A project supported by the European Union's INTERREG VA Programme, managed by the Special EU Programmes Body (SEUPB).

Report for Collaborative Oceanography and Monitoring for Protected Areas and Species (IVA5015)

Deliverable T1.4.1
Data flow to data management systems (glider)

March 2020

Report by: Scottish Association for Marine Science
Report authors: Estelle Dumont, Karen Wilson, Emily Venables, Andrew Dale

Executive Summary

Within the T1 observational programme of COMPASS, glider missions in the summers of 2018 and 2019 have provided high-resolution datasets of water properties from the Malin shelf, spanning coastal Irish waters, coastal Scottish waters and Atlantic influenced waters near the shelf edge. Detailed here are the first two COMPASS glider missions, from 13/8/2018 to 19/10/2018 and from 6/8/2019 to 19/9/2019. In both cases, detailed mission narratives are provided as well as a description of the data processing methodologies used in post-processing. The 2018 mission was problematic due to poor flight behaviour and bad/irregular flow through the conductivity sensor. Both of these issues became worse with time and are suspected to have resulted from biofouling. Measures taken to salvage salinity and density data are described. The generated datasets have been passed into the COMPASS data management system.

Contents

Section A
Glider mission report: COMPASS 1 (2018)

Acknowledgements: The glider was piloted by Karen Wilson, Estelle Dumont, Neil Fraser, Colin Abernethy, Loic Houpert, Mark Inall and Emily Venables.

A.1. Objectives

Funded by the EU INTERREG VA (Special EU Programmes Body SEUPB, https://compass-oceanscience.eu/), the COMPASS project is a 5 year program establishing a network of oceanographic and acoustic moorings within and adjacent to cross-border marine protected areas (MPAs), which will produce new marine monitoring data for emerging areas of environmental concern including ocean acidification and the long-term impacts of anthropogenic noise on marine life. It will also help fulfil international, European and national biodiversity obligations. COMPASS will deliver a clearer understanding of what changes in the oceanographic climate have on underwater habitats, fauna and flora across the region. The project will also develop an innovative acoustic tag programme to understand the migration patterns, the behaviour and mortality of salmon and sea trout in the North Western part of the Irish Sea.
The interregional perspective will allow data to be captured and shared across Northern Ireland, the Border Region of Ireland and Western Scotland and help in the development of effective future monitoring programmes for MPAs.
To complement the mooring installations and ship-based observations, SAMS is conducting underwater glider surveys in the Malin Shelf area for a period of approximately 6 to 8 weeks every summer from 2018 to 2021. The primary aim of these is to collect oceanographic water-column measurements (depth, temperature, salinity, oxygen, fluorescence, optical backscatter), as well as passive acoustic sensor monitoring of marine mammals.

A.2. Equipment and methodology

The Seaglider is a long-range Unmanned Underwater Vehicle (UUV) designed to carry out long-term oceanographic surveys down to a depth of 1,000m. A system of buoyancy engine, moveable internal weights and hydrodynamic design allows the instrument to slowly dive up and down the water column in a saw-tooth pattern whilst using very little energy compared to a propeller-driven UUV, allowing for endurances of up to 7 months. The glider is equipped with GPS for navigation (as well as compass and attitude sensors while underwater) and is remotely operated via Iridium. When at the surface (every few hours) it transmits its location and collected data, and pilots are able to check on its status and adjust technical parameters, trajectory or data sampling.
The glider used for the COMPASS 1 mission is Seaglider SG647 'Corryvreckan', owned and operated by SAMS. It is equipped with:

- SeaBird CTD sail (pressure, temperature and conductivity)
- Aanderaa AA4831 dissolved oxygen optode
- WetLabs triplet (chlorophyll-a, CDOM and uranine fluo)
- DTAG Passive Acoustic Monitoring sensor developed by SMRU (Sea Mammal Research Unit, St Andrews University)

Seaglider technical specifications:

- Dimensions: 1.8 long (+ 1m antenna),
- 30 cm diameter, 1m wing span
- Ogive fairing
- Endurance: 4,000 km or 7 months
- Operating depth range: 50 to 1000 m
- Average horizontal speed: 25 cm/s
- Average vertical speed: vertical speed 10cm/s
- Glide angle: 15-45°
- Power source: 2 x primary Lithium battery packs, 310AH (15V) combined capacity

Figure 1: full view of Seaglider

A.3. Deployment narrative

Diplomatic clearance for this deployment was requested from the Republic of Ireland and obtained in April 2018.
Prior to deployment the standard pre-deployment checks were carried out on the glider (self-test, compass check, compass calibration). The compass readings appeared to show an error of up to 12° on the "calibrated" readings. This error was deemed tolerable for navigation at the start of the deployment, and the plan was to perform an in-situ compass calibration when the glider reached deep water after crossing the shelf break.

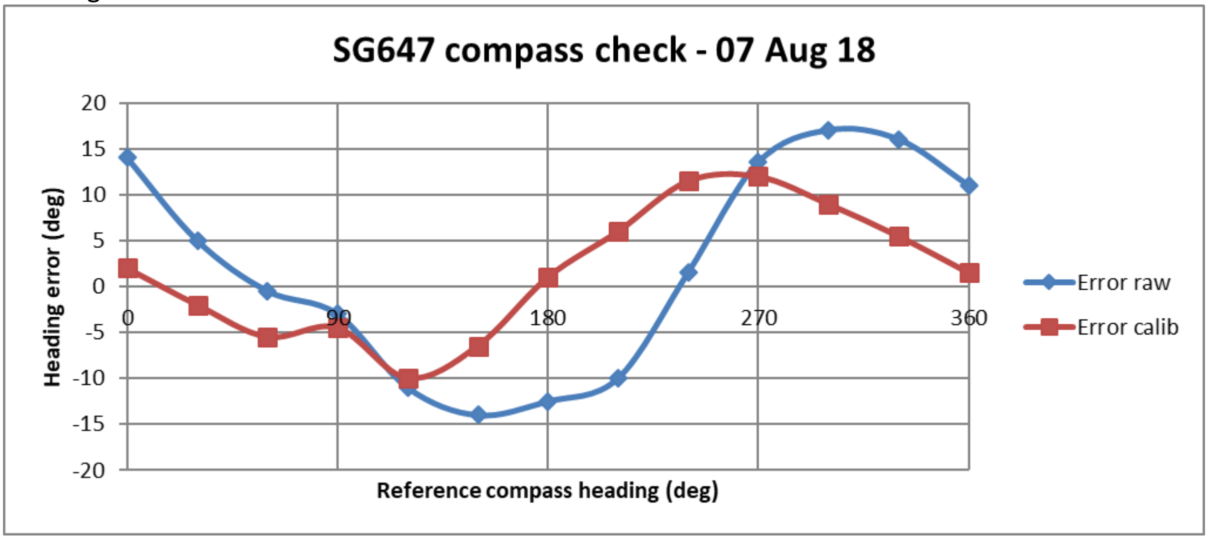


Figure 2: Corryvreckan's compass check pre-deployment. The glider used the calibrated readings for navigation during the mission (in red, max error 12°).

All time noted below are UTC.

13-Aug-18: Glider deployed in position 56° 45.864'N, 6° 59.112'W at 11:45 from RHIB Schiehallion (company Costal Connection, Oban, call sign 2GJN7). A CTD cast was conducted once the glider was in the water. All sensors on (CTD, Aanderaa optode, WetLabs). Boat team: Estelle Dumont, Emily Venables. Pilot: Karen Wilson.
19-Aug-18: Glider reached waypoint S1 (56° 32.000'N, 7° 35.000'W) at dive 147.
24-Aug-18: Glider reached waypoint S2 (56° 20.000'N, 7° 36.000'W) at dive 285.
25-Aug-18: Glider reached waypoint S3 (56° 12.000'N, 7° 32.000'W) at dive 321.
28-Aug-18: Glider reached waypoint S4 (56° 05.000'N, 7° 37.000'W) at dive 417.
29-Aug-18: VBD retries between dives 437 and 453 (increasing up to 6 per dive). A/D rates appear to have dropped to just below the nominal threshold of 4 AD/s which triggered the retries. The drop does not seem significant enough to be caused by a stuck piston, it could be that the pump is running a bit slow (to be confirmed during refurbishment). On the advice of Kongsberg $VBD_PUMP_APOGEE_AD_RATE was lowered from 4 to 3 at dive 454. No further retries observed after that.
29-Aug-18: Glider entered Irish EEZ at dive 447, Irish authorities notified.
31-Aug-18: missing data during some dive phases since yesterday (no raw data for dive, but collected during climb). The problem started to appear intermittently at dive 472, 477, 486, 490, 492 then constantly from dive 497 onwards. The Scicon showed error messages for those at the start of the dive (ok at the start of the climb):
```
HSCICON,N,no prompt after cmd log start
```
Kongsberg advised that they had seen this once before and had come to the conclusion that the problem was due to the SciCon taking longer to start up due to a significant number of files on the SD card. One temporary fix suggested was to activate the debug mode for SciCon. This was implemented at dive 511 and appeared to fix the problem.
10-Sep-18: Glider is in about 85m of water and has been struggling to make much progress over the past few days, target switched to the next waypoint on the shelf break before reaching S5. Southernmost point reached at dive 890 (55° 26.708'N, 8° 20.960'W).
13-Sep-18: optode and WetLabs turned off at dive 1026 onwards to save energy. Issues with real-time data plotting following this so the pilot turned sampling back on at dive 1071. It turned out the plotting problem was unrelated to the change in sampling and due to a SAMS server issue.
14-Sep-18: SciCon problem again (no data collected during dive, data ok during climb) from dive 1080 onwards. Pilot did not detect the problem for a few days.
15-Sep-18: Glider has struggled to head North-West towards the shelf break and has been travelling North-East instead until dive 1085 (55° 46.063'N, 7° 51.825'W).
18-Sep-18: optode and WetLabs turned off from dive 1176 onwards to save energy.
20-Sep-18: files deleted off the SciCon card to fix the start-up bug, data being recorded again on both dive and climb from dive 1229.
22-Sep-18: North-West transect until dive 1295 (56° 00.336'N, 8° 45.006'W). The glider has started rolling a lot and doing sharper turns (flight path showing zigzags).
25-Sep-18: Glider left Irish EEZ at dive 1370, Irish authorities notified.
26-Sep-19: SciCon issue again since yesterday, no dive data for dives 1367 to 1395. Files deleted from card, data ok again from dive 1296.
27-Sep-18: Struggling to head North-West, Northward transect instead until dive 1410 (56° 20.480'N, 8° 39.438'W).
29-Sep-18: The flight behaviour has carried on degrading over the past week. Attempt to reduce the zigzags by adjusting various parameters over the next few weeks:

- Trimming $C_ROLL_DIVE and $C_ROLL_CLIMB often
- Reducing $ROLL_DEG and increasing to minimise the roll amount (down to 10 to 15, less than this and the turns become worse if the roll centres are not exactly trimmed)
- Testing various GC intervals and $HEAD_ERRBAND to get the glider to adjust course (i.e. initiate turns) more or less often

- Test optimal speed: going too slow causes more rolling, but too fast means the glider does not stop a turn in time and starts doing full loops.
- The extra speed caused a lot of pumping to maintain the speed on the climb, making the glider slow, increasing the roll and letting it go in the wrong direction for too long. Extended $T_DIVE but reduced $PITCH_GAIN in order to “trick" the glider into taking a steeper angle while asking for a low speed – i.e. effectively increasing the speed using the diving angle rather than buoyancy.
- Attempt to use auto-roll control ($ROLL_ADJ_GAIN and $ROLL_ADJ_DBAND), which proved unsuccessful

08-Oct-18: Glider has been struggling to fly even more (now sometimes doing loops under water) and has stayed within a 25km radius for the past 10 days. It got within 5km of waypoint S6 without being able to reach it and get into deep water. The flight behaviour problem seems unrecoverable and likely to degrade further so the decision was made to abort the mission and send the glider home at dive 1710 (56° 31.974’N, 8° 54.295’W). Started contacted RHIB charter companies in the Outer Hebrides in case an emergency recovery is required.
13-Oct-18: Glider put into recovery at 09:50 after dive 1840 to observe surface drift and assess if it would help in getting it home. Surface currents pushing the glider South (following the tide rather than wind), which is not where we want to go. Diving resumed at 18:30.
19-Oct-18: Glider has become completely uncontrollable due to all the looping and has been heading North (attempting to fly but mostly being pushed by the currents). Emergency recovery carried out by the Enchanted Isles (company Sea Harris, Tarbert, call sign 2HZQ8) at 13:25 in position 57° 27.088’N, 7° 59.648’W. Boat team: Enchanted Isle crew (no SAMS personnel). Pilot: Estelle Dumont.
The glider was offloaded in Tarbert and brought back to SAMS several weeks later due to staff unavailability and ferry cancellations because of storms. Datafiles not transmitted correctly during the mission were offloaded from the CF and SciCon cards.

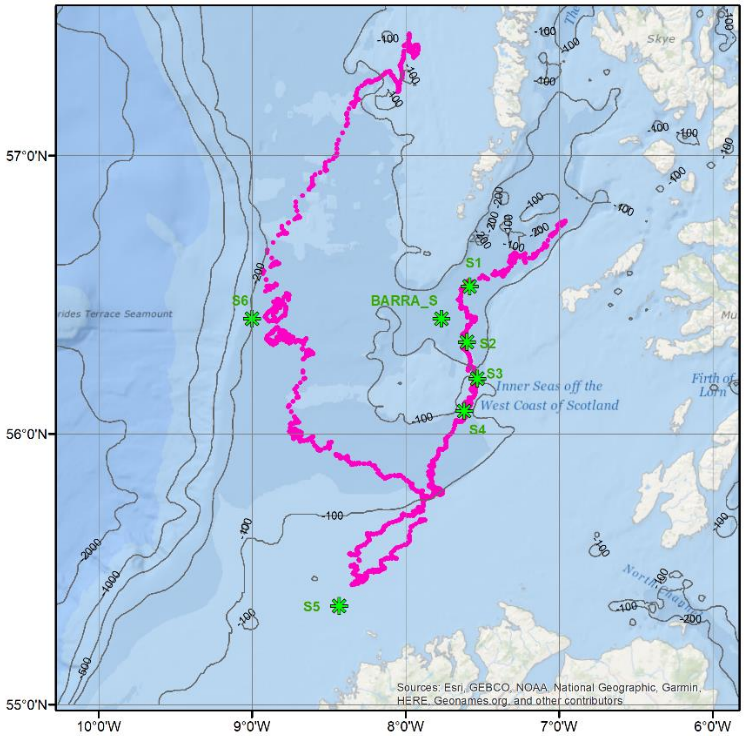


Figure 3: COMPASS1 glider track

A.4. Mission statistics

During this deployment Corryvreckan carried out 2052 dives in 67 days, and covered a distance of 480 km (direct line). The battery usage was 90%, which is very high and due in large part to the increased buoyancy used to maintain speed (to counteract the roll issue), and to the fact that we continued diving in order to get the glider closer to the coast towards the end of the mission.
The very poor flight behaviour meant that the glider could have been lost, had it not been for that emergency boat recovery. We had never encountered this problem before, but another of our gliders (SG616, on mission OSNAP 11), deployed at the same time in the Rockall Trough, displayed the same behaviour. It is suspected heavy biofouling and growth on the glider affected its hydro-dynamism and flight behaviour, made worse by the ogive fairings (all our previous summer missions used standard fairings). Re-runs of the hydrodynamic model show an increase in drag throughout the mission and seem to confirm this theory (see section 5.2).

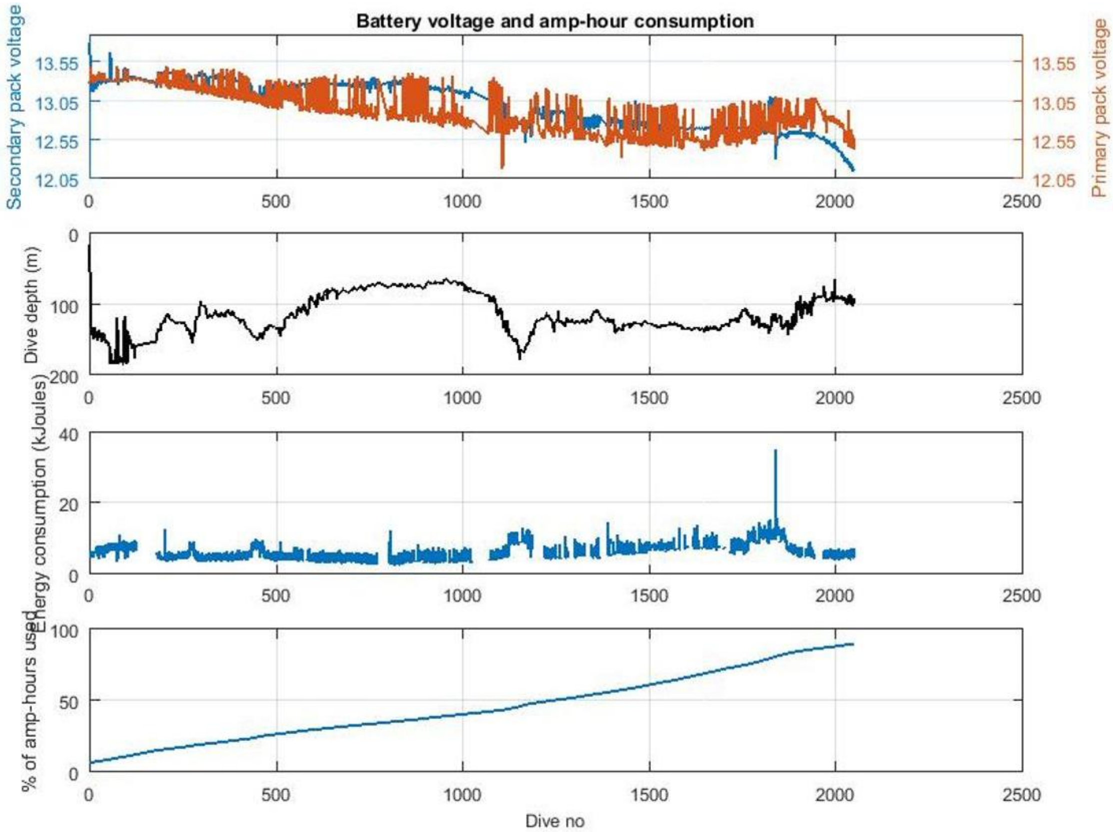


Figure 4: battery data for full mission

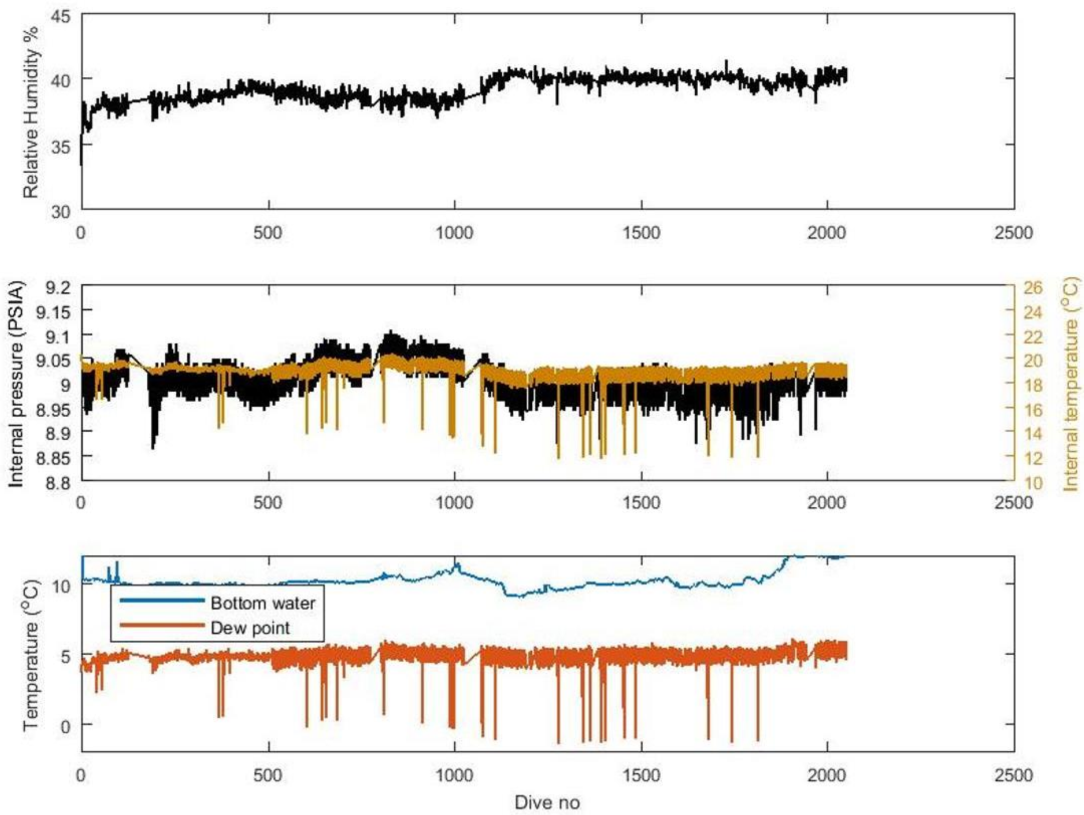


Figure 5: internal sensors data for full mission

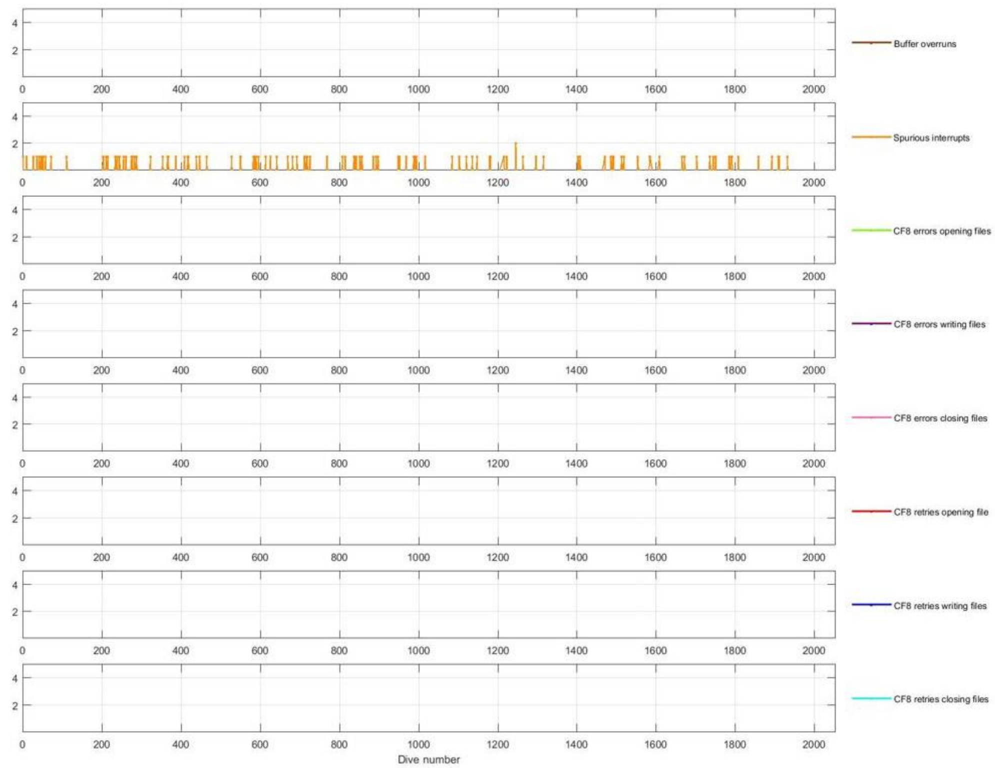


Figure 6: summary of errors during mission (part 1/2)

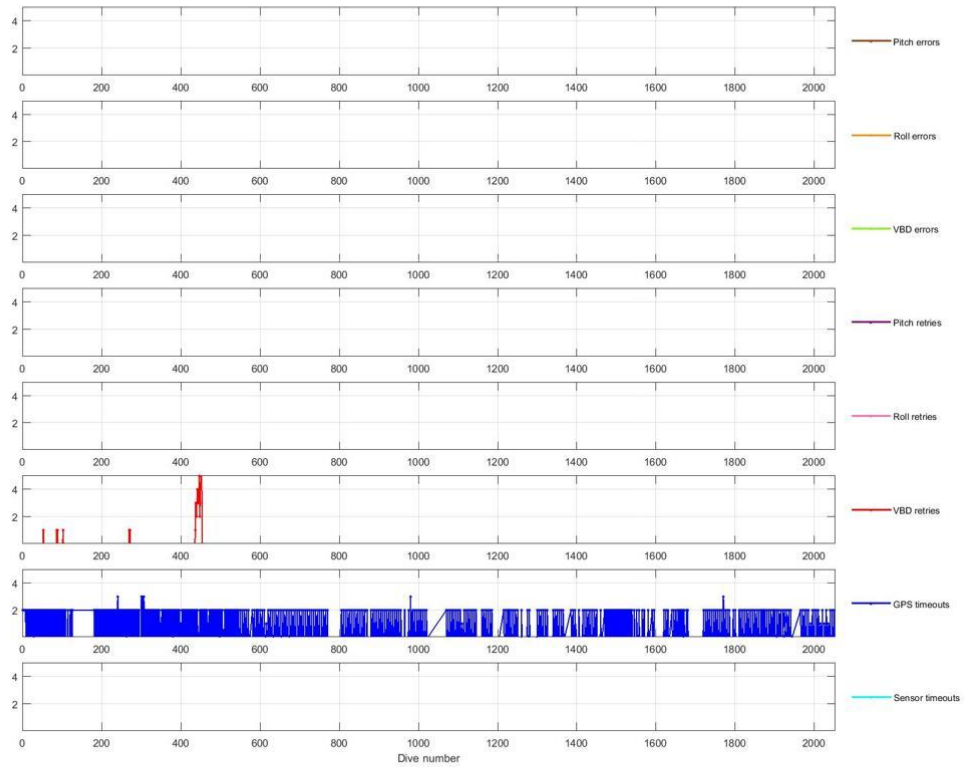


Figure 7: summary of errors during mission (part 2/2)

A.5. Data processing

5.1. Sensor cross-comparison

A CastAway CTD cast was performed at deployment, the glider CTD sensor was in good agreement (see Figure 8).

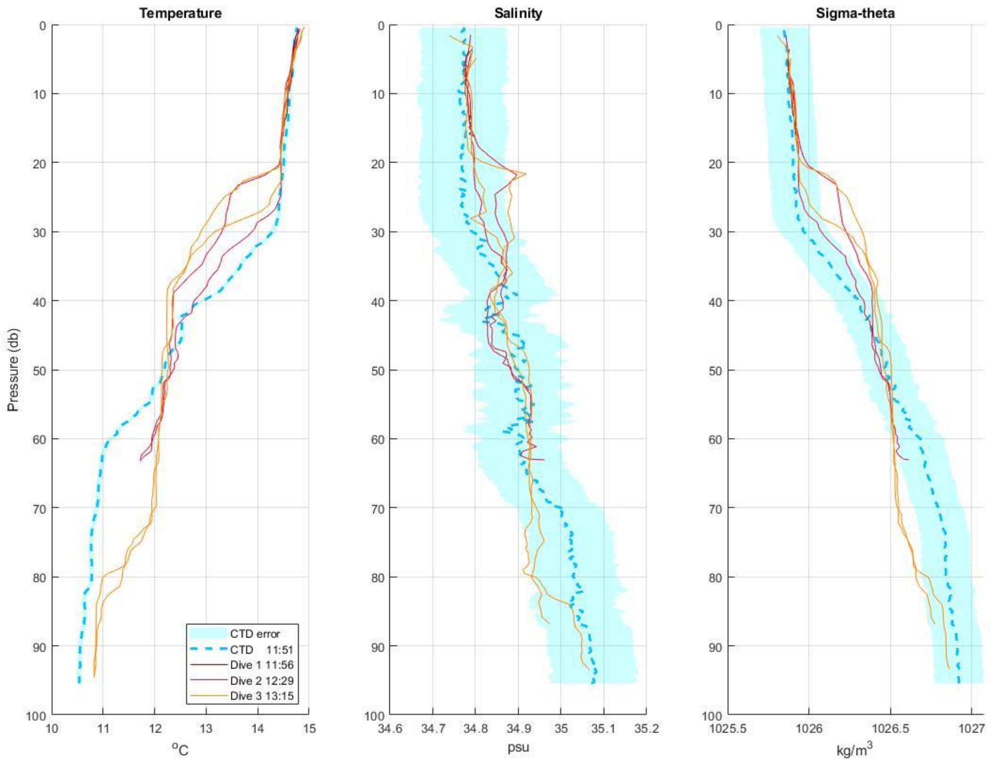


Figure 8: Comparison of glider and CTD data at deployment. The blue bands indicate the CTD nominal accuracy. The glider temperature sensor shows an offset in the thermocline depth at dives 2 and 3, however those dives started 30 and 85 minutes after the CTD cast and might be a result of the tidal effect on the water column. The surface layer values remain in very good agreement. Overall the glider sensors readings were deemed acceptable.

No CTD cast was performed at recovery (emergency recovery, no SAMS personnel onboard).

5.2. CTD data processing and hydrodynamic model regression

During the mission the basestation performs some level of data QC in real-time:

- Conversion of raw sensors readings to scientific units
- Hydro-dynamic model regression using standard coefficients in order to get an estimate of the glider flight and water flow through the conductivity cell
- Calculation of derived variables (salinity, density, etc)
- Removal of large outliers
- Correction of CT thermal mass effect in salinity data, based on empirical equations using the standard glider hydrodynamic coefficients

Post-mission the Seaglider hydrodynamical model was re-run in order to determine the best flight coefficients for this mission: volume (volmax), lift (hd_a), drag (hd_b) and induced drag (hd_c). This is an important step not only to determine the glider's speed and trajectory under water, but also to better estimate the water flow through the conductivity cell which in turn is used in the salinity calculations. Usually the hydrodynamic coefficients are regressed using several deep dives data, selected throughout the mission and showing a wide range of pitch angles. As this mission contains only short dives (shallow water) the data is limited, and it was decided to use all the dives in the regression instead.
As described previously the glider suffered serious issues of excessive rolling and looping, thought to be due to biofouling on the glider. The poor flight behaviour also meant that the basestation flagged a lot (25

to 50%) of the data as “bad” during the real-time processing. Regressions were run in groups of 100 dives, to try establishing the evolution of each hydrodynamic coefficient through time. The initial regressions run were not very successful as there were little data to run the regressions with (due to the basestation processing often flagging whole dive or climb CTD profiles as bad), and the regression script excluding records when the glider was rolling by more than 10° (which, as the mission progressed, was most of the time). The roll tolerance was set to 50° and the model run several times (7), adjusting the coefficients each time, until an acceptable result was produced (judged by the model final RMS, and the effect on CT thermal lag corrections).

The final regression results are presented in Figure 9, and can be summarised as:

- The lift (hd_a) was found to be relatively stable during the mission and an average value was deemed acceptable (minus one outlier, assumed to be the result of an unsuccessful regression).
- The induced drag (hd_c) appeared to change mid-way through the mission. It is unclear why, but the change was very small and would not have a major impact on the final dataset. The two average values were used in the final processing.
- As expected the drag (hd_b) showed a clear increase towards the end of the deployment. For the final processing an average drag value was used up to dive 800 then the individual regression values for each block of 100.
- Volmax appeared stable up to dive 1100, then increasing before remaining stable for the last ~250 dives. The final model regression shows a suspicious decrease in volmax between dive 1200 and 1500. While a slight increase in volume could be conceivable due to the growth on the glider it is difficult to understand why the volume would reduce, therefore those data points were ignored and the same average volmax from dive 1 to 1100 was used instead in the final processing. From dive 1500 onwards the individual hd_b regression values were used for each block of 100 dives.

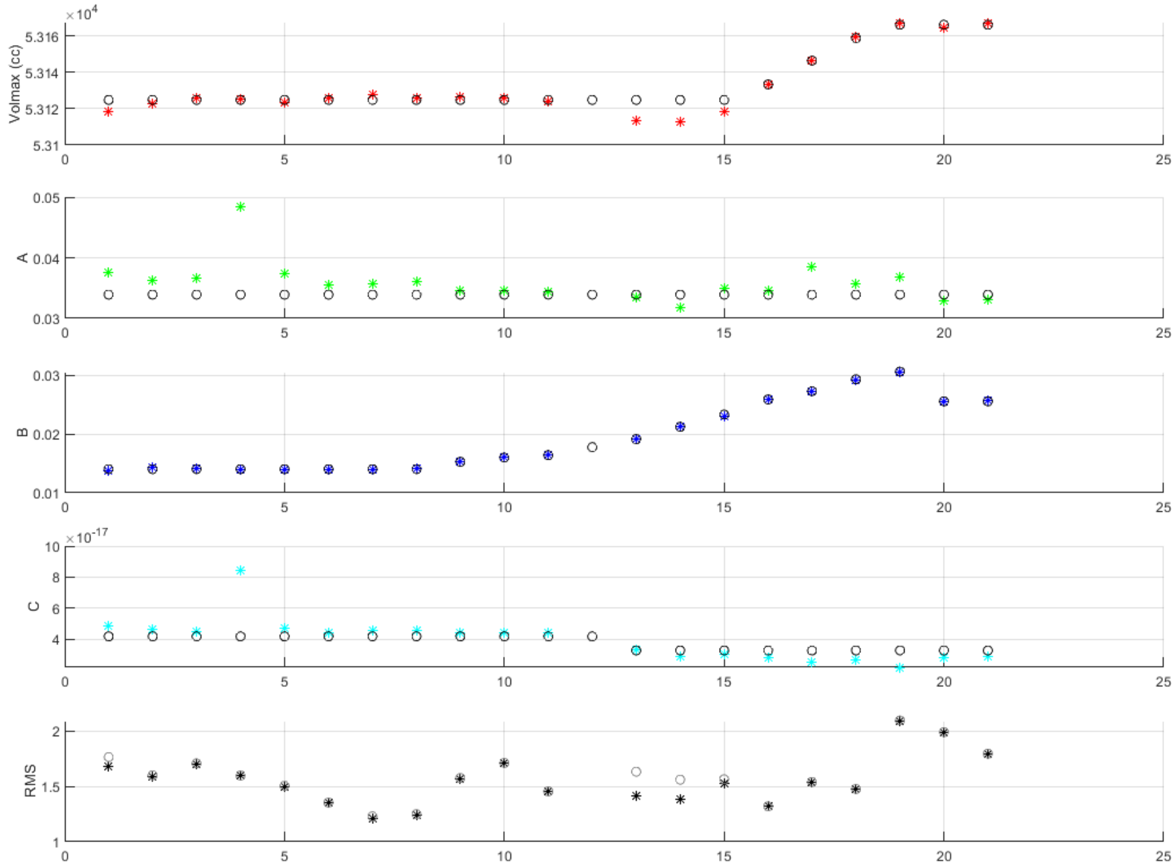


Figure 9: hydrodynamic model regression results for blocks of 100 dives on the x-axis. VOLMAX = glider volume, A = lift, B = drag, C = induced drag, and average values for each (pink). RMS = regression root-mean square error using original coefficients (grey) and new regressed coefficients (black).

<table>
<tr><th>Dives</th><th>VOLMAX</th><th>HD_A</th><th>HD_B</th><th>HD_C</th></tr>
<tr><td>0001 - 0799</td><td rowspan="8">53124.8</td><td rowspan="14">3.392186e-02</td><td>1.403821e-02</td><td rowspan="4">4.205735e-17</td></tr>
<tr><td>0800 - 0899</td><td>1.527715e-02</td></tr>
<tr><td>0900 - 0999</td><td>1.600819e-02</td></tr>
<tr><td>1000 - 1099</td><td>1.641462e-02</td></tr>
<tr><td>1100 - 1199</td><td>1.777978e-02</td><td rowspan="10">3.301600e-17</td></tr>
<tr><td>1200 - 1299</td><td>1.914495e-02</td></tr>
<tr><td>1300 – 1399</td><td>2.124275e-02</td></tr>
<tr><td>1400 – 1499</td><td>2.331705e-02</td></tr>
<tr><td>1500 – 1599</td><td>53133.3</td><td>2.588788e-02</td></tr>
<tr><td>1600 – 1699</td><td>53146.4</td><td>2.730229e-02</td></tr>
<tr><td>1700 – 1799</td><td>53158.8</td><td>2.931840e-02</td></tr>
<tr><td>1800 – 1899</td><td rowspan="3">53166.1</td><td>3.062345e-02</td></tr>
<tr><td>1900 - 1999</td><td rowspan="2">2.556403e-02</td></tr>
<tr><td>2000 - 2052</td></tr>
</table>

Figure 10: Summary table of coefficients used in hydrodynamic model calculation for the final processing

The raw data was reprocessed on the basestation using the coefficients above. The processed salinity data still showed some issues, dealt with in further post-processing in Matlab:

1) Spikes, mostly at the apogee. The outliers were selected and set to NaN when the difference between successive readings was over 10 standard deviations of the mean.
2) The thermal lag effect was not fully corrected by the basestation processing. It was decided that the best course of action was to interpolate the salinity data across the halocline area instead of

performing further empirical corrections. After testing several halocline detection techniques the most optimal parameters were found to be selecting the parts of the profiles with a temperature gradient exceeding ±0.04°C/s and/or a conductivity gradient exceeding ±0.004mS/cm/s, plus an additional 3m vertically either side. Tests with larger thresholds (i.e. selecting areas of stronger gradients) resulted in poor cell thermal lag correction, and smaller thresholds in removing “real” water column features from the data.

Figure 11 shows an example of the difference between the raw salinity data, the data initially processed by the basestation processing, and the final processed data with outliers removed and salinity interpolated across the thermocline.

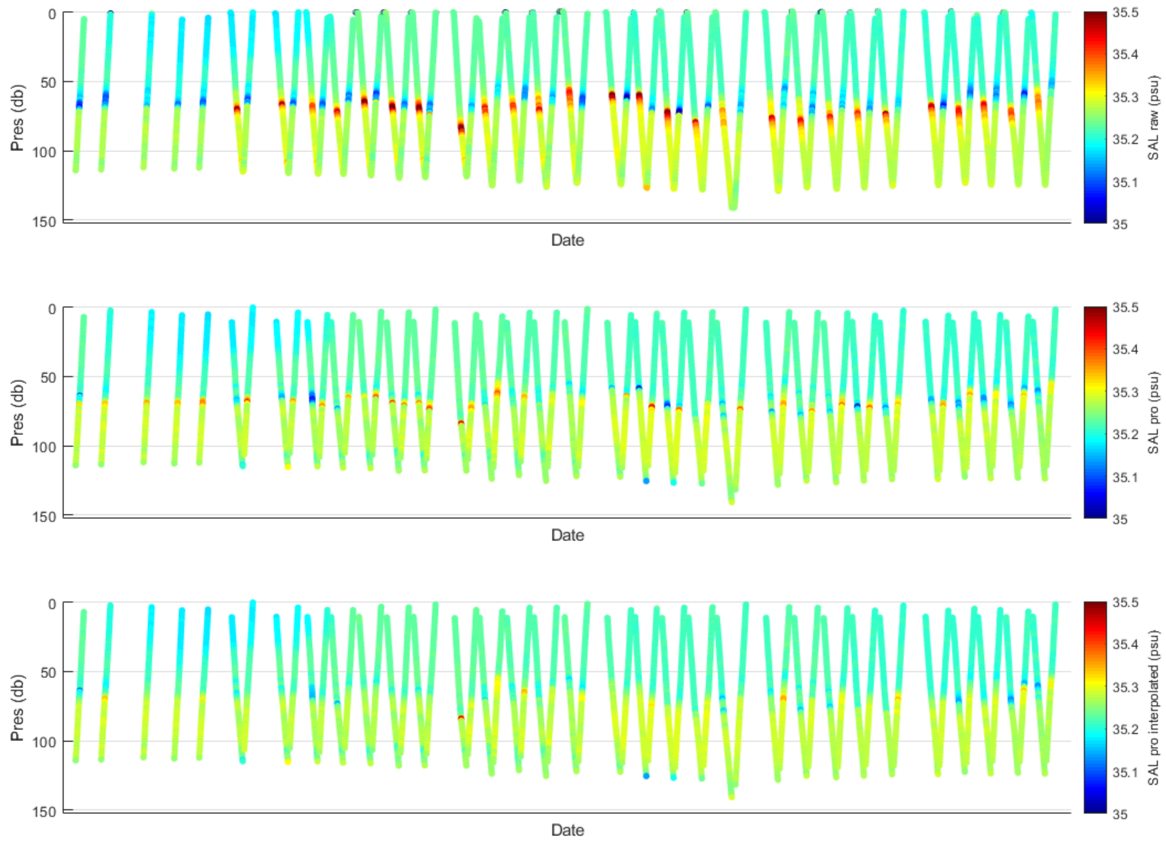


Figure 11: raw (top) vs basestation processing (middle) vs final processing (bottom) of salinity data for a subset of the mission Each dive (up and down profile) lasts about 30 minutes. The raw data is derived from the pressure, temperature and conductivity readings without any thermal lag correction, and shows cell thermal lag effect in the halocline area around 60m (salty water on the dive, fresher water on the climb). This effect is reduced after the basestation processing (empirical thermal lag correction using the water flow through the conductivity cell calculated with the regressed hydrodynamic coefficients), and almost completely removed after interpolating the data across the halocline.

The CTD data quality deteriorated throughout the mission due to the poor flight behaviour and bad / irregular flow through the conductivity cell. The data at the very end at the mission is untrustworthy and should not be used, but it is hard to say exactly when the data became unusable (maybe around dive 1400?). Future users of the dataset are advised to review the data with care and make their own assessment of data quality.

5.3. O2 data processing

The O2 values from the Aanderaa optode were corrected internally by the sensor for temperature, and corrected for salinity and pressure effect during the basestation post-processing. The dive and climb profiles show a slight mismatch, likely to be due to the thermal lag effect in the salinity data.

No cross-comparison with CTD or Winkler titration was performed, however the optode was calibrated before the mission and will be checked again post-mission.

5.4. WetLabs data processing

No further processing was done on the WetLabs data. No calibration or comparison of that sensor has been carried out (apart from the manufacturer in-lab calibration). The data collected seemed reasonable.

5.5. Coordinates remapping

During deep water operations the glider gets GPS fixes between each dive, and the basestation automatically calculates underwater positions based on the GPS fixes and the hydrodynamic model. For shallow water missions the glider is set to do several dives in a row (typically 3 to 5), and the lack of GPS fixes prevents the basestation to calculate underwater position. These were recalculated in Matlab in post-processing, by linearly interpolating coordinates between the GPS fixes at the start and end of a subset of dives. I.e. they do not take into account the glider's behaviour (e.g. speed and turns) but should provide a reasonable estimate of its position within ~100m.

5.6. Transect plots

The transect plots below are of the final processed data.

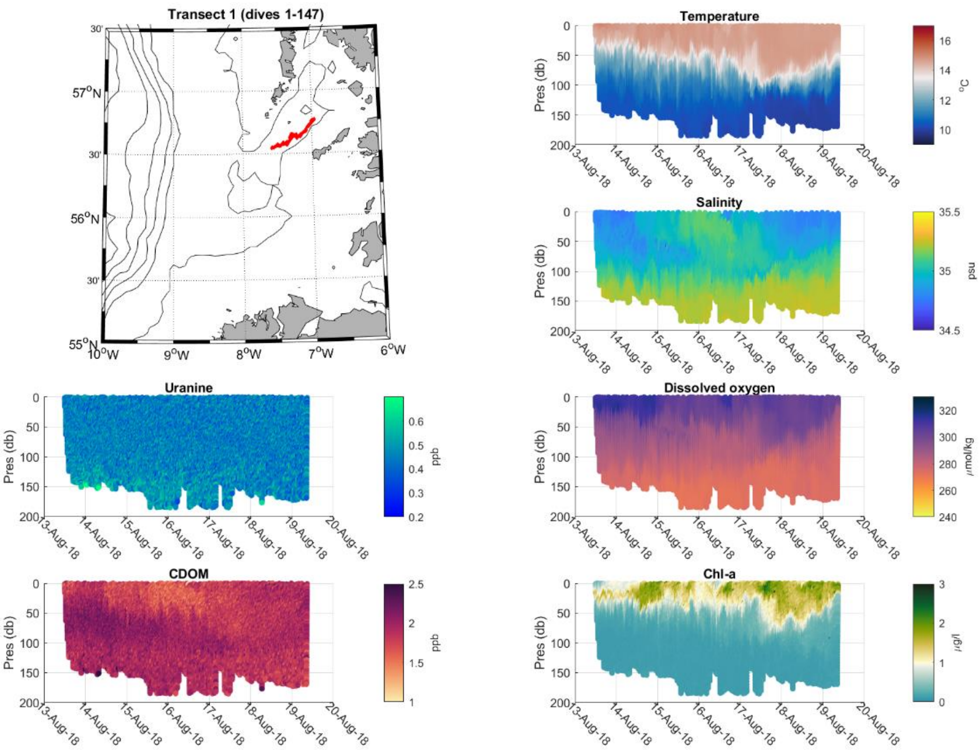


Figure 12: Map and science plots of Leg 1 (SW), 13 to 19 Aug 18, deployment site to S1

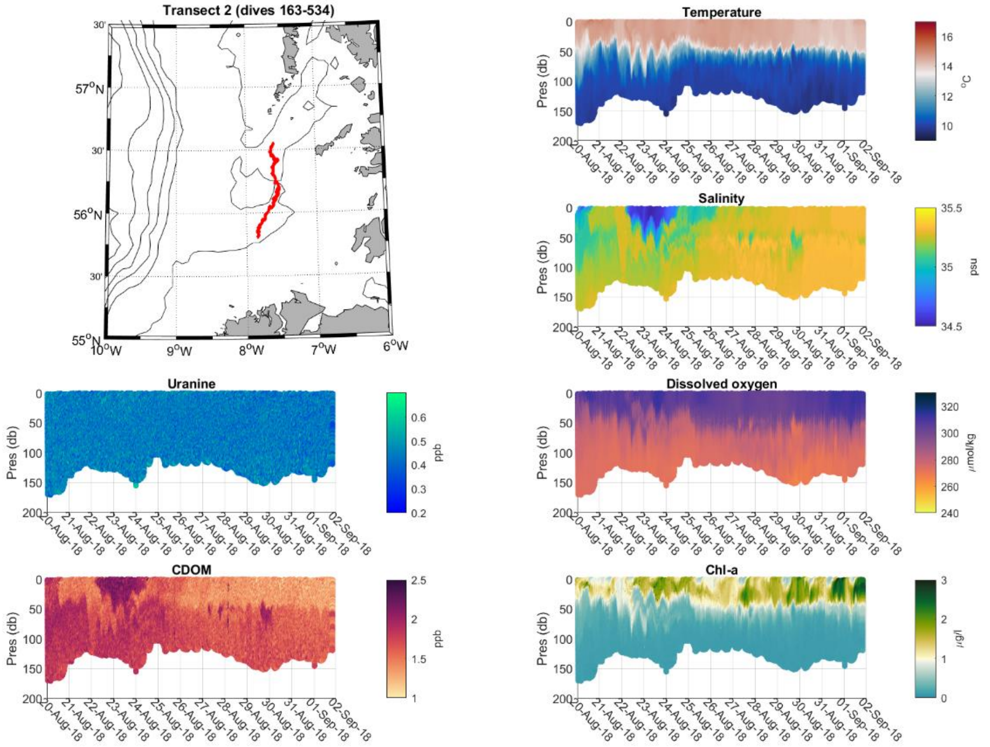


Figure 13: Map and science plots of Leg 2 (S), 20 Aug to 02 Sep 18, S1 to VM1 (half-way between S4 and S5 on the 100m contour).

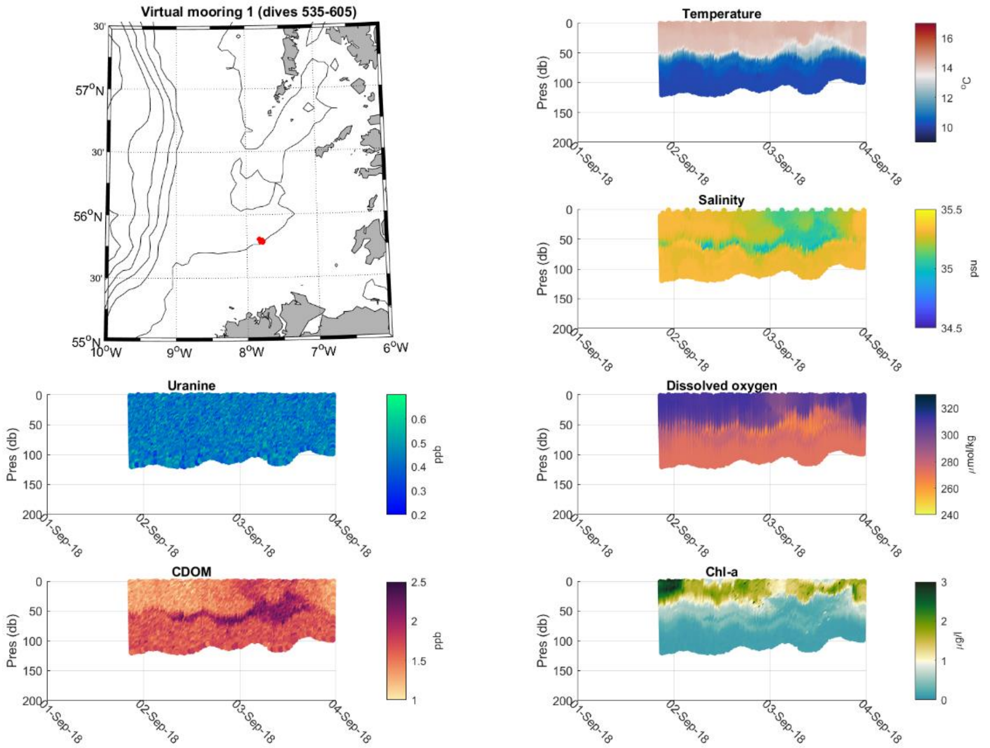


Figure 14: Map and science plots of Virtual Mooring 1, 02 to 04 Sep 18 (55° 45'N 7° 50'W, 120m deep, half-way between S4 and S5).

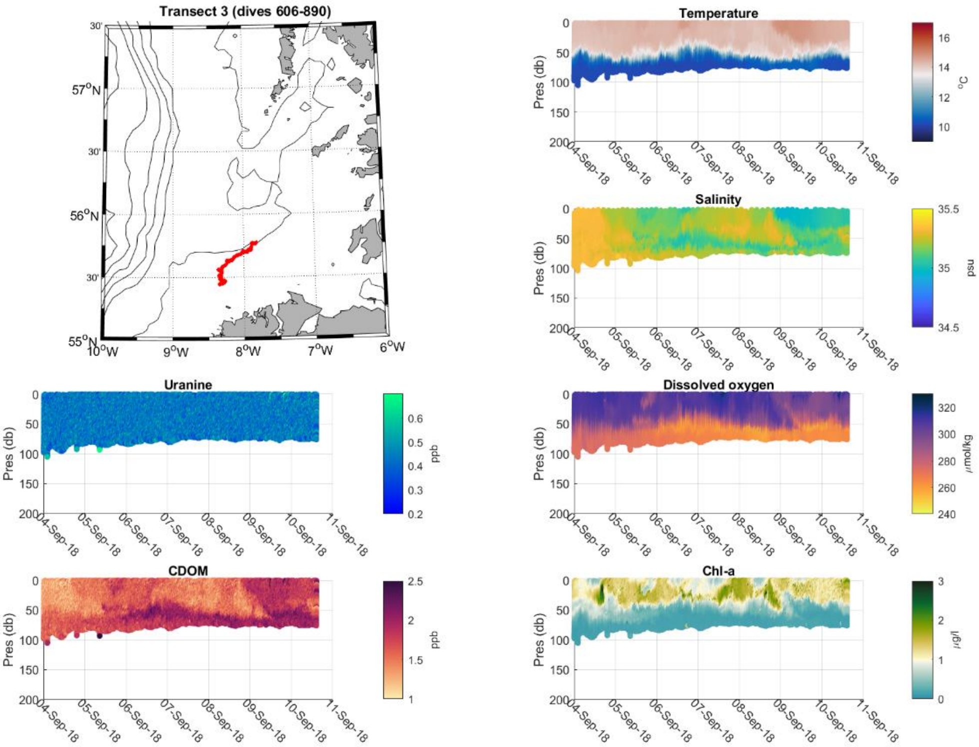


Figure 15: Map and science plots of Leg 3 (SW), 04 to 10 Sep 18, VM1 to ~S5.

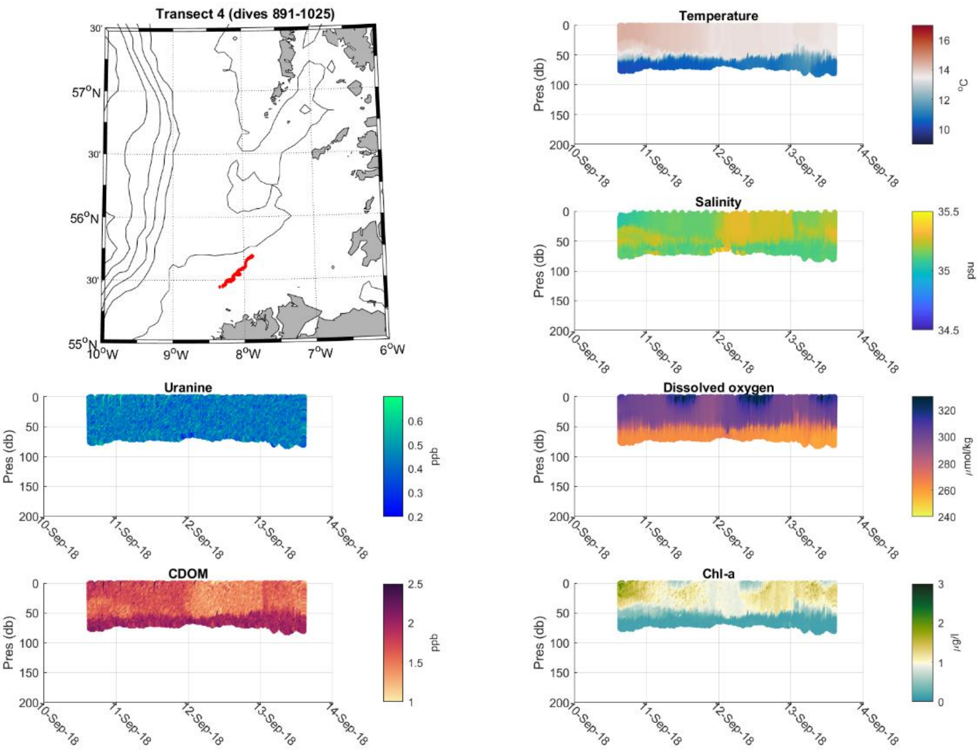


Figure 16: Map and science plots of Leg 4 (NE), 10 to 13 Sep 18, ~S5 to ~VM1.

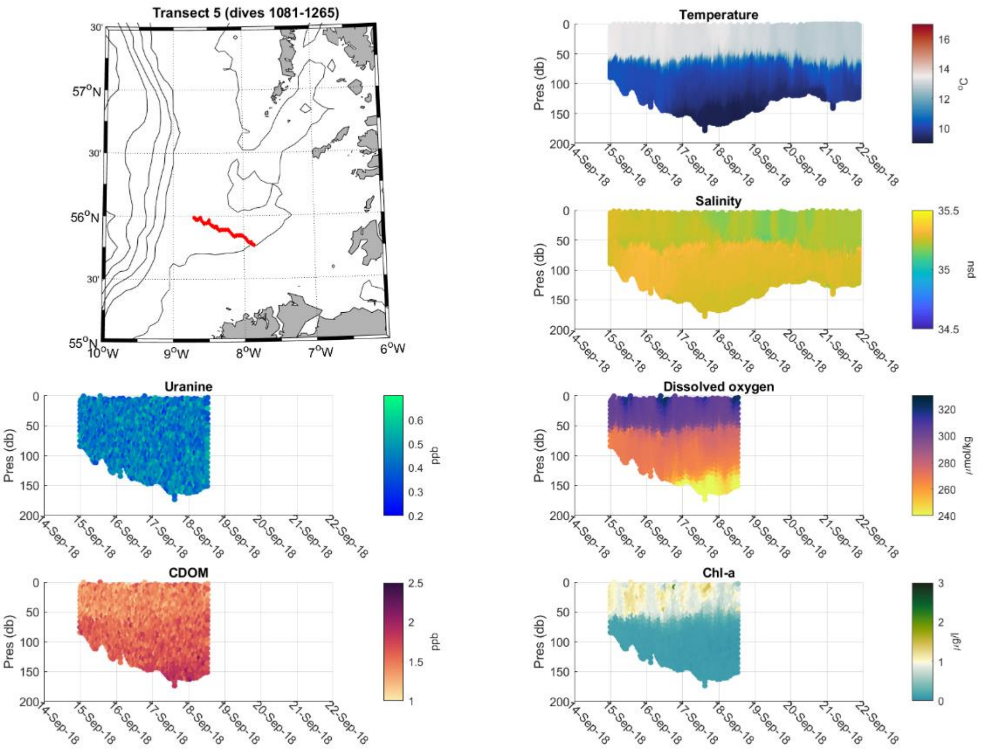


Figure 17: Map and science plots of Leg 5 (WNW), 14 to 22 Sep 18, VM1 to VM2.

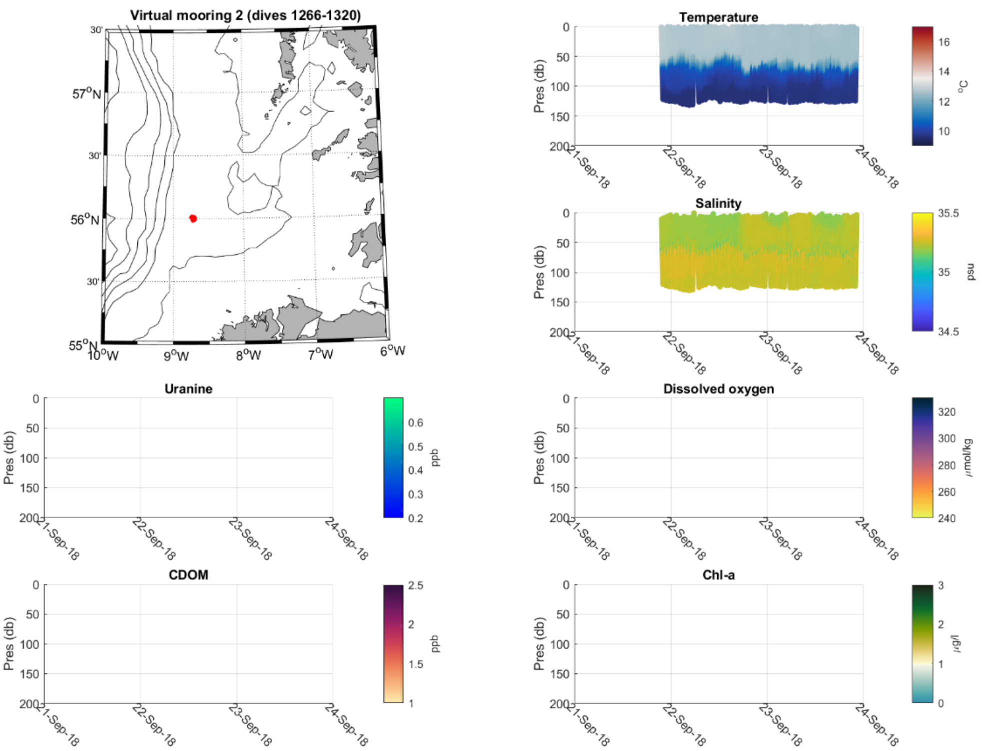


Figure 18: Map and science plots of Virtual Mooring 2, 22 to 24 Sep 18 (56° 00’N 8° 43’W, 140m deep).

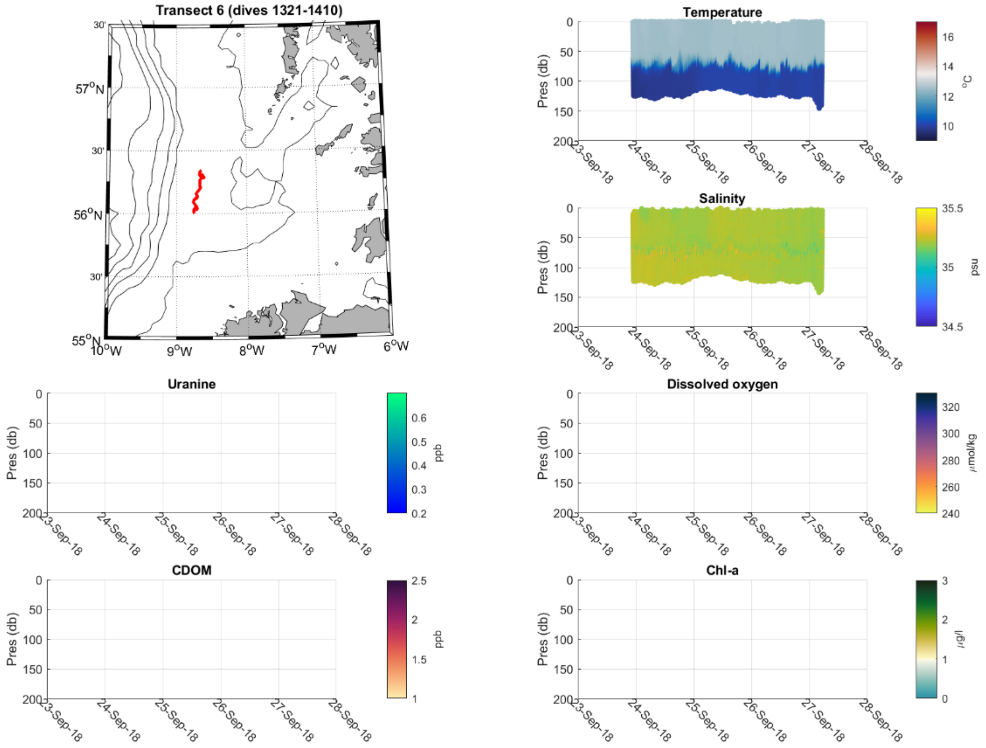


Figure 19: Map and science plots of Leg 6 (N), 24 to 27 Sep 18, VM2 to VM3.

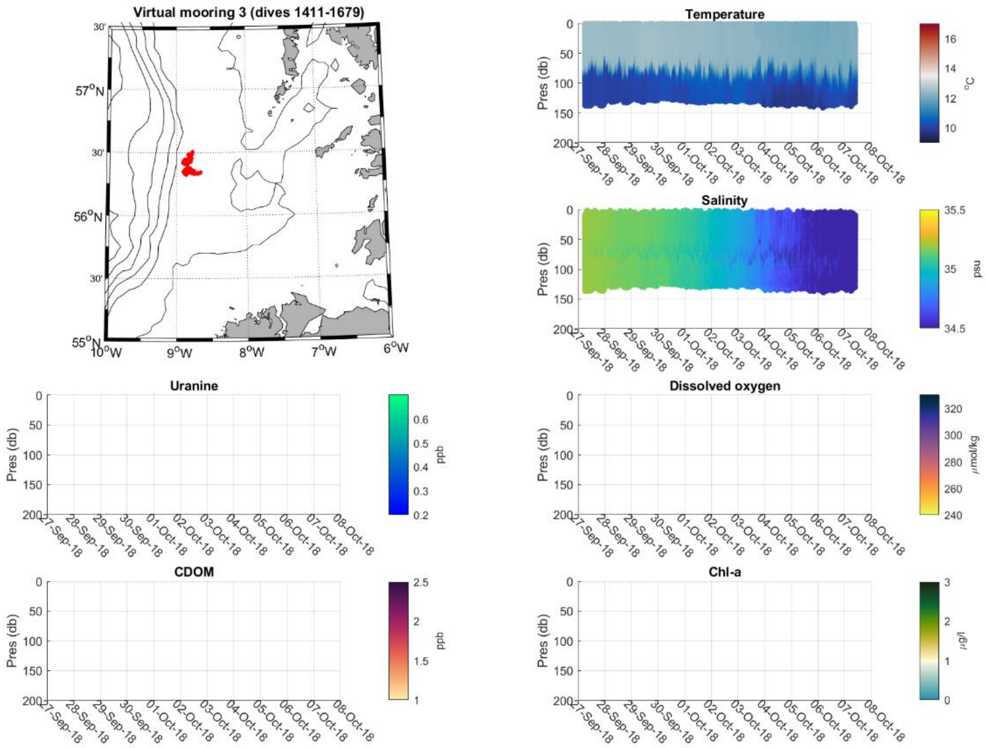


Figure 20: Map and science plots of Virtual Mooring 2, 27 Sep to 07 Oct 18 (56° 23'N 8° 50'W, 150m deep).

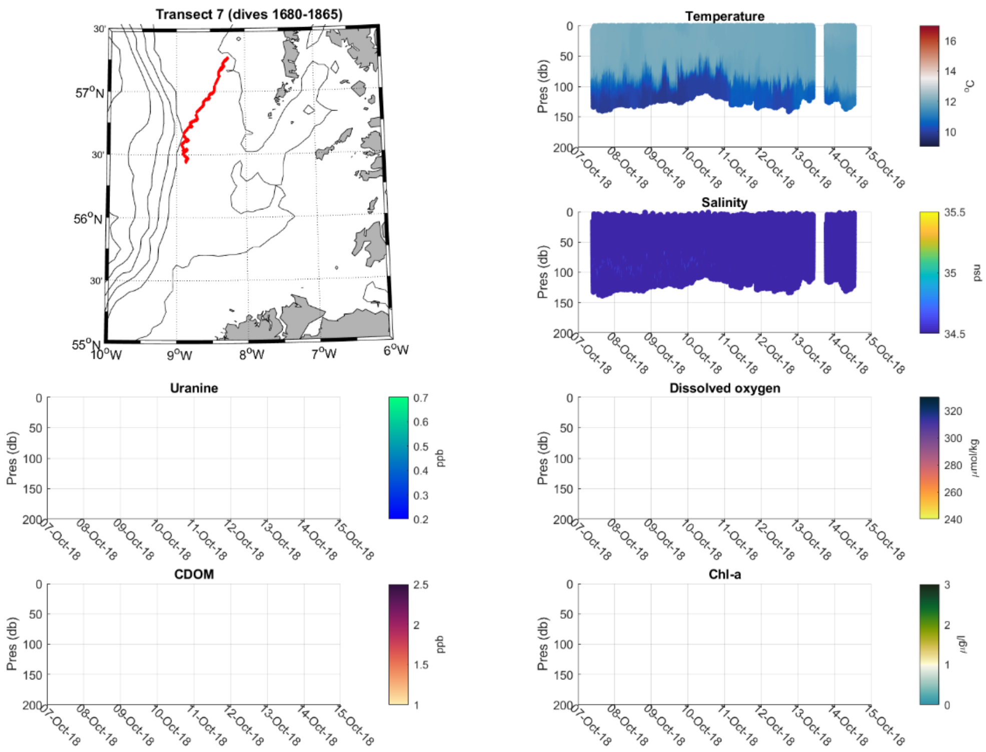


Figure 21: Map and science plots of Leg 7 (NNE), 07 to 15 Oct 18, VM3 to recovery.

A.6. Appendices

6.1. Seaglider sg_calib_constants.m file

```
% sg_calib_constants.m

% basic glider and mission params
id_str='647';
mission_title='SG647 COMPASS 1';
rho0=1027.70;% kg/m3
mass=54.093; % kg, with DTAG

volmax = 53124.8; % d. 1-1499
%volmax = 53133.3; % d. 1500s
%volmax = 53146.4; % d. 1600s
%volmax = 53158.8; % d. 1700s
%volmax = 53166.1; % d. 1800 - end

hd_a = 3.392186e-02; % for all dives

hd_b = 1.403821e-02; % d. 1-799
%hd_b = 1.527715e-02; % d. 800s
%hd_b = 1.600819e-02; % d. 900s
%hd_b = 1.641462e-02; % d. 1000s
%hd_b = 1.777978e-02; % d. 1100s
%hd_b = 1.914495e-02; % d. 1200s
%hd_b = 2.124275e-02; % d. 1300s
%hd_b = 2.331705e-02; % d. 1400s
%hd_b = 2.588788e-02; % d. 1500s
```

```
%hd_b = 2.730229e-02; % d. 1600s
%hd_b = 2.931840e-02; % d. 1700s
%hd_b = 3.062345e-02; % d. 1800s
%hd_b = 2.556403e-02; % d. 1900s + 2000s

hd_c = 4.205735e-17; % d. 1-1199
%hd_c = 3.301600e-17; % d. 1200-end

% Seabird CT Sail sensor cal constants
    calibcomm=' Serial #: 0312  CAL: 18-Jun-2017';%  Serial # and cal date
    t_g=4.42735597E-003;
    t_h=6.48892429E-004;
    t_i=2.67949218E-005;
    t_j=3.31669108E-006;
    c_g=-1.00971209E+001;
    c_h=1.17164207+000;
    c_i=-1.78010707E-003;
    c_j=2.17151948E-004;

% Aanderaa cal constants
comm_oxy_type=' AA4831 '; % make and model e.g. AA4831 or AA4330
calibcomm_optode= ' SN: 694  CAL: 21-Jun-2017 '; % Serial # and cal date
     optode_PhaseCoef0=-5.60000E-01;
     optode_PhaseCoef1=1.00000E00;
     optode_PhaseCoef2=0.0;
     optode_PhaseCoef3=0.0;
     optode_ConcCoef0=-1.341385E+00;
     optode_ConcCoef1=1.067650E+00;
     optode_FoilCoefA0=-2.679283E-06;
     optode_FoilCoefA1=-7.483597E-06;
     optode_FoilCoefA2=0.001960006;
     optode_FoilCoefA3=-0.2072853;
     optode_FoilCoefA4=0.0006012464;
     optode_FoilCoefA5=-6.604267E-07;
     optode_FoilCoefA6=11.18020;
     optode_FoilCoefA7=-0.05148064;
     optode_FoilCoefA8=0.00006898503;
     optode_FoilCoefA9=8.465012E-07;
     optode_FoilCoefA10=-314.3506;
     optode_FoilCoefA11=2.051116;
     optode_FoilCoefA12=-0.002987026;
     optode_FoilCoefA13=-4.449771E-06;
     optode_FoilCoefB0=-1.861349E-06;
     optode_FoilCoefB1=3814.899;
     optode_FoilCoefB2=-32.22806;
     optode_FoilCoefB3=-0.1678000;
     optode_FoilCoefB4=0.01894820;
     optode_FoilCoefB5=-6.901433E-04;
     optode_FoilCoefB6=1.042693E-05;
     optode_FoilCoefB7=0.0;
     optode_FoilCoefB8=0.0;
     optode_FoilCoefB9=0.0;
     optode_FoilCoefB10=0.0;
     optode_FoilCoefB11=0.0;
     optode_FoilCoefB12=0.0;
     optode_FoilCoefB13=0.0;

% Uncomment "optode_SVU_enabled" to process data using SVU algorithm.
%     optode_SVU_enabled
     optode_SVUCoef0=3.577033E-03;
```

```
    optode_SVUCoef1=1.511751E-04;
    optode_SVUCoef2=2.808107E-06;
    optode_SVUCoef3=2.338769E+02;
    optode_SVUCoef4=-2.787805E-01;
    optode_SVUCoef5=-5.768212E+01;
    optode_SVUCoef6=4.536820E+00;

% WETLabs wlfl3 calibration constants.
    WETLabsCalData_wlfl3_calinfo = ' SN FL3IRB-4874, CAL: 10/24/2017 ';
    % Chlorophyll cal constants ug/l/count
    WETLabsCalData.wlfl3.Chlorophyll.wavelength=695;
    WETLabsCalData.wlfl3.Chlorophyll.darkCounts=36;
    WETLabsCalData.wlfl3.Chlorophyll.scaleFactor=1.2000E-02;
    WETLabsCalData.wlfl3.Chlorophyll.maxOutput=4130;
    WETLabsCalData.wlfl3.Chlorophyll.resolution=1.2;
    WETLabsCalData.wlfl3.Chlorophyll.calTemperature=22.5;
    % CDOM cal constants ppb/count
    WETLabsCalData.wlfl3.CDOM.wavelength=460;
    WETLabsCalData.wlfl3.CDOM.maxOutput=4130;
    WETLabsCalData.wlfl3.CDOM.scaleFactor=0.0891;
    WETLabsCalData.wlfl3.CDOM.darkCounts=48;
    WETLabsCalData.wlfl3.CDOM.resolution=1.0;
    WETLabsCalData.wlfl3.CDOM.calTemperature=22.5;
    % Uranine cal constants ppb/count - wavelength 530 nm
    WETLabsCalData.wlfl3.Uranine.wavelength=530;
    WETLabsCalData.wlfl3.Uranine.maxOutput=4130;
    WETLabsCalData.wlfl3.Uranine.scaleFactor=0.0420;
    WETLabsCalData.wlfl3.Uranine.darkCounts=36;
    WETLabsCalData.wlfl3.Uranine.resolution=1.4;
    WETLabsCalData.wlfl3.Uranine.calTemperature=22.5;
```

6.2. Sensors calibration sheets

Sea-Bird Scientific
13431 NE 20th Street
Bellevue, WA 98005
USA

+1 425-643-9866
seabird@seabird.com
www.seabird.com

SENSOR SERIAL NUMBER: 0312
CALIBRATION DATE: 18-Jun-17

Glider APL TEMPERATURE CALIBRATION DATA
ITS-90 TEMPERATURE SCALE

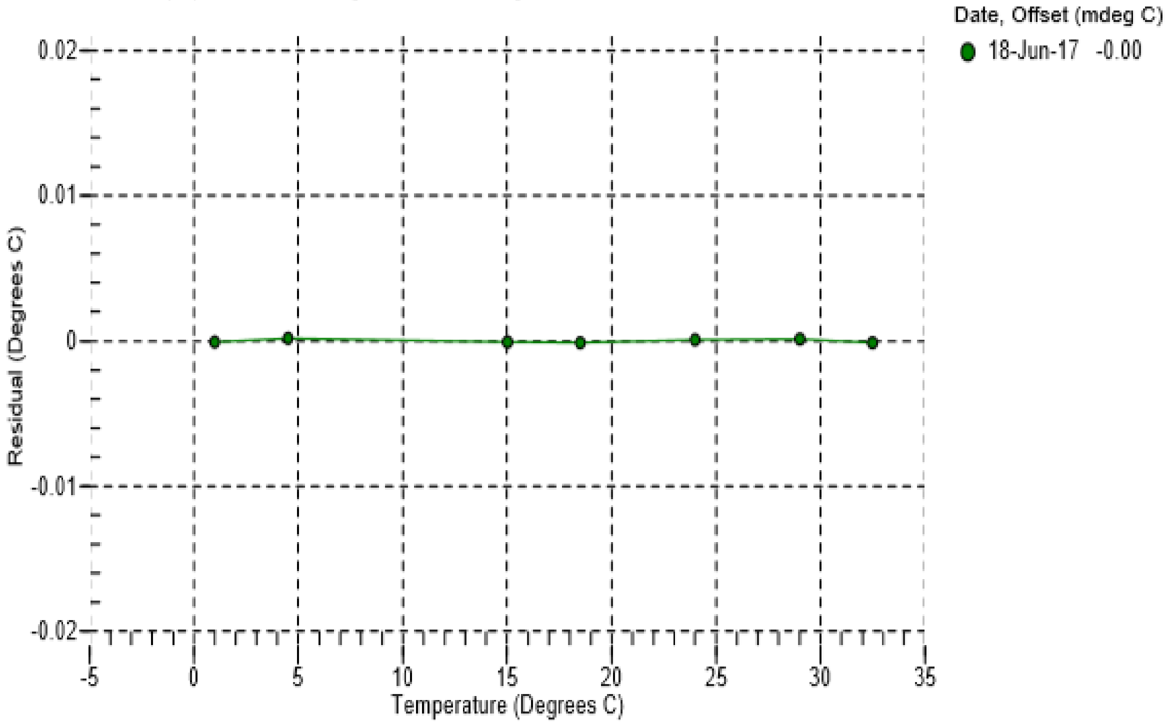
COEFFICIENTS:
g = 4.42735597e-003
h = 6.48892429e-004
i = 2.67949218e-005
j = 3.31669108e-006
f0 = 1000.0

BATH TEMP (° C)	INSTRUMENT OUTPUT (Hz)	INST TEMP (° C)	RESIDUAL (° C)
1.0000	3513.736	0.9999	-0.00009
4.5000	3795.485	4.5002	0.00016
15.0000	4736.954	14.9999	-0.00008
18.5000	5084.127	18.4999	-0.00010
24.0000	5664.685	24.0001	0.00008
28.9999	6230.430	29.0000	0.00014
32.5000	6648.429	32.4999	-0.00011

f = Instrument Output (Hz)

Temperature ITS-90 (°C) = $1/\{g + h[ln(f0 / f)] + i[ln^2(f0 / f)] + j[ln^3(f0 / f)]\} - 273.15$

Residual (°C) = instrument temperature - bath temperature



1

Sea-Bird Scientific
13431 NE 20th Street
Bellevue, WA 98005
USA

+1 425-643-9866
seabird@seabird.com
www.seabird.com

SENSOR SERIAL NUMBER: 0312
CALIBRATION DATE: 18-Jun-17

Glider APL CONDUCTIVITY CALIBRATION DATA
PSS 1978: C(35,15,0) = 4.2914 Siemens/meter

COEFFICIENTS:

```
g =  -1.00971209e+001
h =   1.17164207e+000
i =  -1.78010707e-003
j =   2.17151948e-004

CPcor = -9.5700e-008 (nominal)
CTcor =  3.2500e-006 (nominal)
```

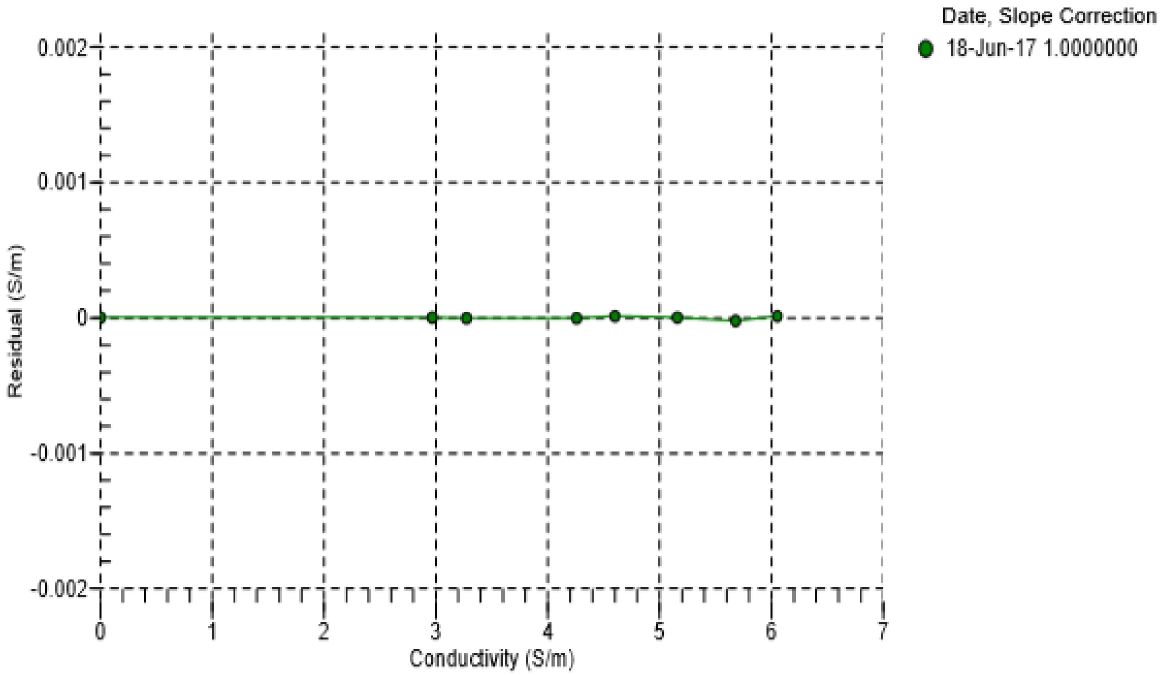
BATH TEMP (° C)	BATH SAL (PSU)	BATH COND (S/m)	INSTRUMENT OUTPUT (kHz)	INSTRUMENT COND (S/m)	RESIDUAL (S/m)
22.0000	0.0000	0.00000	2.93984	0.00000	0.00000
1.0000	34.7534	2.97110	5.83639	2.97110	0.00000
4.5000	34.7339	3.27772	6.05655	3.27771	-0.00000
15.0000	34.6924	4.25802	6.71158	4.25802	-0.00000
18.5000	34.6838	4.60269	6.92695	4.60270	0.00001
24.0000	34.6746	5.15987	7.26137	5.15988	0.00000
28.9999	34.6696	5.68098	7.56047	5.68096	-0.00002
32.5000	34.6656	6.05268	7.76664	6.05269	0.00001

f = Instrument Output (kHz)

t = temperature (°C); p = pressure (decibars); δ = CTcor; ε = CPcor;

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

Residual (Siemens/meter) = instrument conductivity - bath conductivity



1

AANDERAA a xylem brand

CALIBRATION CERTIFICATE

Form No. 710, Nov 2013

Sensing Foil Batch No: 1517
Certificate No:

Product: Oxygen Optode 4831
Serial No: 694
Calibration Date: 21 Jun 2017

This is to certify that this product has been calibrated using the following instruments:

Parameter: Internal Temperature:

Calibration points and readings:

Temperature (°C)	1.00	11.98	24.01	35.99
Reading (mV)	765.01	431.30	44.65	-320.23

Giving these coefficients

Index	0	1	2	3	4	5
TempCoef	2.54160E01	-3.16249E-02	2.93827E-06	-4.32927E-09	0.00000E00	0.00000E00

Parameter: Oxygen:

	O2 Concentration	Air Saturation
Range:	0-500 µM [1]	0 - 120%
Accuracy[1]:	< ±8µM or ±5% (whichever is greater)	±5%
Resolution:	< 1 µM	< 0.4%
Settling Time (63%):	< 25 seconds	

Calibration points and readings[2]:

	Air Saturated Water	Zero Solution (Na_2SO_3)
Phase reading (°)	3.19735E+01	6.28661E+01
Temperature reading (°C)	9.90105E+00	2.31725E+01
Air Pressure (hPa)	9.83244E+02	

Giving these coefficients

Index	0	1	2	3
PhaseCoef	-5.60000E-01	1.00000E00	0.00000E00	0.00000E00
ConcCoef	-1.34139E00	1.06765E00		

[1] *Valid for 0 to 2000m (6562ft) depth, salinity 33 - 37ppt*
[2] *The calibration is performed in fresh water and the salinity setting is set to:* 0

Date: 22 Jun 2017

Sign:
Tor-Ove Kvalvaag
Tor-Ove Kvalvaag, Calibration Engineer

PRESSURE CERTIFICATE

Form No. 667, Sept 2009

Product: Oxygen Optode 4831
Serial No: 694
Date: 12.06.2017

Certificate No: 131845260694

This is to certify that this product has been pressure tested with the following instrument, and we confirm that no irregularities were found during the test:

Autoklav 800 bar – sn: 0210005

Pressure readings:

Pressure (Bar)	Pressure time (hour)
600	1

Date: 03 Jul 2017

Sign:

Vidar Selsvik, Production Engineer

AANDERAA CALIBRATION CERTIFICATE

a xylem brand

Form No 770. , Jun 2008

Certificate No: 3853_1517E_42135
Batch No: 1517E

Product: O2 Sensing Foil PSt3
Calibration Date: 11 May 2015

Serial No: 1517

Calibration points and phase readings

Index	Temperature (°C)	Phase Reading (°)	Oxygen reference (µM)	Index	Temperature (°C)	Phase Reading (°)	Oxygen reference (µM)
0	0.704	63.914	2.03	32	30.082	53.033	21.79
1	0.702	61.285	16.73	33	30.092	49.618	32.39
2	0.719	57.139	43.34	34	30.101	44.269	53.76
3	0.738	54.421	63.59	35	30.106	40.346	74.79
4	0.760	49.766	105.29	36	30.116	35.622	109.76
5	0.772	46.081	146.71	37	30.121	30.977	161.70
6	0.784	41.507	213.10	38	30.120	27.955	212.00
7	0.794	36.385	317.95	39	30.121	25.389	273.03
8	0.807	32.902	419.27	40	5.293	63.610	1.72
9	0.820	30.250	523.15	41	5.433	60.690	15.39
10	9.883	63.306	1.42	42	5.413	56.465	38.58
11	10.165	60.095	14.05	43	5.401	53.624	56.77
12	10.107	55.791	33.82	44	5.396	48.810	94.29
13	10.064	52.826	49.96	45	5.390	45.160	130.52
14	10.031	47.854	83.29	46	5.385	40.458	191.09
15	10.007	44.239	114.32	47	5.382	35.518	282.30
16	9.987	39.409	169.08	48	5.383	32.070	373.06
17	9.970	34.651	246.64	49	5.387	29.438	466.83
18	9.959	31.238	326.85	50	14.836	62.930	1.39
19	9.954	28.625	410.51	51	15.061	59.491	12.90
20	19.789	62.555	1.37	52	15.002	55.063	30.47
21	19.957	58.887	11.74	53	14.954	52.000	44.98
22	19.896	54.335	27.11	54	14.917	46.968	74.66
23	19.843	51.173	40.00	55	14.893	43.238	103.04
24	19.804	46.081	66.03	56	14.875	38.421	152.17
25	19.780	42.237	91.76	57	14.860	33.797	220.64
26	19.764	37.433	135.25	58	14.844	30.439	292.58
27	19.750	32.944	194.65	59	14.836	27.878	367.95
28	19.730	29.641	258.31	60	24.944	61.916	1.83
29	19.718	27.130	325.40	61	25.014	58.346	10.72
30	30.100	61.278	2.30	62	24.989	53.684	24.45
31	30.072	57.804	9.69	63			

CALIBRATION CERTIFICATE

Giving these coefficients

Index	FoilCoefA	FoilCoefB
0	-2.679283E-06	-1.861349E-06
1	-7.483597E-06	3.814899E+03
2	1.960006E-03	-3.222806E+01
3	-2.072853E-01	-1.678000E-01
4	6.012464E-04	1.894820E-02
5	-6.604267E-07	-6.901433E-04
6	1.118020E+01	1.042693E-05
7	-5.148064E-02	0.000000E+00
8	6.898504E-05	0.000000E+00
9	8.465013E-07	0.000000E+00
10	-3.143506E+02	0.000000E+00
11	2.051116E+00	0.000000E+00
12	-2.987026E-03	0.000000E+00
13	-4.449771E-06	0.000000E+00

Using the following monomial degrees

Index	FoilPolyDegT	FoilPolyDegO
0	1	4
1	0	5
2	0	4
3	0	3
4	1	3
5	2	3
6	0	2
7	1	2
8	2	2
9	3	2
10	0	1
11	1	1
12	2	1
13	3	1
14	4	1
15	0	0
16	1	0
17	2	0
18	3	0
19	4	0
20	5	0
21	0	0
22	0	0
23	0	0
24	0	0
25	0	0
26	0	0
27	0	0

Date: 11 May 2015

Sign: Tor-Ove Kvalvaag

Tor-Ove Kvalvaag, Calibration Engineer

PO Box 518
620 Applegate St.
Philomath, OR 97370

WET Labs

(541) 929-5650
Fax (541) 929-5277
www.wetlabs.com

ECO Chlorophyll Fluorometer Characterization Sheet

Date: 10/24/2017 S/N: FL3IRB-4874

Chlorophyll concentration expressed in µg/l can be derived using the equation:

CHL (µg/l) = Scale Factor * (Output - Dark counts)

	Digital
Dark counts	36 counts
Scale Factor (SF)	0.0120 µg/l/count
Maximum Output	4130 counts
Resolution	1.2 counts
Ambient temperature during characterization	22.5 °C

Dark Counts: Signal output of the meter in clean water with black tape over detector.

SF: Determined using the following equation: SF = x ÷ (output - dark counts), where x is the concentration of the solution used during instrument characterization. SF is used to derive instrument output concentration from the raw signal output of the fluorometer.

Maximum Output: Maximum signal output the fluorometer is capable of.

Resolution: Standard deviation of 1 minute of collected data.

The relationship between fluorescence and chlorophyll-a concentrations in-situ is highly variable. The scale factor listed on this document was determined using a mono-culture of phytoplankton (Thalassiosira weissflogii). The population was assumed to be reasonably healthy and the concentration was determined by using the absorption method. To accurately determine chlorophyll concentration using a fluorometer, you must perform secondary measurements on the populations of interest. This is typically done using extraction-based measurement techniques on discrete samples. For additional information on determining chlorophyll concentration see "Standard Methods for the Examination of Water and Wastewater" part 10200 H, published jointly by the American Public Health Association, American Water Works Association, and the Water Environment Federation.

PO Box 518
620 Applegate St.
Philomath, OR 97370

WET Labs

(541) 929-5650
Fax (541) 929-5277
www.wetlabs.com

ECO CDOM Fluorometer Characterization Sheet

Date: 10/24/2017

S/N: FL3IRB-4874

CDOM concentration expressed in ppb can be derived using the equation:

CDOM (ppb) = Scale Factor * (Output - Dark Counts)

	Digital
Dark Counts	48 counts
Scale Factor (SF)	0.0891 ppb/count
Maximum Output	4130 counts
Resolution	1.0 counts
Ambient temperature during characterization	22.5 °C

Dark Counts: Signal output of the meter in clean water with black tape over detector.

SF: Determined using the following equation: SF = x ÷ (output - dark counts), where x is the concentration of the solution used during instrument characterization. SF is used to derive instrument output concentration from the raw signal output of the fluorometer.

Maximum Output: Maximum signal output the fluorometer is capable of.

Resolution: Standard deviation of 1 minute of collected data.

PO Box 518
620 Applegate St.
Philomath, OR 97370

(541) 929-5650
Fax (541) 929-5277
www.wetlabs.com

ECO Uranine (fluorescein) Fluorometer Characterization Sheet

Date: 10/24/2017

S/N: FL3IRB-4874

Uranine concentration expressed in ppb can be derived using the equation:

Uranine (ppb) = Scale Factor * (Output - Dark Counts)

	Digital
Dark Counts	36 counts
Scale Factor (SF)	0.0420 ppb/count
Maximum Output	4130 counts
Resolution	1.4 counts
Ambient temperature during characterization	22.5 °C

Dark Counts: Signal output of the meter in clean water with black tape over detector.

SF: Determined using the following equation: SF = x ÷ (output - dark counts), where x is the concentration of the solution used during instrument characterization. SF is used to derive instrument output concentration from the raw signal output of the fluo

Maximum Output: Maximum signal output the fluorometer is capable of.

Resolution: Standard deviation of 1 minute of collected data.

Section B
Glider mission report: COMPASS 2 (2019)

Acknowledgements: The glider was piloted by: Estelle Dumont, Jason Salt, Sam Jones, Colin Abernethy, Karen Wilson, Emily Venables, Marie Porter.

B.1. Objectives

Funded by the EU INTERREG VA (Special EU Programmes Body SEUPB, https://compass-oceanscience.eu/), the COMPASS project is a 5 year program establishing a network of oceanographic and acoustic moorings within and adjacent to cross-border marine protected areas (MPAs), which will produce new marine monitoring data for emerging areas of environmental concern including ocean acidification and the long-term impacts of anthropogenic noise on marine life. It will also help fulfill international, European and national biodiversity obligations. COMPASS will deliver a clearer understanding of what changes in the oceanographic climate have on underwater habitats, fauna and flora across the region. The project will also develop an innovative acoustic tag programme to understand the migration patterns, the behaviour and mortality of salmon and sea trout in the North Western part of the Irish Sea.
The interregional perspective will allow data to be captured and shared across Northern Ireland, the Border Region of Ireland and Western Scotland and help in the development of effective future monitoring programmes for MPAs.
To complement the mooring installations and ship-based observations, SAMS is conducting underwater glider surveys in the Malin Shelf area for a period of approximately 6 to 8 weeks every summer from 2018 to 2021. The primary aim of these is to collect oceanographic water-column measurements (depth, temperature, salinity, oxygen, fluorescence, optical backscatter), as well as passive acoustic sensor monitoring of marine mammals.

B.2. Equipment and methodology

The Seaglider is a long-range Unmanned Underwater Vehicle (UUV) designed to carry out long-term oceanographic surveys down to a depth of 1,000m. A system of buoyancy engine, moveable internal weights and hydrodynamic design allows the instrument to slowly dive up and down the water column in a saw-tooth pattern whilst using very little energy compared to a propeller-driven UUV, allowing for endurances of up to 7 months. The glider is equipped with GPS for navigation (as well as compass and attitude sensors while underwater) and is remotely operated via Iridium. When at the surface (every few hours) it transmits its location and collected data, and pilots are able to check on its status and adjust technical parameters, trajectory or data sampling.
The glider used for the COMPASS 2 mission is Seaglider SG156 ‘Talisker’, owned and operated by SAMS. It is equipped with:

- SeaBird CTD sail (pressure, temperature and conductivity)
- Aanderaa AA4330 dissolved oxygen optode

- WetLabs triplet (chlorophyll-a fluorescence, 470 and 700nm optical backscatter)
- Passive Acoustic Monitoring sensor (for marine mammal detection)

Seaglider technical specifications:

- Dimensions: 1.8 long (+ 1m antenna), 30 cm diameter, 1m wing span
- Endurance: 4,000 km or 7 months
- Operating depth range: 50 to 1000 m
- Average speed: horizontal speed 25 cm/s, vertical speed 10cm/s
- Glide angle: 15-45°
- Power source: 2 x primary Lithium battery packs, 150AH (24V) and 100AH (10V) capacity

Figure 22 (left): full view of Seaglider

Figure 23: close-up on Seaglider sensors: CTD (bottom), PAM (top) and oxygen optode (right).

B.3. Deployment narrative

Diplomatic clearance for this deployment was requested from the Republic of Ireland and obtained in July 2019, under reference 847/19.
Prior to deployment the standard pre-deployment checks were carried out on the glider (self-test, compass check, compass calibration). The compass readings appeared to show a large error (up to 18° error for the raw readings, 35° for the "calibrated" readings) and a whirly calibration was performed at SAMS. The glider compass readings appeared acceptable after this (maximum error of 2.5° for the calibrated readings).

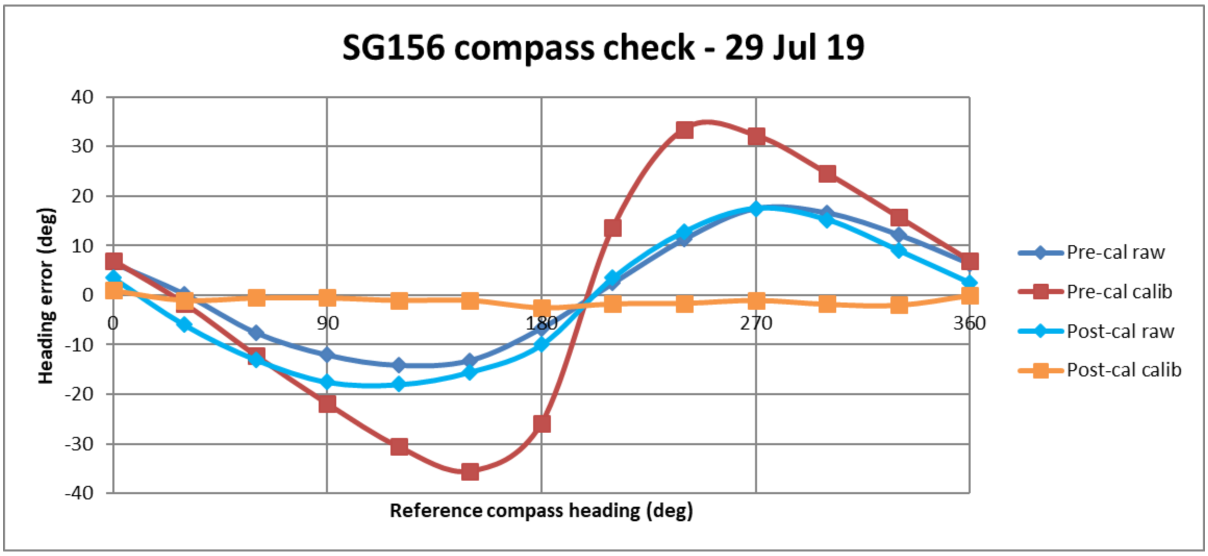


Figure 24: Talisker's compass check pre and post re-calibration. The glider used the calibrated readings for navigation during the mission (error shown in orange in the plot).

All time noted below are UTC.
06-Aug-19 11:35: Glider deployed in position 56° 46.812’N, 6° 57.204’W from RHIB Heyskir (call sign 2HCO5). CTD cast was conducted once the glider was in the water. Boat team: Karen Wilson, Colin Abernethy, Denise Risch. Pilot: Estelle Dumont.
13-Aug-19 20:45: Glider reached waypoint BARRA_SOUTH (56° 25.000’N, 7° 46.000’W) at dive 183.
19-Aug-19 02:40: Glider reached waypoint C1 (56° 25.000’N, 9° 00.000’W) at dive 327.
28-Aug-19 11:45: Glider reached waypoint C2 (55° 25.422’N, 8° 18.607’W) at dive 660.
04-Sep-19 07:10: Glider reached waypoint BARRA_SOUTH (56° 25.000’N, 7° 46.000’W) at dive 955. The altimeter got some false bottom detections during this leg which resulted in the glider turning before reaching the seafloor. It was decided to send the glider back South to perform new profiles and collect the missed data.
11-Sep-19 13:34: Glider reached waypoint C2b (56° 02.000’N, 7° 35.000’W) at dive 1180.
15-Sep-19 16:50: Glider reached waypoint BARRA_SOUTH (56° 25.000’N, 7° 46.000’W) at dive 1295.
17-Sep-19 18:40: Glider in recovery at dive 1341, abort code MAX_CF8_ERRORS (8 errors). After examining the capture file it appears that Talisker had problems opening some files for transmission (sg1336dz.x02 and sg1336lz.x00), although the files eventually transferred without issue. The CF card space appeared fine but a few (already transmitted) datafiles were deleted remotely, in case the issue was memory-related. There were no other errors reported, and all devices seemed to behave normally. We took this as a one-off bug (the manufacturer Kongsberg were of the same opinion), and the glider was sent to resume its mission.
19-Sep-19 13:53: Glider recovered in position 56° 45.858’N, 6° 55.136’W at dive 1385 from RHIB Schiehallion (call sign 2GJN7). Boat team: Emily Venables, Jen Cocking, pilot: Marie Porter.

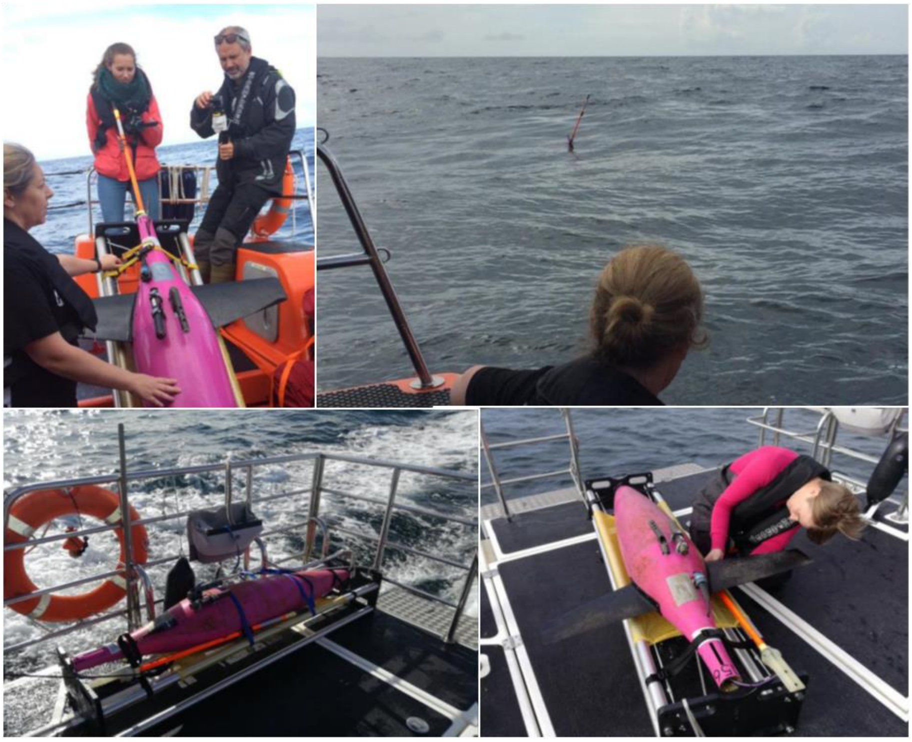


Figure 4: photographs of glider deployment and recovery

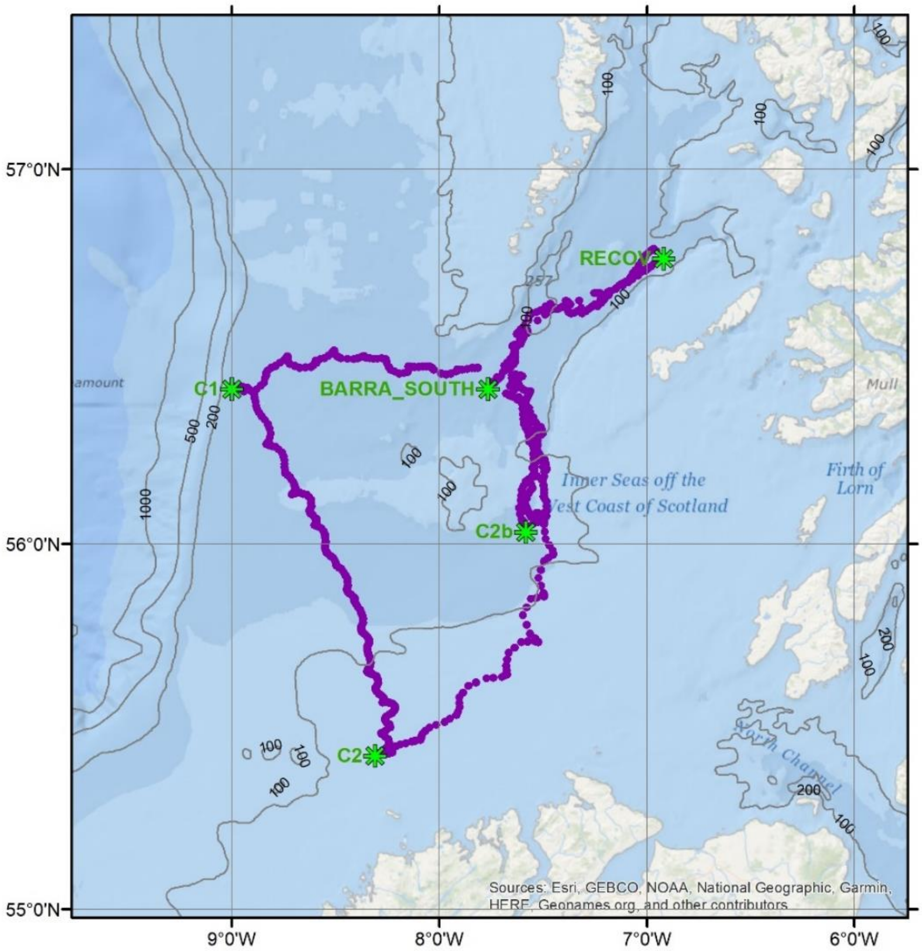


Figure 5: COMPASS2 glider track

B.4. Mission statistics

During this deployment Talisker carried out 1385 dives in 44 days, and covered a distance of 620 km (direct line). The battery usage was 52% on the primary battery pack and 37% on the secondary pack. The glider performed generally well, except for some consistent retries of the buoyancy engine which were noted. While not of concern for this short mission these will be investigated more thoroughly post-recovery.

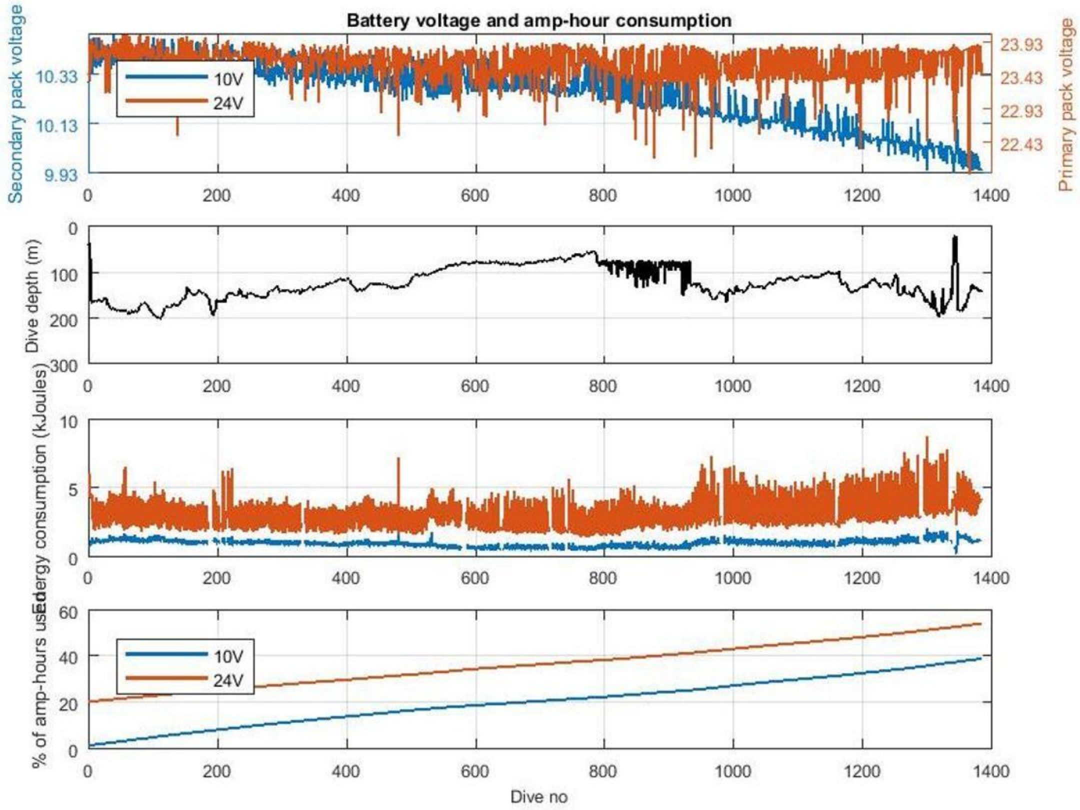


Figure 25: battery data for full mission

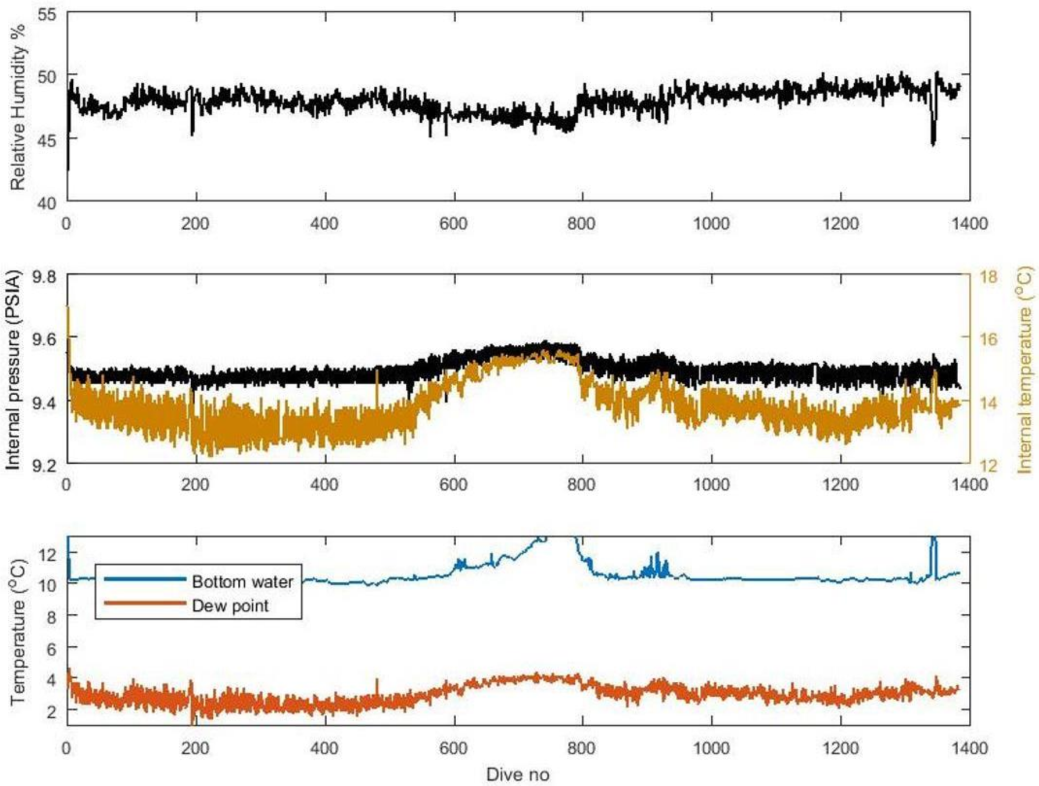


Figure 26: internal sensors data for full mission

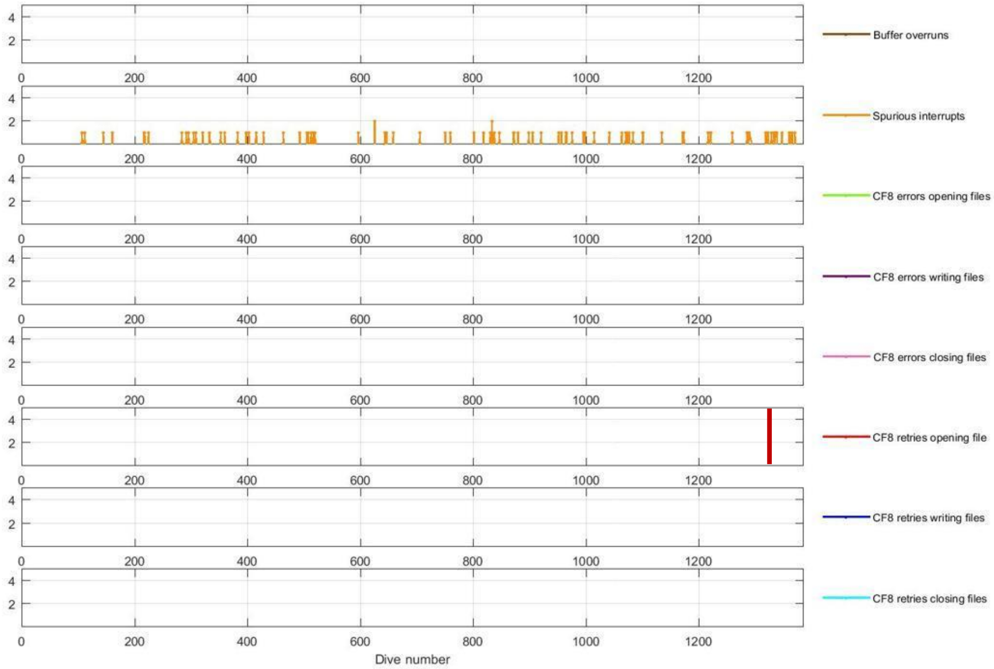


Figure 27: summary of errors during mission (part 1/2)

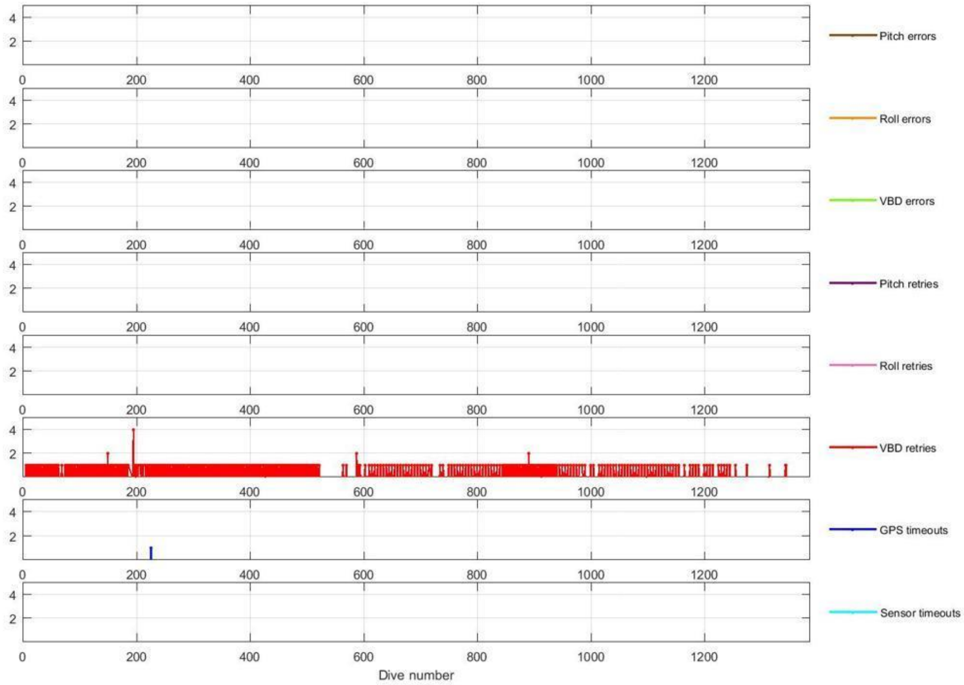


Figure 28: summary of errors during mission (part 2/2)

B.5. Data processing

5.1. Sensor cross-comparison

A CTD cast was performed at deployment, however the instrument did not record any data during the cast due to a technical fault.
No CTD cast was performed at recovery.
Therefore there is no in-situ comparison data available for this mission, however some readings were taken in the ballasting tank at SAMS and the glider sensors were in good agreement with a recently calibrated SBE37 microcat. The glider CTD sensors were calibrated in Jun-2017, and will be sent for post-deployment recalibration in 2020.

5.2. CTD data processing and hydrodynamic model regression

During the mission the basestation performs some level of data QC in real-time:

- Conversion of raw sensors readings to scientific units
- Hydro-dynamic model regression using standard coefficients in order to get an estimate of the glider flight and water flow through the conductivity cell
- Calculation of derived variables (salinity, density, etc)
- Removal of large outliers
- Correction of CT thermal mass effect in salinity data, based on empirical equations using the standard glider hydrodynamic coefficients

Post-mission the Seaglider hydrodynamical model was re-run in order to determine the best flight coefficients for this mission: volume (volmax), lift (hd_a), drag (hd_b) and induced drag (hd_c). This is an important step not only to determine the glider's speed and trajectory under water, but also to better estimate the water flow through the conductivity cell which in turn is used in the salinity calculations.
Usually the hydrodynamic coefficients are regressed using several deep dives data, selected throughout the mission and showing a wide range of pitch angles. As this mission contains only short dives (shallow water) the data is limited, and it was decided to use all the dives in the regression instead.
Like during the first COMPASS mission in 2018 the glider's flight started changing throughout the mission (mainly showing sharper turns / rolls towards the end of the deployment), although the behaviour was not nearly as bad as COMPASS 1. This behaviour was thought to be due to biofouling on the glider.
Regressions were run in groups of 100 dives, to try establishing the evolution of each coefficient through time. The volume, lift and induced drag were found to be relatively stable during the mission and average values were used (minus a few spikes, assumed to be the result of unsuccessful regressions where few data points were available). As expected the drag showed a clear increase towards the end of the deployment. For the final processing an average drag value was used up to dive 900 then the individual regression values for each block of 100.

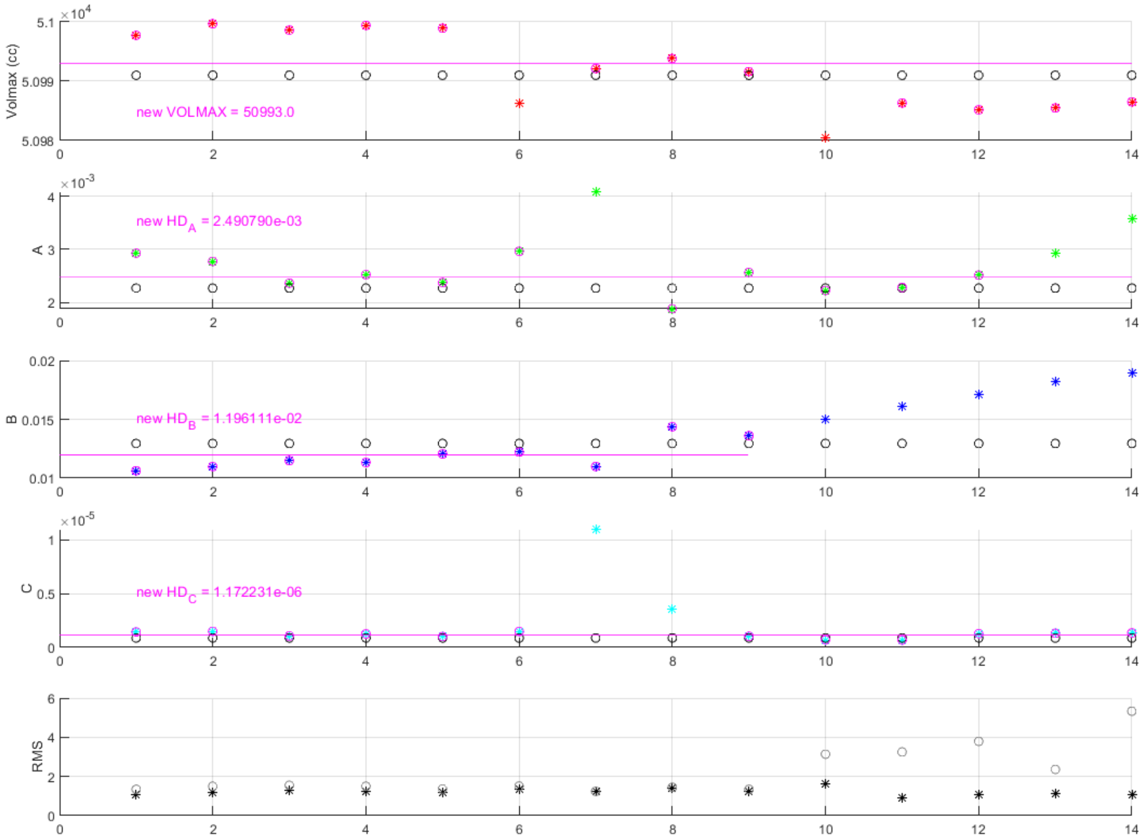


Figure 29: hydrodynamic model regression results for blocks of 100 dives on the x-axis. VOLMAX = glider volume, A = lift, B = drag, C = induced drag, and average values for each (pink). RMS = regression root-mean square error using original coefficients (grey) and new regressed coefficients (black).

<table>
<tr><th>Dives</th><th>VOLMAX</th><th>HD_A</th><th>HD_B</th><th>HD_C</th></tr>
<tr><td>0001 - 0899</td><td rowspan="6">50993.0</td><td rowspan="6">2.49079e-03</td><td>1.19611e-02</td><td rowspan="6">1.17223e-06</td></tr>
<tr><td>0900 - 0999</td><td>1.50123e-02</td></tr>
<tr><td>1000 - 1099</td><td>1.60604e-02</td></tr>
<tr><td>1100 - 1199</td><td>1.71226e-02</td></tr>
<tr><td>1200 - 1299</td><td>1.81700e-02</td></tr>
<tr><td>1300 - 1385</td><td>1.89546e-02</td></tr>
</table>

Figure 30: Summary table of final coefficients used in hydrodynamic model calculations

The raw data was reprocessed on the basestation using the coefficients above. Figure 12 shows an example of the difference between the raw salinity data and the final processed data. The basestation appeared to have correctly flagged all outliers in the data and no further despiking was performed.

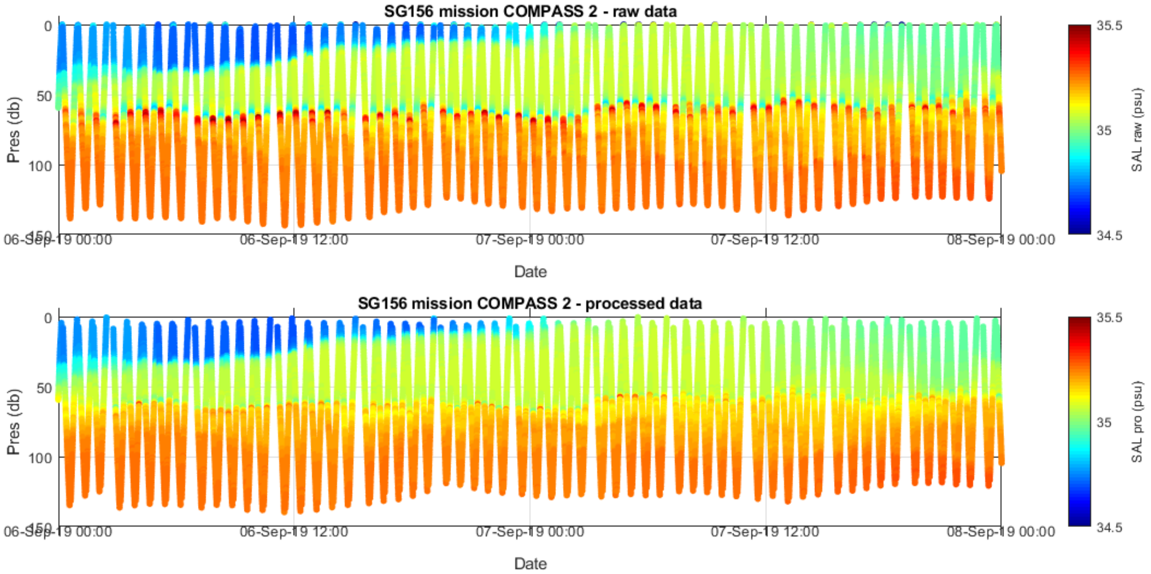


Figure 31: raw (top) vs processed (bottom) salinity data for a subset of the mission. The raw data is derived from the pressure, temperature and conductivity readings without any thermal lag correction, and shows cell thermal lag effect in the halocline area around 60m (salty water on the dive, fresher water on the climb). This effect disappears in the processed data, which has gone through the basestation thermal lag correction using the regressed hydrodynamic coefficients.

5.3. O2 data processing

The oxygen data collected by the Aanderaa optode appeared significantly lower than all previous datasets collected over the past 10 years in the same area. Additionally, the O2 values are very different between the dive and the climb (even after correcting the optode data for temperature, pressure and salinity effect, and recalculating the values using the corrected salinity). A damaged optical foil is suspected (to be confirmed after the sensor is sent back to the manufacturer), and the data appears unusable.

5.4. WetLabs data processing

No further processing was done on the WetLabs data. No calibration or comparison of that sensor has been carried out (apart from the manufacturer in-lab calibration).
The red and blue backscatter data increase quite drastically around the 10th September, however the fluorescence values remains stable indicating that the change in optical backscatter is probably caused by a real change in the water column rather than biofouling of the sensor.

5.5. Coordinates remapping

During deep water operations the glider gets GPS fixes between each dive, and the basestation automatically calculates underwater positions based on the GPS fixes and the hydrodynamic model. For shallow water missions the glider is set to do several dives in a row (typically 3 to 5), and the lack of GPS fixes prevents the basestation to calculate underwater position. These were recalculated in Matlab in post-processing, by linearly interpolating coordinates between the GPS fixes at the start and end of a subset of dives. I.e. they do not take into account the glider's behaviour (e.g. speed and turns) but should provide a reasonable estimate of its position within ~100m.

5.6. Transect plots

The transect plots below are of the final processed data.

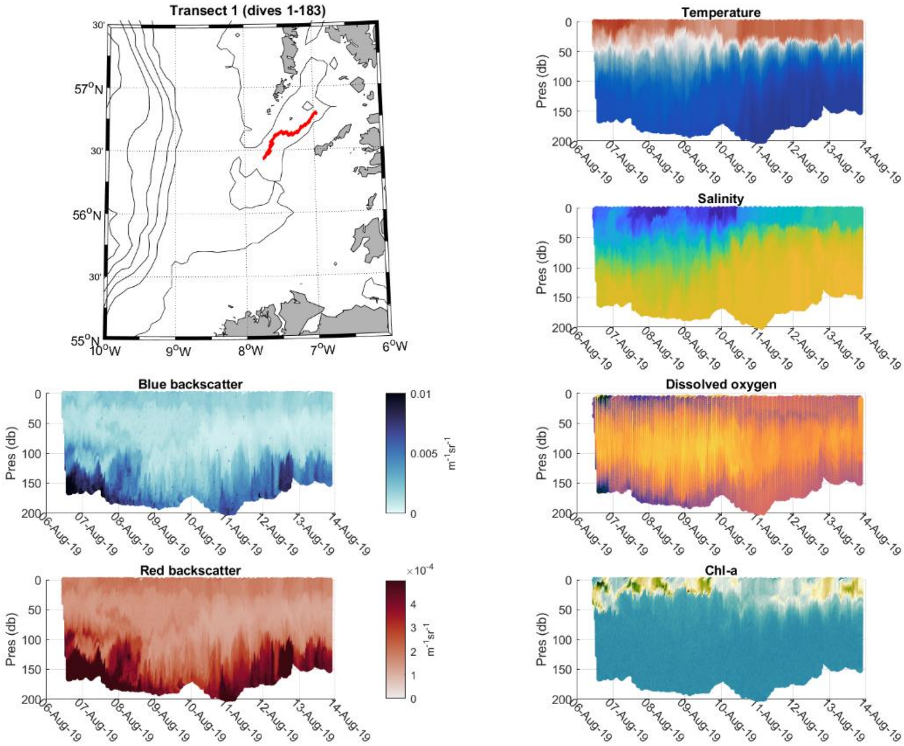


Figure 32: Map and science plots of transect 1, 06 to 14 Aug 19, deployment site to BARRA_SOUTH

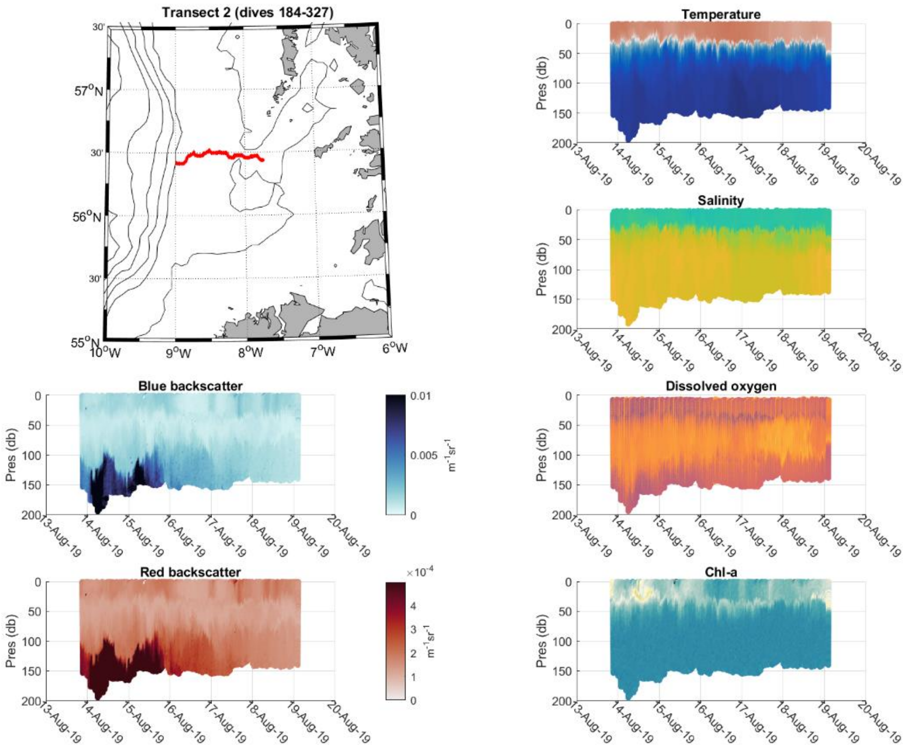


Figure 33: Map and science plots of transect 2, 14 to 19 Aug 19, BARRA_SOUTH to C1 (shelf break)

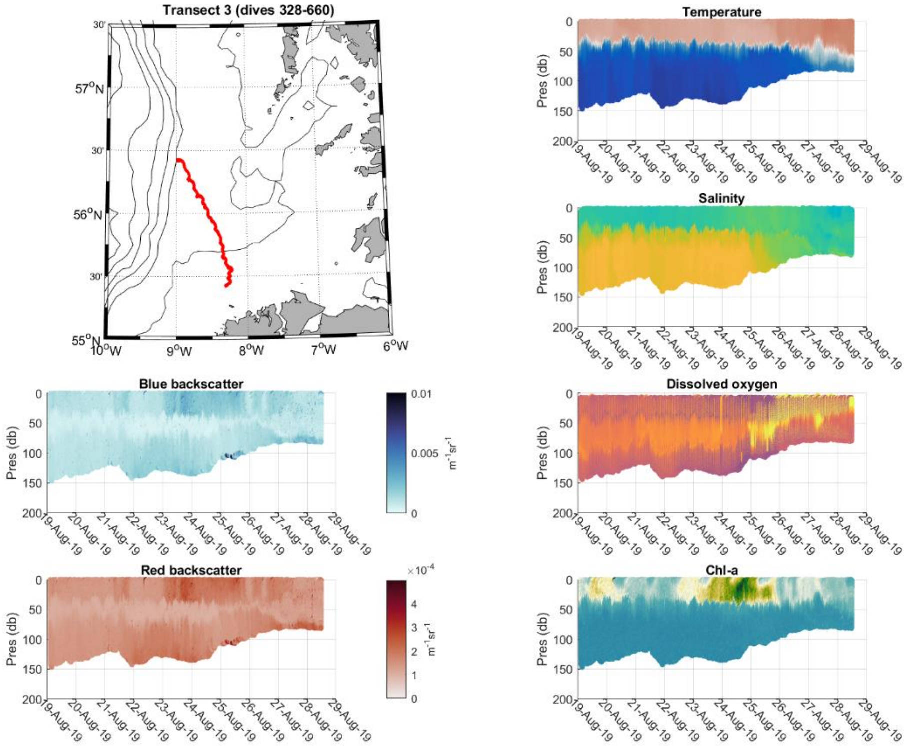


Figure 34: Map and science plots of transect 3, 19 to 28 Aug 19, C1 (shelf break) to C2 (North of Ireland)

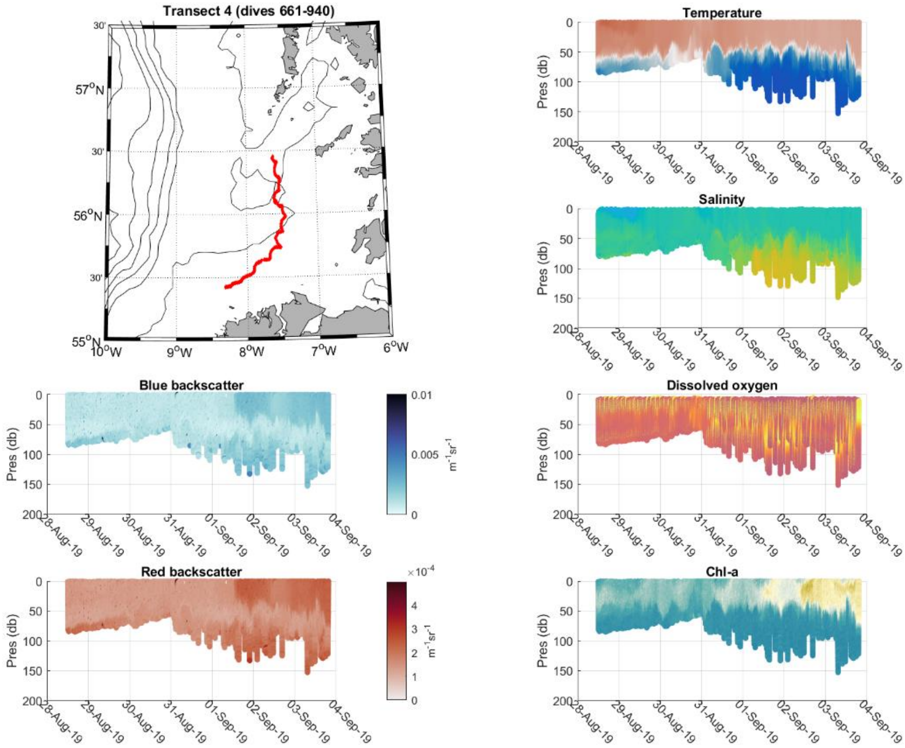


Figure 35: Map and science plots of transect 4a, 28 Aug to 04 Sep 19, C2 (North of Ireland) to BARRA_SOUTH. False altimeter bottom detections from the 31st Aug onwards made the glider turn around prematurely at some dives, and data was not collected for the full water column.

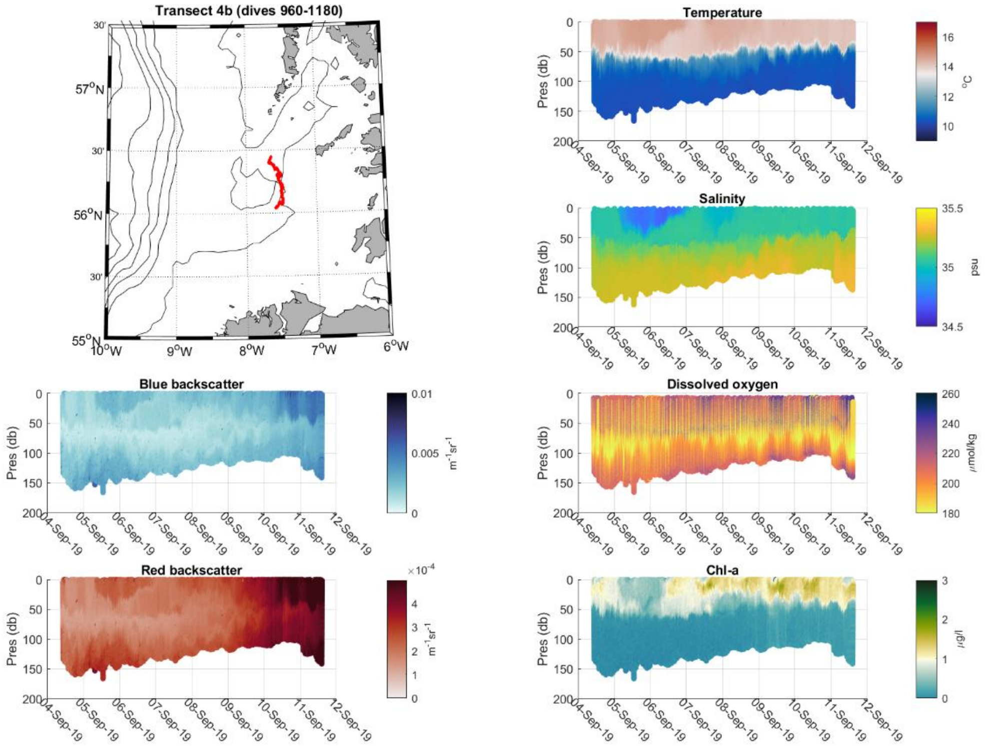


Figure 36: Map and science plots of transect 4b, 04 to 11 Sep 19, BARRA_SOUTH to C2b

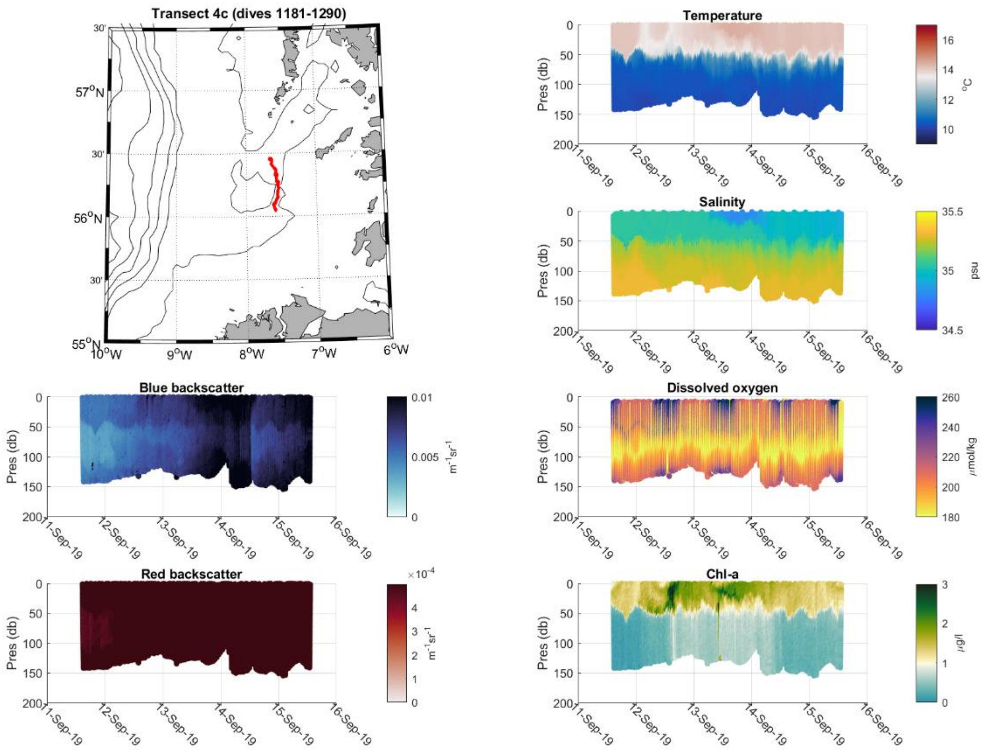


Figure 37: Map and science plots of transect 4c, 11 to 15 Sep 19, C2b to BARRA_SOUTH

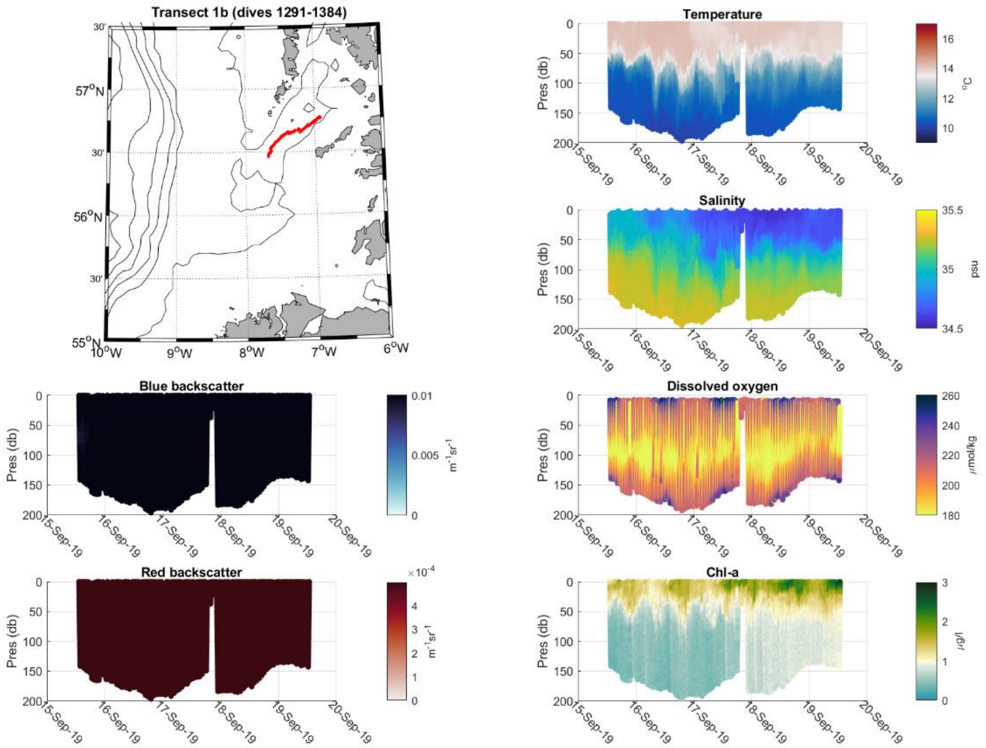


Figure 38: Map and science plots of transect 1b, 15 to 19 Sep 19, BARRA_SOUTH to recovery site

B.6. Appendices

6.1. Seaglider sg_calib_constants.m file

```
% sg_calib_constants.m
% Edited 06-Aug-19 by ED, SAMS

% basic glider and mission params
id_str   =        '156'    ;
mass     =        51.934   ; % in kg, with PAM (edit ED)
mission_title     = 'Talisker COMPASS 2';
rho0     =        1027.7   ; % for open ocean waters

% Coefficients used during mission
% hydrodynamic params & vol_max
% % final regression after PS sea trials
% % 31-Oct-2017 14:21:21 RMS=1.2023 cm/s SAMS-Talisker Dives: 6 9:17 19
% volmax = 51105; % Edit ED, to include PAM
% hd_a = 1.25156e-03;
% hd_b = 1.46323e-02;
% hd_c = 5.34926e-06;

% Reprocessing 2, ESDU, 25-Nov-19
% Regressions run in blocks of 100. Use average coeffs (eliminating a few
% outliers). Volamx, a and c constant, b (drag) increasisng toward the end.
volmax = 50993;
hd_a = 2.49079e-03;
hd_c = 1.17223e-06;
hd_b = 1.19611e-02; % d. 1-900
% hd_b = 1.50123e-02; % d. 900s
% hd_b = 1.60604e-02; % d. 1000s
% hd_b = 1.71226e-02; % d. 1100s
% hd_b = 1.81700e-02; % d. 1200s
% hd_b = 1.89546e-02; % d. 1300s

% CT sensors cal constants
calibcomm ='SN 0086 cal 25-Jun-17';       % SN and cal date
t_g      =        4.38724917E-03 ;
t_h      =        6.37439883E-04 ;
t_i      =        2.48503147E-05  ;
t_j      =        2.65839261E-06  ;
c_g      =        -1.01703612E+01  ;
c_h      =        1.15131850E+00  ;
c_i      =        -2.08139571E-03  ;
c_j     =         2.50198153E-04  ;
ctcor    =        3.2500000E-06    ;
cpcor    =        -9.57000000E-08 ;

% Aanderaa Optode SN 229 - (NOT fast-foil unit as was pre-2010)
% last factory calibration
comm_oxy_type= 'Optode 4831';
calibcomm_optode = 'Optode 4831 SN: 229 Foil ID: 4909E calibrated 09/12/2014';
% from selftest pt1560045.eng 3/28/2016 16:42:15
optode_st_calphase = 30.88;  % the mean of the optode calphase column in the selftest
eng file
optode_st_temp = 8.28; % the mean of the optode temp colin the selftest eng file
optode_st_slp = 1022.5; % the sea level pressure in air in mbar
calibcomm_optode = 'Optode 4330 SN: 229 Foil ID: 4909E calibrated 15-Sep-2017';
optode_PhaseCoef0 = 0;
optode_PhaseCoef1 = 1;
optode_PhaseCoef2 = 0;
optode_PhaseCoef3 = 0;
```

```
optode_ConcCoef0 = -2.02199;
optode_ConcCoef1 = 1.22744;

optode_TempCoef0 = 28.1663;
optode_TempCoef1 = -0.0309343;
optode_TempCoef2 = 3.0032e-06;
optode_TempCoef3 = -4.49273e-09;
optode_TempCoef4 = 0;
optode_TempCoef5 = 0;

optode_FoilCoefA0 = -2.8228e-06;
optode_FoilCoefA1 = -6.77631e-06;
optode_FoilCoefA2 = 0.00180391;
optode_FoilCoefA3 = -0.193033;
optode_FoilCoefA4 = 0.000629133;
optode_FoilCoefA5 = -2.98282e-07;
optode_FoilCoefA6 = 10.499;
optode_FoilCoefA7 = -0.0545574;
optode_FoilCoefA8 = 9.2565e-05;
optode_FoilCoefA9 = -4.39704e-07;
optode_FoilCoefA10 = -297.128;
optode_FoilCoefA11 = 2.23673;
optode_FoilCoefA12 = -0.00795345;
optode_FoilCoefA13 = 4.77958e-05;

optode_FoilCoefB0 = 7.51173e-08;
optode_FoilCoefB1 = 3624.94;
optode_FoilCoefB2 = -37.6247;
optode_FoilCoefB3 = 0.245448;
optode_FoilCoefB4 = -0.00331533;
optode_FoilCoefB5 = 4.75364e-05;
optode_FoilCoefB6 = -4.88391e-07;
optode_FoilCoefB7 = 0;
optode_FoilCoefB8 = 0;
optode_FoilCoefB9 = 0;
optode_FoilCoefB10 = 0;
optode_FoilCoefB11 = 0;
optode_FoilCoefB12 = 0;
optode_FoilCoefB13 = 0;

optode_SVU_enabled = 0;
optode_SVUCoef0 = 0;
optode_SVUCoef1 = 0;
optode_SVUCoef2 = 0;
optode_SVUCoef3 = 0;
optode_SVUCoef4 = 0;
optode_SVUCoef5 = 0;
optode_SVUCoef6 = 0;

% WET Labs BB2FL-VMG SN 512 - calibration 17-Jul-2017
% For blue scattering channel
wlbb2fl_sig470nm_dark_counts = 54;
wlbb2fl_sig470nm_max_counts = 4095;
wlbb2fl_sig470nm_resolution_counts = 1.0;
wlbb2fl_sig470nm_scale_factor = 1.595E-05;
% For red scattering channel
wlbb2fl_sig700nm_dark_counts = 49;
wlbb2fl_sig700nm_max_counts = 4095;
wlbb2fl_sig700nm_resolution_counts = 2.5;
wlbb2fl_sig700nm_scale_factor = 3.758E-06;
% For chlorophyll fluorescence channel
wlbb2fl_sig695nm_dark_counts = 57;
wlbb2fl_sig695nm_max_counts = 4120;
wlbb2fl_sig695nm_resolution_counts = 2.5;
wlbb2fl_sig695nm_scale_factor = 0.0122;

% end of file
```

6.2. Sensors calibration sheets

SEA·BIRD SCIENTIFIC

Sea-Bird Scientific
13431 NE 20th Street
Bellevue, WA 98005
USA

+1 425-643-9866
seabird@seabird.com
www.seabird.com

SENSOR SERIAL NUMBER: 0086
CALIBRATION DATE: 25-Jun-17

Glider APL TEMPERATURE CALIBRATION DATA
ITS-90 TEMPERATURE SCALE

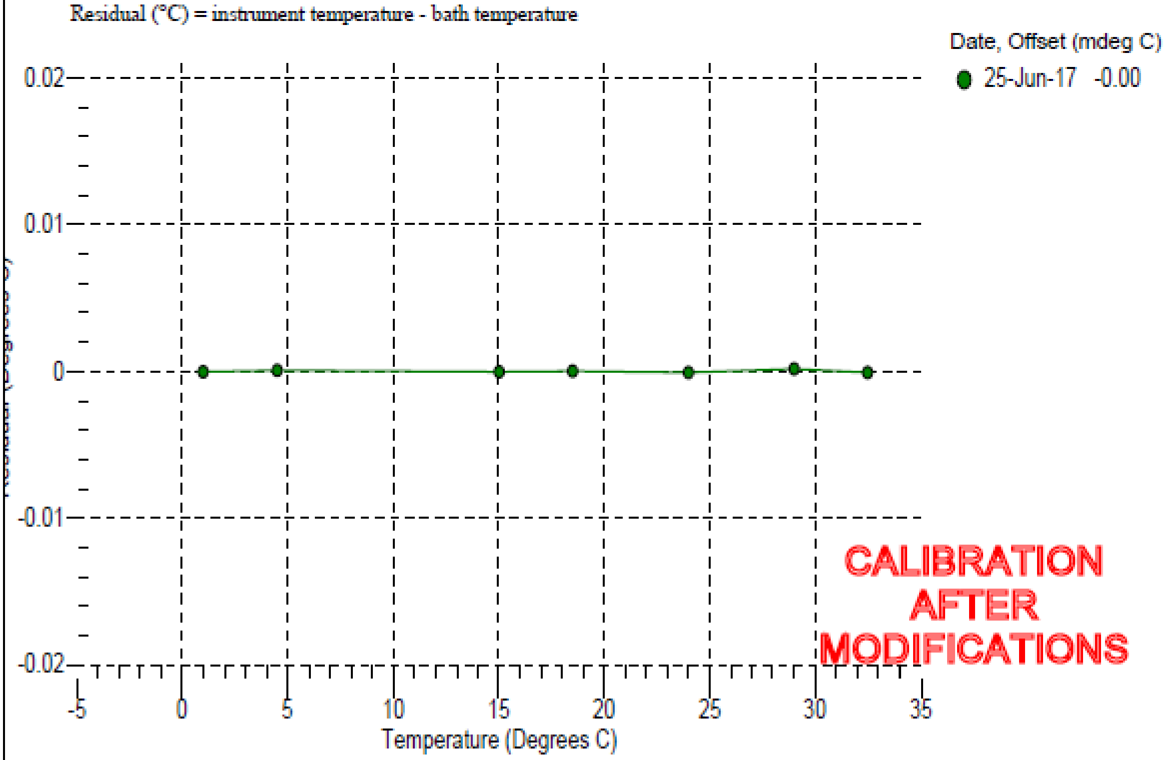
COEFFICIENTS:
g = 4.38724917e-003
h = 6.37439883e-004
i = 2.48503147e-005
j = 2.65839261e-006
f0 = 1000.0

BATH TEMP (° C)	INSTRUMENT OUTPUT (Hz)	INST TEMP (° C)	RESIDUAL (° C)
1.0000	3353.383	1.0000	-0.00003
4.5000	3626.243	4.5001	0.00006
15.0000	4540.853	15.0000	-0.00003
18.5000	4879.156	18.5000	0.00001
24.0000	5446.018	23.9999	-0.00009
29.0000	5999.849	29.0002	0.00019
32.5001	6409.850	32.5000	-0.00010

f = Instrument Output (Hz)

Temperature ITS-90 (°C) = $1/\{g + h[ln(f0 / f)] + i[ln^2(f0 / f)] + j[ln^3(f0 / f)]\} - 273.15$

Residual (°C) = instrument temperature - bath temperature



1

SEA·BIRD SCIENTIFIC

Sea-Bird Scientific
13431 NE 20th Street
Bellevue, WA 98005
USA

+1 425-643-9866
seabird@seabird.com
www.seabird.com

SENSOR SERIAL NUMBER: 0086
CALIBRATION DATE: 25-Jun-17

Glider APL CONDUCTIVITY CALIBRATION DATA
PSS 1978: C(35,15,0) = 4.2914 Siemens/meter

COEFFICIENTS:

```
g =  -1.01703612e+001
h =   1.15131850e+000
i =  -2.08139571e-003
j =   2.50198153e-004

CPcor = -9.5700e-008 (nominal)
CTcor =  3.2500e-006 (nominal)
```

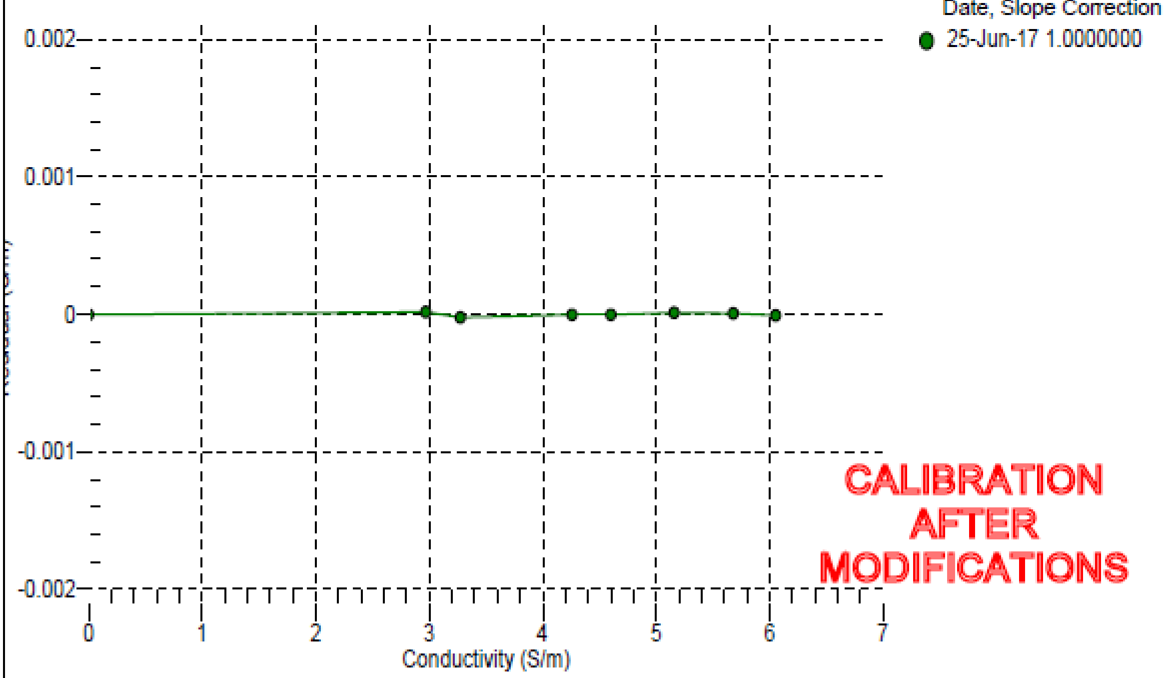
BATH TEMP (° C)	BATH SAL (PSU)	BATH COND (S/m)	INSTRUMENT OUTPUT (kHz)	INSTRUMENT COND (S/m)	RESIDUAL (S/m)
22.0000	0.0000	0.00000	2.97730	0.00000	0.00000
1.0000	34.7663	2.97210	5.89547	2.97212	0.00002
4.5000	34.7470	3.27883	6.11738	3.27881	-0.00002
15.0000	34.7052	4.25942	6.77759	4.25942	-0.00000
18.5000	34.6965	4.60419	6.99465	4.60419	-0.00000
24.0000	34.6872	5.16154	7.33167	5.16155	0.00001
29.0000	34.6823	5.68284	7.63309	5.68284	0.00001
32.5001	34.6791	6.05478	7.84087	6.05477	-0.00001

f = Instrument Output (kHz)

t = temperature (°C); p = pressure (decibars); δ = CTcor; ε = CPcor;

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

Residual (Siemens/meter) = instrument conductivity - bath conductivity



1

AANDERAA a xylem brand

CALIBRATION CERTIFICATE

Form No. 710, Nov 2013

Sensing Foil Batch No: 4909
Certificate No:

Product: Oxygen Optode 4330
Serial No: 229
Calibration Date: 15 Sep 2017

This is to certify that this product has been calibrated using the following instruments:

Parameter: Internal Temperature:

Calibration points and readings:

Temperature (°C)	1.01	11.97	24.02	36.01
Reading (mV)	857.76	529.08	135.48	-245.46

Giving these coefficients

Index	0	1	2	3	4	5
TempCoef	2.81663E01	-3.09343E-02	3.00320E-06	-4.49273E-09	0.00000E00	0.00000E00

Parameter: Oxygen:

	O2 Concentration	Air Saturation
Range:	0-500 µM [1]	0 - 120%
Accuracy[1]:	< ±8µM or ±5% (whichever is greater)	±5%
Resolution:	< 1 µM	< 0.4%
Settling Time (63%):	< 25 seconds	

Calibration points and readings[2]:

	Air Saturated Water	Zero Solution (Na_2SO_3)
Phase reading (°)	3.25740E+01	6.06835E+01
Temperature reading (°C)	9.89265E+00	2.33573E+01
Air Pressure (hPa)	9.56812E+02	

Giving these coefficients

Index	0	1	2	3
PhaseCoef	0.00000E00	1.00000E00	0.00000E00	0.00000E00
ConcCoef	-2.02200E00	1.22744E00		

[1] *Valid for 0 to 2000m (6562ft) depth, salinity 33 - 37ppt*
[2] *The calibration is performed in fresh water and the salinity setting is set to:* 0

Date: 15 Sep 2017

Sign:

Tor-Ove Kvalvaag

Tor-Ove Kvalvaag, Calibration Engineer

AANDERAA a xylem brand

CALIBRATION CERTIFICATE

Form No 770, Jun 2008

Certificate No: 3853_4909E_40239 **Product:** O2 Sensing Foil PSt3 **Serial No:** 4909
Batch No: 4909E **Calibration Date:** 05 Feb 2010

Calibration points and phase readings

Index	Temperature (°C)	Phase Reading (°)	Oxygen reference (µM)	Index	Temperature (°C)	Phase Reading (°)	Oxygen reference (µM)
0	3.237	63.051	0.00	32	39.412	33.610	84.17
1	3.242	58.698	18.65	33	39.415	25.601	175.91
2	3.247	55.688	37.29	34	39.419	22.147	252.49
3	3.249	48.603	93.21	35	6.661	62.823	0.00
4	3.256	40.791	186.38	36	6.666	58.276	17.14
5	3.274	31.831	389.36	37	6.668	55.160	34.27
6	3.275	27.624	558.88	38	6.670	47.886	85.67
7	10.085	62.596	0.00	39	6.673	39.991	171.33
8	10.090	57.854	15.63	40	6.682	31.069	357.99
9	10.089	54.631	31.26	41	6.683	26.963	513.85
10	10.091	47.169	78.14	42	15.002	62.235	0.00
11	10.091	39.191	156.28	43	15.004	57.227	14.06
12	10.091	30.306	326.63	44	15.006	53.850	28.11
13	10.092	26.302	468.83	45	15.006	46.168	70.28
14	19.918	61.875	0.00	46	15.006	38.175	140.56
15	19.918	56.599	12.48	47	15.006	29.419	293.77
16	19.922	53.069	24.97	48	15.006	25.499	421.67
17	19.922	45.168	62.42	49	24.800	61.485	0.00
18	19.922	37.159	124.84	50	24.818	55.916	11.34
19	19.921	28.531	260.91	51	24.822	52.270	22.68
20	19.920	24.697	374.52	52	24.820	44.226	56.71
21	29.682	61.095	0.00	53	24.821	36.230	113.42
22	29.719	55.233	10.20	54	24.819	27.745	237.06
23	29.722	51.471	20.40	55	24.819	24.007	340.28
24	29.719	43.285	51.01	56	34.553	60.509	0.00
25	29.720	35.300	102.01	57	34.570	54.453	9.31
26	29.718	26.960	213.21	58	34.571	50.609	18.62
27	29.719	23.318	306.04	59	34.570	42.363	46.54
28	39.424	59.923	0.00	60	34.566	34.455	93.09
29	39.422	53.673	8.42	61	34.567	26.281	194.56
30	39.420	49.748	16.83	62	34.569	22.732	279.26
31	39.421	41.440	42.08	63			

AANDERAA CALIBRATION CERTIFICATE

a xylem brand

Giving these coefficients

Index	FoilCoefA	FoilCoefB
0	-2.822802E-06	7.511727E-08
1	-6.776306E-06	3.624938E+03
2	1.803907E-03	-3.762469E+01
3	-1.930332E-01	2.454485E-01
4	6.291334E-04	-3.315326E-03
5	-2.982824E-07	4.753640E-05
6	1.049904E+01	-4.883913E-07
7	-5.455740E-02	0.000000E+00
8	9.256500E-05	0.000000E+00
9	-4.397045E-07	0.000000E+00
10	-2.971280E+02	0.000000E+00
11	2.236731E+00	0.000000E+00
12	-7.953454E-03	0.000000E+00
13	4.779584E-05	0.000000E+00

Using the following monomial degrees

Index	FoilPolyDegT	FoilPolyDegO
0	1	4
1	0	5
2	0	4
3	0	3
4	1	3
5	2	3
6	0	2
7	1	2
8	2	2
9	3	2
10	0	1
11	1	1
12	2	1
13	3	1
14	4	1
15	0	0
16	1	0
17	2	0
18	3	0
19	4	0
20	5	0
21	0	0
22	0	0
23	0	0
24	0	0
25	0	0
26	0	0
27	0	0

Date: 05 Feb 2010

Sign:

PO Box 518
620 Applegate St.
Philomath, OR 97370

(541) 929-5650
Fax (541) 929-5277
www.wetlabs.com

ECO Chlorophyll Fluorometer Characterization Sheet

Date: 7/17/2017

S/N: BB2FVMG-512

Chlorophyll concentration expressed in µg/l can be derived using the equation:

CHL (µg/l) = Scale Factor * (Output - Dark counts)

	Digital
Dark counts	57 counts
Scale Factor (SF)	0.0122 µg/l/count
Maximum Output	4120 counts
Resolution	2.5 counts
Ambient temperature during characterization	22.3 °C

Dark Counts: Signal output of the meter in clean water with black tape over detector.

SF: Determined using the following equation: SF = x ÷ (output - dark counts), where x is the concentration of the solution used during instrument characterization. SF is used to derive instrument output concentration from the raw signal output of the fluorometer.

Maximum Output: Maximum signal output the fluorometer is capable of.

Resolution: Standard deviation of 1 minute of collected data.

The relationship between fluorescence and chlorophyll-a concentrations in-situ is highly variable. The scale factor listed on this document was determined using a mono-culture of phytoplankton (Thalassiosira weissflogii). The population was assumed to be reasonably healthy and the concentration was determined by using the absorption method. To accurately determine chlorophyll concentration using a fluorometer, you must perform secondary measurements on the populations of interest. This is typically done using extraction-based measurement techniques on discrete samples. For additional information on determining chlorophyll concentration see "Standard Methods for the Examination of Water and Wastewater" part 10200 H, published jointly by the American Public Health Association, American Water Works Association, and the Water Environment Federation.

PO Box 518
620 Applegate St.
Philomath, OR 97370

WET Labs

(541) 929-5650
Fax (541) 929-5277
www.wetlabs.com

Scattering Meter Calibration Sheet

7/17/2017
Wavelength: 470 S/N BB2FVMG-512

Use the following equation to obtain "scaled" output values:

$$\beta(\theta_c)\ m^{-1}\ sr^{-1} = \text{Scale Factor} \times (\text{Output - Dark Counts})$$

- **Scale Factor for 470 nm** = 1.595E-05 $(m^{-1}sr^{-1})$/counts
- **Output** = meter reading counts
- **Dark Counts** = 54 counts

Instrument Resolution = 1.0 counts 1.60E-05 $(m^{-1}sr^{-1})$

Definitions:

- **Scale Factor**: Calibration scale factor, $\beta(\theta_c)$/counts. Refer to User's Guide for derivation.
- **Output**: Measured signal output of the scattering meter.
- **Dark Counts**: Signal obtained by covering detector with black tape and submersing sensor in water.

Instrument Resolution: Standard deviation of 1 minute of collected data.

PO Box 518
620 Applegate St.
Philomath, OR 97370

WET Labs

(541) 929-5650
Fax (541) 929-5277
www.wetlabs.com

Scattering Meter Calibration Sheet

7/17/2017
Wavelength: 700 S/N BB2FVMG-512

Use the following equation to obtain "scaled" output values:

$$\beta(\theta_c)\ m^{-1}\ sr^{-1} = \text{Scale Factor} \times (\text{Output} - \text{Dark Counts})$$

- **Scale Factor for 700 nm** = 3.758E-06 $(m^{-1}sr^{-1})$/counts
- **Output** = meter reading counts
- **Dark Counts** = 49 counts

Instrument Resolution = 2.5 counts 9.39E-06 $(m^{-1}sr^{-1})$

Definitions:

- **Scale Factor**: Calibration scale factor, $\beta(\theta_c)$/counts. Refer to User's Guide for derivation.
- **Output**: Measured signal output of the scattering meter.
- **Dark Counts**: Signal obtained by covering detector with black tape and submersing sensor in water.

Instrument Resolution: Standard deviation of 1 minute of collected data.