during MV1206 and recovered during PS1306.

LDEO Standard Ocean-Bottom Seismometer

Ocean-Bottom Seismology Laboratory
Lamont-Doherty Earth Observatory
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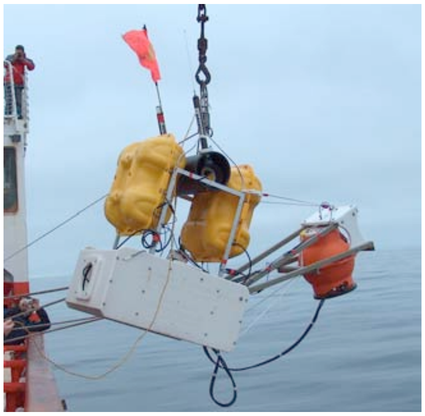


The LDEO standard seismometer design has been in use for nearly 10 years. The LDEO OBS lab has built and operates 25 standard OBSs as part of the NSF OBS Instrumentation Pool. The seismometer sensor is an L4C 1 Hz geophone, with a low-noise amplifier, giving useful response down to 100 s, and a differential pressure gauge. This instrument has been used in both year-long passive-source and shorter-term active-source experiments. The design includes dual redundancy with two transponders and two dropweights.

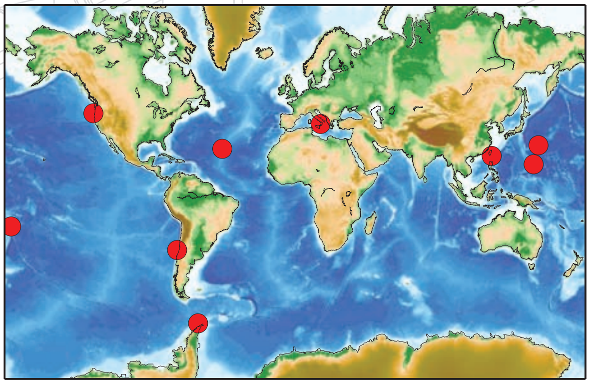
Variants and add-ons

Trawl-resistant OBS
Moored DPG/hydrophone
Ocean-bottom magnetometer
Diffuse flowmeter
Trillium Compact sensor
Absolute pressure gauge
Hydrophone

Specifications

Max. Depth	5000 m
Max. Duration	400 days @ 125 sps
Channels	4, 24-bit recording
Sensors	L4C 3-component geophones; differential pressure gauge
Response	100 s - 60 Hz (seismometer) 0-20 Hz (DPG)
Leveling system	Active 360°,motor-driven
Weight	750 lb in air
Footprint	3'X4'
Flotation	9X12" glass spheres
Sampling	40-100-125 sps
Release	Dual dropweights
Acoustics	Two ORE 12 kHz transponders
Power	Lithium battery pack, +/- 7.5 V
Oscillator	Seascan 10 MHz clock
Sensor housing	17" glass sphere
Burnwires	LDEO design
Recovery aids	Radio, strobe, flag
Recording	2 X 32 Gb CompactFlash cards
Dropweights	Two steel weights (75 lb in air)
Datalogger	LDEO ultra-low power OBS datalogger (300 mW @ 125 sps)

Deployment History



Ocean-Bottom Seismology Laboratory
Lamont-Doherty Earth Observatory
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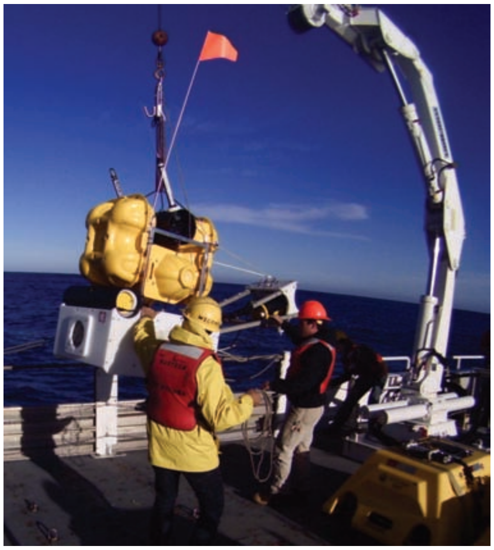
LDEO 2011 Model OBS

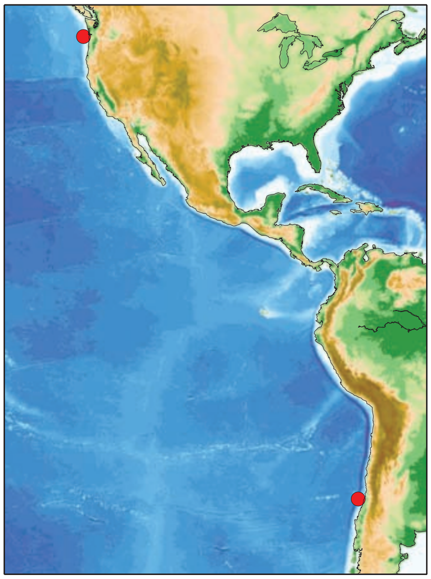
The LDEO 2011 seismometer design is a recent update of the standard LDEO design. Each OBS is equipped with a Trillium Compact seismometer, a Paroscientific absolute pressure gauge, and a hydrophone. The LDEO OBS lab has built 15 2011 OBSs: 5 for use in the standard OBSIP fleet and 10 for use in the Cascadia Initiative. The design includes dual redundancy with two transponders and two dropweights.



Specifications

Max. Depth	5000 m
Duration	400 days
Channels	6, 24-bit recording
Sensors	Trillium Compact seismometer absolute pressure gauge (APG) hydrophone
Response	120 s - 60 Hz (seismometer)
Leveling system	Active 360°,motor-driven
Weight	850 lb in air
Footprint	3'X4'
Flotation	11X12" glass spheres
Sampling	40, 100, or 125 sps
Release	Dual dropweights
Acoustics	Two ORE 12 kHz transponders
Power	Lithium battery pack, +/- 7.5 V
Oscillator	Seascan 10 MHz clock
Sensor housing	8" diameter Al tube
Burnwires	LDEO design
Recovery aids	Radio, strobe, flag
Recording	2 X 32 Gb CF cards (seismo) 1 X 16 Gb SD card (APG)
Dropweights	Two steel weights (100 lb in air)
Datalogger	LDEO OBS datalogger LDEO APG datalogger

Deployment History



Appendix 2:

Preliminary comments on data quality during the 2012-2013 Chile-PEPPER project based on data exploration with pql (originally prepared by Anne Trehu, April 9, 2013; revised and updated, June 20, 2013 and on August 24, 2013.)

Summary of results from the new LDEO-APG instruments developed with ARRA funding for the Cascadia Initiative:

1) Clock drifts were small (<1.0 s) on all instruments. However, examination of local impulsive earthquake arrivals indicated problems with timing on APGs. Arrivals on 3 of the APGs (CP02, CP03, CP04) are early compared to arrivals observed on the L4C seismometers, and the advance increases with time during the experiment, growing to ~2 minutes towards the end of the deployment. This problem is attributed by the LDEO OBSIP Instrument Center (LDEO-IIC) to occasional skipping of samples and is also present in Cascadia Initiative (CI) year 1 data. The data have been corrected by the LDEO-IIC.

2) No useful data were recorded from the Trillium Compact seismometers on the LDEO-CI OBSs. The LDEO-IIC suspects that this results from a problem with the leveling system. A similar problem affects a subset of the CI year 1 data. The problem was aggravated for ChilePEPPER by a change in parameters controlling the leveling process. This problem was fixed prior to the year 2 CI deployment as indicated by data on the OBSs recovered from the CI-yr 2 deployment (see AT26-02 Cruise Report on the Cascadia Initiative web site).

3) Determination of ad-hoc empirical calibration constants for each APG from recorded counts, the deployment depth obtained from swath bathymetry, and an estimate for the average density of seawater results in calibration factors that are similar (within 5%) for all 5 instruments. The apparent tidal amplitude derived from the observations using these empirical calibration factors is generally consistent with (although ~50% larger than) the tidal amplitude predicted by the Egbert and Erofeeva TOPEX8 model. A (very) quick look at data throughout the deployment suggests that absolute pressure was stable over the course of a year, although long-term stability will be analyzed more carefully to evaluate the utility of these data for marine geodesy.

4) Three of the 5 APGs (S01, S04 and S10) recorded good data at frequencies of interest for teleseismic data. APG S02 and S03, however, both appear to lose sensitivity to frequencies in the range of interest for broadband seismology (>0.001 Hz) over the course of ~1 week. For S02, this occurred near day 230 (100 days after deployment). For S03, it occurred near day 140 (10 days after deployment). The problem is more severe for S03 than for S02, which retains some sensitivity to earthquake-generated signals in spite of this problem.

5) All APGs have increasing self-noise above 1 Hz. Signals from very large earthquakes rise above this noise floor, but small local events and T-phases from more distant events

that are observed on DPGs or seismometers are not observed on the APGs. This limits the utility of the APG data for addressing the primary objectives of ChilePEPPER.

6) All APGs show occasional small step-like offsets in which the signal level changes approximately linearly over a time period of ~1 s. Steps have both positive and negative polarity, and the time interval between steps is variable. These are more pronounced on APGs S02 and S03, possibly because of the lowered sensitivity of these instruments to Earth "noise" in the microseismic band, which has a similar amplitude.

Summary of results from the LDEO-Standard OBSs (Sites S05-S09):

1) Clock drifts were small (<1.2 s) on all instruments. Impulsive arrivals from a deep earthquake were used to verify timing. An advance of a few seconds between the SL-OBSs and time-corrected APG was tracked down to a constant 2.07 s advance in the SL-OBS resulting from a bug in the software used to generate miniseed while on board ship. This will be fixed before submission of data to the IRIS DMC. Empirical data-based tests that include this constant time shift indicate that timing for all ChilePEPPER OBSs is accurate to within uncertainties related to possible departures from the linear clock drift model used to apply clock drift corrections. Remaining timing residuals are small enough to be explained by variations in velocity structure beneath the instruments.

2) Many local and regional earthquakes were recorded per day, as indicated by S-P times <20 s.

3) Two out of 4 recovered LDEO-Standard OBS (S06, S09) have good waveform quality on all 3 seismometers components. Both of these instruments had intermittent spikes on the DPG (large amplitude for S09; small amplitude for S06).

4) Two out of 4 recovered LDEO-Standard OBS (S07, S08) have significant problems with waveform distortion (e.g. spikes, steps) on the seismometers that affect a significant percentage of the data and will make it very difficult, if not impossible, to apply automated data analysis techniques to the data.

5) One LDEO-Standard OBS (S05) was not recovered. We were able to communicate acoustically with the instrument, but it did not release in spite of many attempts on several different days. Attempt to recover the instrument by dragging were not successful.

6) DPGs do not show sensitivity to tidal frequencies. This contrasts with strong tidal sensitivity at similar water depth of SIO DPGs in the CI yr 1 data set and in other data sets.

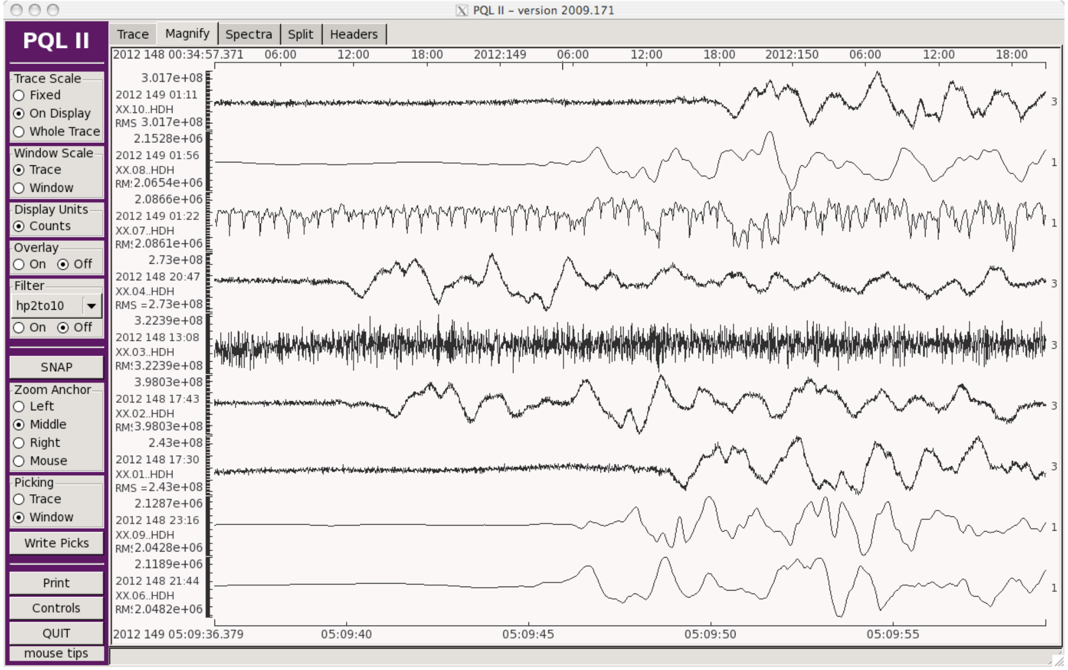
Empirical timing checks and evaluation of waveform quality for all instruments:

Measured clock drifts are all <1.2 s (see Table 1), suggesting good timing control. As an independent check, I looked at P-wave arrivals from 3 earthquakes - a relatively large regional event that was not reported by ANSS but was well-recorded across the array and two regional deep events reported by ANSS - to see if arrival times are compatible with what is expected for the array geometry. P-wave arrival times observed on the 4 LDEO-Standard OBSs (S06, S07, S08, S09) vary within a range that is compatible with the array aperture and reasonable structural heterogeneity within the array. Arrival times on the APGs are not compatible with these observations: S01 and S10 are late by a few seconds; S02, S03 and S04 are early by several seconds in May, 2012. The timing discrepancy grows to ~2 minutes by February, 2013. As mentioned above, both timing issues have been tracked down to software issues when converting raw data to miniseed on board, and both have been fixed.

These plots also point to problems with temporal variations in signal quality, especially for the SL-LDEO instruments. These temporal variations will complicate establishment of an automated approach towards searching for various types of events in different frequency bands in the data (e.g. non-volcanic tremor or long-period earthquakes) since these data faults can masquerade as "events" in filtered data. For example:

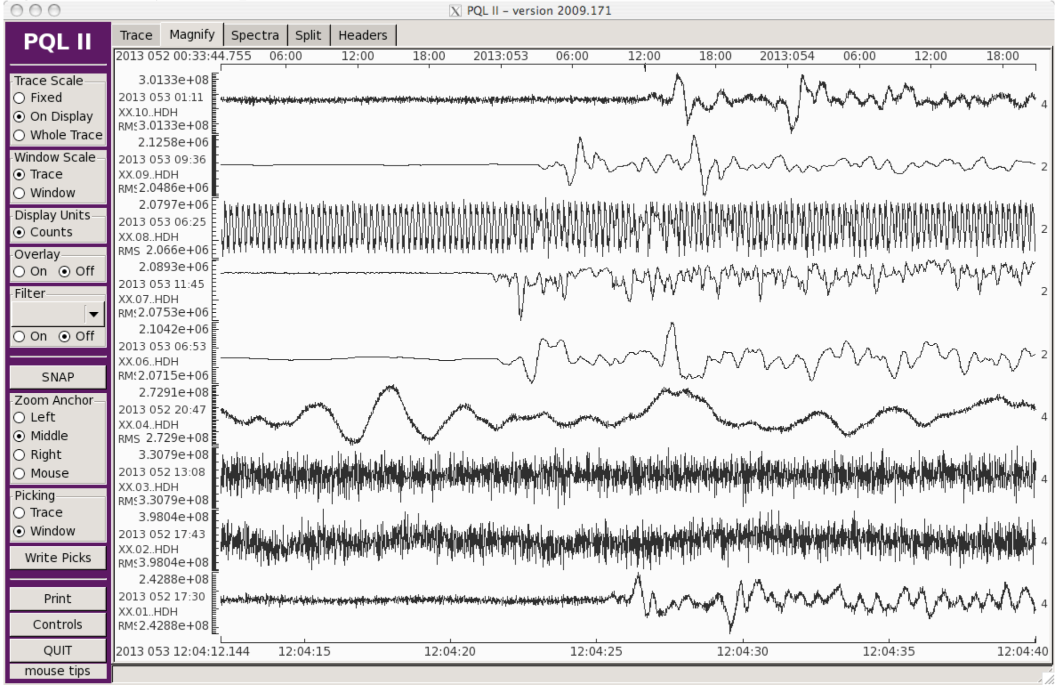
- For the May 28, 2012 event (day 148), the S07 DPG (channel HDH) was not useable because of very frequent, small spikes. The S03 APG (HDH) was also very noisy (no signal observed from the earthquake). Note, also, the higher level of high frequency noise on the APGs compared to the DPGs. This observation led to the general observation that the APGs have increasing instrument noise above 2 hz.
- For the October 11, 2012 event (day 245), the H1 channel on S08 is affected by spikes and step-like offsets in the signal. The Z channel on S07 is clipped. The DPG on S07 has occasional spikes, but is better than on May 28. APG S02 is very noisy (no signal observed from the earthquake).
- For the February 22, 2013 event (day 053), APG S03 shows no signal associated with the earthquake. APGs S02 and S04 show long period signal that is part of the S-wave coda from the event, and the P-wave first arrival is at ~12:02 (more than 2 minutes earlier than expected). The signal on DPG S08 is dominated by a narrow-band resonance. While the signal on DPG S07 is useable for picking the arrival time, the waveform appears distorted and is not suitable for waveform modeling.

Figure A1. All DPG (06, 07, 08, 09) and APG (01, 02, 03, 04, 10) data for the P-wave from a M6.8 earthquake on May 28, 2012 (day 149) at 05:07:23.45, lat -28.0430, lon -63.0940, depth 586 km (hypocenter from ANSS catalog).



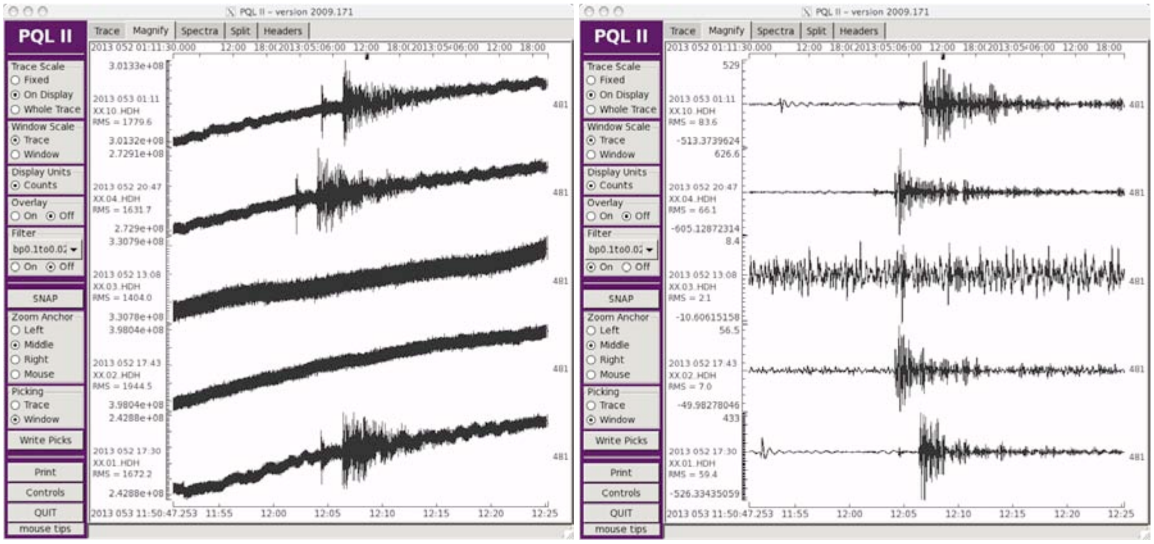
Trace Scale: ● On Display
Window Scale: ● Trace
Display Units: ● Counts
Overlay: ● Off
Filter: hp2to10 ● Off
Zoom Anchor: ● Middle
Picking: ● Window

Figure A2. All DPG (06, 07, 08, 09) and APG (01, 02, 03, 04, 10) data for the P-wave from a M6.1 earthquake on Feb. 22, 2012 (day 053) at12:01)59.20, lat -27.9930, lon -63.1950, depth 581 km (hypocenter from ANSS catalog). The P-wave arrival on S04 occurs at ~12:02, prior to the window shown here. The S-wave arrival from this event is observable at approximately the same time on S02 as on S04, although low-pass filtering is needed to reveal it because of the higher level of short period noise on this instrument at this time; P is not observable on S02.



Trace Scale: ● On Display
Window Scale: ● Trace
Display Units: ● Counts
Overlay: ● Off
Filter: ● Off
Zoom Anchor: ● Middle
Picking: ● Window

Figure A3. A longer window of APC data for the earthquake shown above. Data on the left are unfiltered. Data on the right are filtered 0.02-0.10 Hz. This shows that the earthquake is seen with ~2 minutes advance on both S02 and S04, although the background noise level is higher on S02 than on the others so that the P-wave is not observed. It is not observed on S03.



Figures A4 to A6 from a regional earthquake on October 11, 2012 illustrate several features about waveform distortion on the SL-LDEO OBSs. The top 4 traces are Z, H2, H1 and DPG for S09, followed by the 4 components for S08, S07, and S06 in the same order. The first plot shows an overview of the event, showing P and S waves. The second plot shows the P-waves at larger scale. Amplitudes are scaled to the maximum amplitude in each trace. The number on the right of each trace is the decimation factor of the data for the plot. In keeping with its "quick look" character, pql does not apply an antialiasing filter before plotting. Examples of waveform problems later in the deployment are shown in Figures A7 and A8.

Some general observations about the data are:

- signal offsets on H2 for S08 (similar problems are also evident on Z and H1, but the signal from the earthquake, in this case, rose above this background level of signal distortion).
- similar P-waveform for Z and DPG for S06, S07 and S09. When looked at in detail, a shift of ~0.02s is observed between these two sensors, which should be taken into account if mixing times from the two sensors for earthquake locations or tomography.

Figure A4.

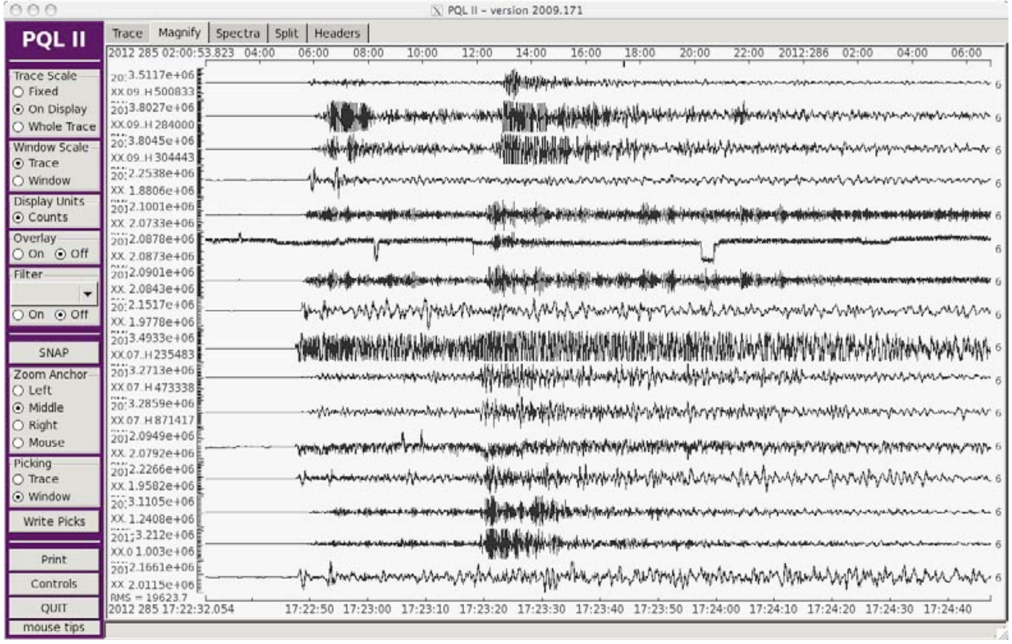


Figure A5.

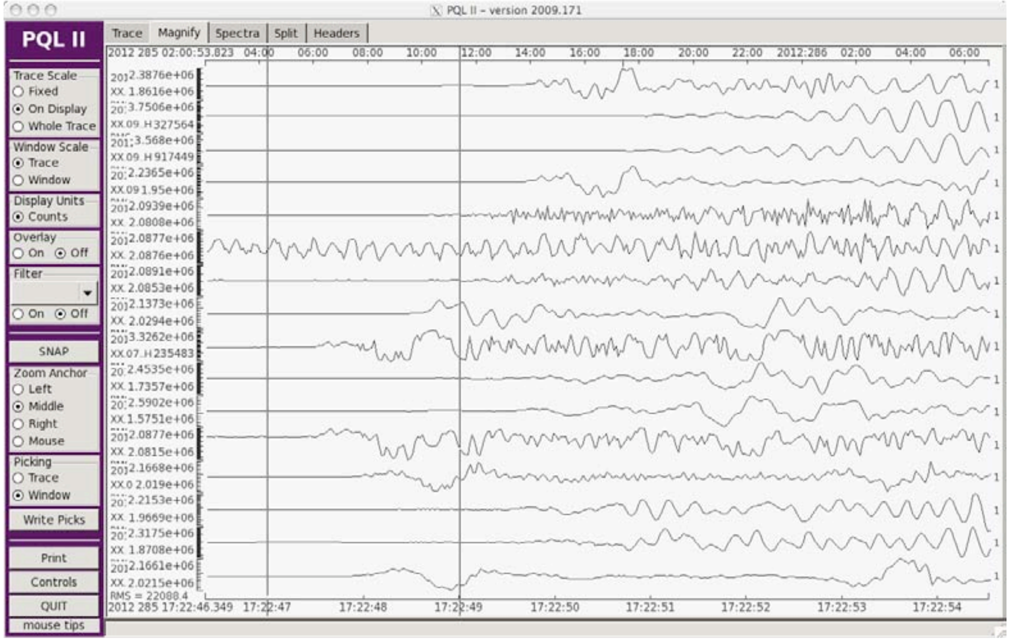
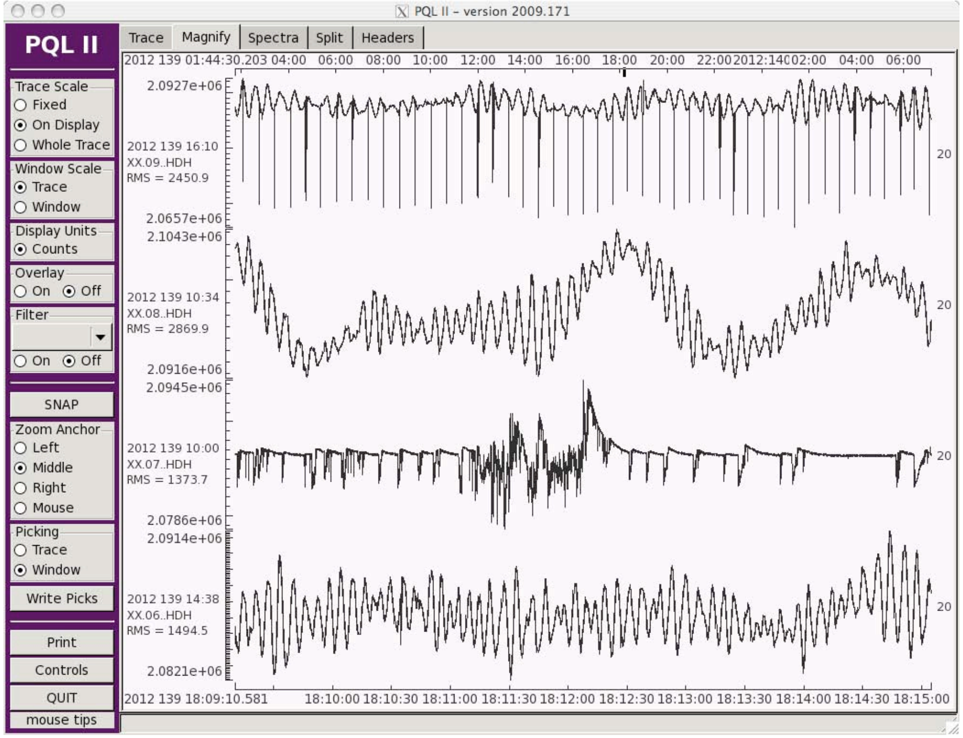
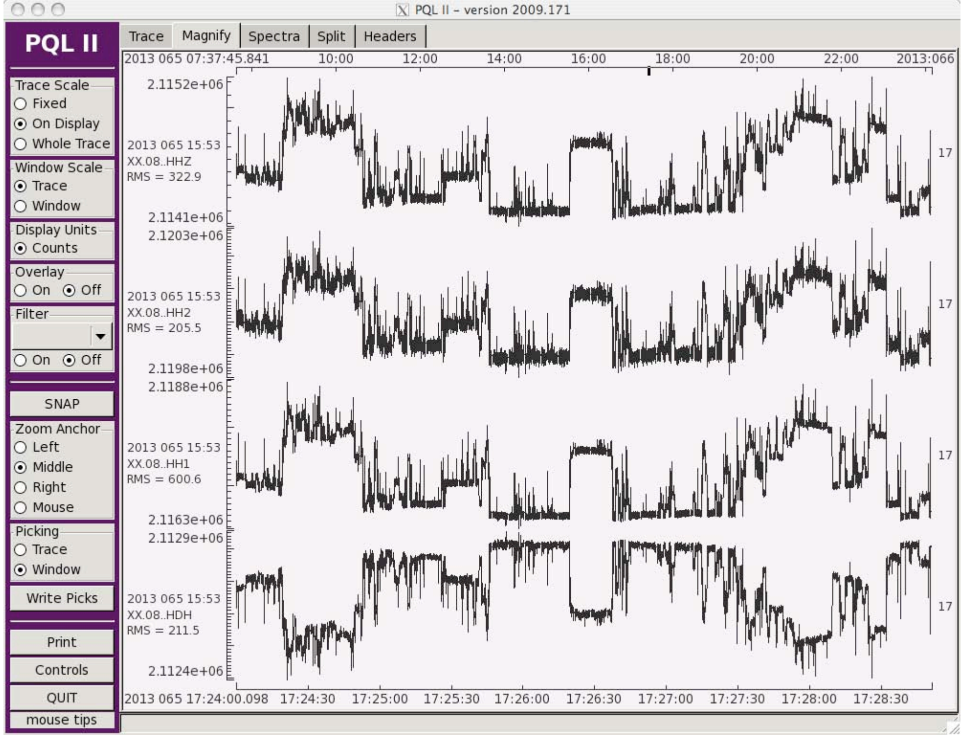


Figure A6. Example of problems with DPG waveforms on S07 and S09. Similar (but smaller amplitude) spikes are intermittently observed on S06 and S08. While the data on S08 are good at this early stage of the deployment, data quality deteriorates with time.



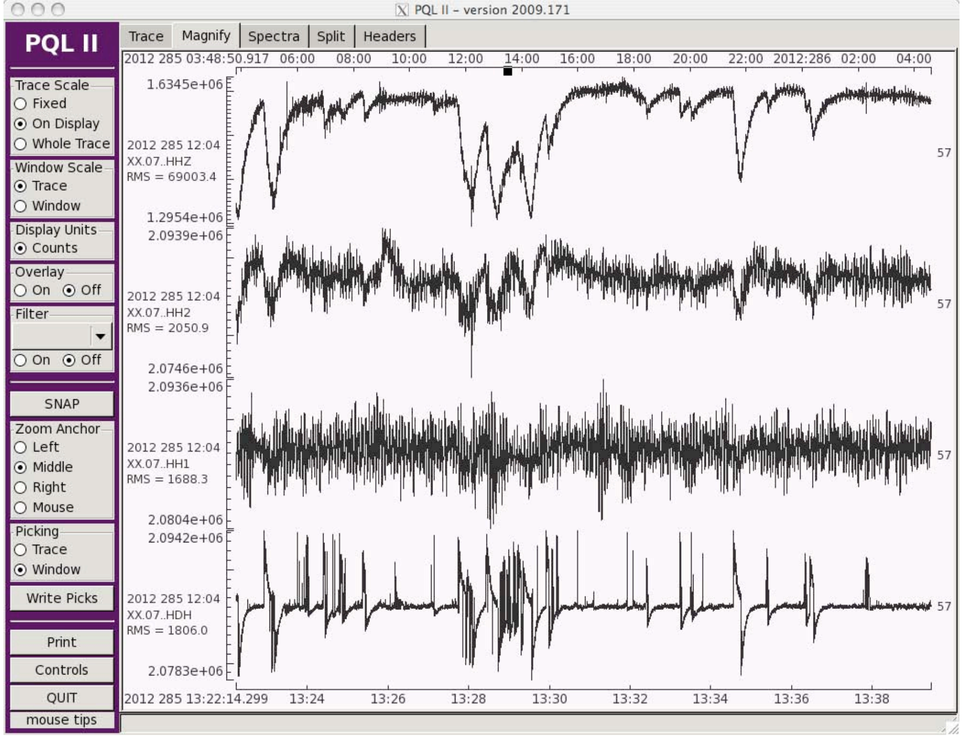
Trace Scale: ○ Fixed ● On Display ○ Whole Trace
Window Scale: ● Trace ○ Window
Display Units: ● Counts
Overlay: ○ On ● Off
Filter: ○ On ● Off
Zoom Anchor: ○ Left ● Middle ○ Right ○ Mouse
Picking: ○ Trace ● Window

Figure A7. 4 component data on S08 late in the deployment. Somewhat earlier in the deployment, the seismometers has the problem shown here while the DPG has a spiky signal similar to that for S09 in the previous figure.



Trace Scale: ○ Fixed ● On Display ○ Whole Trace
Window Scale: ● Trace ○ Window
Display Units: ● Counts
Overlay: ○ On ● Off
Filter: ○ On ● Off
Zoom Anchor: ○ Left ● Middle ○ Right ○ Mouse
Picking: ○ Trace ● Window

Figure A8. Signal quality problems on S07. These problems are seen intermittently throughout the entire deployment.



Trace Scale
○ Fixed
● On Display
○ Whole Trace

Window Scale
● Trace
○ Window

Display Units
● Counts

Overlay
○ On ● Off

Filter
○ On ● Off

Zoom Anchor
○ Left
● Middle
○ Right
○ Mouse

Picking
○ Trace
● Window

2012 285 12:04
XX.07..HHZ
RMS = 69003.4

2012 285 12:04
XX.07..HH2
RMS = 2050.9

2012 285 12:04
XX.07..HH1
RMS = 1688.3

2012 285 12:04
XX.07..HDH
RMS = 1806.0

APG response:

An examination of high-pass filtered data to look for small, local earthquakes indicated that the background noise level on the APGs rises steadily for frequencies above 1-2 Hz. This is in contrast to the DPG or seismometer data. Small earthquakes that are observable on the DPG and seismometer channels are not observed on the APGs. In addition, two of the 5 APGs (S02 and S03) show a progressive loss of response in the frequency band of 0.001-1 Hz that occurred over a period of a few days 10 days into the deployment for S03 and 100 days into the deployment on S02. This has been attributed to corrosion and subsequent clogging of an intake tube so that pressure is not equalized properly between two chambers. These two characteristics of the APG data can be seen in the spectra below, which represent spectra on S02 for 6 different days. The increase in noise above 1-2 Hz is stable for the entire deployment and is similar for all APGs. From day 225 to 230, sensitivity to background noise in the microseismic and infragravity bands is gradually lost.

Figure A9. Spectra for S02 for a day soon after deployment (red), day 150 (blue), day 225 (green), day 227 (light blue), day 230 (purple) and day 250 (ochre). (figure provided by Spahr Webb, June 20, 2013).