NOAA Pacific Marine Environmental Laboratory
Ocean Climate Stations Project

TECHNICAL NOTE 9

Salinity Drift in Deep Seabird Instruments

www.pmel.noaa.gov/ocs January 2021

Salinity Drift in Deep Seabird Instruments

Introduction

The Ocean Climate Stations (OCS) group operates the Kuroshio Extension Observatory (KEO) mooring in the North Pacific Ocean off the coast of Japan. Located near 32˚N 145˚E, the mooring is instrumented to collect data from the atmosphere and ocean. All gear is recovered, and the data are downloaded each year after a new mooring is deployed. The recovered instruments are returned, and calibrations are performed in-house, or by respective manufacturers.

Since 2012, the OCS KEO mooring has been deployed with an SBE37SM-TCP instrument attached to the acoustic release, with a deployment depth around 5,700m. Analysis of the recovered data has shown year-to-year salinity discontinuities at the KEO site, which exceed instrument accuracy specifications.

Note: For more conclusive details on KEO salinity drift, see Anderson et al., 2020.

Data Anomaly

The KEO mooring's deep SBE37s have experienced repeated salinity drift. Each deployment started around 34.69 PSU and drifted to 34.66 PSU or less. Over each of four deployment years, and with two separate instruments, salinity drifted downward (fresh) throughout the year and was discontinuous with the following year by 0.03 – 0.06 PSU (See Figure 1). Given the instrument accuracy of ±0.0003 S/m and measurement stability of 0.0003 S/m per month, the conductivity drift in a yearlong deployment could reach 0.0039 S/m. This corresponds to ~0.04 PSU, given constant temperature and pressure. However, Freitag et al. (1999) determined that data corrected by a linear (or higher order) combination of pre-deployment and post-recovery calibrations corrected data to within 0.02 PSU.

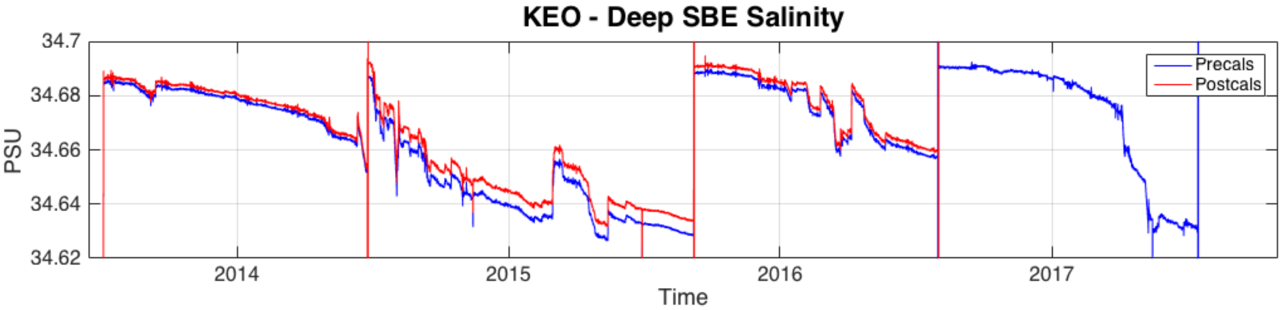


Figure 1: Salinity time-series of the 5,700m instrument over four deployments.

The lines in Figures 1 and 2 labelled "Precals" and "Postcals" were calculated using the Seabird equations below. The blue lines are the data with calibration coefficients measured prior to deployment applied (Precals). Red lines show the same data with the application of calibration coefficients measured after recovery (Postcals).

These "Precal" and "Postcal" values are calculated from the raw sensor measurements. An xml file downloaded directly off the instrument after recovery contains the raw hexadecimal outputs from the thermistor, pressure sensor, and conductivity cell. These raw values are input into the Seabird equations alongside either pre-calibration coefficients or post-calibration coefficients, to calculate the Precal or Postcal time-series of the desired parameter. Calibration summary sheets contain the Seabird equations, calibration coefficients, and other parameters as shown below.

$$n = \text{Instrument Output (counts)}$$

$$\text{Temperature ITS-90 } (^\circ\text{C}) = 1/\{a0 + a1[\mathit{ln}(n)] + a2[\mathit{ln}^2(n)] + a3[\mathit{ln}^3(n)]\} - 273.15$$

Equation 1: Seabird temperature equation. Coefficients a0, a1, a2, and a3 are provided.

$$y = \text{thermistor output (counts)}$$

$$t = PTEMPA0 + PTEMPA1 * y + PTEMPA2 * y^2$$

$$x = \text{instrument output} - PTCA0 - PTCA1 * t - PTCA2 * t^2$$

$$n = x * PTCB0 / (PTCB0 + PTCB1 * t + PTCB2 * t^2)$$

$$\text{pressure (PSIA)} = PA0 + PA1 * n + PA2 * n^2$$

Equation 2: Seabird pressure equation. Coefficients (capitalized) are provided.

$$f = \text{Instrument Output(Hz)} * \text{sqrt}(1.0 + WBOTC * t) / 1000.0$$

$$t = \text{temperature } (^\circ\text{C}); \quad p = \text{pressure (decibars)}; \quad \delta = \text{CTcor}; \quad \varepsilon = \text{CPcor};$$

$$\text{Conductivity (S/m)} = (g + h * f^2 + i * f^3 + j * f^4) / 10 (1 + \delta * t + \varepsilon * p)$$

Equation 3: Seabird conductivity equation. Coefficients are provided by Seabird.

Salinity is calculated using the UNESCO equations (Fofonoff and Millard, 1983). These equations output salinity, given in-situ temperature, conductivity, and pressure data.

As shown in Figure 1, the application of post-recovery calibrations did not correct the observed salinity drift, and thus only precals are applied to the deep SBE at KEO. In fact, salinity differences between pre-deployment and post-recovery calibrations were less than 0.01 PSU. This might imply that the change in salinity throughout the deployment could be real, except that each newly deployed instrument doesn't continue the trend. This indicates that instruments drift, but recover to their initial, pre-deployment state by the time the post-calibration is performed.

The CPcor parameter was examined as a potential way to correct the data, but cannot account for salinity drift with time. Varying CPcor scales the denominator of Equation 3 by the magnitudes of pressure, not time. Unless pressure drift is suspected, CPcor should not contribute to conductivity drift. Seabird recently proposed changes to CPcor based on whether epoxy or urethane encapsulates the conductivity cell, but the change corrects for small offsets (not drift).

Hypotheses

Hypothesis #1: Nepheloid Layers / Turbidity Currents

Nepheloid layers (suspended particles caused by bottom turbulence or slides) could cause small sediment particles to accumulate within the conductivity cell of the SBE instrument and affect measurements gradually over time. When the acoustic release is fired, the fast ascent could clean out the particles, returning the instrument to its initial state upon recovery. This hypothesis aligns with the reversibility of the drift, and could explain the smaller scale salinity jumps in Years 2 and 3, as sediment builds up and falls off throughout the year. High velocities associated with the Kuroshio current or uneven topography could explain why this effect is seen at KEO, but not at other deep mooring sites.

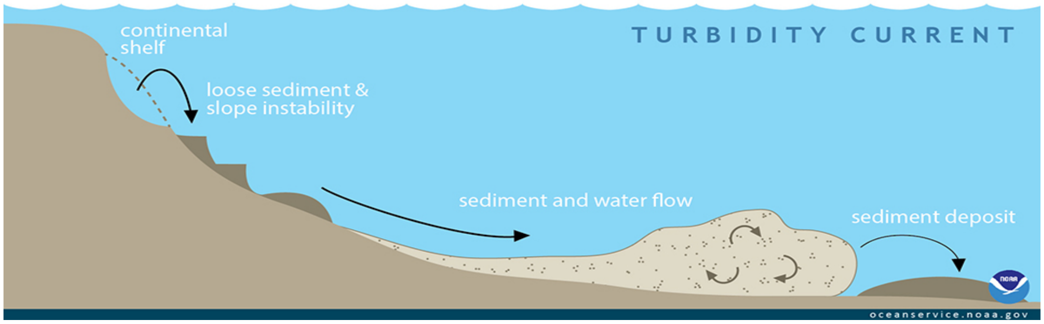
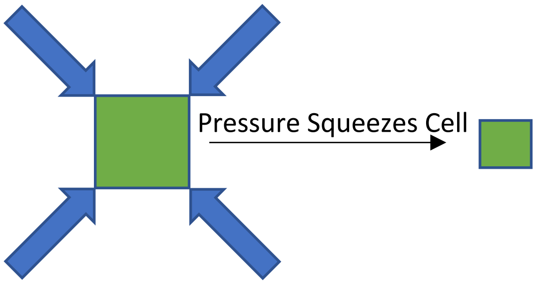


*Image from NOAA's National Ocean Service.

Hypothesis #2: Compression of the Conductivity Cell (unlikely)

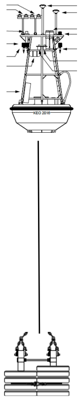
Based on our data and prior communication with Seabird, another hypothesis is a reversible time-dependent pressure effect on the conductivity cell. Over time, the conductivity cell may compress under pressure, causing the salinity measurement to change. Accuracy is thought to be highest when the instrument is first deployed. Initial measurements near 34.69 PSU are confirmed by historic CTD casts and deep ocean salinity maps (Talley et al., 2011).

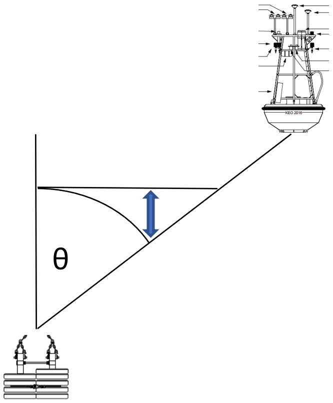


Two instruments are used at the KEO site, deployed in alternating years. In the salinity plot shown above, the instrument deployed in Year 1 is the same instrument deployed in Year 3. Years 2 and 4 are measured by the second instrument. With no intentional changes to the conductivity cell between recovery and redeployment, the redeployed instruments measure early-deployment values similar to their prior deployment, indicating reversibility of the salinity drift. The nature of this compression effect and recovery, including any deformation that occurs in the conductivity cell at depth, is not well understood. This hypothesis is largely discredited by the immediate restoration of accuracy witnessed within the first measurements during ascent.

Hypothesis #3: Mooring Motion (unlikely)
The effects of mooring motion (e.g. small pressure variations affecting salinity) were initially considered, but deep ocean salinity is largely homogenous. CTD casts indicate that a change of 0.03 PSU, the smallest observed drift, would require a vertical displacement to around 3,100m depth to observe a salinity of 34.66 PSU when the seafloor salinity is 34.69 PSU. Based on pressure sensor data, the instruments move less than 20m in the vertical during a deployment.

Temperature begins to increase with depth past about 4,100m at KEO (potential temperature continues to decrease), but does so slowly enough that pressure effects on temperature due to mooring line motion are negligible. For example, the SBE37 was deployed 40m deeper in Year 3 as compared with Year 2, and measured temperatures were less than 0.01˚C warmer. A plot of potential temperature adjusted to a reference pressure of 6,000m was continuous (Figure 5), showing that Year 3 temperatures fit into the context of the other deployments. Despite depth differences, Year 3 salinity calculated from T/C/P matched the range of values and fresh drift seen in surrounding years. Therefore, the hypothesis that salinity differences are due to changes in instrument depth during a deployment, or from pressure differences from one deployment to the next, has minimal support.





Deep SBE Plots

Plots were generated to visualize data in post-processing. An overview of the SBE37 data is provided in Figure 2. Observed year-to-year discontinuities in salinity highlight the issue. Note that post-calibration coefficients from Years 1 and 2 are the same as the pre-calibration coefficients from Years 3 and 4, respectively. This again points toward the drift being highly reversible.

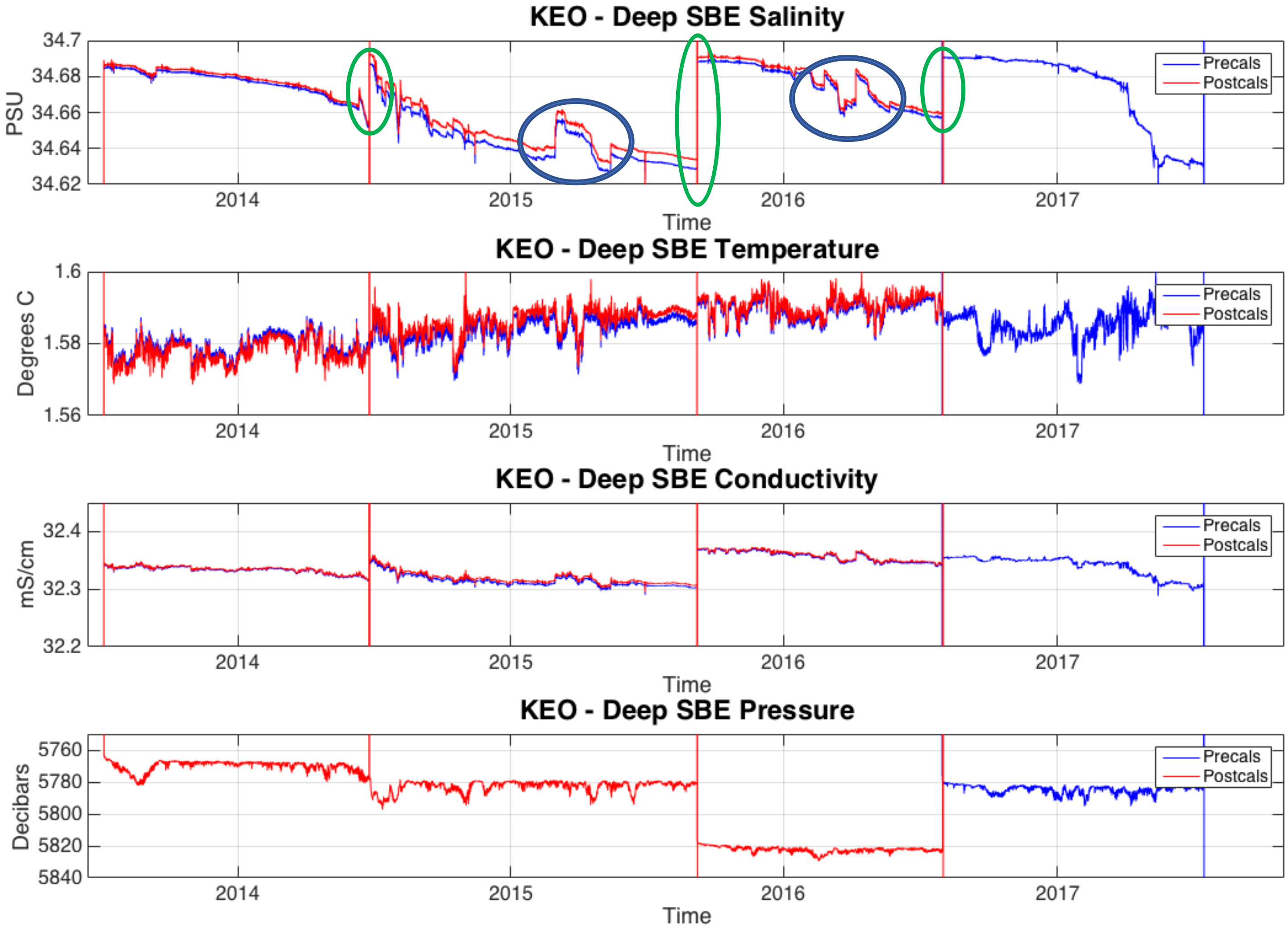


Figure 2: Salinity, temperature, conductivity, and pressure from the KEO deep SBE37 instrument. Blue circles show smaller jumps that could be sediment accumulation/clearing (hypothesis #2). The green circles highlight the salinity discontinuities between deployments, which could be attributed to hypothesis #1 or #2. As described above, lines labeled "Precals" are calculated from instrument coefficients provided by Seabird prior to deployment. "Postcals" are data calculated from coefficients measured after recovery.

CTD Casts

For additional data verification, CTD cast data were obtained. Though deep CTDs are unavailable from the U.S. vessel currently servicing the KEO mooring, deep casts have been performed by JAMSTEC over the years.

Below are plots from four CTD casts relevant to the discussion of drift. Casts from 2011 and 2012 had redundant CTDs, while the 2013 and 2016 casts had one instrument per cast. Figures 3 a/b show temperature and salinity data with respect to depth, highlighting how consistent the ocean becomes with depth.

Figures 4-7 use SBE37 variables or derived parameters to scrutinize the cause of the drift. Since post-calibration coefficients did not explain the salinity drift, only the data that have the pre-calibration coefficients applied will be used in Figures 4-7. Ultimately, the plots points toward the conductivity cell experiencing issues at depth.

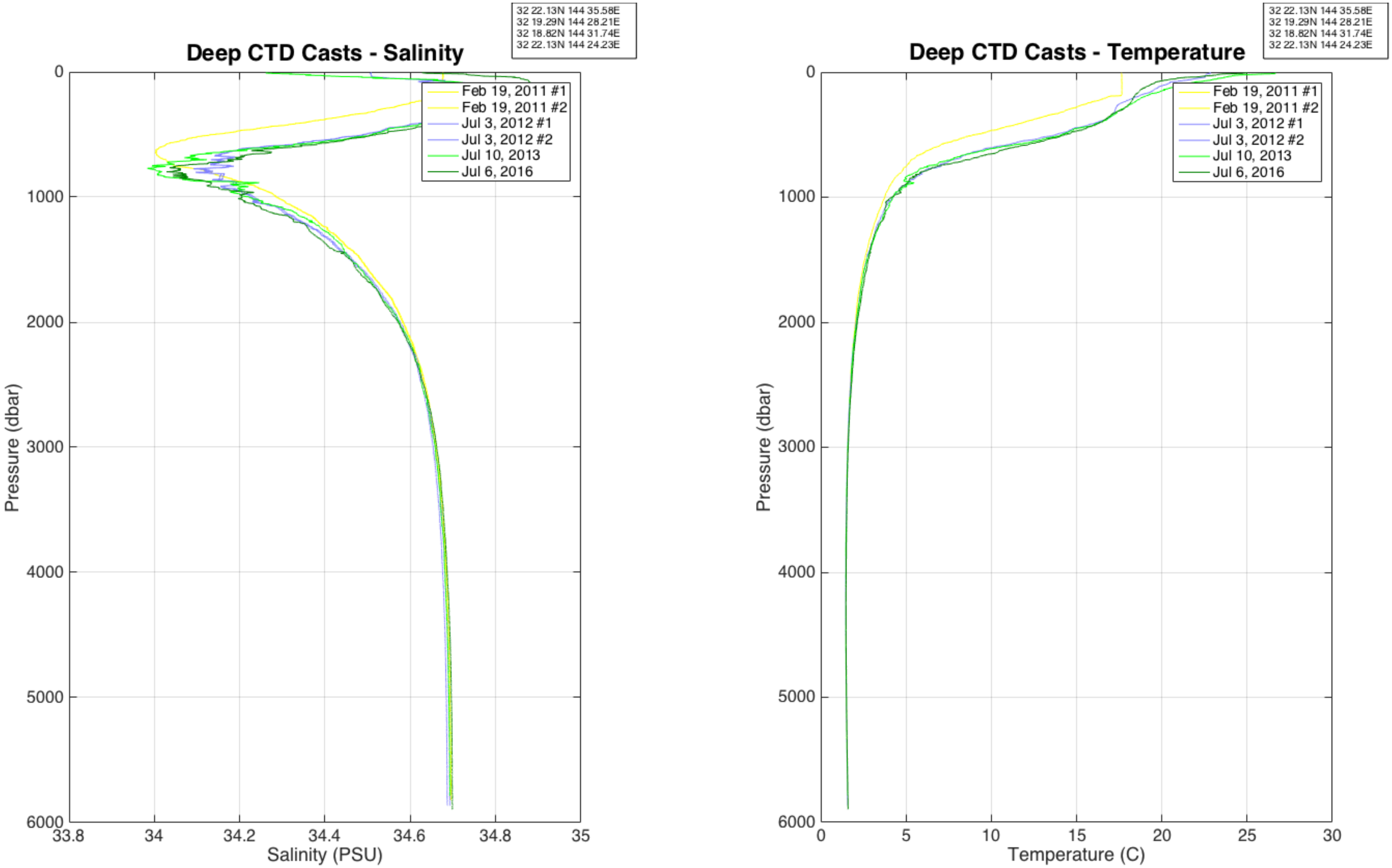


Figure 3: Deep TS casts of pressure vs a) salinity (left) and b) temperature (right), for context. Note that >2,000m of vertical displacement would be required to find water that is 0.03 PSU less than seafloor salinity (the minimal yeardrift witnessed).

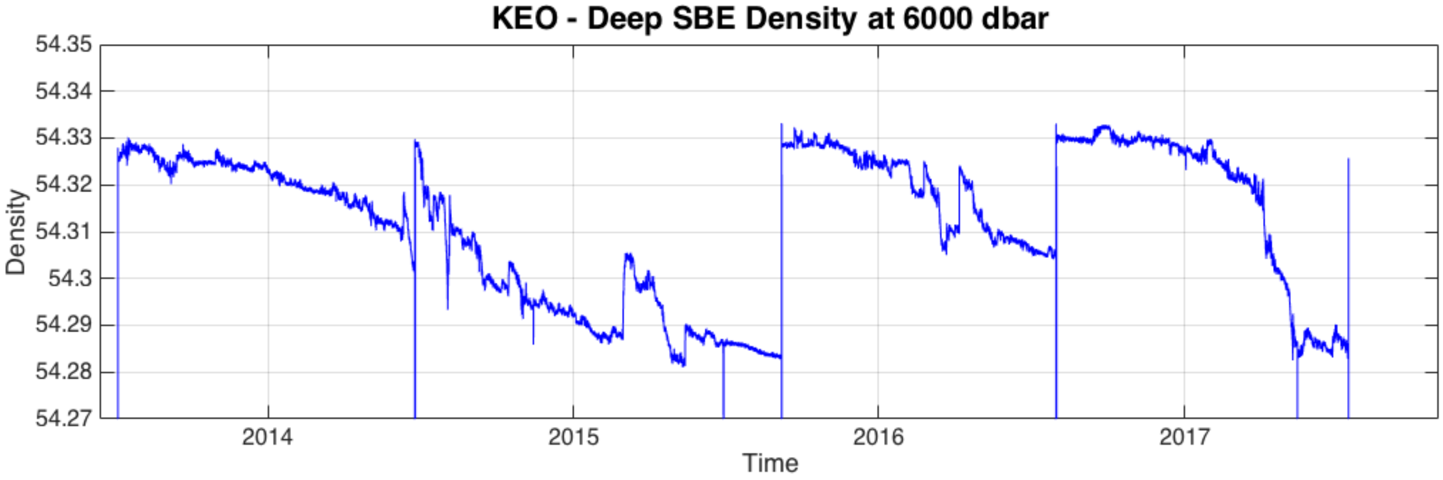


Figure 4: Potential density anomaly at 6,000 dbar (represented as $\sigma_6 = \rho_6 - 1000$ kg/m^3, where ρ_6 is potential density at 6,000 dbar), showing that the salinity drift affects the calculation of density, creating unrealistic density differences.

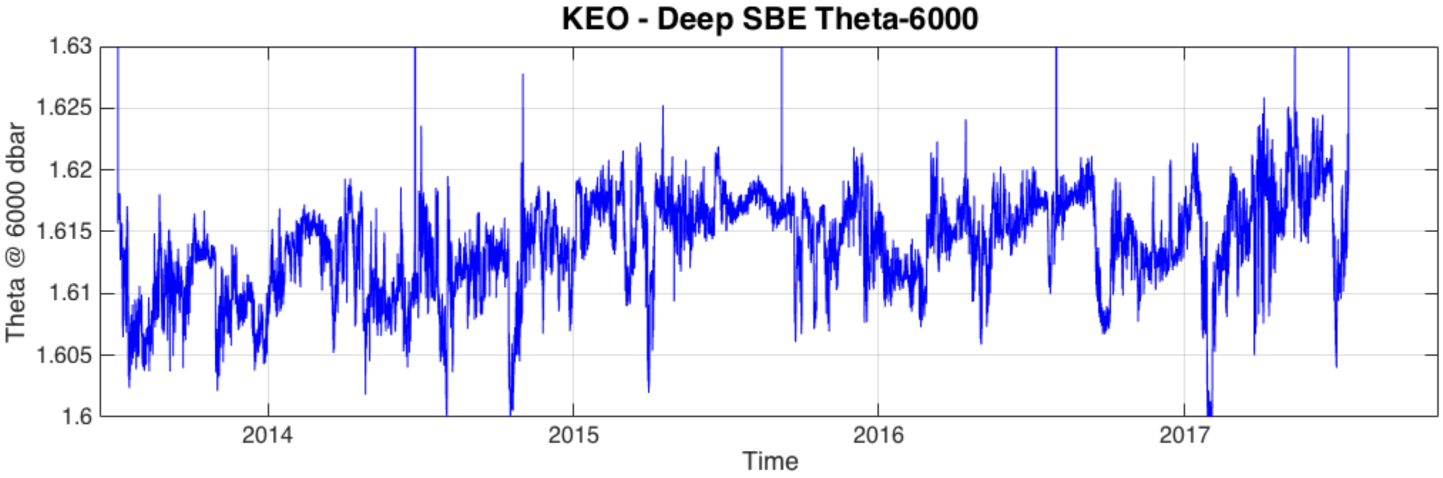


Figure 5: Potential temperature at 6,000 dbar (represented as θ_6) is continuous, suggesting that temperature and pressure are being measured correctly (potential temperature is conserved for adiabatic processes). The SBE37 measures in the ITS-90 temperature scale, but is converted to IPTS-68 for salinity/density/theta calculations (UNESCO, 1983). ITS-90 * 1.00024 = IPTS-68.

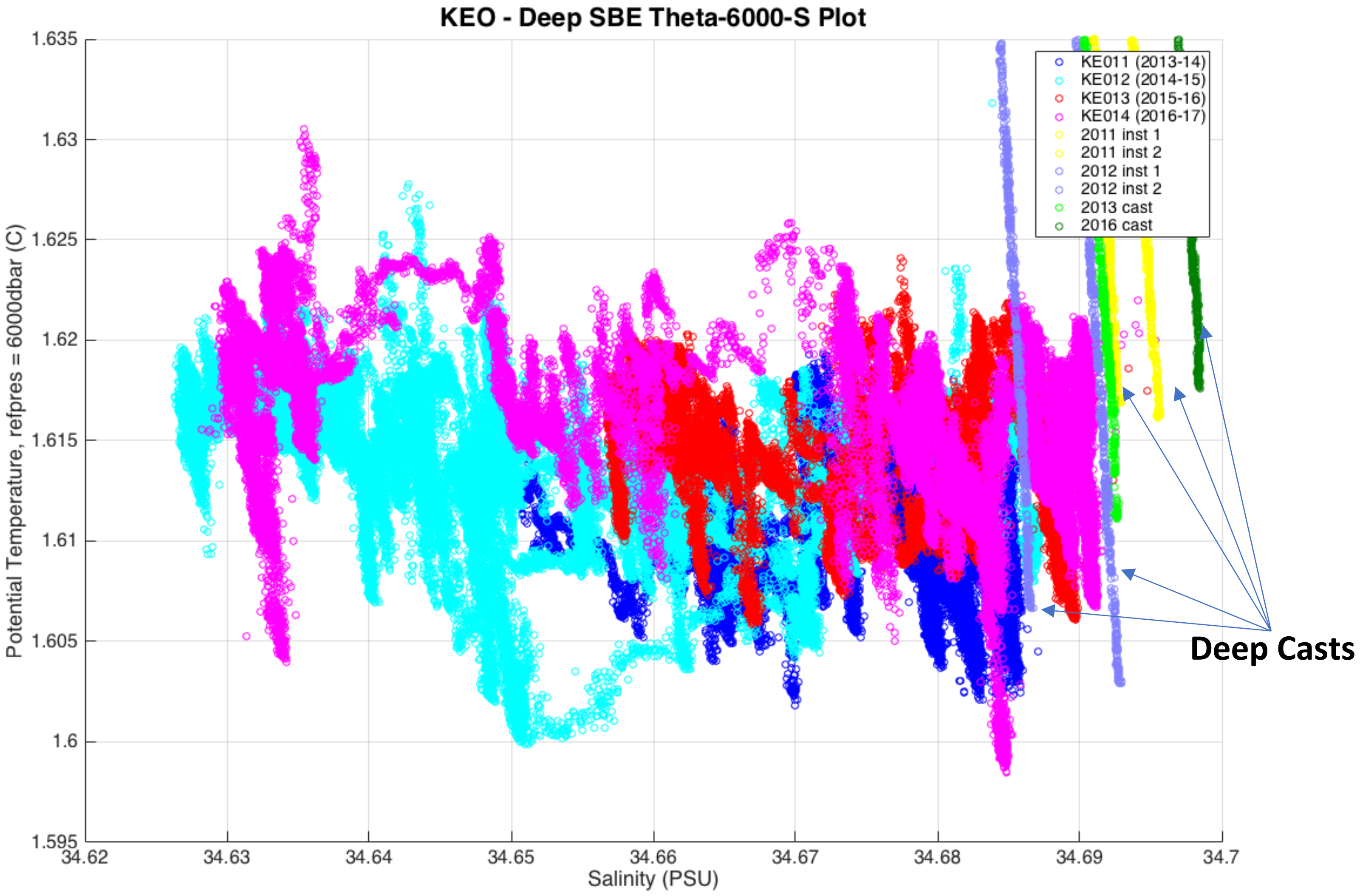


Figure 6: Potential temperature at 6,000m vs salinity for the 4 KEO deployments, with deep casts overlaid. Shows relative consistency of water masses/trends each year, but does not capture time passage.

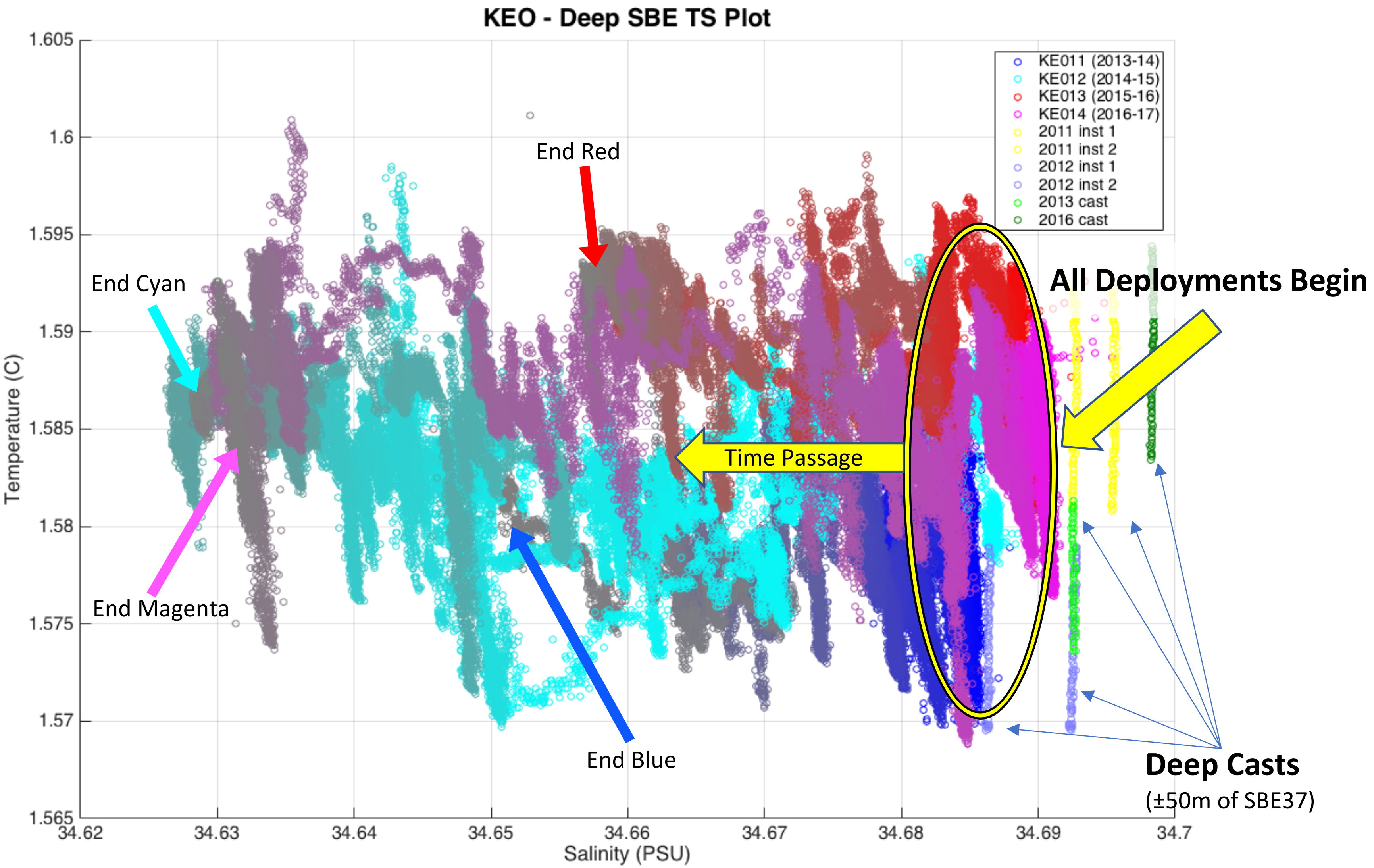


Figure 7: Same as previous, but with *in-situ* temperature, deployment data colors fading to gray with time, and superimposed cast data within 50m of the SBE37. Note that deployments begin around 34.69 PSU (circled yellow) and drift left/gray with time (arrow). Temperature actually increases with depth past about 4,100m, so unlike Figure 6, the CTD casts on this plot move "up" with depth.

OceanSITES Deep T-S Challenge: Why is KEO different?

OCS participates in the OceanSITES network, a group dedicated to long-term, high-frequency mooring observations. A deep TS ("microcat") subgroup was formed specifically to promote deep ocean (>2,000m) data, which culminated in a challenge to increase the number of sites with deep instruments to 100. Starting in 2011, the challenge set out to achieve better geographic coverage by incentivizing deployments through a donation pool that would provide an "instrument match" to PIs.

To better test instruments at great depths, Seabird provides free calibrations in exchange for the Principal Investigator's contributions of data collection, shipping costs, batteries, and other expendables. CTD casts were also required to verify instrument performance. Once data are processed and quality controlled, they are submitted and made available on the OceanSITES Global Data Assembly Centers (GDACs).

The anomalous drift noted at the KEO site was not found in other OceanSITES data (platforms/arrays such as MOVE, IRMINGSEA, PAP, CORC, and WHOTS). Discontinuities at these sites of above 0.01 PSU are rare, even when deployment depths differ by hundreds of meters, since the vertical (and horizontal) deep ocean salinity gradients are small.

At 5,700m, KEO depths exceed other OceanSITES mooring depths by over 1,000m, with the exception of the MOVE moorings, which have an average instrument depth around 5,000m. The additional sediment buildup at the KEO site is suspected of affecting the conductivity cell over time.

Summary and Next Steps

- Two alternated instruments deployed at 5,700m (rated to 7,000m) have repeatedly shown salinity drift over the course of yearlong deployments.

- Discontinuities between deployments, combined with CTD cast data, suggest the drift is instrumental (not a true change in deep ocean salinity). Sediment intrusion is suspected of affecting the conductivity cell over time, with immediate recovery upon ascent.

- By the time the instrument is returned for post-recovery calibration (3-6 months later), it has returned to its original state, having cleared debris from the conductivity cell. This results in post-calibrations nearly matching pre-calibrations (drift is not captured by the standard pre-to-post interpolation). When the instrument goes in the water the following year, salinity values return to within 0.02 PSU of historic CTD casts and previous years.

- PMEL was granted an additional SBE37SM-TCP from the OceanSITES pool. Three instruments were deployed simultaneously on the 2018 KEO mooring. **[update 2021 – instruments at 2 different depths both drifted, and a third (pumped) failed]**

- A field test to compare an instrument at the end of its deployment to a CTD cast is recommended. By gauging if salinities recover immediately (sediment clearing) or gradually (slow decompression) when the instrument is extracted from depth, this test could point to which hypothesis is correct. **[update 2021 – the deep SBE recovers immediately during the first datapoint during ascent + subsequently matches a reference cast performed at the surface]**

- ***It is recommended that Seabird tests whether salinity measurements drift with time in a controlled high-pressure environment, to confirm that sediment is responsible for the drift.***

References

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Acknowledgements

Thank you to all the scientists supporting the collection of this data from deployment/recovery operations to data processing, analysis and interpretation.

PMEL:

- Jennifer Keene, Meghan Cronin, and Dongxiao Zhang – Idea development & data processing decisions.

- John Lyman, Kristy McTaggart, Kenneth Connell, and Dan Dougherty – T-S diagram guidance, general counsel on salinity drift, and python scripts for decoding hex files that allowed independent verification of the Seabird equations and UNESCO salinity equations.

Fisheries and Oceans Canada / Bedford Institute of Oceanography:

- John Loder and Yuri Geshelin – Deep ocean SBE37/MicroCAT expertise, plot ideas, and best practices.

Contributed by Nathan Anderson (UW CICOES, OCS)