DY018 Towed Temperature and Fluorometer (T-F) Chain processing report

17/11/14 to 19/11/14
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Section 1: Introduction

Project Overview

Between 9/11/2014 to 3/12/2014 the ship RRS Discovery sailed for a research cruise referred to as *DY018*. During this cruise at the coordinates 48°34'13.1"N 9°30'34.6"W (station CS2) a T-F chain with temperature and fluorescence logging instruments attached was towed from 09:43 17/11/14 to 17:07 19/11/14. This was done to try to capture data related to cross-shelf exchange; this document contains the processing report of the collected data.

The cruise was done as part of the NERC and DEFRA funded Shelf Sea Biogeochemistry (SSB) research programme that seeks to reduce uncertainty of nutrient and carbon cycling in Shelf Seas and their role in the larger global biogeochemical cycle. Shelf seas will be important for future developments including carbon storage and the biogeochemical cycles that maintain primary production and so also higher tropic levels (Groeger et al., 2013). The SSB is split into five work packages; the cruise was a part of the Carbon and nutrient dynamics and fluxes over shelf systems (CANDYFLOSS) work package. DY018 was one of three cruises for CANDYFLOSS; these cruises looked to study the seasonal cycle of biological and chemical processes and their role in carbon and nutrient cycling.

Background Science

The Shelf seas are highly productive regions of the global oceans. Although relatively small they contribute 16% of the world's oceanic primary production (Simpson & Sharples, 2012). Shelf seas support society in numerous ways; carbon and nutrient cycling (Huthnance, 2009), storage, waste removal, recreation (Creel, 2003), and renewable energy resources (Baker, 1991). Shelf sea productivity support more than 90% of the world's fisheries (Pauly et al., 2002). As more people are set to continue to move to the coasts in the future the shelf seas will only become more important (Creel, 2003).

Between the deep Open Ocean and shallow shelf there is a steep bathymetric slope, the continental slope. This rapid change in depth leads to a bathymetrically steered along shelf current forming and limits cross-shelf exchange (Simpson & Sharples, 2012). Cross-slope exchange can only occur due to a number of processes, namely lenses, eddies, tidal pumping, Ekman transport at the wind and benthic boundary layers and internal waves (Huthnance, 2015). These processes and how they transport materials are largely unknown explaining the push to try to understand them.

This cross-shelf transport helps to move carbon and nutrients between the open ocean and shelf seas. Off-shelf transport moves carbon from the productive shelf seas into the deep ocean allowing the long term storage of the carbon. Open oceans may also supply the shelf seas with in-organic nutrients which support the massive shelf production (Huthnance, 2009).

Internal tides as mentioned above are a process that can lead to cross-shelf transport; the Celtic Sea is a 'hot spot' for the generation of these internal tides. As barotropic tides flow over the steep topography offered by the continental slope and shelf break internal waves are created with the frequency of tides these internal tides can propagate as much as 100 km into the shelf often mixing water and enabling vertical nutrient fluxes, allowing for the increased production (Stephenson et al., 2015).

The geostrophic along-shelf flows can breakdown in the presence of friction and other forces, e.g. in the surface and bottom boundary layers (SBL and BBL respectively). Wind forcing at the surface if parallel to the shelf edge can, via an Ekman spiral, lead to water movement across the shelf. If the wind forcing leads to loss of water from the shelf to the ocean upwelling will occur at the bottom layer bringing deep ocean water to the surface (Williams & Carmack, 2015). Ekman spirals can also affect cross-shelf transport in another manner. Ekman steering can deflect the along shelf current to the left near the sea bed and positions the flow off the shelf, this flow has been shown to be persistent. This process is called the 'Ekman Drain', on the north-west European shelf it is estimated to transport ~1.6 Sv (Simpson & McCandliss, 2013).

Section 2: Experiment & Processing

Aims

The experiment was done to capture the changes in the chlorophyll and temperature of a region at the Celtic Shelf Edge. The timing of the experiment, during November, might have meant the collapse of the summer stratification could have been captured. The measurements of the experiment had a high temporal resolution of 30 seconds to gain an improved resolution over CTD casts. From these observations the experiment hopes to clarify, measure and monitor some of the processes that lead to cross-shelf transport including fluxes in the BBL.

Description

The towed T-F chain was deployed between 09:43 17/11/14 to 17:07 19/11/14, a 55 hours and 24 minute period, during the DY018 cruise. The ship was located near the Celtic Sea shelf edge to observe changes in the water column at the shelf break. The cable used was a 200 m long 10mm diameter stainless wire with ferrules every 2.5 m along the cable. It was hung off the aft deck with a 380 kg spherical lead weight on the end to maintain tension on the wire and keep it vertical. 33 instruments where attached to the wire to capture the desired data. The data from the T-F chain was calibrated against 10 CTD casts that occurred over the period of the experiment. Some data was taken from the Ship underway data, when such data is used it will be signified, one example was the use of the ship echo sounder as the assumed benthic depth when results were plotted. Table 1 shows the planned instruments arranged in their intended order.

Instrument Type	Inst Number
FLB775/DST3604 T only	1
FLB776/DST3613 T only	2
Microcat 4966 RS232+ pressure	3
FLB777/DST 3608 T only	4
FLB778/DST 3619 T only	5

FLB779/DST3270 T+P(100m,0.05m)	6
StarmonMini 2849 T	7
FLB780/DST3271 T+ P(100m,0.05m)	8
FLB907/DST3655 T+P(240m,0.1m)	9
StarmonMini 2842 T	10
FLB937/DST5269 T+P(100m,0.05m)	11
Microcat SN 5793 RS232 + pressure	12
StarmonMini 2841 T	13
FLB938/DST 5270 T+P(1400m,0.5m)	14
RBRSolo 76797 T	15
RBRSolo 76798 T	16
RBRSolo 76799 T	17
FLB1712/DST5269 T+P (1400m,0.5)	18
RBRSolo 76800 T	19
Microcat 2991 RS485 No pressure	20
RBRSolo 76801 T	21
StarmonMini 2840 T	22
RBRSolo 76802 T	23
StarmonMini 2838 T	24
StarmonMini 2836 T	25
StarmonMini 2837 T	26
RBRSolo 76803 T	27
RBRSolo 76804 T	28
RBRSolo 76805 T	29
Microcat 5433 RS232 with pressure	30
RBRSolo 76806 T	31
RBRSolo 76807 T	32
Microcat 5790 RS232 with pressure	33

Table 1: A table showing the planned instruments identified by their serial number and their order on the chain. Lower numbers are near the surface.

<u>**Key:**</u>

FLB	Wetlabs internally recording Eco Chlorophyll-a fluorometer
DST	Star Oddi Centi internally recording Temperature/ T+ pressure logger
Starmon Mini	Star Oddi internally recording temperature logger
RBR Solo	Internally recording temperature logger
Microcat	Seabird SBE37 internally recording CT/CTD sensor

Deployment

At 06:00 17/11/14 the instruments were placed in a sink of saltwater to get measurement comparisons these were removed by 07:45 17/11/14. Deployment of the T-F chain at the shelf edge occurred at 09:43 at 48° 35.250N 9° 30.580W. During plotting it was found that all instruments were settled by 10:00 so this was chosen as the start time for all data processing.

Recovery

The recovery of the chain was completed by 17:07 on the 19th of November at 48° 33.769N, 9° 30.16W. Upon recovery several issues were noted including erroneous placement and loss of some instruments, these will be addressed in greater detail in the problems sub-section. The remaining instruments were placed in a sink of saltwater for measurement comparison between 17:30 and 19:00 on 19/11/14. Instruments seem to be affected by recovery as early as 16:27. Due to this the end time for the experiment was placed at 16:26:30. Table 2 shows the estimated depth before pressure adjustments and the missing instruments.

Estimated Depth (M)	Instrument Type	Inst Number
7.5	FLB775+ DST3604 T only	1
10	FLB776/DST3613 T only	2
17.5	Microcat 4966 RS232 + pressure	3
20	FLB777/DST 3608 T only	4
25	FLB778/DST 3619 T only	5
xx	FLB779/DST3270T + P (100m,0.05m) (Lost)	6
40	StarmonMini 2849 T	7
xx	FLB780/DST3271T + P (100m,0.05m) (Lost)	8
xx	FLB907/DST3655T + P(240m,0.1m) (Lost)	9
60	StarmonMini 2842 T	10
xx	FLB937/DST5269T + P(100m,0.05m) (Lost)	11
xx	Microcat SN 5793 RS232+ pressure (Lost)	12
82.5	StarmonMini 2841 T	13
90	FLB938/DST 5270 T + P(1400m,0.5m)	14
95	RBRSolo 76797 T	15
97.5	RBRSolo 76798 T	16
105	RBRSolo 76799 T	17
xx	FLB1712/DST5269 T+P (1400m,0.5) (Lost)	18
120	RBRSolo 76800 T	19
130	Microcat 2991 RS485 Nopressure	20
132.5	RBRSolo 76801 T	21
135	StarmonMini 2840 T	22
140	RBRSolo 76802 T	23
142.5	StarmonMini 2838 T	24
145	StarmonMini 2836 T	25
147.5	StarmonMini 2837 T	26
150	RBRSolo 76803 T	27
157.5	RBRSolo 76804 T	28
164	RBRSolo 76805 T	29
xx	Microcat 5433 RS232 with pressure (Lost)	30
177.5	RBRSolo 76806 T	31
185	RBRSolo 76807 T	32
xx	Microcat 5790 RS232 with pressure (Lost)	33

Table 2: A table showing the planned instruments and their estimated depths. If the instruments were lost it is also shown denoted by XX as an estimated depth.

Key:

FLB	Wetlabs internally recording Eco Chlorophyll-a fluorometer
DST	Star Oddi Centi internally recording Temperature/ T+ pressure logger
Starmon Mini	Star Oddi internally recording temperature logger
RBR Solo	Internally recording temperature logger
Microcat	Seabird SBE37 internally recording CT/CTD sensor

Problems

Upon recovery it was realized that the instruments seemed to have been placed at erroneous depths. It is thought that as the deepest instruments were placed on the cable first an offset began to occur when the higher instruments seem to differ then the intended placement. It was decided to estimate the depths of the instruments by counting the ferrules; each sitting 2.5 meters from the next and then to relate this to the cable's sea surface target marker. Further improvements of estimated depth will be done with inclusion of pressure readings from 'Microcat 4966'.

As mentioned in the recovery subsection several instruments were missing when the chain was recovered. In total 8 instruments were missing leaving 25 instruments on the chain. The missing instruments, which can be seen in table 2 marked by a depth of XX, included 5 of the fluorometers and 3 of the Seabird instruments. This only left half the planned fluorometers to be used in processing. These losses were thought to be due to a weakening in their clamps during deployment and that they fell from the chain during the duration of the experiment. To further exacerbate the loss of spatial resolution, the 'Starmon Mini 2840 T' failed to log data meaning only 24 of the 33 instruments was used during processing.

The ship did not remain stationary for the entirety of the T-F chain experiment. Though this did not normally affect the data gathered, as it was being weighed down by the 380kg spherical lead weight, for one period from 12:48 and 13:09 on the 18th it would appear that the chain was raised higher into the water column. A pressure drop was recorded by **'**Microcat 4966' at this period where normally depth values ranged between 18 to 20 m increased to a range of 4 to 6 m and can be seen in figure 2, a similar pressure drop was recorded by 'FLB938/DST 5270' shown in figure 3 at the same period. A warming can be seen in some of the instruments shown in figures 4 and 5 during this period, though this is more obvious in figure 5 which contains the deeper instruments. Ship underway data showed that the ship was traveling in excess of 2 m/s, higher than most other periods, demonstrated in figure 1. During data processing this period was removed so as not to affect the longer data series. This movement could have been linked to the ship repositioning.

'Microcat 2991' and 'Microcat 4966' did not constantly keep a 30 second temporal spacing. The two instruments started a second later than the rest of the instruments and occasionally deviated from the 30 second sampling period by a few seconds either side. The temperature and other recorded variables were interpolated onto a regular spaced 30 second time vector to fix this.

While two pressure recording instruments were recovered only ‘Microcat 4966’, shown in figure 2, was used for adjustment of the chain placement depth. While ‘FLB938/DST 5270’ the other pressure sensor shown in figure 3 was not used as it significantly disagreed with the both the ‘Microcat 4966’ and the chain position calculated depth, which were more in agreement. While ‘FLB938/DST 5270’ measures itself around 65 m depth, the ferrule estimated depth placed it at 90 m and the ‘Microcat 4966’ placed it at 90.928 m.

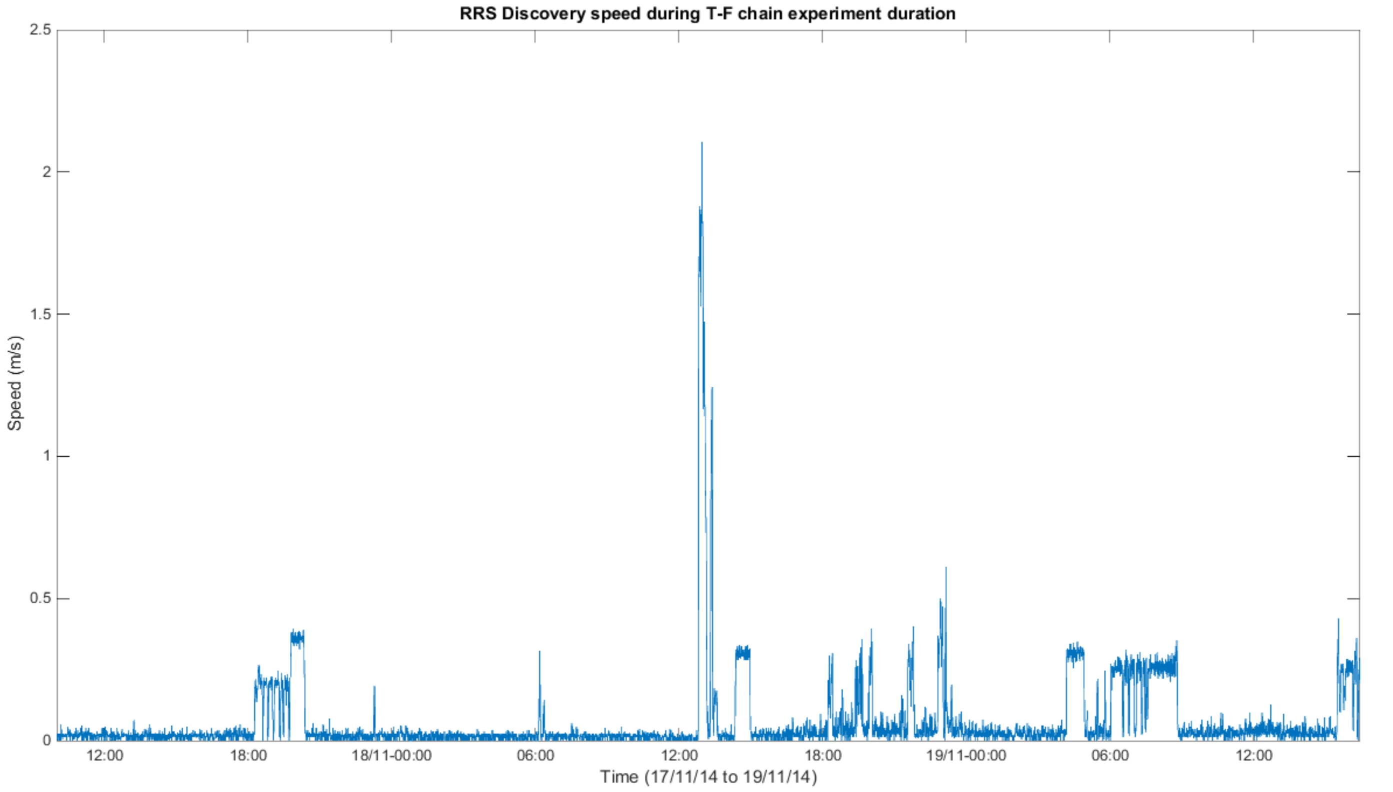

Figure 1: A graph of ship speed data taken from the Ship Underway data for the duration of the experiment. The speed was obtained as the absolute value of the northerly and easterly velocity components.

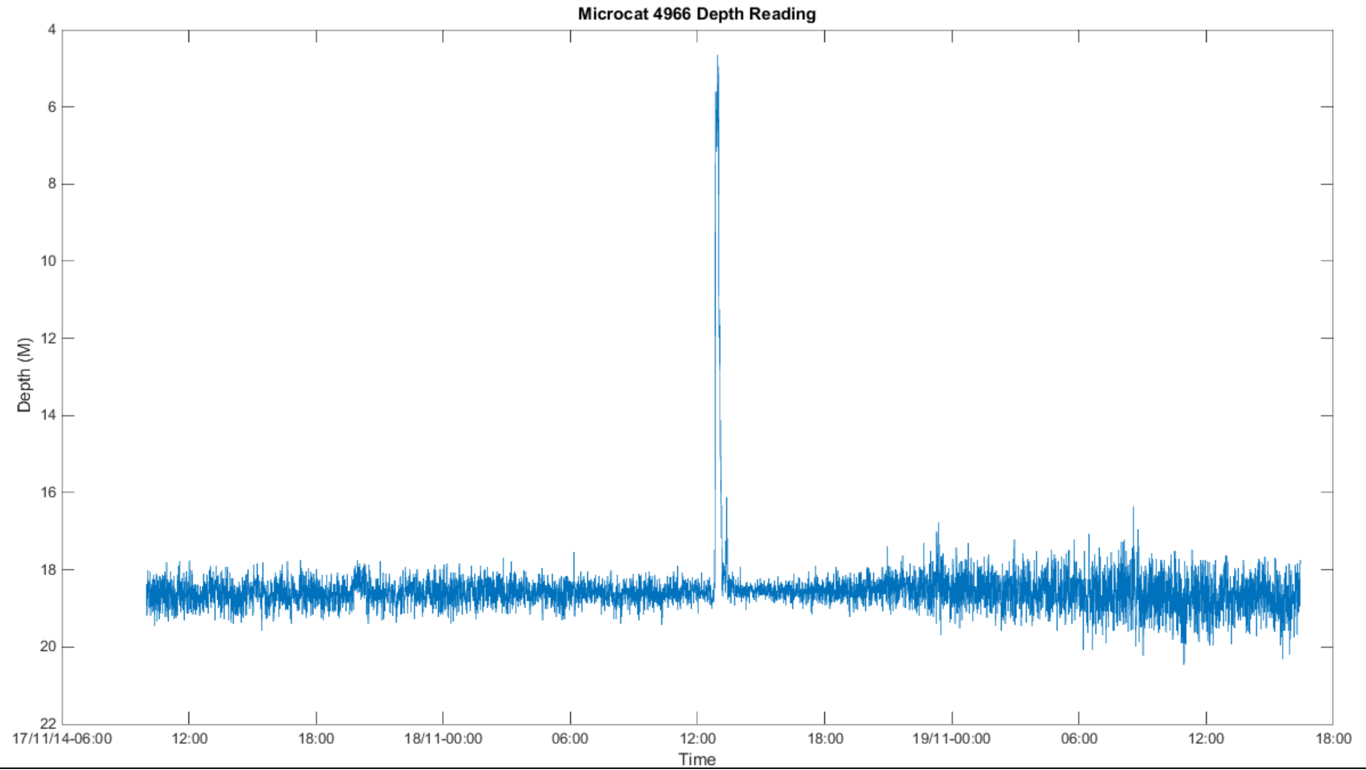

Figure 2: A graph showing the depth recorded by Microcat 4966 for the duration of the experiment. The period between 12:48 and 13:09 on the 18th shows a sudden movement towards the surface.

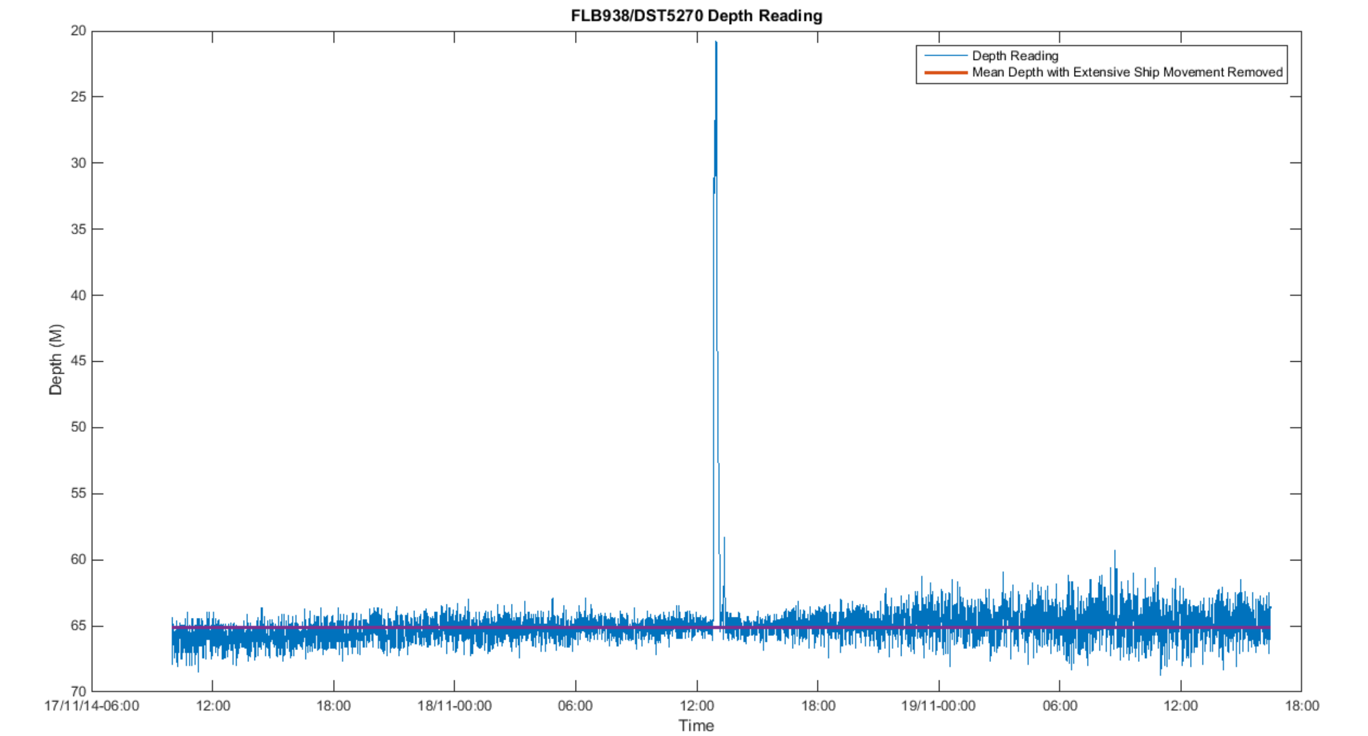

Figure 3: A graph showing the depth recorded by FLB938/DST 5270T for the duration of the experiment. The period between 12:48 and 13:09 on the 18th shows a sudden movement towards the surface.

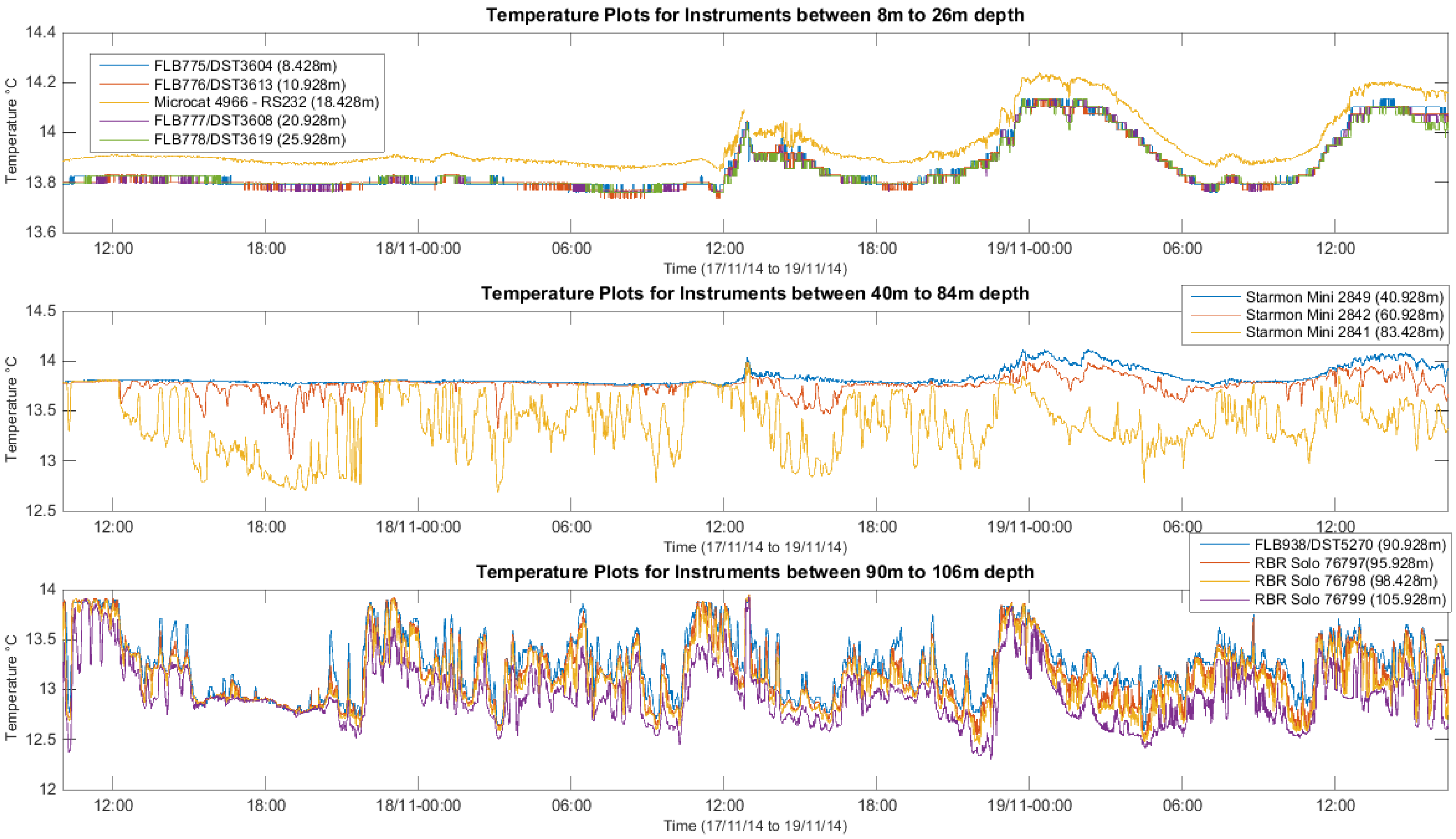

Figure 4: Plots for unprocessed temperature data from the usable instruments between the surface to 106 m depth plotted over the duration of the experiment. These are separated into three groups to make information more clear.

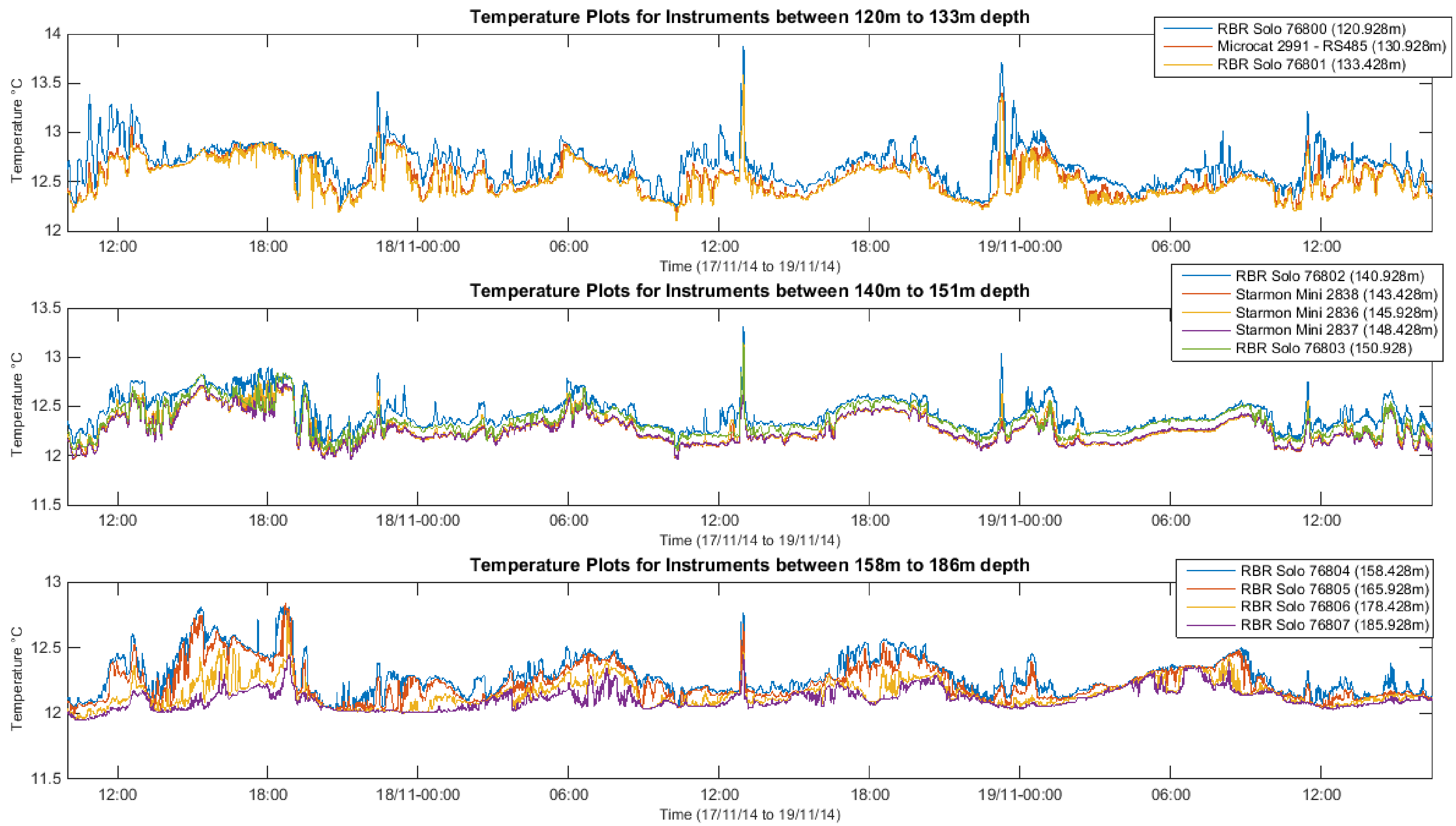

Figure 5: Unprocessed temperature data from the usable instruments for depths 120 m to 186 m in the water column plotted over the duration of the experiment. At the period between 12:48:00 and 13:09:00 on the 18th a spike in temperature can be seen, this is believed to be linked to the chain being raised in the water column. These are also separated into three groups to make data clearer.

Processing

Applications and Data Used

The data was processed primarily in Matlab. 9 instruments of the planned 33 instruments are not represented in the data as they were lost or failed to log, leaving 24 instruments for processing. Ships underway data and CTD casts taken during the experiment were included to calibrate or enhance the instrument data. Table 3 shows the instruments used in data processing along with their corrected depths. This depth was calculated from a mean depth reading of the **'**Microcat 4966' and through knowing the difference in the number of ferrules on the chain between the instruments. For ease each instrument was given a shorthand name, these were used as the names for the Matlab structures, and are shown in table 3.

Final Deployment Depth (m)	Instrument Type	Inst №	Shorthand
8.428	FLB 775 + DST3604 T only	1	DST1 (for temperature data) FLB1 (for chlorophyll data)
10.928	FLB 776/ DST 3613 T only	2	DST2 (for temperature Data) FLB2 (for chlorophyll data)
18.428	Microcat 4966 RS232 + pressure	3	MCWP1
20.928	FLB 777/ DST 3608 T only	4	DST3 (for temperature data) FLB3 (for chlorophyll data)
25.928	FLB 778/ DST 3619 T only	5	DST4 (for temperature data) FLB4 (for chlorophyll data)
40.928	Starmon Mini 2849 T	7	Starmon1
60.928	Starmon Mini 2842 T	10	Starmon2
83.428	Starmon Mini 2841 T	13	Starmon3
90.928	FLB 938/DST 5270 T+P (1400m,0.5m)	14	DSTWP1 (for temperature and pressure data) FLB5(for chlorophyll data)
95.928	RBR Solo 76797 T	15	RBR1
98.428	RBR Solo 76798 T	16	RBR2
105.928	RBR Solo 76799 T	17	RBR3
120.928	RBR Solo 76800 T	19	RBR4
130.928	Microcat 2991 - RS485 No pressure	20	MCNP1
133.428	RBR Solo 76801 T	21	RBR5
140.928	RBR Solo 76802 T	23	RBR6
143.428	Starmon Mini 2838 T	24	Starmon4
145.928	Starmon Mini 2836 T	25	Starmon5
148.428	Starmon Mini 2837 T	26	Starmon6
150.928	RBR Solo 76803 T	27	RBR7
158.428	RBR Solo 76804 T	28	RBR8
165.928	RBR Solo 76805 T	29	RBR9
178.428	RBR Solo 76806 T	31	RBR10
185.928	RBR Solo 76807 T	32	RBR11

Table 3: A table showing the instruments used during data processing with their final deployment depths and designated shorthand

Instruments

The raw data files used in processing can be seen in table 4.

Instrument Type	Data Files
FLB 775 + DST3604 T only	1.-FL775 and DST 3604 at -7-5m--19-11-14. ENG 0-14C3604. DAT
FLB 776/ DST 3613 T only	2.-FL776 and DST 3613 at -10m--19-11-14. ENG 0-16C3613. DAT
Microcat 4966 RS232 + pressure	3.-SBE37 SN4966 - RS232 - Unpumped - Pressure at -17-5m--20-11-14.ASC
FLB 777/ DST 3608 T only	4.-FL777 and DST 3608 at -20m--19-11-14.ENG 0-10C3608.DAT
FLB 778/ DST 3619 T only	5.-FL778 and DST 3619 at -25m--19-11-14.ENG 0-12C3619.DAT
Starmon Mini 2849 T	0-21T2849.DAT
Starmon Mini 2842 T	0-20T2842.DAT
Starmon Mini 2841 T	0-18T2841.DAT
FLB 938/DST 5270 T+P (1400m,0.5m)	14.-FL1938 and DST 5270 at 90m--19-11-14.ENG 0-6C5270.DAT
RBR Solo 76797 T	15.-SN76797 RBR Solo T at -95m--20-11-14.TXT
RBR Solo 76798 T	16.-SN76798 RBR Solo T at -97-5m--20-11-14.TXT
RBR Solo 76799 T	17.-SN76799 RBR Solo T at -105m--20-11-14.TXT
RBR Solo 76800 T	19.-SN76800 RBR Solo T at -120m--20-11-14.TXT
Microcat 2991 - RS485 No pressure	20.-SBE37 SN2991- RS485 - Unpumped - NO Pressure at -130m.ASC
RBR Solo 76801 T	21.-SN76801 RBR Solo T at -132-5m--20-11-14.TXT
RBR Solo 76802 T	23.-SN76802 RBR Solo T at -140m-20-11-14.TXT
Starmon Mini 2838 T	0-18T2838.DAT
Starmon Mini 2836 T	0-16T2836.DAT
Starmon Mini 2837 T	0-11T2837.DAT
RBR Solo 76803 T	27.-SN76803 RBR Solo T at -150m-20-11-14.TXT
RBR Solo 76804 T	28.-SN76804 RBR Solo T at -157-5m--20-11-14.TXT
RBR Solo 76805 T	29.-SN76805 RBR Solo T at -165m--20-11-14.TXT
RBR Solo 76806 T	31.-SN76806 RBR Solo T at -177-5m--20-11-14.TXT
RBR Solo 76807 T	32.-SN76807 RBR Solo T at -185m--20-11-14.TXT

Table 4: A table showing the data files used in data import for the individual instruments

The raw data was imported into Matlab and after plotting, the period between 10:00 17/11/14 to 16:26:30 19/11/14 was chosen for the experiment duration as it was not seemingly affected by the deployment or recovery. As mentioned in the problems section the chain was seemingly lifted in the water column due to the ships speed, this period was removed. The main duration of the experiment and the two periods from 6:05 to 7:45 on the 17th and 17:30 to 19:00 on the 19th, when the instruments were in sinks of saltwater for comparison, were saved as different time vectors. The recorded variables of each instrument were applied to these durations. These variables along with the serial number and depth were recorded in Matlab structures. For each of the instruments their differently formatted date records were each converted into more a standardized datenumber vectors in Matlab. The chlorophyll data for FLB instrument was smoothed as outliers seemed more prevalent than in temperature data. Between the 24 instruments 7 different configurations of recorded variables exists. Examples of these different structures can be seen in table 5.

serialnumber 'FLB775/DST3604' Depth 8.4280 dd *6534x1 double* s1dd *201x1 double* s2dd *181x1 double* TempDur *6534x1 double* TempSink1 *201x1 double* TempSink2 *181x1 double* TempDif -0.0876	The Matlab structure for the FLB/DST temperature recorder that did not measure pressure. The structure contains the timings for each period represented as Matlab datenumber form where 'dd' is the experiment duration, 's1dd' is the first period in the sink and 's2dd' is the after experiment period in the sink. The structure contains the serial number and pressure adjusted depth of the instrument. The 'TempDif' contains the mean difference between the CTD casts and the instrument. This was used to calibrate the three periods of temperature recording. 'TempDur' relates to the duration while the sink temperature vectors are related to the numbered sink periods. All temperature readings were measured in °C. Instruments: FLB 775 + DST3604 T only, FLB 776/ DST 3613 T only, FLB 777/ DST 3608 T only, FLB 778/ DST 3619 T only
serialnumber 'FLB775/DST3604' Depth 8.4280 dd *6534x1 double* s1dd *201x1 double* s2dd *181x1 double* ChlorDur *6534x1 double* ChlorSink1 *201x1 double* ChlorSink2 *181x1 double* Chlodif -0.0108	The Matlab structure for the FLB/DST chlorophyll recorder for instruments that did not measure pressure. The structure contains the serial number, depth and the shared period timings. The chlorophyll measurements were separated into the three periods and 'Chlodiff' representing the mean difference for the calibration of the periods. The chlorophyll was measured in µg/l. Instruments: FLB 775 + DST3604 T only, FLB 776/ DST 3613 T only, FLB 777/ DST 3608 T only, FLB 778/ DST 3619 T only, FLB 938/DST 5270 T+P (1400m,0.5m)
serialnumber 'RBR Solo 76797' Depth 95.9280 dd *6534x1 double* s1dd *201x1 double* s2dd *181x1 double* TempDur *6534x1 double* TempSink1 *201x1 double* TempSink2 *181x1 double* TempDif -0.0034	The structure for the RBR solo instruments is also an instrument that only measured temperature. Due to this the information is organized in exactly the same way as the DST temperature structure and is also measured in °C. Instruments: RBR Solo 76797 T, RBR Solo 76798 T, RBR Solo 76799 T, RBR Solo 76800 T, RBR Solo 76801 T, RBR Solo 76802 T, RBR Solo 76803 T, RBR Solo 76804 T, RBR Solo 76805 T, RBR Solo 76806 T, RBR Solo 76807 T
serialnumber 'Starmon Mini 2849' Depth 40.9280 dd *6534x1 double* s1dd *201x1 double* s2dd *181x1 double* TempDur *6534x1 double* TempSink1 *201x1 double* TempSink2 *181x1 double* TempDif -0.0905	This is the layout for the Starmon instrument structure. Due to the Starmon only measuring temperature it is organized like the RBR solo and DST structures and is measured in °C. Instruments: Starmon Mini 2849 T, Starmon Mini 2842 T, Starmon Mini 2841 T, Starmon Mini 2838 T, Starmon Mini 2836 T, Starmon Mini 2837 T

serialnumber 'Microcat 4966 - RS232' Depth 18.4280 dd *6534x1 double* s1dd *201x1 double* s2dd *181x1 double* TempDur *6534x1 double* TempSink1 *201x1 double* TempSink2 *181x1 double* SalinDur *6534x1 double* SalinSink1 *201x1 double* SalinSink2 *181x1 double* ConducDur *6534x1 double* ConducSink1 *201x1 double* ConducSink2 *181x1 double* PressDur *6534x1 double* PressSink1 *201x1 double* PressSink2 *181x1 double* RefDepth 18.4276 TempDif -0.0021 Salindif -0.0172 Conducdif -0.1351	This is the structure for the Microcat instrument that measured pressure. This instrument logs the most variables out of all the instruments. It contains the basic information such as serial number, depth and the common timing periods which all the structures share. The four variables recorded by this structure are all separated into these periods. Temperature is measured in °C and shortened to 'Temp'. Salinity is measured in PSU and is shortened to 'Salin'. Conductivity is measured in S/m and is shortened to 'Conduc'. These three variables were all calibrated with CTD casts so all have mean difference values related to them. The pressure, shortened to 'Press', was recorded in dbars but was not calibrated. The mean of a moving average of the duration pressure was used to get the 'RefDepth', the reference depth, which was used against ferrules to gauge the depth of all instruments. Instruments: Microcat 4966 + pressure
serialnumber 'Microcat 2991 - RS485' Depth 130.9280 dd *6534x1 double* s1dd *201x1 double* s2dd *181x1 double* TempDur *6534x1 double* TempSink1 *201x1 double* TempSink2 *181x1 double* SalinDur *6534x1 double* SalinSink1 *201x1 double* SalinSink2 *181x1 double* ConducDur *6534x1 double* ConducSink1 *201x1 double* ConducSink2 *181x1 double* TempDif -0.0049 Salindif -0.0237 Conducdif -0.0024	This is the structure of the Microcat instrument that did not record pressure. Due to this it is similarly organized as the previous structure with the exception of a pressure reading. The relevant variables are measured in the same units as the other Microcat instrument. Instruments: Microcat 2991 - RS485 No pressure
serialnumber 'FLB938/DST5270' Depth 90.9280 dd *6534x1 double* s1dd *201x1 double* s2dd *181x1 double* TempDur *6534x1 double* TempSink1 *201x1 double* TempSink2 *181x1 double* PressDur *6534x1 double* PressSink1 *201x1 double* PressSink2 *181x1 double* TempDif 0.0118	The structure for the DST instrument that also recorded pressure. The serial number and the depth are recorded along with the shared timing periods. Temperature and pressure are separated into the desired timing periods however only temperature was calibrated so has a mean difference. Temperature was recorded in °C while pressure was recorded in dbars. Instruments: FLB 938/DST 5270 T+P (1400m,0.5m)

Table 5: A table showing the information stored in the seven Matlab structure combinations after calibration.

CTD and Calibration

Over the course of the T-F chain experiment 10 CTD casts were taken, numbering 45 through 54. Two CTD frames were used during the cruise, a stainless steel frame and a titanium frame. Casts 49 and 52 were with the titanium frame while remaining casts were with the steel frame. These CTDs offer additional information and allow the T-F chain loggers to be calibrated. CTDs had already been processed with problem readings having been accounted for so no modifications were required. These were used to calibrate chlorophyll, temperature, salinity and conductivity where applicable. Not all the casts penetrated the full length of the chain so some instruments had to be calibrated with fewer than 10 casts. A diagram showing which instruments were calibrated against which casts is shown in table 6.

Instruments	Cast 45	Cast 46	Cast 47	Cast 48	Cast 49	Cast 50	Cast 51	Cast 52	Cast 53	Cast 54
FLB 775 + DST3604 T only	Green	Green	Green	Green	Green	Red	Green	Green	Green	Green
FLB 776/ DST 3613 T only	Green	Green	Green	Green	Green	Red	Green	Green	Green	Green
Microcat 4966 RS232 + pressure	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
FLB 777/ DST 3608 T only	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
FLB 778/ DST 3619 T only	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
Starmon Mini 2849 T	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
Starmon Mini 2842 T	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
Starmon Mini 2841 T	Green	Red	Green	Green	Green	Red	Green	Green	Green	Green
FLB 938/DST 5270 T+P (1400m,0.5m)	Green	Red	Green	Green	Green	Red	Green	Green	Green	Green
RBR Solo 76797 T	Green	Red	Green	Green	Green	Red	Green	Green	Green	Green
RBR Solo 76799 T	Green	Red	Green	Green	Green	Red	Green	Green	Green	Red
RBR Solo 76800 T	Green	Red	Green	Green	Green	Red	Green	Green	Green	Red
Microcat 2991 - RS485 No pressure	Green	Red	Green	Green	Green	Red	Green	Green	Green	Red
RBR Solo 76801 T	Green	Red	Green	Green	Green	Red	Green	Green	Green	Red
RBR Solo 76802 T	Green	Red	Green	Green	Green	Red	Green	Green	Green	Red
Starmon Mini 2838 T	Green	Red	Green	Green	Green	Red	Green	Green	Green	Red
Starmon Mini 2836 T	Green	Red	Green	Green	Green	Red	Green	Green	Green	Red
Starmon Mini 2837 T	Green	Red	Green	Green	Green	Red	Green	Green	Green	Red
RBR Solo 76803 T	Green	Red	Green	Green	Green	Red	Green	Green	Green	Red
RBR Solo 76804 T	Green	Red	Green	Green	Green	Red	Green	Green	Green	Red
RBR Solo 76805 T	Green	Red	Green	Green	Green	Red	Green	Green	Green	Red
RBR Solo 76806 T	Green	Red	Green	Green	Green	Red	Green	Green	Green	Red
RBR Solo 76807 T	Green	Red	Green	Green	Green	Red	Green	Green	Green	Red

Table 6: A table showing which instruments were calibrated against which CTD casts. A red box shows the cast lacked data for the corresponding depth so could not be used to calibrate any loggers at that depth. Green boxes show that the cast was used to calibrate an instrument.

The times that a cast passed an instrument depth were identified and the relevant measurements were compared to the logger readings for the same time. The logger values used for comparison were an average of 5 minutes either side of the intersection time. This reduced the impact of potential outliers on the mean difference between CTD and logger measurements. These mean differences are recorded in the instrument structures. This method was used to calibrate all recorded variables. Error bars were added to the instrument data of 1 standard deviation to see if the CTD data fell into the range. The implementation of this method can be seen in figures 6 and 7.

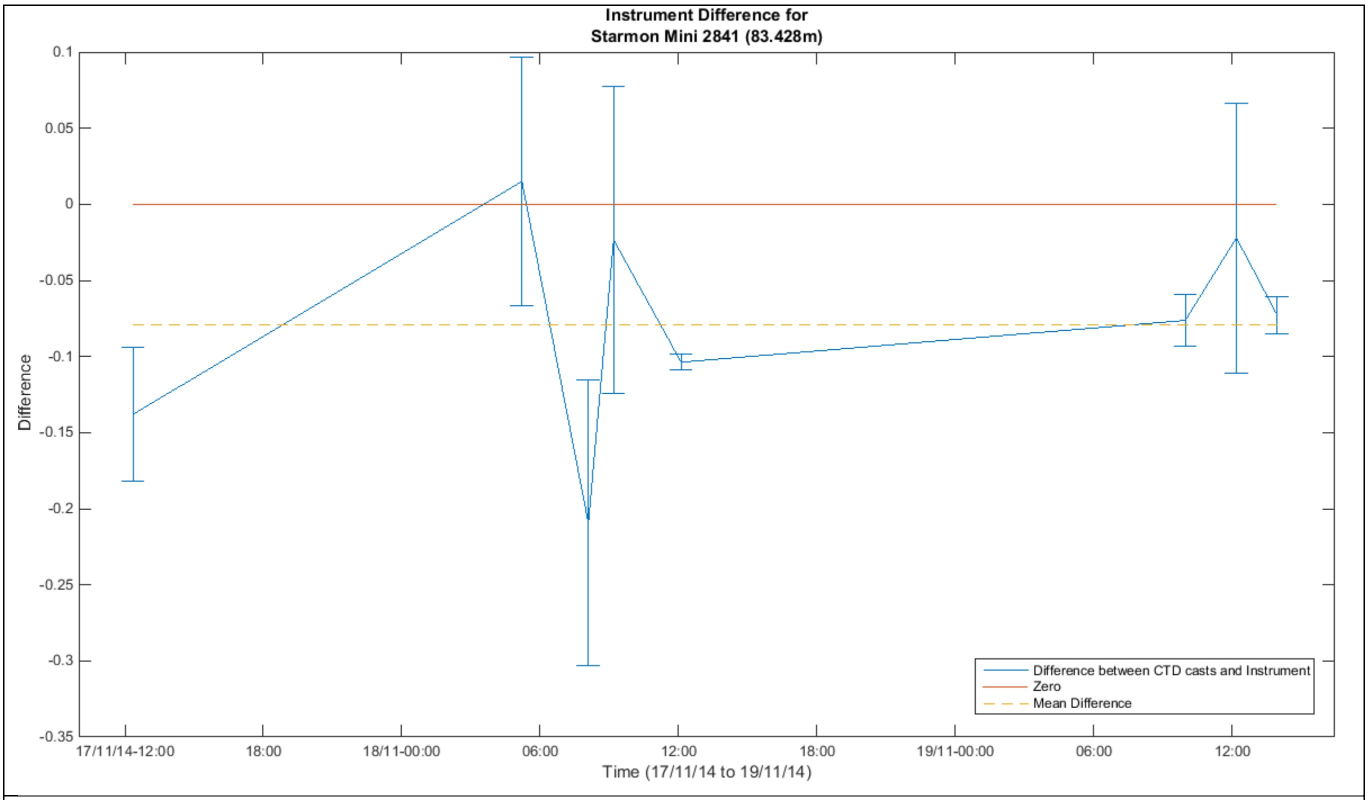

Figure 6: A graph showing the calibration method used in the T-F chain data processing. The dotted line shows the mean difference between the instrument and the CTD casts. This shows the pre-calibration stage. Error bars of 1 standard deviation are also included.

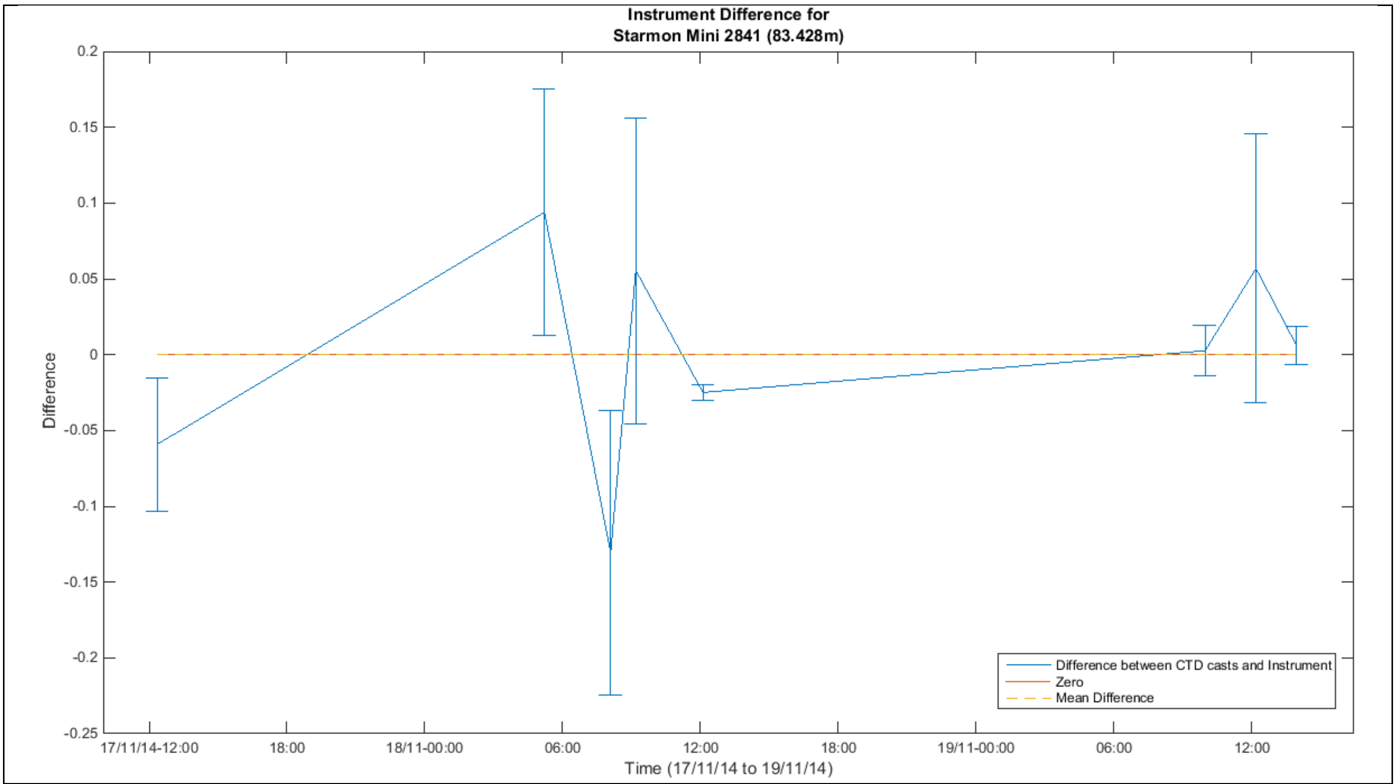

Figure 7: A graph showing the calibration process once the adjustment is done and the mean difference (dotted line) is equal, or very close, to zero. Error bars of 1 standard deviation are also included.

The results for this calibration method are seen in the differences between figures 8 & 9 and figures 10 & 11. The water column shown in figure 8 is unstable while after calibration, as seen in figure 9, the column becomes more stable. The profile shown in figure 11 follows the CTD cast more closely than its pre-calibrated form shown in figure 10.

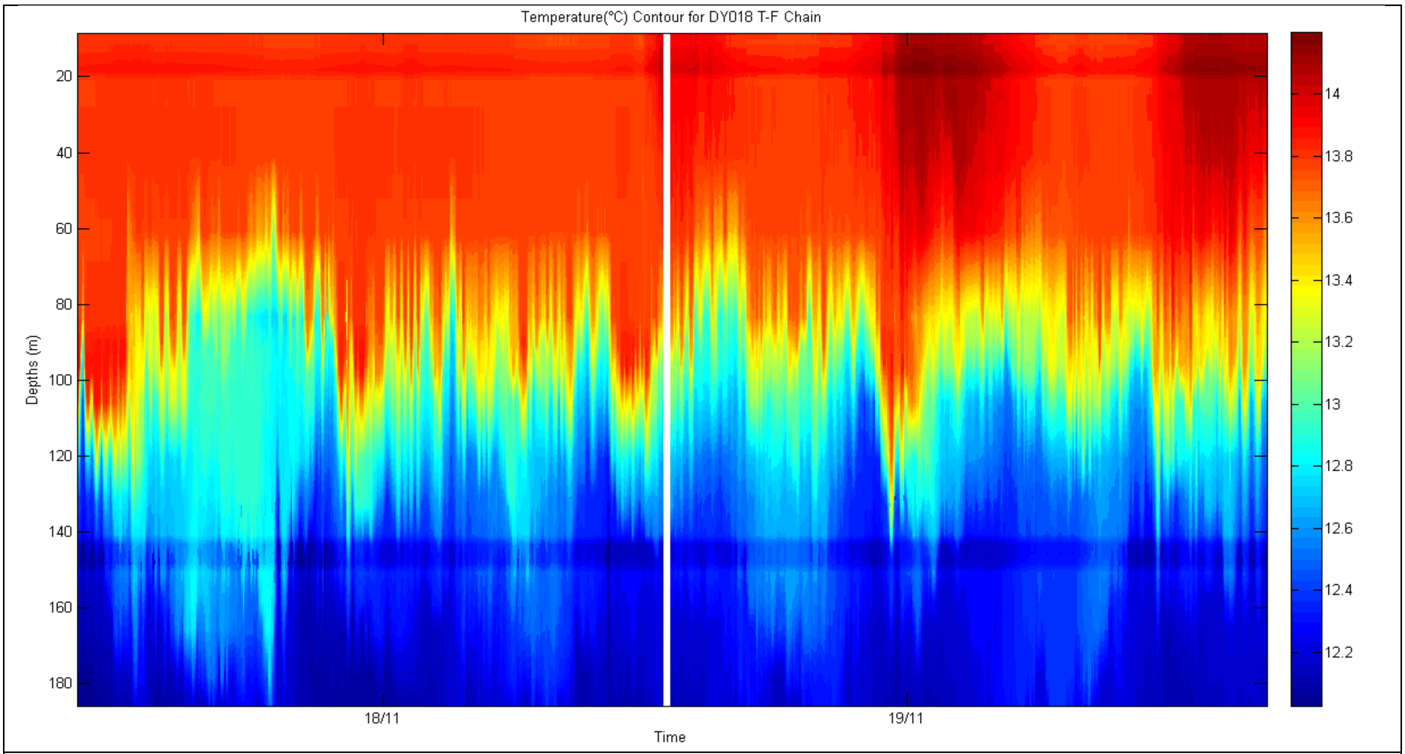

Figure 8: A contour plot of temperature data from the T-F chain without any calibration.

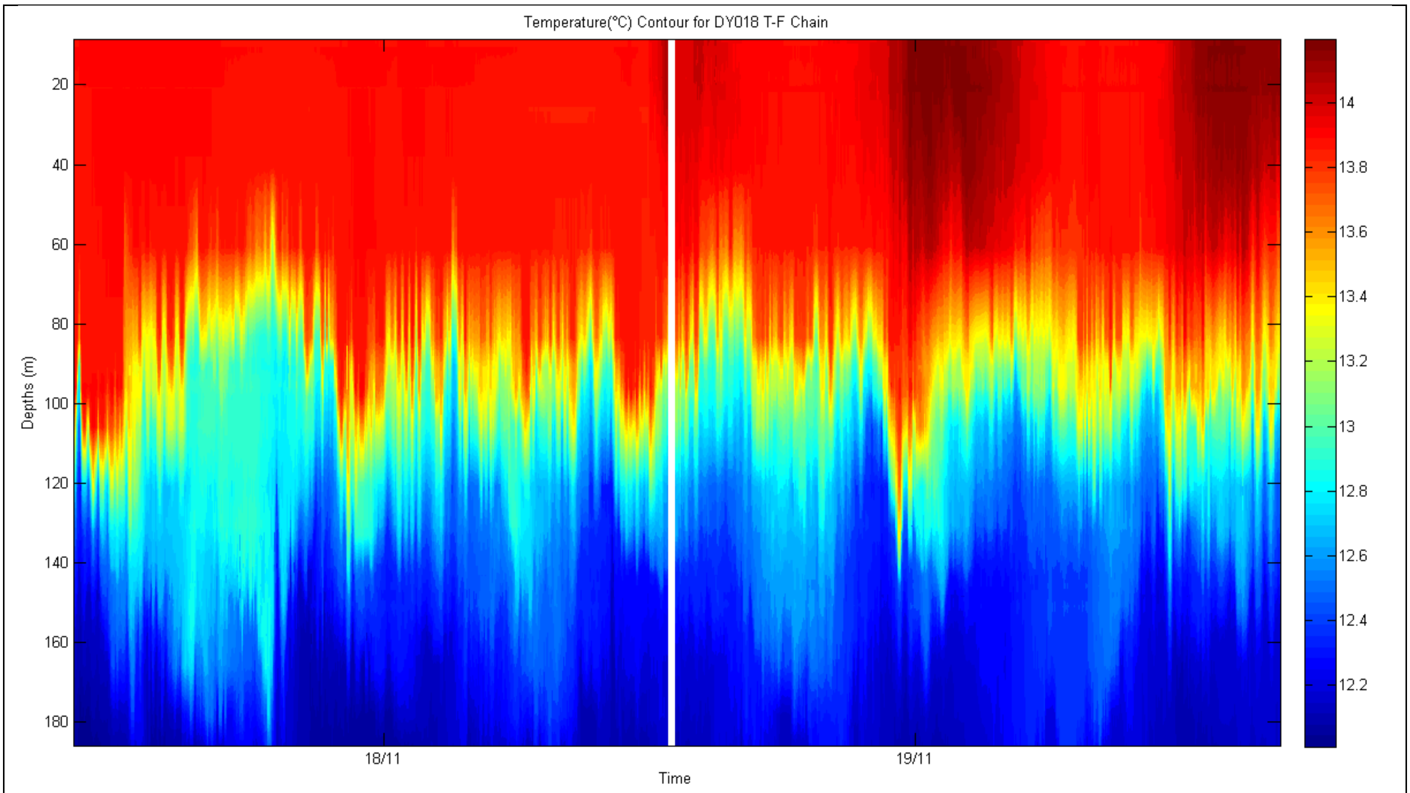

Figure 9: The contour of temperature data from the T-F chain with calibration applied to the data.

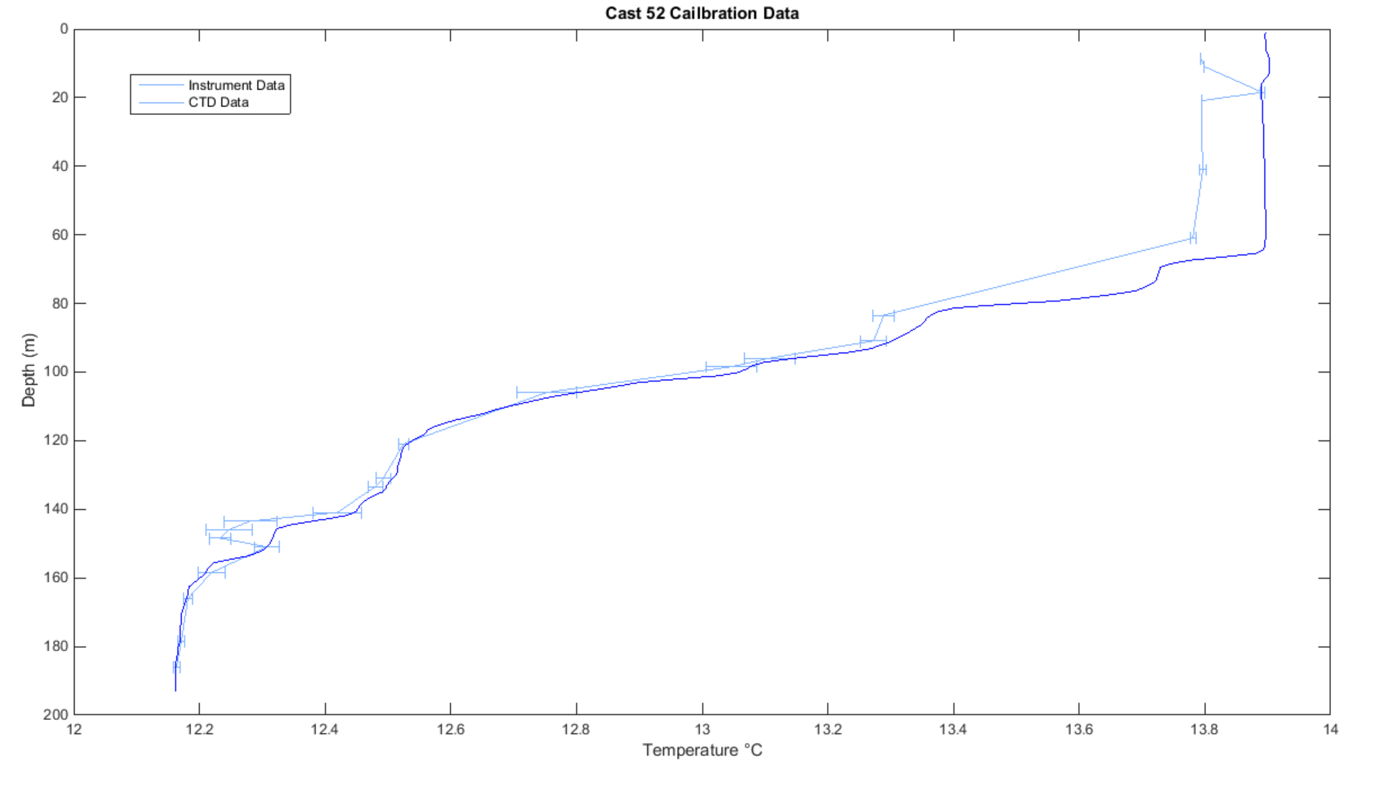

Figure 10: A profile of CTD cast 52 and the corresponding instrument readings organized as a profile, showing the difference between them before calibration. Error bars of 1 standard deviation are also included.

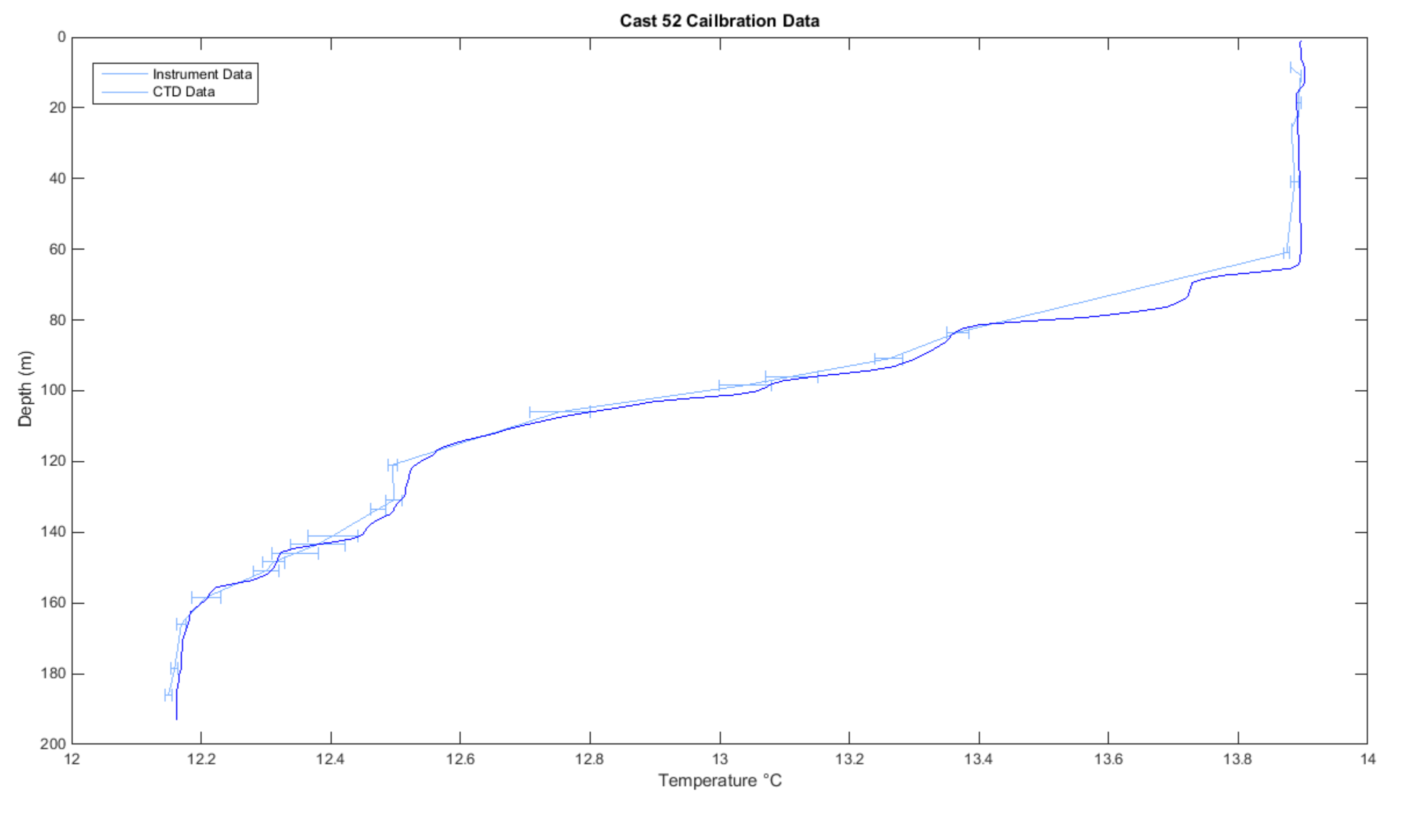

Figure 11: A profile of CTD cast 52 and the corresponding instruments readings organized as a profile, showing the difference between them after calibration. Error bars of 1 standard deviation are also included.

Chlorophyll Calibration and Quenching

As can be seen in figure 12 chlorophyll measurements by instruments and CTD casts were often very different. Potentially these problems could be linked to quenching. Ship underway data referring to photosynthetically active radiation (PAR) could help to identify if quenching had occurred which could explain the difficulty with chlorophyll. Quenching would be visible if there was a chlorophyll minimum with a corresponding PAR maximum. Though not clearly visible in figure 15 there are some periods where an increase in PAR is accompanied by a dip in chlorophyll which could be characteristic of quenching. To account for this only CTDs with low PAR, namely 47 and 48, where used to calibrate. The recorded PAR values for the CTD casts are represented in figure 14. Titanium frame casts lacked a PAR sensor so could not be used. This should mean that casts possibly affected by quenching will not skew the data and the results can be seen in figure 13. Figure 16 shows the same information as figure 15 but after calibration.

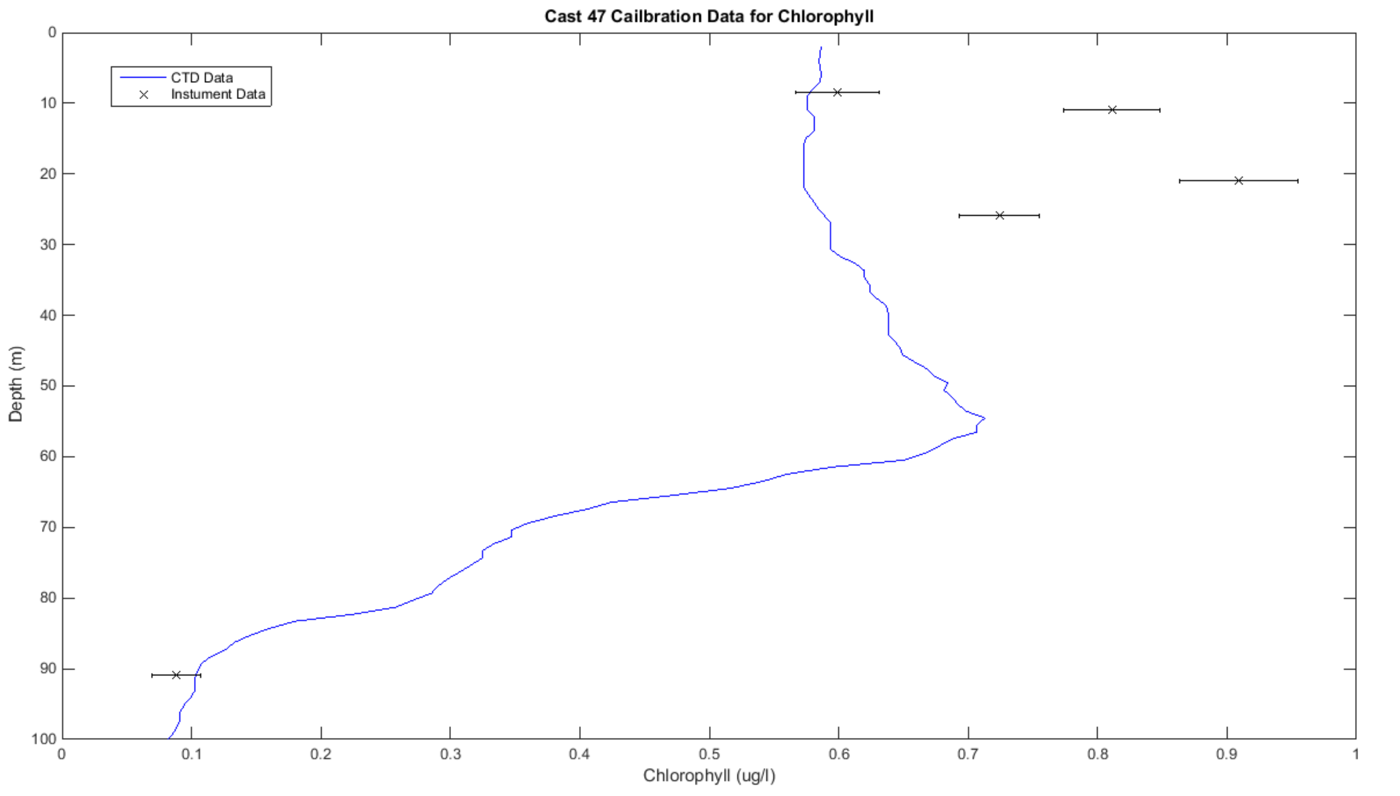

Figure 12: A profile of measured chlorophyll of cast 47 and the instrument measurements at the time of the cast before calibration with the low PAR casts. Error bars of 1 standard deviation are also included.

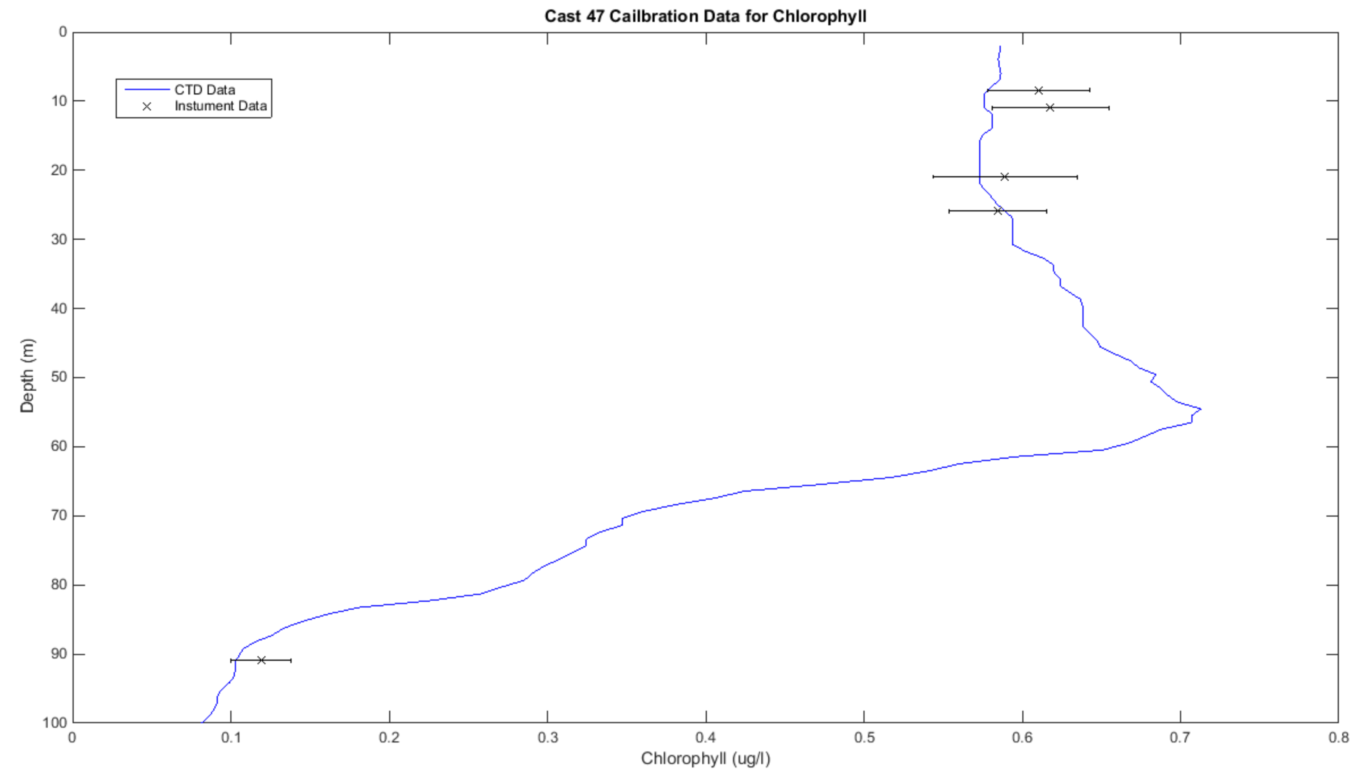

Figure 13: A profile of measured chlorophyll of cast 47 and the instrument measurements at the time of the cast after calibration with the low PAR casts. Error bars of 1 standard deviation are also included.

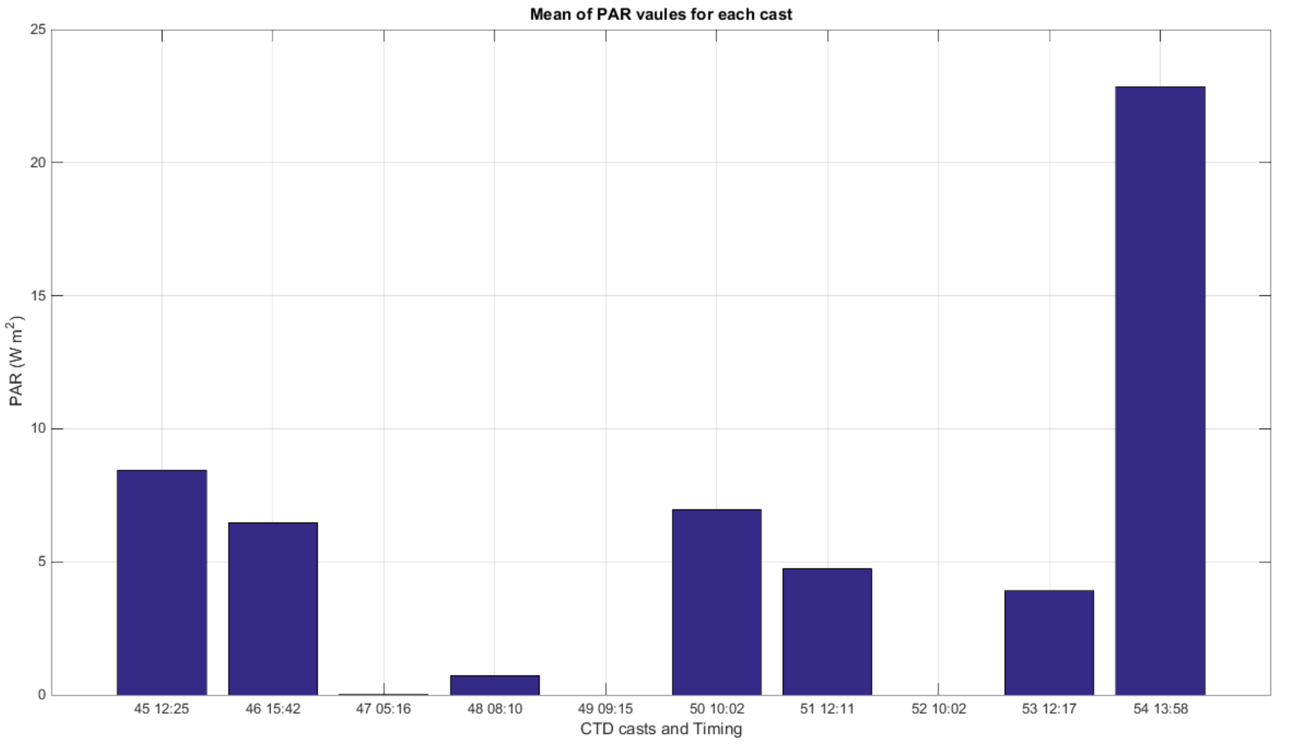

Figure 14: A graph showing the mean PAR of each cast. It should be noted that casts might not cover the same depths such as cast 50 which began recording around 10 meters deep. However it still highlights that casts 47 and 48 have the lowest PAR recordings. Casts 49 and 52 were done with the titanium CTD frame that lacked a PAR sensor.

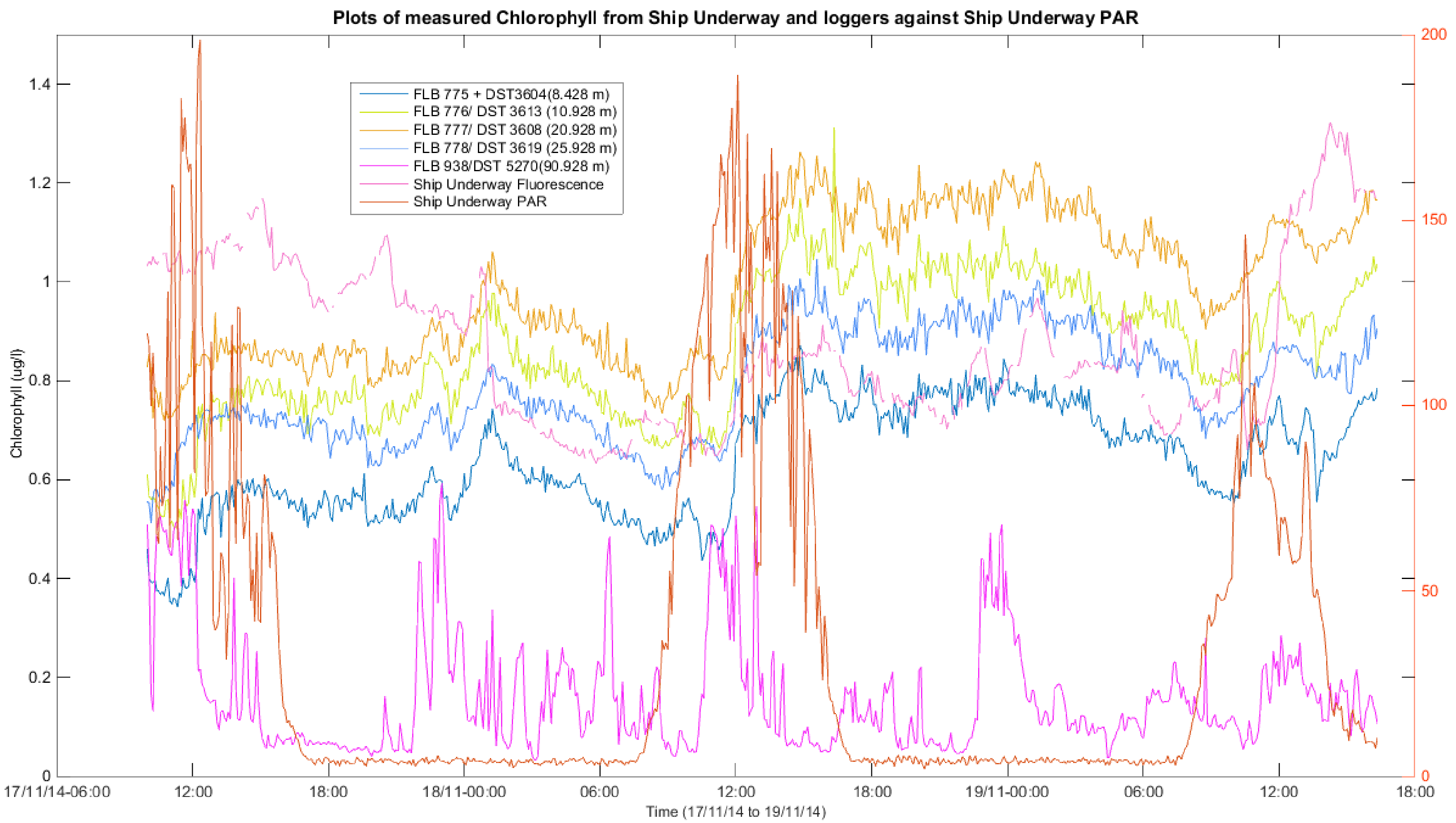

Figure 15: A graph showing the ship underway PAR data against the uncalibrated chlorophyll measurements from the FLB instruments and the ship underway chlorophyll measurements to see if quenching has occurred during data collection.

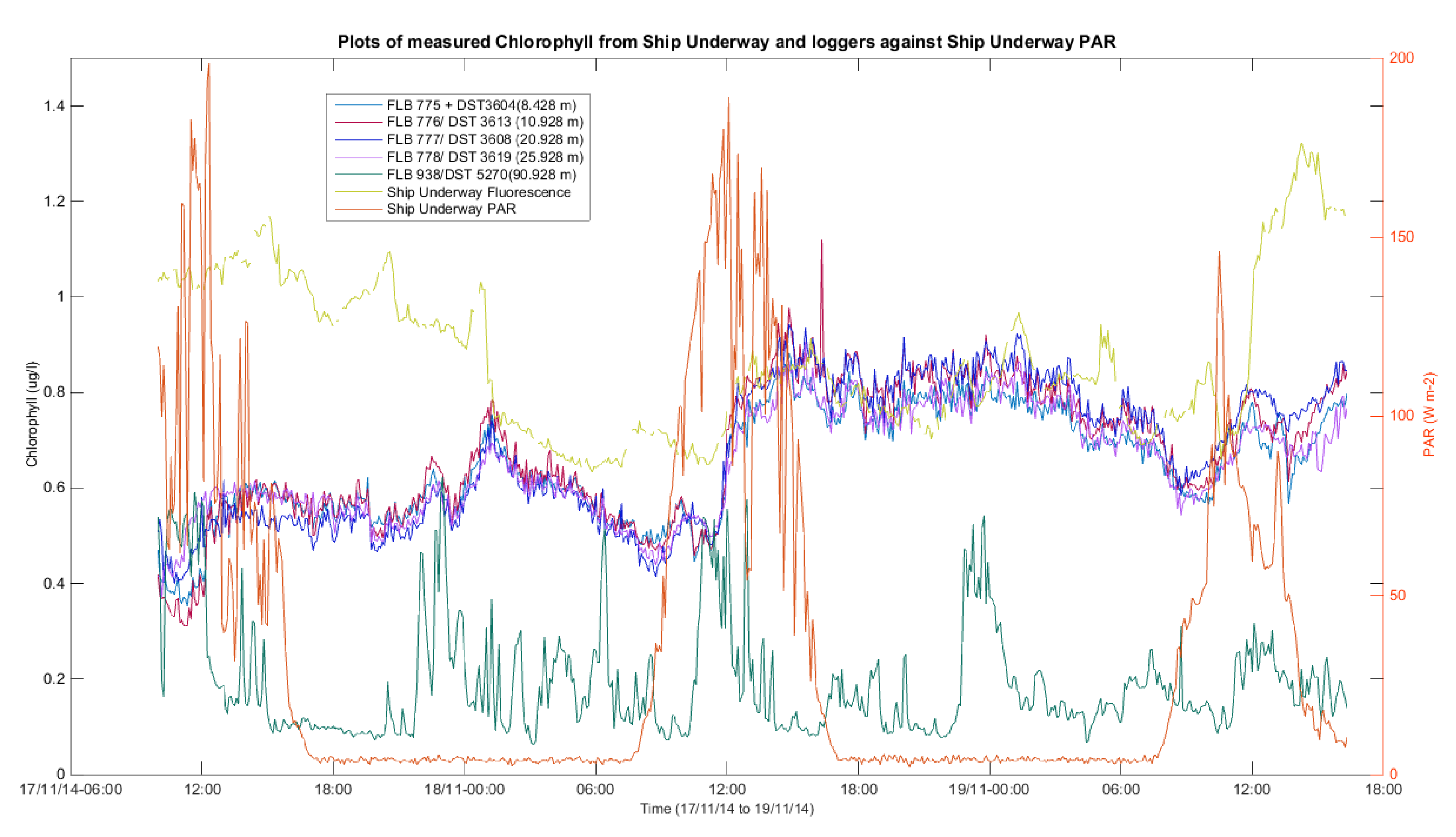

Figure 16: A graph showing the ship underway PAR data against the calibrated chlorophyll measurements from the FLB instruments and the ship underway chlorophyll measurements

Other Calibrations

The other measured variables of the water, conductivity and salinity, measured by the Microcat instruments were similarly calibrated via the measured difference between CTD cast measurements and the corresponding instrument measurements.

Final plot and Supplied Data

Figure 17 shows the completed temperature contour plot for the T-F chain. This is done using data supplied in the file 'DY018_TF_Chain_data.mat'. The 'BenthicDepth' vector contains the seabed depth given by the shipboard echo sounder. The other depth vectors 'ChlorophyllDepth' and 'TemperatureDepth' give vectors for the depths of the instruments that measured the corresponding values in depth order. The data matrices 'ChlorophyllData' and 'TemperatureData' give a 2D matrix with the instrument data for the defined experiment duration in depth order. The 'Date' structure contains three different version of the processed experiment period between 10:00 17/11/14 to 16:26:30 19/11/14. These are 'Date.JulianDay' which contains the julian date of the year, 'Date.DateNumber' which contains Matlab datenumber format and 'Date.DateChar' which contains text format date. The instrument Matlab structures have also been included.

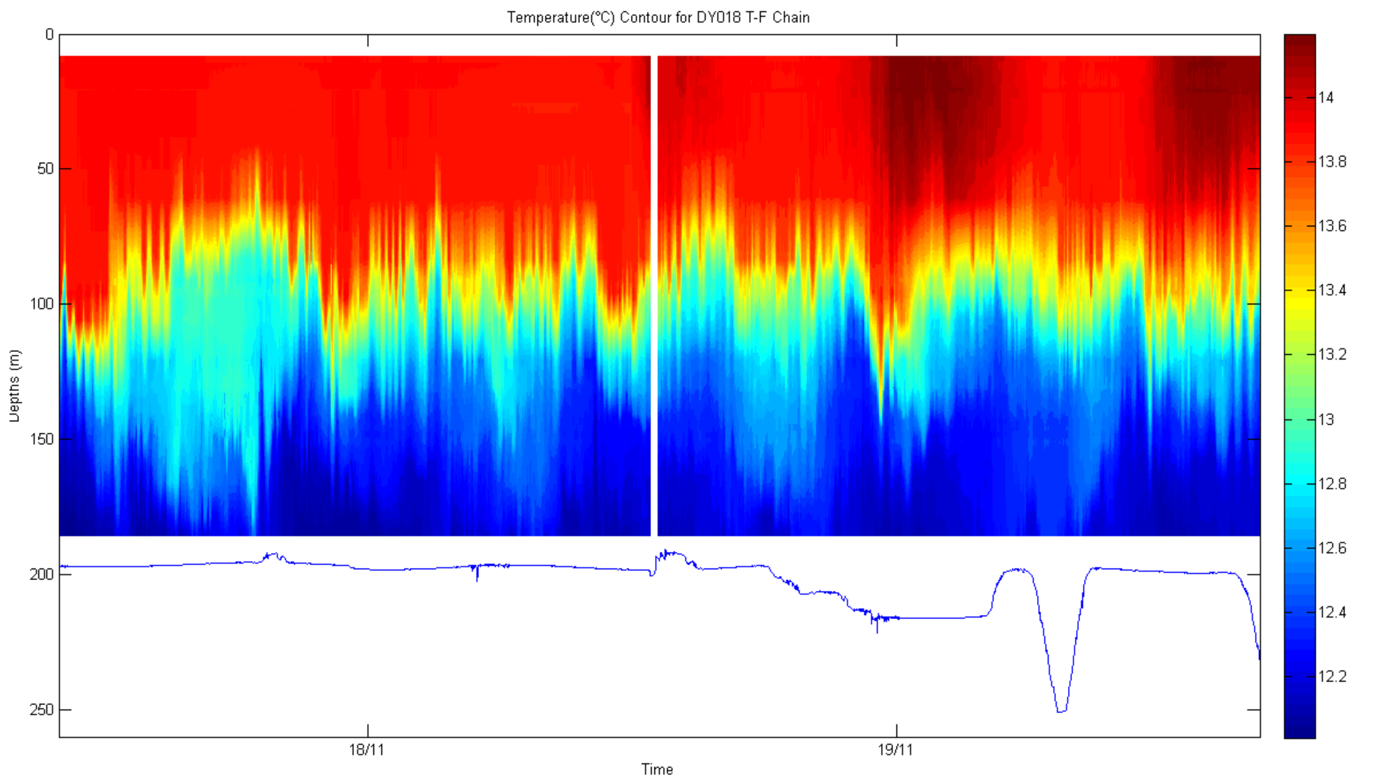

Figure 17: The contour of temperature against depth and time of the T-F chain temperature data also plotted with sea bed depth.

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