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Improving Argo Float Data: Steps Toward Implementing Onboard Cell Thermal Mass Corrections

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ABSTRACT

Accurate computation of physical oceanographic parameters, such as salinity and density using CTD data, requires knowledge of the temperature and conductivity sensor response times and the ability to temporally align data. Conductivity sensors have a response-time dependence on the water volume flow rate through the sensor, and also experience a temporal lag while traversing temperature gradients due to heat stored in the sensor materials. The latter causes a cell thermal mass error in conductivity values and subsequent derived parameters, such as salinity. The amplitude and lag of the thermal mass error is typically corrected in conductivity data prior to computing salinity, using an exponential function with a flow-dependent response amplitude and time-lag. However, for Argo profiling floats, salinity is computed before any cell thermal mass corrections are applied to conductivity data and then, data are averaged into approximately 10 m depth bins for transmission. This makes it difficult to correct for thermal mass errors in Argo data via post processing, and may cause Argo salinity data to be incorrect in thermally inhomogeous regions of the ocean. Here, new data gathered during sea trials of the SBE 61 Deep Argo CTD are used to evaluate cell thermal mass errors and possible corrections. This work is compared to previous efforts and is aimed at helping determine appropriate onboard data processing schemes for improving Argo data.

INSTRUMENTATION AND FIELD TESTS

- 2 Argo CTDs were deployed alongside an SBE 25*plus* profiling CTD near Seattle on September 26, 2013. (Figures 1 & 2).
- The deep-rated SBE 61 sampling protocols are essentially the same as the SBE 41CP. Both pump at ~10 ml/s and sample at 1 Hz with C, T, and P logged simultaneously. Only raw data were logged and no bin-averaging was implemented.
- The SBE 61s, powered by the SBE 25*plus*, logged data at 1 Hz internally with no time stamp. The SBE 25*plus* logged data at 16 Hz with time stamps.
- The TC intake for each CTD was co-located to sample as close to the same sample stream as possible.
- 2 complete profiles with all 3 instruments were conducted, each with different descent rates:
  Cast 1 ~25 cm/s, Cast 3 ~45 cm/s
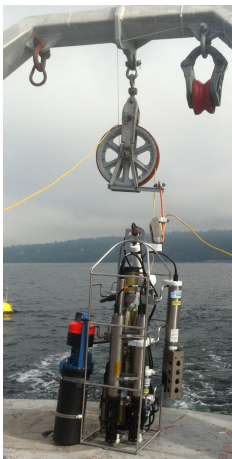- Argo floats ascend at slower rates (8 - 12 cm/s) that vary due to intermittent buoyancy controls.

Figure 1. SBE 25plus CTD with 2 SBE 61s attached side-by-side.

Figure 2. Location of SBE 61 sea trails in Puget Sound, Washington State, USA.

DATA CONSIDERATIONS AND PROCESSING STEPS

- SBE 25*plus* data were post-processed, including cell thermal mass corrections, prior to deriving salinity, and are used as the reference profile of T, C, P, and salinity (S).
- SBE 25*plus* and SBE 61 profile alignment was conducted using temperature, as scan times varied and pressure was not resolved well enough to match data (Figure 3).
    - o SBE 61 pressures were adjusted according to this temperature alignment;
    - o SBE 25*plus* data were decimated to 1 Hz by matching nearest SBE 25*plus* pressure scan line to temperature-aligned SBE 61 final pressures.
- A conductivity ratio between SBE 25*plus* and each SBE 61 was computed using several minutes of soak data from bottom of each cast (~152 dbar). Applied ratios were < 0.02% for both SBE 61s.
- Temporal alignment of SBE 61 T and C data did not significantly improve salinity results. Relative sensor response times for given flow rate and transit time between T and C sensors yielded alignment difference of ~0.1 s, which is small compared to 1 Hz sample rate.
- Final adjusted 1 Hz SBE 61 data and reference SBE 25*plus* data were used to derive cell thermal mass parameters following methods outlined in Lueck 1990; Lueck and Picklo 1990; and Morison et al. 1994.
- Differences between a_τ_{CTM} corrected SBE 61 and reference salinity were used to evaluate goodness of the fit as the sum of squared residuals (SSR).
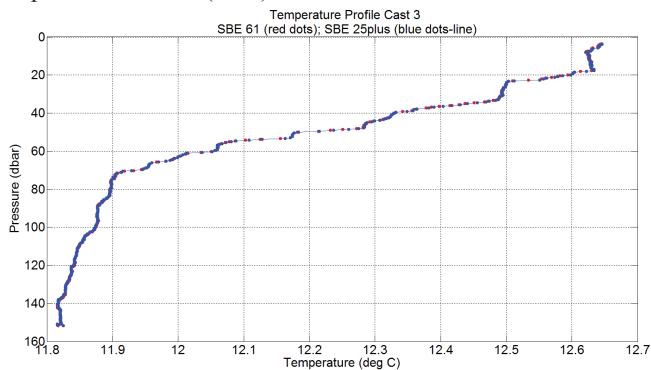

Figure 3. SBE 61 temperature (red dots) adjusted to match nearest SBE 25plus temperature points (blue dots). Cast 3, SBE 61 SN 5571.
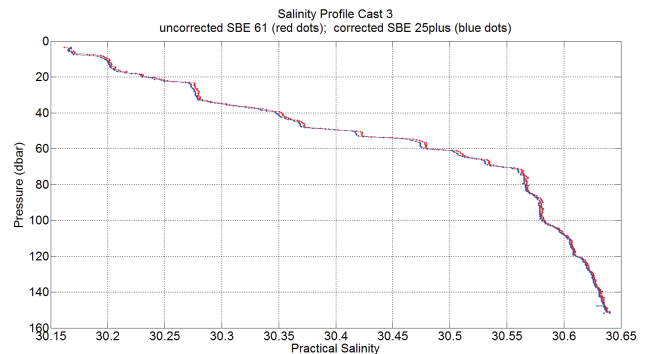

Figure 4. SBE 61 uncorrected salinity (red dotted line) and SBE 25plus reference salinity corrected for cell thermal mass (blue dotted line). Cast 3, SBE 61 5571. SBE 61 salinity is consistently high of reference salinity on down cast, indicative of cell thermal mass error.

RESULTS

- Thermal mass parameter results were consistent between casts, between SBE 61s, and for various sections of data (i.e., whole profile and subsectioned profiles where largest thermal change occurred).
- Contours of SSR results all indicate a similar minima, or saddle, which represents the span of a_τ_{CTM} producing the best match between corrected SBE 61 salinity and reference salinity (Figure 5).
    - o Doubling speed of profiler does not appear to make a significant impact on a_τ_{CTM} SSR results.
- Multiple values are possible as represented by saddle minima. Testing derived parameters with raw SBE 61 salinity profile is required to narrow range of best parameter choice.
- Small variations between contour plots matter less than finding a consistent combination of alpha and tau that can be identified for producing onboard Argo CTD corrections.
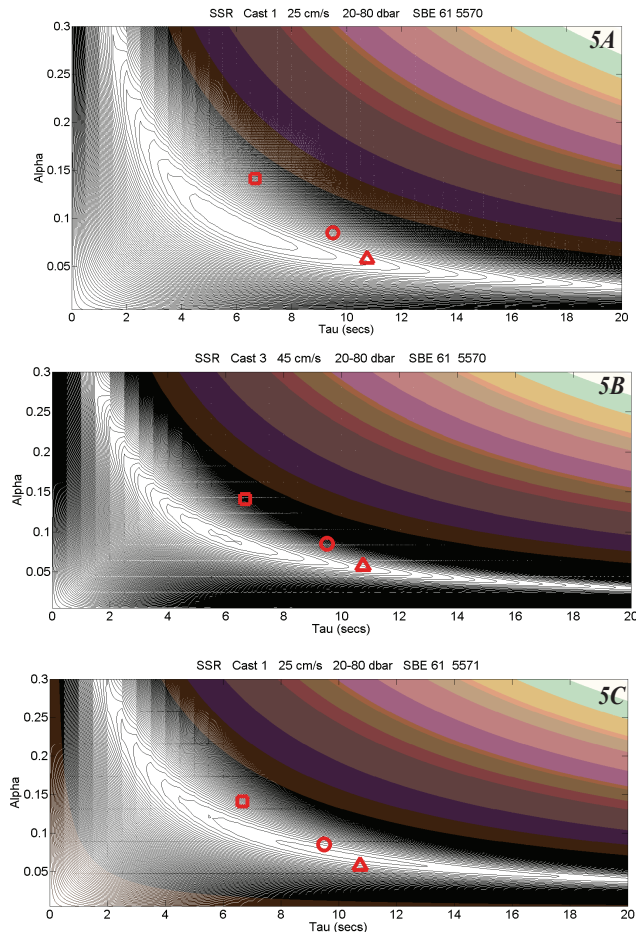

Figure 5. Contours of sum of squared residuals between SBE 61 and reference salinities for a matrix range of a and τ_{CTM} combinations:

A) SBE 61 5570, Cast 1 at 25 cm/s;
B) SBE 61 5570, Cast 2 at 45 cm/s;
C) SBE 61 5571, Cast 1 at 25 cm/s.

a and τ_{CTM} parameters derived by:
- square - Johnson et al., 2007
- triangle - Morison et al., 1994
- circle - Janzen et al., 2014

DISCUSSION

Assuming similar heat diffusion rates between the various CTD cells, and using their well documented correction parameters, expected a_τ_{CTM} corrections based on flow speed through the conductivity cell can be roughly scaled by the following relationships:
- Amplitude of cell thermal mass error (alpha or a) is proportional to inverse of flow velocity (V) through C cell: $a \propto V^{-1}$
- Time it takes to dissipate a temperature-step change (tau or τ) is proportional to square root of inverse flow velocity: $\tau_{CTM} \propto V^{-1/2}$

Scaled expected values:
- a for a CTD pumping at ~10 ml/s should increase by fractional decrease in flow speed (factor of 3 compared to the 30 ml/s SBE 9-11 and factor of 2 compared to 20 ml/s CTDs) (Table 1).
- τ_{CTM} is less dependent on flow, therefore we do not expect a 2-3 fold jump in τ_{CTM} for slower pumped CTDs. Given Argo CTD's slower flushing and profile speed (as it relates to external flushing), the lag should be equal to or longer than what is observed on other CTDs ($\geq$ 7 to 8 s).

Morison et al. (1994) developed a more robust method to estimate cell thermal mass corrections if the pump flow rate is known. Using Argo pump rates, this produces an a_τ_{CTM} that lies within the minima saddle derived here. Johnson et al. (2007) empirically derived cell thermal mass correction parameters using ice-tethered-profile SBE 41CP data, and found higher amplitude and shorter lag time corrections (Figure 5 and Table 1).

Table 1. Possible data processing parameters

| Data Processing Parameter Estimates for continuously pumped Argo CTDs	Johnson et al., 2007 Empirically Derived Values	Morison et al., 1994 Flow Estimate Method	Janzen et al., 2014 Scaled Expected Values
Thermistor response time lag τ_T relative to P	0.39 s	-	0.5 s
τ_{Cond} Conductivity sensor lag relative to T	0.05 s	-	0.1 s
a Amplitude of cell thermal mass error	0.141	0.0465 - 0.0575	0.08 - 0.09
τ_{CTM} Temporal lag of cell thermal mass error	6.68 s	10.26 - 10.75 s	9 - 10 s
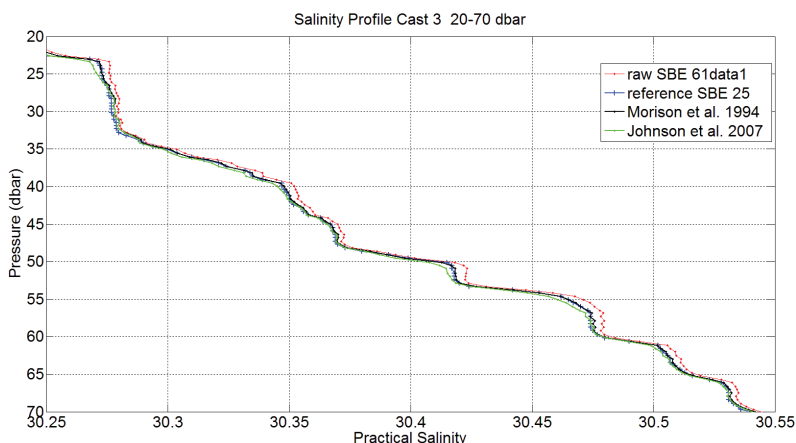
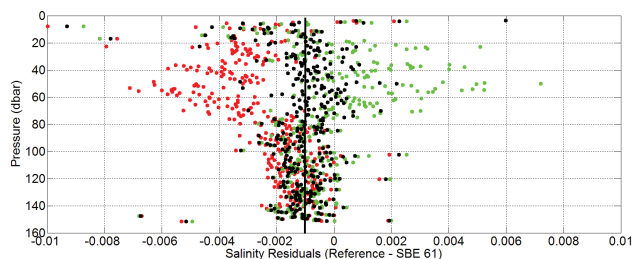*Figure 6. Salinity profile for Cast 3. Corrected salinity using values from Table 1.*

Figure 7. Salinity residuals between SBE 25plus reference and SBE 61. Johnson et al. corrected (green), Morison et al. corrected (black), uncorrected (red).

REFERENCES

- G.C. Johnson, J.M. Toole, and N. Larson, 2007. "Sensor Corrections for Sea-Bird SBE-41CP and SBE-41 CTDs," Journal of Atmospheric and Oceanic Technology (JAOT), vol. 24, pp. 1117-1130.
- R.G. Lueck, 1990. "Thermal Inertia of Conductivity Cells: Theory," Journal of Atmospheric and Oceanic Technology (JAOT), vol. 7(5), pp. 741-755.
- R.G. Lueck and J.J. Picklo, 1990. "Thermal Inertia of Conductivity Cells: Observations with a Sea-Bird Cell," Journal of Atmospheric and Oceanic Technology (JAOT), vol. 7(5), pp. 756-768.
- J. Morison, R. Andersen, N. Larson, E. D'Asaro, and T. Boyd, 1994. "The correction for Thermal-Lag Effects in Sea-Bird CTD Data," Journal of Atmospheric and Oceanic Technology (JAOT), vol. 11(4), pp. 1151-1164.