Observations from the CALYPSO 2022 Field Campaign: Data Report

September 20, 2024

Abstract

This report describes the data set from the CALYPSO 2022 Campaign and the processing and quality-control steps that were taken in producing the data set. The CALYPSO Campaign was conducted from both the R/V *Pourquoi Pas?* from February 17-March 12, 2022 and the R/V *Pelagia* from February 20-March 16. For questions please contact Leo Middleton at leo.middleton@whoi.edu.

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Contents

1 Background

The Coherent Lagrangian Pathways from the Surface Ocean to Interior (CALYPSO) project is focused on the role of submesoscale ocean dynamics in subduction of organic and inorganic ocean tracers from the surface ocean to the interior [?]. The CALYPSO 2022 study region is the Balearic Sea, between Majorca and the coast of mainland Spain. The CALYPSO program has had three major field campaigns: a Pilot Campaign (conducted during May-June 2018 in the Alboran Sea) in 2018 and two Intensive Operations Periods. The first was in the Alboran Sea through March-April 2019, and the second was in the Balearic Sea, and is the topic of this data report.

In this report we will outline the data processing, quality control and formatting for all the relevant data products to come out of the CALYPSO 2022 campaign. Specifically this report covers the EcoCTD operations aboard the *Pourquoi Pas?*, the UCTD operations aboard the *Pelagia*, the data from two WireWalkers (CITE) deployed from the *Pourquoi Pas?*, the CTD Rosette data from the *Pourquoi Pas?*, Drifter data, float data and glider data. For Model and Satellite data, please see the relevant sections of the CALYPSO Cruise Report (CITE).

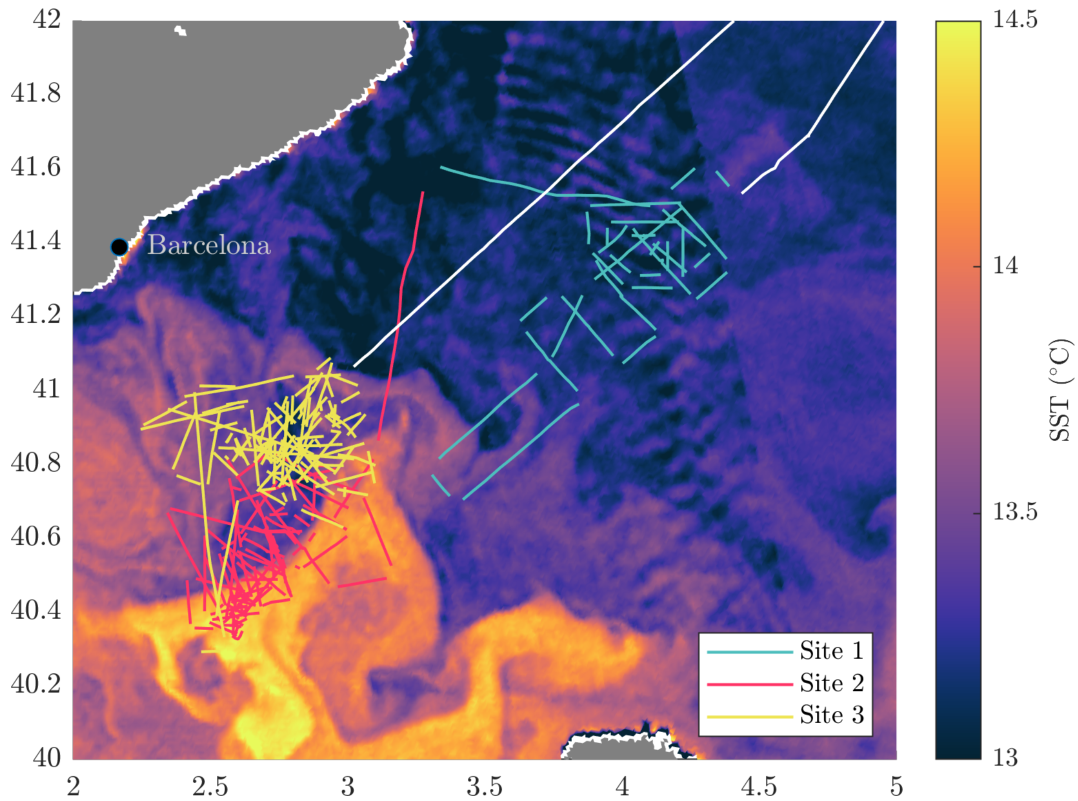

Figure 1: Map showing the study region for the CALYPSO 2022 Campaign. Sea Surface Temperature map from Sentinel 3 on the 22nd February 2022. R/V *Pourquoi Pas?* ship track split into 254 transects and three study sites.

Pourquoi Pas? Mobilize: Feb 16-17, 2022 Toulon, France
Pourquoi Pas? Depart: Feb 17, 2022 Toulon, France
Pelagia Depart: Feb 21, 2022 Palma, Majorca
Pourquoi Pas? Arrive: Mar 11, 2022 Toulon, France

Pourquoi Pas? Demobilize: Mar 12, 2022 Toulon, France
Pelagia Arrive: Mar 13(?), 2022 Palma, Majorca

2 Methodology

2.1 Calibration Chain

Due to the large quantity of different observational platforms used during the CALYPSO 2022 campaign, we have formalised the methodology for calibrating across the platforms. This is to ensure that the measurements are as comparable as possible across different sensors and instruments.

The chain of calibrations can be found in Figure 2, where different line colours correspond to different measured properties. The arrows imply a direction of calibration, so to understand the chain of calibration you must start at the beginning for a given property. For example, the ultimate reference point for the salinity is given by the CTD casts taken aboard the Pourquoi Pas? which were pre- and post-calibrated to ensure consistency (referred to using the self-referential arrow).

2.2 In-situ calibration casts

Some of the instruments had specific calibration casts made to ensure the best match between sensors (e.g. the EcoCTD was strapped to the CTD Rosette, and the MVP was alternated with the EcoCTD for calibration). However, other sensors had no specific calibrations during the cruise, so we make in-situ comparisons between casts that were taken in proximity to other sensors for calibration. To standardise across the dataset we have used the same methodology to identify these comparable casts and then another standard methodology for using those comparable casts for calibration of temperature and salinity.

To identify comparable casts, we first use a cut off time and distance for comparison, i.e. we only consider casts from the two instruments that are within 10 km and 12 hours of each other. We then compare each pair of casts from the two instruments, that fall within that space-time threshold. We interpolate onto a common pressure grid and take the root-mean-squared (RMS) difference between both the measured conductivity and temperature. Plotting these quantities against each other we can take a line of best fit and use that scaling between T_{RMS} and C_{RMS} to create a single metric for goodness-of-fit (shown using the color scale). For example, in Figure 3 we have plotted the RMS difference between conductivity and temperature across pairs of comparable casts for the EcoCTD and the CTD Rosette. The line of best fit has a slope of 0.78, so we use $C_{RMS}+0.78T_{RMS}$ as our metric.

To calibrate conductivity and temperature once there are comparable casts, we compare the casts in Temperature/Salinity space (although note that the calibration is made using a multiplicative

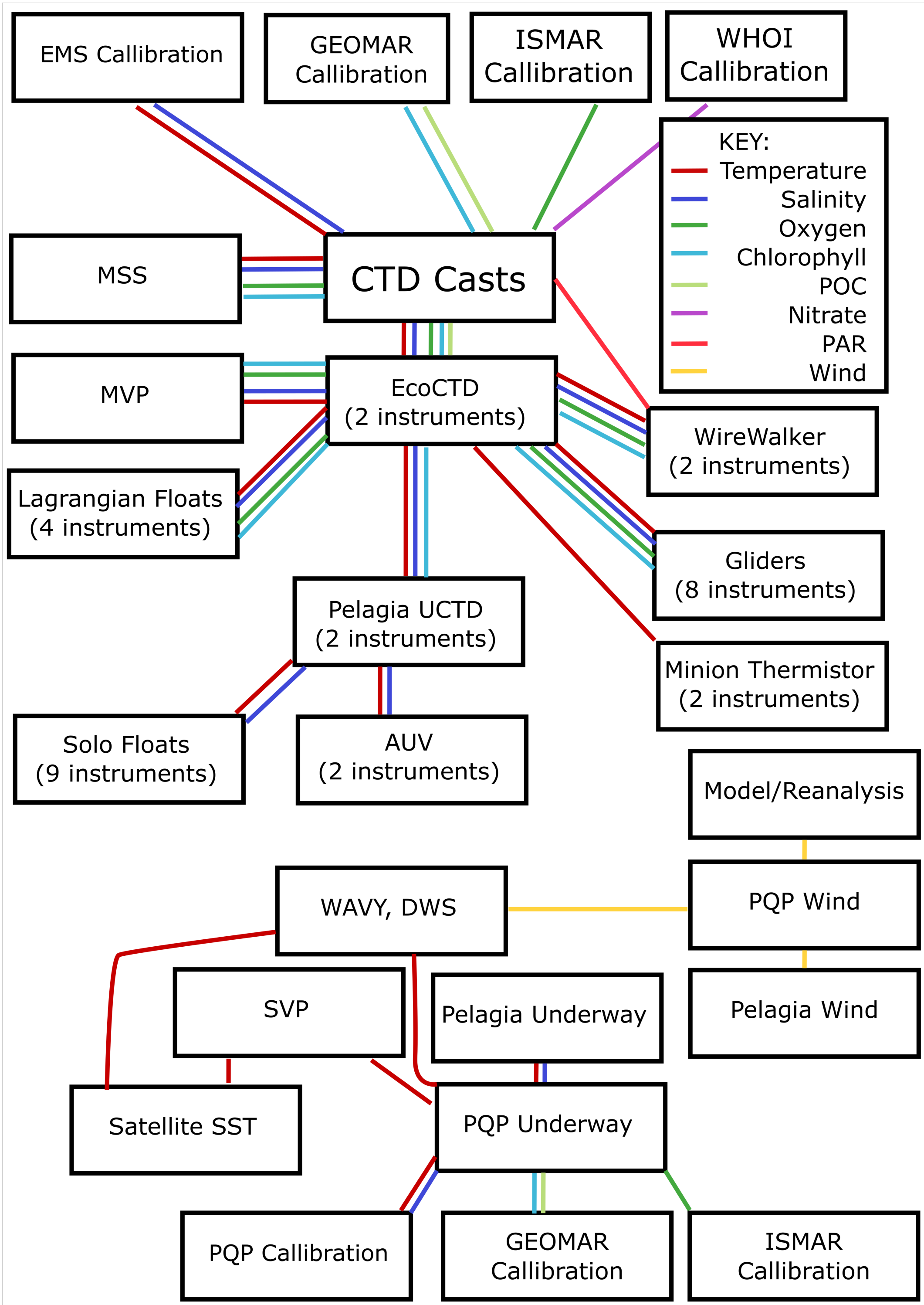

Figure 2: Schematic showing the chain of calibration for the different instruments during the CALYPSO 2022 campaign. Colours denote different properties that require calibration and the connections denote a calibration between the connected instruments.

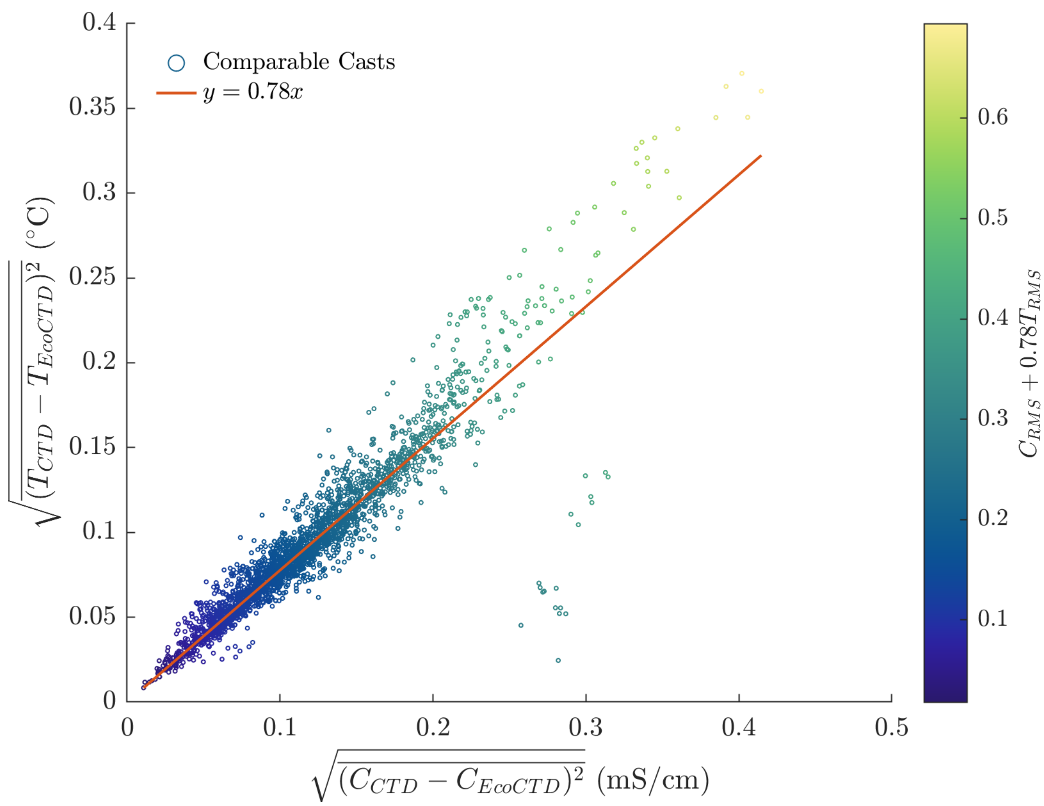

Figure 3: Root-mean-square difference between all comparable pairs of casts between the EcoCTD (specifically Rutherto S/M 66098) and the mean of the two CTD sensors on the Rosette. Line of best fit is given in red.

factor in conductivity space). This gives two 2D distributions for each sensor that we wish to align. This process is often done by-eye, which is used here as a check, however to standardise across the data we use a metric for comparing two distributions: the Kolmogorov-Smirnov (KS) index *Fasano and Franceschini* [1987]. We attempt to minimise this statistic by searching through possible corrections in temperature/conductivity space to find the best calibration for the input data. We then add more calibration data, including the cast with the next best goodness-of-fit metric as described above, and repeat the process. We find the optimum number of casts to include to minimise the KS index to achieve the closest match between the two distributions at a certain calibration.

3 CTD Rosette

The CTD Rosette (pictured in Figure 4) was used throughout the cruise to take water samples, as well as having a variety of sensors attached. A total of 61 CTD stations were recorded during the cruise. The depths of the profiles ranged from 244 to 611 meters, with the majority of casts falling between 250 and 300 meters in depth. Sensors on the CTD rosette included two Seabird SBE3 temperature sensors (S/Ns 6394 and 5136), two Seabird SBE4 conductivity sensors (S/Ns 3646 and 4855), a Seabird SBE43 Oxygen optode (S/N 3734), a FLNTU turbidity sensor (S/N FLNTURTD-5187), a WetLabs C-Star transmissometer (S/N CST-383PR), a WET-Star Chlorophyll-a fluorometer (WS3S-699P), a SUNA V2 Nitrate sensor (S/N 1162), a Seabird SBE18/27 pH sensor (S/N 0504), a Chelsea PAR light sensor (S/N 0491) and an Underway Visual Profiler.

3.1 CTD sensors

The two conductivity and temperature probes on the CTD Rosette performed well throughout the cruise with few major errors. On the third cast there was a significant error in the sensors in the upper 60 dbar during the downcast. This error gave a large difference between the two sensors, and the first was reading very fresh values (down to around 20 psu), so the error may be due to a problem with the pumping system for circulating ocean water, unable to flush out the fresh water used for cleaning. The data above 5 dbar also shows a large deviation between the two sensors on the upcast and downcast. Discarding the above mentioned data, the remaining data is plotted in Figure 5, where we have shown the difference between the two sensors for every cast in temperature, conductivity and salinity. The sensors show good agreement across the 61 casts, with a mean difference in temperature across all casts of -4.8×10^{-5} °C on the downcasts and -2.7×10^{-4} °C on the upcasts. The mean difference in salinity across all the casts is 5.4×10^{-4} ppt on upcasts and 6.4×10^{-4} on downcasts. These averages show that the temperature sensor S/N 6394 is reading slightly warmer than the sensor S/N 5136, and the conductivity sensor 4855 is reading slightly less conductive than the sensor 3646.

The mean difference between the two sensors, with a shaded standard deviation, is shown for all casts in Figure 6. For both the temperature and conductivity sensors, the mean difference/scaling

Figure 4: CTD Rosette

factor between the two sensors stays within a standard deviation of no difference between the sensors, for both the upcast and the downcast. However, for the conductivity sensor, there is a more obvious bias, that is on the limits of being within a factor of the variability for the downcasts. This mean bias appears in the later casts, suggesting a slight drift in the conductivity sensor. This drift is particularly noticeable if you consider the deep casts shown in Figure 5, where at depth the later casts clearly give a larger conductivity difference than the early casts. This difference results in a maximum salinity offset of around 0.0009 between the two sensors, drifting from an initial offset of around 0.0001. The deep casts do not have sufficiently stable T/S to determine which of the two sensors is drifting. There are also no measurable drift in the stability of the water column when using density derived from the two sensors separately i.e. the number of spurious overturns that occur due to signals from one sensor and not the other does not have a significant trend.

The CTD sensors are post-calibrated as well as pre-calibrated. The post calibration suggests a gain of 0.999995 for the first conductivity sensor (S/N 3646) and a gain of 1.0000153 for the second conductivity sensor (S/N 4855). These conductivity offsets are consistent with the observed drift (see Figure 6), so we apply linear drifts of

$$C_1^{corrected} = \left(1 + 0.0000153 \frac{t - t_{start}}{t_{end} - t_{start}}\right) C_1, \quad (1)$$

$$C_2^{corrected} = \left(1 - 0.000005 \frac{t - t_{start}}{t_{end} - t_{start}}\right) C_2. \quad (2)$$

The temperature sensors both had negative drifts, of -0.07×10^{-3} °C for the first temperature sensor (S/N 5136) and -0.28×10^{-3} °C in the post-calibration. These drifts are too small to be

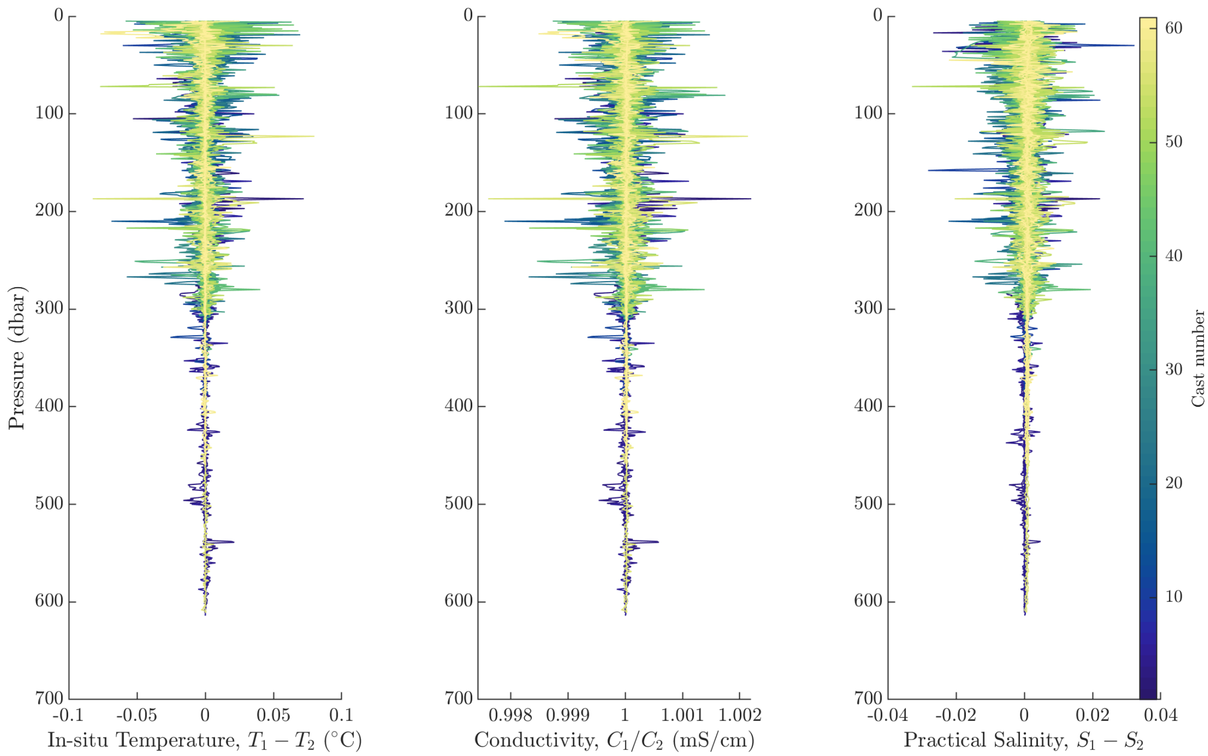

Figure 5: Difference plots between the two sensors mounted on the CTD Rosette for temperature (T_1 refers to S/N 5136 and T_2 refers to S/N 6394) and conductivity (C_1 refers to S/N 3646 and C_2 refers to S/N 4855). Salinity is also shown for reference.

visible above the noise in the difference between the two sensors (see Figure 6), and when applied they slightly increase the difference between the two sensors, so we do not apply a correction to the temperature sensors.

3.2 Chlorophyll

Chlorophyll was calibrated using bottle samples taken from the CTD casts at various points. FILL Description of sampling and measurement.

Plotting the CTD fluorescence data against the bottle samples in Figure 7, you can see a good fit between the two. One sample that does not fit the trend has very high PAR and so may be affected by non-photochemical quenching, and the other anomalous point is part of a triplicate, so is not weighted heavily in the fit.

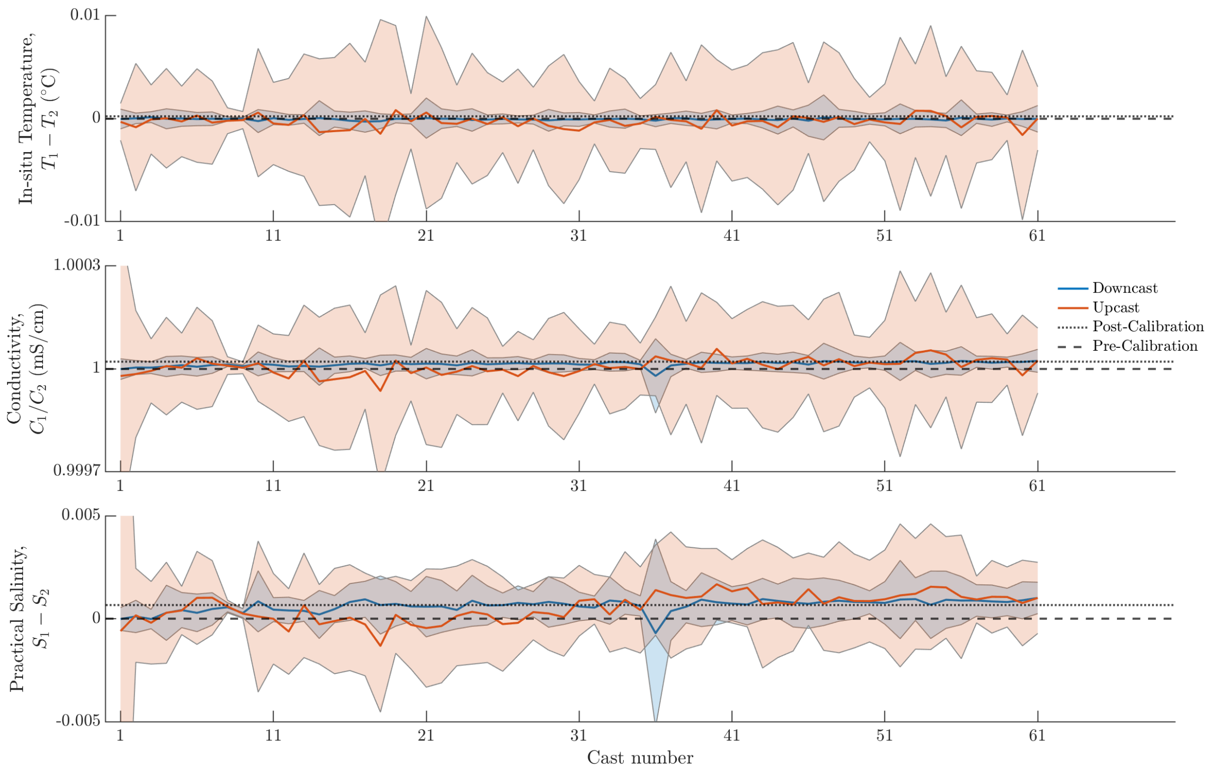

Figure 6: Difference plots between the two sensors mounted on the CTD Rosette for temperature (T_1 refers to S/N 5136 and T_2 refers to S/N 6394) and conductivity (C_1 refers to S/N 3646 and C_2 refers to S/N 4855) plotted against cast number. The shading designates a standard deviation in the sensor difference. The post-calibration offset is marked with a dotted line. Salinity is also shown for reference.

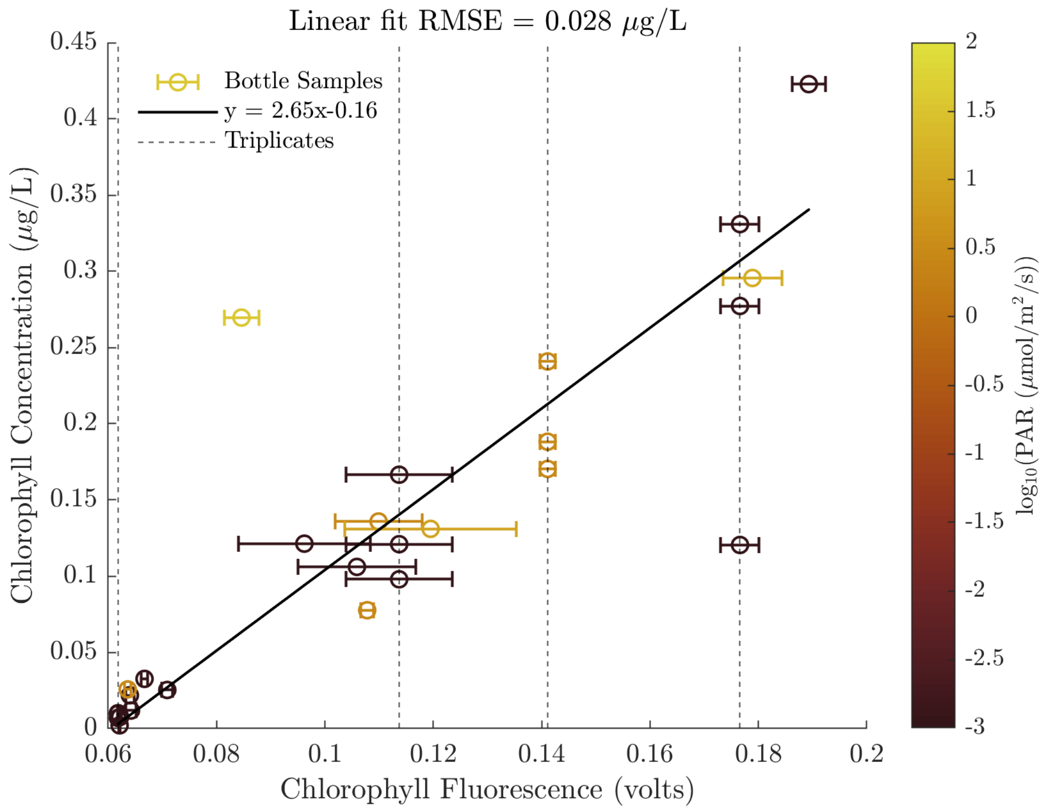

Figure 7:

3.3 Backscatter

3.4 Oxygen

4 EcoCTD

The EcoCTD [*Dever et al.*, 2020] is a profiling instrument that can be deployed from a moving vessel in a tow-yo mode or in a single-cast mode to measure temperature, salinity, dissolved oxygen, and bio-optical properties. The EcoCTD was a key measurement in the CALYPSO 2022 Campaign because of its ability to measure physical and biological properties at high horizontal resolution. This report describes the EcoCTD data set from the Campaign and the processing and quality-control steps that were taken in producing the data set.

The CALYPSO 2022 Campaign involved two ships: the R/V *Pourquoi Pas?* (PQP) and R/V *Pelagia*. The Campaign also included 8 gliders, AUV operations, hundreds of drifters and multiple floats. The study region is depicted in Figure 1, split into 3 study sites and 254 transects. The *Pourquoi Pas?* set sail from Toulon, France on February 17, 2022 and returned to Newport on 11 March.

4.1 File Formats and Dataset Management

Data processing was organized in three levels:

- **Level-0:** Raw data as downloaded directly from the instruments. Raw files from the EcoCTD are SQLite databases with the *.rsk file extension. Because the instruments were used in tow-yo mode, one file may include many profiles. The cruise was split into 40 transects based on the ship track for ease of analysis (Table **??** and Figure **??**). For convenience, Level-0 files in a *.csv format are also generated. These files contains an exact replica of the raw data, minus some of the metadata included in the *.rsk files.
- **Level-1:** Data are geo-referenced, split into down- and up-casts and separated into individual NetCDF files (see section 5.3). Calibration coefficients are applied to measured bio-optical variables (backscatter and chlorophyll) and derived quantities (e.g. salinity, sea pressure, depth ...) are included. Only downcasts are processed for EcoCTD profiles. The profile numbers associated with each cruise transect are listed in Table **??**.
- **Level-2:** Quality analysis is completed using ancillary datasets, and corrections are applied. These corrections include sensor alignment and cross-calibration with the shipboard CTD. QC flags are also included in the NetCDF files
- **Level-3:** Level-2 data are interpolated vertically onto a common depth grid and merged into a single netCDF file. Dimensions are depth and profile number.

INCLUDE TRANSECT TABLE?

A total of 2795 profiles were collected to depth ranging from 160 to 250 m. The profiles can be separated into 254 transects that are selected based on the RV PQP's heading. Three sampling phases or 'sites' were also defined for convenience. Two distinct EcoCTD probes were used during the CALYPSO 2022 cruise with serial numbers 66098 (known as 'Rutherto') and 203743 (known as 'Sedna'). Rutherto was primarily used (2595 casts), with only 200 casts made with Sedna.

4.2 EcoCTD probe

The EcoCTD is composed of three sensors, all sampling at 8 Hz (Figure 15):

- One RBR Concerto[3] (SN066098) Conductivity-Temperature-Depth (CTD), which also acts as a logger. The CTD head is facing downward during free-fall and is protected by a plastic guard.
- One JFE-Advantech Rinko III dissolved oxygen sensor (SN<**FIX ME: ####**>). The sensor is facing downward at an angle of 25^o from the vertical, and is located 48 cm from the CTD sensor.

- One Wet Labs BB2F ECO Puck (SN BB2FLRBR-6136). This optical sensor is oriented at 90^o from the longitudinal axis of the EcoCTD and is located 72 cm from the CTD sensor.

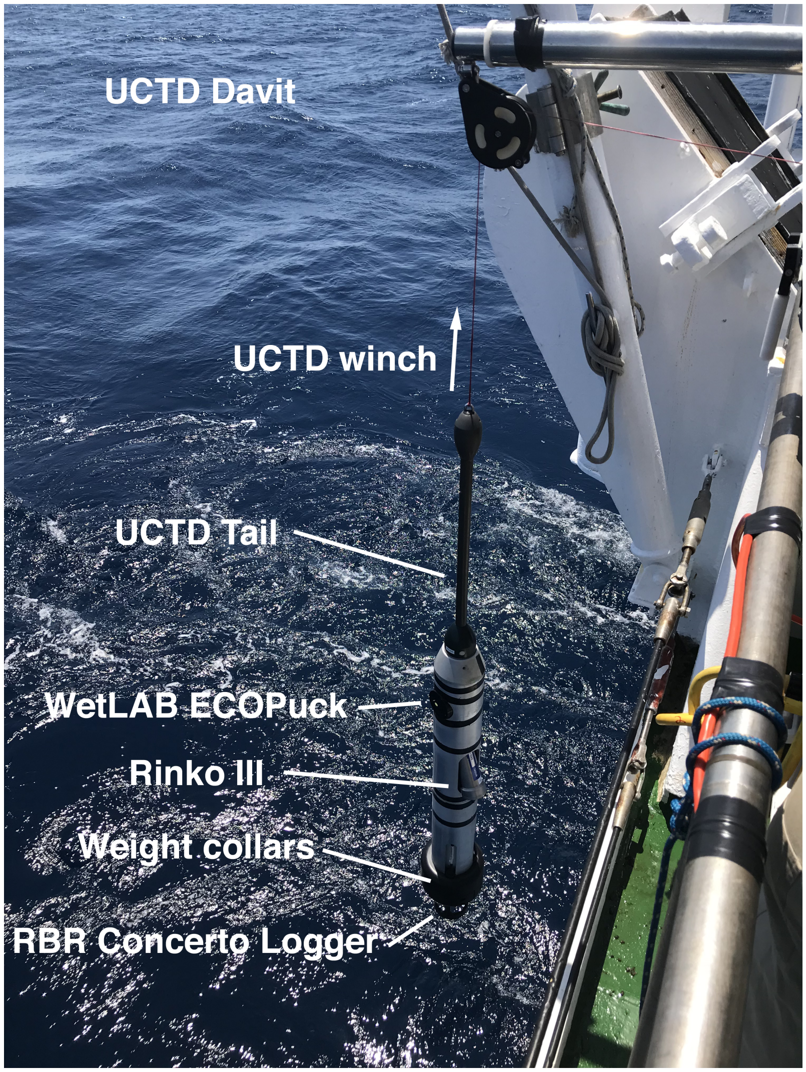

Figure 8: EcoCTD probe attached to a UCTD winch at the back of the NRV Alliance. The EcoCTD includes a CTD sensor and logger (Concerto^3), an oxygen sensor (Rinko III), and a WetLab ECO Puck. The EcoCTD uses the same spectra line and tail attachment as a UCTD probe.

The three sensors are integrated into an instrument package using a housing designed in-house at the Woods Hole Oceanographic Institution. The housing is wet (i.e., floods), measures 0.9 m in length, has an outer diameter of 10 cm, and weighs 12.5 kg in air. It has a UCTD mechanical coupling at the top to be able to easily adapt to the UCTD system (i.e., winch). The pressure rating of the EcoCTD is determined by the pressure rating of the ECO Puck (500 m), which is lower than for the Rinko and Concerto^3 (7,000 m and 750 m, respectively). The fall rate of the EcoCTD varies mostly between 2 and 4 m/s (Figure 9).

The EcoCTD's main advantage is that it collects biophysical variables (i.e. oxygen, fluorescence, and backscatter) in conjunction with CTD data. Operationally, the EcoCTD was developed to track water masses and identify subduction events at submesoscales using the biophysical signature of the water (see Section 5.3).

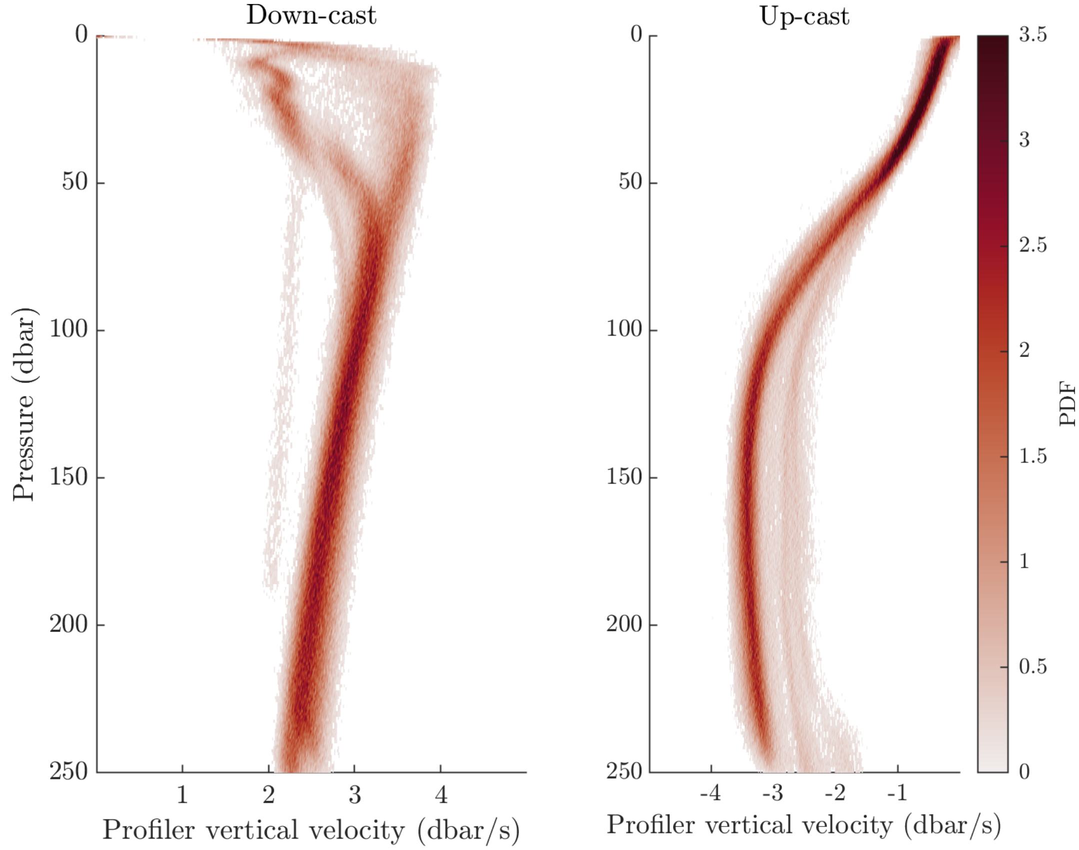

Figure 9: 2-D histogram of the profiling rate in dbar/s as a function of pressure.

4.3 EcoCTD Data Processing Steps

4.3.1 Level-1 processing steps

GPS data Each EcoCTD profile is geo-referenced by using the GPS positioning of the ship at the start of each profile. The EcoCTD is assumed to profile vertically, so each profile is associated with a single GPS position. A linear interpolation in time is used to align EcoCTD profiles and GPS positioning from the ship (sampled at 1Hz)

Timestamp adjustment FILL TIMESTAMP INITIAL PROBLEM

Analog-to-digital zero hold correction Every minute, the analog-to-digital converter located in the RBR Concerto[3] recalibrates. As a result, a sample is missed and filled by the last measured value, a technique often referred to as a zero-order hold. These values are easily identified in the time series by finding repeated values, and are replaced by NaNs in the Level-1 data. In the Level-3 data these values are in-painted using linear interpolation.

Calibration The ECO Puck sensor data were calibrated against the CTD casts (FILL SENSORS), where the FILL LAB CALIBRATIONS. These calibrations convert the optical data from counts to more standard units. The calibrations include:

Chlorophyll fluorescence:

$$Chl\ [\mu g/L] = SF * (Output - Dark\ counts) \tag{3}$$

where for Rutherto ... FILL and for Sedna ... FILL

Backscatter at 470 nm:

$$\beta(\theta_c)\ [m^{-1}sr^{-1}] = SF * (Output - Dark\ Counts) \tag{4}$$

where for Rutherto ... FILL and for Sedna ... FILL

Backscatter at 700 nm:

$$\beta(\theta_c)\ [m^{-1}sr^{-1}] = SF * (Output - Dark\ Counts) \tag{5}$$

where for Rutherto ... FILL and for Sedna ... FILL

Derived variables *Sea Pressure* – Sea pressure is computed by removing the atmospheric pressure from the absolute pressure measured by the CTD. This is done by taking the maximum of the PDF of the pressure readings between 9 and 11 dbar, which encompasses potential values of atmospheric pressure.

Absolute Salinity – Absolute Salinity SA is derived using the GSW toolbox

Conservative Temperature – Conservative Temperature CT is derived using the GSW toolbox

4.3.2 Level-2 processing steps

Level-2 data includes all post-processing steps details in the previous section for Level-1 data. However, the additional processing applied to the data is described below.

Sensor alignment *CTD sensor* – Misalignment of temperature and conductivity measurements results in spikes in salinity because conductivity is temperature dependent. We use an optimal C-T lag of -0.074 s which was determined as an average across the CALYPSO cruise data. We calculate the optimal lag by iteratively searching for the lag that minimises the RMS values for both the

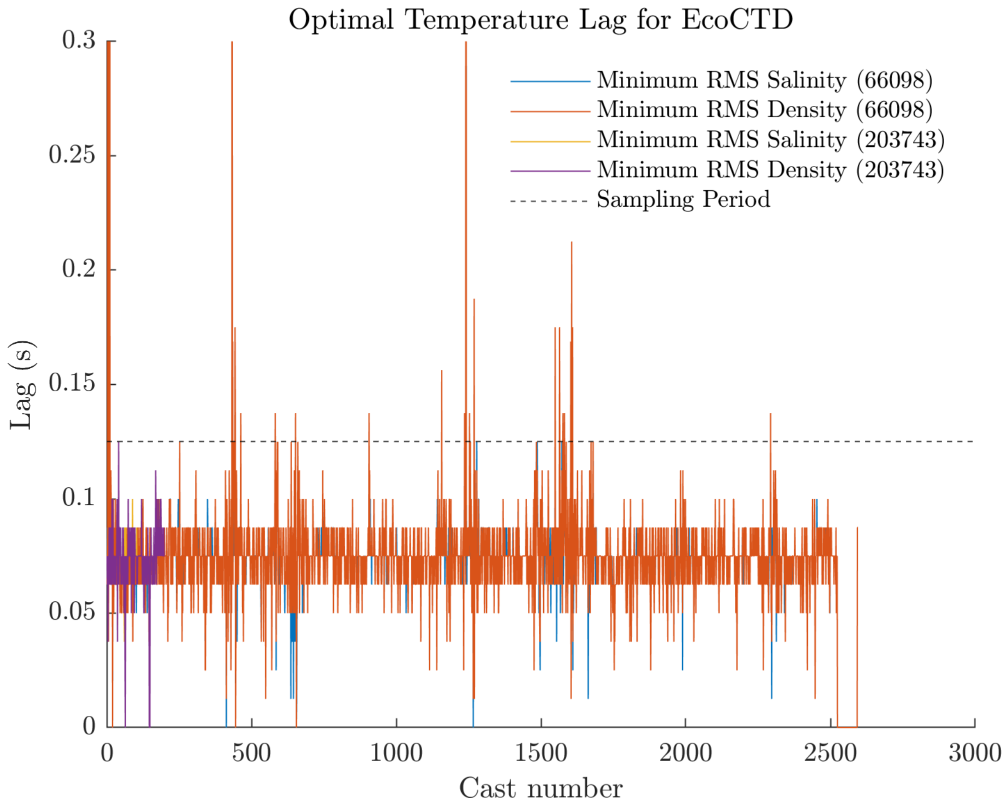

Figure 10: Optimal lag for minimising the RMS value of the salinity and density for both Rutherto (S/N 66098) and Sedna (S/N 203743). The sampling period of 0.125 seconds is also noted.

salinity and density. The optimal lag is plotted in Figure 10 for salinity and density optimisation for the two separate sensors, that agree well. We apply the lag during data processing by interpolating the temperature data onto a shifted time axis.

Oxygen sensor – Misalignment between the oxygen sensor and the CTD measurements occurs both because of the physical separation of the oxygen sensor from the CTD and because the oxygen sensor has a slower response time than the CTD. It is important to properly align observations collected for the two instruments because dissolved oxygen concentration is temperature and salinity dependent. Following recommendations from *Dever et al.* [2019], we apply both a constant lag of 0.75 s to account for the difference in response time of the sensors, as well as a fall-rate dependent lag to account for the physical separation of the oxygen and CTD sensors, resulting in an "advective" lag. Considering that both temperature and salinity probes are located at the same distance from the oxygen sensor, the advective lag is computed using:

$$\Delta S_{adv} = \frac{\Delta h \times F_s}{w_s} \tag{6}$$

where ΔS_{adv} is the lag in number of scans, Δh is the distance between the two sensors (48 cm), F_s is the sampling frequency (8 Hz), and w_s is the fall-rate computed from the ratio of first-order differences of pressure to time ($\Delta P/\Delta t$). Advective lags are thus positive on the downcast ($w_s > 0$) and negative on the upcast ($w_s < 0$).

ECO Puck sensor – As with the oxygen sensor, an advective lag is applied to the measurements collected by the ECO Puck using Equation 6 with $\Delta h = 0.72$ m and $F_s = 8$ Hz. As with the oxygen advective lag, for fall rates with an absolute value slower than 1, we reset the lag to the value it would have for a fall rate of ± 1, and flag these data points as questionable.

Cross-calibration with shipboard CTD During the cruise, four cross-calibration casts were conducted with the EcoCTD mounted on the shipboard CTD. Three calibration casts were conducted with Rutherto (S/N 66098), with one occuring near the start of the cruise and two occuring near the end of the cruise. Only one calibration cast was conducted with Sedna (S/N 203743) near the end of the cruise, however significantly fewer casts were made with Sedna during the cruise.

Shipboard profiles of temperature, salinity, oxygen, chlorophyll fluorescence and backscatter at 700nm were interpolated onto a 1-meter depth grid. EcoCTD measurements were interpolated onto the same depth grid and directly compared to measurements from the shipboard CTD. Figure 12 shows the comparison between temperature and conductivity data between the CTD and EcoCTD during the four casts. Each cast is given as a different colour, and a comparison between both CTD sensors and the EcoCTD individually are included in the same colour. We have shown only downcast data, as the up-cast data contain significant differences likely due to wake effects from the orientation of the EcoCTD on the Rosette (see Figure **??**). There is a clear offset in conductivity between the CTD and the EcoCTD for both sensors. The offset is common across calibration casts, so likely to be a true bias, however we also performed in-situ comparisons with CTD to confirm that artifacts of the way the EcoCTD was strapped to the rosette are not influencing the offset. It is possible that the attachment of the EcoCTD to the rosette is responsible for the pressure dependence with depth in Sedna (S/N 203743). There were pieces of metal and rubber within proximity to the conductivity sensor, which can create spurious signals due to deformation of the materials with depth.

For the in-situ comparisons we followed the methodology outlined in Section 2.2. Using the top 8 most comparable casts for S/N 66098 and the top 2 most comparable casts for S/N 203743, we have confirmed that the calibrations from the calibration casts are sufficient to correct for the observed biases in conductivity and temperature. In Figures 13 and 14 we have plotted the pre-calibration temperature/conductivity comparison and the post-calibration comparison for the most comparable casts.

Filtering At sharp interfaces, the conductivity sensor responds faster than the temperature sensor. Along with the lag correction, we also smooth the salinity using a 3-point median filter.

Quality flags Level-2 data include a quality flag for each variable. A flag of "1" means good data, "0" means questionable, and "-1" means bad data that should not be used unless taking extra precautions.

- Pressure has a quality flag of "1".
- Temperature has a flag of "1", unless measured above the draft depth of the ship (i.e., upper 6 m), where it is flagged "0".

Figure 11: EcoCTD probe affixed to the CTD Rosette for calibration casts.

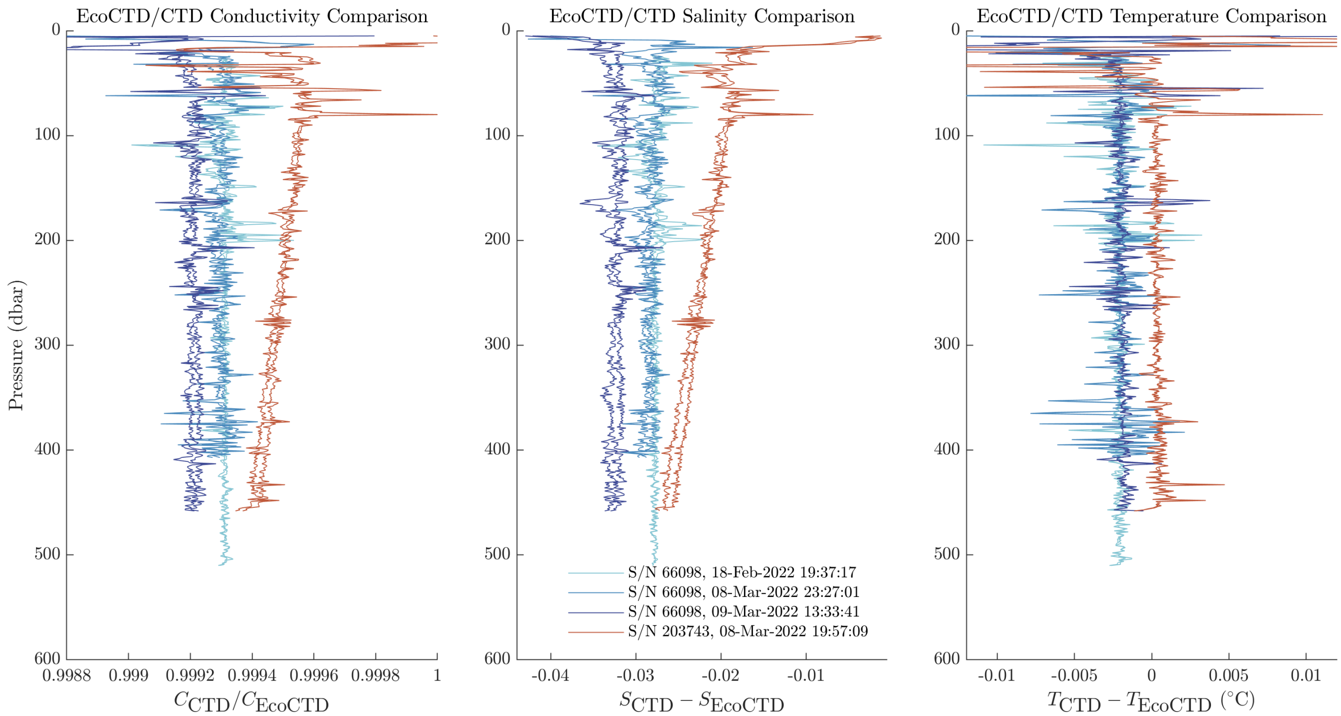

Figure 12: Comparison between ship's CTD and EcoCTD conductivity (left), salinity (middle) and temperature (right) during the calibration cast. Four calibration casts are included in different colours. The three in different shades of blue, are from Rutherto (S/N 66098) and the cast in red is using Sedna (S/N 203743). All casts shown are down casts, and both CTD sensors are compared individually to the EcoCTD, giving two lines for each cast.

- Conductivity and oxygen saturation have a flag of "1", unless measured above the draft depth of the ship (i.e., upper 6 m), where it is flagged "-1". Data is flagged to "0" if the EcoCTD is profiling slower than 1 dbar/s, as good flushing is preferred.
- Optode temperature, backscatter, and chlorophyll as flagged the same way as temperature.
- All computed variables adopt the lowest-quality flag from their source measured variables.
- Optode measurements were flagged as "-1" if the protective cap was mistakenly left in place during deployment.

4.3.3 Level-3 product

Binning Individual downcast profiles from the EcoCTD are gridded onto a vertical grid of 1 m. The flag associated with each bin the minimal flag value within the bin.

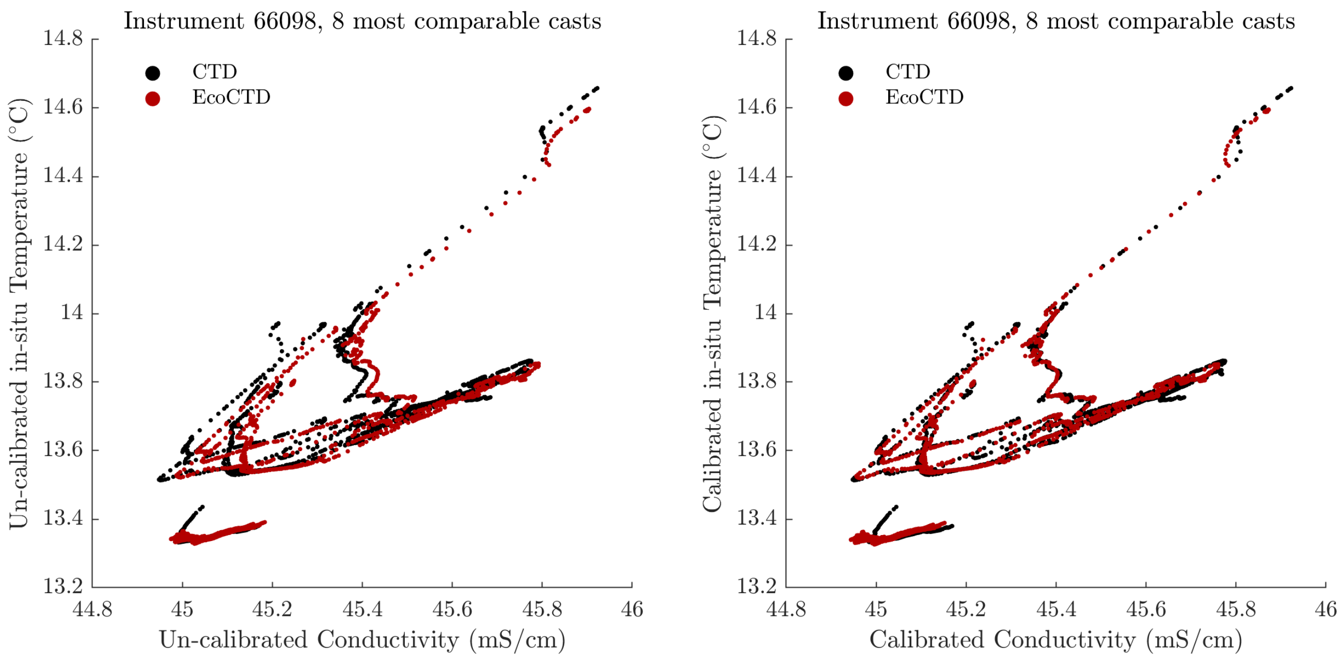

Figure 13: Temperature versus Conductivity scatter plots for the most comparable data between CTD Rosette and EcoCTD sensor S/N 66098. On the left is un-calibrated EcoCTD data and on the right is the EcoCTD data calibrated using the calibration casts.

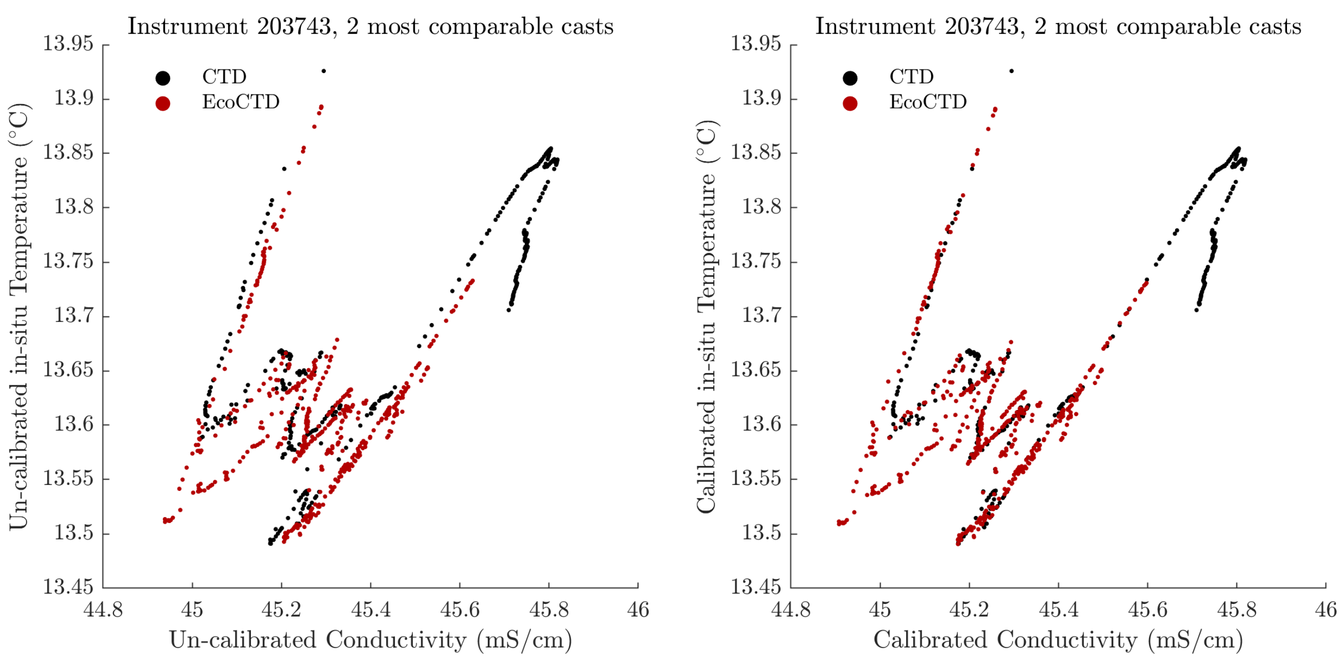

Figure 14: Temperature versus Conductivity scatter plots for the most comparable data between CTD Rosette and EcoCTD sensor S/N 203743. On the left is un-calibrated EcoCTD data and on the right is the EcoCTD data calibrated using the calibration casts.

5 MVP

The MVP [*Furlong et al.*, 2006] is a profiling instrument that can be deployed from a moving vessel in a tow-yo mode to measure temperature, salinity, dissolved oxygen, and bio-optical properties. The MVP was used as a replacement system for the EcoCTD in both times when the EcoCTD winch was broken, and in poor weather conditions. The MVP is operated remotely and broadcasts real-time data back to the ship for monitoring. It doesn't require personnel to be located on the deck to operate the winch, so is suitable for poor weather. This report describes the MVP data set from the Campaign and the processing and quality-control steps that were taken in producing the data set. We used the MVP for 362 profiles throughout the cruise, collected to depth ranging from 150 to 212 m.

5.1 File Formats and Dataset Management

Data processing was organized in three levels:

- **Level-0:** Raw data as downloaded directly from the instrument. Raw files from the MVP are ASCII text files with the *.raw file extension.
- **Level-1:** Data are geo-referenced, split into down- and up-casts and separated into individual .mat files. Calibration coefficients are applied to measured chlorophyll and derived quantities (e.g. salinity, sea pressure, depth ...) are included. Only downcasts are processed for MVP profiles.
- **Level-2:** Quality analysis is completed using ancillary datasets, and corrections are applied. These corrections include sensor alignment and cross-calibration with the shipboard CTD. QC flags are also included in the .mat files
- **Level-3:** Level-2 data are interpolated vertically onto a common depth grid and merged into a single .mat file. Dimensions are depth and profile number.

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5.2 MVP probe

The MVP probe (S/N 9138) is composed of three sensors (Figure 15):

- One AML-X2Change Conductivity-Temperature-Depth (CTD) (SN 451065).
- One JFE-Advantech Rinko FT dissolved oxygen sensor (SN 700101).
- One Turner Cyclops optical sensor (SN FILL).

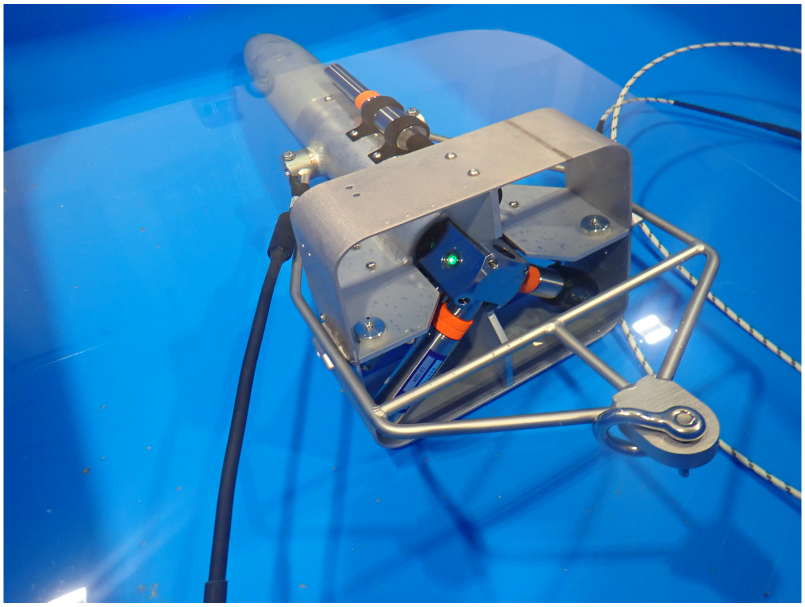

Figure 15: MVP fish in a testing tank at AML Oceanographic. The fish includes a CTD sensor, an oxygen sensor (Rinko), and a Turner Cyclops optical sensor.

FILL MVP size, weight, winch system, pressure rating. The fall rate of the MVP varies mostly between 2 and 4 m/s (Figure 16).

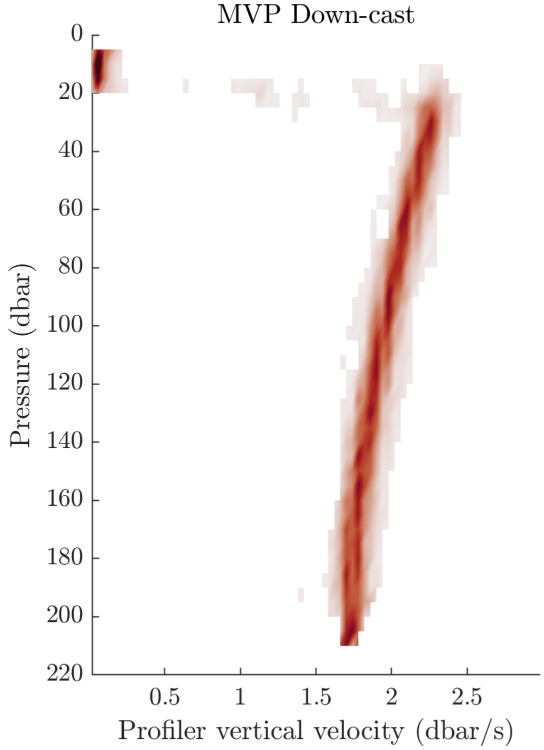

Figure 16: 2-D histogram of the profiling rate in dbar/s as a function of pressure.

5.3 MVP Data Processing Steps

5.3.1 Level-1 processing steps

GPS data Each MVP profile is geo-referenced by using the GPS positioning of the ship at the start of each profile. The MVP is assumed to profile vertically, so each profile is associated with a single GPS position. A linear interpolation in time is used to align EcoCTD profiles and GPS positioning from the ship (sampled at 1Hz)

FILL: Is there a zero hold?

Factory calibration The Turner Cyclops sensor data were calibrated against the EcoCTD casts in-situ, by alternating MVP and EcoCTD casts along a transect (see Section FILL). The backscatter sensor was only used for a few casts, and the data were not of usable quality, so we will only discuss the Chlorophyll measurements.

Chlorophyll fluorescence:

$$Chl\ [\mu g/L] = SF * (Output - Dark\ counts) \tag{7}$$

where ... FILL

Derived variables *Sea Pressure* – Sea pressure is computed by removing the atmospheric pressure from the absolute pressure measured by the CTD. This is done by taking the maximum of the PDF of the pressure readings between 9 and 11 dbar, which encompasses potential values of atmospheric pressure.

Absolute Salinity – Absolute Salinity SA is derived using the GSW toolbox

Conservative Temperature – Conservative Temperature CT is derived using the GSW toolbox

5.3.2 Level-2 processing steps

Level-2 data includes all post-processing steps details in the previous section for Level-1 data. However, the additional processing applied to the data is described below.

Sensor alignment *CTD sensor* – Misalignment of temperature and conductivity measurements results in spikes in salinity because conductivity is temperature dependent. We use an optimal C-T lag of FILL s which was determined from an ensemble of cruise data. We apply the lag during data processing by interpolating the temperature data onto a shifted time axis.

Oxygen sensor – FILL O2 Information *Turner Cyclops Chlorophyll* FILL CHL Info

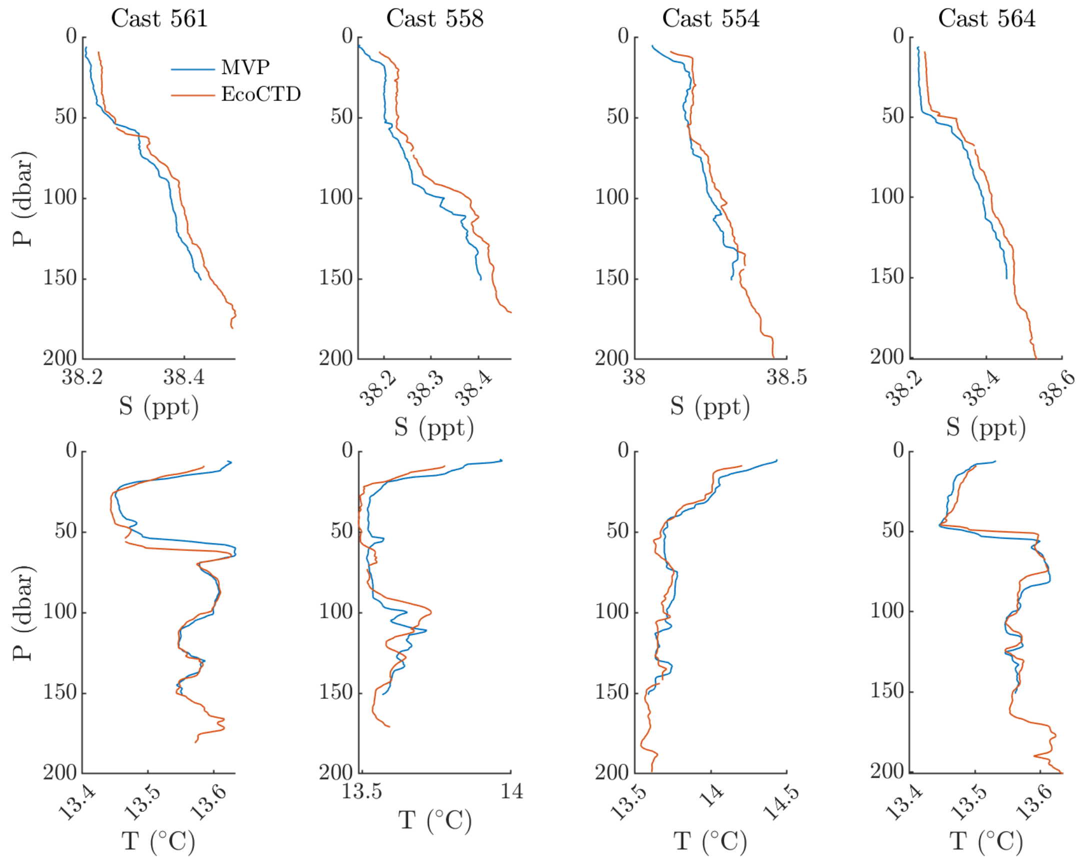

Figure 17: Four sample casts from the 12 calibration casts made with the EcoCTD and MVP. MVP and EcoCTD casts were alternated, giving a time lag between casts of ~ 6 minutes. MVP is given in blue and EcoCTD is given in red. All EcoCTD casts were made with Rutherto (S/N 66098). Here the EcoCTD casts have been calibrated according to the CTD (see Figure 12), but the MVP is un-calibrated.

Cross-calibration with EcoCTD To calibrate the MVP sensors, we performed in-situ alternating casts with the EcoCTD probe. This consisted of FILL casts on the FILL March 2022 (transect FILL). These casts plotted with depth are shown in Figure FILL. In Figure FILL we have plotted the FILL casts in T/S space. You can see an offset in both temperature and salinity of FILL and FILL respectively. In Figure FILL we have also shown the results of calibrating both the MVP and the EcoCTD. The EcoCTD conductivity offset observed between the CTD and EcoCTD is of the opposite sign to the offset between the EcoCTD and MVP, which gives further evidence to suggest that the EcoCTD offset is correct. We have applied the offset of FILL in the calibrated MVP data.

The oxygen sensor was not correctly logging at the time of the comparison casts, so we cannot use it to calibrate the O_2 data. Instead we use the best in-situ comparison casts described in Section 2.2.

Filtering At sharp interfaces, the conductivity sensor responds faster than the temperature sensor. Along with the lag correction, we also smooth the salinity using a 3-point median filter.

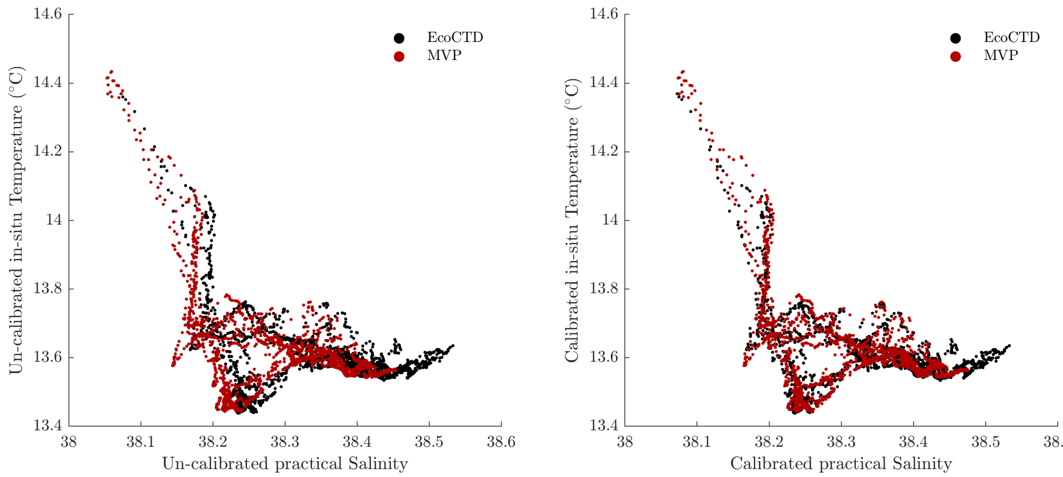

Figure 18: Calibration casts between the MVP and the EcoCTD compared in T/S space. On the left the data shows the calibrated EcoCTD data and the uncalibrated MVP data. On the right shows the calibrated EcoCTD data and the calibrated MVP data. The MVP calibration suggests an around ~ 0.02 fresh salinity bias.

Quality flags Level-2 data include a quality flag for each variable. A flag of "1" means good data, "0" means questionable, and "-1" means bad data that should not be used unless taking extra precautions.

- Pressure has a quality flag of "1".
- Temperature has a flag of "1", unless measured above the draft depth of the ship (i.e., upper 6 m), where it is flagged "0".
- Conductivity and oxygen saturation have a flag of "1", unless measured above the draft depth of the ship (i.e., upper 6 m), where it is flagged "-1". Data is flagged to "0" if the EcoCTD is profiling slower than 1 dbar/s, as good flushing is preferred.
- Optode temperature, backscatter, and chlorophyll as flagged the same way as temperature.
- All computed variables adopt the lowest-quality flag from their source measured variables.
- Optode measurements were flagged as "-1" if the protective cap was mistakenly left in place during deployment.

5.3.3 Level-3 product

Binning Individual downcast profiles from the EcoCTD are gridded onto a vertical grid of 1 m. The flag associated with each bin the minimal flag value within the bin.

6 WireWalker

Two WireWalkers *Pinkel et al.* [2011], from CMRE and URI respectively, were used during the CALYPSO 2022 campaign. Both were used in three deployments (with one additional test deployment for the URI WireWalker). These deployments are shown in Figure 19.

Two Wirewalker profilers manufactured by Del Mar Oceanographic in San Diego, CA, USA were used in freely-drifting configuration to monitor the upper water column (down to 200 m depth) with high-frequency sampling (period as little as 15 min). The Wirewalker goes up and down along a wire that is powered by the motion of the surface waves for descent and uses its own positive buoyancy for ascent (Pinkel et al., 2011). One Wirewalker (Fig. 9 left) owned by CMRE was fitted with a RBR Concerto CTD (S/N 203723), and Nortek Signature 1000 AD2CP (S/N: 101670, downward-looking at 22.5°) powered by a RBR Fermata external battery pack. The CTD data were retrieved inductively by a RBR Cervello (S/N: 203724) data controller and transmitted in real time via iridium. The sampling frequency of the CTD was 4 Hz. Positions were monitored with a GlobalStar SPOT Trace (ESN: 0-3184257, sampling every 5 min) and an Iridium Xeos Rover (IMEI 300434063292990, sampling every 30 min). A 200-m cable was attached to the surface buoy (0.9 m diameter) and had a double weight (two $\frac{3}{4}$-inch steel plates with weight 32 kg) at its bottom end. The other Wirewalker (Fig. 9 right), owned by URI was equipped with an RBR Maestro CTD (S/N: 80280) was powered by an RBR Fermata and served as a logger for a Rinko oxygen sensor (S/N: 0322), a WetLABS ECO BBFL2 chlorophyll/CDOM fluorometer and 700-nm backscatter meter (S/N: ECO BBFL2SSC-1309), and a WetLABS 650-nm C-Star beam transmissometer (S/N: CST-1811PR). These sampled continuously at 6 Hz. Internally logging JFE Advantech DEFI2-L PAR sensors were mounted on both the profiler (S/N: 0AAO036) and the buoy (S/N: 0B1C018), and sampled at 1 Hz. A Nortek Signature1000 AD2CP (S/N: 100234), supplied by Andrey Shcherbina (APL/UW), was mounted on the profiler in an upward-looking orientation. It was powered by its own internal battery and logged internally; its sampling configuration was adjusted from deployment to deployment. Positions were supplied at 10-minute intervals by a GPS/Iridium beacon integrated into the buoy (S/N: DMO-GLBCN-0005, IMEI: 300234066300020), and also at 5-minute intervals by SPOT Trace tracker (ESN: 0-3184266). The buoy diameter was 0.75 m, the cable length was 175 m, and weight at the bottom consisted of a single rectangle of $\frac{3}{4}$-inch steel plate (dimensions 8 by 24 inches, weight 16 kg).

The same processing steps for the FILL CTD as outlined for the EcoCTD were applied to both WireWalkers, given the same data format and sensor type. For the additional sensors aboard the URI WireWalker we discuss the data processing steps below. Using in-situ comparisons we found a

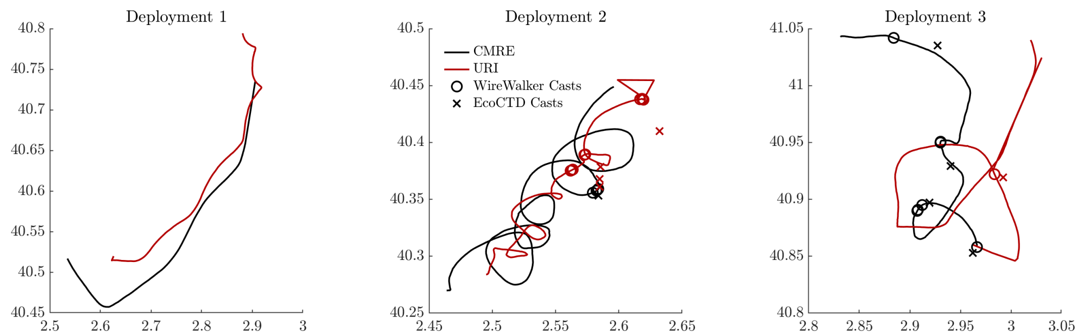

Figure 19: The WireWalker tracks for three deployments are shown in the three figures. Individual lines are given for the CMRE WireWalker track and the URI WireWalker track. Also denoted are the locations used for in-situ comparisons between the EcoCTD casts (in crosses) and the WireWalker casts (as circles).

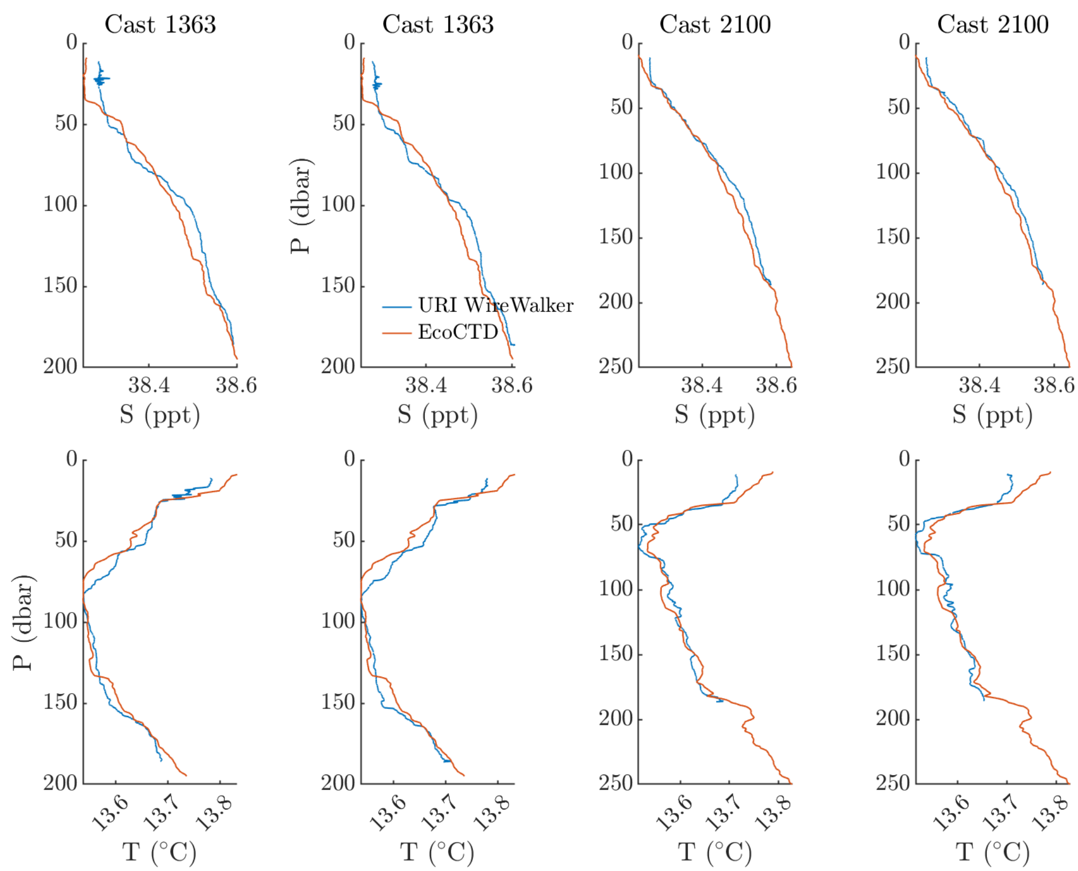

Figure 20: Four randomly taken calibration casts from the set of most comparable URI WireWalker and EcoCTD casts.

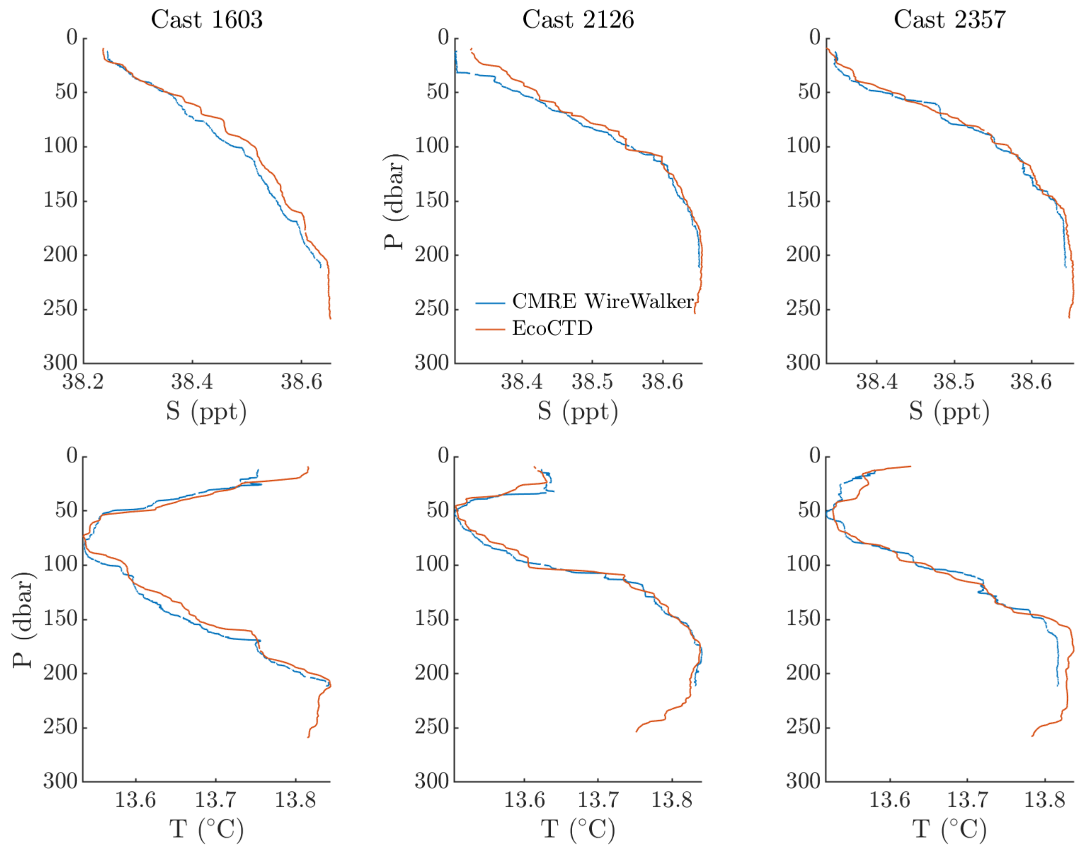

Figure 21: Four randomly taken calibration casts from the set of most comparable CMRE WireWalker and EcoCTD casts.

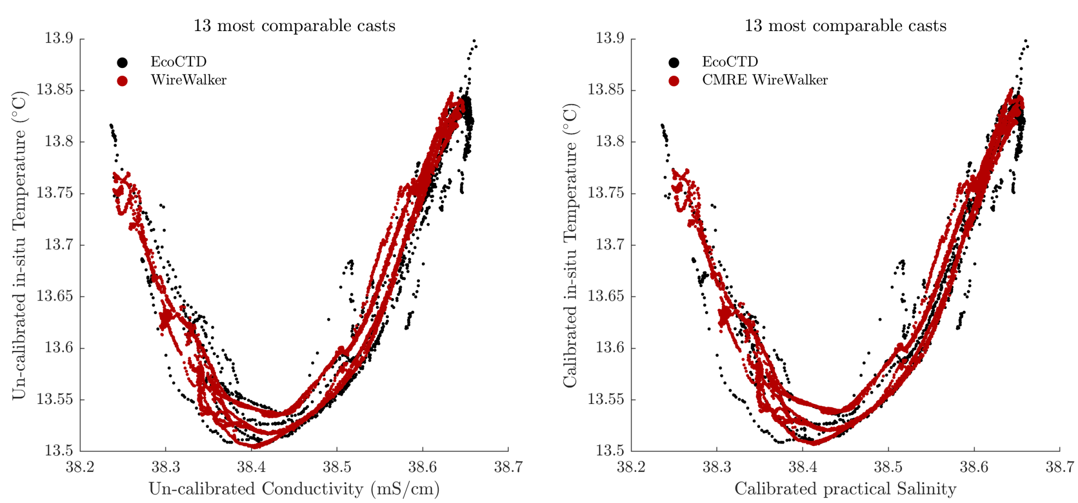

Figure 22: Most comparable casts between the CMRE WireWalker and EcoCTD plotted in T/S space.

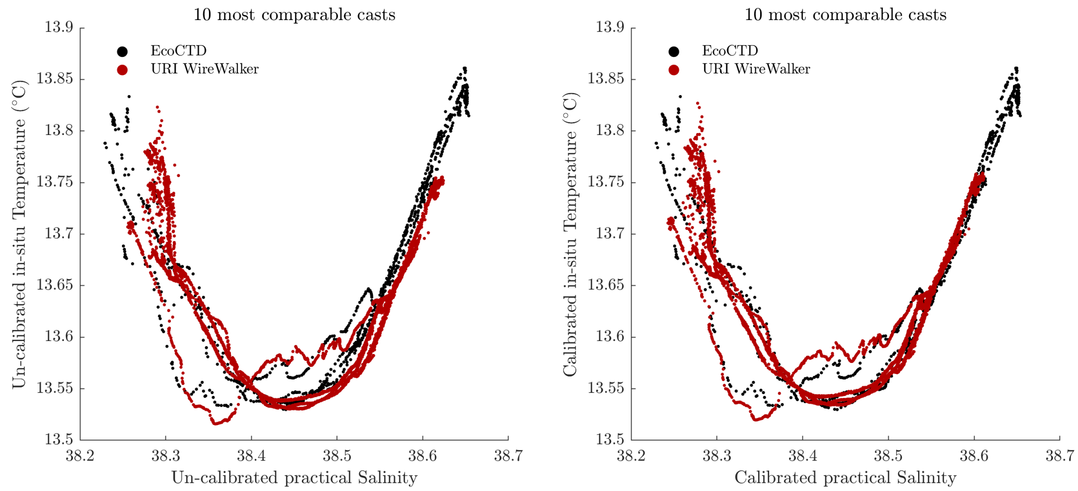

Figure 23: Most comparable casts between the URI WireWalker and EcoCTD plotted in T/S space.

7 Flow-through and TSG

7.1 TSG

For the Thermosalinograph (TSG) on board, temperature and conductivity measurements were taken every 6 seconds between the 17-Feb-2022 at 16:54:23 and 11-Mar-2022 at 13:12:43. Temperature was measured at the intake (around 6 m below sea level) and at the TSG device where conductivity was measured. The practical salinity is calculated from the conductivity using the intake temperature, lagged by 36.1 seconds to account for the time it takes to reach the TSG device.

For calibration, we compared the average TSG readings in the 10 minutes surrounding a CTD, or EcoCTD cast to the values recorded at 6 m depth from the post-calibrated CTD and EcoCTD casts. We have plotted a scatter of the conductivity and temperature measured by the TSG compared to these upper values from the casts in Figure 24, along with the subsequently calibrated values.

7.2 Flow-through

7.2.1 Oxygen

The SEB43 oxygen sensor (S/N 3734) installed in the flow-through system suffered significant drift throughout the deployment. A post-calibration confirmed a change in gain of 0.9145 compared to pre-calibration. To provide a reference point for the oxygen sensor we compare it to the EcoCTD oxygen sensor (see Section 5.3) data measured at 6 m depth (the nominal depth of the flow-through system). In Figure 25 we have plotted the raw measured oxygen saturation from the flow through system in grey, compared to the EcoCTD measured oxygen in yellow. When comparing the flow-

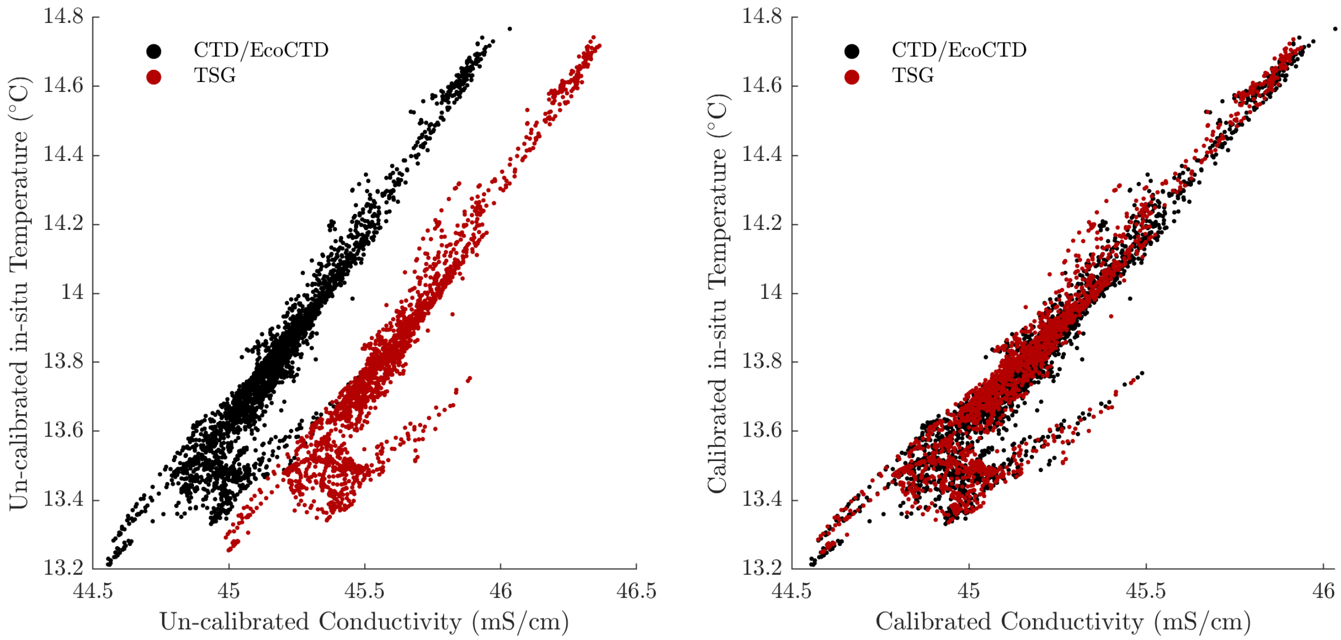

Figure 24: Comparison of the TSG data in conductivity and temoerature space, before (left) and after (right) calibration against the CTD and EcoCTD data from the upper 5 m.

through oxygen to the EcoCTD oxygen at the timepoints of the EcoCTD casts, it is clear that the drifting oxygen sensor has a non-linear drift with time. Fitting polynomial or exponential curves to the entire time series does not correct for the drift, as it seems to follow varying drifts for different sections of the time series.

Considering the flow rate of the flow-through instrumentation, plotted in Figure 26, gives a potential reason for the changing oxygen drift in time. The instrumentation was periodically modified such that the flow rate spikes and sometimes starts at a new average. We assume that the spikes denote adjustments of the instrumentation which lead to a changed drift. To apply this assumption, we define 6 sections of the data, corresponding to the regions between perturbations, as shown in Figure 26. Initial perturbations are ignored as there is no significant drift between the EcoCTD and flow-through oxygen data. To correct the flow-through oxygen sensor, we fit polynomials to the difference between the EcoCTD values and the flow-through values. Drift only occurs after the first time period, so we do not adjust the first section. For the ith section we apply the gain g_i, fitting to the EcoCTD trends:

$$g_1^{O_2} = 1, \tag{8}$$
$$g_2^{O_2} = 0.09572 t_0^{0.02}, \tag{9}$$
$$g_3^{O_2} = 0.05952 t_0^{0.32}, \tag{10}$$
$$g_4^{O_2} = 0.01347 t_0, \tag{11}$$
$$g_5^{O_2} = 0.00039 t_0^{2.42}, \tag{12}$$
$$g_6^{O_2} = 0.00098 t_0^{2.10}, \tag{13}$$
$$g_7^{O_2} = 0.00108 t_0^{2.04}, \tag{14}$$

where t_0 is the number of days since the initial EcoCTD cast (16-Feb-2022 12:50:40).

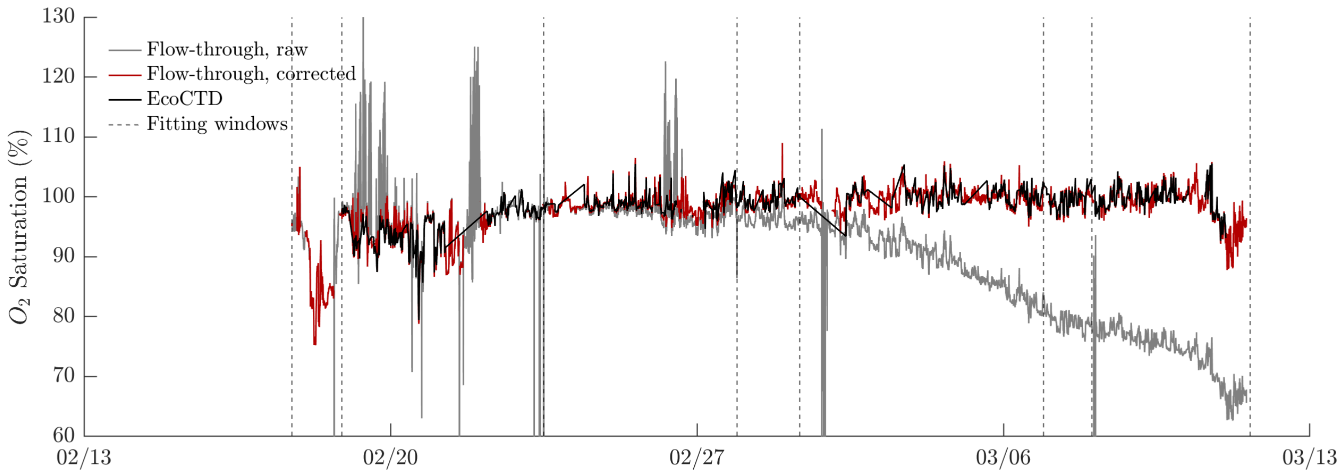

Figure 25: Comparison of Oxygen saturation between the flow-through SBE43 sensor (S/N 3747) in grey and the EcoCTD Rinko III sensor (S/N FILL) in black. In red we include the corrected flow-through oxygen sensor data using the gains $g_i^{O_2}$ in each of the i sections marked using dashed lines.

Quality control has then been applied to the oxygen signal based on a few different criterion which were determined to remove the abnormal data visible in the raw signal in Figure 25. First we remove all data within 2.5 minutes of any abnormality in the flow rate (defined as a change in flow rate of at least 1 L/min). Then we remove all samples with oxygen saturation lower than 60 %, or an oxygen saturation gradient greater than 0.15 mg/L/s. Finally, for periods when we have consistent EcoCTD sampling, we remove all flow-through data that differs from the EcoCTD measurements by more than 4 %.

7.2.2 Chlorophyll

The chlorophyll sensor suffered from similar issues to the oxygen sensor in terms of varying drift during each of the periods of varying flow rate. The differences here are much smaller between the EcoCTD sensor and the flow-through sensor, but there is still noticeable drift when the two sensors are compared. We use the same method as described for the oxygen sensor to correct this drift. The results of this calibration are visible in Figure 27.

For the ith section we apply the gain g_i^c, fitting to the EcoCTD trends:

$$g_1^c = 1, \tag{15}$$
$$g_2^c = 0.30366 t_0^{0.08}, \tag{16}$$
$$g_3^c = 0.26097 t_0^{0.33}, \tag{17}$$
$$g_4^c = 0.17152 t_0^{0.52}, \tag{18}$$
$$g_5^c = 0.29534 t_0^{0.09}, \tag{19}$$
$$g_6^c = 0.00146 t_0^{2.01}, \tag{20}$$
$$g_7^c = 2.87629 t_0^{-0.70}, \tag{21}$$

where t_0 is the number of days since the initial EcoCTD cast (16-Feb-2022 12:50:40).

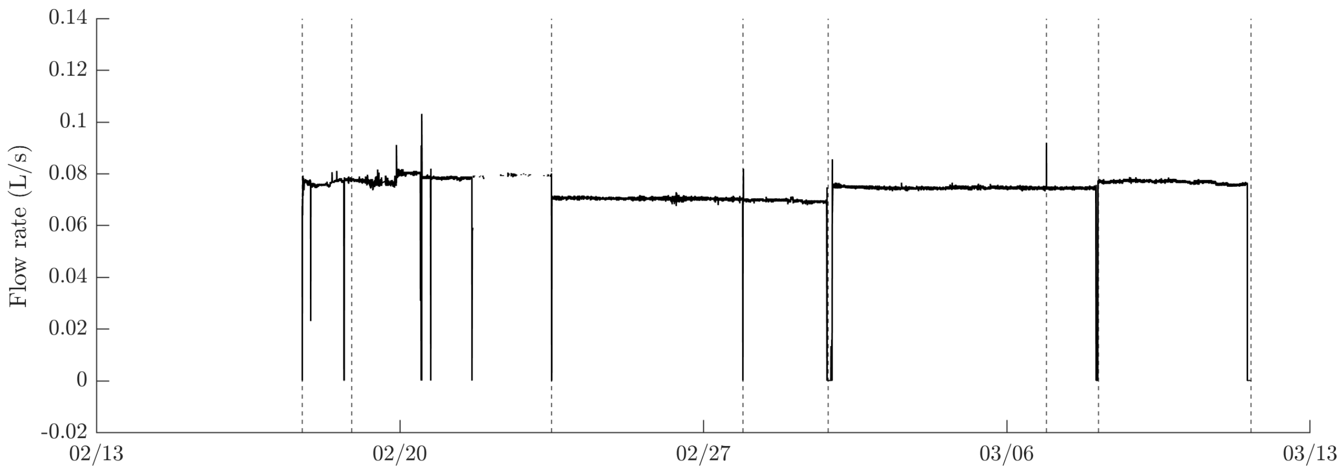

Figure 26: Flow-through system flow rate plotted with time. Perturbations to the flow rate are marked with dotted lines, dividing up the time series into 6 regions (ignoring the initial perturbations which did not lead to a significant drift in the oxygen sensor).

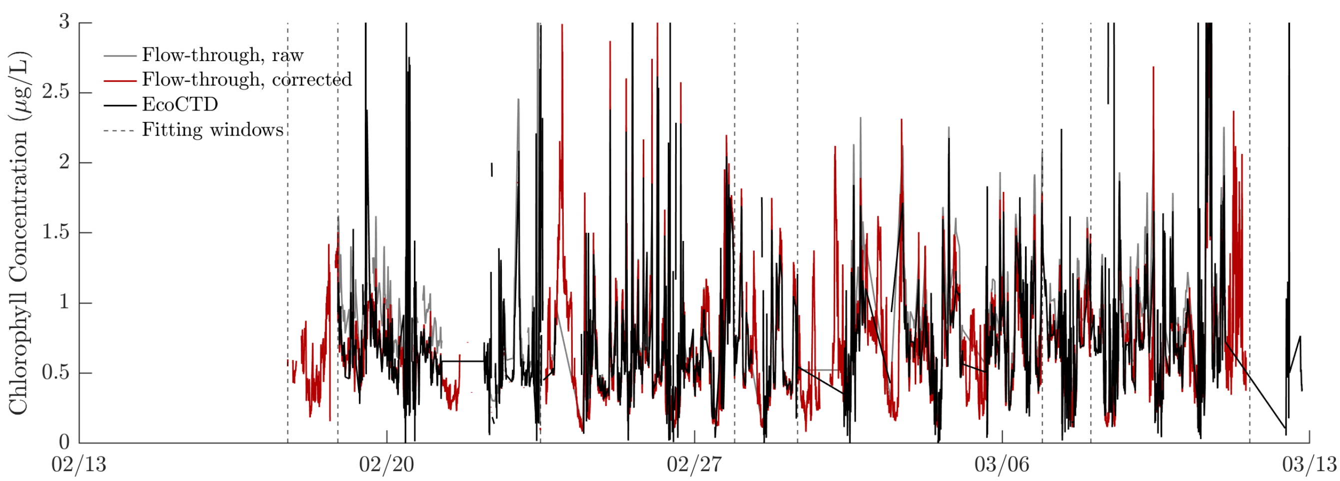

Figure 27: Comparison of chlorophyll concentration between the flow-through (FILL SENSOR) in grey and the EcoCTD sensor (S/N FILL) in black. In red we include the corrected flow-through chlorophyll data using the gains g_i^c in each of the i sections marked using dashed lines.

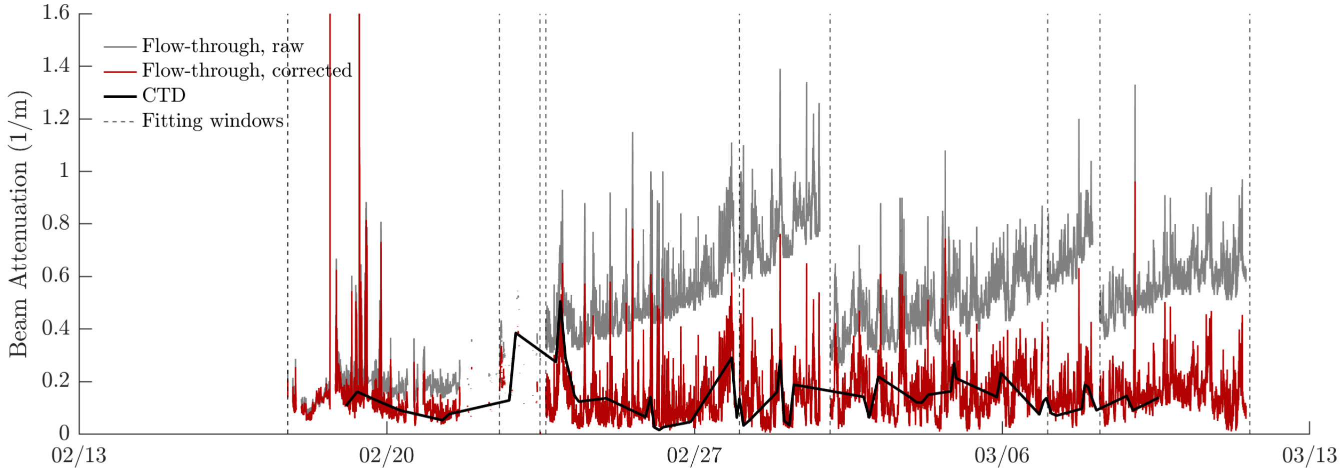

Figure 28: Comparison of beam attenuation between the flow-through (FILL SENSOR) in grey and the CTD sensor (S/N FILL) in black. In red we include the corrected flow-through beam attenuation data using the gains g_i^{at} in each of the i sections marked using dashed lines.

7.2.3 Beam Attenuation

The beam attenuation suffered similar problems to the oxygen and chlorophyll sensors. The distinct regions in the beam attenuation which required correcting separately were not aligned with the chlorophyll and oxygen however. Instead, there was missing data that divided the regions which were drifting with distinct slopes, so we used these periods to divide up the timeseries into sections. The second problem is that the EcoCTD did not have a measurement of beam attenuation on it. Instead, we rely on the CTD measurements of beam attenuation, however there were only 61 casts: an insufficient amount to detect the changing trend. To identify the trend, we fit a polynomial to the beam attenuation signal itself to remove the trend, then we normalise the section to agree with the CTD casts within that time period. The specific trends that are subtracted from the signal are:

$$g_1^{at} = 0.13734 t_0^{0.20}, \tag{22}$$
$$g_2^{at} = 0.00875 t_0^{2.14}, \tag{23}$$
$$g_3^{at} = 0.28000, \tag{24}$$
$$g_4^{at} = 0.05700 t_0^{1.00}, \tag{25}$$
$$g_5^{at} = 0.01256 t_0^{1.67}, \tag{26}$$
$$g_6^{at} = 0.00578 t_0^{1.60}, \tag{27}$$
$$g_7^{at} = 0, \tag{28}$$
$$g_8^{at} = 0.00044 t_0^{2.36}, \tag{29}$$

where t_0 is the number of days since the initial flow-through measurements (17-Feb-2022 17:58:29). The results are shown in Figure 28

8 Pelagia UCTD

9 Floats

9.1 Solo Floats

9.2 Arvor

9.3 Argo

10 ADCPs

10.1 Pourquoi Pas? Shipboard

Mounted on the R/V Pourquoi Pas? were three shipboard Acoustic Doppler Current Profilers (ADCPs): a 38kHz Teledyne Ocean Surveyor; a 150kHz Teledyne Ocean Surveyor; and a 300 kHz Teledyne Workhorse Monitor.

10.2 Alignment

The 300 kHz ADCP was installed specifically for the CALYPSO cruise, so it is placed in a a different part of the ship to the 150 kHz and 38 kHz instruments. To check for offsets in the orientation of the instrument, an alignment check was applied to all three ADCPs. Minimising the absolute velocity across rotations of the ship's velocity suggests an alignment offset of -2.25° for the 300 kHz, 0.085° for the 150 kHz, and -0.02° for the 38 kHz. We also compared the difference between the depth-averaged velocities between the 150 kHz and the 300 kHz as it varies with heading, plotted in Figure 29. This plot shows that the 300 kHz ADCP has a misalignment that leads to a sinusoidal offset depending on the ship's heading. We take a best fit sinusoid and apply a heading offset to the 300 kHz data.

10.2.1 Quality Control

Various quality control measures were applied to filter out data from all three ADCPs. We identified bad data using six metrics: error velocity, percent good reported, correlation magnitude, vertical velocity magnitude, horizontal velocity magnitude and echo intensity. In Figures 30, 31 and 32, you can see these six metrics plotted in terms of average, standard deviation and range with depth, across the entire deployment. Considering the data in each case, we set thresholds

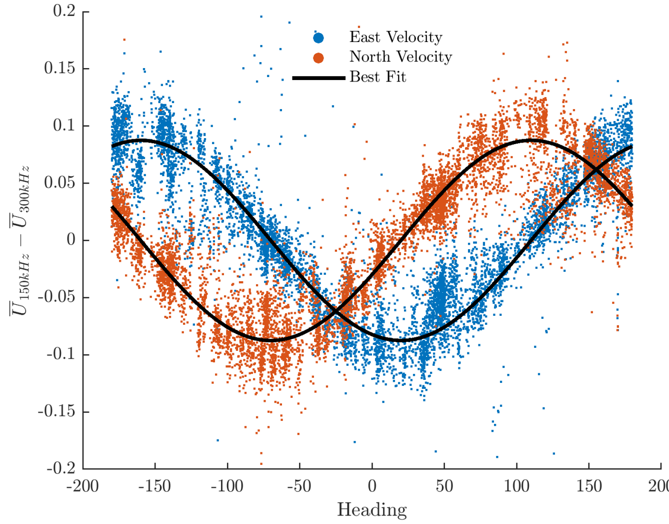

Figure 29: Plot of the difference in depth-averaged velocity data between the 150 kHz and 300 kHz data, plotted as a function of ship's heading.

(marked on the Figures) for each instrument separately. Data points that exceed the threshold value for more than one quality control parameter are removed.

The other major source of error derived from when the ship was taking corners. The reason for this error is to do with the inaccurate calculation of the ship's velocity during corners, which leads to an error in the absolute velocity when the ship's velocity is subtracted from the relative velocity. We have removed all the points where the ship's heading changed by more than 1.45° per second. This did not correct for all of the corner problems, so we also removed all the points with a large correlation between the depth-averaged speed for both the 38 kHz and 150 kHz ADCP, as the error is the same across both instruments. Specifically, all points where $\overline{\mathbf{U}}_{150kHz} \times \overline{\mathbf{U}}_{38kHz} > 0.001$ were removed. Finally, points with abnormally large velocity gradients in time, averaged with depth, were removed. If the value of $\frac{d\overline{U}}{dt}$ or $\frac{d\overline{V}}{dt}$ exceeded a 5-point running median by 5.8 ms^{-2} then the point was removed. Further work to recover the data measured during corners is on-going.

We compare the depth averaged values between 30 m and 60 m, where all three ADCPs overlap in Figure 33. For profiles where the difference between the 38 kHz and the 150 kHz differ by more than 1.5 standard deviations, those profiles are removed from the 38 kHz. The same process is repeated for the 300 kHz as the 150 kHz is considered more reliable. In total we remove 4778 profiles (31%) from the 38 kHz, 4951 profiles (32%) from the 150 kHz, and 5129 profiles (39%) from the 300 kHz.

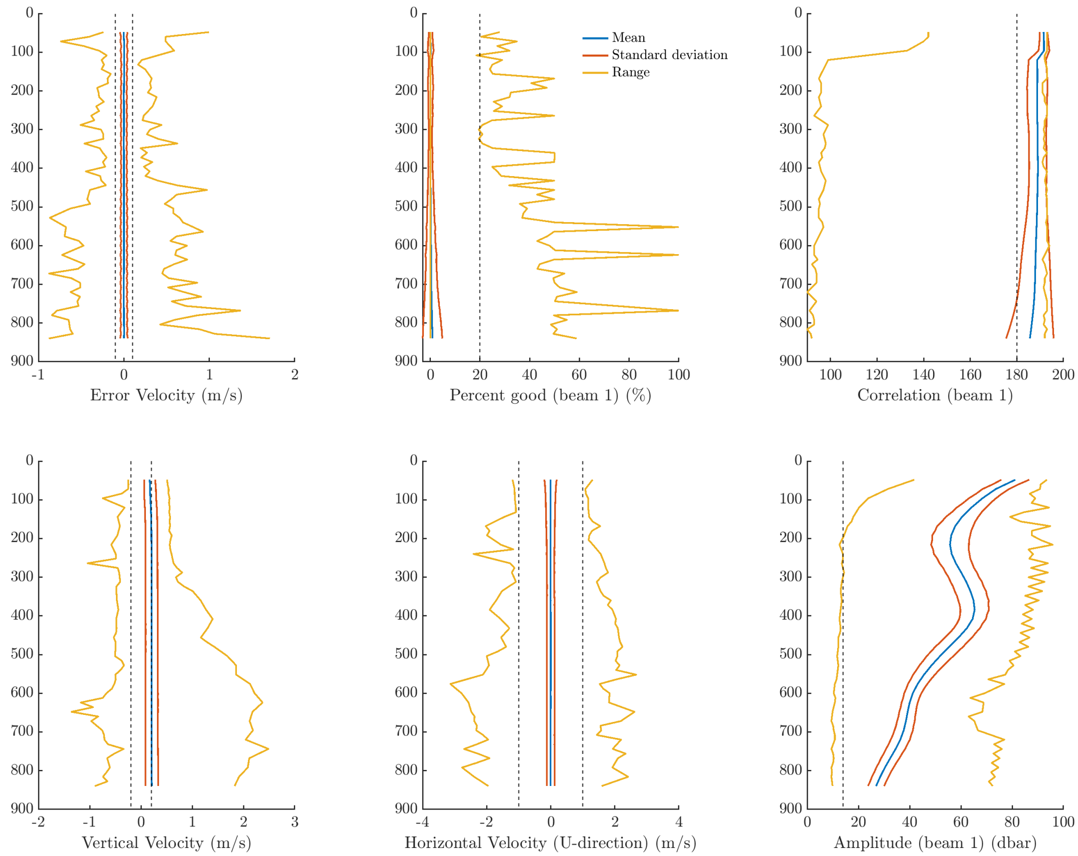

Figure 30: Quality control parameters for the 38 kHz ADCP. Thresholds used for QC marked with dashed lines.

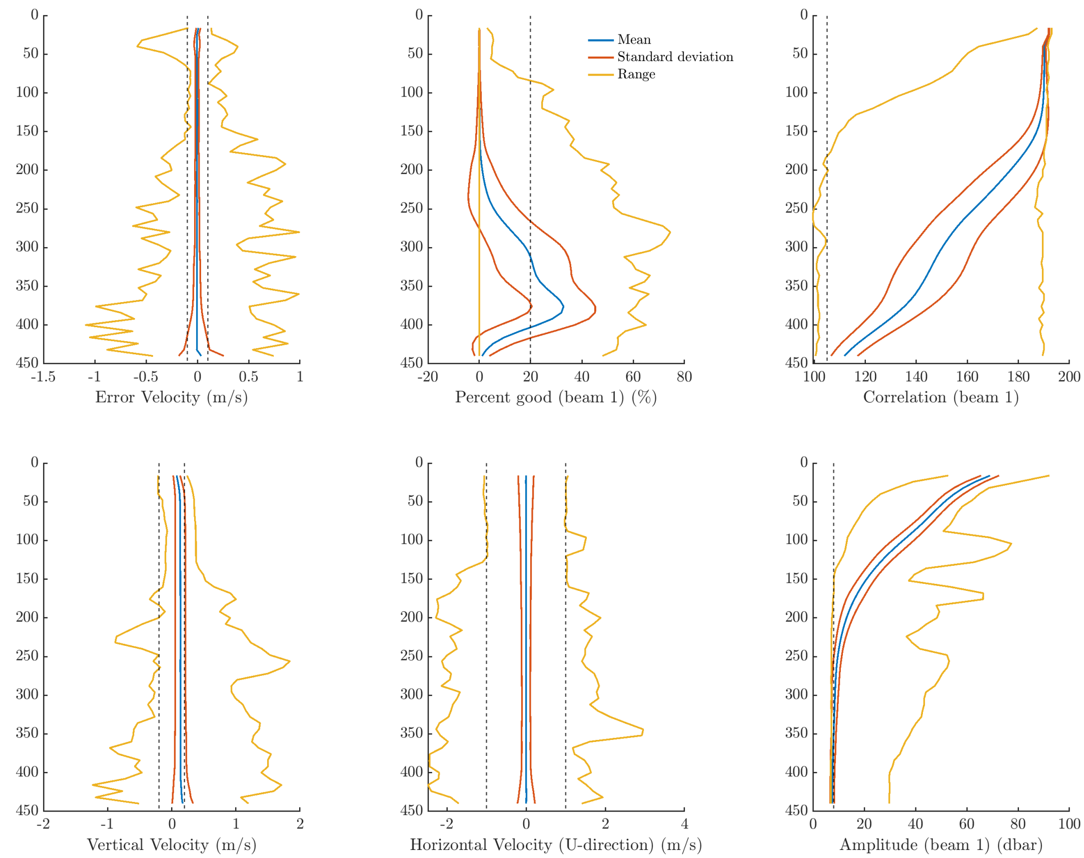

Figure 31: Quality control parameters for the 150 kHz ADCP. Thresholds used for QC marked with dashed lines.

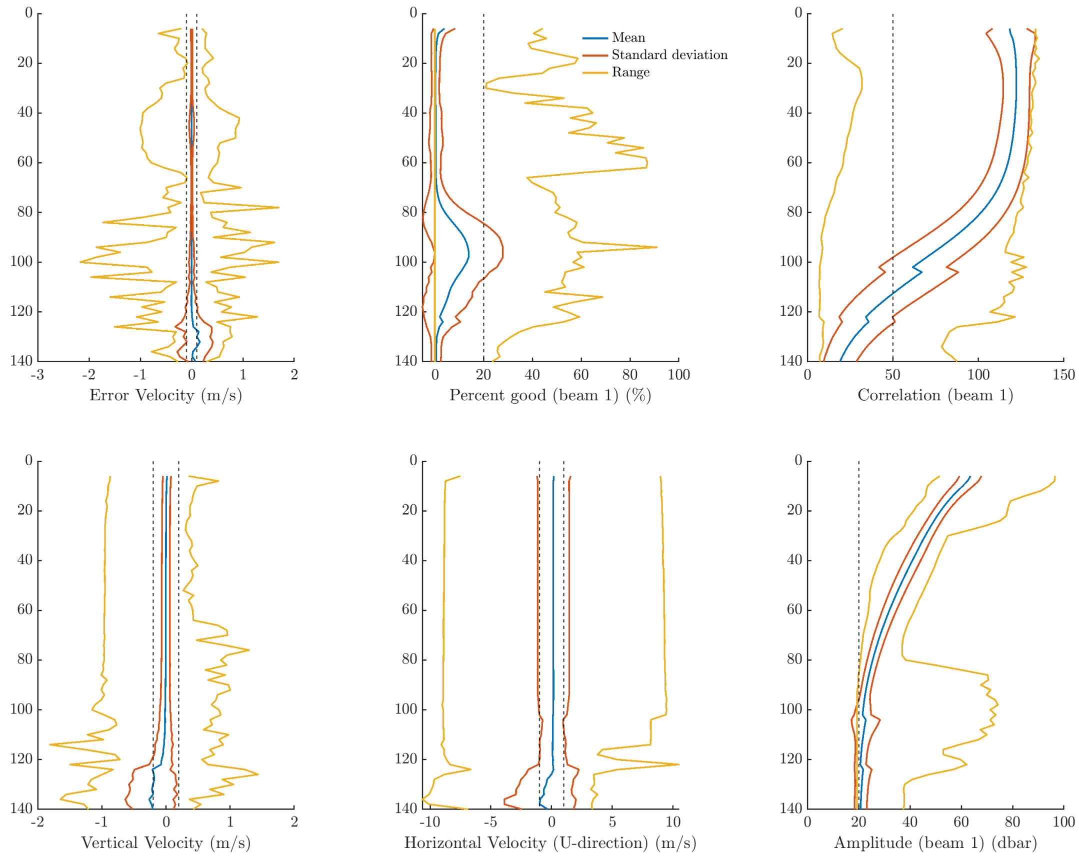

Figure 32: Quality control parameters for the 300 kHz ADCP. Thresholds used for QC marked with dashed lines.

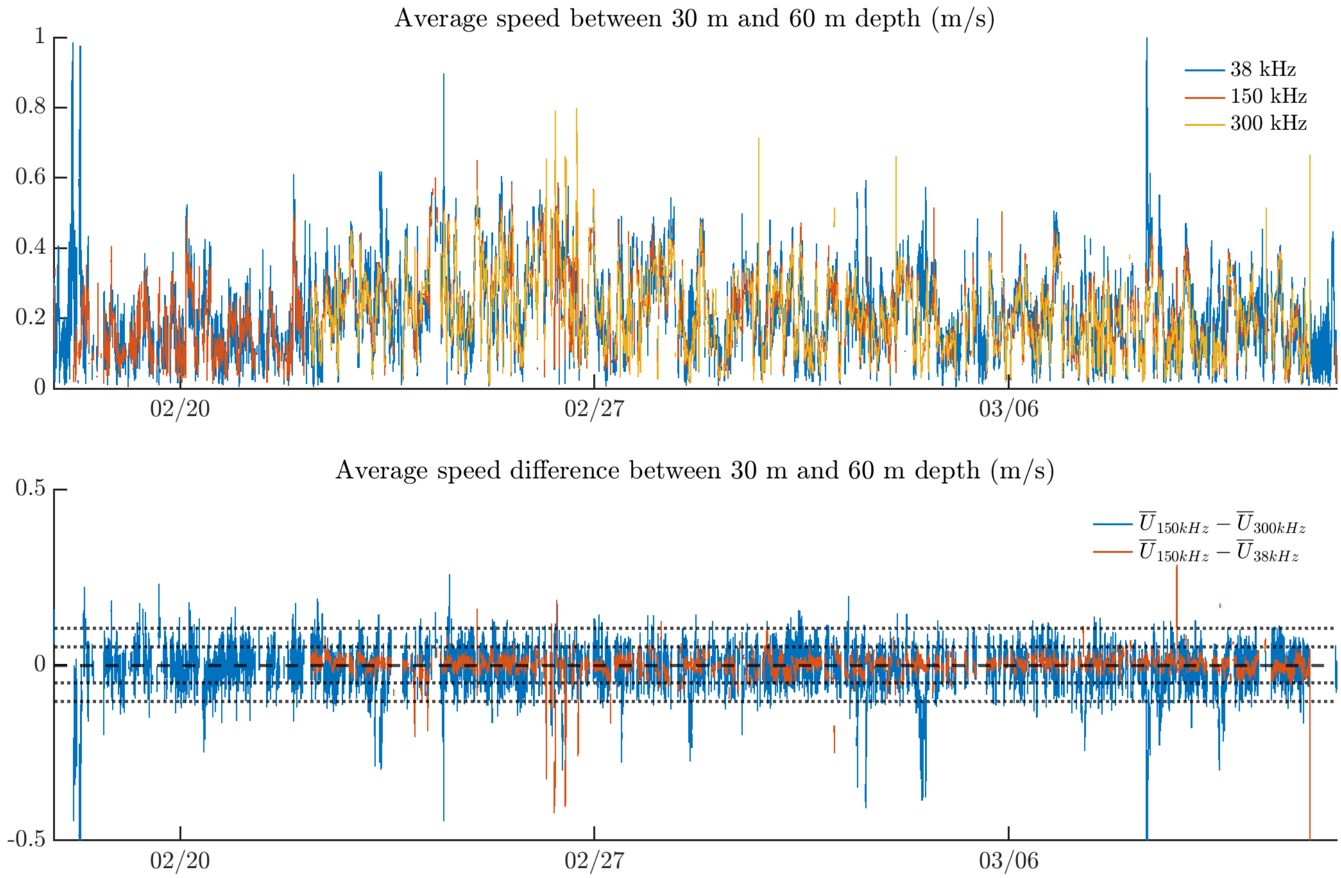

Figure 33: Depth averaged speed compared between the 38 kHz, 150 kHz and 300 kHz ADCPs. Lower plot shows the difference between the 150 kHz and the 300 kHz as well as the difference between the 150 kHz and the 38 kHz. Thresholds for QC are marked using dotted lines.

10.2.2 Comparison with Lowered ADCP

10.3 Pelagia Shipboard

10.4 Pourquoi Pas? Lowered

10.5 WireWalker

Acknowledgement

This work was funded by ONR, as part of the CALYPSO project. We thank the captain and crew of the RV Pourquoi Pas? and the RV Pelagia and all the cruise participants and for their work on the vessel and in port.

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