CLOCKS AND TIMING VERIFICATION

WHOI Ocean Bottom Seismograph Laboratory

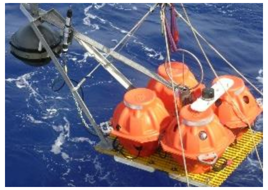
Timing requirements for Ocean Bottom Seismology

- Desired timing accuracy is ~1 ms
- Experiments range from a few weeks to one year in duration, with a recent push for even longer experiments
- 1 ms / 365 days ≈ 3.2e-11 frequency accuracy required
- Post-processing (linear drift correction) improves timing accuracy
- Typical power budget:
  - ~ 1 W for entire system
  - < 100 mW for clock
- Large arrays (30+), so unit cost is important

Timebases used in WHOI OBS

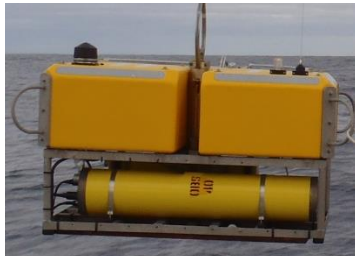
Seascan Timebase

- 5e-8 frequency stability from -5 to +35 °C
- Aging not specified but typically <2e-8 per year; many units much better than this
- Must return to factory for recalibration
- Expected worst-case clock-corrected time-stamp error during 1 year deployment <40 ms for carefully selected clocks
- 5 mW power consumption
- Used in D2s, Broadbands, and Kecks

Symmetricom CSAC (ca. 2011)

- 5e-10 frequency stability from -10 to +70 °C
- <1e-9 per year aging spec
- Frequency can be adjusted in the field
- Expected worst-case clock-corrected time-stamp error during 1 year deployment <4 ms for all clocks meeting spec
- 120 mW power consumption
- Used in ARRAs



Seascan and CSAC Lab Testing at 2° C

- All WHOI clocks are tested in the lab at ocean bottom temperatures for several months prior to use in OBS
- Poorly performing clocks will be recalibrated or removed from service as necessary

PC logs, processes, and displays clock performance

GPS clock provides highly stable reference time for measurements

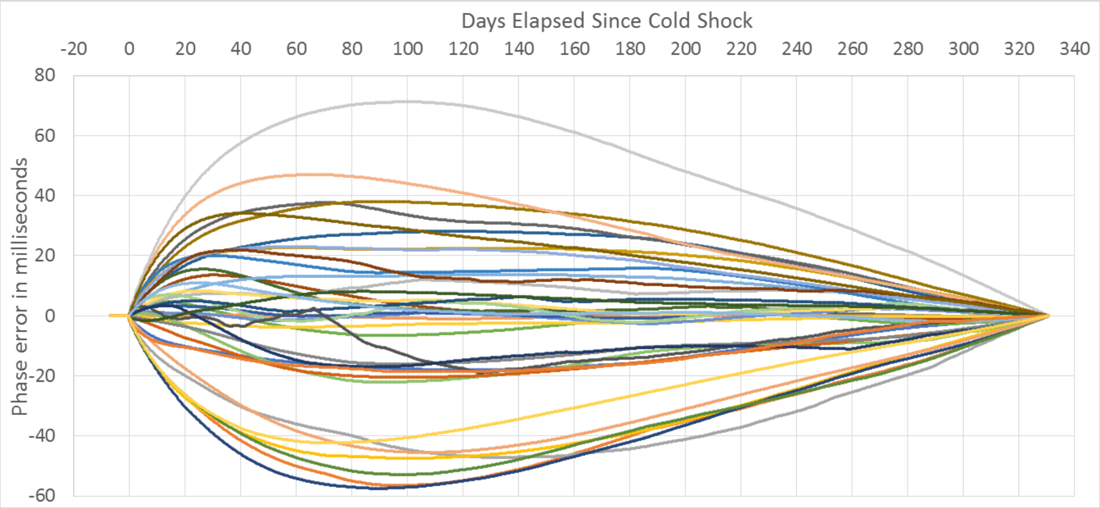
CSACs under test on WHOI CSAC Interface Boards

Seascan multiplexer boards allow up to 64 Seascans to be tested concurrently

Temperature chamber adjustable from -10 to +40 ° C

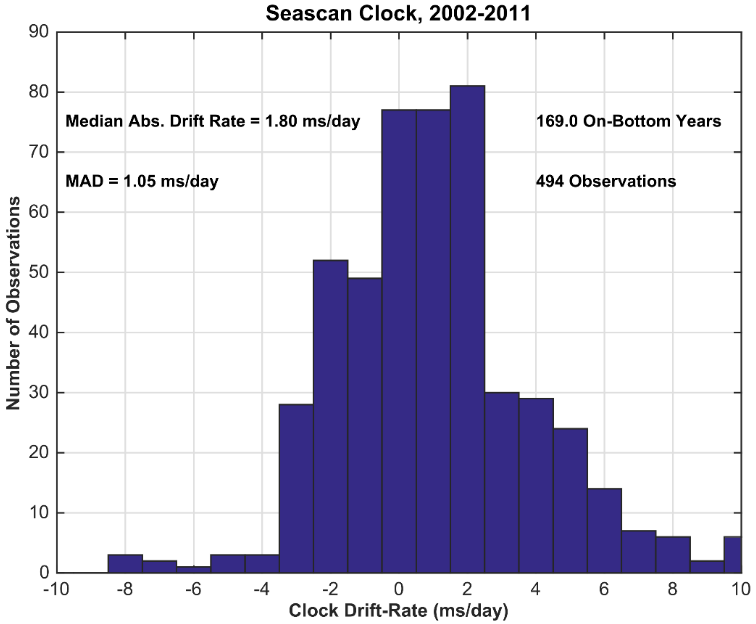
Woods Hole Oceanographic Institution

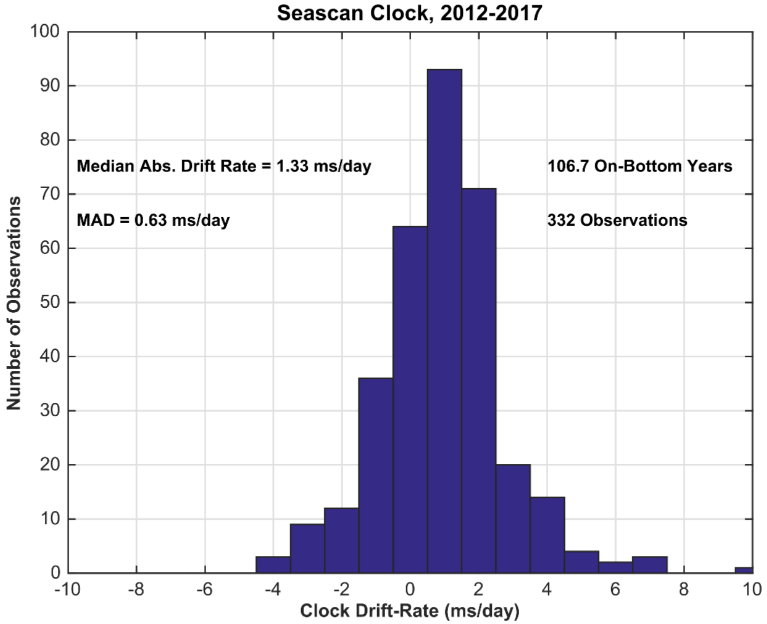
Seascan Testing



The figure to the left shows Seascans tested in a temperature chamber at 2°C over an 11 month simulated deployment. Offset between each clock and GPS is measured once per minute. At the end of the experiment we apply a linear clock drift correction based on end-points, as is done in an actual OBS experiment. This figure shows the difference between the drift-corrected time and the true time as measured by the GPS clock. We use these tests to select the best performing clocks.

Eliminating poorly performing clocks and recalibrating where possible leads to significantly better timed data. The histograms below show improvements in the drift attributable to this testing.

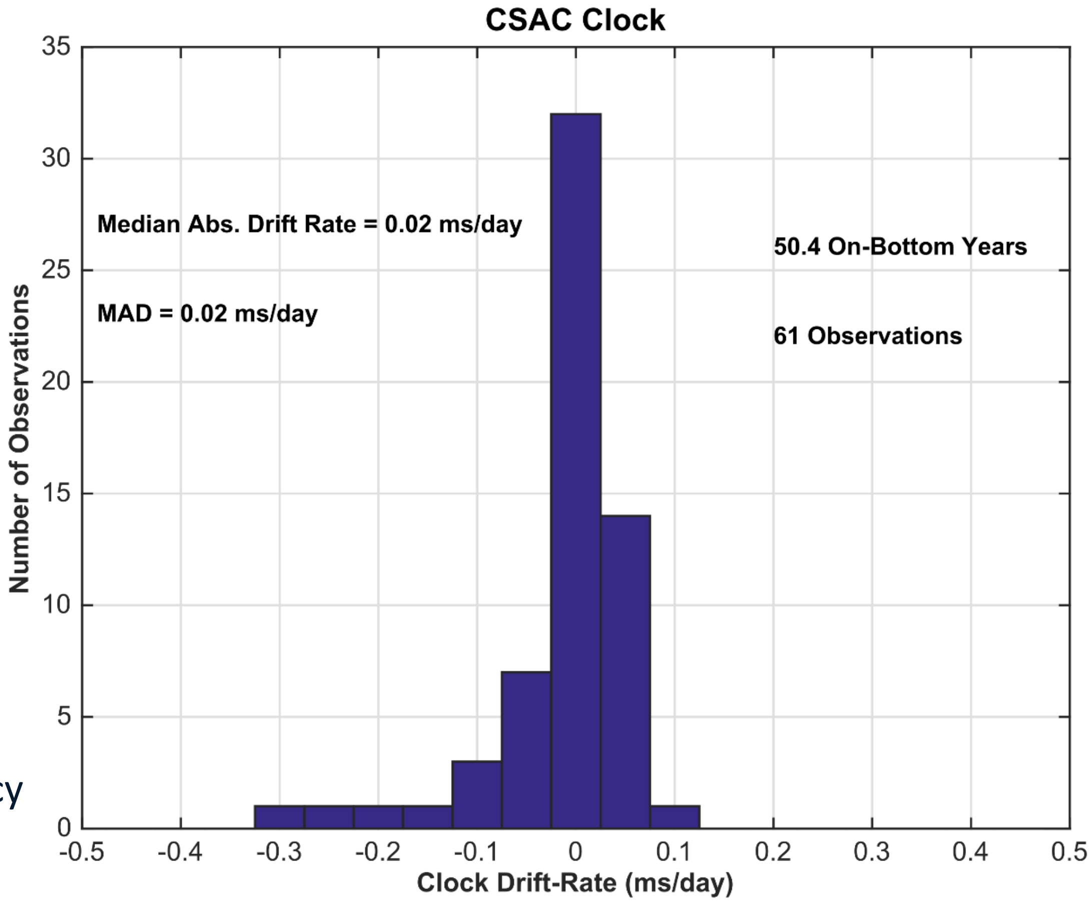




WHOI CSAC Interface Board

WHOI Designed CSAC Interface Board

- Simulates a GPS NMEA output to digitizer
- Regulates power, maintains real time clock, logs engineering values
- Built-in phase meter accurate to 100nS automatically records frequency and phase of CSAC every hour when GPS is available
- Clock performance is monitored in temperature chamber, in shelf in lab, and on deck of ship, with no additional equipment or setup needed
- The histogram to the right shows the impressively low drift of the CSACs



Current and Future

Current status of CSACs

- Symmetricom bought out by Microsemi in Oct 2013
- Manufacturing issues led to poor reliability (vacuum leak)
- Reliability now (2017) restored
- However aging spec (1e-8/yr; equivalent to ~40 ms residual timing error over 1 year) is order of magnitude worse than original (1e-9/yr; ~4 ms residual timing error over 1 year)
- Cost increased from $1500 to $5000

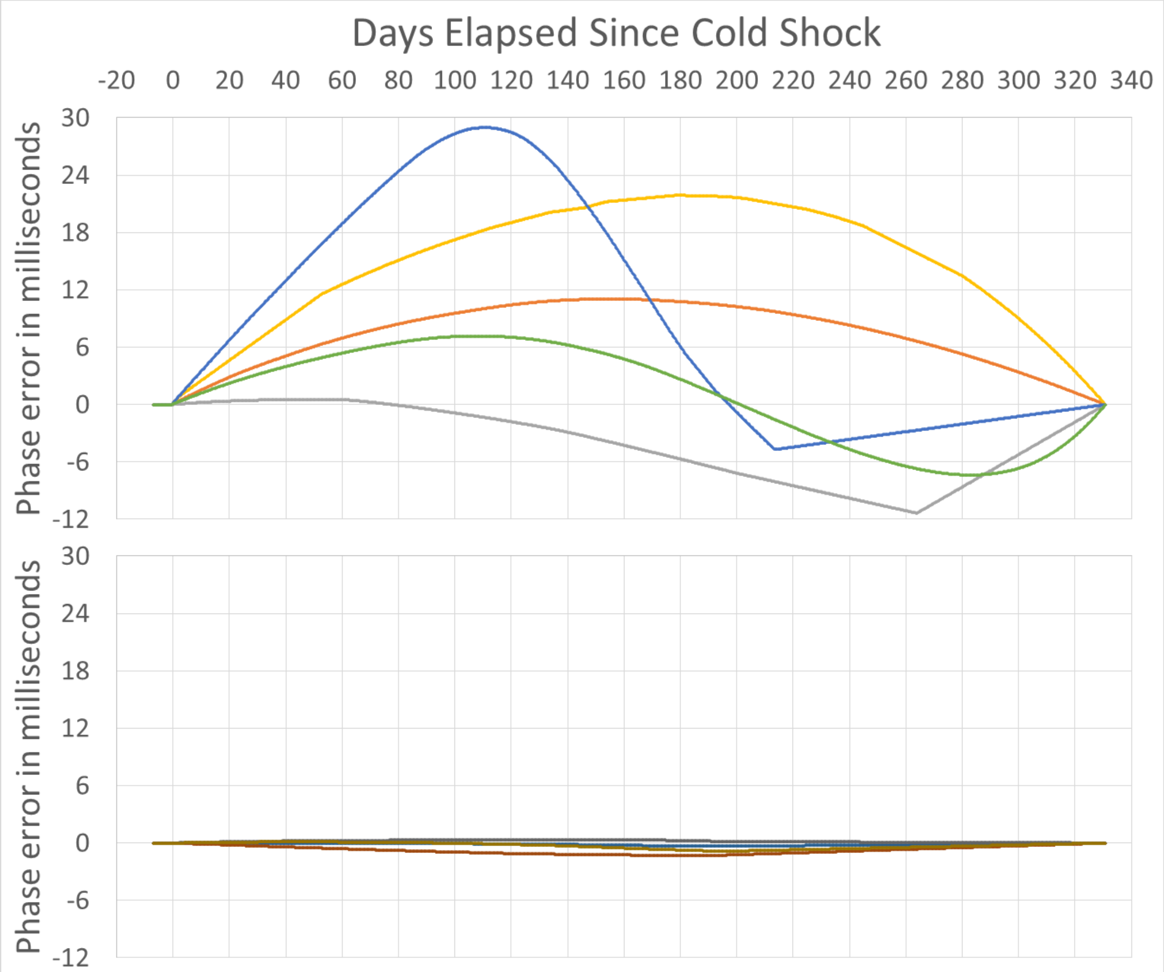
Future plans for WHOI OBS timing

- We have 20 good CSACs in service meeting the original aging spec
- We are continuing to monitor Microsemi's product improvements
- We are in contact with multiple other potential CSAC manufacturers
- We are testing a promising new prototype CSAC since early Sept 2017

For more information:

Gardner, A.T. and Collins, J. A., "A second look at Chip Scale Atomic Clocks for long term precision timing," *OCEANS 2016 MTS/IEEE Monterey*, Monterey, CA, 2016, pp. 1-9. (http://www.obsip.org/documents/Gardner_IEEE_Oceans_2016.pdf)

Gardner, A.T. and Collins, J.A., "Advancements in high-performance timing for long term underwater experiments: A comparison of chip scale atomic clocks to traditional microprocessor-compensated crystal oscillators," *2012 Oceans*, Hampton Roads, VA, 2012, pp. 1-8. (http://www.obsip.org/documents/IEEE_Oceans2012_ATG_AsSubmitted.pdf)



The figures above show lab test results from 9 CSACs purchased after the initial pilot run. The methodology is similar to that used for the Seascans to predict the residual timing error between the drift-corrected time and the true time as measured by a GPS clock. The 5 CSACs in the top figure show errors ranging from 10 to 30 ms, on par with good Seascans. The 4 CSACs in the bottom figure show errors less than 1.3 ms, comparable to the original pilot run of CSACs, much better than expected from Seascans, and matching desired OBS timing performance.