Alleged 1-s time shift of SIO Cascadia I Deployment in 2012

Gabi Laske, IGPP, SIO *(DRAFT: Feb 27, 2013)*

1. Summary

On February 13, 2013, Paul showed me an email-exchange involving Brandon Schmandt at Caltech and IRIS personnel. It is proposed that the SIO OBS records are wrongly corrected for a leap second.

Schmandt compared body wave arrivals from an event in Dec 2011 with one in March 2012. There is a clear ~1-s discrepancy at 4 OBS station in March 2012 that did not occur in Dec 2011. The inference therefore was that the 4 OBSs (which are allegedly 4 SIO OBSs) had a leap-second error. However, the leap second did not occur until the end of June 2012.

My suggestion therefore was that an error in the SEED data headers could have occurred at the end of 2011/beginning of 2012, or a 1-s data tear was introduced when converting the raw data to miniSEED. I have inspected the records of all Cascadia OBS and I find that there is no data tear at the end of the year 2011/beginning of 2012.

Then I tried to verify a systematic time shift in p-travel times for SIO stations for a local-to-regional earthquake in April 2012. There is strong evidence that there is no systematic shift between WHOI and SIO stations. I therefore argue that there is no time shift for SIO stations in 2012. I performed this analysis on raw data, assuming that there is no time shift to be accounted for when applying instrument response corrections.

2. Brandon Schmandt's Body Wave Plots

An email exchange between Brandon Schmandt, Doug Toomey and IRIS was forwarded to SIO OBSIP that SIO records may have a leap-second problem traced back to the start of 2012. The basis for this assumption is that p-travel time residuals were compatible with those at other Cascadia OBS sites but SIO sites appeared ~1 seconds early for (all??) 2012 events (Figure 1). The problem with this assumption is that the leap second in 2012 was not applied at 23:59:59 on 31 December 2011 but on 30 June 2012. It is therefore not clear why a "leap-second" problem should be apparent for the two events in March 2012 as shown in Figure 1.

Brandon states that he can confirm the ~1-s problem for the deeper stations (J35A, J36A, J43A and J44A) but could not confirm it for the shallower stations because noise levels are too high. Incidentally, the four deeper SIO stations underwent NAVY filtering.

An initial reply from Paul and Jeff is that time drift corrections were applied correctly to the SIO records so it is unclear why early 2012 should be off by 1 s.

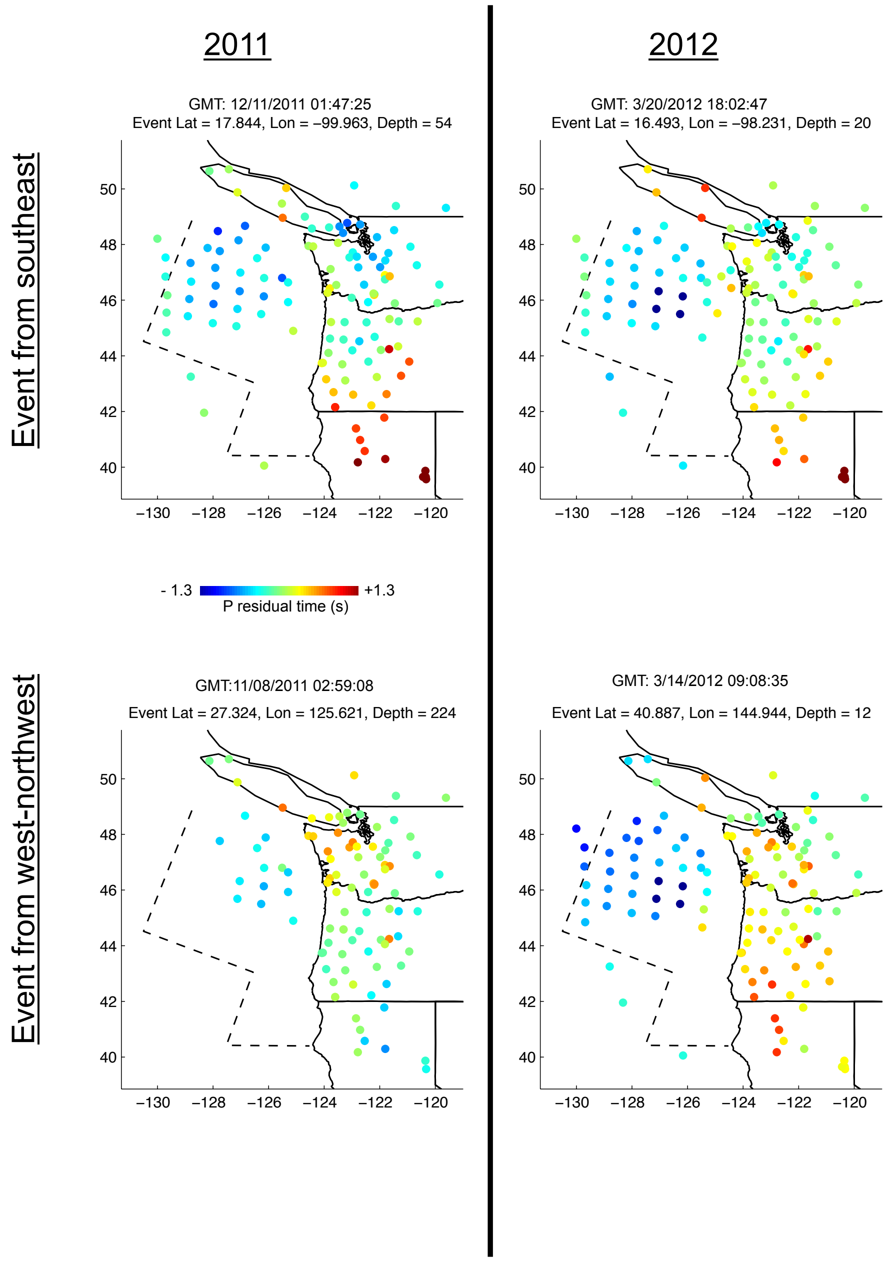

Figure 1: Brandon Schmandt's p-travel time residual plots for 2 pairs of earthquakes (similar back-azimuth and distance), one from the southeast (top) and the west-northwest (bottom); left are events in late 2011 and right are events in March 2012. There is some variability across the array (structure) and varying with time (reason unknown) but for OBSs stand out that consistently appear too fast by ~ 1s in March 2012. These are J35A, J36A, J43A and J44A, all deep SIO NAVY/SAIC-filtered stations.

3. Inspection of Records across the End-of-the-Year Mark

An obvious and easy-to-track-and-verify possibility would be that at some time on the way from raw data to filtered data to miniSEED files sent to the DMC to SEED files requested and processed by the enduser a second was added to a SEED header, or data added or lost, that should not be there. In this case, a requested record should reveal a "tear" in the data (i.e. not be continuous).

I remember from an earlier GSN case that data requested before the end of the year that reach into the new year were out of phase in the new year with data that start in the new year. I do not remember the cause of the problem but a wrong header could have this effect.

I therefore requested data from the IRIS DMC and performed two checks with all Cascadia OBS records:

1) are they continuous from the old into the new year?
2) do the data remain in phase between those I request from 2011 that reach into 2012 and those that start in 2012?

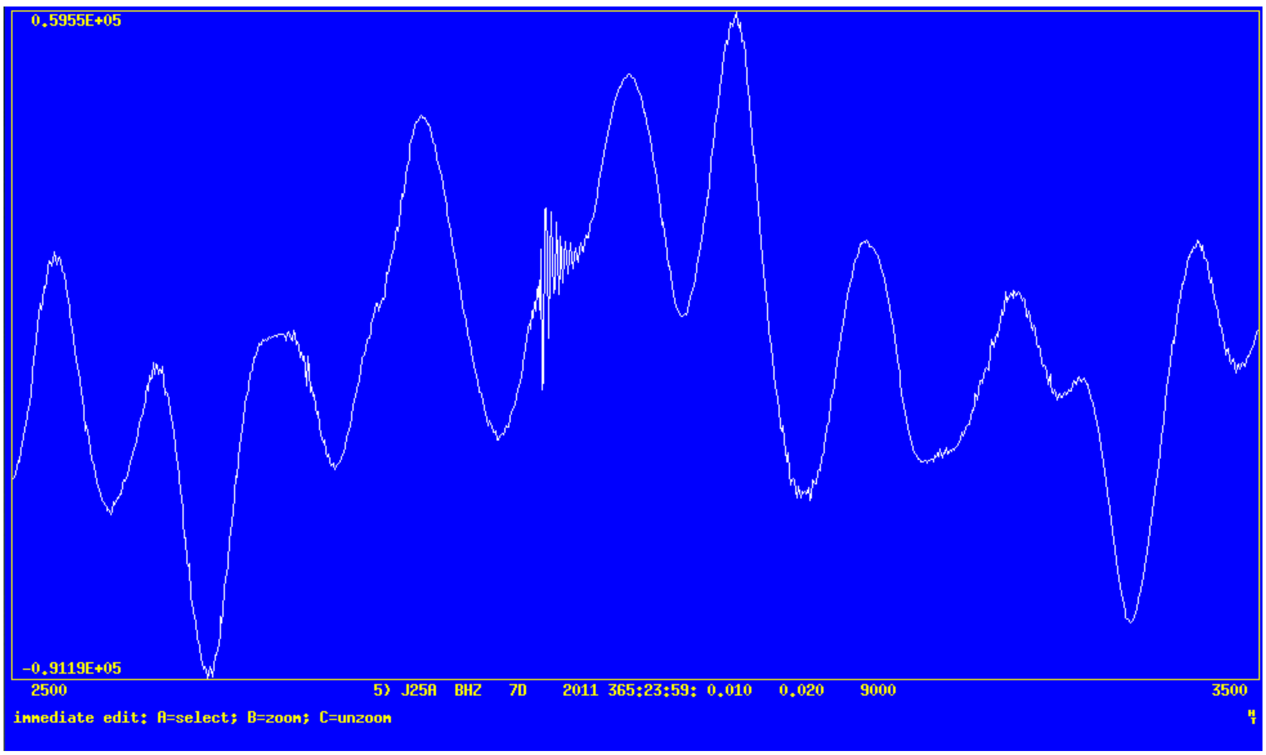

Figure 2a: BHZ record of site J25A starting at 23:59 in day 365 (Dec 31) 2011. The window shown here is a zoom-in, with a start at 23:59:50 and ending at 00:00:10. 00:00:00 is in the middle of the window and no data tear is visible, i.e. the data are continuous. This station was occupied by an SIO OBS.

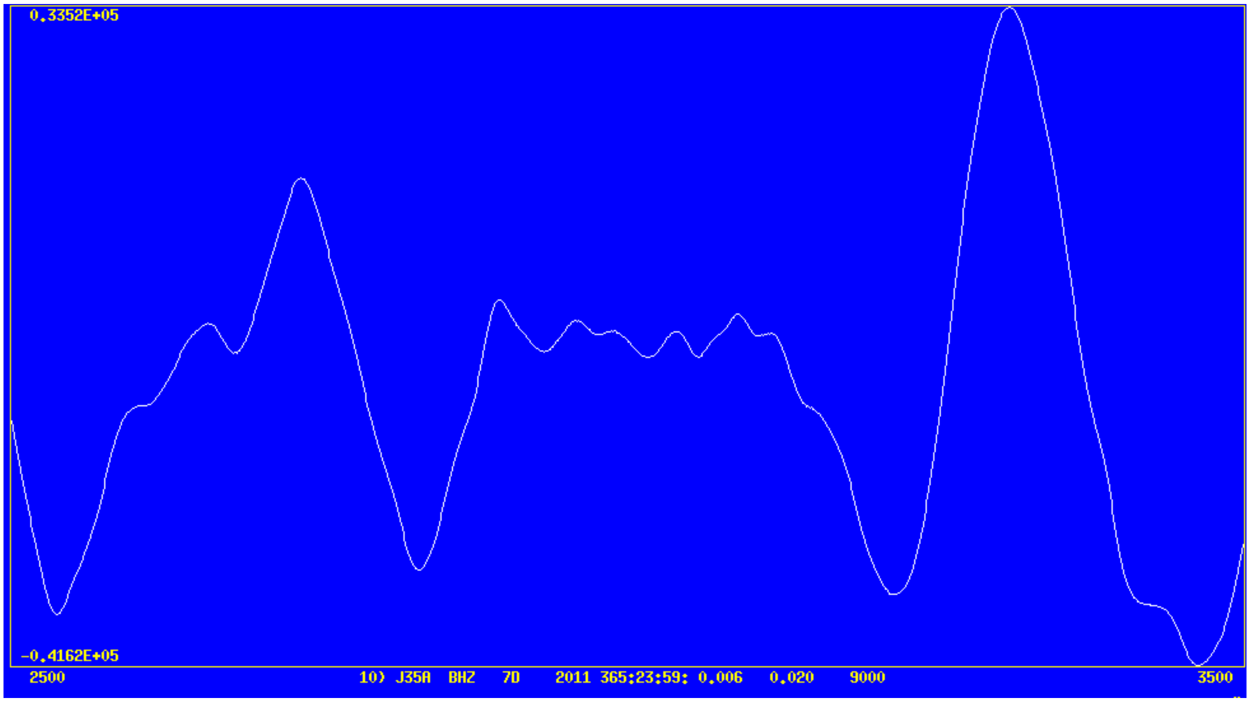

Figure 2b: BHZ record of site J35A. For details see Figure 2a. This station was occupied by an SIO OBS and the data were SAIC-filtered.

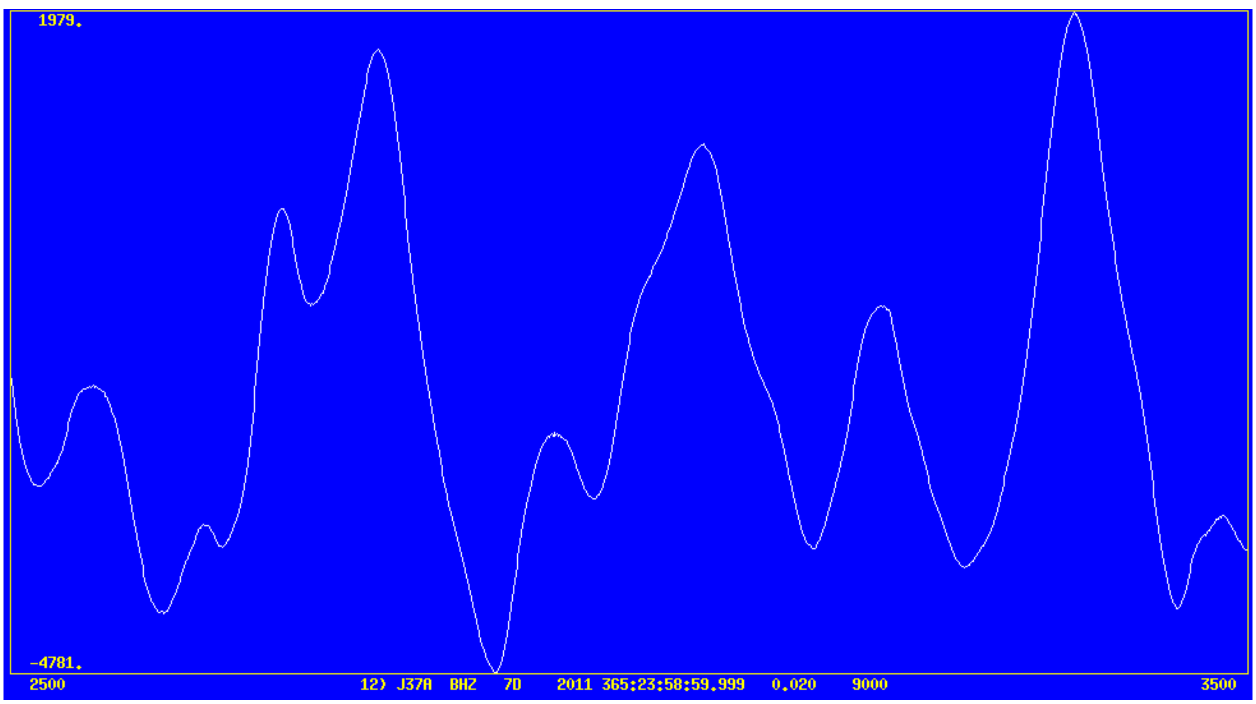

Figure 2c: BHZ record of site J37A. For details see Figure 2a. This station was occupied by an WHOI OBS. I did not check whether or not this is a filtered station.

TEST 1: I requested BH data from the DMC that started at 23:00 on Dec 31. The data were read on an Intel Mac with RDSEED 5.0 and converted to SAC. I used my own routine to convert them to our own binary "gfs" file system (Guy's file system). I then used our in-house interactive screen software to visually inspect the records. I zoomed in on the time window between 23:59 and 0:01 and looked at all OBS vertical components. Virtually all records were continuous at 23:59:59, with no obvious tear in the data, regardless of the OBSIP group and whether they were filtered data or not (Figure 2).

TEST 2: In addition, I requested BH data from the DMC that started at 00:01 on Jan 1. I wanted to check whether SEED headers are consistent between start dates in the old year reaching into the new one and those starting in the new one. The processing occurred in the same way as with test 1. This time, I opened two screen windows side by side and interactively took a time tag of a specific waveform in both windows. For all three OBSs I inspected, the timing of the same waveform was identical (Figure 3). This means that the data and the SEED headers are consistent during the change into the new year.

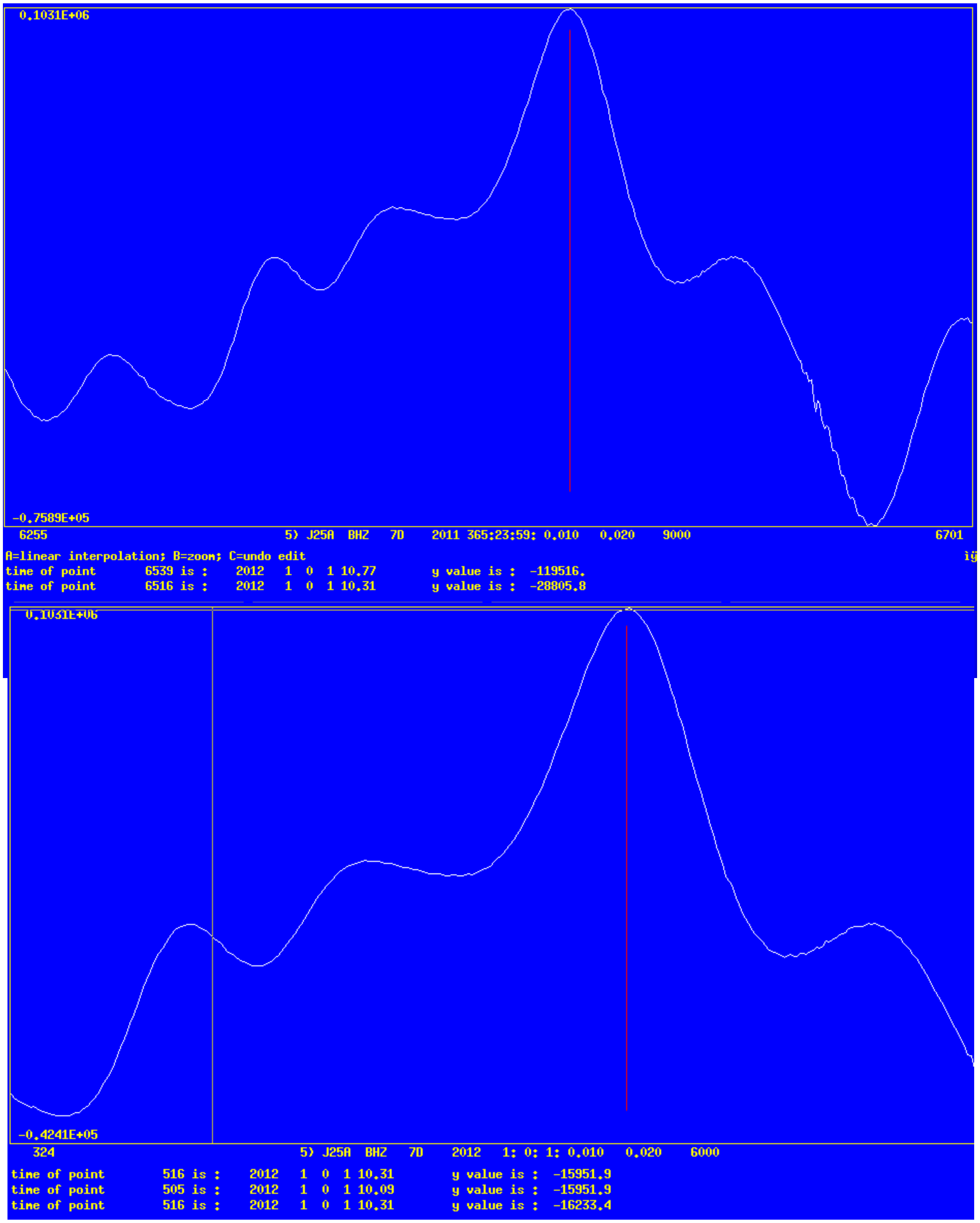

Figure 3a: Timing of a peak on Jan 1 at 00:01 in the BHZ record of site J25A. Top: record starting in 2011; Bottom: record starting in 2012. In both cases, the timing of the peak is at 10.31 s after the minute, i.e. there is no 1-s difference. Note that the zoomed-in window in top and bottom are different, with the bottom one slightly shorter. This has no impact on the time tag reading.

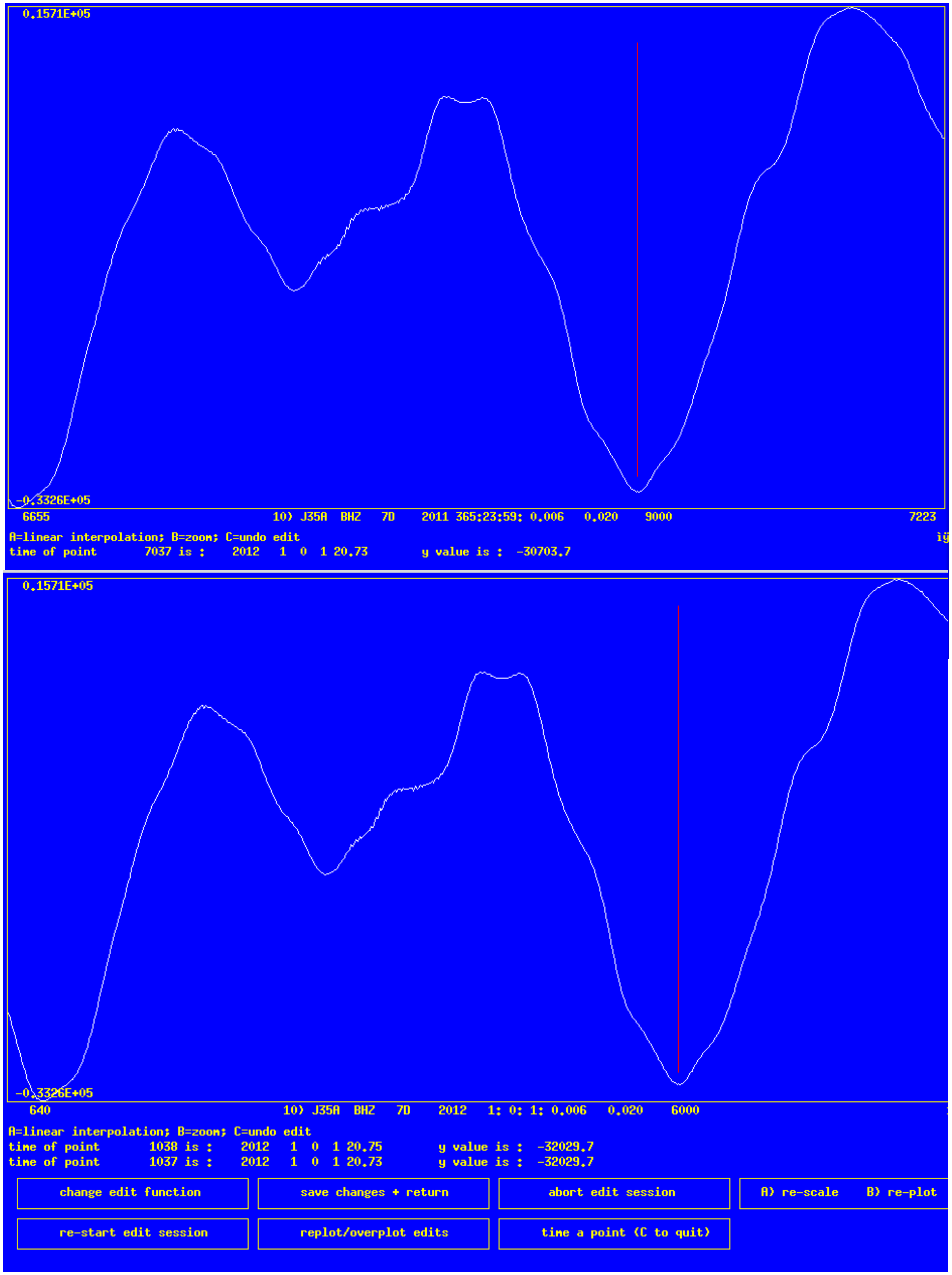

Figure 3b: Timing of a trough on Jan 1 at 00:01 in the BHZ record of site J35A. Top: record starting in 2011; Bottom: record starting in 2012. In both cases, the timing of the peak is at 20.73 s after the minute, i.e. there is no 1-s difference. Note that the zoomed-in window in top and bottom are different, with the bottom one slightly shifted. This has no impact on the time tag reading.

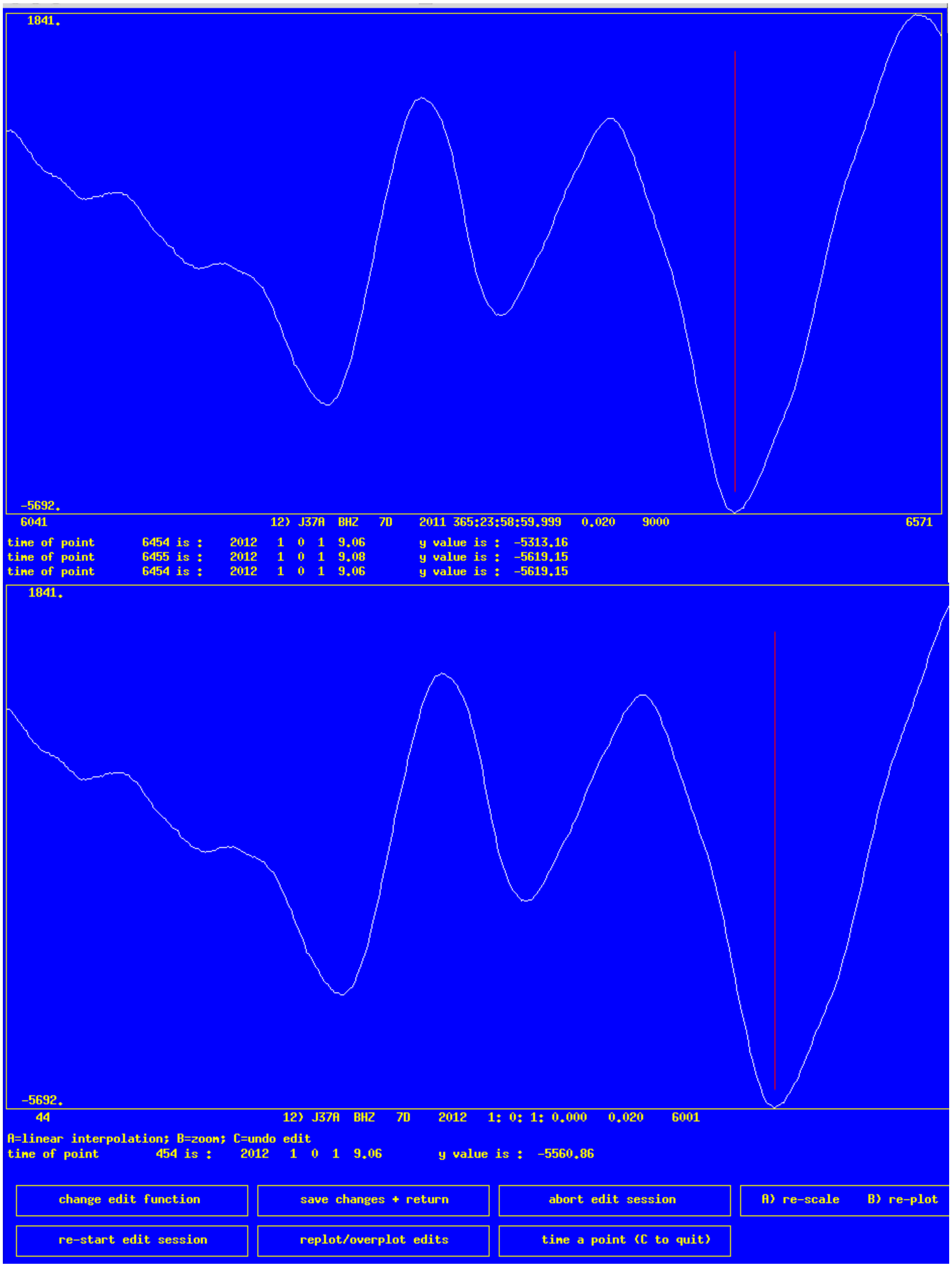

Figure 3c: Timing of a trough on Jan 1 at 00:01 in the BHZ record of site J37A. Top: record starting in 2011; Bottom: record starting in 2012. In both cases, the timing of the peak is at 9.06 s after the minute, i.e. there is no 1-s difference. Note that the zoomed-in window in top and bottom are different, with the bottom one slightly shorter. This has no impact on the time tag reading.

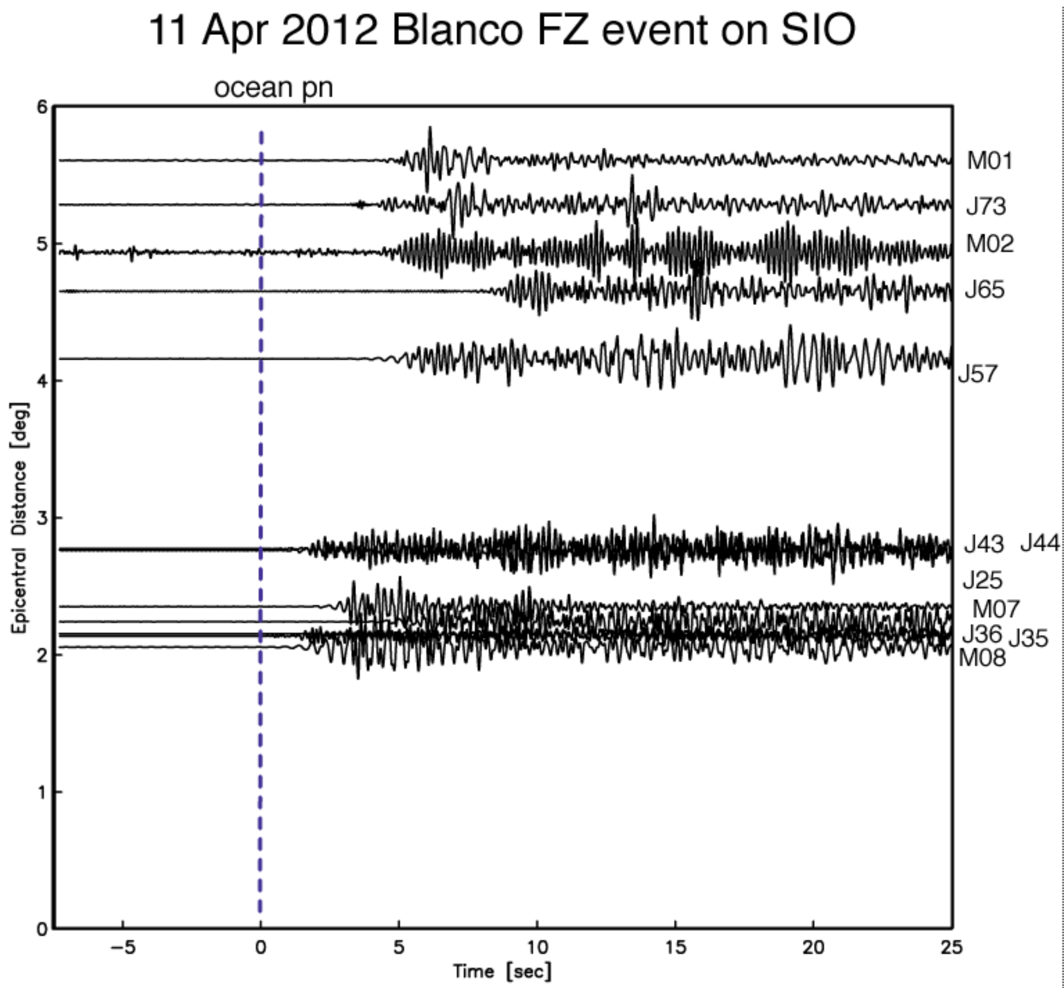

Figure 4a: Record section of SIO stations for the 11 April 2012 earthquake on the Blanco FZ. Records are aligned for a pn-travel times beneath an oceanic crust. A PREM crust would result in a signal arriving about 5 s later.

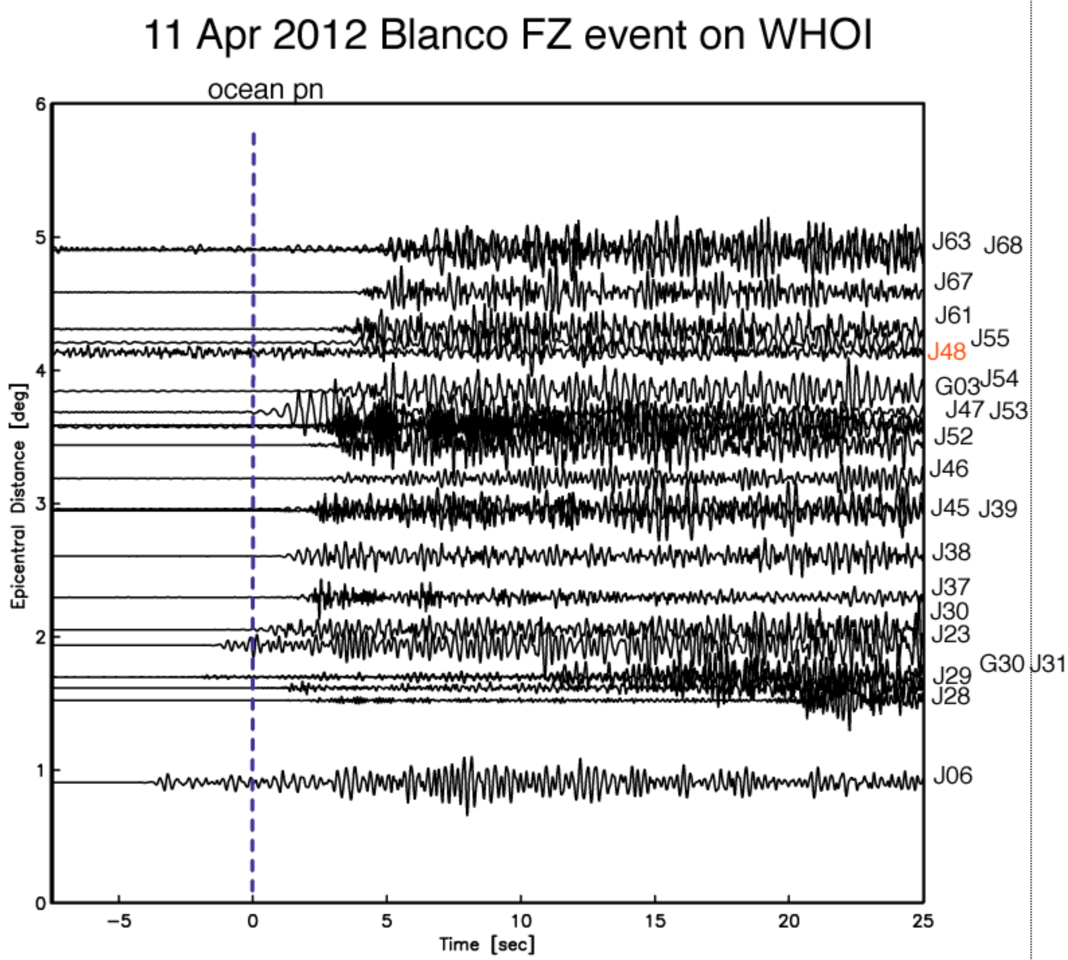

Figure 4b: Record section of WHOI stations for the 11 April 2012 earthquake on the Blanco FZ. Records are aligned for a pn-travel time beneath an oceanic crust. Station J48 had no useful data.

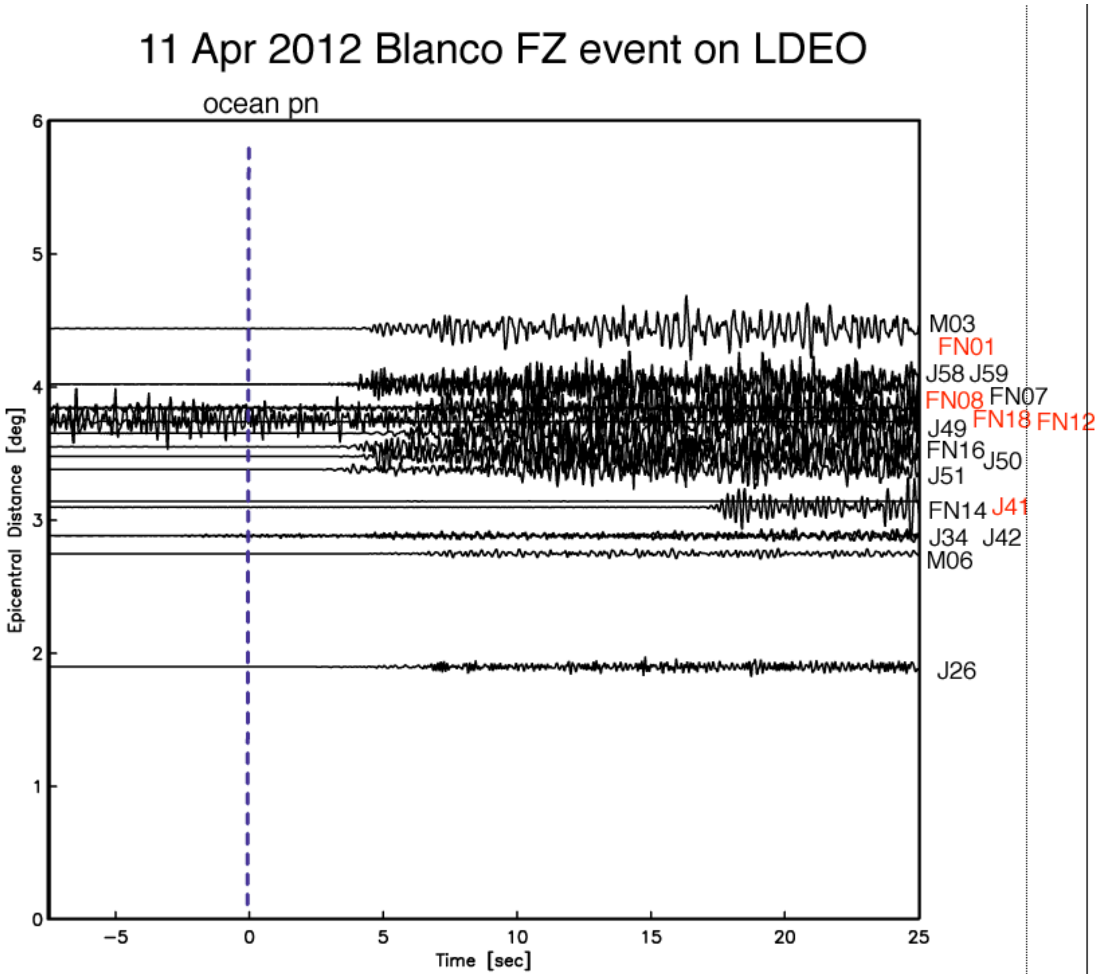

Figure 4c: Record section of LDEO stations for the 11 April 2012 earthquake on the Blanco FZ. Records are aligned for a pn-travel time beneath an oceanic crust. Several stations (in red) had no useful seismic data.

4. The 11 April 2012 Blanco FZ Earthquake

I then analyzed an earthquake on 11 April 2012 which is 1 month after Schmandt's earthquakes for which he sees a "leap-second" problem. This is EQR3 from my previous report (Oct 2011) (see Table 1).

day	date	lat	long	ime	M0	Ms	dist/az	
035.12	04 feb 12	48.87	-127.88	20:05:32	0.004	5.7	5.17/337.57	EQR1
046.12	15 feb 12	43.62	-127.52	03:31:21	0.009	6.0	1.96/256.19	EQR2
102.12	11 apr 12	43.58	-127.56	22:41:47	0.011	5.9	2.00/255.31	EQR3
171.12	19 jun 12	43.44	-127.27	13:40:57	no cmt	5.2	1.85/249.29	EQR4

Table 1: Regional earthquakes with magnitudes MW=5.2 and larger and epicentral distances 5.2^{o} or less to station Y1M8. No CMT is available for event EQR5

I requested BHZ data from the IRIS DMC (thereby initially by-passing LDEO's HHZ data that are sampled at 125 Hz). The data were read, processed and converted in the same way as described in TEST 1. Finally, I bandpass-filtered the data between 2 and 10 Hz using a zero-phaseshift Butterworth filter (forward and reverse filtering). I treated the SIO, WHOI and LDEO data in separate files. The LDEO data were read from a separate SEED file and then decimated by a factor of 4 to a sampling rate of 31.25 Hz before applying the bandpass filter. Record sections are shown in Figure 4. While there is an apparent delay of wave packets with increasing epicentral distance, this overall trend is observed in both the WHOI and the SIO record sections. The LDEO stations occupied a more limited epicentral distance range.

Since pn is a low-amplitude phase at regional distances, there is a chance that the displayed wave packets are not associated with pn. To make sure that I compare the same phase for all stations, I therefore hand-picked all first arrivals in all records. I found that some stations were more difficult to pick than others, where some stations appear to have a very small emergent phase within about 1s of the first noticeable arrival. Overall, however, I find that the first arrivals are consistent across different OBS types, and ***I did not find a systematic shift of SIO arrivals vs WHOI arrivals, nor LDEO arrivals*** (Figure 5). My results provide strong evidence against a "leap-second problem" for SIO stations.

I should mention that I did this analysis on the raw data, thereby assuming that the instrument responses cause either no time delay at all or the same time delay between different OBS types. The instrument responses remain to be verified as a final check.

Finally, I find delays by a few seconds at SIO stations M07 and J65. I verified the station coordinates with the OBS lab staff. LDEO station NF14 is too late by about 10 s and LDEO station J34 too early by several seconds. I verified the station coordinates in my file against the information in the original SEED file. The first arrival is a very strong phase, with little noise leading the wave packet, so I am reasonably confident about the quality of the pick. However, it is conceivable that some type of noise or signal mutes the actual first arrival. I will have to verify these four timing inconsistencies with another earthquake before further conclusions can be made.

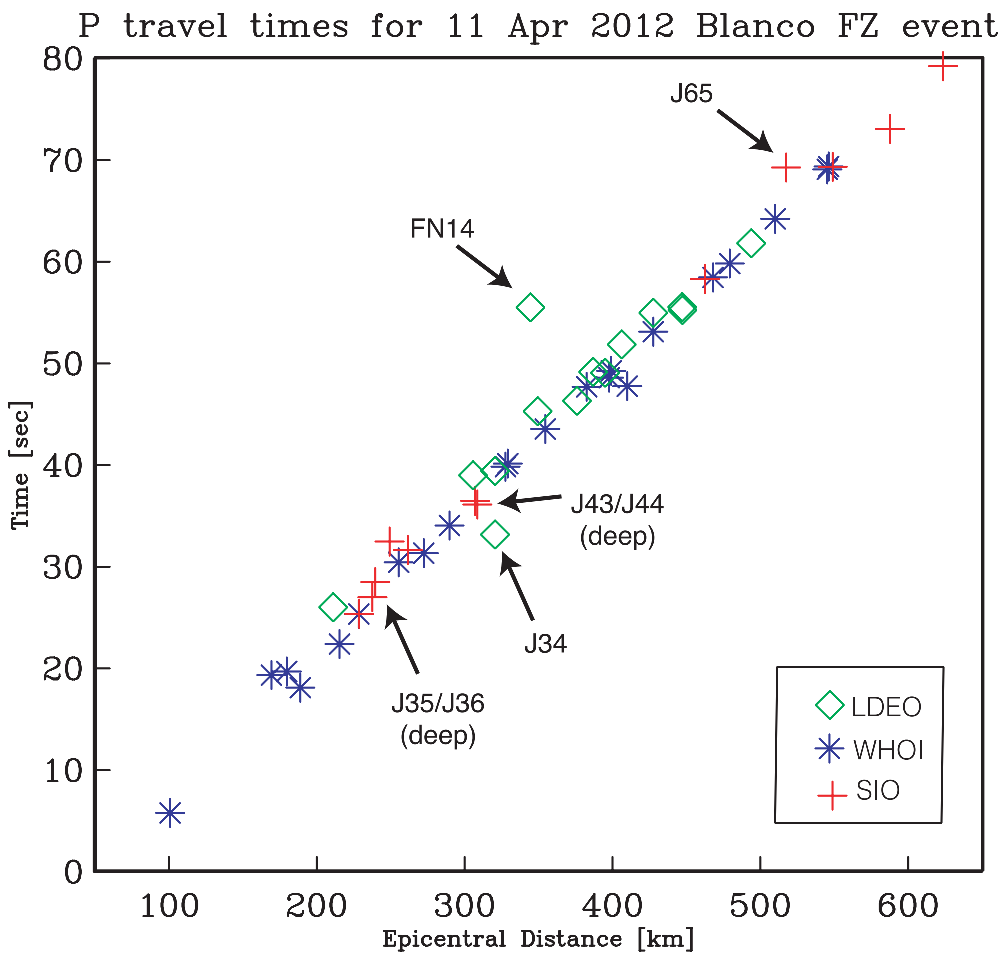

Figure 5: First-arrival travel time picks for the 11 April 2012 Blanco FZ earthquake. While the picks are somewhat inconsistent overall, there is no apparent systematic 1-s shift between WHOI and SIO picks. The 4 deeper SIO stations, J35, J36, J43 and J44 are SAIC-filtered SIO stations that allegedly are leading by 1 sec in two March events. Station J65 appear to be delayed by several seconds. The picks for LDEO stations are also shown. Station FN14 appears to be delayed by about 10 s (also visible in Figure 4c) and station J34 appears to be fast by several seconds. See text for details.

5. Instrument Responses

I also read the instrument responses from the SEED files requested at the IRIS DMC (Figure 6). I used RDSEED5.0 and evalresp-3.3.3 to extract the instrument responses.

The phase responses of the WHOI and the SIO responses are virtually identical, thereby confirming that the data acquisition does not produce any relative delay between the systems. Therefore, any apparent travel time differences between WHOI and SIO records cannot be explained by not taking into account instrument responses. Note however, that the absolute calibrations are different and relative amplitude measurements have to be corrected between the systems. The same applies to amplitude corrections for LDEO data, where the trawl resistant system appears to have the same instrument response as the traditional deep ocean package. The phase behavior for LDEO systems is different from that of the other systems, at frequencies higher than 1 Hz, so measuring phase velocities at high frequencies may be affected by not accounting for instrument responses. I verified with a spike-synthetic, applying the instrument response and filtering with the same bandpass as the real data in this report that ***none of the instrument responses, as read with RDSEED5.0 and evalresp-3.3.3 cause any time shifts***.

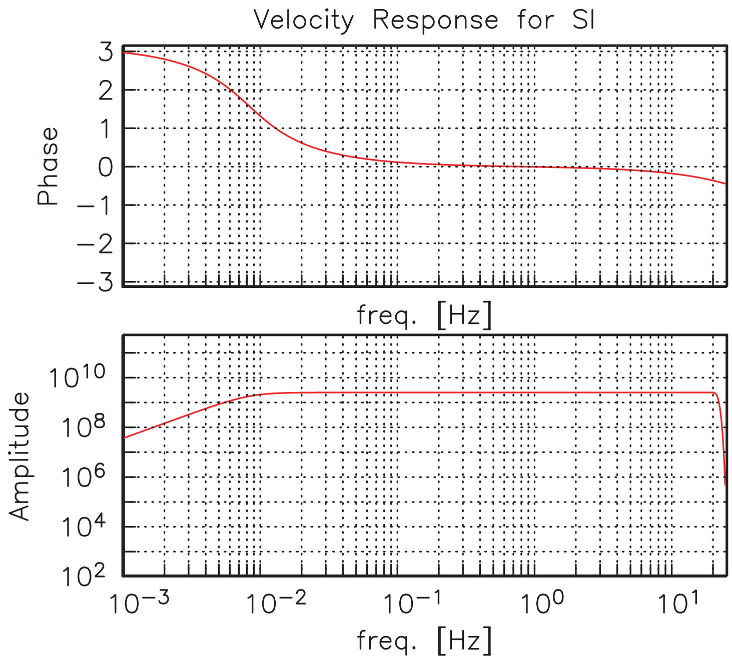

Figure 6a: Velocity instrument response for an SIO Abalone system, as recovered from the SEED file obtained from the IRIS DMC.

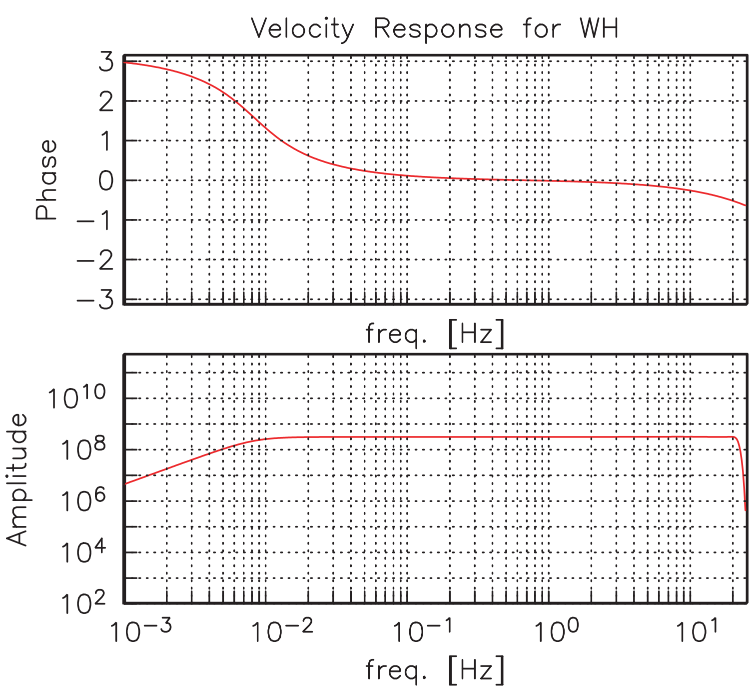

Figure 6b: Velocity instrument response for a WHOI system.

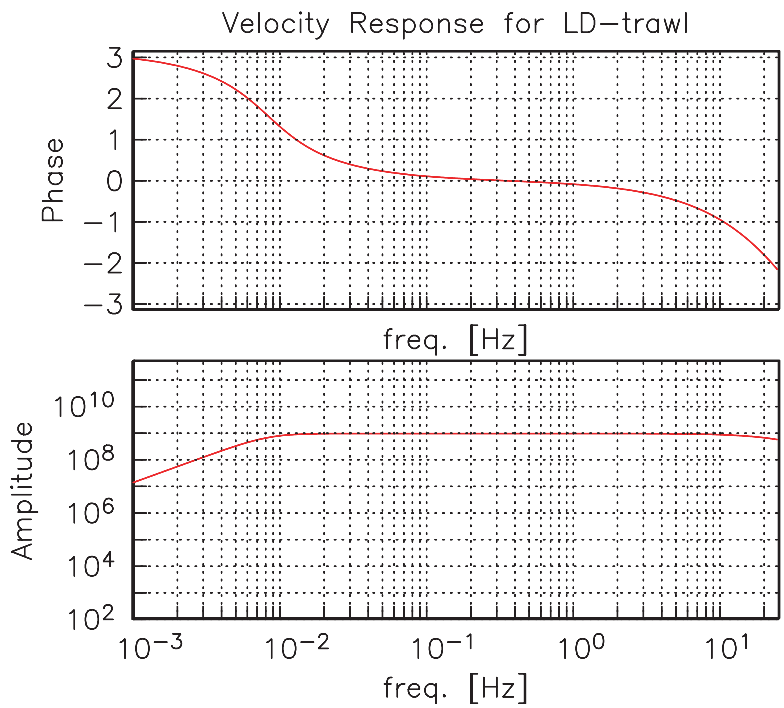

Figure 6c: Velocity instrument response for a LDEO trawl-resistant system.

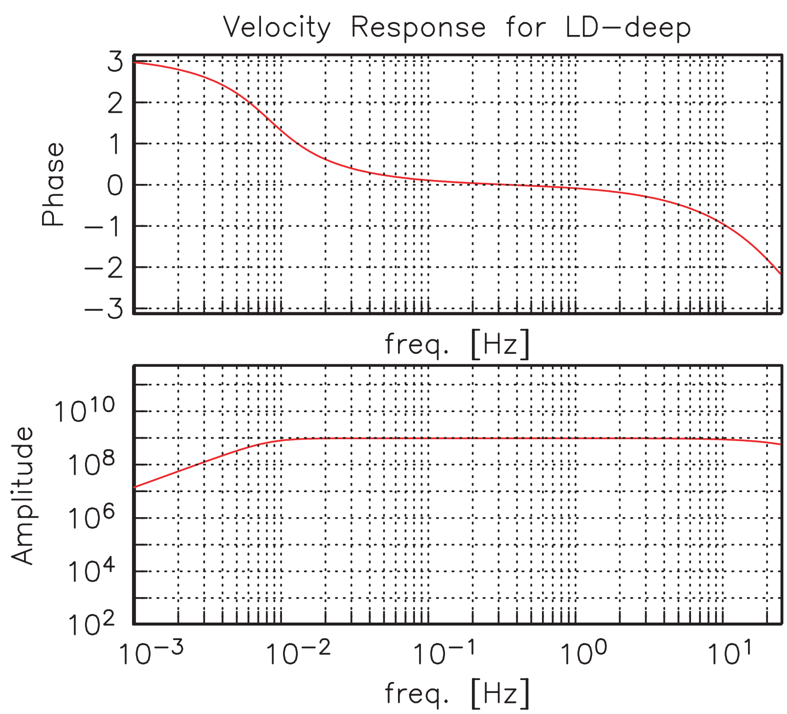

Figure 6d: Velocity instrument response for a LDEO traditional deep-ocean system.

6. Conclusions

I determined that there is no data tear in the Cascadia OBS records at the change from 2011 to 2012. The apparent advance of p-travel times for events in 2012 for at least four of the SIO OBSs cannot be due to an official leap-second problem because the leap second was actually added on June 30, 2012 and not on Dec 31, 2011 as was probably assumed.

I also analyzed a regional event in April 2012, which is a month after the events for which Schmandt proposed to have identified a "leap-second error". My analysis of this earthquake provides clear evidence that there is no time-shift between the SIO stations and other Cascadia OBSs. Hence, I am unable to reproduce Schmandt's 1-s problem. I suspect that it is sometimes difficult to pick an emerging p-phase where a 1-s error is entirely possible.

A sources for Schmandt's observations could be:

• wrong application of leap second on 31 Dec 2011: unlikely as my April 2012 event did not reveal a 1-s problem even though it should have one
• incorrectly applied clock drift corrections: unlikely as my April 2012 event did not reveal a 1-s problem even though it should have accumulated a larger time error
• inconsistent sampling rate which would translate into an apparent time drift: unlikely as my April 2012 event did not reveal a 1-s problem even though it should have accumulated a larger time error
• SAIC used a non-zero-phase shift filter to filter the SIO records: unlikely because in this case, the 2011 events should also be shifted by ~1 s. In addition, I do not see a systematic shift between the deeper, SAIC-filtered SIO stations and the rest of the stations. Furthermore, it is my understanding that filtered data are not stored at the DMC but rather redacted versions of the raw data.
• coincidence. Though the blue dots on the right in Schmandt's figure are very suggestive of an SIO timing problem, some stations on land also exhibit significant time differences even though this stations are supposed to run GPS clocks. Currently, this appears to me as a likely possibility.
• erroneously applied instrument corrections: this would depend on the version of evalresp used and on how Q330 operators stored the 1-s system delay in the headers (or not). This has been a long-standing problem with GSN stations that has been addressed only in 2012 with a new release of evalresp. Unfortunately, different network operators still report the 1-s delay differently so that some GEOSCOPE stations operating a Q330 now have a 1-s problem. It is my understanding that WHOI and SIO provide data and responses that have already accounted for the delays in the data acquisition so that the end-user never faces this problem. I currently do not know how LDEO handles this.
• erroneous waveform picks: an increasing possibility. It is possible that local geology or topography produces "pathological" waveform cases for certain distances and azimuths that make a travel time pick difficult.

7. Suggestions

1) ask Schmandt if the time inconsistency for SIO OBSs really remains at ~1 s in 2012 or whether it increases.
2) if it increases, then SIO OBS group should verify that clock drift corrections were applied correctly. However, I find this an increasingly unlikely scenario.
3) if the time inconsistency remains at 1 s not, then it is not clear where the ~1 s time difference for the March events originate
4) ask Schmandt to do a more comprehensive report to find out exactly when he started to experience the ~1 s timing error
5) if Schmandt's data were response-corrected, it may be worthwhile to find out which version of evalresp he used and if he updated to a newer version while he still did his analysis. It may be unlikely that OBS data are affected but I checked only one version of evalresp and other versions may have given different phase responses for a Q330. It may be worthwhile to ask him for his own plots of the responses and check if they agree with mine.
6) unless Schmandt produces a consistent log that shows that ALL events in spring 2012 show the same 1-s problem, I suggest that travel-time picking errors or pathological wave propagation effects for certain back-azimuths and distances could also be a possible scenario.