Greg Johnson et al. et al.

RBR

Instrument performance of the RBR*argo*^{3} CTD

Outline

Temperature

Pressure

Conductivity

RBR

$$T_{meas} = \frac{1}{C_0 + C_1 \cdot \left(\ln\left(\frac{1}{VR\text{-}1}\right)\right) + C_2 \cdot \left(\ln\left(\frac{1}{VR\text{-}1}\right)\right)^2 + C_3 \cdot \left(\ln\left(\frac{1}{VR\text{-}1}\right)\right)^3} - 273.15$$

Temperature

Calibration facility: Fluke/Hart baths

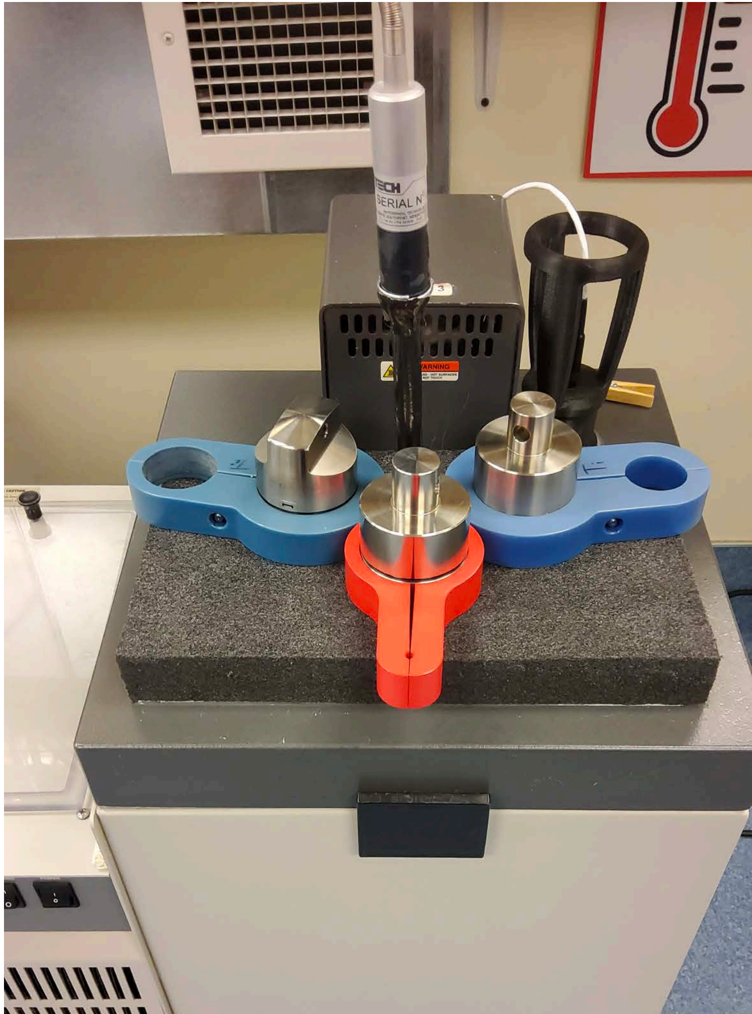
Fluke quartz sheath SPRTs
Isotech Inconel sheath SPRTs
Fluke/Hart Superthermometers

All data streamed to SQL database. All baths controlled from Ruskin

Primary standards:
TPW (0.0100°C)
Gallium (melting point: 29.7646°C)
Hg (triple point: -38.8344°C)
TPW checked every day (SPRT corrected to ±0.3mK)
Gallium/Hg every three months

Procedure:

- Complete immersion of instrument in self-contained pressure vessel, battery powered, internally logging
- Eight points (approximately every 6°C from -5° to 35°C)
- One hour dwell time for each plateau (1.5h required in total including transition)
- Steinhart-Hart thermistor equation (cubic with pre-scaling natural log)



$$P_{meas} = C_0 + C_1 \cdot VR + C_2 \cdot VR^2 + C_3 \cdot VR^3$$

$$P_{corr} = P_{cal} + \frac{(P_{meas} - P_{cal}) - X_1 \cdot (T_{pres} - T_{cal}) - X_2 \cdot (T_{pres} - T_{cal})^2 - X_3 \cdot (T_{pres} - T_{cal})^3}{1 + X_4 \cdot (T_{pres} - T_{cal})}$$

Pressure

Mensor CPC6050
Modules for pressure (dbar): 2110, 1035, 515, 130
IS-50 accuracy (0.01% of reading from 0-50% FS, 0.01% of FS from 50%-100%)
Module calibrated every 12 months (highest observed drift over 2019 was 0.003% FS)

Complete immersion in DI water in two pressure tanks.
N2 pressure media

Procedure:
TCal performed first (immersion, constant pressure, variable temperature)
10 plateaus (every 200 dbar)

Repeated at two different temperatures (21 °C, 1.5 °C)

Cubic polynomials as fit surface bounded by two constant temperature, FS pressure; and one constant pressure, FS temperature

Corrections:
temperature correction applied numerically
No trimming resistors.
Per unit calibration (NOT per model)

$$C_{meas}=C_0+C_1\cdot VR$$

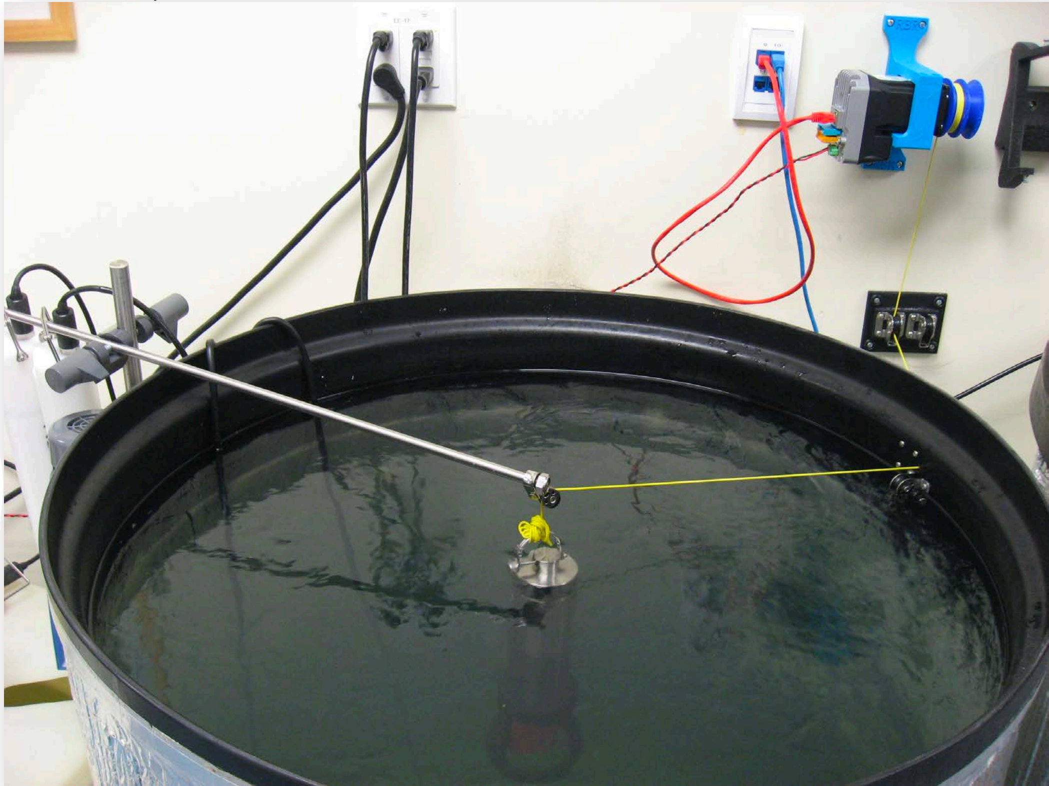
$$C_{corr}=\frac{C_{meas} - X_0\cdot(T_{cond}-T_{cal})}{1 + X_1\cdot(T_{cond} - T_{cal}) + X_2\cdot(P_{corr} - P_{cal}) + X_3\cdot(P_{corr} - P_{cal})^2 + X_4\cdot(P_{corr} - P_{cal})^3}$$

Conductivity

<u>Calibration facility</u>:
Precision resistor set (8 values, OC, 47 - 690 ohm (0-90mS/cm) to verify linearity against conductance (T15)
T15S35 700L bath (compared to salinometer, establishes cell constant for T15)
T25S35 700L bath (compared to salinometer)

<u>Corrections</u>:
internal temperature correction (per serial number)

MRV



$$T_{meas} = \frac{1}{C_0 + C_1 \cdot \left(\ln\left(\frac{1}{VR\text{-}1}\right)\right) + C_2 \cdot \left(\ln\left(\frac{1}{VR\text{-}1}\right)\right)^2 + C_3 \cdot \left(\ln\left(\frac{1}{VR\text{-}1}\right)\right)^3} - 273.15$$

$$P_{meas} = C_0 + C_1 \cdot VR + C_2 \cdot VR^2 + C_3 \cdot VR^3$$

$$P_{corr} = P_{cal} + \frac{(P_{meas} - P_{cal}) - X_1 \cdot (T_{pres} - T_{cal}) - X_2 \cdot (T_{pres} - T_{cal})^2 - X_3 \cdot (T_{pres} - T_{cal})^3}{1 + X_4 \cdot (T_{pres} - T_{cal})}$$

$$C_{meas} = C_0 + C_1 \cdot VR$$

$$C_{corr} = \frac{C_{meas} - X_0 \cdot (T_{cond} - T_{cal})}{1 + X_1 \cdot (T_{cond} - T_{cal}) + X_2 \cdot (P_{corr} - P_{cal}) + X_3 \cdot (P_{corr} - P_{cal})^2 + X_4 \cdot (P_{corr} - P_{cal})^3}$$

Thank You

Contact Us

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Photo: Teledyne Marine

RBR*argo*^{3}: long-term salinity stability

- Long-term stability was investigated using all four RBR-equipped Argo floats deployed in the Pacific.
- Relies on OWC analytical method (Owen and Wong, 2009; Cabanes, 2016), combined with a MATLAB toolbox *ArgoOWCviewer* (manuscript to be submitted to MethodsX)
- Makes use of both climatologies and near-by floats

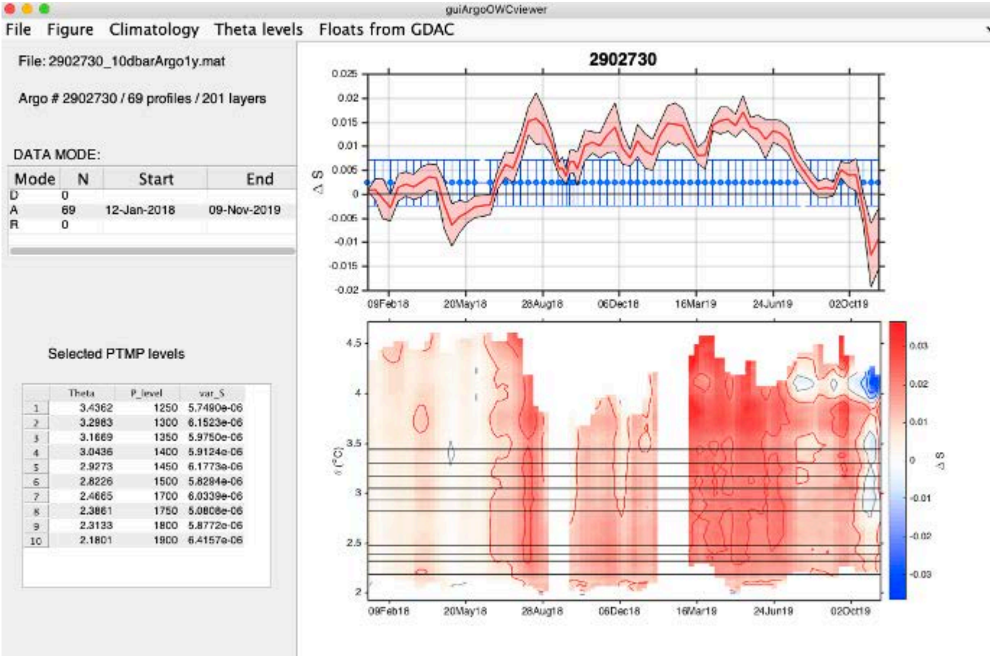
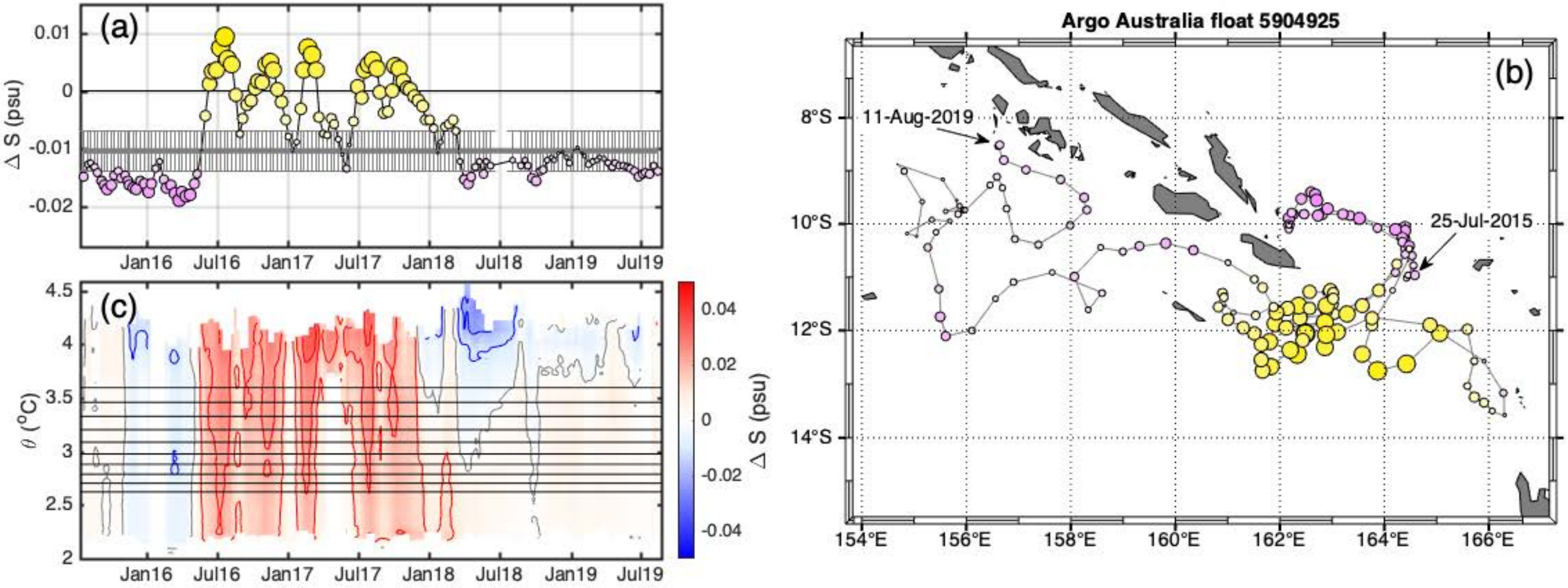


Figure: [top] time series of the OWC profile fit coefficients, and [bottom] differences between OWC reference salinity and climatology.

rgo Australia float equipped with RBR*argo*



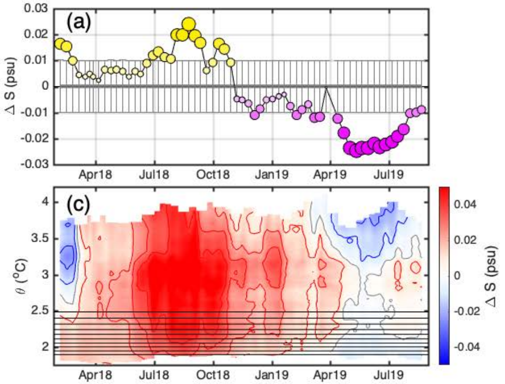
→ OWC calibration disagreement caused by oceanographic variability not captured by reference data

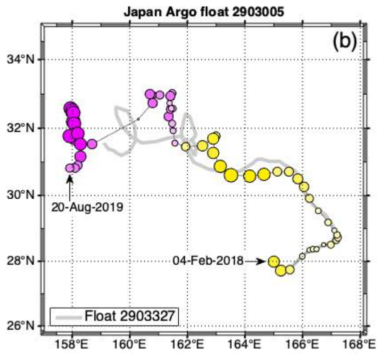
- All profiles with OWC salinity offsets different from the constant level were located over one region (a, b)
- During that period, the reference salinity calculated by OWC method was different from climatology (a, c)
- The problematic data originates from the front formed by the northern extension of low-salinity Antarctic Intermediate Water (AAIW)

No drift over 4 years, -0.01 psu offset

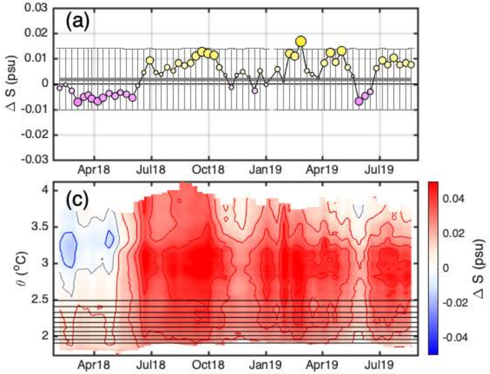
Argo Japan floats equipped with RBR*argo*³

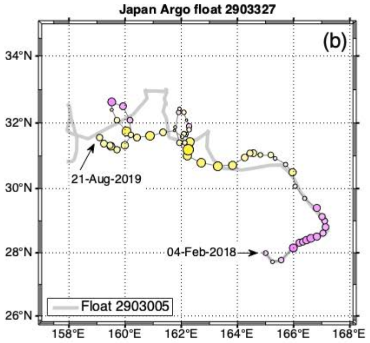
Float 2903005





Float 2903327





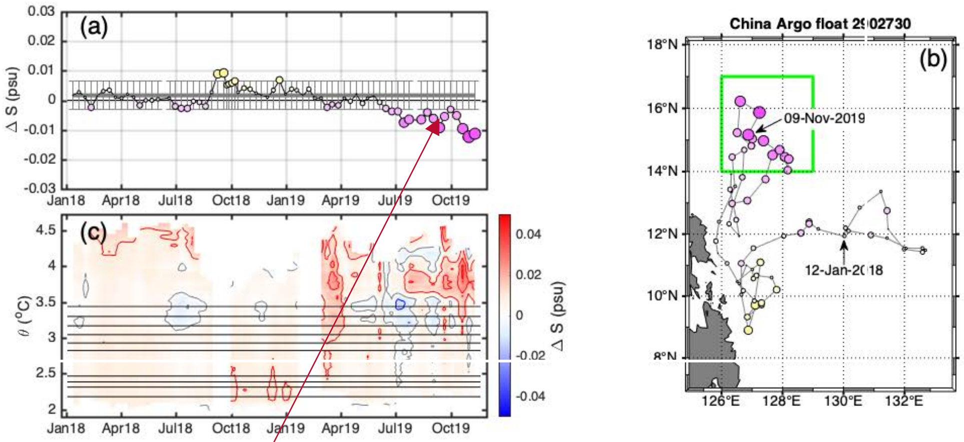
- Increasing difference between OWC profile fit coefficients and constant offset in the end of the float lifetime
  - Can be misinterpreted as salinity sensor drift
  - Associated with float movement to highly variable region influenced by the Kuroshio extension

- Stable salinity offset during the float lifetime

No drift, no offset

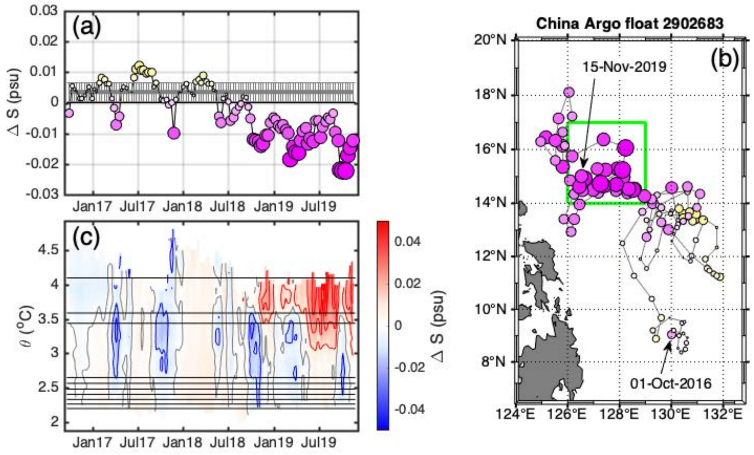
Argo China float equipped with RBR*argo*³

Float 2902730



China Argo

Float 2902683 (SBE)



Increasing difference between OWC profile fit coefficients and constant offset in the end of the float lifetime can be misinterpreted as salinity sensor drift.

→ However, other floats operating in the same area (2902703, 2902708, 2902688, 2902683, 2902707, 2901545) demonstrate similar trends in salinity offsets.

No drift no offset

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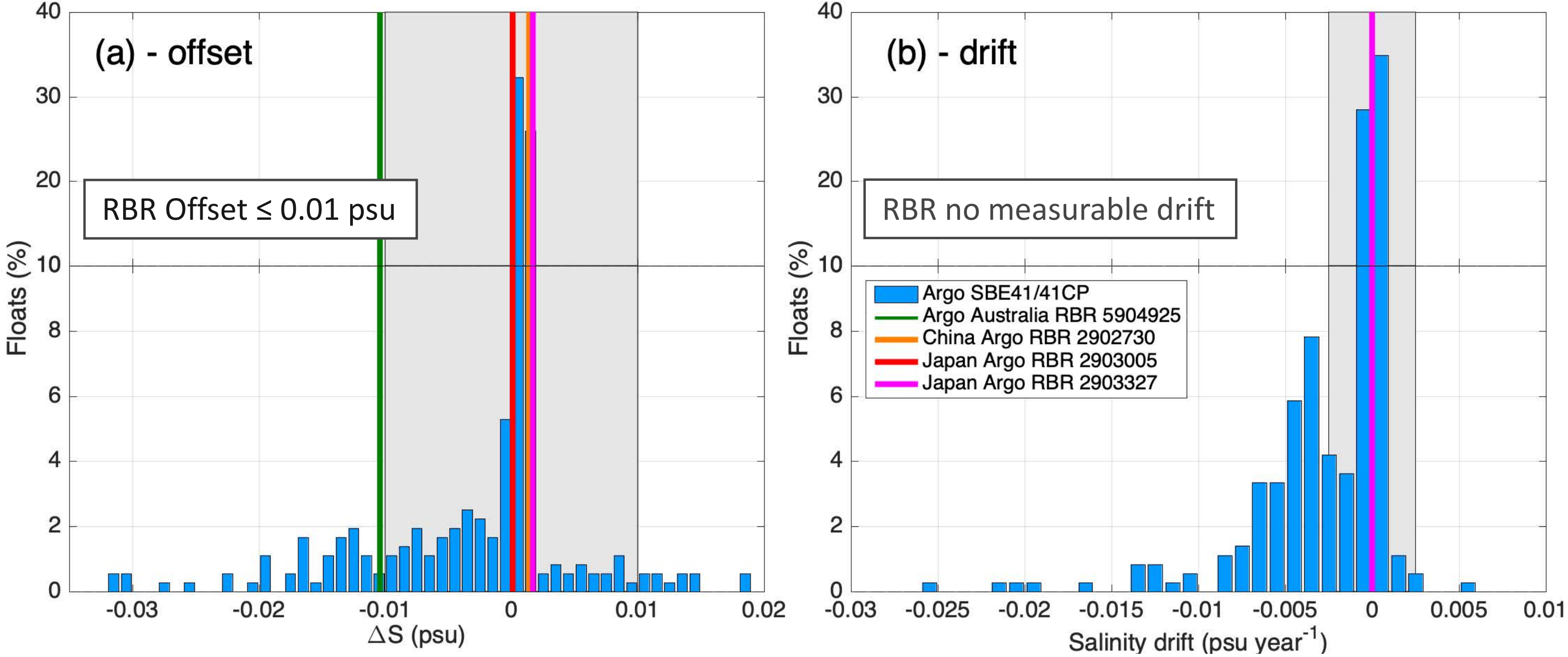
RBR*argo*³ bias and drift corrections compared to DM data from nearby floats



The averaged salinity correction (a) bias and (b) linear drift rate

4 floats with RBR*argo* CTDs

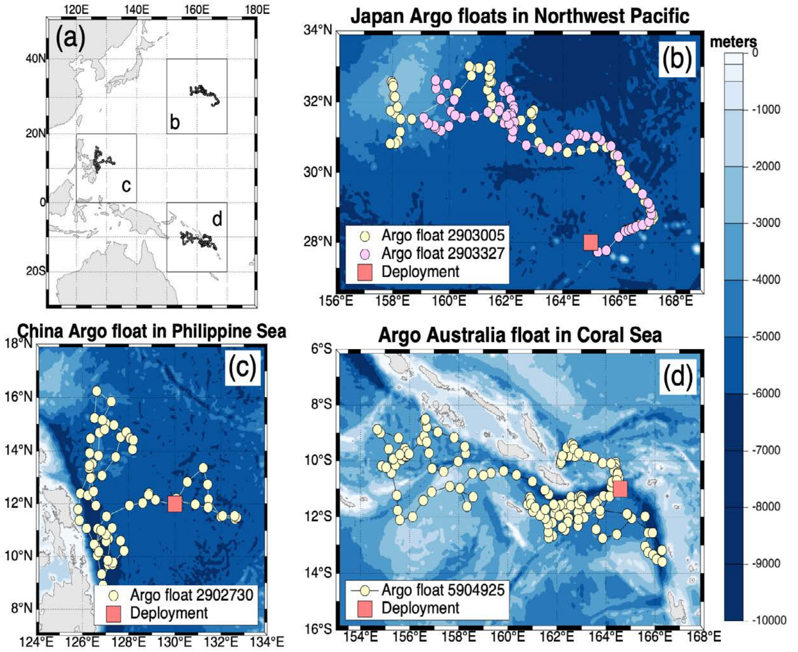
360 Argo floats with SBE41 CTDs

Accuracy and long-term stability assessment of inductive conductivity cell measurements on Argo Floats

Nikolay Nezlin[1], Mark Halverson[1], Guillaume Maze[2], Clark Richards[3], Jean-Michel Leconte[1], Igor Shkvorets[1], Rui Zhang[1], and Greg Johnson[1]

[1]RBR Ltd, Ottawa, ON, Canada
[2]IFREMER, Brest, France
[3]BIO/DFO, Dartmouth, NS, Canada

Submitted to JTECH in April 2020.



Submitted manuscript shared in RBR DTT Google Drive

RBR*argo*^{3} CTD dynamic corrections

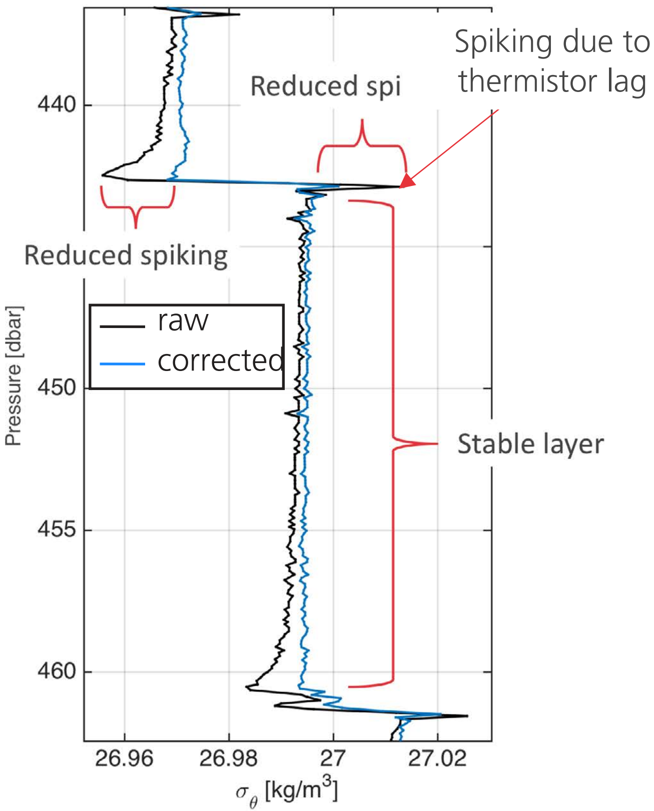
1. Thermistor inertia lag
2. C-cell thermal mass

Thermistor inertia: Theory

- Temperature lags conductivity
- Results in misalignment of temperature and conductivity and salinity spiking
- Generated by two mechanisms:
  1. Thermistor's slower time response
     - Inherent to sensor characteristics
     - Independent of fall-rate (to 1st order)
  2. Physical separation of C and T ("advective lag")
     - Lag = separation/fall-rate
     - Fall-rate dependent

RBR*argo*^{3} was designed to have T and C aligned wrt the direction of the flow, minimizing advective lag.

1 Hz sampling rate; 10 cm/s profiling rate



Caribbean Sea, MRV/RBRargo ALAMO #9139

Thermistor inertia lag: Method and approach

Based on the assumption that changes in conductivity are mostly due to changes in temperature

Optimal C-T lag is determined for all profiles, all six instruments and all five cruises:

1. Compute ΔC and ΔT for each profile
2. Separate profiles into 5-s segments
3. Segments located in the mixed layer are discarded (P < 50 dbar)
   - Would bias results towards a zero-lag
4. Compute cross-covariance function
5. Isolate lag maximizing the cross-covariance function
   - If max(xcov) < 0.5, segment is discarded as it violates the underlying assumption. This often occurs in the halocline.
6. A second order polynomial is fitted using 3 points centered on the lag maximizing covariance
   - Allows for non-integer lags and helps removing dependence on sampling rate
7. Record
   - optimal lag (i.e., polynomial maximum)
   - Average fall-rate over the segment

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Barth et al. 1996, Ullman and Hebert 2011, Dever et al. 2020

Thermistor inertia lag: Results

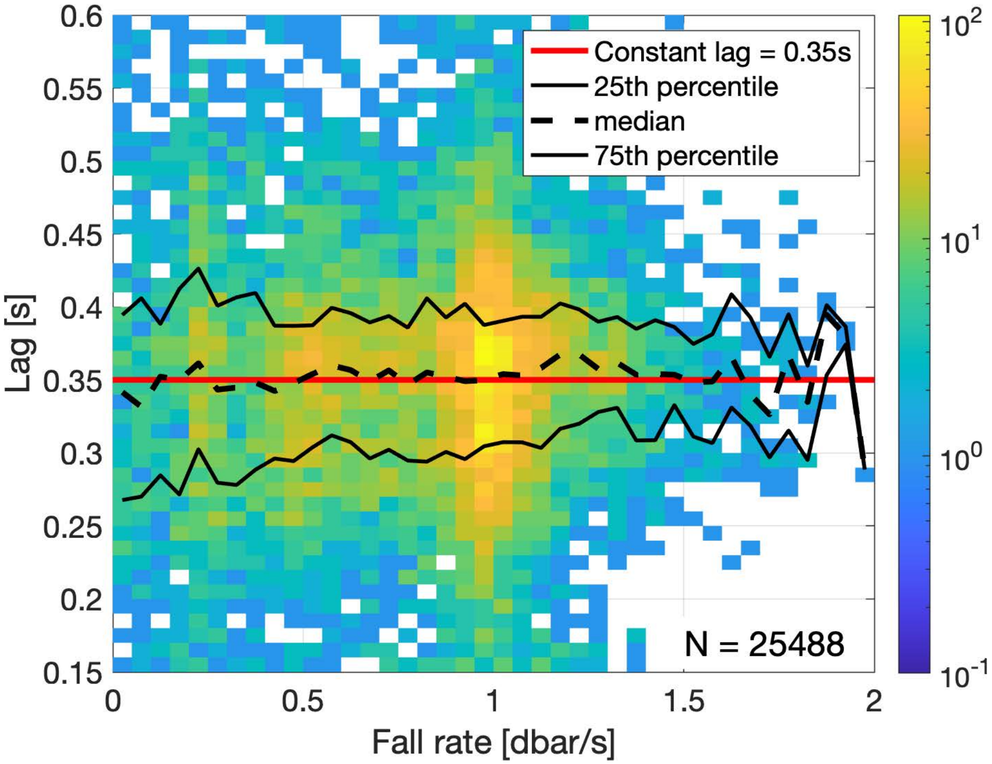
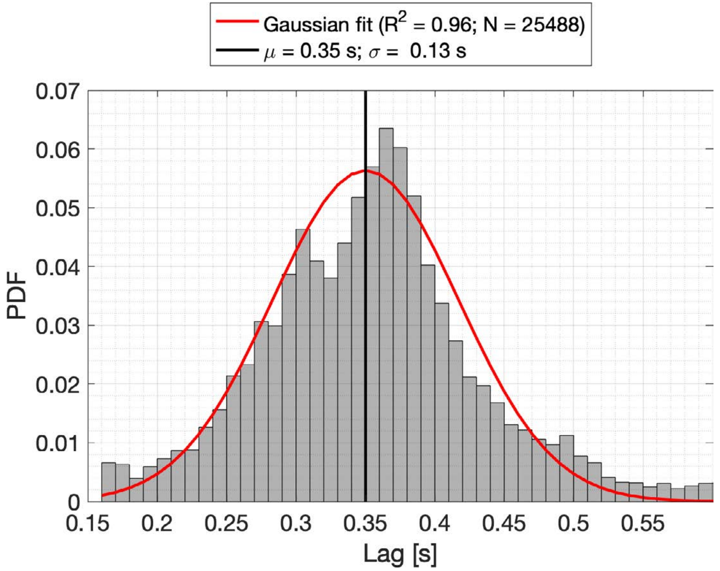
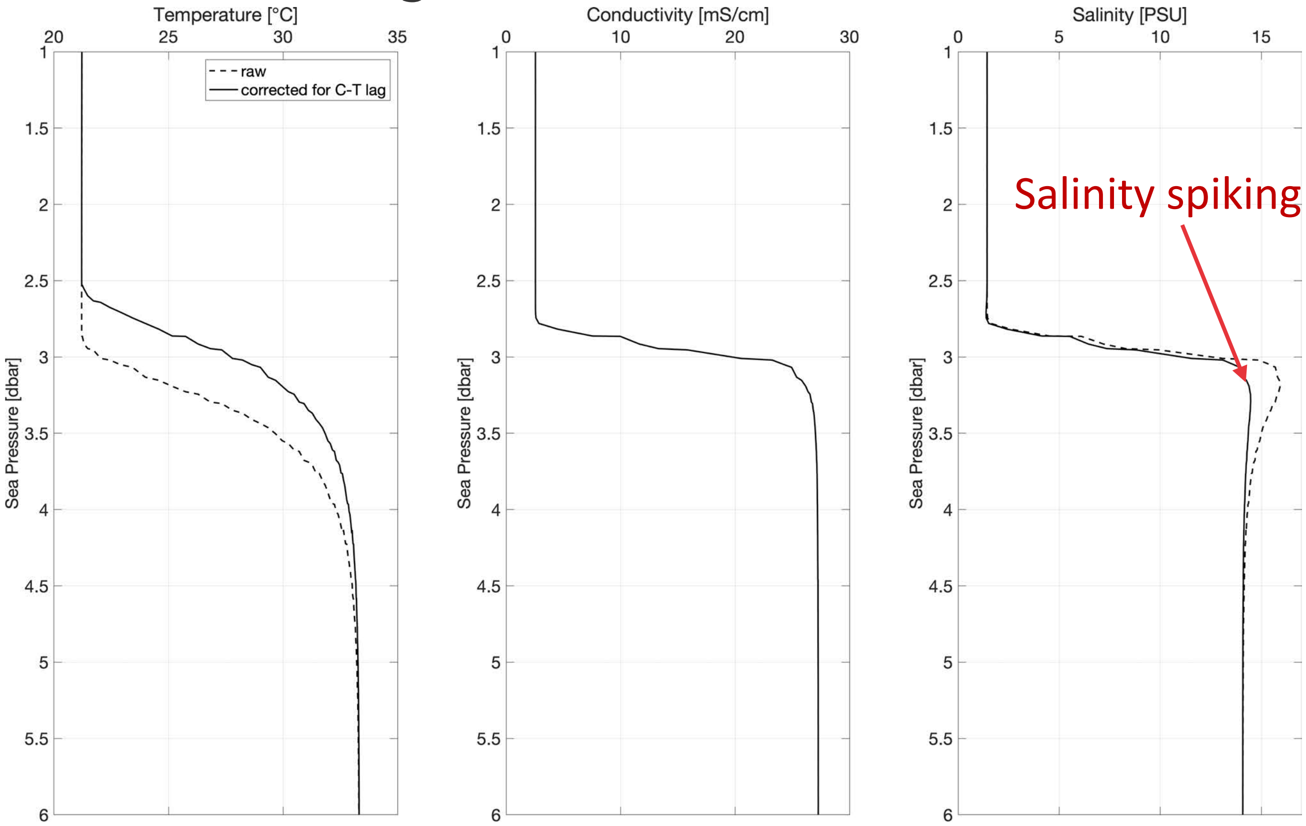


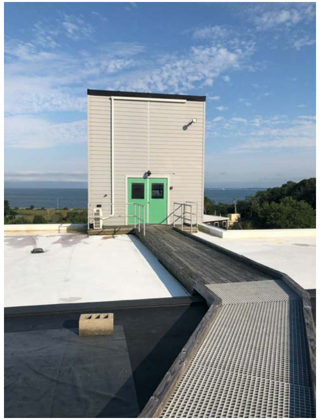
Figure: 2D histogram of optimal lag as a function of fall-rate (log scale)

1. 3 “nodes” of high-density data (0.25, 0.5 and 1 dbar/s)
2. No dependence on fall-rate
3. Normal distribution
4. Mean of a normal distribution fitted to all lags yields 0.35 s



Thermistor inertia lag: Validation from WHOI tank

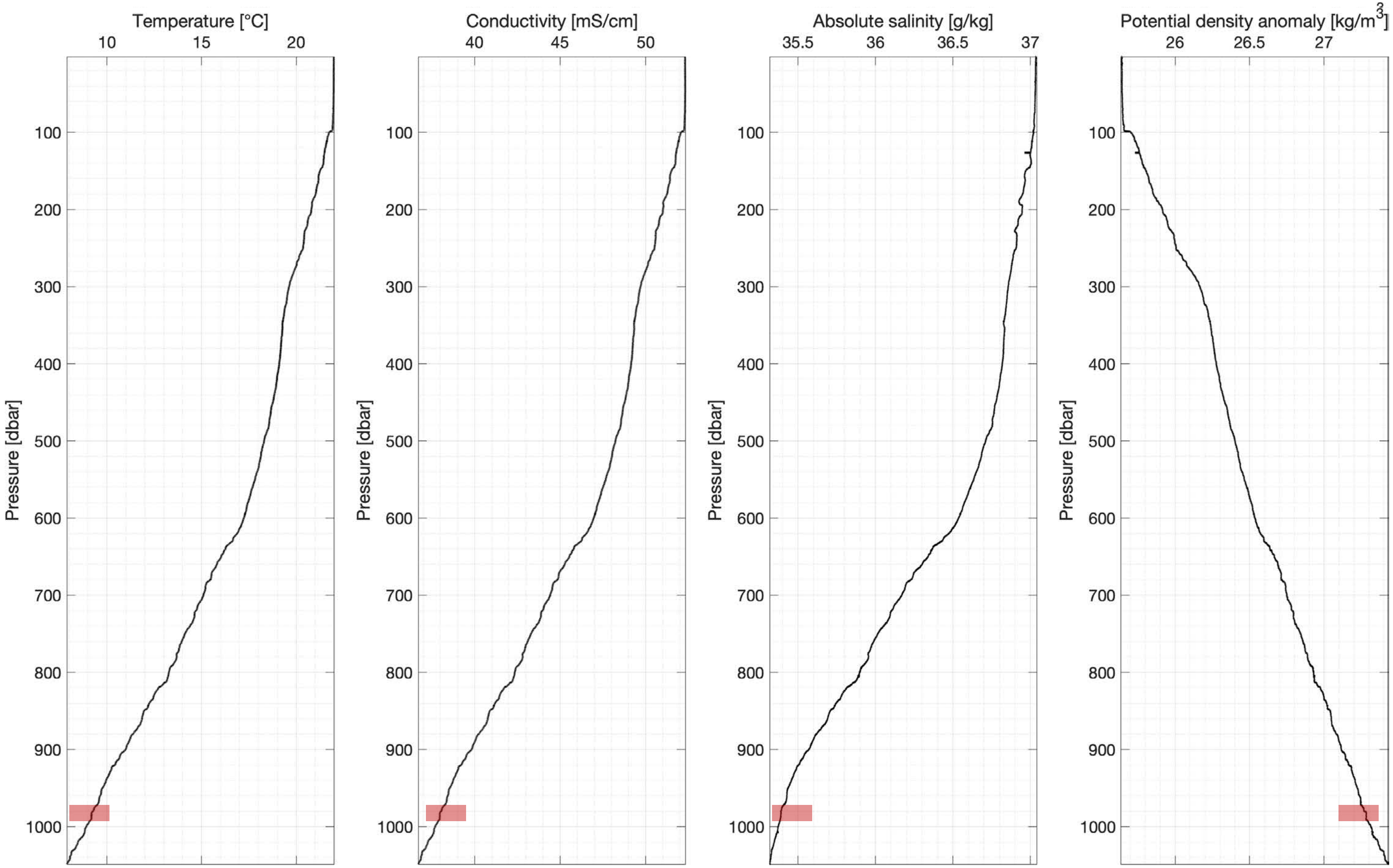




Can be combined with a sharpening of T, or a smoothing of C in post-processing (see RBR report)

See Schmitt et al. (2005)

Thermistor inertia lag: Validation from Webb float (f7395, 1Hz, 8 cm/s)



C-cell thermal mass: Theory

- Heat stored into the conductivity cell is transferred to water and affect conductivity measurements

- Thermal mass errors often result in density inversions and unstable layers

- Traditionally, corrections rely on a model developed by Lueck and Picklo (1990), further adjusted by Morison (1994)

$$T_T(n) = -bT_T(n-1) + a[T(n) - T(n-1)]$$

with
$$a = 4 f_n \alpha \tau \, (1 + 4 f_n \tau)^{-1}$$
$$b = 1 - 2a\alpha^{-1}$$

- Rely on 2 key parameters:
  - α – amplitude of the correction
  - τ – timescale of the correction

C-cell thermal mass: Methods and approach

Used an ALAMO float in the Gulf of Mexico that profiled through a staircase

+ ideal dataset, as it contains many sharp interfaces separated by non-stratified layers

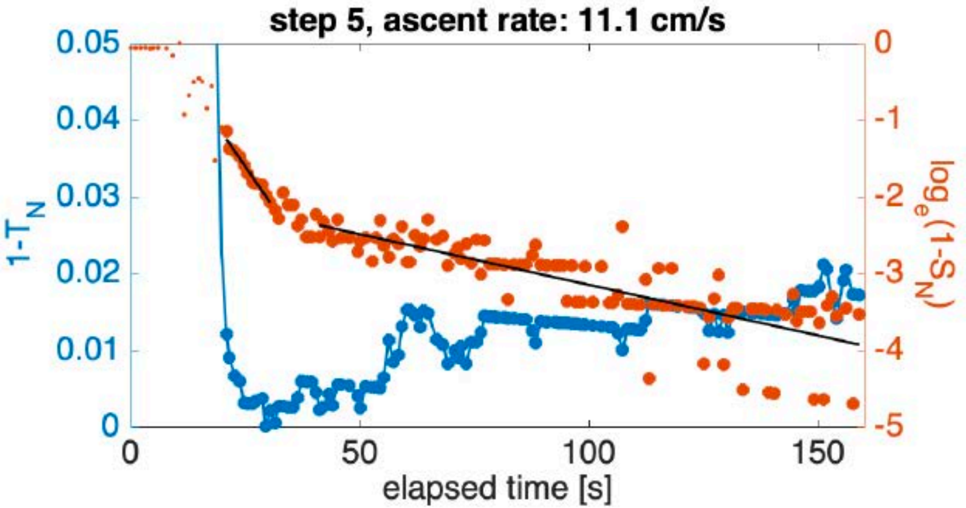


Figure: Normalized temperature gradient and log of normalized salinity gradient. The slope in the latter provides insights on the time constants over which equilibrium is achieved (cf. RBR report).

Analysis revealed two dominating timescales:

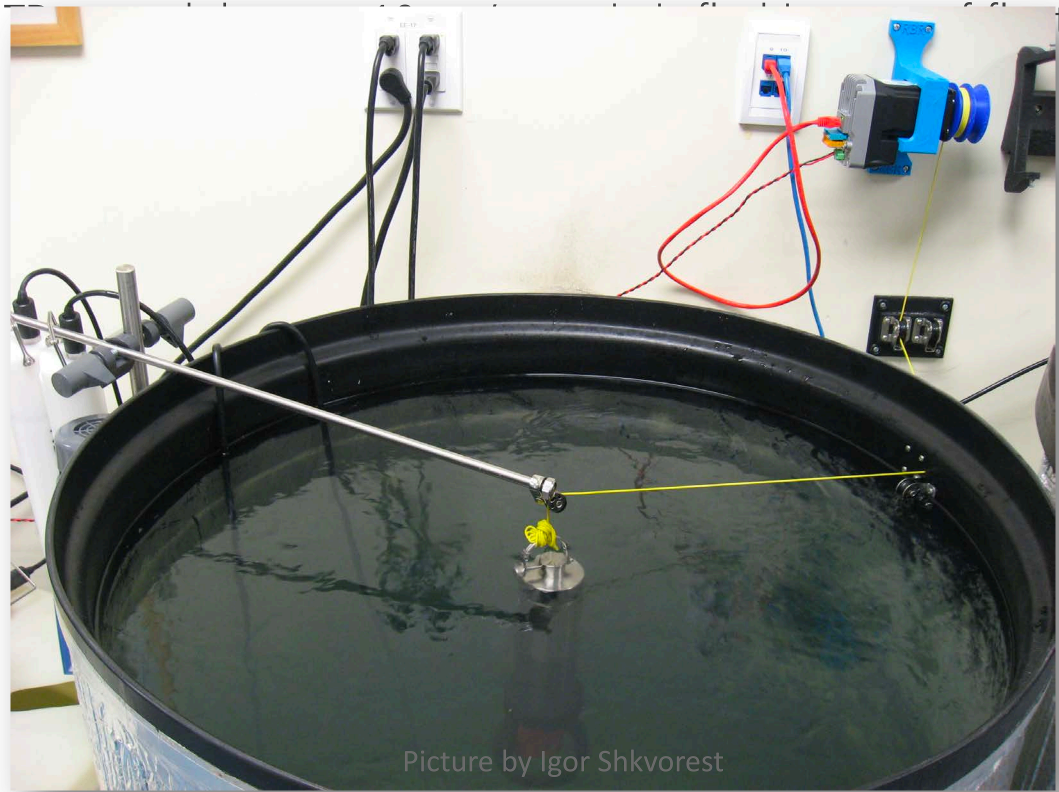
+ one “longer” $\mathcal{O}$(60 s)
+ one “shorter” $\mathcal{O}$(8 s)

Data: courtesy of Elizabeth Sanabia and Steven Jayne

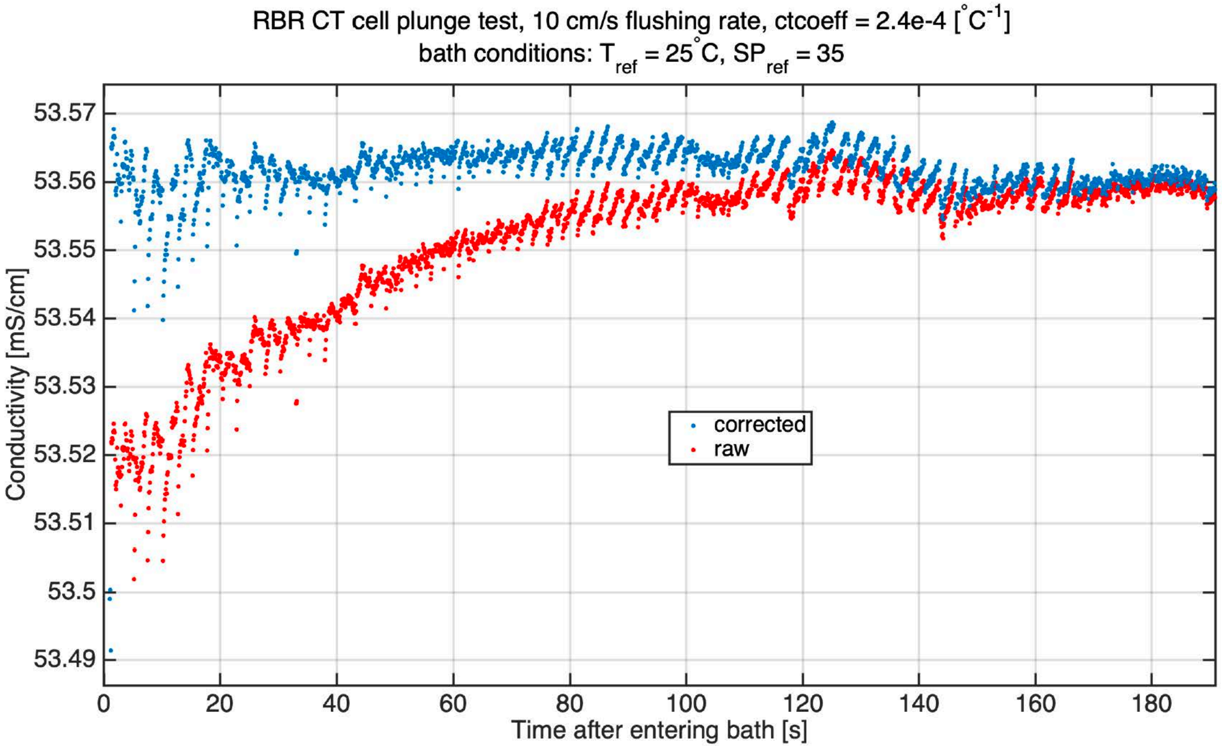
C-cell thermal mass: The plunge test

1- Plunge an RBR*argo*^{3} CTD into a 1 m deep calibration bath to simulate step change in T (ΔT = 3.5°C).

2- “Jiggle” the C … ts



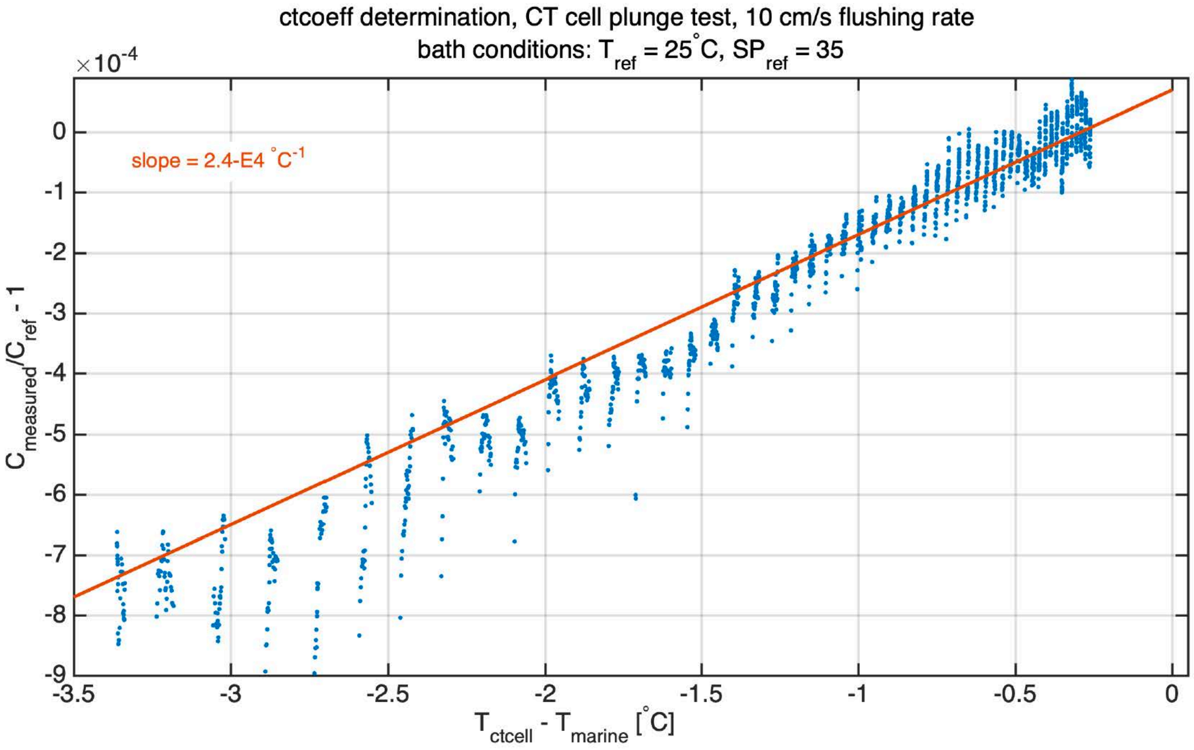
C-cell thermal mass: The plunge test



+ At t = 0 s, measured conductivity is low because of colder CT cell cooled the water it is sensing.

+ Measured conductivity increased as the cell equilibrated thermally with the water.

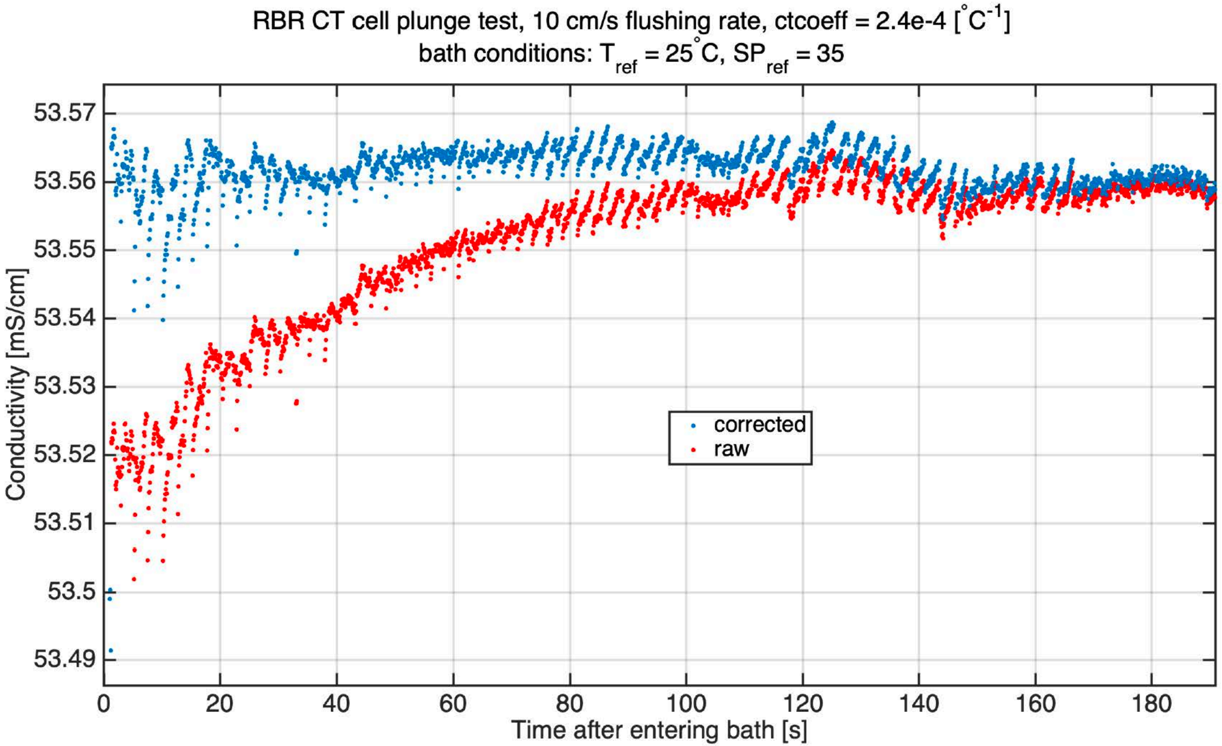
C-cell thermal mass: The plunge test



+ The difference between the internal CT-cell temperature and the water temperature is a proxy for the heat flux between the cell and the water.

$$C_{cor} = \frac{C_{measured}}{1 + ctcoeff * (T_{ctcell} - T_{marine})}$$

C-cell thermal mass: The plunge test



+ Time constant for this adjustment is 60s

+ referred to as $\boldsymbol{\tau_{60}}$ correction:

$$C_{cor} = \frac{C_{measured}}{1 + 2.4\times10^{-4} * (T_{ctcell} - T_{marine})}$$

C-cell thermal mass: Methods and approach

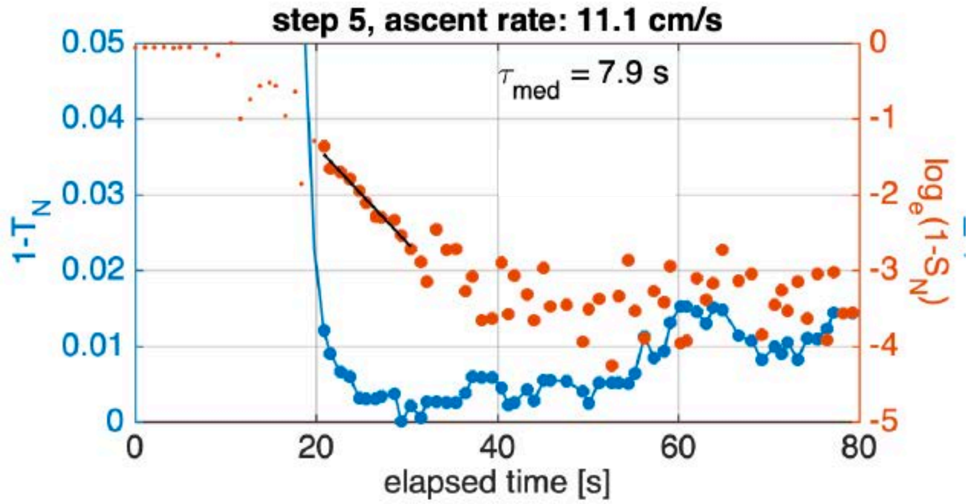


Figure: Normalized temperature gradient and log of normalized salinity gradient. The slope in the latter provides insights on the time constants over which equilibrium is achieved (cf. RBR report).

Two dominating timescales:

+ ~~one “longer” $\mathcal{O}$(60 s)~~
+ one “shorter” $\mathcal{O}$(8 s)

Median value of slope for all “steps” is 8 s:

$$\boldsymbol{\tau_8} = 8\ s$$

$$\alpha = 0.08$$

C-cell thermal mass: Results summary

1. Heat transfer between water and cell characterized by **two time constants**
2. τ_{60} uses the marine temperature (T_{marine}) and the internal cell temperature (T_{ctcell})
3. τ_8 uses the Morison's (1994) application of the Lueck and Picklo (1990) model

τ_{60}:

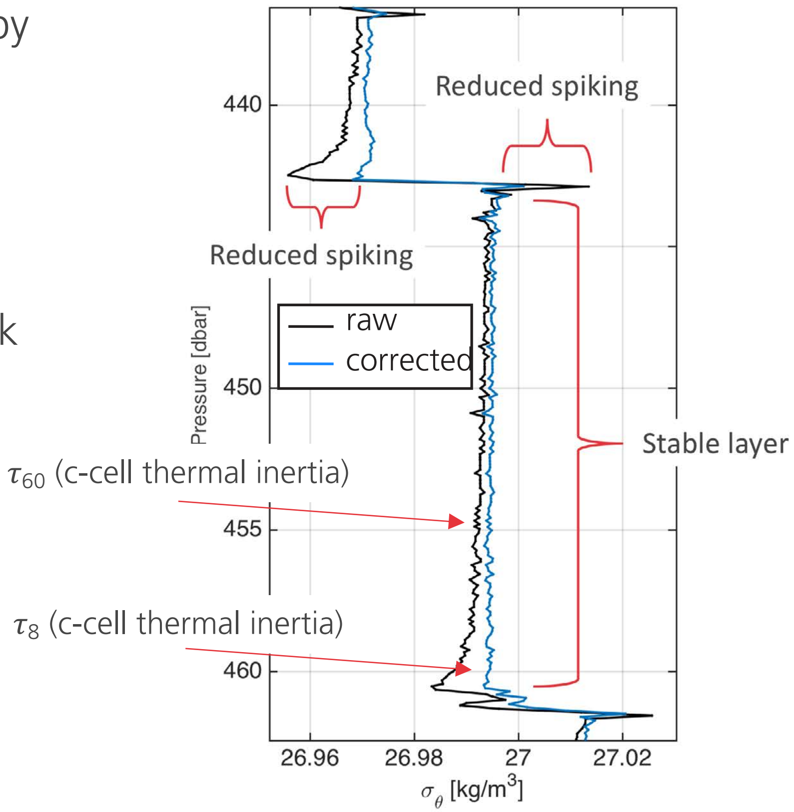
$$C_{\tau60}(n) = \frac{C_{meas}}{1 + 2.4\times10^{-4}[T_{ctcell}(n) - Tmarine(n)]}$$

τ_8:

$$T_T(n) = -bT_T(n-1) + a[T(n) - T(n-1)]$$

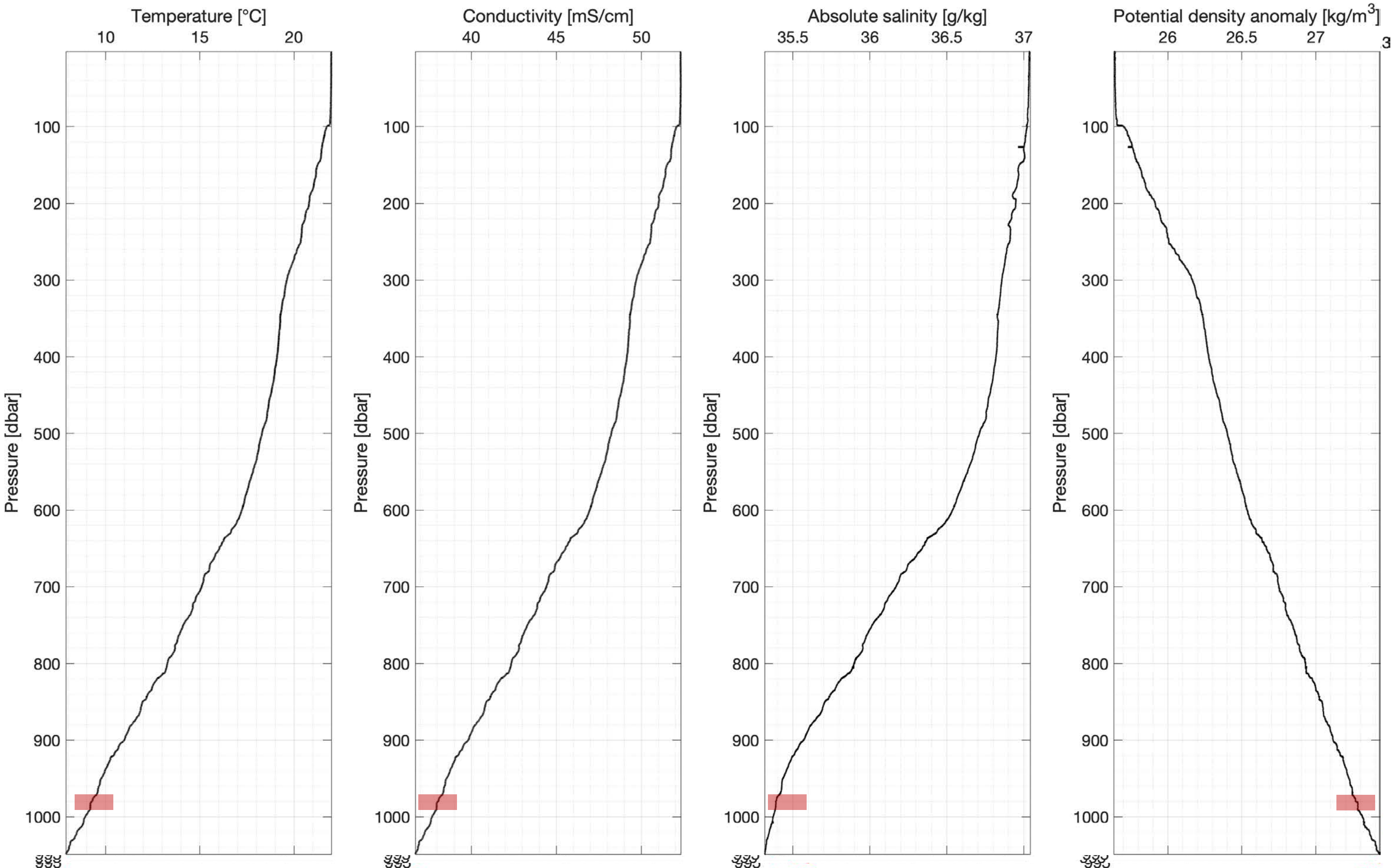
using α = 0.08 and τ = 8 s

1 Hz sampling rate; 10 cm/s profiling rate



Caribbean Sea, MRV/RBRargo ALAMO #9139

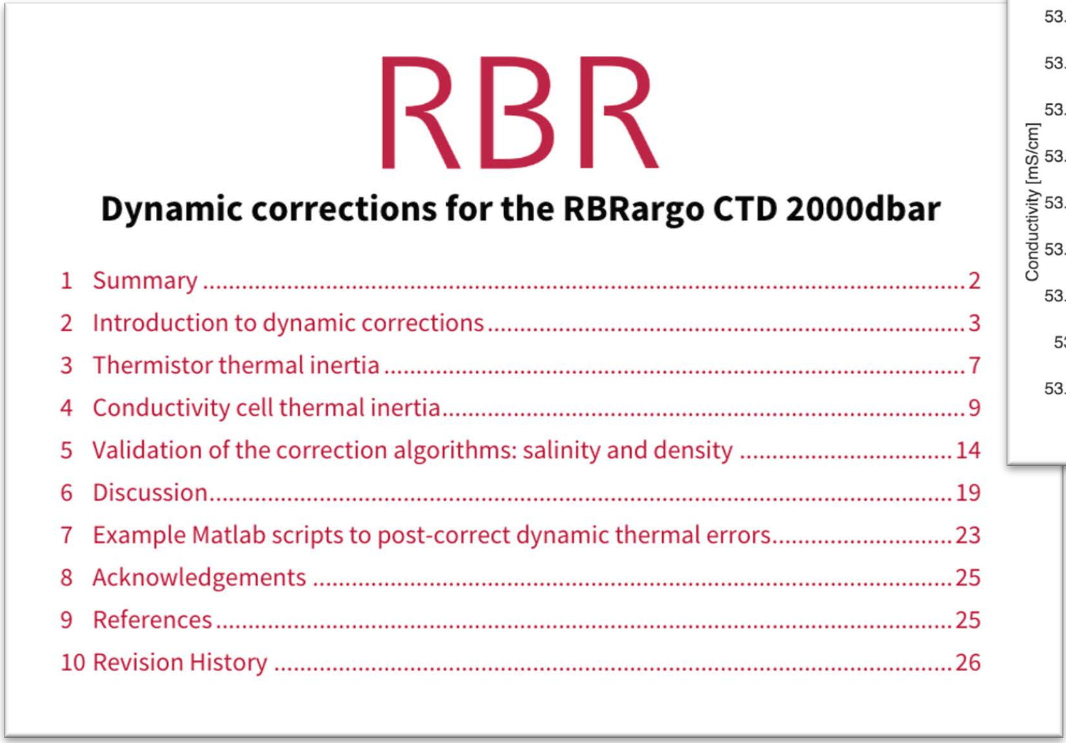
C-cell thermal mass: Validation from Webb float (f7395, 1Hz, 8 cm/s)



Public report

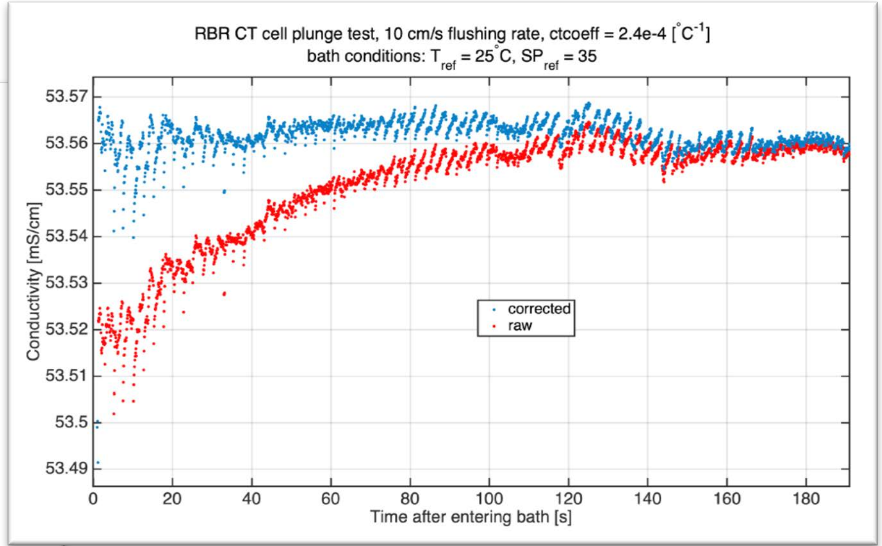
Report detailing and quantifying the algorithms and correction parameters:

https://oem.rbr-global.com/floats



RBR

Dynamic corrections for the RBRargo CTD 2000dbar



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How does profiling rate affect the correction parameters?

Correction parameters change with ascent rate (Lueck 1990):

$$\alpha \propto \frac{1}{V} \quad and \quad \tau \propto \frac{1}{\sqrt{V}}$$

- Argo ascent is variable: ~10 cm/s ± 20%
- Leading to an error in α $\mathcal{O}(20\%)$ and τ $\mathcal{O}(10\%)$
- Measurement uncertainties in α and τ are $\mathcal{O}(50 \text{ to } 100\%)$

> sitive to the value of its two coefficients. A misjudgment of as much as a factor of 2 in the value of the coefficients still results in profiles that are superior to uncorrected profiles.

(Lueck and Picklo 1990)

For Argo, a fixed thermal mass correction is appropriate

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