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Woods Hole Oceanographic Institution

UCTD and EcoCTD Observations from the CALYPSO Pilot Experiment (2018): Cruise and Data Report

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M. Dever, M. Freilich, B. Hodges, T. Farrar, T. Lanagan, and A. Mahadevan

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Technical Report

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Approved for Distribution:

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January 18, 2019

Abstract

From May 27, 2018 to June 02, 2018, a scientific campaign was conducted in the Alboran Sea as part of an ONR Departmental Research Initiative, CALYPSO. The pilot cruise involved two ships: the R/V Socib, tasked with sampling fixed lines repeatedly, and the NRV Alliance that surveyed along the trajectory of Lagrangian platforms. A large variety of assets were deployed from the NRV Alliance, with the objective to identify coherent Lagrangian pathways from the surface ocean to interior. As part of the field campaign, an Underway-CTD (UCTD) system was used to measure vertical profiles of salinity, temperature and other properties while steaming, to achieve closely spaced measurements in the horizontal along the ship's track. Both a UCTD probe and an bio-optically augmented probe, named EcoCTD, were deployed. The EcoCTD collects concurrent physical and bio-optical observations. This report focuses exclusively on the data collected by these two underway systems. It describes the datasets collected during the pilot cruise, as well as the important processing steps developed for the EcoCTD.

Contents

1 Background

From May 27, 2018 to June 02, 2018, a scientific campaign was conducted in the Alboran Sea as part of an ONR Departmental Research Initiative, CALYPSO[1]. The pilot cruise involved two ships: the NRV Alliance (93 m long), and the R/V SOCIB (24 m long). While the R/V Socib was tasked with sampling fixed lines repeatedly (see data report by Johnston, Rudnick, Tintoré and Wirth[2]), the NRV Alliance surveyed along the trajectory of Lagrangian platforms.

A large variety of assets were deployed from the NRV Alliance, with the objective to identify coherent Lagrangian pathways from the surface ocean to interior. Assets included a neutrally-buoyant float, different designs of surface and drogued drifters (CODE, SVP, CARTHE), a ship-based CTD rosette, a hull-mounted acoustic current profiler, and a flow-through thermosalinograph. Additionally, an Underway-CTD (UCTD) system was used to measure vertical profiles of salinity, temperature and other properties while steaming, to achieve closely spaced measurements in the horizontal along the ship's track. Two different probes were used: a UCTD probe [*Rudnick and Klinke*, 2007], as well as an augmented probe, named EcoCTD, that collects concurrent physical and bio-optical observations (Figure 1). This report focuses exclusively on the data collected by the UCTD and EcoCTD probes. It describes the datasets collected during the pilot cruise, as well as the important processing steps developed for the EcoCTD.

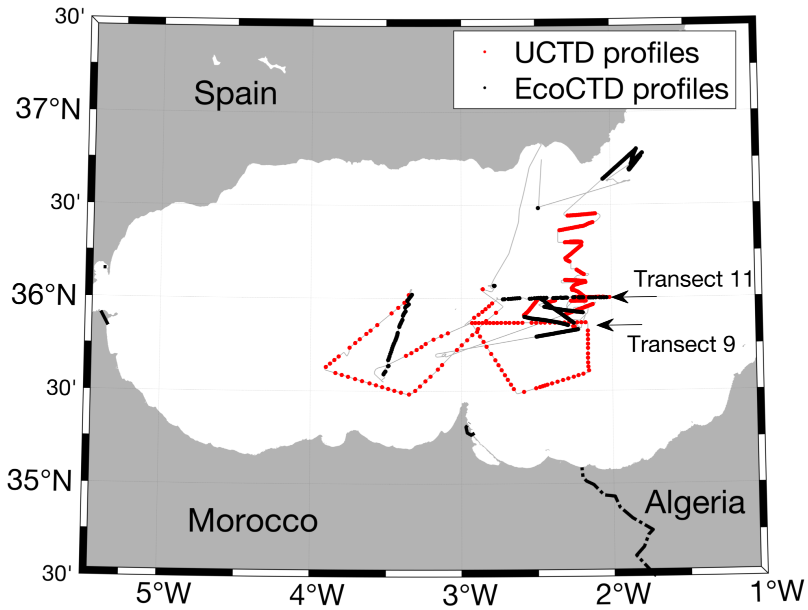

Figure 1: Distribution of profiles collected using the UCTD probe (red dots), and the EcoCTD probe (black dots) during the CALYPSO cruise in the Western Mediterranean. Ship track is shown in grey, and transects 9 and 11 are highlighted.

[1]https://calypsodri.whoi.edu/
[2]http://scrippsscholars.ucsd.edu/tmsjohnston/book/calypso-pilot-cruise-report

2 Science Party

Amala Mahadevan	Woods Hole Oceanographic Institution (co-chief scientist)
Eric D'Asaro	University of Washington, APL (co-chief scientist)
John Allen	SOCIB
Alexander Beyer	Harvard University
Andrea Cabornero	SOCIB
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Andrey Shcherbina	University of Washington, APL
Tamay Ozgokmen	University of Miami

3 Cruise Narrative

`May 27, 2018:`
Departure from the port of Almeria at 0700 UTC. EcoCTD was first deployed for testing purposes at 1107 UTC to determine the fall-rate of the EcoCTD probe. The EcoCTD was mounted onto the UCTD winch and four profiles were completed where the EcoCTD was allowed to free-fall for 10, 20, 30 and 70 s. Each profile reached a depth of about 50, 90, 110, and 248 m, respectively. Ship was moving at 3 knots. At 1239 UTC, a 500 m deep calibration cast was completed using the shipboard CTD. The EcoCTD was mounted onto the CTD rosette for cross-calibration purposes.

`May 28, 2018:`
EcoCTD was deployed at 0537 UTC to sample in tow-yo mode between CTD stations along transect 4 (see Figure 2). Seven sections were completed as part of the transect across the main Atlantic water jet, for a total of 73 profiles.

`May 29, 2018:`
Completed additional UCTD sections around Alboran Island, avoiding Moroccan territorial waters. A CTD line (9 stations) with biological sampling was done across the front with 44 EcoCTD profiles completed between CTD stations.

May 30, 2018:
Completed 7 transects of the front that included four transects with EcoCTD and three transects using the UCTD. Collected 165 profiles from EcoCTD and 57 profiles from UCTD probe.

May 31, 2018:
Stopped UCTD and EcoCTD operations to retrieve drifting float and deploy an array of surface drifters, in coordination with RV SOCIB. UCTD operations resumed at 1800 UTC once the drifter array was deployed, completing transects of the front while following drifting assets. 91 profiles were collected as part of 5 transects. UCTD operations stopped at 2300 UTC for the deployment of a second array of drifters.

June 01, 2018:
UCTD operations resumed at 0124 after the deployment of a Lagrangian float. Twelve transects were completed using the UCTD exclusively, for a total of 176 profiles. RV Alliance then headed to the north side of the Almeria-Oran (A-O) front. At 2230 UTC, EcoCTD operations resumed to sample 2 transect of the A-O front, collecting 58 profiles in total.

June 02, 2018:
EcoCTD operations continued through the night to complete 2 more transects across the A-O front, collecting an additional 31 profiles. Sampling operations stopped at 0403 UTC. An additional 500 m deep calibration cast was conducted in coordination with the RV SOCIB at 1230 UTC. Once again, the EcoCTD was mounted onto the CTD rosette. Arrival in port of Almeria at 1600 UTC.

4 File Formats and Dataset Management

EcoCTD and UCTD data processing was organized in three different processing levels:

- **Level-0:** Raw data as downloaded directly from the instruments. Raw files from the UCTD probe are text files with the *.asc file extension. Raw files from the EcoCTD are SQLite databases with the *.rsk file extension. If the instrument was being used in tow-yo mode, one file may include many profiles. The cruise was split into 40 transects for ease of analysis (Table 1 and Figure 2).
- **Level-1:** Data are processed (see Sections 5 and 6.4), split into down- and up-casts, and cross-calibrated with the shipboard CTD. Longitude, latitude, and other derived quantities (e.g., salinity) are included into Level-1 files. Data are provided as individual files for each profile, in NetCDF-files formatted to follow the Climate and Forecast (CF) metadata conventions[3] (see Appendix A). Only downcasts are processed for UCTD profiles, while both upcasts and downcasts are processed for EcoCTD profiles. The Level-1 profile numbers associated with each cruise transect are listed in Table 1.
- **Level-3:** EcoCTD and UCTD profiles are binned vertically and merged into a single NetCDF-file formatted along the CF metadata convention (see Appendix B). Only downcasts are

[3] http://cfconventions.org/

included, as the UCTD has no data on the upcast, and the data quality on the upcast from the EcoCTD remains to be evaluated. Dimensions are depth (from 0 to 300 m at a 0.5 m resolution) and profile number. The Level-3 profile numbers associated with each cruise transect are listed in Table 1.

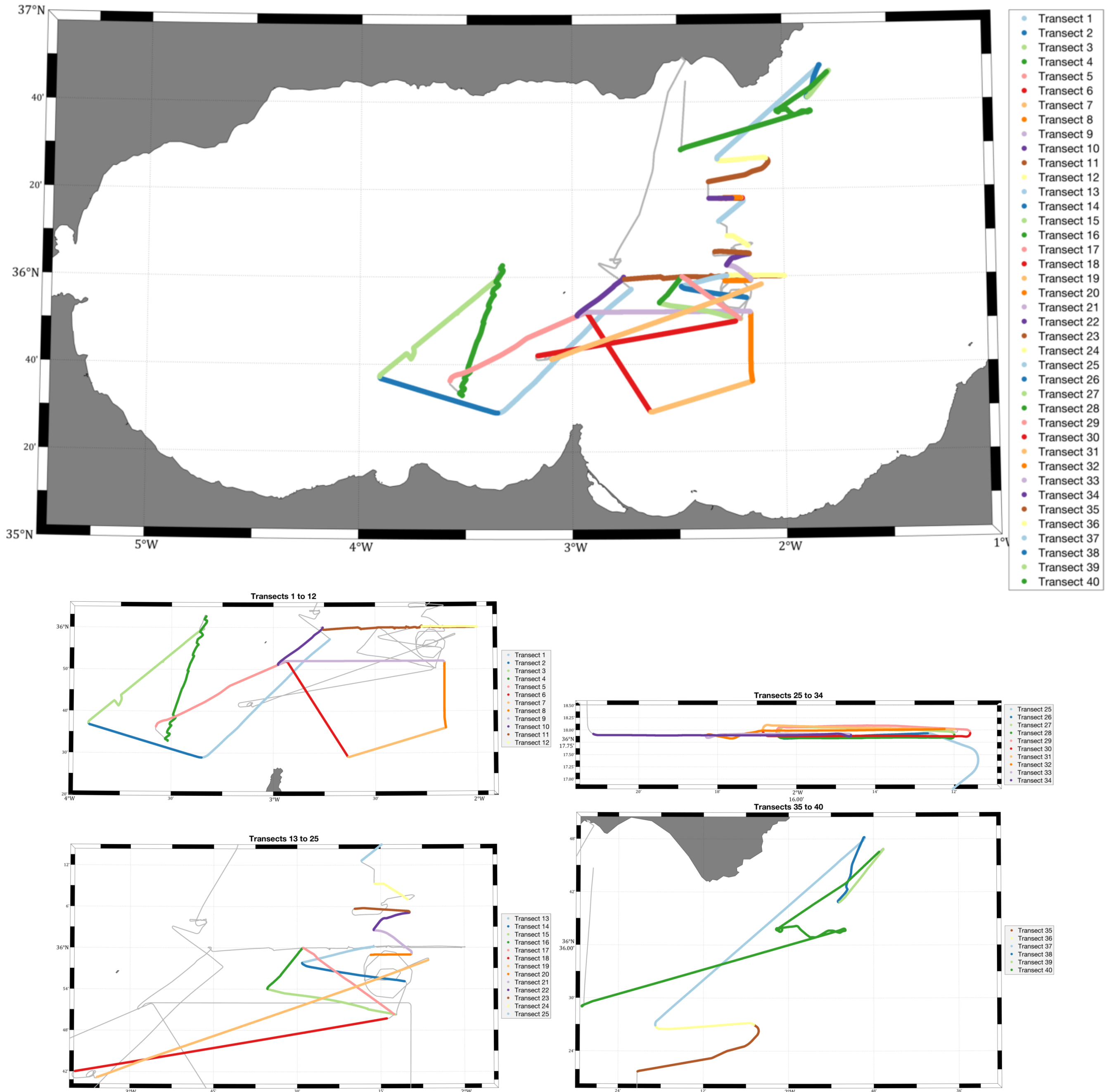

Figure 2: Map showing all 40 transects completed during the CALYPSO cruise (top). Four zoom-ins are included to better distinguish transects 1 through 12, 13 through 25, 25 through 34 and 35 through 40.

Table 1: Reference table indicating Level-0 file (UCTD) and section (EcoCTD) numbers, Level-1 and Level-3 profile numbers, and start and end time of each cruise transect shown in Figure 1.

Transect #	UCTD file # (L0)	UCTD Profile # (L1)	Eco-CTD section # (L0)	Eco-CTD profile # (L1)	L3 Profile #	Start date	End date
1	2 to 14	P002 to P014	-	-	002 to 020	27-May-2018 14:53:30	27-May-2018 19:29:30
2	15 to 27	P016 to P026	-	-	021 to 031	27-May-2018 19:29:31	27-May-2018 22:50:09
3	27 to 42	P027 to P042	-	-	032 to 045	27-May-2018 22:50:10	28-May-2018 04:08:40
4	-	-	S1 to S7	P006 to P061	046 to 103	28-May-2018 04:51:05	28-May-2018 17:05:28
5	43 to 50	P043 to P050	-	-	104 to 111	28-May-2018 18:22:56	28-May-2018 22:50:24
6	51 to 62	P051 to P062	-	-	112 to 123	28-May-2018 22:50:25	29-May-2018 01:56:35
7	63 to 76	P063 to P075	-	-	124 to 137	29-May-2018 01:56:36	29-May-2018 04:40:03
8	76 to 86	P076 to P085	-	-	138 to 147	29-May-2018 04:40:04	29-May-2018 06:47:42
9	86 to 112	P086 to P112	-	-	148 to 174	29-May-2018 06:47:43	29-May-2018 12:53:05
10	113 to 118	P113 to P118	-	-	175 to 180	29-May-2018 12:53:05	29-May-2018 14:48:36
11	-	-	S8 to S14	P062 to P106	181 to 225	29-May-2018 15:34:05	30-May-2018 01:29:06
12	119 to 124	P120 to P144	-	-	226 to 250	30-May-2018 02:01:49	30-May-2018 04:36:07
13	126	P145 to P151	-	-	251 to 257	30-May-2018 04:36:08	30-May-2018 06:36:21
14	-	-	S15	P107 to P138	258 to 289	30-May-2018 06:36:22	30-May-2018 09:29:13
15	-	P151 to P154	S16	P144 to P193	290 to 347	30-May-2018 11:04:53	30-May-2018 16:01:46
16	129 to 130	P155 to P179	-	-	348 to 372	30-May-2018 16:01:47	30-May-2018 17:46:29
17	-	-	S17	P194 to P236	373 to 415	30-May-2018 17:46:29	30-May-2018 21:24:25
18	-	-	S18	P237 to P280	416 to 459	30-May-2018 21:49:23	31-May-2018 04:41:18
19	131 to 132	P180 to P209	-	-	460 to 489	31-May-2018 06:49:49	31-May-2018 11:50:58
20	133 to 135	P210 to P225	-	-	490 to 505	31-May-2018 17:19:51	31-May-2018 18:34:02
21	136 to 138	P226 to P239	-	-	506 to 519	31-May-2018 18:34:03	31-May-2018 19:48:31
22	139 to 142	P240 to P253	-	-	520 to 533	31-May-2018 19:48:32	31-May-2018 21:01:23
23	143 to 146	P254 to P271	-	-	534 to 551	31-May-2018 21:01:24	31-May-2018 22:33:13
24	147 to 148	P272 to P280	-	-	552 to 560	01-Jun-2018 01:24:57	01-Jun-2018 02:32:37
25	149 to 150	P281 to P308	-	-	561 to 588	01-Jun-2018 03:39:52	01-Jun-2018 05:24:02
26	151	P309 to P312	-	-	589 to 592	01-Jun-2018 05:24:02	01-Jun-2018 06:16:34
27	151	P313 to P323	-	-	593 to 603	01-Jun-2018 06:16:35	01-Jun-2018 07:04:48
28	152	P324 to P336	-	-	604 to 616	01-Jun-2018 07:04:49	01-Jun-2018 08:08:56
29	153 to 154	P337 to P350	-	-	617 to 630	01-Jun-2018 08:08:57	01-Jun-2018 09:10:47
30	154 to 155	P351 to P363	-	-	631 to 643	01-Jun-2018 09:10:48	01-Jun-2018 10:09:39
31	156 to 157	P364 to P378	-	-	644 to 658	01-Jun-2018 10:09:40	01-Jun-2018 11:13:26
32	158 to 160	P379 to P392	-	-	659 to 672	01-Jun-2018 11:20:55	01-Jun-2018 12:41:06
33	161	P393 to P400	-	-	673 to 680	01-Jun-2018 12:41:07	01-Jun-2018 13:32:46
34	162 to 163	P401 to P411	-	-	681 to 691	01-Jun-2018 13:32:47	01-Jun-2018 14:35:57
35	164 to 166	P412 to P430	-	-	692 to 710	01-Jun-2018 15:04:22	01-Jun-2018 17:05:02
36	167 to 169	P431 to P448	-	-	711 to 728	01-Jun-2018 17:05:03	01-Jun-2018 18:47:06
37			S19	P281 to P319	729 to 767	01-Jun-2018 18:47:07	01-Jun-2018 23:54:12
38			S20 to S21	P320 to P339	768 to 787	01-Jun-2018 23:54:13	02-Jun-2018 02:08:37
39			S21	P340 to P356	788 to 804	02-Jun-2018 02:08:38	02-Jun-2018 03:57:26
40			S22	P357 to P371	805 to 819	02-Jun-2018 04:03:34	02-Jun-2018 11:23:04

5 UCTD data

5.1 UCTD Probe

The UCTD probe measures temperature, conductivity, and pressure. The UCTD system consists of a battery-powered, internally recording CTD with a tail spool, a tail-spool winder, and a winch (Figure 3). Three different probes were used during the cruise, mostly to shorten turn-over time between profiles. In “free cast” mode, the winch line is spooled on the tail with a winder, and the probe is dropped over the stern of the ship while steaming. The fall rate of UCTD probes varies between 3 and 4.5 m/s and is fairly constant with depth (Figure 4). Data were collected at 16 Hz, with a target depth of about 200 to 250 m.

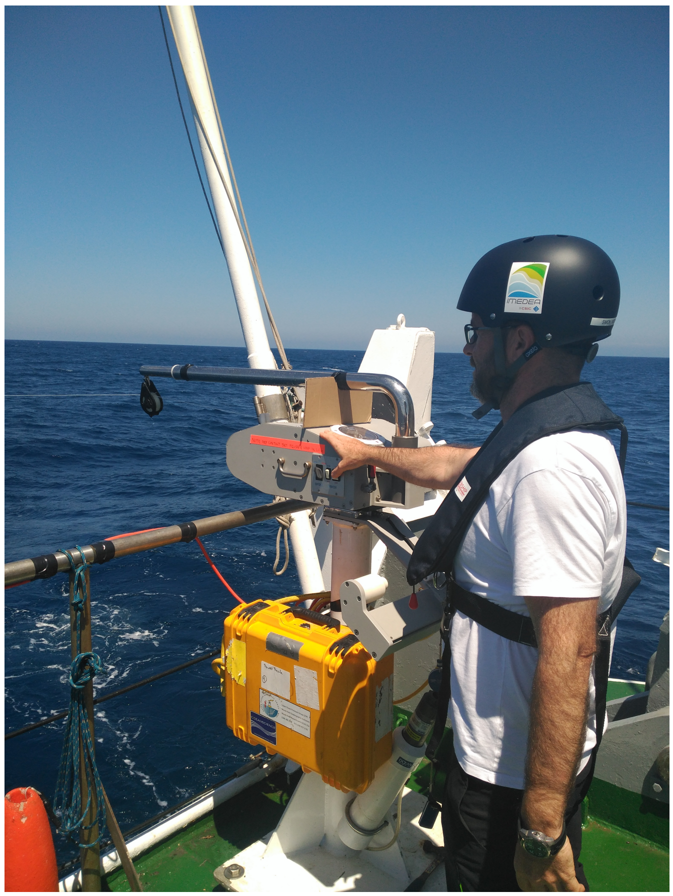

Figure 3: UCTD winch operation during the CALYPSO cruise.

5.2 UCTD Data Processing Steps

Processing of the UCTD data consists in two simple steps:

1. Sensor Alignment: A lag of two scans (0.125 s) is applied to the temperature record to align conductivity and temperature measurements and correct for the longer time-response of the

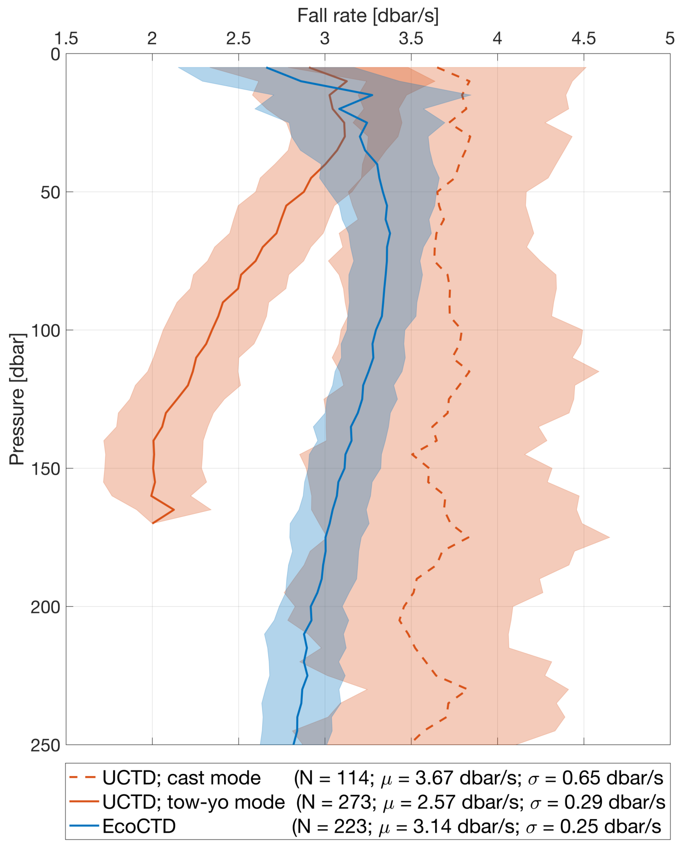

Figure 4: Fall rate (in dbar/s) as a function of pressure (in dbar) for the UCTD in both cast (dashed red; N = 114) and tow-yo modes (solid red; N = 273), as well as for the EcoCTD in tow-yo mode (blue; N = 208). Thick lines represent the averaged fall rate, and the shading shows one standard deviation from the mean.

thermistor. The appropriate lag is determined by maximizing the first-order difference in temperature and conductivity. A lag of 2 scans is coherent with previous efforts to align conductivity and temperature for UCTD probes [see *Ullman and Hebert*, 2014]

2. Derived quantities: Profiles are geo-referenced using the position of the ship at the beginning of each profile. The same longitude and latitude are assigned for the entire profile, assuming the UCTD drops vertically through the water column and is independent from the ship's motion. Other derived quantities such as practical salinity, absolute salinity, conservative temperature and in-situ density are computed using the Gibbs-Seawater package in MATLAB [*McDougall and Barker*, 2011].

5.3 UCTD dataset example

The UCTD was used to collect 448 profiles over 32 different transects of the Almerian front (Figure 1). Measurements were made using two different sampling modes: (1) free cast mode, where the winch line is spooled around the UCTD tail between each profile, and (2) tow-yo mode, where the UCTD is not brought back on board between each profile, but simply released once the probe is close to the ship. Tow-yo mode reduces turn-over time between profiles, thus increasing horizontal resolution, but introduces a depth-dependant fall-rate as the UCTD probe is now more sensitive to the line drag [Figure 4; *Ullman and Hebert*, 2014].

Temperature, salinity, and density as measured by the UCTD along Transect 9 are shown in Figure 5. Transect 9 is composed of 27 profiles separated by 2.6 km on average. In this transect, the Atlantic water entering the Mediterranean Sea through the Strait of Gibraltar can be observed over the eastern part of the transect. This water mass is characterized by fresher water, and lower-density. The western side of the transect reveals a more saline water mass, corresponding to a mixture of Mediterranean and Atlantic water (see Figure 5). East of -2.5^o, isopycnals are tilted downwards showing the subduction of denser Mediterranean water underneath less-dense Atlantic water. Whether or not water is being actively subducted along these isopycnals is difficult to determine from temperature and salinity fields alone.

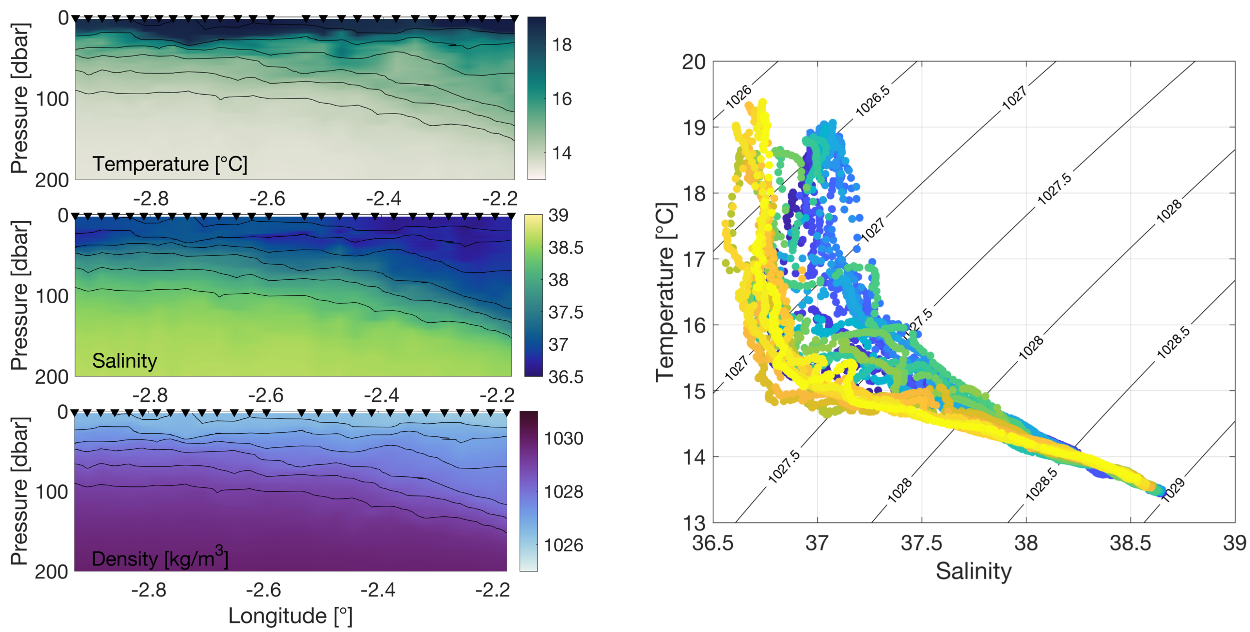

Figure 5: [Left] Temperature (^{o}C; top), salinity (middle), and density (kg/m^3; bottom) measured along transect 9 using the UCTD. Each measured profile is represented by a black triangle. [Right] Temperature-Salinity diagram along transect 9, where the longitude is shown in color.

6 EcoCTD data

6.1 EcoCTD probe

The EcoCTD was specially designed for the CALYPSO project. It is composed of three sensors, all sampling at 8 Hz (Figure 6):

- One RBR Concerto^3 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. 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 ECOPuck. This optical sensor is oriented at 90^o from the vertical and is located 72 cm away from the CTD sensor.

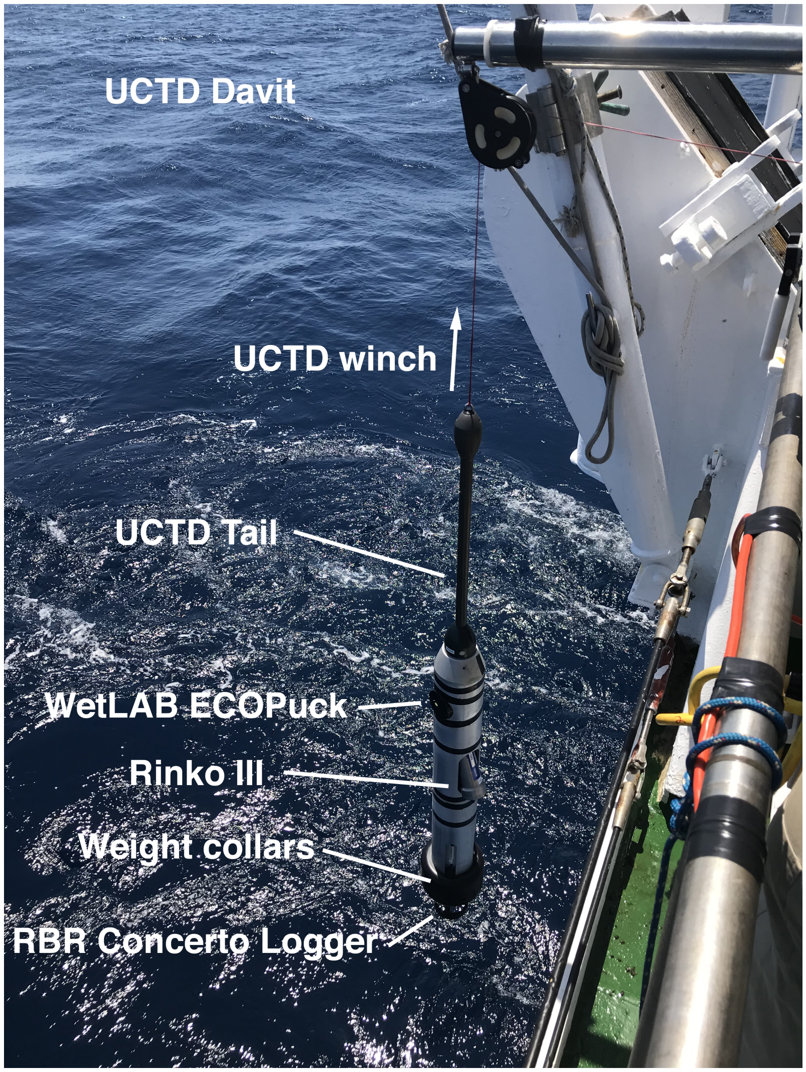

Figure 6: EcoCTD probe attached to a UCTD winch at the back of the NRV Alliance. The EcoCTD includes a CTD sensor and logger (Concerto^3), an oxygen sensor (Rinko III), and a WetLab ECOPuck. The EcoCTD uses the same spectra line and tail attachment as a UCTD probe.

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 possesses a UCTD adapter at the top to be able to easily swap UCTD and EcoCTD probes. The pressure rating of the EcoCTD is determined by the pressure rating of the ECOPuck (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 2.5 and 3.5 m/s, which is slightly slower than the UCTD probe when used in cast mode, but faster than the UCTD probe used in tow-yo mode (Figure 4). Due to its higher weight, the EcoCTD is also less sensitive to the line drag compared to the UCTD probe used in tow-yo mode, and therefore does not exhibit as much of a depth-dependent fall rate (Figure 4).

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 6.4).

6.2 EcoCTD Data Processing Steps

6.2.1 Sensor alignment

CTD sensor – Misalignment of temperature and conductivity measurements results in spikes in salinity because conductivity is temperature dependent. There are a number of differences between the EcoCTD and UCTD probes, including the physical arrangement of the temperature and conductivity sensors, data logging frequency, and fall-rate which warranted slight differences in the processing of the EcoCTD and UCTD data. We determined the appropriate lag for the EcoCTD data empirically using the methodology of *Barth et al.* [1996]. The lag was determined as the number of scans for which the first-difference conductivity ($\Delta C = C_t - C_{t-1}$) and temperature ($\Delta T = T_t - T_{t-1}$) had the maximum correlation. In order to find the correlations, each profile was divided into non-overlapping 60 scan (7.5 second) segments. Fractional values of the lag were found by fitting a second order polynomial around the maximum integer value of lag correlation and finding the maximum of that function, as described in *Ullman and Hebert* [2014]. We found that the maximum correlation is between zero and one for 70% of the data segments. For the remaining 30% of the segments, the misalignment of the temperature and conductivity measurements was not the dominant signal. In contrast to the results of *Ullman and Hebert* [2014], we did not find a relationship between drop rate and lag and so use a constant value of lag for all profiles. Empirically, we found that a lag of 0.5 scans minimizes the salinity spiking. We apply the lag by interpolating the conductivity 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. Properly aligning observations collected for the two instruments is crucial, as dissolved oxygen concentration is temperature and salinity dependent. Following recommendations from *Halverson et al.* [2017], the appropriate lag is determined from T-O_2 curve, and the time necessary to "collapse" the up and down casts.

The appropriate value for the lag was also independently inferred using lag correlations between the first difference in temperature and oxygen saturation, similarly to the derivation of the lag for conductivity and temperature [*Barth et al.*, 1996]. For the oxygen lag analysis we used non-overlapping segments of 120 scans (15 seconds). This analysis confirms that the lag should be between 4 and 8 scans and that the lag is fall rate dependent (Figure 7).

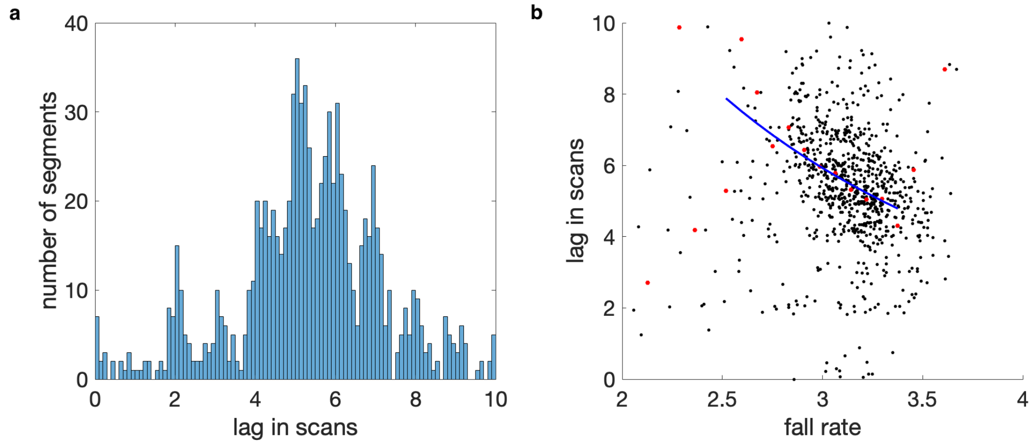

Figure 7: (a) Histogram of lag value of the maximum correlation between first difference temperature and first difference oxygen percent saturation. (b) Scatter plot of lag value in scans and fall rate in decibars per second. The red dots are the median at each lag value and the blue line is a best fit curve for lag as a function of inverse fall rate.

The fall rate dependence of the lag is due to 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:

$$\Delta S_{adv} = \frac{\Delta h \times F_s}{w_s} \tag{1}$$

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 ($w_s < 0$). The empirical change in lag due to 1 m/s difference in fall rate is 4 scans (Figure 7b), which is consistent with Equation 1. Advective lags are fall rate dependent and range between 0.8 and 2 scans, with 91% of the lags between 1 and 1.5 scans and a median of 1.23 scans.

Similarly to the sensor alignment performed for the CTD, a fall-rate-independent lag is also applied to account for the difference in response time of the probes after the advective lag is applied. The value for lag is adjusted until the mismatch in the up and down casts in oxygen profile is similar to the mismatch observed in the corresponding temperature and conductivity profiles (∼5 dbar). A lag of 6 scans (0.75 s) is chosen, which is slightly shorter than, but similar to, the 0.9 s response time of the oxygen sensor advertised by the manufacturer.

In their study, *Bittig et al.* [2014] also found a relationship in effective response lag with temperature and fall rate. These second order relationships were not considered when aligning the oxygen and CTD sensors. Because profiles were confined to the upper 250 m, the range of observed temperature is relatively small [∼6^oC; see Figure 5 in *Bittig et al.*, 2014]. The change in the EcoCTD's fall rate with depth is generally less than 0.5 dbar/s (Figure 4), which is not expected to greatly affect the effective response time of the oxygen sensor [see Figure 6 in *Bittig et al.*, 2014].

ECOPuck sensor – Similarly to the oxygen sensor, an advective lag is applied to the measurements collected by the ECOPuck using Equation 1 with $\Delta h = 0.72$ m. Advective lags range between 1.2 and 3 scans, with 91% of the lags between 1.5 and 2.25 scans and a median of 1.85 scans.

6.2.2 Analog-to-digital zero hold correction

Every minute, the analog-to-digital converter located in the RBR Concerto^3 needs to recalibrate. As a result, a sample is missed and filled by the last measure value, technique often referred to as a zero-order hold. This values are easily identified in the time series by finding repeated values, and are replaced by NaNs in the Level-1 data.

6.2.3 Filtering

At sharp interfaces, the conductivity sensor responds faster than the temperature sensor. As a result, in order to align the temperature and conductivity records, we smooth the conductivity using a 3-point median filter after we apply the lag correction.

Backscatter profiles typically include large spikes, often attributed to aggregates [*Briggs et al.*, 2011]. Spikes are present in Level-1 data, but are filtered out in the Level-3 data product using a method equivalent to the one used in *Briggs et al.* [2011]. A 7-point running minimum filter followed by a 7-point running maximum filter is applied to each profile before binning (see Section 6.3).

6.2.4 Cross-calibration with shipboard CTD

On both the first and last day of the cruise, a cross-calibration cast was conducted to 500 m. The EcoCTD was mounted onto the shipboard CTD. Shipboard profiles of salinity, oxygen and Chl-F were calibrated using water samples [*Alou et al.*, 2018], and binned into 5-meter bins. Similarly, EcoCTD measurements were binned into 5-meter bins and directly compared to measurements from the shipboard CTD.

Temperature and oxygen records of the EcoCTD and the ship's CTD presented a good match with linear regression close to the 1:1 line (Figure 8). However, there was a constant offset between the conductivity profiles of the ship's CTD and the EcoCTD. Although the RBR Concerto^3 was factory calibrated before the cruise, we added a number of metal components, namely a guard, a casing, and a weight. Each of these contributed to a conductivity offset during testing in a tank and we believe these are the source of the difference between the EcoCTD and the ship's CTD. We apply this correction by adding 0.04361 to all conductivity data.

Finally, Chl-F was measured from the shipboard CTD using a Chelsea Aqua 3 fluorometer, and calibrated using 34 samples from 17 stations. For quantification of chlorophyll-a, 0.5 L of seawater was filtered onto 45 mm GF/F Whatman filters and analyzed at SOCIB. Samples were extracted for 24h in 90% acetone in the dark for fluorometric determination (Turner Designs, trilogy fluorometer)

[*Alou et al.*, 2018]. A linear regression was then computed to convert Chl-F measured from the EcoCTD from number of counts to $\mu g/L$.

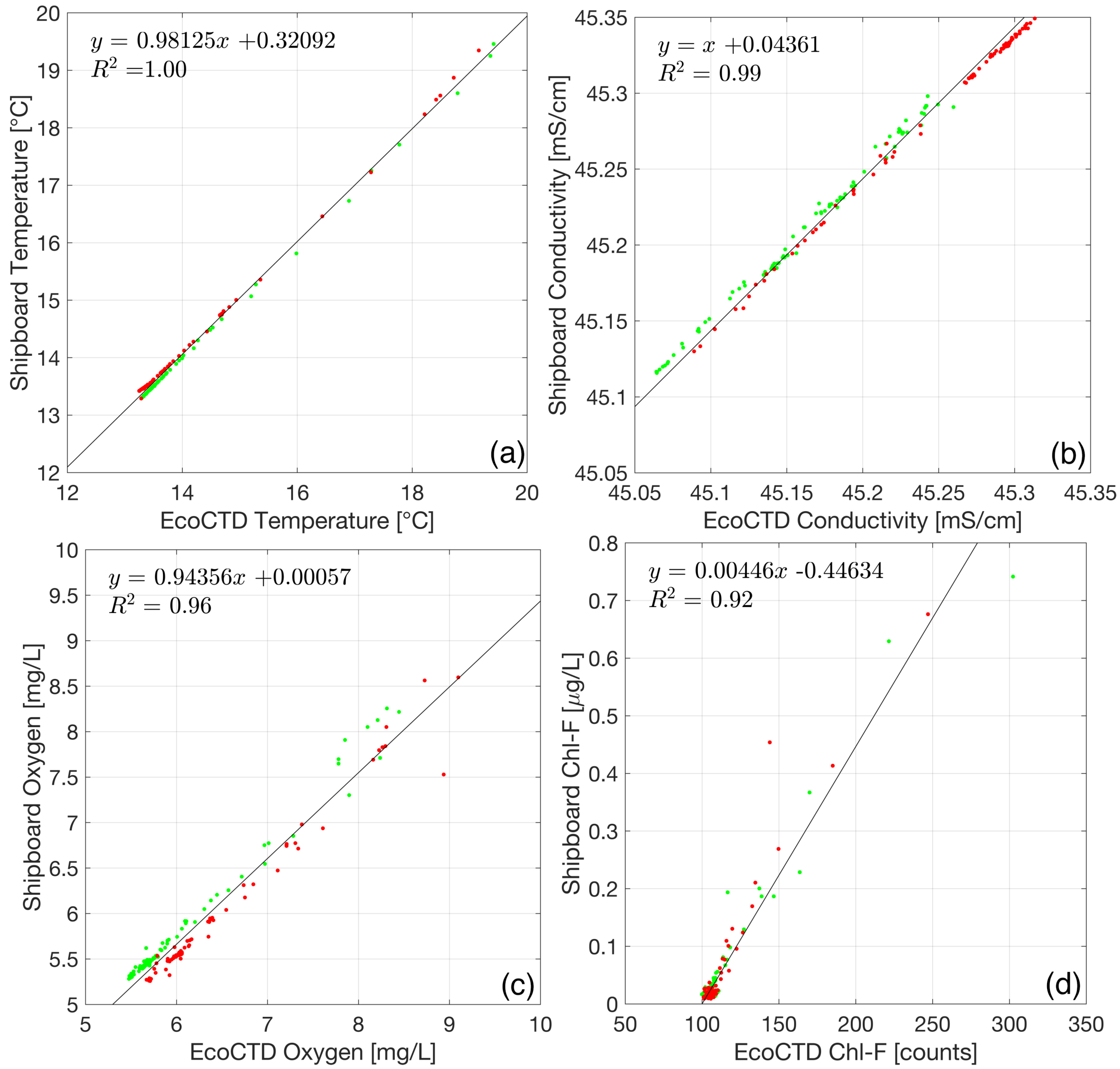

Figure 8: Comparison between ship's CTD and EcoCTD (a) temperature, (b) conductivity, (c) Oxygen concentration, and (d) chlorophyll-Fluorescence during calibration casts on the first (green dots) and last day of the cruise (red dots). Black lines show the best fit. Equation of fit and goodness of fit are indicated in each panel.

6.3 Binning the data - Level-3 product

Individual downcast profiles from both UCTD and EcoCTD probes are binned using a spline interpolation onto a vertical grid of 0.5 m. Using a spline interpolation prevents discontinuities in the data due to binning in discrete bins. Data processing is identical to Level-1 data, with the exception of backscatter at 470 and 700 nm. Profiles of backscatter were despiked using the method from *Briggs et al.* [2011] and described in Section 6.2.3. A single NetCDF-file following CF conventions (see Appendix B) is produced, and contains all 819 profiles collected during the cruise.

6.4 EcoCTD dataset example

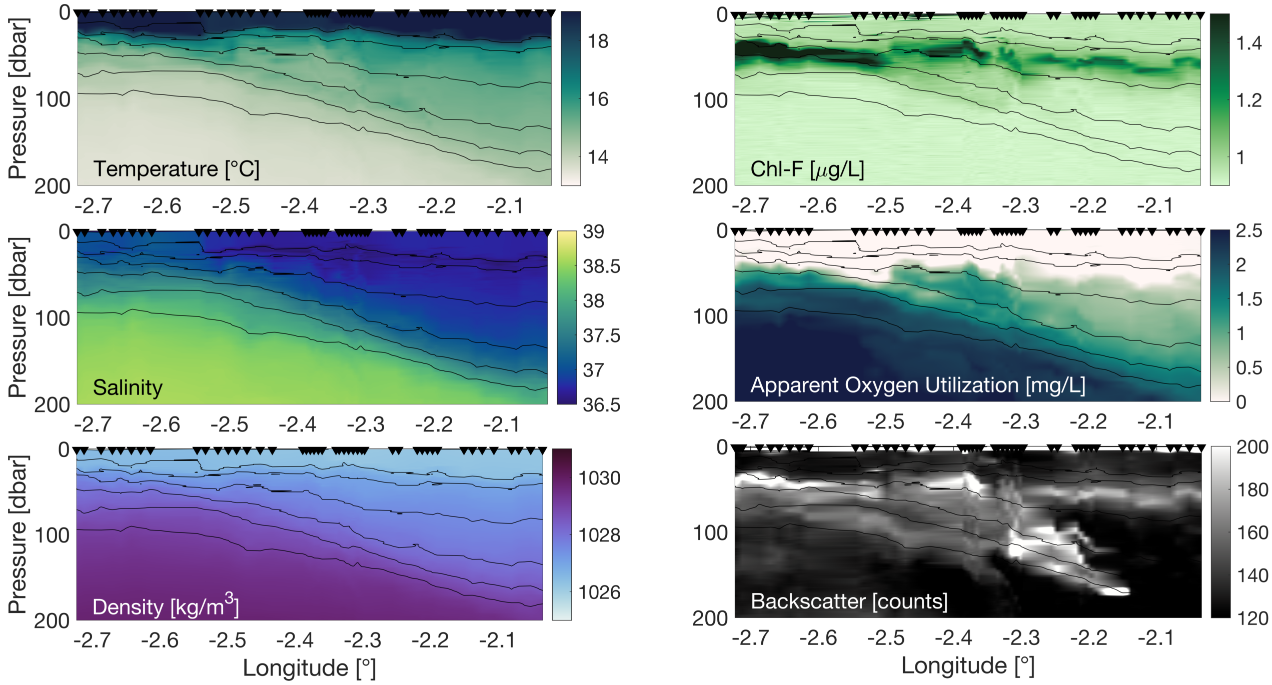

Figure 9: [left] Temperature (^{o}C; top), salinity (middle), and density (kg/m^3; bottom). [right] Chlorophyll fluorescence (μg/L; top), apparent oxygen utilization (mg/L; middle), and backscatter at 700nm (counts; bottom) measured along transect 11 using the EcoCTD in tow-yo mode.

A cross-front transect using the EcoCTD was completed parallel to the UCTD transect shown in Figure 5. It reveals not just the sloping isopycnal surfaces and water mass contrast across the front, but also heterogeneity in water mass composition in the vertical and evidence of past subduction events (Figure 9). Transect 11 is composed of 45 profiles separated in the horizontal by 0.6 to 6 km (1.4 km average). During transect 11, in addition to profiling with the EcoCTD, the ship completed 8 casts with the shipboard CTD rosette in order to sample for biological community composition and calibrate the instrument measurements. Within the fresher Atlantic water on the Eastern side of transect 11, there is some heterogeneity in temperature, suggesting vertical variability in water mass structure. The deep water biological production in the western Mediterranean occurs in a deep chlorophyll maximum (DCM) that is at around 40 meters in transect 11. It is at approximately constant depth in this transect and consequently on a lighter density surface on the eastern (Atlantic) side of the front than the Mediterranean side of the front. At the point where the density surface begin sloping down from the DCM (around -2.5 to -2.4 longitude), there is higher chlorophyll concentration below the DCM. However, the most obvious subduction signal is in backscatter, which has high concentrations in the DCM and in a subsurface plume that crosses isopycnal surfaces. The observation that a subducted plume is present in backscatter, but not to the same extent in oxygen or chlorophyll, suggests that the subducted particulates are non-photosynthetic material or, alternatively, represent subduction of photosynthetic organisms that occurred far enough in the past that they are no longer fluorescing. In this transect, the bio-optical properties reveal subduction and stirring that is not visible in the temperature and salinity alone, and suggests information about the time history of the observed water parcels.

Acknowledgement

This work was funded by the Office of Naval Research (ONR), as part of the CALYPSO research initiative. We thank the captain and crew of the NRV Alliance, IMEDEA and SOCIB in Spain for logistic support, and all the cruise participants including Sebastian Essink, Eric D'Asaro, John Allen, Alexander Beyer, Benjamin Casas Perez, Kausalya Mahadevan, Daniel Rodriguez Tarry, and Simon Ruiz Valero for their work on the vessel and in port. We thank Ben Pietro for logistical support and Ruth Musgrave for graciously loaning spare instrumentation.

A Metadata for Level-1 datasets

A.1 Metadata for UCTD's Level-1 file

```
Format:
            classic
Global Attributes:
            title              = 'Level-1 processed data from CTD instrument
               on EcoCTD package'
            institution        = 'Woods Hole Oceanographic Institution'
            source             = 'ocean profile observations'
            history            = '01-Jan-2019 22:07:08 - File generated by Dr
               . M. Dever'
            references         = 'CALYPSO Data Report'
            external_variables = ''
            Conventions        = 'CF-1.7'
            creation_date      = '01-Jan-2019 22:07:08'
            Comment            = ''
Dimensions:
            Time = 1382
Variables:
    seaPress
            Size:        1382x1
            Dimensions:  Time
            Datatype:    double
            Attributes:
                         long_name     = 'Sea Pressure'
                         standard_name = 'sea_water_pressure_due_to_sea_water'
                         units         = 'dbar'
                         valid_range   = [0   600]
                         actual_range  = [2.031          330.906]
                         missing_value = -999
    time
            Size:        1382x1
            Dimensions:  Time
            Datatype:    double
```

```
        Attributes:
                    long_name     = 'Time'
                    units         = 'days'
                    axis          = 'T'
                    valid_range   = [737207.669         737207.67]
                    actual_range  = [737207.669         737207.67]
                    missing_value = -999
                    notes         = 'days since [0000 0 0 0 0 0]'
lon
        Size:       1382x1
        Dimensions: Time
        Datatype:   double
        Attributes:
                    long_name     = 'Longitude'
                    standard_name = 'longitude'
                    units         = 'degree_east'
                    valid_range   = [-180   180]
                    actual_range  = [-2.8896        -2.8896]
                    missing_value = -999
lat
        Size:       1382x1
        Dimensions: Time
        Datatype:   double
        Attributes:
                    long_name     = 'Latitude'
                    standard_name = 'latitude'
                    units         = 'degree_north'
                    valid_range   = [-90   90]
                    actual_range  = [35.8345        35.8345]
                    missing_value = -999
T
        Size:       1382x1
        Dimensions: Time
        Datatype:   double
        Attributes:
                    long_name     = 'In-situ Temperature'
                    standard_name = 'sea_water_temperature'
                    units         = 'Celsius'
                    valid_range   = [0   40]
                    actual_range  = [13.288         18.723]
                    missing_value = -999
                    origin        = 'Measured'
T_qc
        Size:       1382x1
        Dimensions: Time
        Datatype:   double
        Attributes:
                    long_name     = 'In-situ Temperature Quality'
                    standard_name = 'status_flag'
                    units         = '1'
```

```
                valid_range   = [-1   1]
                actual_range  = [-1   1]
                missing_value = -999
                flag_values   = [-1   0   1]
                flag_meanings = 'bad questionable good'
C
        Size:          1382x1
        Dimensions:    Time
        Datatype:      double
        Attributes:
                long_name     = 'Conductivity'
                standard_name = 'sea_water_electrical_conductivity'
                units         = 'mS cm-1'
                valid_range   = [45.0833       48.6312]
                actual_range  = [45.0833       48.6312]
                missing_value = -999
                origin        = 'Measured'
C_qc
        Size:          1382x1
        Dimensions:    Time
        Datatype:      double
        Attributes:
                long_name     = 'Conductivity Quality'
                standard_name = 'status_flag'
                units         = '1'
                valid_range   = [-1   1]
                actual_range  = [-1   1]
                missing_value = -999
                flag_values   = [-1   0   1]
                flag_meanings = 'bad questionable good'
CT
        Size:          1382x1
        Dimensions:    Time
        Datatype:      double
        Attributes:
                long_name     = 'Conservative Temperature'
                standard_name = 'sea_water_conservative_temperature'
                units         = 'Celsius'
                valid_range   = [0   40]
                actual_range  = [13.1479       18.6635]
                missing_value = -999
                origin        = 'Computed'
                notes         = 'Computed using the GibbsSeawater
                   toolbox (gsw_CT_from_t)'
CT_qc
        Size:          1382x1
        Dimensions:    Time
        Datatype:      double
        Attributes:
                long_name     = 'Conservative Temperature Quality'
```

```
                standard_name = 'status_flag'
                units         = '1'
                valid_range   = [-1   1]
                actual_range  = [-1   1]
                missing_value = -999
                flag_values   = [-1   0   1]
                flag_meanings = 'bad questionable good'
SP
        Size:       1382x1
        Dimensions: Time
        Datatype:   double
        Attributes:
                long_name     = 'Practical Salinity'
                standard_name = 'sea_water_practical_salinity'
                units         = '1'
                valid_range   = [0   45]
                actual_range  = [36.4066       38.5286]
                missing_value = -999
                origin        = 'Computed'
                notes         = 'Computed using the GibbsSeawater
                   toolbox (gsw_SP_from_C)'
SP_qc
        Size:       1382x1
        Dimensions: Time
        Datatype:   double
        Attributes:
                long_name     = 'Practical Salinity Quality'
                standard_name = 'status_flag'
                units         = '1'
                valid_range   = [-1   1]
                actual_range  = [-1   1]
                missing_value = -999
                flag_values   = [-1   0   1]
                flag_meanings = 'bad questionable good'
SA
        Size:       1382x1
        Dimensions: Time
        Datatype:   double
        Attributes:
                long_name     = 'Absolute Salinity'
                standard_name = 'sea_water_absolute_salinity'
                units         = 'gram kilogram-1'
                valid_range   = [0   45]
                actual_range  = [36.5796       38.7119]
                missing_value = -999
                origin        = 'Computed'
                notes         = 'Computed using the GibbsSeawater
                   toolbox (gsw_SA_from_SP)'
SA_qc
        Size:       1382x1
```

```
        Dimensions: Time
        Datatype:   double
        Attributes:
                    long_name     = 'Absolute Salinity Quality'
                    standard_name = 'status_flag'
                    units         = '1'
                    valid_range   = [-1  1]
                    actual_range  = [-1  1]
                    missing_value = -999
                    flag_values   = [-1  0  1]
                    flag_meanings = 'bad questionable good'
    rho
        Size:       1382x1
        Dimensions: Time
        Datatype:   double
        Attributes:
                    long_name     = 'In-situ Density'
                    standard_name = 'sea_water_density'
                    units         = 'kilogram meter-3'
                    valid_range   = [1000  1050]
                    actual_range  = [1026.398      1030.5363]
                    missing_value = -999
                    origin        = 'Computed'
                    notes         = 'Computed using the GibbsSeawater
                       toolbox (gsw_rho)'
    rho_qc
        Size:       1382x1
        Dimensions: Time
        Datatype:   double
        Attributes:
                    long_name     = 'In-situ Density Quality'
                    standard_name = 'status_flag'
                    units         = '1'
                    valid_range   = [-1  1]
                    actual_range  = [-1  1]
                    missing_value = -999
                    flag_values   = [-1  0  1]
                    flag_meanings = 'bad questionable good'
```

A.2 Metadata for EcoCTD's CTD Level-1 file

```
Format:
        classic
Global Attributes:
        title              = 'Level-1 processed data from CTD instrument
           on EcoCTD package'
        institution        = 'Woods Hole Oceanographic Institution'
        source             = 'ocean profile observations'
```

```
        history           = '02-Jan-2019 00:11:01 - File generated by Dr
           . M. Dever'
        references        = 'CALYPSO Data Report'
        external_variables = ''
        Conventions       = 'CF-1.7'
        creation_date     = '02-Jan-2019 00:11:01'
        Comment           = ''
Dimensions:
        Time = 106
Variables:
    P
        Size:       106x1
        Dimensions: Time
        Datatype:   double
        Attributes:
                    long_name     = 'Absolute Pressure'
                    standard_name = 'sea_water_pressure'
                    units         = 'dbar'
                    valid_range   = [0    600]
                    actual_range  = [10.714        50.8815]
                    missing_value = -999
                    origin        = 'Measured'
    time
        Size:       106x1
        Dimensions: Time
        Datatype:   double
        Attributes:
                    long_name     = 'Time'
                    units         = 'days'
                    axis          = 'T'
                    valid_range   = [737207.4637       737207.4639]
                    actual_range  = [737207.4637       737207.4639]
                    missing_value = -999
                    origin        = 'Measured'
                    notes         = 'days since [0000 0 0 0 0 0]'
    lon
        Size:       106x1
        Dimensions: Time
        Datatype:   double
        Attributes:
                    long_name     = 'Longitude'
                    standard_name = 'longitude'
                    units         = 'degree_east'
                    valid_range   = [-180   180]
                    actual_range  = [-2.7783       -2.7783]
                    missing_value = -999
                    origin        = 'Computed'
    lat
        Size:       106x1
        Dimensions: Time
```

```
        Datatype:    double
        Attributes:
                     long_name     = 'Latitude'
                     standard_name = 'latitude'
                     units         = 'degree_north'
                     valid_range   = [-90   90]
                     actual_range  = [36.0662        36.0662]
                     missing_value = -999
                     origin        = 'Computed'
T
        Size:        106x1
        Dimensions:  Time
        Datatype:    double
        Attributes:
                     long_name     = 'In-situ Temperature'
                     standard_name = 'sea_water_temperature'
                     units         = 'Celsius'
                     valid_range   = [0   40]
                     actual_range  = [15.9308        20.3473]
                     missing_value = -999
                     origin        = 'Measured'
T_qc
        Size:        106x1
        Dimensions:  Time
        Datatype:    double
        Attributes:
                     long_name     = 'In-situ Temperature Quality'
                     standard_name = 'status_flag'
                     units         = '1'
                     valid_range   = [-1   1]
                     actual_range  = [-1   1]
                     missing_value = -999
                     flag_values   = [-1   0   1]
                     flag_meanings = 'bad questionable good'
C
        Size:        106x1
        Dimensions:  Time
        Datatype:    double
        Attributes:
                     long_name     = 'Conductivity'
                     standard_name = 'sea_water_electrical_conductivity'
                     units         = 'mS cm-1'
                     valid_range   = [35.572        49.2723]
                     actual_range  = [35.572        49.2723]
                     missing_value = -999
                     origin        = 'Measured'
C_qc
        Size:        106x1
        Dimensions:  Time
        Datatype:    double
```

```
        Attributes:
                    long_name     = 'Conductivity Quality'
                    standard_name = 'status_flag'
                    units         = '1'
                    valid_range   = [-1   1]
                    actual_range  = [-1   1]
                    missing_value = -999
                    flag_values   = [-1   0   1]
                    flag_meanings = 'bad questionable good'
seaPress
        Size:       106x1
        Dimensions: Time
        Datatype:   double
        Attributes:
                    long_name     = 'Sea Pressure'
                    standard_name = 'sea_water_pressure_due_to_sea_water'
                    units         = 'dbar'
                    valid_range   = [0   600]
                    actual_range  = [0.581462         40.749]
                    missing_value = -999
                    origin        = 'Computed'
                    notes         = 'Computed as P-10.1325 dbar'
CT
        Size:       106x1
        Dimensions: Time
        Datatype:   double
        Attributes:
                    long_name     = 'Conservative Temperature'
                    standard_name = 'sea_water_conservative_temperature'
                    units         = 'Celsius'
                    valid_range   = [0   40]
                    actual_range  = [15.8544        20.6574]
                    missing_value = -999
                    origin        = 'Computed'
                    notes         = 'Computed using the GibbsSeawater
                       toolbox (gsw_CT_from_t)'
CT_qc
        Size:       106x1
        Dimensions: Time
        Datatype:   double
        Attributes:
                    long_name     = 'Conservative Temperature Quality'
                    standard_name = 'status_flag'
                    units         = '1'
                    valid_range   = [-1   1]
                    actual_range  = [-1   1]
                    missing_value = -999
                    flag_values   = [-1   0   1]
                    flag_meanings = 'bad questionable good'
SP
```

```
        Size:        106x1
        Dimensions:  Time
        Datatype:    double
        Attributes:
                     long_name     = 'Practical Salinity'
                     standard_name = 'sea_water_practical_salinity'
                     units         = '1'
                     valid_range   = [0   45]
                     actual_range  = [24.9072        37.2607]
                     missing_value = -999
                     origin        = 'Computed'
                     notes         = 'Computed using the GibbsSeawater
                        toolbox (gsw_SP_from_C)'
SP_qc
        Size:        106x1
        Dimensions:  Time
        Datatype:    double
        Attributes:
                     long_name     = 'Practical Salinity Quality'
                     standard_name = 'status_flag'
                     units         = '1'
                     valid_range   = [-1   1]
                     actual_range  = [-1   1]
                     missing_value = -999
                     flag_values   = [-1   0   1]
                     flag_meanings = 'bad questionable good'
SA
        Size:        106x1
        Dimensions:  Time
        Datatype:    double
        Attributes:
                     long_name     = 'Absolute Salinity'
                     standard_name = 'sea_water_absolute_salinity'
                     units         = 'gram kilogram-1'
                     valid_range   = [0   45]
                     actual_range  = [25.0287         37.437]
                     missing_value = -999
                     origin        = 'Computed'
                     notes         = 'Computed using the GibbsSeawater
                        toolbox (gsw_SA_from_SP)'
SA_qc
        Size:        106x1
        Dimensions:  Time
        Datatype:    double
        Attributes:
                     long_name     = 'Absolute Salinity Quality'
                     standard_name = 'status_flag'
                     units         = '1'
                     valid_range   = [-1   1]
                     actual_range  = [-1   1]
```

```
                    missing_value = −999
                    flag_values   = [−1   0   1]
                    flag_meanings = 'bad questionable good'
    rho
            Size:         106x1
            Dimensions:   Time
            Datatype:     double
            Attributes:
                    long_name     = 'In−situ Density'
                    standard_name = 'sea_water_density'
                    units         = 'kilogram meter−3'
                    valid_range   = [1000   1050]
                    actual_range  = [1017.0057        1027.6864]
                    missing_value = −999
                    origin        = 'Computed'
                    notes         = 'Computed using the GibbsSeawater
                       toolbox (gsw_rho)'
    rho_qc
            Size:         106x1
            Dimensions:   Time
            Datatype:     double
            Attributes:
                    long_name     = 'In−situ Density Quality'
                    standard_name = 'status_flag'
                    units         = '1'
                    valid_range   = [−1   1]
                    actual_range  = [−1   1]
                    missing_value = −999
                    flag_values   = [−1   0   1]
                    flag_meanings = 'bad questionable good'
```

A.3 Metadata for EcoCTD's OXY Level-1 file

```
Format:
          classic
Global Attributes:
          title              = 'Level−1 processed data from Oxygen
             instrument on EcoCTD package'
          institution        = 'Woods Hole Oceanographic Institution'
          source             = 'ocean profile observations'
          history            = '02−Jan−2019 00:11:01 − File generated by Dr
             . M. Dever'
          references         = 'CALYPSO Data Report'
          external_variables = ''
          Conventions        = 'CF−1.7'
          creation_date      = '02−Jan−2019 00:11:01'
          Comment            = ''
Dimensions:
```

```
        Time = 106
Variables:
    P
           Size:          106x1
           Dimensions:    Time
           Datatype:      double
           Attributes:
                          long_name     = 'Absolute Pressure'
                          standard_name = 'sea_water_pressure'
                          units         = 'dbar'
                          valid_range   = [0   600]
                          actual_range  = [10.714        50.8815]
                          missing_value = -999
                          origin        = 'Measured'
    time
           Size:          106x1
           Dimensions:    Time
           Datatype:      double
           Attributes:
                          long_name     = 'Time'
                          units         = 'days'
                          axis          = 'T'
                          valid_range   = [737207.4637       737207.4639]
                          actual_range  = [737207.4637       737207.4639]
                          missing_value = -999
                          origin        = 'Measured'
                          notes         = 'days since [0000 0 0 0 0 0]'
    lon
           Size:          106x1
           Dimensions:    Time
           Datatype:      double
           Attributes:
                          long_name     = 'Longitude'
                          standard_name = 'longitude'
                          units         = 'degree_east'
                          valid_range   = [-180   180]
                          actual_range  = [-2.7783       -2.7783]
                          missing_value = -999
                          origin        = 'Computed'
    lat
           Size:          106x1
           Dimensions:    Time
           Datatype:      double
           Attributes:
                          long_name     = 'Latitude'
                          standard_name = 'latitude'
                          units         = 'degree_north'
                          valid_range   = [-90   90]
                          actual_range  = [36.0662       36.0662]
                          missing_value = -999
```

```
                 origin        = 'Computed'
sP
        Size:        106x1
        Dimensions:  Time
        Datatype:    double
        Attributes:
                 long_name     = 'Sea Pressure'
                 standard_name = 'sea_water_pressure_due_to_sea_water'
                 units         = 'dbar'
                 valid_range   = [0   600]
                 actual_range  = [0.581462        40.749]
                 missing_value = -999
                 origin        = 'Computed'
                 notes         = 'Computed as P-10.1325 dbar'
O2_sat
        Size:        106x1
        Dimensions:  Time
        Datatype:    double
        Attributes:
                 long_name           = 'Oxygen Saturation'
                 standard_name       = '
                    fractional_saturation_of_oxygen_in_sea_water'
                 units               = 'percent'
                 valid_range         = [0   100]
                 actual_range        = [99.19696       101.6542]
                 missing_value       = -999
                 ancillary_variables = 'O2_sat_qc'
                 origin              = 'Computed'
                 notes               = 'Computed using Gibbs SeaWater
                    routine gsw_O2sol'
O2_sat_qc
        Size:        106x1
        Dimensions:  Time
        Datatype:    double
        Attributes:
                 long_name     = 'Oxygen Saturation Quality'
                 standard_name = 'status_flag'
                 units         = '1'
                 valid_range   = [-1   1]
                 actual_range  = [-1   1]
                 missing_value = -999
                 flag_values   = [-1   0   1]
                 flag_meanings = 'bad questionable good'
O2_umolkg
        Size:        106x1
        Dimensions:  Time
        Datatype:    double
        Attributes:
                 long_name           = 'Oxygen concentration in
                    micromolar per kilogram'
```

```
                    standard_name       = '
                       moles_of_oxygen_per_unit_mass_in_sea_water'
                    units               = 'micromole kilogram-1'
                    valid_range         = [0         243.5836]
                    actual_range        = [226.2568       243.5836]
                    missing_value       = -999
                    ancillary_variables = 'O2_umolkg_qc'
                    origin              = 'Computed'
                    notes               = 'Computed using Gibbs SeaWater
                       routine gsw_O2sol'
    O2_umolkg_qc
           Size:        106x1
           Dimensions:  Time
           Datatype:    double
           Attributes:
                    long_name     = 'Oxygen concentration in micromolar
                       per kilogram Quality'
                    standard_name = 'status_flag'
                    units         = '1'
                    valid_range   = [-1   1]
                    actual_range  = [-1   1]
                    missing_value = -999
                    flag_values   = [-1   0   1]
                    flag_meanings = 'bad questionable good'
```

A.4 Metadata for EcoCTD's FLS Level-1 file

```
Format:
           classic
Global Attributes:
           title              = 'Level-1 processed data from EcoPuck
              instrument on EcoCTD package'
           institution        = 'Woods Hole Oceanographic Institution'
           source             = 'ocean profile observations'
           history            = '02-Jan-2019 00:11:02 - File generated by Dr
              . M. Dever'
           references         = 'CALYPSO Data Report'
           external_variables = ''
           Conventions        = 'CF-1.7'
           creation_date      = '02-Jan-2019 00:11:02'
           Comment            = ''
Dimensions:
           Time = 106
Variables:
    P
           Size:        106x1
           Dimensions:  Time
           Datatype:    double
```

```
        Attributes:
                    long_name     = 'Absolute Pressure'
                    standard_name = 'sea_water_pressure'
                    units         = 'dbar'
                    valid_range   = [0    600]
                    actual_range  = [10.714        50.8815]
                    missing_value = -999
                    origin        = 'Measured'
time
        Size:       106x1
        Dimensions: Time
        Datatype:   double
        Attributes:
                    long_name     = 'Time'
                    units         = 'days'
                    axis          = 'T'
                    valid_range   = [737207.4637       737207.4639]
                    actual_range  = [737207.4637       737207.4639]
                    missing_value = -999
                    origin        = 'Measured'
                    notes         = 'days since [0000 0 0 0 0 0]'
lon
        Size:       106x1
        Dimensions: Time
        Datatype:   double
        Attributes:
                    long_name     = 'Longitude'
                    standard_name = 'longitude'
                    units         = 'degree_east'
                    valid_range   = [-180   180]
                    actual_range  = [-2.7783       -2.7783]
                    missing_value = -999
                    origin        = 'Computed'
lat
        Size:       106x1
        Dimensions: Time
        Datatype:   double
        Attributes:
                    long_name     = 'Latitude'
                    standard_name = 'latitude'
                    units         = 'degree_north'
                    valid_range   = [-90   90]
                    actual_range  = [36.0662       36.0662]
                    missing_value = -999
                    origin        = 'Computed'
sP
        Size:       106x1
        Dimensions: Time
        Datatype:   double
        Attributes:
```

```
                long_name     = 'Sea Pressure'
                standard_name = 'sea_water_pressure_due_to_sea_water'
                units         = 'dbar'
                valid_range   = [0   600]
                actual_range  = [0.581462         40.749]
                missing_value = -999
                origin        = 'Computed'
                notes         = 'Computed as P-10.1325 dbar'
bb470
        Size:       106x1
        Dimensions: Time
        Datatype:   double
        Attributes:
                long_name           = 'Backscatter at 470 nm'
                units               = '1'
                valid_range         = [0        4114.3969]
                actual_range        = [39.497555        4114.3969]
                missing_value       = -999
                ancillary_variables = 'bb470_qc'
                origin              = 'Measured'
                notes               = 'Non-standard units of [counts
                   ]'
bb470_qc
        Size:       106x1
        Dimensions: Time
        Datatype:   double
        Attributes:
                long_name     = 'Backscatter at 470 nm Quality'
                standard_name = 'status_flag'
                units         = '1'
                valid_range   = [-1   1]
                actual_range  = [-1   1]
                missing_value = -999
                flag_values   = [-1   0   1]
                flag_meanings = 'bad questionable good'
bb700
        Size:       106x1
        Dimensions: Time
        Datatype:   double
        Attributes:
                long_name           = 'Backscatter at 700 nm'
                units               = '1'
                valid_range         = [0        3957.0209]
                actual_range        = [115.56349        3957.0209]
                missing_value       = -999
                ancillary_variables = 'bb700_qc'
                origin              = 'Measured'
                notes               = 'Non-standard units of [counts
                   ]'
bb700_qc
```

```
        Size:         106x1
        Dimensions:   Time
        Datatype:     double
        Attributes:
                      long_name     = 'Backscatter at 700 nm Quality'
                      standard_name = 'status_flag'
                      units         = '1'
                      valid_range   = [-1   1]
                      actual_range  = [-1   1]
                      missing_value = -999
                      flag_values   = [-1   0   1]
                      flag_meanings = 'bad questionable good'
chl_raw
        Size:         106x1
        Dimensions:   Time
        Datatype:     double
        Attributes:
                      long_name = 'Raw Chlorophyll-Fluorescence'
                      units     = '1'
                      origin    = 'Measured'
chl_cal
        Size:         106x1
        Dimensions:   Time
        Datatype:     double
        Attributes:
                      long_name           = 'Calibrated Chlorophyll-
                         Fluorescence'
                      units               = 'microgram liter-1'
                      valid_range         = [0          881.8869]
                      actual_range        = [-717.053          881.8869]
                      missing_value       = -999
                      ancillary_variables = 'chl_cal_qc'
                      origin              = 'Computed'
chl_cal_qc
        Size:         106x1
        Dimensions:   Time
        Datatype:     double
        Attributes:
                      long_name     = 'Calibrated Chlorophyll-Fluorescence
                         Quality'
                      standard_name = 'status_flag'
                      units         = '1'
                      valid_range   = [-1   1]
                      actual_range  = [-1   1]
                      missing_value = -999
                      flag_values   = [-1   0   1]
                      flag_meanings = 'bad questionable good'
```

B Metadata for Level-3 dataset

```
Format:
            classic
Global Attributes:
            title              = 'Level-3 Merged product of downcasts from
               EcoCTD and UCTD probes.'
            institution        = 'Woods Hole Oceanographic Institution'
            source             = 'ocean profile observations'
            history            = '02-Jan-2019 01:01:07 - File generated by Dr
               . M. Dever'
            references         = 'CALYPSO Data Report'
            external_variables = ''
            Conventions        = 'CF-1.7'
            creation_date      = '02-Jan-2019 01:01:07'
            Comment            = ''
Dimensions:
            Profile number = 819
            Depth          = 601
Variables:
    Profile_number
            Size:       819x1
            Dimensions: Profile number
            Datatype:   double
            Attributes:
                        long_name     = 'Profile number'
                        units         = '1'
                        valid_range   = [1   819]
                        actual_range  = [1   819]
                        missing_value = -999
    Depth
            Size:       601x1
            Dimensions: Depth
            Datatype:   double
            Attributes:
                        long_name    = 'Depth grid'
                        units        = 'meters'
                        positive     = 'down'
                        axis         = 'Z'
                        valid_range  = [0   300]
                        actual_range = [0   300]
    Instrument_ID
            Size:       601x819
            Dimensions: Depth,Profile number
            Datatype:   double
            Attributes:
                        long_name     = 'ID number of instrument used'
                        standard_name = 'platform_id'
                        units         = '1'
```

```
                    valid_range   = [1    2]
                    actual_range  = [1    2]
                    missing_value = -999
                    notes         = '1- EcoCTD; 2- UCTD'
time
          Size:       601x819
          Dimensions: Depth,Profile number
          Datatype:   double
          Attributes:
                    long_name     = 'Time'
                    units         = 'days'
                    valid_range   = [737207.4637        737213.4718]
                    actual_range  = [737207.4637        737213.4718]
                    missing_value = -999
                    origin        = 'Measured'
                    notes         = 'days since [0000 0 0 0 0 0]'
lon
          Size:       601x819
          Dimensions: Depth,Profile number
          Datatype:   double
          Attributes:
                    long_name     = 'Longitude'
                    standard_name = 'longitude'
                    units         = 'degree_east'
                    valid_range   = [-180   180]
                    actual_range  = [-999        -1.784721]
                    missing_value = -999
                    origin        = 'Computed'
lat
          Size:       601x819
          Dimensions: Depth,Profile number
          Datatype:   double
          Attributes:
                    long_name     = 'Latitude'
                    standard_name = 'latitude'
                    units         = 'degree_north'
                    valid_range   = [-90   90]
                    actual_range  = [-999          36.79914]
                    missing_value = -999
                    origin        = 'Computed'
T
          Size:       601x819
          Dimensions: Depth,Profile number
          Datatype:   double
          Attributes:
                    long_name     = 'In-situ Temperature'
                    standard_name = 'sea_water_temperature'
                    units         = 'Celsius'
                    valid_range   = [0   40]
                    actual_range  = [-999          20.2855]
```

```
                missing_value = −999
                origin        = 'Measured'
T_qc
        Size:       601x819
        Dimensions: Depth,Profile number
        Datatype:   double
        Attributes:
                long_name     = 'In−situ Temperature Quality'
                standard_name = 'status_flag'
                units         = '1'
                valid_range   = [−1   1]
                actual_range  = [−1   1]
                missing_value = −999
                flag_values   = [−1   0   1]
                flag_meanings = 'bad questionable good'
CT
        Size:       601x819
        Dimensions: Depth,Profile number
        Datatype:   double
        Attributes:
                long_name     = 'Conservative Temperature'
                standard_name = 'sea_water_conservative_temperature'
                units         = 'Celsius'
                valid_range   = [0   40]
                actual_range  = [−999        20.22842]
                missing_value = −999
                origin        = 'Computed'
                notes         = 'Computed using the GibbsSeawater
                   toolbox (gsw_CT_from_t)'
CT_qc
        Size:       601x819
        Dimensions: Depth,Profile number
        Datatype:   double
        Attributes:
                long_name     = 'Conservative Temperature Quality'
                standard_name = 'status_flag'
                units         = '1'
                valid_range   = [−1   1]
                actual_range  = [−1   1]
                missing_value = −999
                flag_values   = [−1   0   1]
                flag_meanings = 'bad questionable good'
SP
        Size:       601x819
        Dimensions: Depth,Profile number
        Datatype:   double
        Attributes:
                long_name     = 'Practical Salinity'
                standard_name = 'sea_water_practical_salinity'
                units         = '1'
```

```
                valid_range   = [0   45]
                actual_range  = [-999        38.56628]
                missing_value = -999
                origin        = 'Computed'
                notes         = 'Computed using the GibbsSeawater
                   toolbox (gsw_SP_from_C)'
SP_qc
        Size:       601x819
        Dimensions: Depth, Profile number
        Datatype:   double
        Attributes:
                long_name     = 'Practical Salinity Quality'
                standard_name = 'status_flag'
                units         = '1'
                valid_range   = [-1   1]
                actual_range  = [-1   1]
                missing_value = -999
                flag_values   = [-1   0   1]
                flag_meanings = 'bad questionable good'
SA
        Size:       601x819
        Dimensions: Depth, Profile number
        Datatype:   double
        Attributes:
                long_name     = 'Absolute Salinity'
                standard_name = 'sea_water_absolute_salinity'
                units         = 'gram kilogram-1'
                valid_range   = [0   45]
                actual_range  = [-999        38.74969]
                missing_value = -999
                origin        = 'Computed'
                notes         = 'Computed using the GibbsSeawater
                   toolbox (gsw_SA_from_SP)'
SA_qc
        Size:       601x819
        Dimensions: Depth, Profile number
        Datatype:   double
        Attributes:
                long_name     = 'Absolute Salinity Quality'
                standard_name = 'status_flag'
                units         = '1'
                valid_range   = [-1   1]
                actual_range  = [-1   1]
                missing_value = -999
                flag_values   = [-1   0   1]
                flag_meanings = 'bad questionable good'
rho
        Size:       601x819
        Dimensions: Depth, Profile number
        Datatype:   double
```

```
        Attributes:
                    long_name     = 'In-situ Density'
                    standard_name = 'sea_water_density'
                    units         = 'kilogram meter-3'
                    valid_range   = [1000   1050]
                    actual_range  = [-999        1030.3998]
                    missing_value = -999
                    origin        = 'Computed'
                    notes         = 'Computed using the GibbsSeawater
                       toolbox (gsw_rho)'
rho_qc
        Size:       601x819
        Dimensions: Depth, Profile number
        Datatype:   double
        Attributes:
                    long_name     = 'In-situ Density Quality'
                    standard_name = 'status_flag'
                    units         = '1'
                    valid_range   = [-1   1]
                    actual_range  = [-1   1]
                    missing_value = -999
                    flag_values   = [-1   0   1]
                    flag_meanings = 'bad questionable good'
bb470
        Size:       601x819
        Dimensions: Depth, Profile number
        Datatype:   double
        Attributes:
                    long_name           = 'Backscatter at 470 nm'
                    units               = '1'
                    valid_range         = [0          4119.37]
                    actual_range        = [-999          4119.37]
                    missing_value       = -999
                    ancillary_variables = 'bb470_qc'
                    origin              = 'Measured'
                    notes               = 'Non-standard units of [counts
                       ]'
bb470_qc
        Size:       601x819
        Dimensions: Depth, Profile number
        Datatype:   double
        Attributes:
                    long_name     = 'Backscatter at 470 nm Quality'
                    standard_name = 'status_flag'
                    units         = '1'
                    valid_range   = [-1   1]
                    actual_range  = [-1   1]
                    missing_value = -999
                    flag_values   = [-1   0   1]
                    flag_meanings = 'bad questionable good'
```

```
bb700
        Size:        601x819
        Dimensions:  Depth, Profile number
        Datatype:    double
        Attributes:
                     long_name           = 'Backscatter at 700 nm'
                     units               = '1'
                     valid_range         = [0        4111.3912]
                     actual_range        = [-999        4111.3912]
                     missing_value       = -999
                     ancillary_variables = 'bb700_qc'
                     origin              = 'Measured'
                     notes               = 'Non-standard units of [counts
                        ]'
bb700_qc
        Size:        601x819
        Dimensions:  Depth, Profile number
        Datatype:    double
        Attributes:
                     long_name     = 'Backscatter at 700 nm Quality'
                     standard_name = 'status_flag'
                     units         = '1'
                     valid_range   = [-1   1]
                     actual_range  = [-1   1]
                     missing_value = -999
                     flag_values   = [-1   0   1]
                     flag_meanings = 'bad questionable good'
chl_cal
        Size:        601x819
        Dimensions:  Depth, Profile number
        Datatype:    double
        Attributes:
                     long_name           = 'Calibrated Chlorophyll-
                        Fluorescence'
                     units               = 'microgram liter -1'
                     valid_range         = [0        7.4484]
                     actual_range        = [-999        7.448423]
                     missing_value       = -999
                     ancillary_variables = 'chl_cal_qc'
                     origin              = 'Computed'
chl_cal_qc
        Size:        601x819
        Dimensions:  Depth, Profile number
        Datatype:    double
        Attributes:
                     long_name     = 'Calibrated Chlorophyll-Fluorescence
                        Quality'
                     standard_name = 'status_flag'
                     units         = '1'
                     valid_range   = [-1   1]
```

```
                 actual_range  = [-1   1]
                 missing_value = -999
                 flag_values   = [-1   0   1]
                 flag_meanings = 'bad questionable good'
O2_sat
        Size:        601x819
        Dimensions:  Depth,Profile number
        Datatype:    double
        Attributes:
                 long_name           = 'Oxygen Saturation'
                 standard_name       = '
                    fractional_saturation_of_oxygen_in_sea_water'
                 units               = 'percent'
                 valid_range         = [0   100]
                 actual_range        = [-999        110.8546]
                 missing_value       = -999
                 ancillary_variables = 'O2_sat_qc'
                 origin              = 'Computed'
                 notes               = 'Computed using Gibbs SeaWater
                    routine gsw_O2sol'
O2_sat_qc
        Size:        601x819
        Dimensions:  Depth,Profile number
        Datatype:    double
        Attributes:
                 long_name     = 'Oxygen Saturation Quality'
                 standard_name = 'status_flag'
                 units         = '1'
                 valid_range   = [-1   1]
                 actual_range  = [-1   1]
                 missing_value = -999
                 flag_values   = [-1   0   1]
                 flag_meanings = 'bad questionable good'
O2_umolkg
        Size:        601x819
        Dimensions:  Depth,Profile number
        Datatype:    double
        Attributes:
                 long_name           = 'Oxygen concentration in
                    micromolar per kilogram'
                 standard_name       = '
                    moles_of_oxygen_per_unit_mass_in_sea_water'
                 units               = 'micromole kilogram-1'
                 valid_range         = [0         283.171]
                 actual_range        = [-999        283.171]
                 missing_value       = -999
                 ancillary_variables = 'O2_umolkg_qc'
                 origin              = 'Computed'
                 notes               = 'Computed using Gibbs SeaWater
                    routine gsw_O2sol'
```

```
O2_umolkg_qc
        Size:           601x819
        Dimensions:     Depth,Profile number
        Datatype:       double
        Attributes:
                        long_name     = 'Oxygen concentration in micromolar
                           per kilogram Quality'
                        standard_name = 'status_flag'
                        units         = '1'
                        valid_range   = [-1   1]
                        actual_range  = [-1   1]
                        missing_value = -999
                        flag_values   = [-1   0   1]
                        flag_meanings = 'bad questionable good'
```

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16. Abstract (Limit: 200 words)
From May 27, 2018 to June 02, 2018, a scientific campaign was conducted in the Alboran Sea as part of an ONR Departmental Research Initiative, CALYPSO. The pilot cruise involved two ships: the R/V Socib, tasked with sampling fixed lines repeatedly, and the NRV Alliance that surveyed along the trajectory of Lagrangian platforms. A large variety of assets were deployed from the NRV Alliance, with the objective to identify coherent Lagrangian pathways from the surface ocean to interior. As part of the field campaign, an Underway-CTD (UCTD) system was used to measure vertical profiles of salinity, temperature and other properties while steaming, to achieve closely spaced measurements in the horizontal along the ship's track. Both a UCTD probe and an bio-optically augmented probe, named EcoCTD, were deployed. The EcoCTD collects concurrent physical and bio-optical observations. This report focuses exclusively on the data collected by these two underway systems. It describes th e datasets collected during the pilot cruise, as well as the important processing steps developed for the EcoCTD.

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