C-PROOF Processing Overview V.1

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Version: This document is an updated version of the reports found at `https://cproof.uvic.ca/gliderdata/deployments/reports/`. Some descriptions are adapted from the original report.

Preamble: This document describes the conductivity, temperature, and pressure processing procedures applied to delayed-mode data collected by the Canadian Pacific Ocean Observing Facility (C-PROOF).

C-PROOF gliders are equipped with either a pumped Sea-Bird GPCTD or an unpumped RBRlegato CTD, each requiring different correction methods. Delayed-mode corrections for RBRlegato CTDs are not yet implemented. This report demonstrates the GPCTD correction procedures using the Calvert Line mission dfo-eva035-20230620 as an example. Mission specific reports can be found on the C-PROOF website on the "deployments" page.

Future work will include corrections for RBRlegato CTDs and dissolved oxygen sensors.

Contents

1 Quality Flags

C-PROOF applies quality flags to delayed-mode data following Argo standards. Each data point is assigned a quality flag, summarized in Table 1. The interpretation of these flags within this workflow is described in Section 2.

Quality Flag	Description
QC 1	Good data. Measurements pass all quality tests.
QC 3	Potentially correctable bad data. Often caused by partial clogging of the conductivity cell.
QC 4	Bad data that fail quality-control tests. Typically caused by air bubbles or severe clogging.
QC 8	Estimated values.

Table 1: Quality flag definitions used for C-PROOF delayed-mode CTD data. Information adapted from `https://argo.ucsd.edu/data/how-to-use-argo-files/`.

2 GPCTD Delayed-Mode Corrections

This section describes the corrections applied to data collected using the Sea-Bird GPCTD. Two issues commonly affect derived salinity: (1) anomalous spikes, often due to bubbles or partial clogging, and (2) up/downcast salinity offsets caused by thermal lag. While the temperature sensor also experiences thermal inertia, this effect is minimized by the GPCTD design and does not require correction. The following steps describe how anomalous measurements are flagged and corrected to produce the final adjusted products (e.g., *salinity_adjusted* and *salinity_adjusted_QC*).

2.1 Identification and Flagging of Anomalous Conductivity Values

We first identify any conductivity values that are clearly unphysical, typically caused by air entering the conductivity cell. Data points more than five standard deviations from the mean (within profile–depth bins) are temporarily excluded so that the mean and standard deviation can be recomputed without their influence. This criterion is applied using 50-profile bins and 5-m depth bins, chosen to accommodate variability in time and depth while isolating unphysical outliers. Points still differing from the mean by more than 3 standard deviations are flagged as **QC 4** (Figure 1). Values that differ from the mean by less than the GPCTD accuracy (0.0003 S/m) are not flagged. Measurements passing this criterion receive **QC 1**.

We then inspect the conductivity field to identify remaining anomalies (Figure 2). In the example mission, profiles 480–522 exhibit anomalous striping in the conductivity signal that warrants further investigation. Tempera-

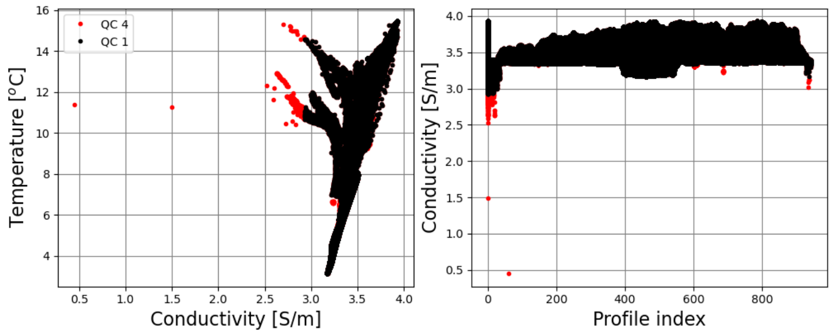

Figure 1: Examples of unphysical conductivity values flagged as QC 4 (red). Panels show temperature vs. conductivity (left), depth vs. conductivity (middle), and conductivity vs. profile index (right).

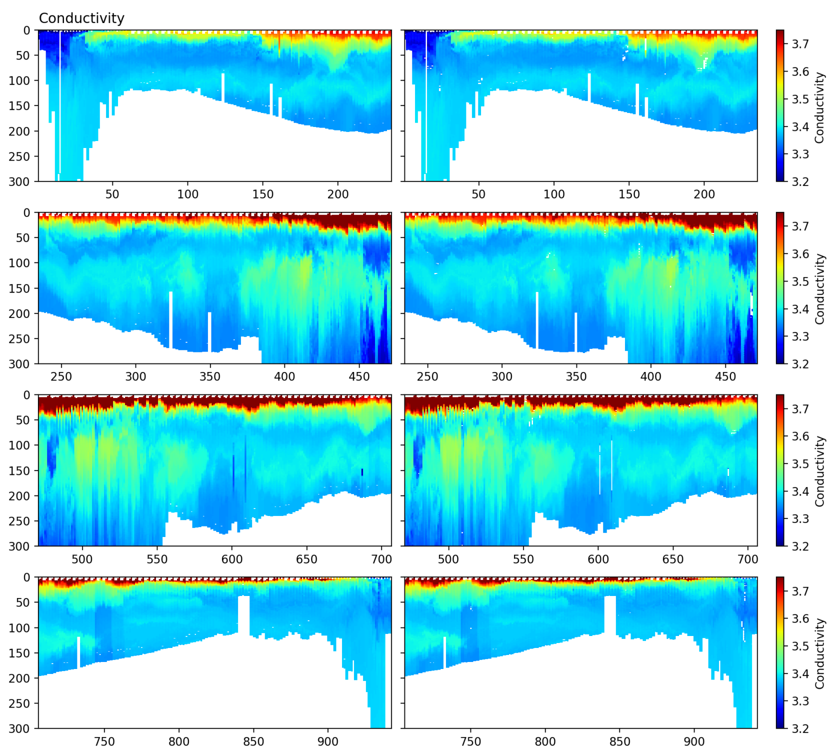

Figure 2: Delayed-mode conductivity (left) and delayed-mode conductivity with QC 4 values removed (right). Remaining anomalies motivate additional investigation.

ture–salinity (T–S) diagrams are used to distinguish thermal-lag artifacts from clogged-sensor behaviour. Thermal-lag errors produce smooth, nearly overlapping upcast and downcast curves, whereas clogged sensors produce irregular striping and clear divergence between casts. In this example, the upcast and downcast T–S curves for profiles 480–522 diverge, indicating partial clogging (Figure 3). Profiles affected by clogging are flagged as **QC 3**.

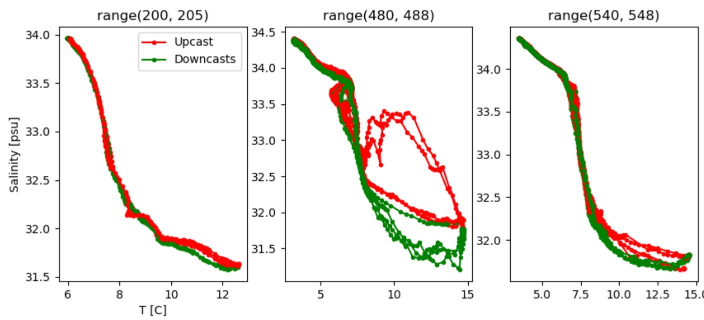

Figure 3: T–S diagrams for three profile ranges: 200–205 (left), 480–488 (middle), and 540–548 (right). Profiles 480–522 exhibit up/downcast divergence indicative of partial clogging.

2.2 Identification of Anomalous Temperature Values

Temperature anomalies are flagged as **QC 4** (Figure 4) when there are temperature spikes, defined as differences greater than 0.75 °C between a measurement and the mean of its neighbours. Temperature in conductivity-clogged regions is also flagged **QC 3**.

2.3 Flagging Salinity Values

Because salinity is derived from temperature and conductivity, the worst QC flag from these variables (QC 3 or QC 4) is applied to salinity.

2.4 Sensor Alignment Correction

A sensor-alignment correction is often applied to shift conductivity and temperature into temporal alignment relative to pressure, minimizing spikes across sharp gradients. We typically do not apply a correction because there is usually no measurable lag between conductivity and temperature; spikes occurred simultaneously (ex. Figure 5).

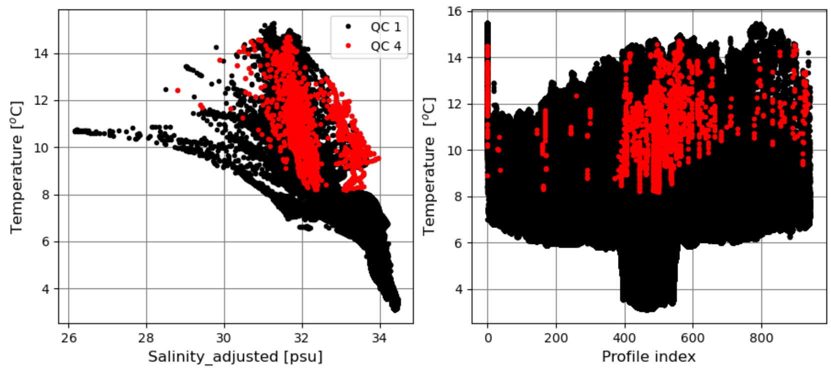

Figure 4: Examples of anomalous temperature behaviour flagged as QC 4 (red). Panels show temperature–salinity space (left) and temperature vs. profile index (right).

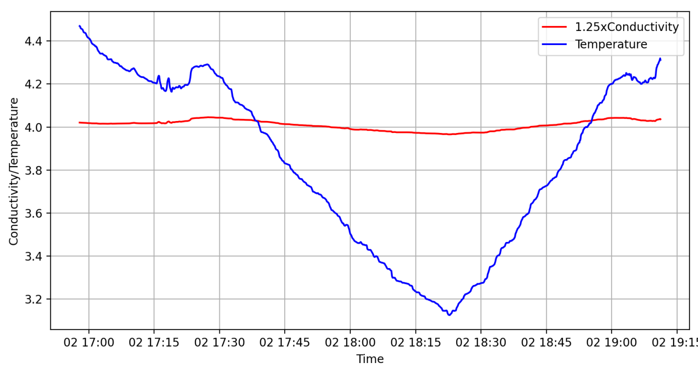

Figure 5: Temperature and conductivity (scaled) versus time. Co-located spikes suggest no measurable sensor misalignment.

2.5 Thermal Lag Correction

Thermal lag arises from the thermal mass of the conductivity cell altering the temperature of water passing through it. We use the method of Garau et al. [2011], building upon Morison et al. [1994]. Because gliders sample continuously at a nearly constant rate, thermal lag can be treated as constant throughout a mission.

A recursive filter estimates the temperature inside the conductivity cell:

$$T_T(n) = -b\,T_T(n-1) + a\,T(n) - a\,T(n-1), \tag{1}$$

where

$$a = \frac{4f_n\alpha\tau}{1+4f_n\tau}, \qquad b = 1 - \frac{2a}{\alpha},$$

and f_n is the mean sampling frequency. The parameter α represents the strength of thermal coupling between the water and conductivity cell, and τ is the associated time constant; both are strictly positive physical parameters.

Previous C-PROOF processing used fixed values $\alpha = 0.06$ and $\tau = 10$ s [Janzen and Creed, 2011]. However, optimal values can vary by sensor. We identify optimal α and τ by minimizing the area between paired up/downcast salinity profiles across 20 representative profile pairs (Figure 6). Once constants are determined for a given sensor using a sample mission, they are applied to subsequent missions using the same instrument.

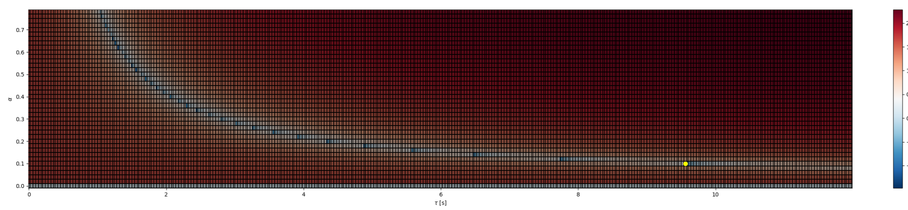

Figure 6: Example of brute-force search for optimal thermal-lag parameters of Calvert mission dfo-eva035-20230620. Colours show $\log_{10}$ error; the darkest region indicates parameter combinations minimizing up/downcast mismatch. α and τ were determined to be 0.1 and 9.56 s.

The thermal-lag–corrected temperature is inserted into the salinity calculation, replacing delayed-mode salinity values for **QC 1** measurements. QC 8 regions are not thermal-lag corrected because the smoothing reduces the effective resolution.

Thermal lag correction substantially reduces up/downcast asymmetry (Figures 7–9). This is visible in the TS plots, as data points from the up and downcast sit more closely on top of each other (Figure 10).

3 Summary of Quality-Control Procedure

The following steps summarize the delayed-mode quality control workflow applied to Sea-Bird GPCTD data in C-PROOF. This procedure assigns quality flags to conductivity, temperature, and salinity and generates adjusted products for downstream use.

1. Conductivity Quality Control

1. **Outlier detection (QC 4):** Conductivity is binned by 50-profile segments and 5-m depth bins. Values more than three standard deviations from the bin mean (after an initial $5\,\sigma$ pre-screening) are flagged as bad (QC 4) unless the deviation is within the sensor accuracy (0.0003 S/m).

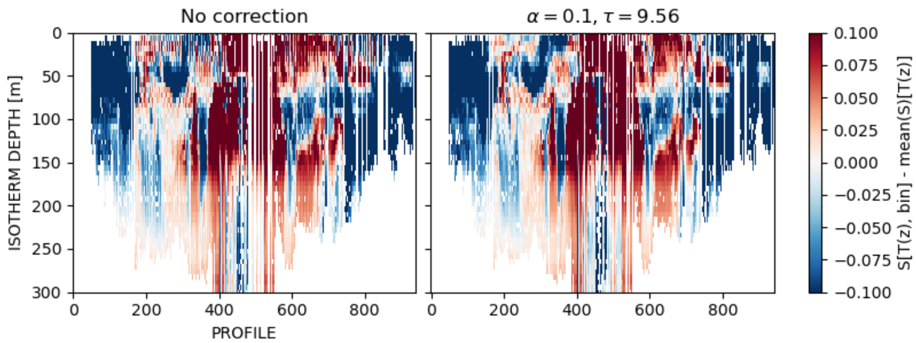

Figure 7: Salinity anomaly along an isopycnal without (left) and with (right) thermal lag correction. Reduced striping indicates improved up/down consistency.

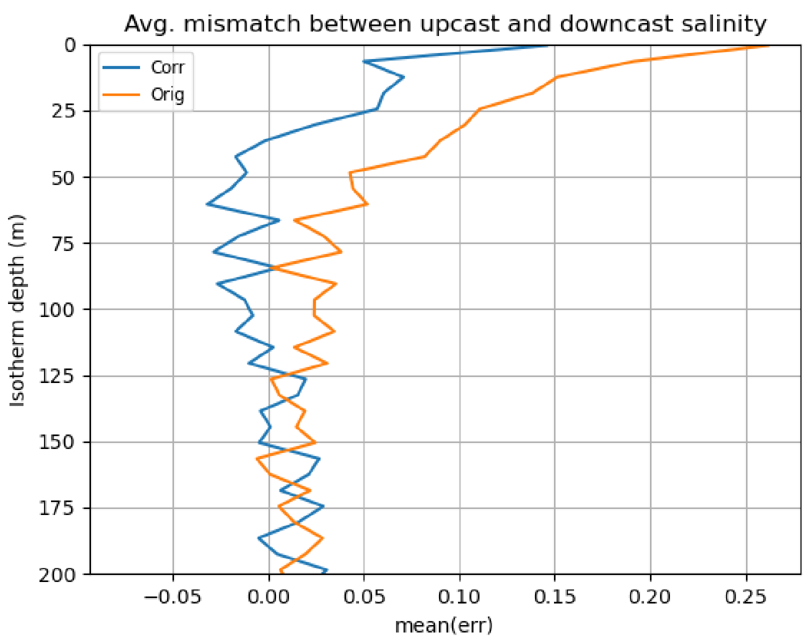

Figure 8: Depth-dependent mean error (the average mismatch between upcast and downcast salinity across all temperature bins) without (orange) and with (blue) thermal lag correction.

2. **Clogged-sensor identification (QC 3):** Remaining anomalies are evaluated using conductivity sections and T–S diagrams. Partial clogging is

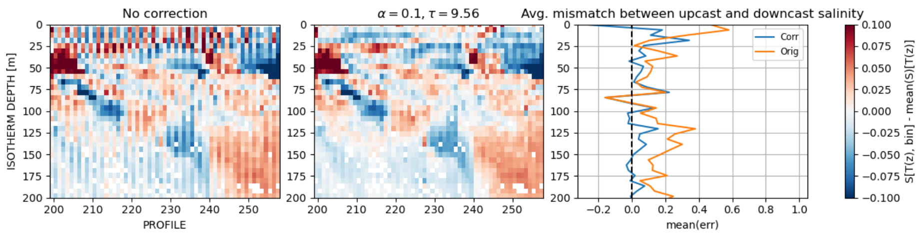

Figure 9: Subset analysis showing improved salinity anomaly symmetry (left vs. right) and reduced up/downcast salinity mismatch (right).

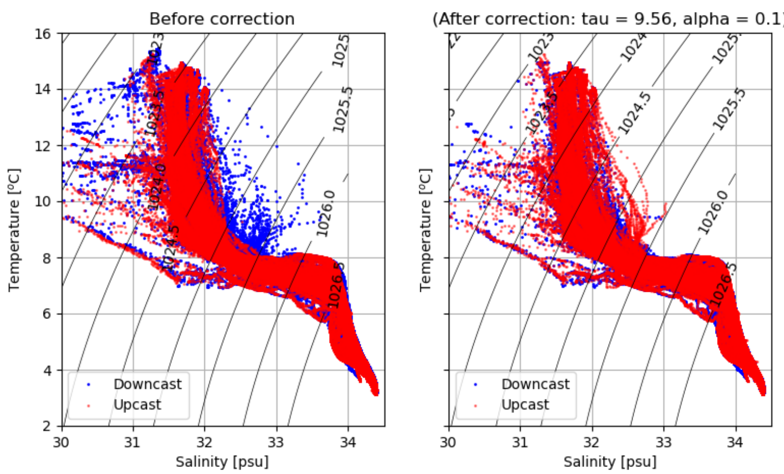

Figure 10: Temperature-salinity plots without (left) and with a thermal-lag correction (right). QC 4 values are removed from both plots.

diagnosed when: (a) conductivity structure shows irregular striping, and (b) upcast and downcast T–S curves diverge. These data are flagged as QC 3.

2. Temperature Quality Control

1. **Spike detection (QC 4):** Temperature spikes exceeding 0.75 °C relative to adjacent samples are flagged QC 4.

2. **Clogged-sensor temperature (QC 3):** Temperature in conductivity-clogged regions is also flagged QC 3

3. Salinity Quality Control

1. **Flag propagation:** Salinity inherits the *worst* QC flag applied to either temperature or conductivity (QC 4 > QC 3 > QC 1).

4. Thermal Lag Correction

1. **Estimation of thermal-lag parameters:** Optimal α and τ are determined using a brute-force search that minimizes up/downcast salinity mismatch across a subset of profiles.

2. **Application of correction:** Thermal-lag–corrected temperature is used to recompute salinity. The correction is applied only to QC 1 data.

5. Final QC Assignment

- QC 1: Physically consistent, unflagged data.
- QC 3: Potentially correctable data (e.g., clogging).
- QC 4: Bad or unphysical data (spikes, bubbles).
- QC 8: Estimated data

This procedure ensures consistent and reproducible treatment of GPCTD data, producing final delayed-mode fields suitable for scientific and operational use.

References

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