Preliminary comments on data quality during the 2012-2013 ChilePEPPER project based on data exploration with pql (originally prepared by Anne Trehu, April 9, 2013; revised and updated, June 20, 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 impulsive earthquake arrivals indicated problems with timing. 2 instruments are late; 3 are early. This problem is attributed by LDEO to occasional skipping of samples and is also present in Cascadia Initiative (CI) year 1 data. LDEO is working on a fix.

2) No useful data were recorded from the Trillium Compact seismometers on the LDEO-CI OBSs. LDEO 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.

3) Determination of ad-hoc empirical calibration constants for each instrument 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 needs to 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.

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. Arrival time differences on the LDEO-Standard OBSs 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 serious problems with waveform distortion (spikes, offsets, and other problems) 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.

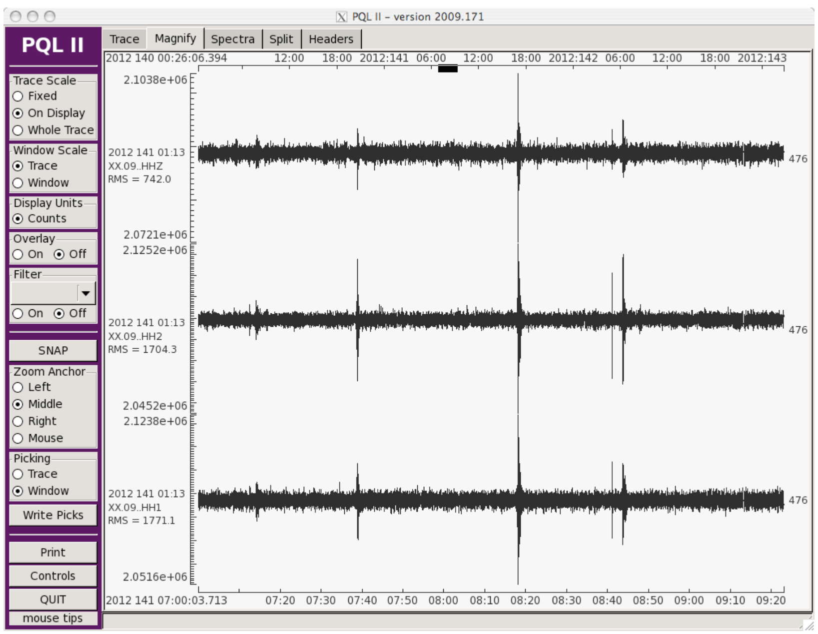
5) One LDEO-Standard OBS (S05) was not recovered. We were able to communicate acoustically with the instrument, but it did not release in spite of many attempts on several different days. Attempt to recover the instrument by dragging were not successful.

6) DPGs do not show sensitivity to tidal frequecies. This contrasts with strong tidal sensitivity at similar water depth of SIO DPGs during COLZA. For the CI yr 1 data set, SIO DPGs are sensitive to tides, whereas LDEO and WHOI DPGs are not.

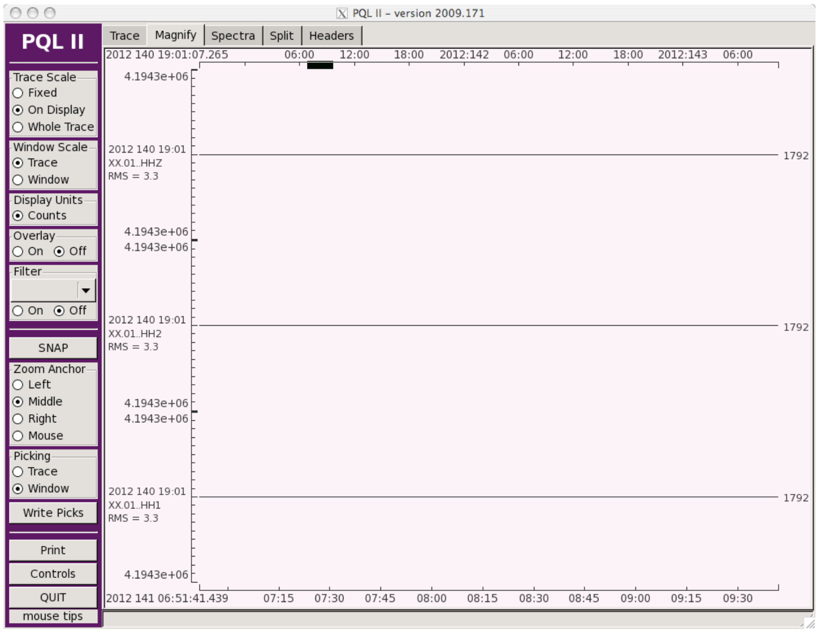
Seismometers in the LDEO-CI instruments:

No valid data are available from the seismometers in the LDEO-CI instruments. In some cases, the signal values are constant and very large or 0. At times, spikes or step-like offsets are observed. However, theses occur at different times on different channels, suggesting that they come from the recording system and not from the sensors, for which faults should be cross-coupled between the components for Trillium Compact seismometers. Some of the channels appear to have data, although no earthquakes are observed in time windows were earthquakes are detected by the LDEO-Standard OBSs.

Three seismometer components on S09 - LDEO-Standard. Several small earthquakes with S-P times of 8-15 are observed in this time window.



The following 5 screengrabs (generated with PASSCAL program "PQL") show approx. the same time window on the 5 LDEO-CI instruments. The instrument number follows XX in the trace label. Note the maximum and minimum values on the amplitude axes, which indicate the range of values (in counts) of the data.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PQL II
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Controls
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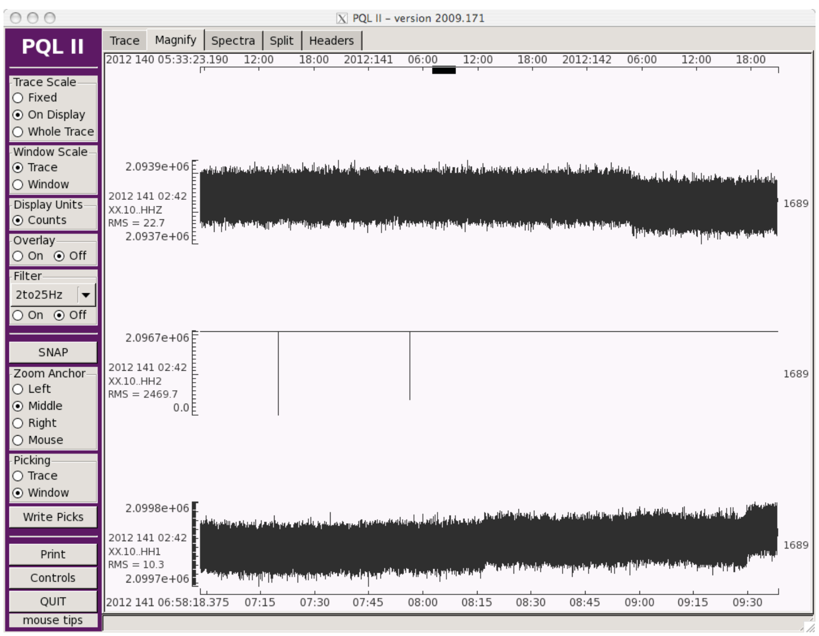
2012 140 19:01:07.265
2012 140 19:01
XX.01..HHZ
RMS = 3.3
2012 140 19:01
XX.01..HH2
RMS = 3.3
2012 140 19:01
XX.01..HH1
RMS = 3.3
4.1943e+06
1792
2012 141 06:51:41.439


PQL II – version 2009.171
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SNAP
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Picking
Trace
Window
Write Picks
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Controls
QUIT
mouse tips
2012 140 05:33:23.190
2.0939e+06
2012 141 02:42
XX.10..HHZ
RMS = 22.7
2.0937e+06
2.0967e+06
2012 141 02:42
XX.10..HH2
RMS = 2469.7
0.0
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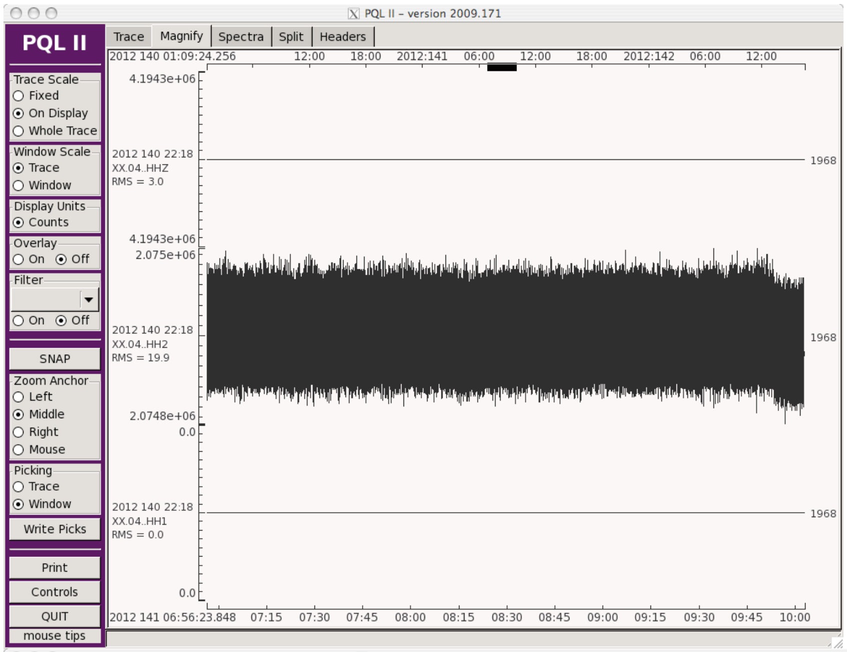
XX.10..HH1
RMS = 10.3
2.0997e+06
1689
2012 141 06:58:18.375



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SNAP
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Left
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Mouse
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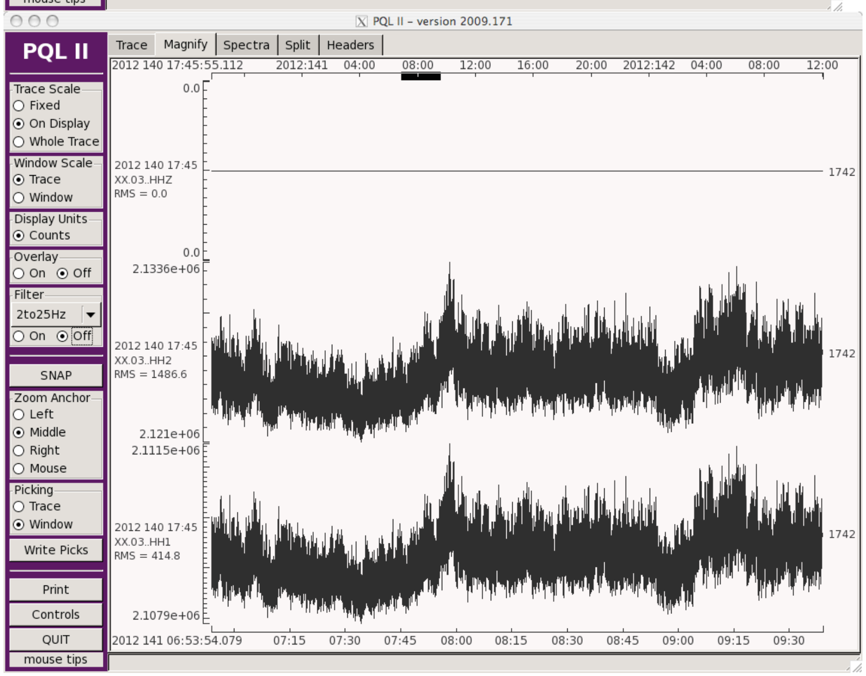
Trace
Window
Write Picks
Print
Controls
QUIT
mouse tips
2012 140 01:09:24.256
2012 140 22:18
XX.04..HHZ
RMS = 3.0
XX.04..HH2
RMS = 19.9
XX.04..HH1
RMS = 0.0
2012 141 06:56:23.848



PQL II – version 2009.171
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Filter
2to25Hz
On
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SNAP
Zoom Anchor
Left
Middle
Right
Mouse
Picking
Trace
Window
Write Picks
Print
Controls
QUIT
mouse tips
2012 140 17:45:55.112
2012 140 17:45
XX.03..HHZ
RMS = 0.0
XX.03..HH2
RMS = 1486.6
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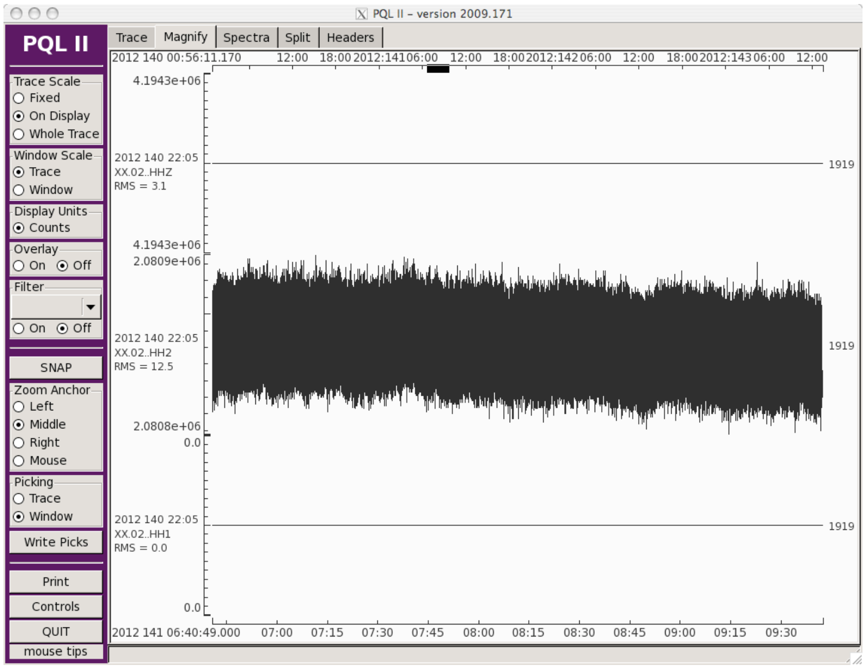
2012 141 06:53:54.079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SNAP
Zoom Anchor
Left
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Right
Mouse
Picking
Trace
Window
Write Picks
Print
Controls
QUIT
mouse tips
2012 140 00:56:11.170
4.1943e+06
2012 140 22:05
XX.02..HHZ
RMS = 3.1
1919
4.1943e+06
2.0809e+06
2012 140 22:05
XX.02..HH2
RMS = 12.5
1919
2.0808e+06
0.0
2012 140 22:05
XX.02..HH1
RMS = 0.0
1919
0.0
2012 141 06:40:49.000
07:00
07:15
07:30
07:45
08:00
08:15
08:30
08:45
09:00
09:15
09:30

Timing checks:

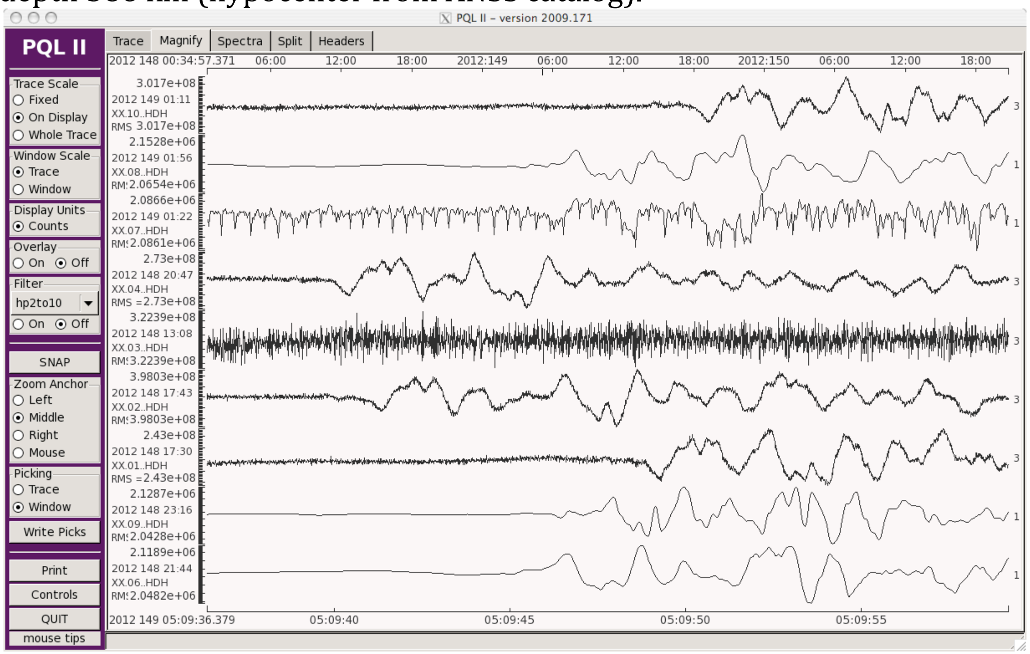
Measured clock drifts are all <1.2 s, suggesting good timing control. As an independent check, I looked at P-wave arrivals from 3 earthquakes - a relatively large regional event that was not reported by ANSS but was well-recorded across the array and two regional deep events reported by ANSS - to see 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. **This indicates either that timing variations during the deployment are highly non-linear for the LDEO-CI OBSs or that there are problems with the playback program that converts the raw data to miniseed or with the parameters used when running that program. The latter is more likely and should be relatively easy to fix.**

[note: The APG data shown for the two deep events were converted to miniseed but not corrected for clock drift because the clock drift-corrected data for S03 and S04 could not be read with pql for reasons not yet identified. The APG data at S01, S02 and S10 for the third event were corrected for clock drift and leap second. We have also compared corrected and uncorrected data for S01 and S10. The magnitude of the correction is smaller than the apparent timing mismatches.]

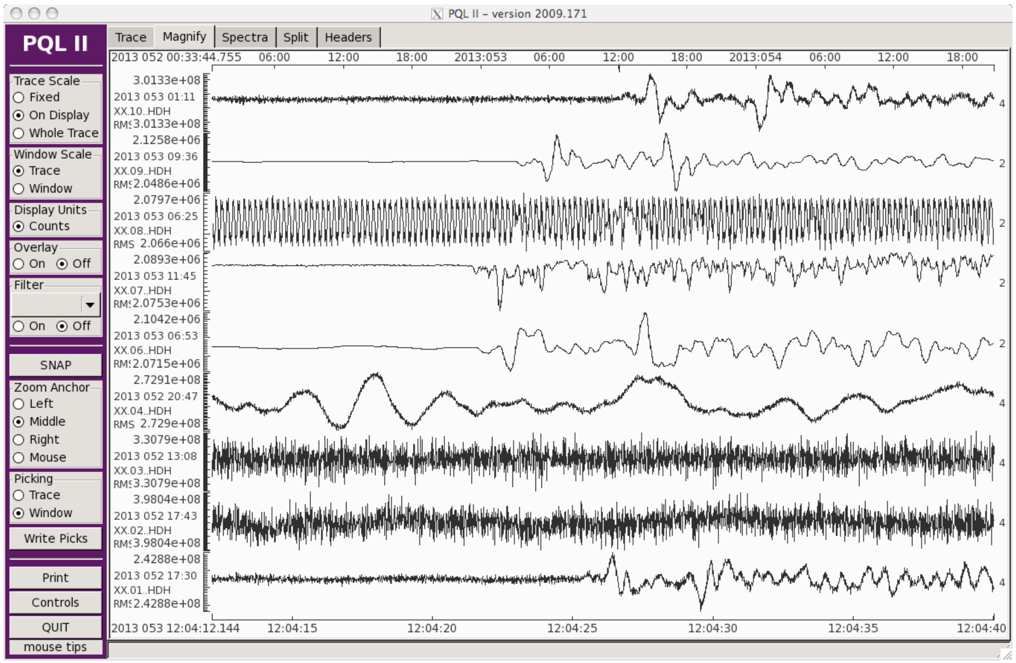
These plots also point to problems with temporal variations in signal quality. These temporal variations complicated establishment of an automated approach towards searching for various types of events in different frequency bands in the data (e.g. non-volcanic tremor or long-period earthquakes) since 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 S03APG (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.
- 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.

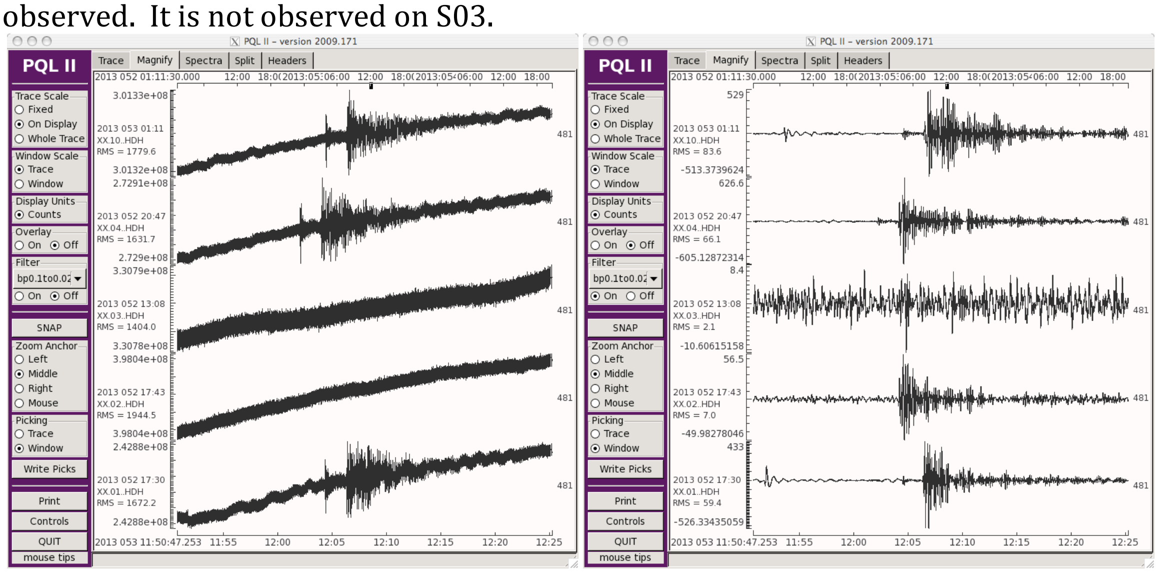
All DPG (06, 07, 08, 09) and APG (01, 02, 03, 04, 10) data for the P-wave from a M6.8 earthquake on May 28, 2012 (day 149) at 05:07:23.45, lat -28.0430, lon -63.0940, depth 586 km (hypocenter from ANSS catalog).



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.



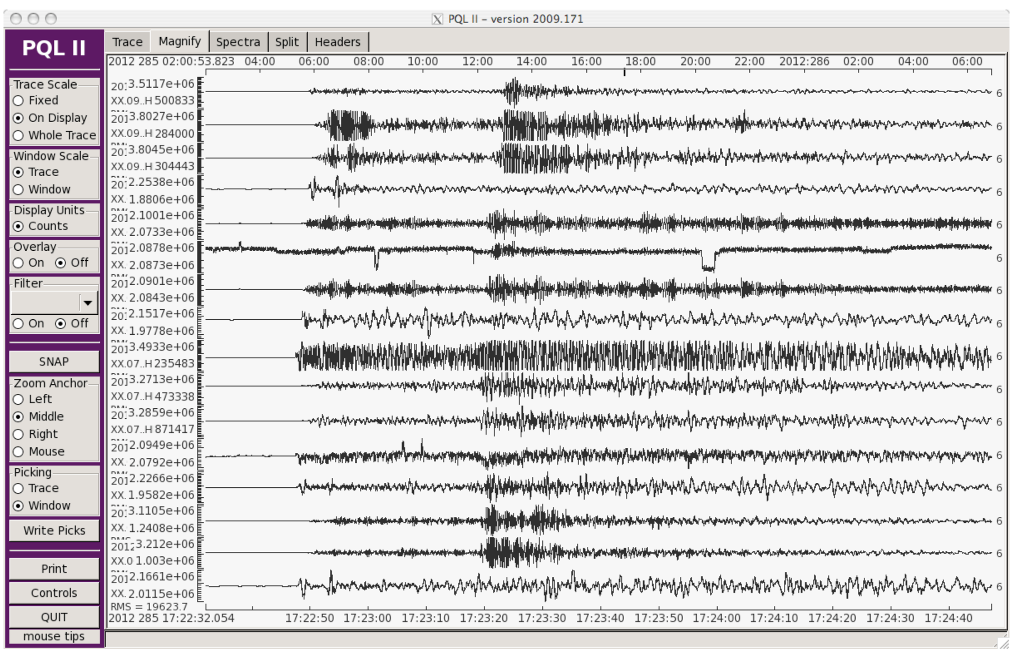
A longer window of APC data for the earthquake shown above. Data on the left are unfiltered. Data on the right are filtered 0.02-0.10 Hz. This shows that the earthquake is seen with ~2 minutes advance on both S02 and S04, although the background noise level is higher on S02 than on the others so that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

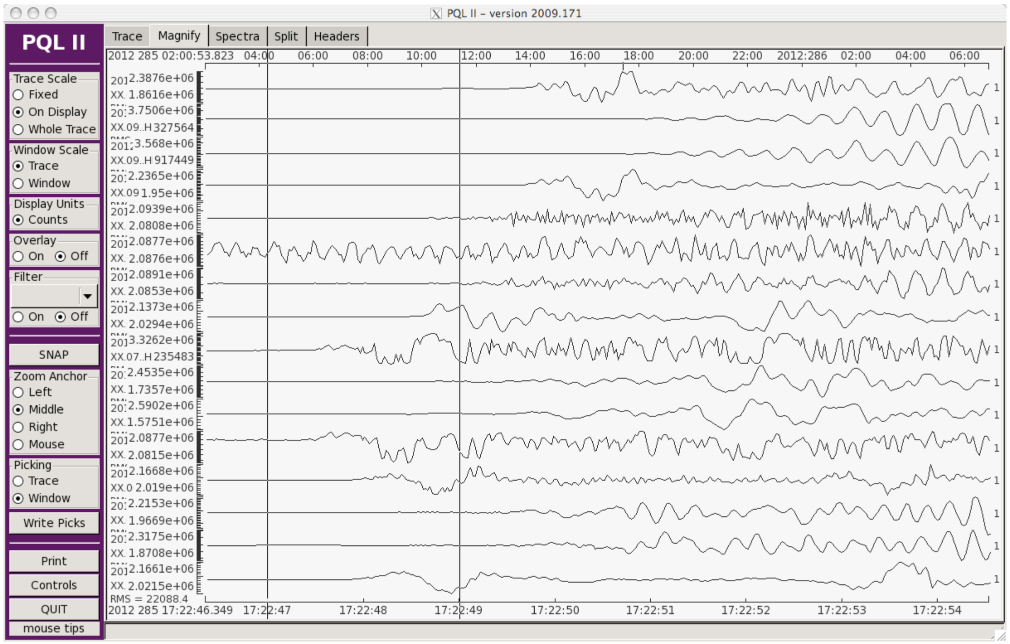


Waveform distortion on the LDEO-Standard OBSs:

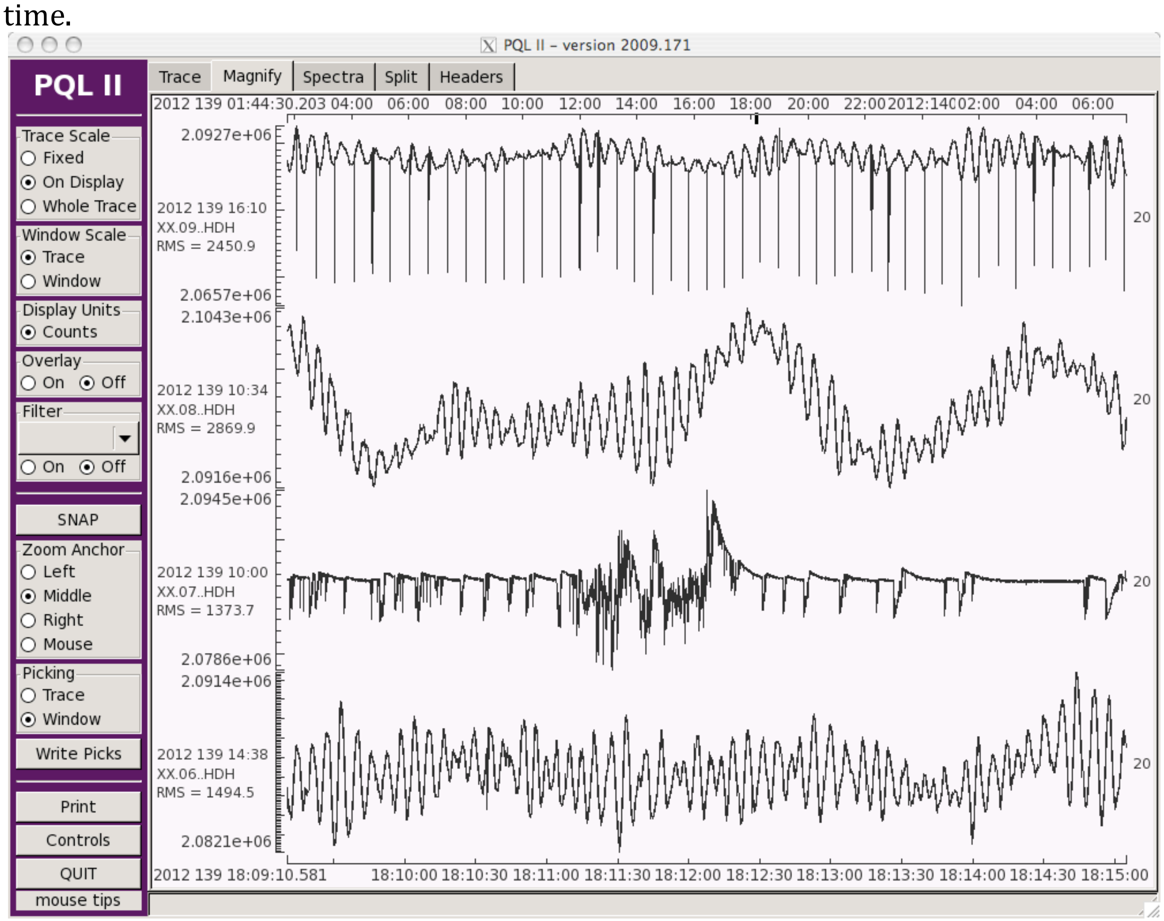
The next three screengrabs are from a regional earthquake on October 11, 2012 illustrate several features about the data. The top 4 traces are Z, H2, H1 and DPG for S09, followed by the 4 components for S08, S07, and S06 in the same order. The first plot shows an overview of the event, showing P and 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. Some observations about the data include:

- 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.

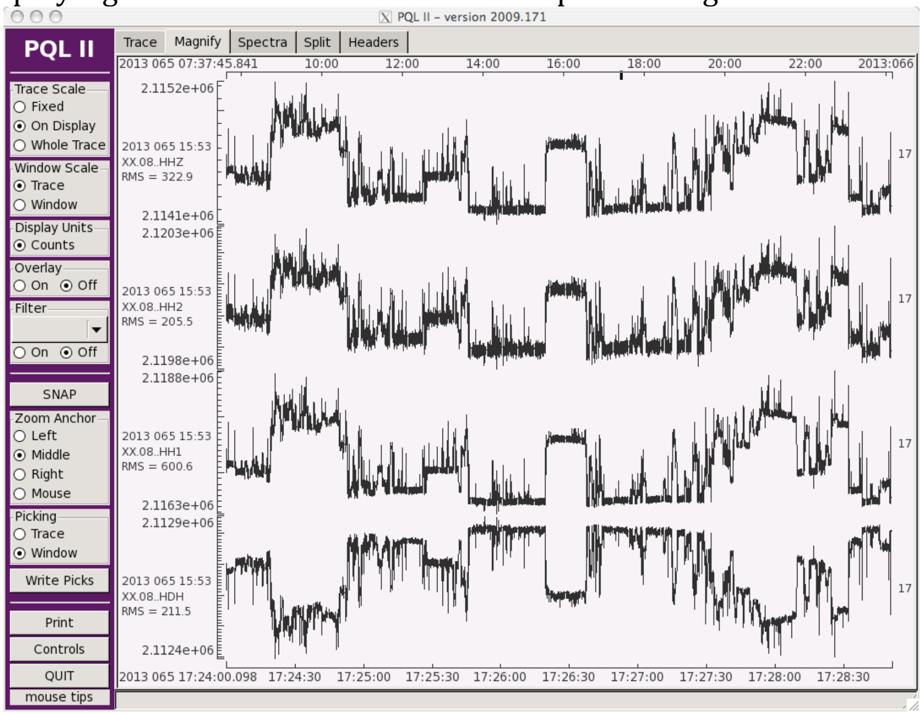




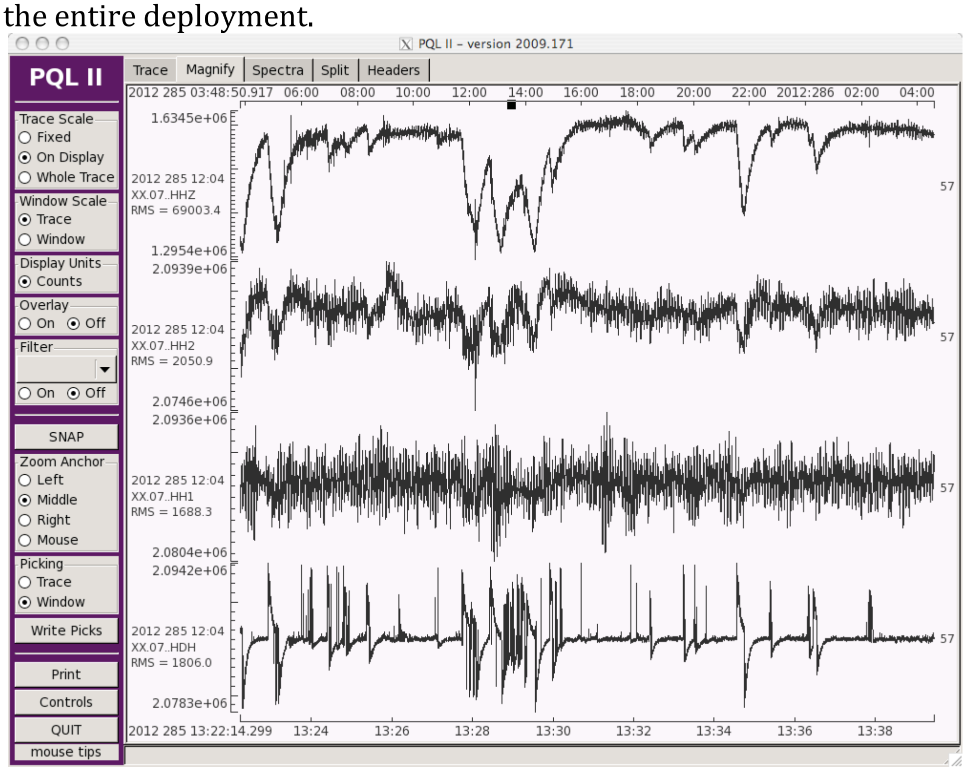
Example of problems with DPG waveforms on S07 and S09. Similar (but smaller amplitude) spikes are intermittently observed on S06 and S08. While the data on S08 are good at this early stage of the deployment, data quality deteriorates with time.



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.



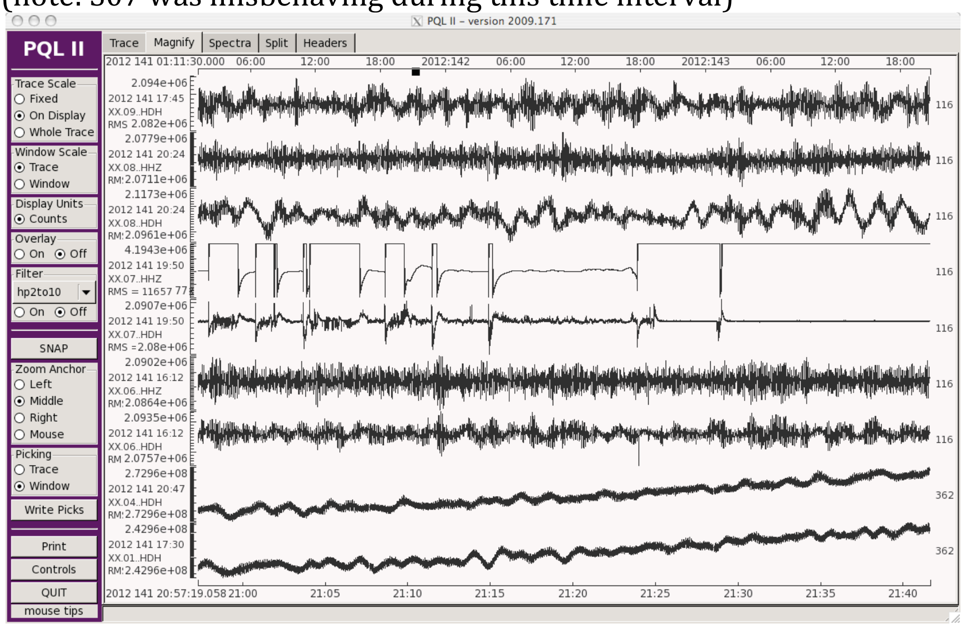
Signal quality problems on S07. These problems are seen intermittently throughout the entire deployment.

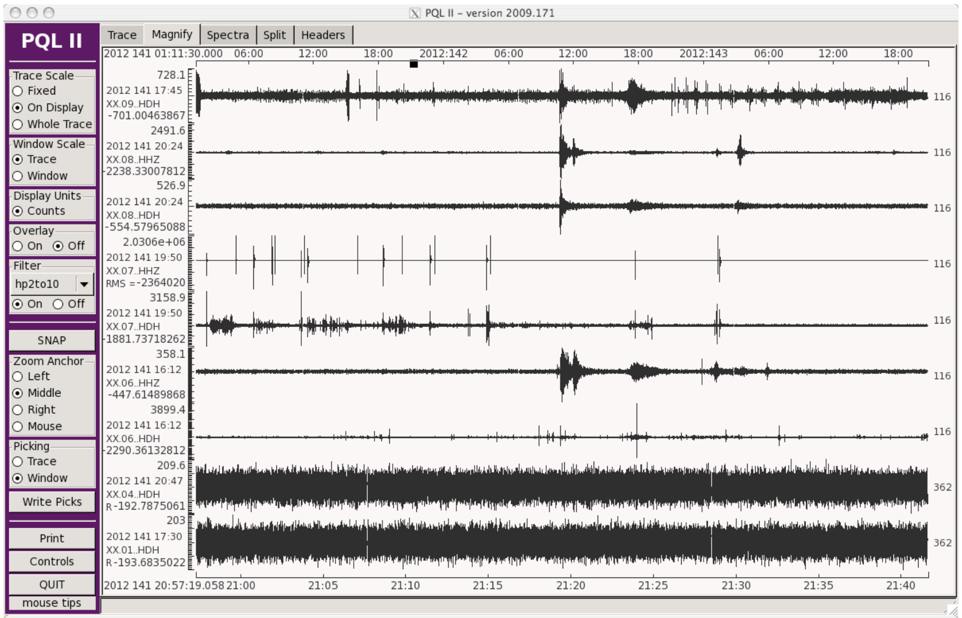


Noise above 2 Hz on APGs:

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 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. This suggests that the noise level above 2 Hz on the APGs is controlled by instrument noise and not the natural background noise level.

This is illustrated in the following figures from day 141. The first shows a 40 m window of data in which there are several small earthquakes, which can only been seen when data are high-pass filtered. DPG signals from S06, S07, S08 and S09, Z from S06, S07, S08, and APG from S01 and S04 are shown. The data are first shown unfiltered and then with a 2-10 Hz bandpass. The third figure shows spectra of the unfiltered data. The earthquakes are not detectable in the APG data and the spectral level increases at frequencies above 2 Hz, unlike the spectra for the other sensors. (note: S07 was misbehaving during this time interval)




PQL II – version 2009.171
PQL II
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Window Scale
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hp2to10
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SNAP
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Write Picks
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QUIT
mouse tips
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Magnify
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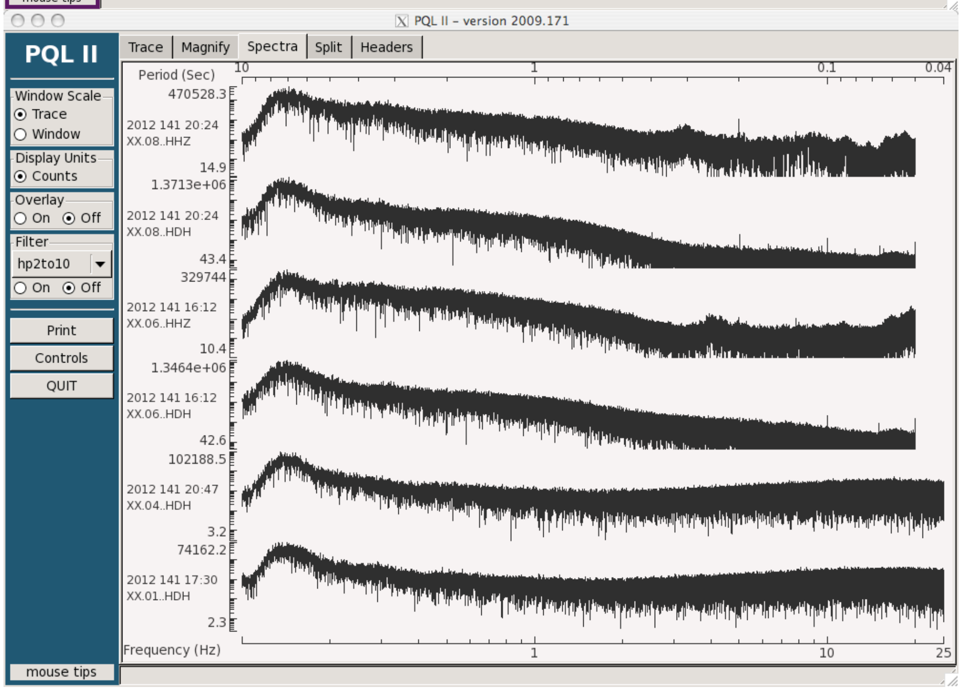
Headers
2012 141 01:11:30.000
2012 141 20:57:19.058
XX.09..HDH
XX.08..HHZ
XX.08..HDH
XX.07..HHZ
XX.07..HDH
XX.06..HHZ
XX.06..HDH
XX.04..HDH
XX.01..HDH


PQL II – version 2009.171
PQL II
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Display Units
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Filter
hp2to10
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Magnify
Spectra
Split
Headers
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2012 141 20:24
XX.08..HHZ
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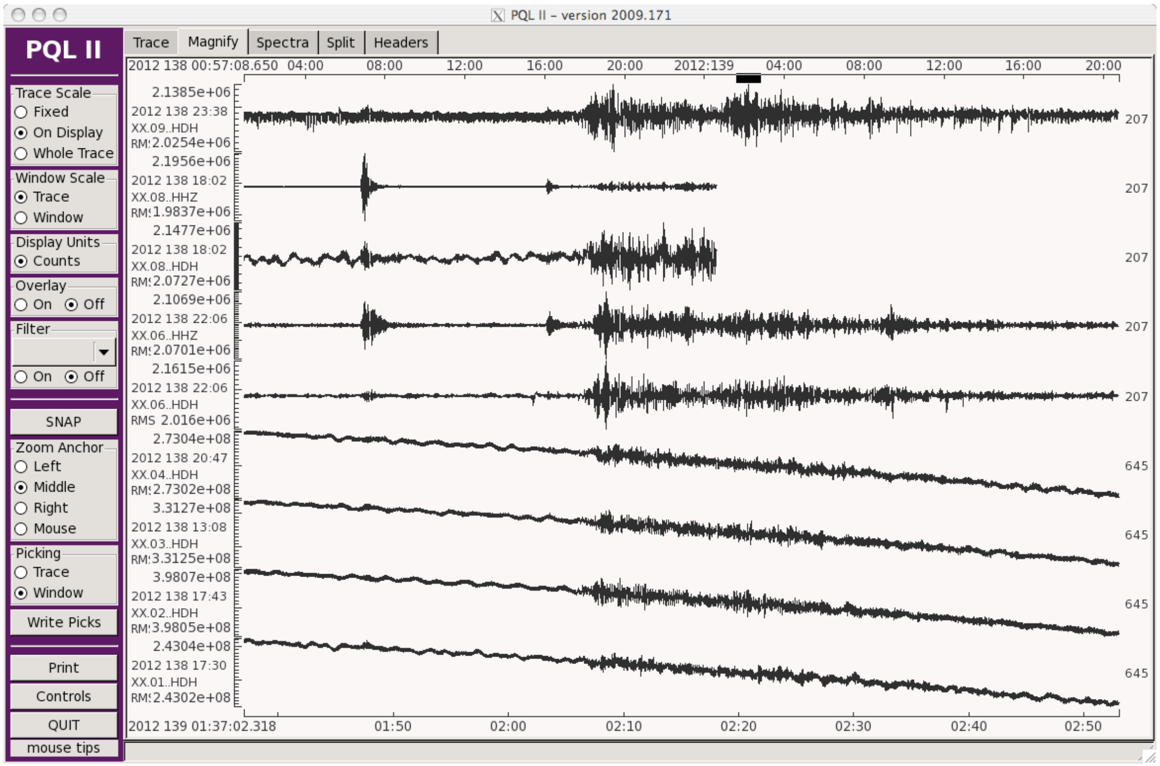
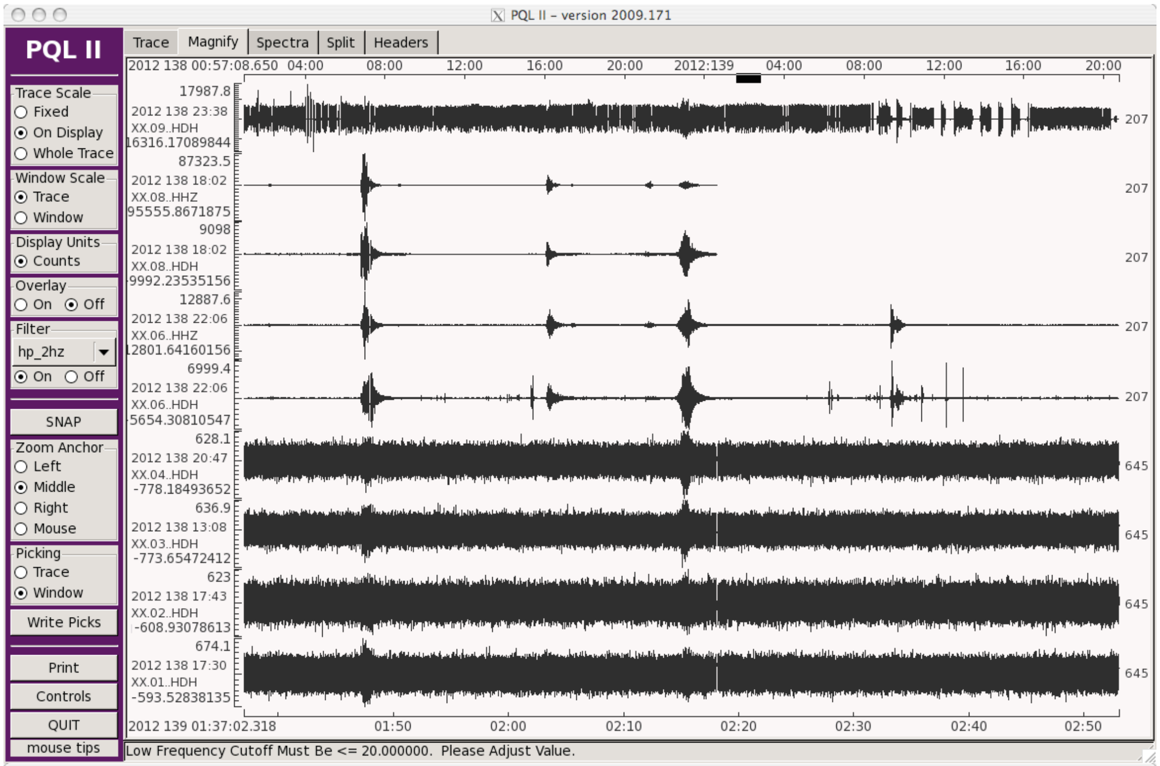
XX.08..HDH
2012 141 16:12
XX.06..HHZ
2012 141 16:12
XX.06..HDH
2012 141 20:47
XX.04..HDH
2012 141 17:30
XX.01..HDH
Frequency (Hz)

Here is a window of data on S01, S02, S03, S04, S06, S08 and S09 containing a local and a teleseismic event in a variety of different passbands. This is a time when S09 DPG had large spikes in the data. The better sensitivity of the Z and DPG components compared to the APGs is clear.

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Write Picks
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2012 138 00:57:08.650
2012:139
17987.8
2012 138 23:38
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87323.5
2012 138 18:02
XX.08..HHZ
9098
2012 138 18:02
XX.08..HDH
12887.6
2012 138 22:06
XX.06..HHZ
6999.4
2012 138 22:06
XX.06..HDH
628.1
2012 138 20:47
XX.04..HDH
-778.18493652
636.9
2012 138 13:08
XX.03..HDH
-773.65472412
623
2012 138 17:43
XX.02..HDH
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XX.01..HDH
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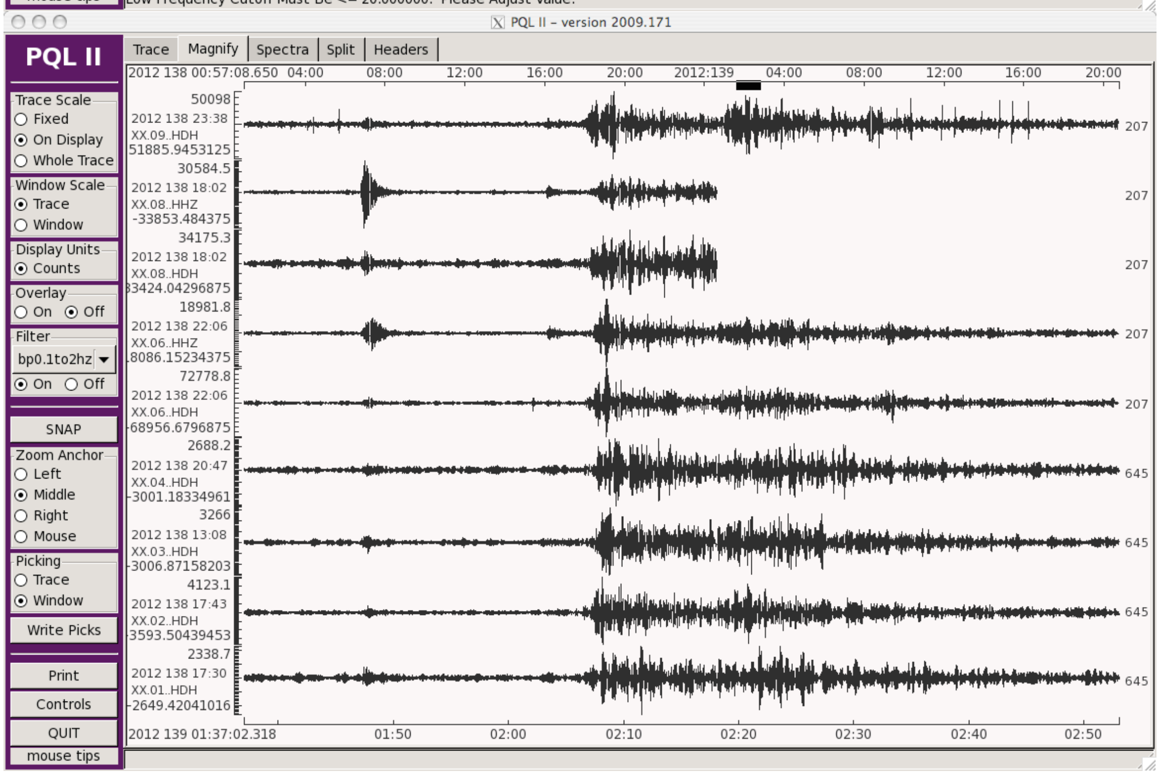
2012 139 01:37:02.318
Low Frequency Cutoff Must Be <= 20.000000. Please Adjust Value.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2012 138 00:57:08.650
2012:139
50098
2012 138 23:38
XX.09..HDH
51885.9453125
30584.5
2012 138 18:02
XX.08..HHZ
-33853.484375
34175.3
2012 138 18:02
XX.08..HDH
18981.8
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XX.06..HHZ
72778.8
2012 138 22:06
XX.06..HDH
2688.2
2012 138 20:47
XX.04..HDH
3266
2012 138 13:08
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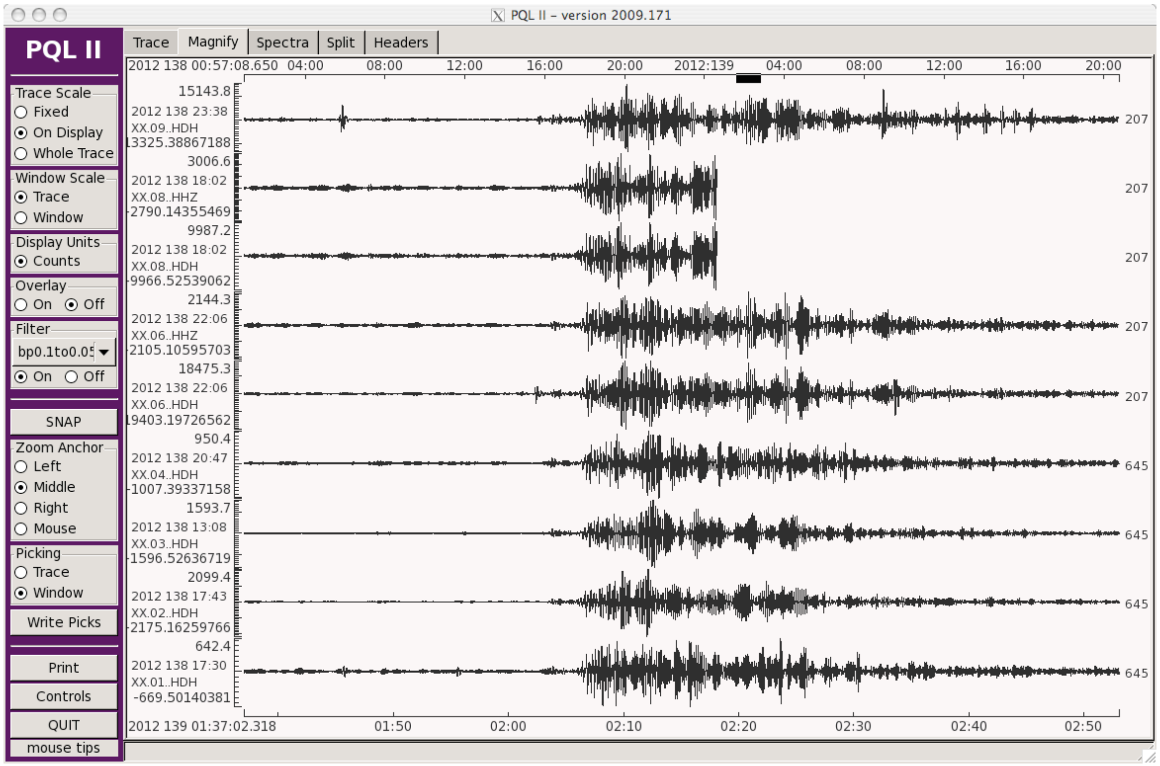
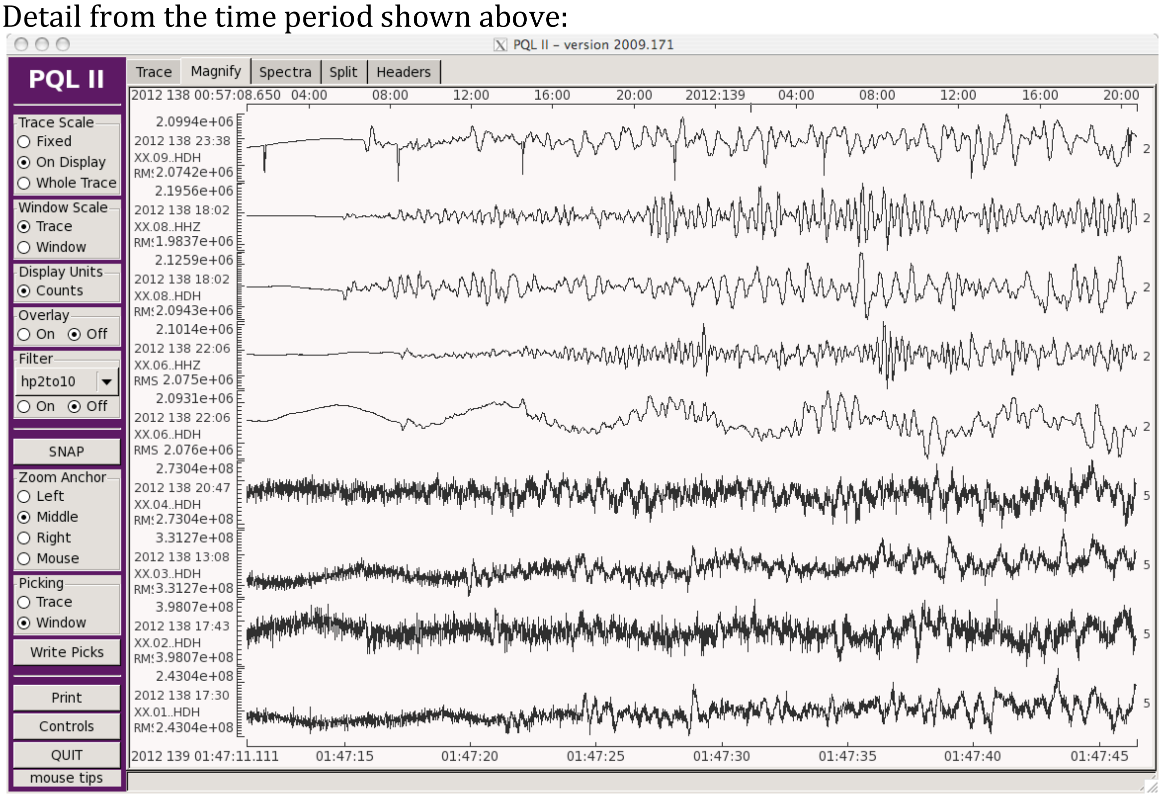
2012 139 01:37:02.318

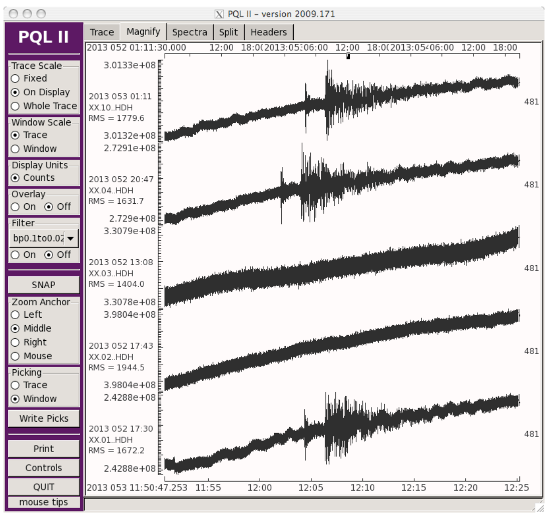


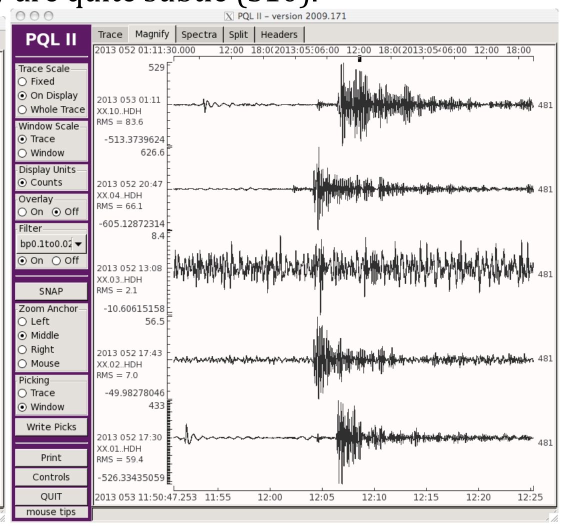
Detail from the time period shown above:



Step-like offsets in APG data:

On the left are unfiltered data from a teleseismic event on the APGs. On the right are data filtered to 0.1-0.02 Hz. Impulsive signals followed by long-period ringing that appear in the filtered data for S01 and S10 prior the earthquake result from small step-like offsets in the data. In some cases, these are clear in the unfiltered timeseries (S01) but in other cases, they are quite subtle (S10).





Detail from S01: