

Report on correction of dissolved oxygen sensor (Aanderaa Optode) data collected with gliders during the Long Bay field program in 2012

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This report documents findings during examination of the level 1 data collected with gliders during the Long Bay project and actions taken to improve data quality as a result of these findings. The initial concern was that sequential up- and down-casts displayed large offsets in the depths of large changes in DO. The problem is typically associated with slow sensor response. An additional concern is the best way to implement re-calculation of the DO concentration and saturation values using temperature, salinity and pressure measured with the CTD, rather than relying on the Optode internal temperature sensor and fixed, default values for salinity and pressure. Lastly, implementing calibrations performed at Skidaway also needs to be worked out.

DO Internal T Compared to External (from CTD)

We first document issues with the internal temperature sensors on the Optodes in ramses and pelagia. Figures 1a, 1b, and 1c below compare the dissolved oxygen (DO) sensor's internal temperature with that of the CTD (external) temperature. Note that the dissolved oxygen (DO) sensor's internal temperature lags the CTD (external) temperature. This lag is estimated by finding the lag that corresponds to the peak of the cross-correlation between the two time series. Table 1 reports this lag for Level 1 (L1) data.

<i>Glider Deployment</i>	<i>Lag (seconds)</i>
Ramses 1	213
Ramses 2	189
Pelagia 3	174

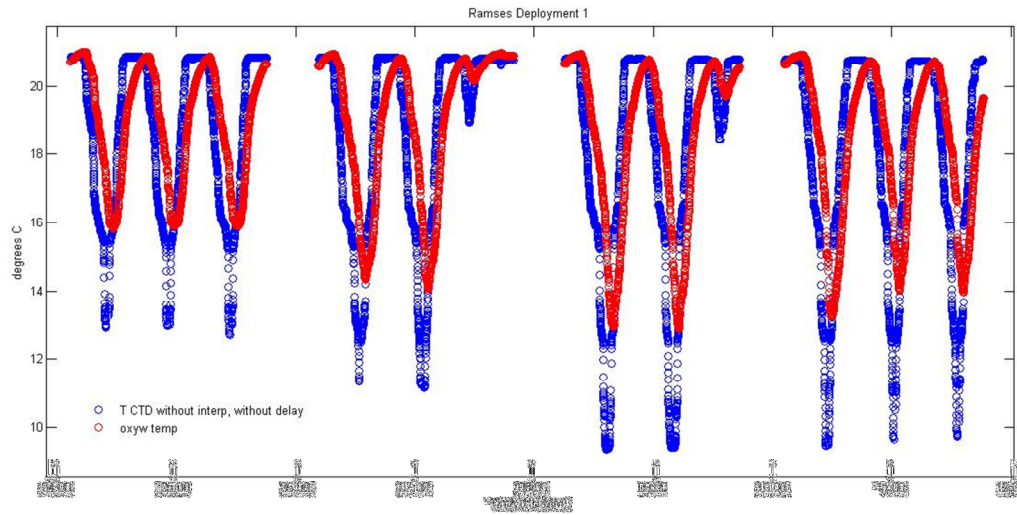


Figure 1a: For Ramses Deployment1, External Temperature (from CTD) vs. time and Internal Temperature (DO sensor) vs. time.

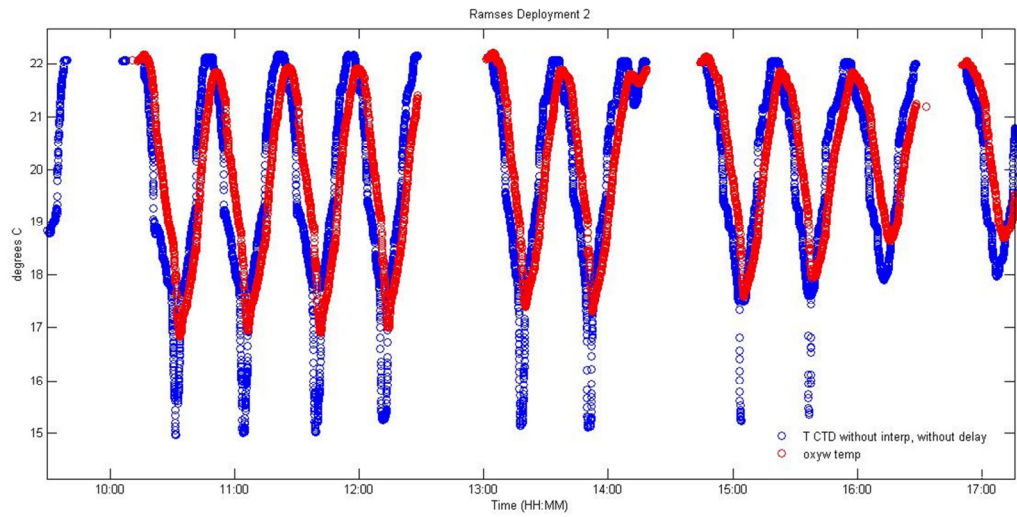


Figure 1b: For Ramses Deployment2, External Temperature (from CTD) vs. time and Internal Temperature (DO sensor) vs. time.

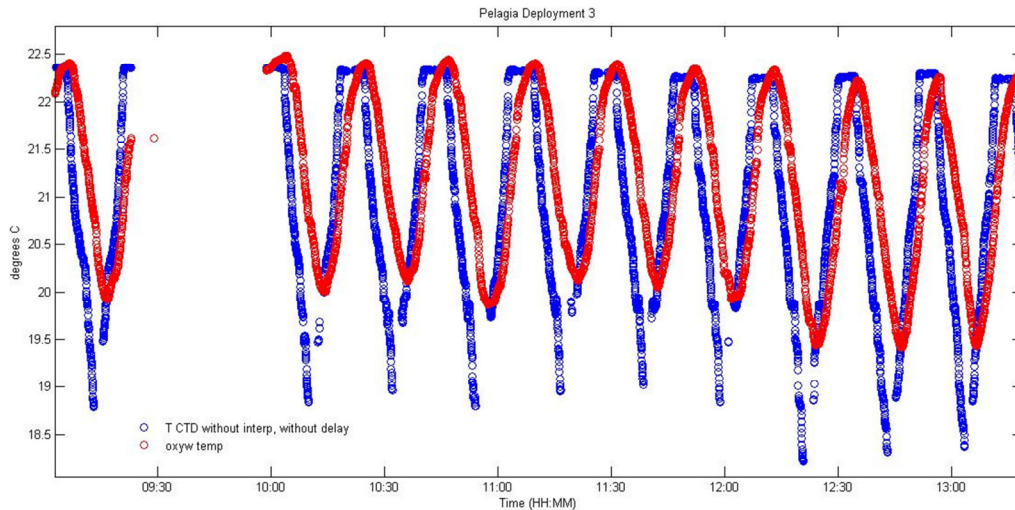


Figure 1c: For Pelagia Deployment3, External Temperature (from CTD) vs. time and Internal Temperature (DO sensor) vs. time.

The Problem with L1 Data: Hysteresis

Since the internal temperature sensor's response time is so long, we used the external (CTD) temperature--as well as salinity and pressure from the CTD--to calculate the L1 TSP-corrected $[O_2]$, implementing the polynomials in the Optode manual. The TSP correction changes the range of $[O_2]$. However, there is still a problem with this L1 data--hysteresis. Figure 2a, 2b, and 2c show examples of this hysteresis issue in up-down sections of L1 data from Ramses Deployment1, Ramses Deployment2, and Pelagia Deployment3, respectively, where

O2 (oxyw oxygen) is $[O_2]$ from the sensor using the internal temperature—**not** using the external temperature;

O2 (TSP Corr) is $[O_2]$ corrected **using CTD data** (TSP)—in L1, there is no delay of the CTD Data.

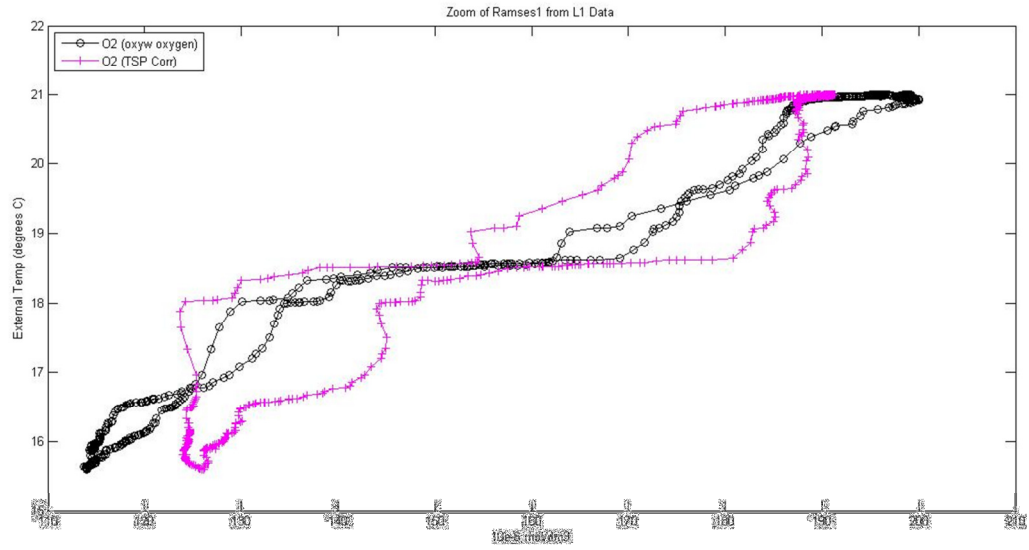


Figure 2a: External T vs. O2 (oxyw oxygen) and O2 (TSP Corr) for a section of L1 Ramses1 data (from 30-Jan-2012 20:43:48 to 30-Jan-2012 21:13:48)

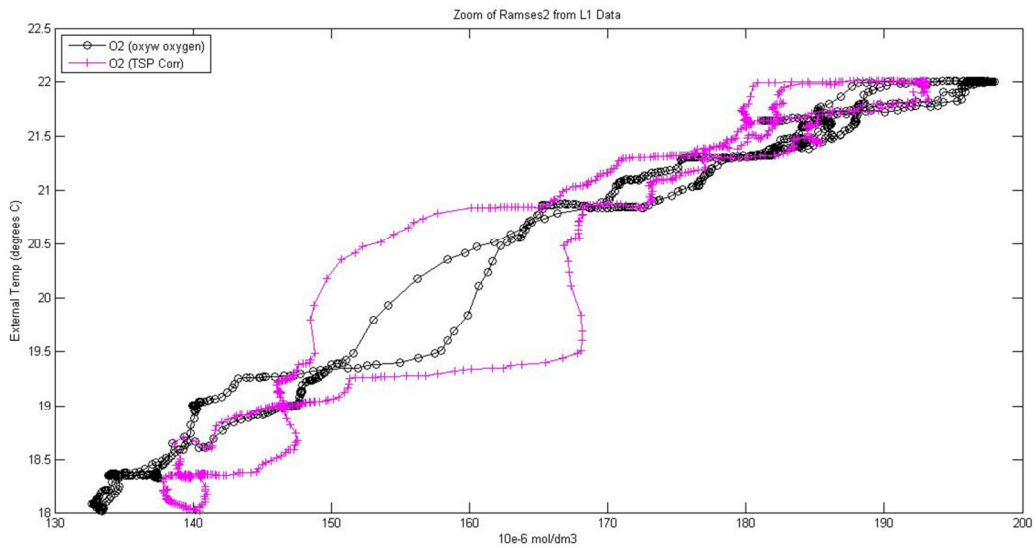


Figure 2b: External T vs. O2 (oxyw oxygen) and O2 (TSP Corr) for a section of L1 Ramses2 data (from 16-Feb-2012 17:20:21 to 16-Feb-2012 18:00:21)

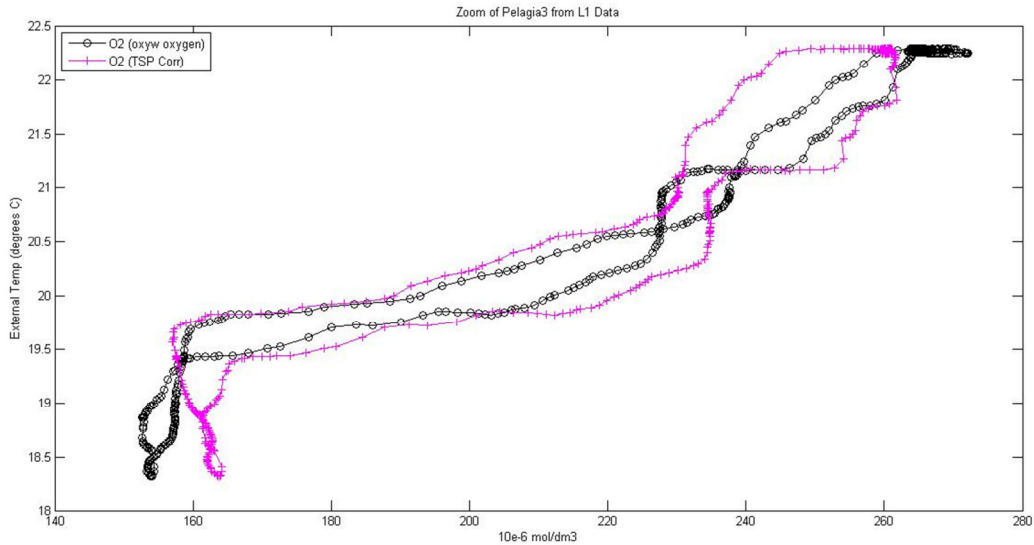


Figure 2c: External T vs. O2 (oxyw oxygen) and O2 (TSP Corr) for a section of L1 Pelagia 3 data (from 22-Mar-2012 12:31:00 to 22-Mar-2012 12:56:00)

Clearly the TSP correction alters the values but fails to address the hysteresis, and in fact appears to make it worse.

The Solution to Hysteresis—Use Filtered and Delayed CTD Data

The solution to the hysteresis problem observed in the L1 data is to filter the external (CTD) temperature (and salinity) and delay the CTD variables 27 seconds *before* they are used to calculate the TSP-Corrected dissolved oxygen concentration. The suggestion to do simply lag the data about 30 seconds came from Josh Kohut at Rutgers, who shared simple code to implement a lag. This modified data set is called “Regen From L0” to indicate that it is regenerated from Level 0 data, with these changes. The improvement is seen in Figures 3a, 3b, and 3c below.

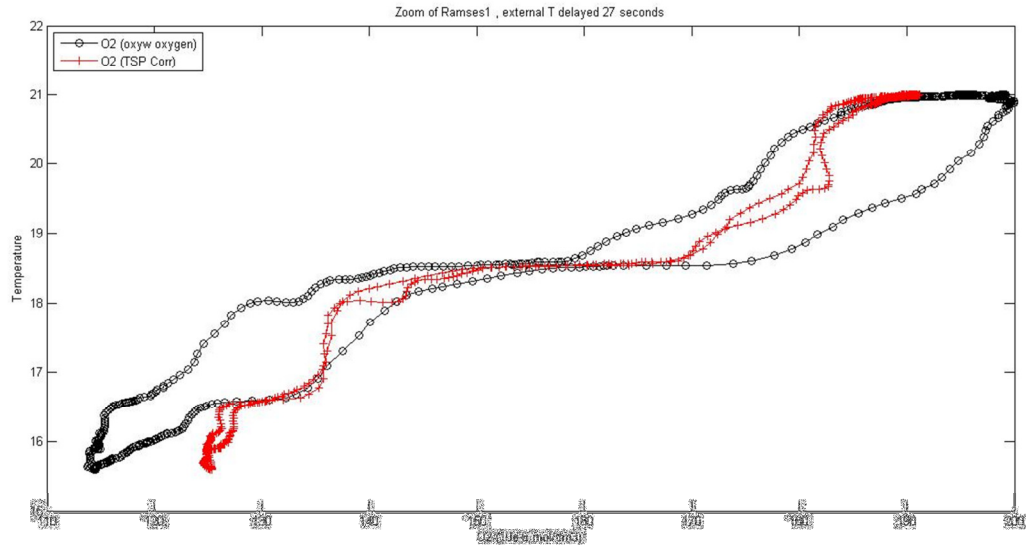


Figure 3a: External T vs. O2 (oxyw oxygen) and O2 (TSP Corr) for a section of Ramses1 data which was regenerated from Level0--after filtering the CTD's T,S and delaying the CTD variables by 27 seconds.

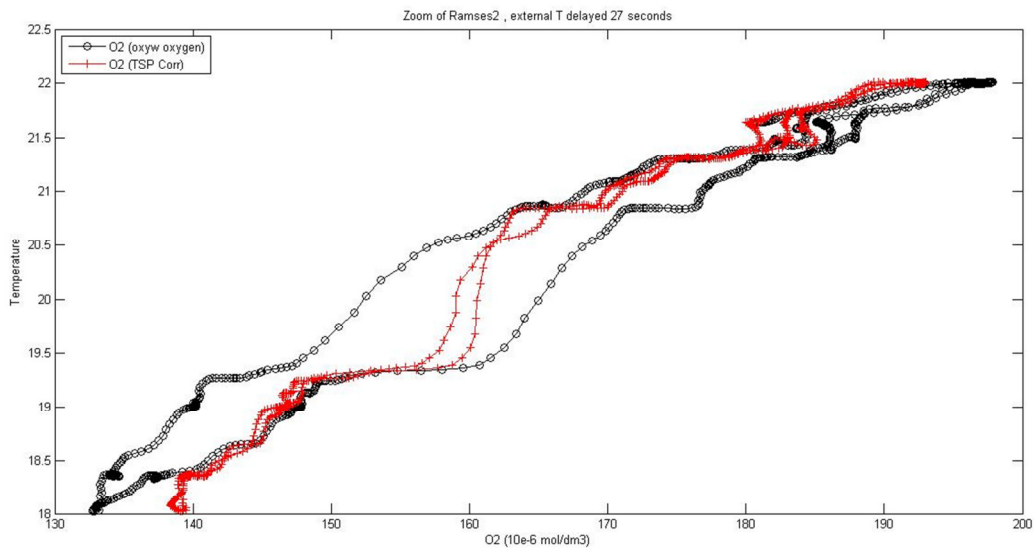


Figure 3b: External T vs. O2 (oxyw oxygen) and O2 (TSP Corr) for a section of Ramses2 data which was regenerated from Level0, after filtering the CTD's T,S and delaying the CTD variables by 27 seconds.

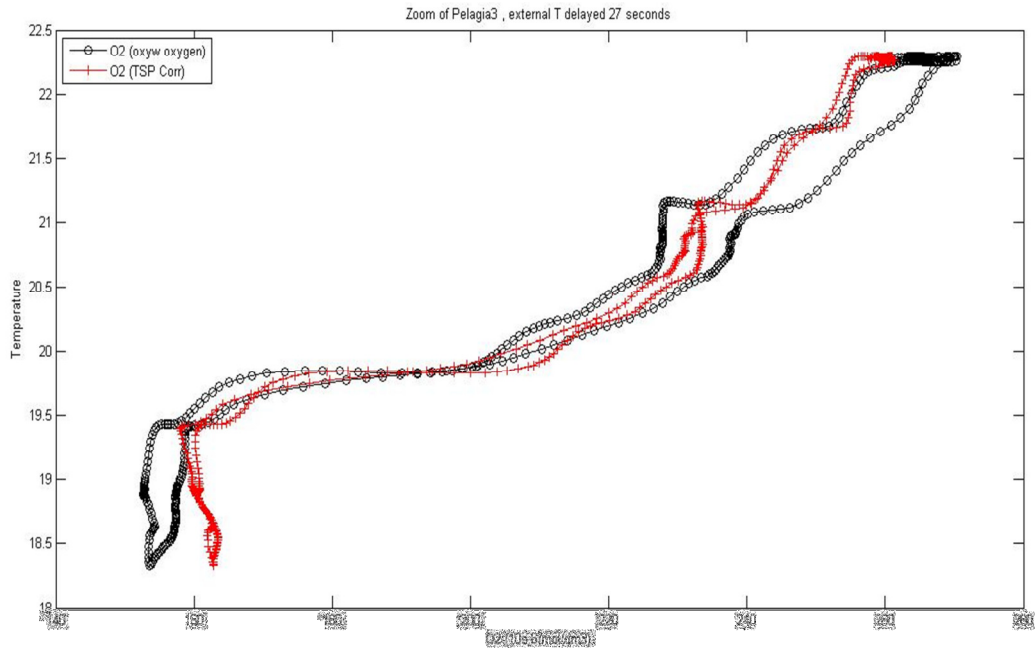


Figure 3c: External T vs. O2 (oxyw oxygen) and O2 (TSP Corr) for a section of Pelagia3 data which was regenerated from Level0, after filtering the CTD's T,S and delaying the CTD variables by 27 seconds.

Calibration Fix

There is another problem with the internal temperature of the DO sensor. Not only is there a poor response time, but there is also an offset. We can see that best during periods when the temperature is not changing much. Figures 4a and 4b show that for Ramses2 and Pelagia3, respectively.

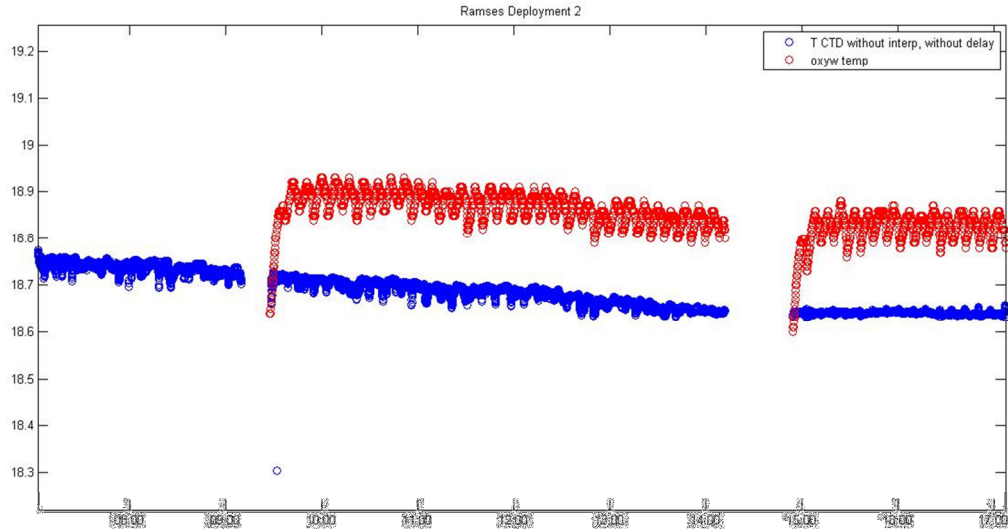


Figure 4a: View of offset for Ramses, during a period when temperature is not changing much.

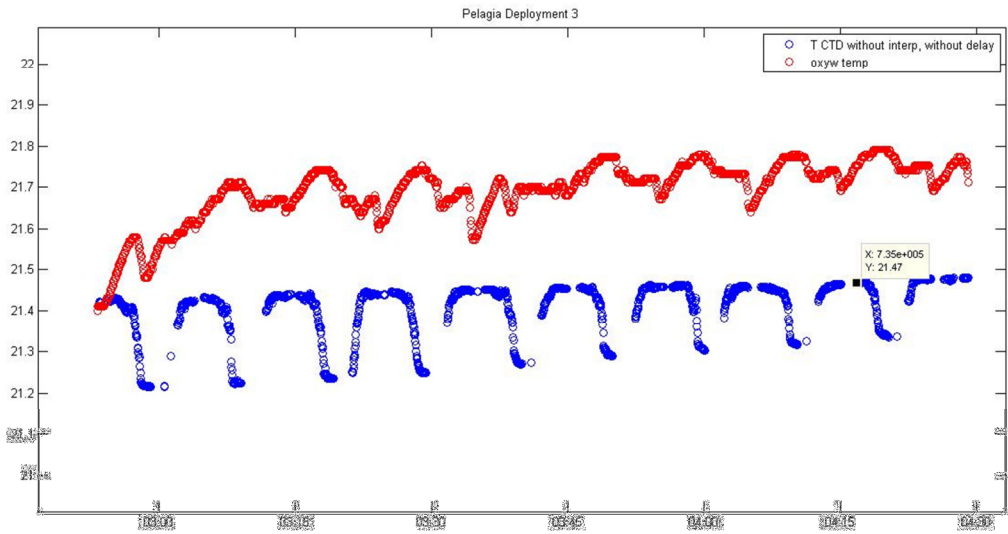


Figure 4b: View of offset for Pelagia, during a period when temperature is not changing much.

For, Ramses, the offset is about +0.2 degrees C; i.e. the actual temperature should be 0.2 degrees C lower. For Pelagia (3rd deployment), the offset is about 0.32 degrees C, with the internal sensor biased high.

Why is the offset important? Neither the original L1 dataset nor the “Regen From L0” dataset use the internal temperature. On the other hand, it is important when we consider the initial calibration process; during calibration, the instrument’s [O₂] measurements **were** derived from the internal temperature sensor. Therefore, we must revisit the calibration and try to estimate what the calibration would have been if the internal temperature was **not** offset—i.e. if the temperature was 0.2 degrees C lower for Ramses1 and Ramses2 and 0.32 degrees C lower for Pelagia3.

From the calibration, we have three data points (low, medium, high) of the actual (Winkler) [O₂] and the instrument’s reported [O₂]. These are pre-calibration values from the instrument. To fix the calibration, we can follow the following steps (per instrument):

1. Working backwards from the instrument’s reported [O₂], we can estimate the dphase for each calibration data point.
2. Then, for each calibration data point, we can adjust the internal temperature to remove the offset and calculate what the instrument **would have reported** at this lower temperature and this dphase. Now, we have revised calibration data points.
3. Get a linear fit to the revised calibration data points. This revised linear fit (slope and intercept) should then be applied to the data, resulting in *calibrated* TSP-corrected [O₂]. The revised calibration curves are shown in Figures 5a and 5b.

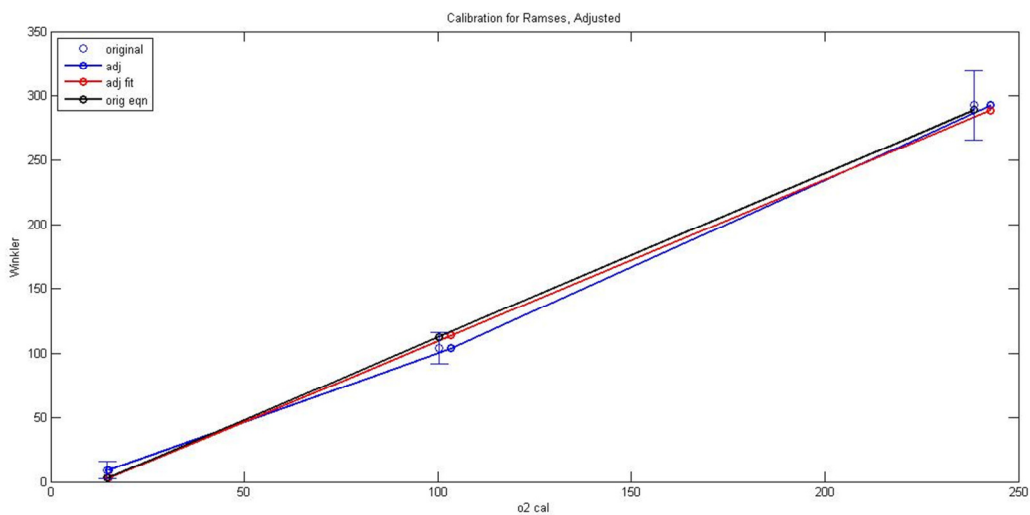


Figure 5a: Adjustments to calibration curve for Ramses

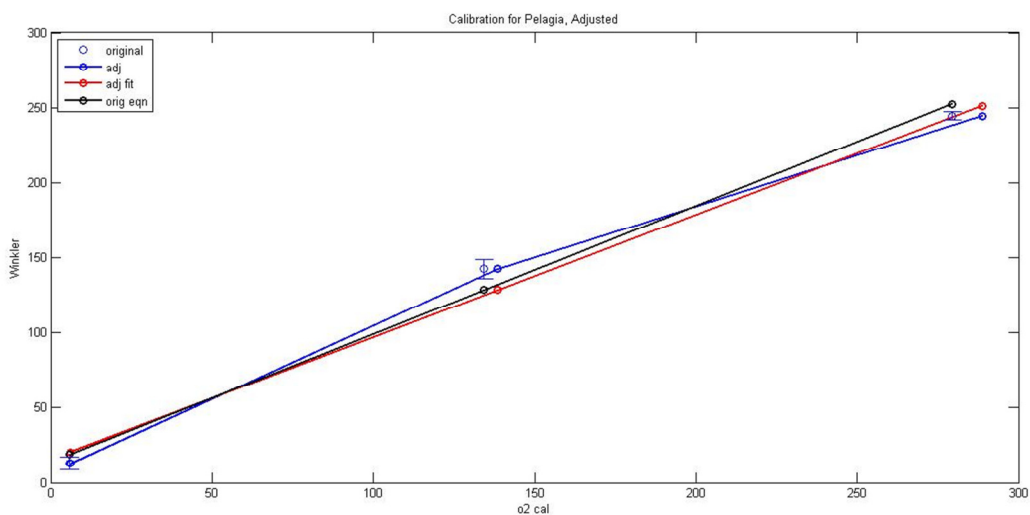


Figure 5b: Adjustments to calibration curve for Pelagia, where revisions were made to the 4/24/12 calibration

In Figures 5a and 5b, the "original" calibration points are plotted in blue circles (no line) with the Winkler standard deviations. The original fit is plotted as "orig eqn" in black. The calibration points are then adjusted as documented above to generate the blue circles (*with* line). The new, adjusted fit is in red.

Future calibrations: it will be important in the future to make sure that during calibrations the dphase, internal temperature, as well as reported concentration, is recorded, as well as the external temperature and conductivity/salinity. Doing so will allow for a comparison of the default concentration with that corrected for temperature and salinity, and to document offsets between the internal and external temperature sensors.

O2 Sat—Using CTD Data (L1)

In this section, we show the O2 Saturation %, using the external temperature, from the L1 data set.

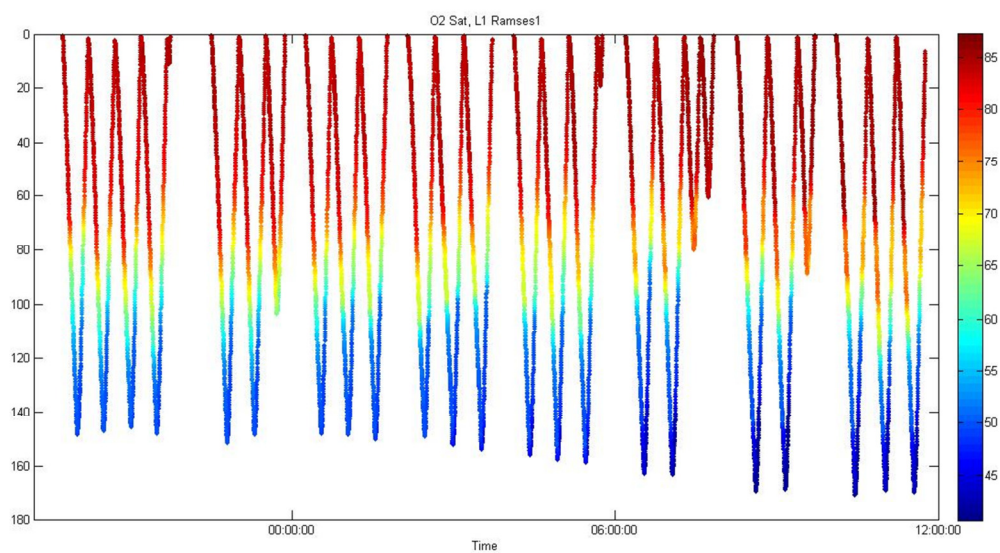


Figure 6a: O2 Sat for Ramses 1, L1 (using external T)

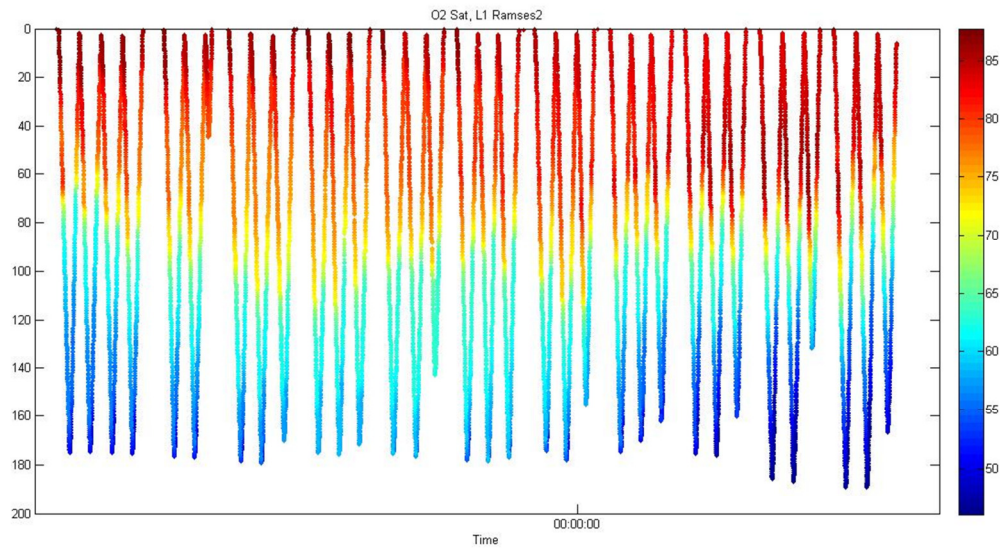


Figure 6b: O2 Sat for Ramses 2, L1 (using external T)

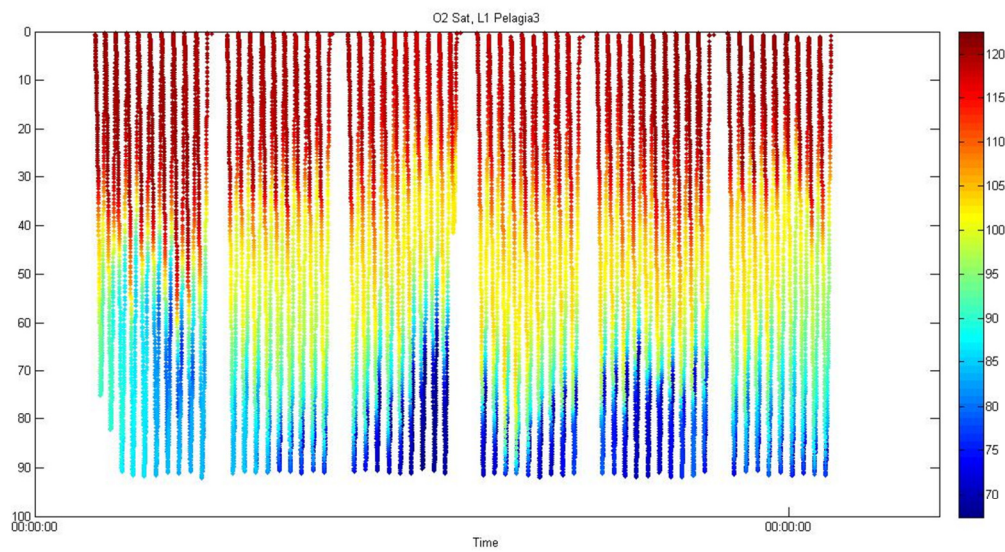


Figure 6c: O2 Sat for Pelagia 3, L1 (using external T)

O2 Sat--Using Filtered and Delayed CTD Data

In this section, we show the O2 Saturation %, using the external temperature which was filtered and delayed 27 seconds (before calculating o2 sat).

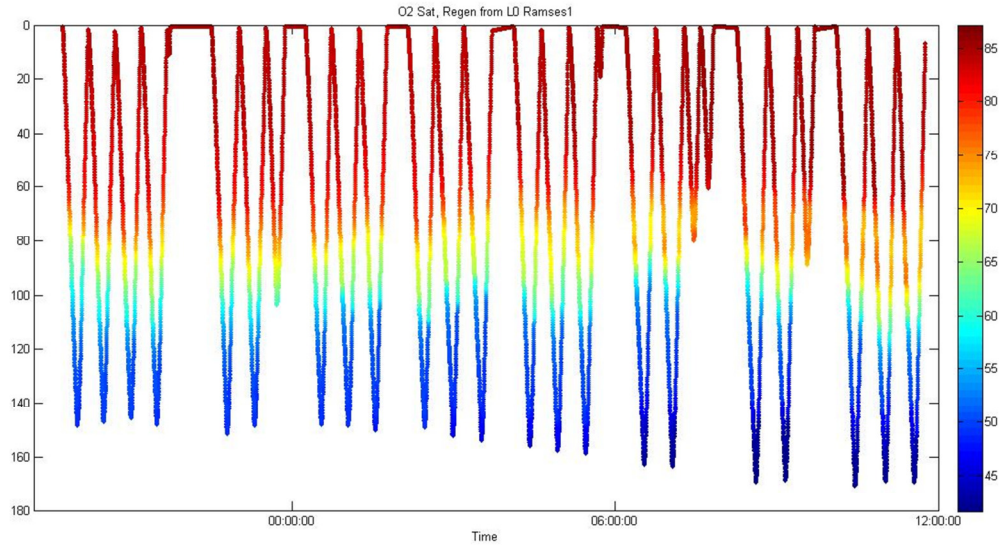


Figure 7a: O2 Sat for Ramses 1 "Regen from L0" using external T, filtered and delayed 27 seconds.

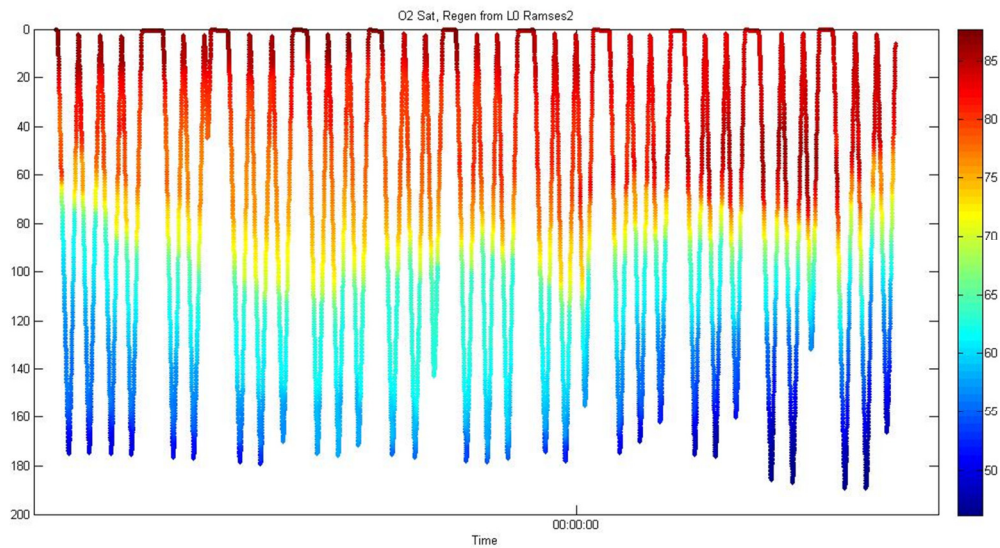


Figure 7b: O2 Sat for Ramses 2 "Regen from L0" using external T, filtered and delayed 27 seconds.

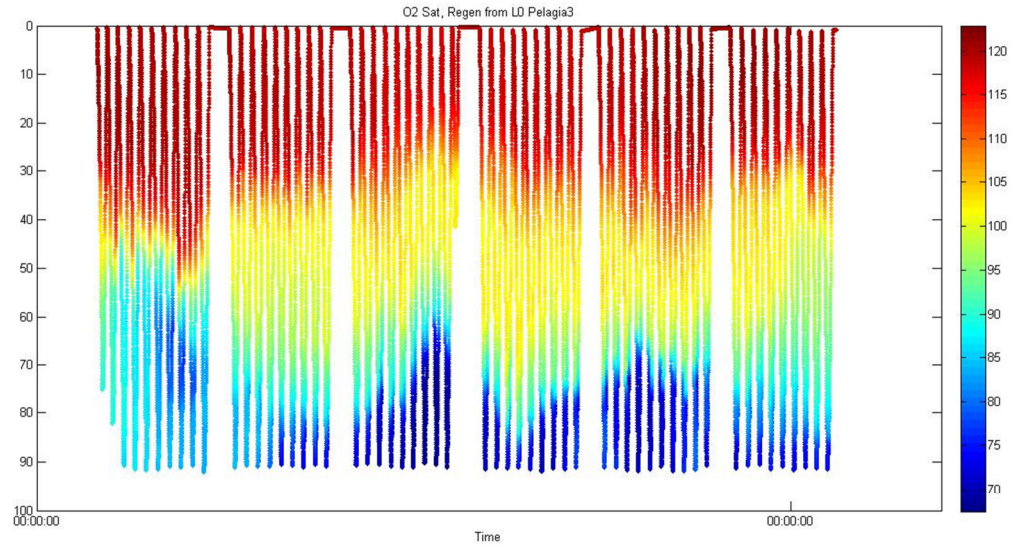


Figure 7c: O2 Sat for Pelagia3 “Regen from L0” using external T, filtered and delayed 27 seconds.

O2 Sat— Using Filtered and Delayed CTD Data + Calibration Fix

In this section, we show the O2 Saturation %--using the external temperature which was filtered and delayed 27 seconds (before calculating o2 sat). Also, the calibration fix was applied.

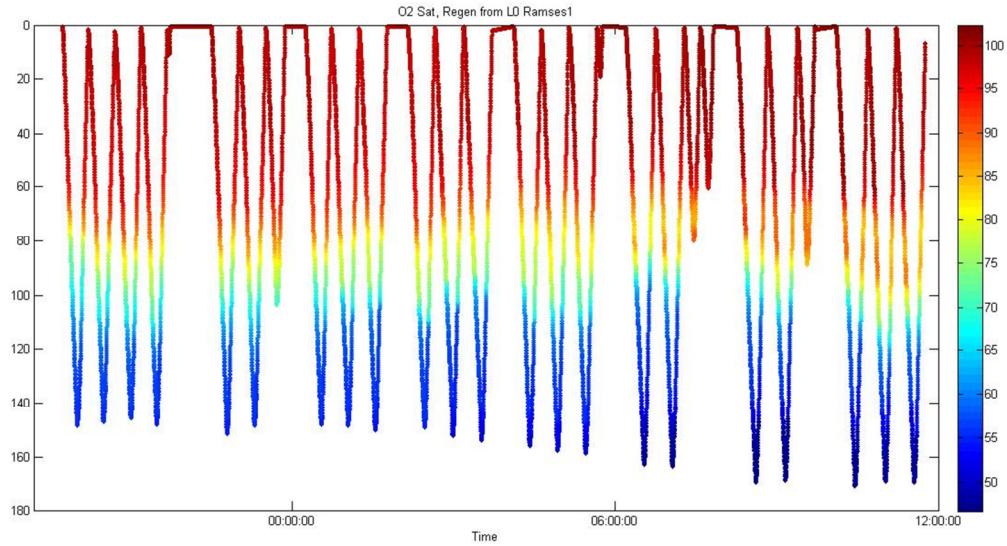


Figure 8a: O2 Sat for Ramses1 "Regen from L0" using external T, filtered and delayed 27 seconds. Also calibration fix is applied.

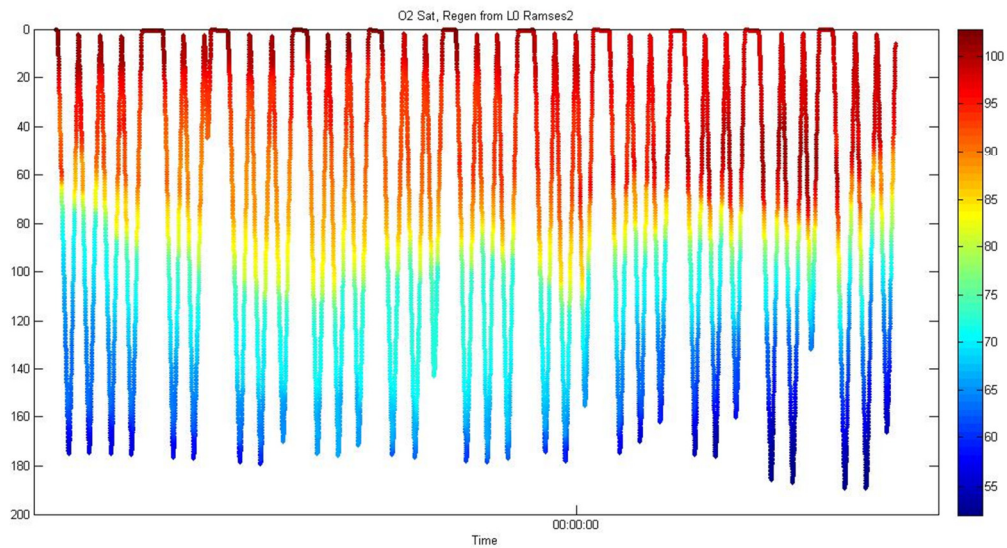


Figure 8b: O2 Sat for Ramses2 "Regen from L0" using external T, filtered and delayed 27 seconds. Also calibration fix is applied.

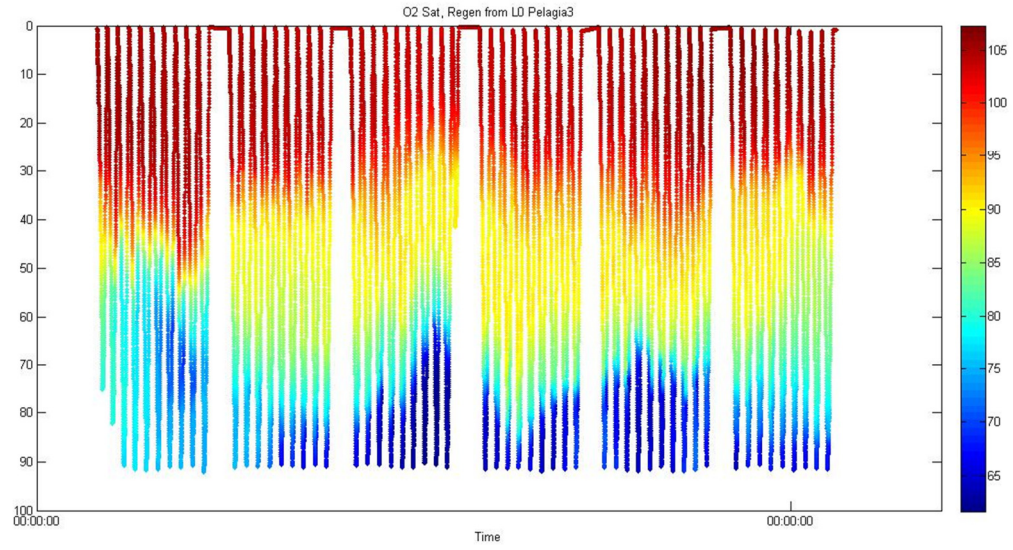


Figure 8c: O2 Sat for Pelagia3 “Regen from L0” using external T, filtered and delayed 27 seconds. Also calibration fix is applied.

The calibrations largely correct the concentration values so that near saturation is present at the surface.

Figures 9a,b, and c show scatter plots of DO vs. External Temperature for the entire data set (per deployment).

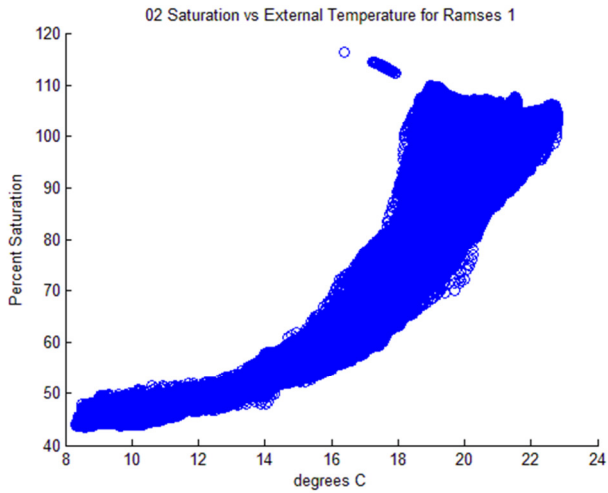


Figure 9a: O2 Sat vs. External Temperature for Ramses1 "Regen from L0" using external T, filtered and delayed 27 seconds. Also calibration fix is applied.

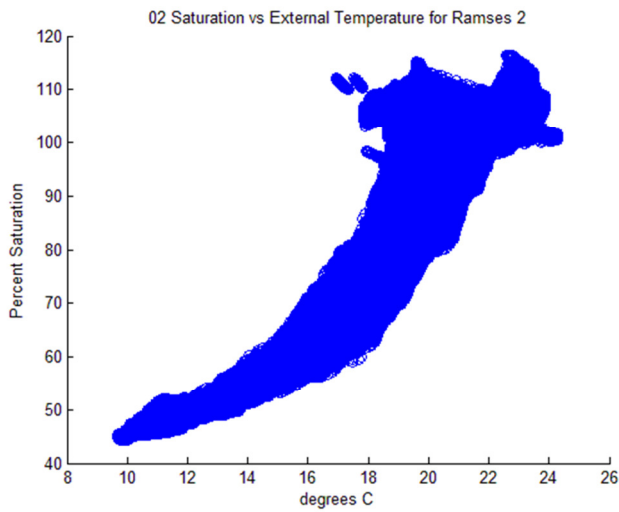


Figure 9b: O2 Sat vs. External Temperature for Ramses2 "Regen from L0" using external T, filtered and delayed 27 seconds. Also calibration fix is applied.

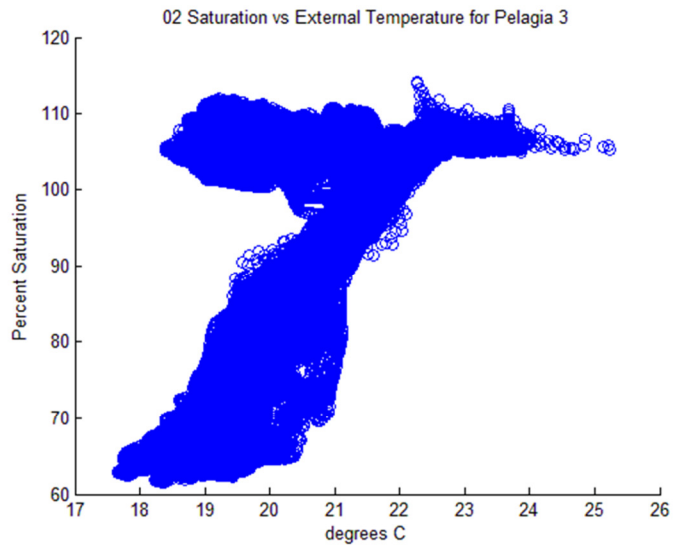


Figure 9c: O2 Sat vs. External Temperature for Pelagia3 "Regen from L0" using external T, filtered and delayed 27 seconds. Also calibration fix is applied.

Details on “Regen From L0”

This section documents the specific steps that were applied in the “Regen from L0” solution—i.e. the specific differences between this new L2 data set and the original L1 data set.

Regular sample interval	The CTD variables (temperature, salinity, and depth) are resampled at a 3 second sample interval.
Filter the CTD’s temperature and salinity	Filter the temperature and salinity (from the CTD), using cut-off frequency $f_c = 1/30$ per second i.e. $T_c = 30$ seconds. Matlab <code>filtfilt</code> was used with a 4 th order butterworth filter i.e. 4 th order forward- and 4 th order reverse-filtered.
Delay the CTD variables	Delay the CTD variables by 27 seconds.
Interpolate CTD data to the DO time base	The delayed CTD variables (filtered temperature, filtered salinity, and depth) are interpolated to the DO sensor’s time base, which has an irregular sample interval (median approximately 3.3 seconds).
Recalculate DO output variables	The TSP-corrected oxygen concentration <code>o2_tspcorr</code> is calculated using the modified CTD data: <ul style="list-style-type: none">• Temperature filtered, delayed, and interpolated• Salinity filtered, delayed, and interpolated• Depth delayed and interpolated.
Apply Calibration Curve	The calibration curve (i.e. the slope and intercept described above in the “Calibration Fix” section) is applied. So, the calibrated TSP-corrected oxygen concentration is: $\text{slope} * \text{o2_tspcorr} + \text{intercept}$.

FYI, My code currently resides on my laptop in:

- C:\Users\slockhar\Projects\LongBay\External\from_Chris_Calloway\gliderproc_modBySBL\gliderproc\gliderOptode_Generate_L2_Data_modBySBL.m, my modification of Chris Calloway’s program.
- Plotting routines in C:\Users\slockhar\Projects\LongBay\External\O2