RRS Discovery Cruise 361

7 February – 19 March 2011

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1 Narrative cruise overview D361

The *RRS Discovery* departed on cruise D361 from Tenerife, Canary Islands, Spain, at 1522 h on Monday 7th February 2011 and docked in Tenerife, UK, after a period of 41 days at 1400 h on Saturday 19th March. Cruise 361 was the sole cruise of the project: Physical and chemical forcing of diazotrophy in the (sub)-tropical Atlantic Ocean/GEOTRACES project. The main aim of the cruise was to assess the supplies of Fe and P to nitrogen fixers in the tropical Atlantic and determine their uptake rates, and undertake deep trace metal clean CTDs as part of the International GEOTRACES programme; cruise participants are listed in Table 1.1. The cruise was severely curtailed due to propulsion problems with the vessel, we lost a total of 11 days as a consequence. In addition, problems with the winch and CTD systems resulted in cancelled and reduced depth trace metal clean CTD casts. Upon sailing from Tenerife on February 7, we returned to port on February 9 for repairs. We sailed again on February 11, and undertook engine trials and instrument deployment tests in Tenerife Bay until February 18. We then sailed to our first proper station on the Senegalese slope. The reduced cruise time resulted in a reduction in the total cruise track from 6600 nm to 5100 nm. Nevertheless, we still managed to sample at 21 stations, obtain a wealth of biological samples and undertake deep trace metal clean CTDs at ca. 19 stations.

During the cruise all scientific work was recorded on Greenwich Mean Time (GMT) and ship time was altered from GMT to GMT-1 h on February 20. The cruise track during D361 is shown in Figure 1.1, covering a distance of 5100 nautical miles. A total of 21 stations were occupied from 16th February – 15th March 2011, with a test station in Tenerife Bay and 20 scientific sampling stations (Table 1.2). After an initial long passage, intensive over the side scientific work commenced on 21st February, with one major station being occupied daily from 21st February –27th February on the east-west transect between the Senegalese coast and ca. 27°W, along 12°35 to 12°N. Once commenced at 2100 h on 18th February underway sampling from a trace metal clean tow fish was maintained while off station at two hourly intervals for all parameters. Dates, times and locations of stations together with detailed information of scientific activities on station are provided in the CTD report and the narrative cruise diary (Appendix A). Dates, times and positions of underway samples are also provided in Appendix B.

A five day transect to the most southerly station of the cruise (07º13 S 25º0 W), allowed us to reach the South Atlantic Gyre. From that station, daily stations were occupied up to ca. 19°N, 28°W.

In general, stations were commenced in the early morning (typically at 0500 h; ship's time) and consisted of sampling from the tow fish for biological experiments, a number of CTD casts, using both a stainless steel and a titanium rosette frame, zooplankton net hauls, vertical profiler deployments, marine snow catcher

deployments, and every 3 days Stand Alone Pump Systems (SAPS) deployments. The order of events on station and exact timings of deployments were adjusted depending on scientific staff work schedules and in order to keep bioassay tow fish sampling, zooplankton net hauls and biological stainless steel CTD casts during the hours of darkness where possible. We have had vertical profiler operations aborted due to instrument failure, and some trace metal clean rosette deployments were repeated due to non-firing of bottles. No cruise time was lost due to adverse weather conditions.

A trace metal clean tow fish was also deployed throughout the cruise commencing at the start of the cruise with samples being collected every 2 hours whilst off station from February 8, 0800 h (only three samples until engine problems occurred), and restarted following the engine problems on February 18, 1600 h to 2100 h on 15th March (Figure 1.2). Water from the epoxy coated fish was pumped directly into a clean chemistry filtering container and the biology container, using a Teflon pump system through acid washed PVC tubing. The system performed well, with one recovery to undertake repairs to the hose. A wide variety of samples were collected from both the underway supply and during CTD stations (see scientific reports and Appendix B and C). Although some parameters were measured at sea, the majority of samples will be returned to shore laboratories for analysis.

The trace metal clean CTD work was conducted using a Ti rosette frame attached to a plasma rope. The internally Teflon coated trace metal clean OTE bottles were closed at a pre-set depths using a General Oceanics programmable bottle triggering system. This approach worked well, following familiarisation with the system.

At sea, dissolved iron and aluminium were determined using flow-injection approaches in samples from all trace metal clean casts. Samples were also analysed on-board for oxygen, salts, and total alkalinity and dissolved inorganic carbon (using a Vindta 3C). A full range of GEOTRACES samples were collected from the casts, to be analysed by researchers directly involved in the cruise, and other International GEOTRACES researchers (Appendix C). Full details are provided in cruise reports.

Experimental work was also performed on the cruise to measure nitrogen fixation rates, and uptake of Fe and P radiotracers by the microbial community and the diazotrophs *Trichodesmium* in particular. In addition samples were collected for measurement of the alkaline phosphatise activity.

On February 21 we sailed to the Senegalese shelf edge and commenced sampling on the east-west section (ca. 12°N) on a transect with the N Atlantic oxygen minimum zone at depths between ca. 150-800 m. The dissolved Fe and Al were enhanced in surface waters on this transect, due to atmospheric dust inputs (away from the immediate influence of the shelf). The N and P concentrations were low in

the surface waters. The transect provided stations with a high abundance of nitrogen fixers. The most southerly visited station, provided crucial samples and data to our cruise programme, as it had very low dissolved Fe and N concentrations, with relatively enhanced P concentrations. The abundance of *Trichodesmium* was low at this station. The transect towards the north, with daily stations, observed enhanced diazotrophs abundance, regions with enhanced surface water Fe and Al. The cruise re-visited the CLIVAR A16N 12°N, 29°W station, which also served as the station which was furthest west on our east-west transect. The last station was undertaken at 15th March (19º10 N 28º07 W), and the underway sampling stopped at 2100 h on that day.

No incidents occurred on the cruise.

We ran a scientific blog on the NOC website for the cruise.

A more detailed description of event and activities is provided within the narrative diary provided in Appendix A.

We thank NERC for funding our research programme and providing us with ship time. We thank the crew and officers of the RRS *Discovery* for their excellent assistance at sea.

Table 1.1 Cruise participants

Name	Institution
Eric Achterberg	University of Southampton
Anouska Bailey	University of Liverpool
Jeff Benson	National Marine Facility (NMF)
Martin Bridger	NMF
Rosie Chance	University of East Anglia
Allan Davies	NMF
Alex Forryan	University of Southampton
Toby Großkopf	IFM-GEOMAR
David Honey	University of Southampton
Jessy Klar	University of Southampton
Jon Lauderdale	University of Southampton
François-Eric Legiret	University of Southampton
Maeve Lohan	University of Plymouth
Claire Mahaffey	University of Liverpool
Angie Milne	University of Plymouth
Mark Moore	University of Southampton
Felix Morales	University of Canary Island/Tenerife
Katsia Pabortsava	National Oceanography Centre, University of Southampton
Richie Phipps	NMF
Sarah Reynolds	University of Liverpool
Elliot Roberts	University of Southampton
Elizabeth Sargent	National Oceanography Centre, University of Southampton
Christian Schlosser	University of Southampton
Joe Snow	University of Southampton
Eithne Tynan	University of Southampton
Bronwyn Wake	University of Southampton
Malcolm Woodward	Plymouth Marine Laboratory

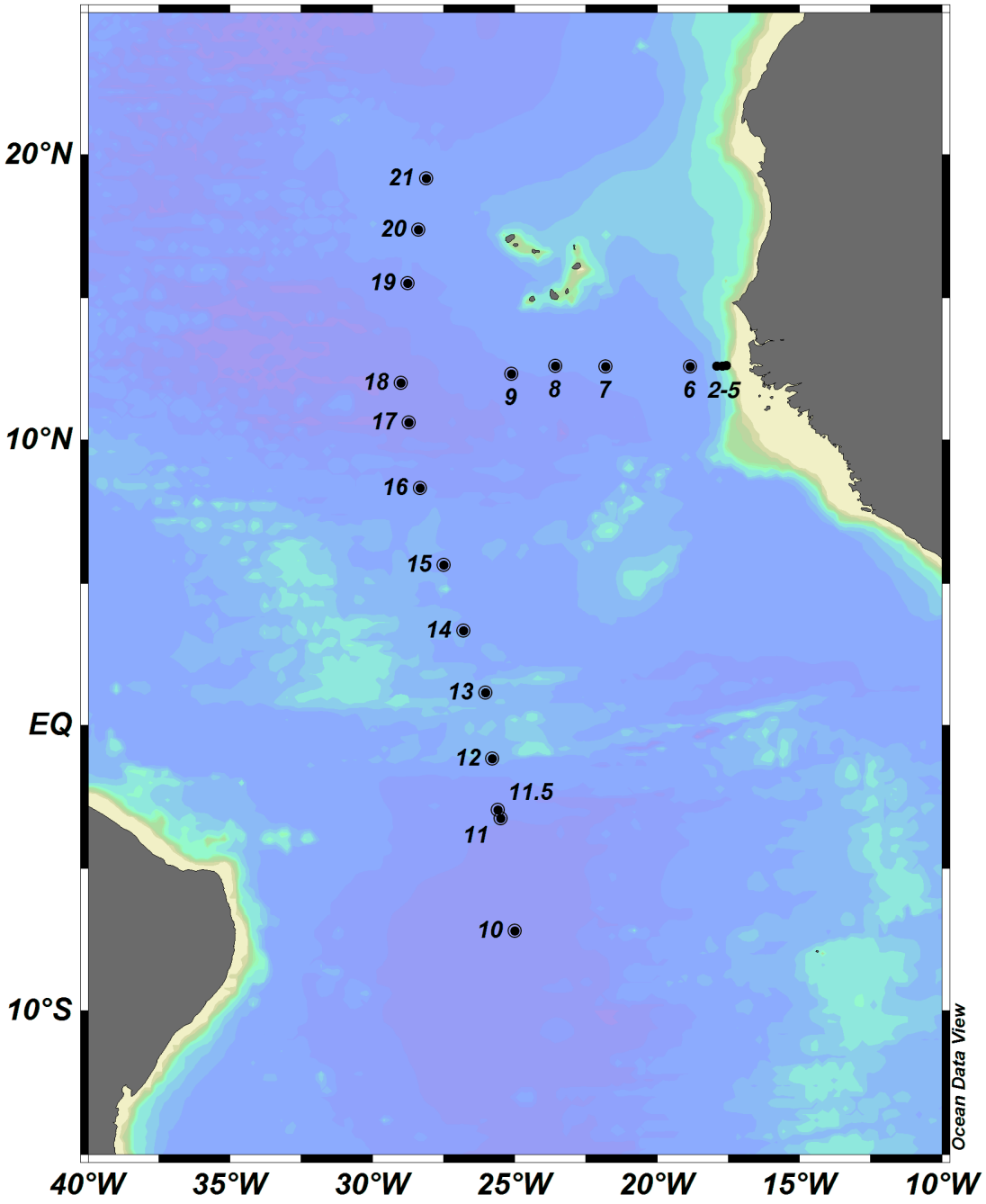


Figure 1.1 Station map for cruise D361, with station numbers indicated next to station position.

Table 1.2 Station list

Station	Julian day	Latitude	Longitude
2	52	12°35 N	17°55 W
3	53	12°35 N	17°43 W
4	53	12°37 N	17°34 W
5	53	12°36 N	17°34 W
6	54	12°34 N	18°50 W
7	55	12°34 N	21°49 W
8	56	12°35 N	23°34 W
9	57	12°18 N	25°07 W
10	62	07°13 S	25°00 W
11	64	03°15 S	25°30 W
11.5	64	02°57 S	25°36 W
12	65	01°10 S	25°47 W
13	66	01°09 N	26°02 W
14	67	03°19 N	26°48 W
15	68	05°39 N	27°30 W
16	69	08°20 N	28°20 W
17	70	10°37 N	28°43 W
18	70	12°00 N	29°00 W
19	72	15°30 N	28°46 W
20	73	17°23 N	28°23 W
21	74	19°10 N	28°07 W

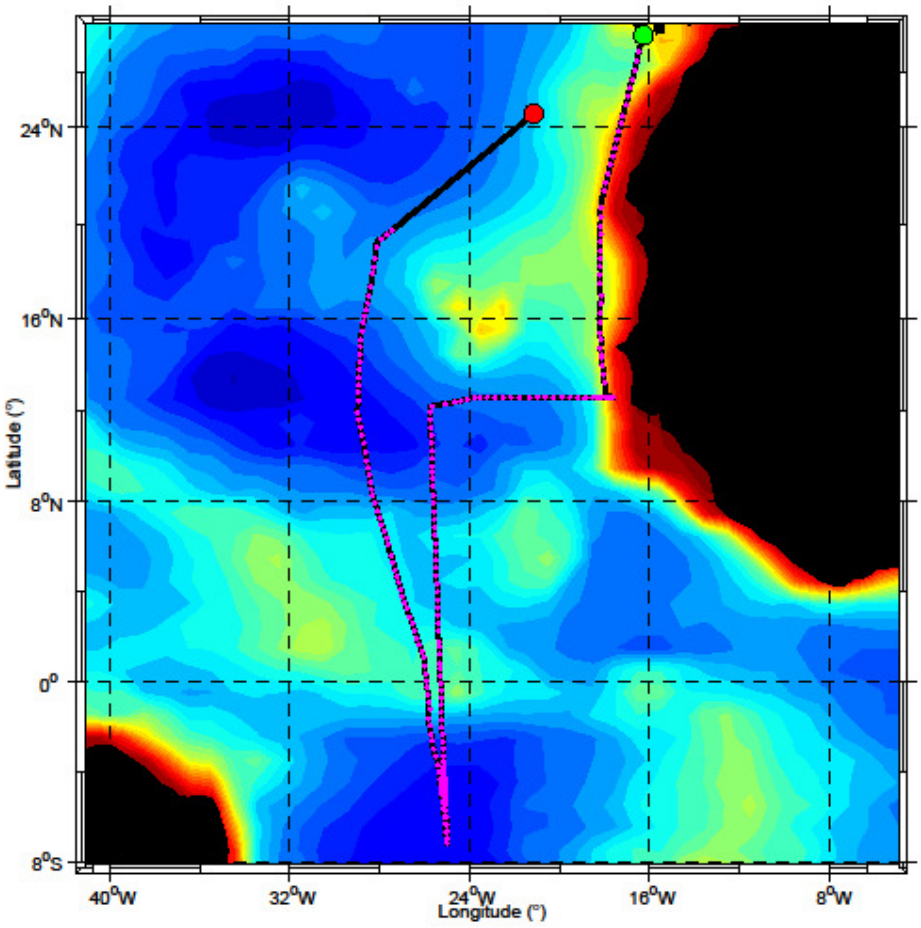


Figure 1.2 Cruise track and fish sampling locations

2 Lowered Acoustic Doppler Current Profiler (LADCP)

Alex Forryan and Jonathan Lauderdale

2.1 Instrument Setup

One RDI 300kHz Workhorse LADCP unit was fitted to each CTD frame used on cruise D361. Both LADCP were configured to have a standard 16 x 10 m bins, one water track and one bottom track ping in a one second ensemble and a 5 m blank at the surface. The instruments were both mounted in a downward-looking orientation on the CTD frame.

2.2 Data Processing

The data collected by the instrument were downloaded after each cast and stored as RDI binary files and corresponding text files.

The data were then processed using two different tools. Primarily a software package from the University of Hawaii (UH) was used to calculate absolute current velocities using the shear. This also provides information about the heading and tilt of the CTD package. The second piece of software originates from Lamont-Doherty Earth Observatory (LDEO). It calculates velocities using an inverse method and was also used for obtaining bottom track profiles and to monitor the beams of the instrument. Data were collected in beam coordinates, as this is the recommended method of collection. The sequence of the routine processing for the LADCP data is outlined below.

2.2.1 UH Processing

The initial stages of processing allow the user to examine the quality of the data and to calculate relative velocity profiles in the absence of CTD data.

After navigating to the directory ~/cruise/data/ladcp/uh, source LADall sets up the paths required for the processing. The raw files downloaded from the LADCP units were copied from the network and symbolic links were created to the required filenames. The software requires a filename of dnnn_02.000, where nnn is the station number. The suffix 02 refers to the LADCP being down-looking.

The processing steps were then as follows :

cd proc; perl –S scan.prl nnn_02 : to scan the raw data and create a station

specific directory in the proc/casts directory. Data printed to screen should be checked to ensure the details of the cast (i.e. depth, downcast/upcast times) agree approximately with the CTD logsheet.
matlab; m_setup; putpos(nnn,02) gets position of the cast by accessing the TECHSAS data streams; *magvarsm(nnn.02)* applies the magnetic correction to the compass on the LADCP.
perl –S load.prl nnn_02 loads the raw data, applying magnetic compass corrections from *magvar.tab* to start processing. It is very important that this step is only carried out once. If it needs to be repeated the database files (~/proc/casts/dnnn_02/scdb) must be deleted first.
perl –S domerge.prl –c0 nnn_02 to merge the velocity shear profiles from individual pings into full upcast and downcast profiles. The option –c0 refers to the fact that CTD data has not yet been included.
cd Rnav; matlab; make_sm makes a smoothed navigation file for the cast.
cd proc; matlab; plist = nnn.02; do_abs; calculates the relative velocity profiles. Check that these plots look sensible, i.e. reasonable agreement between downcast and upcast and that the vertical velocity changes sign between downcast and upcast (it may be necessary to rescale some of the plots).

Once the CTD data has been processed this can be incorporated into the LADCP processing to make more accurate estimates of depth and sound velocity and to obtain a final absolute velocity profile.The inclusion of CTD data requires an ASCII file containing 1Hz CTD data for the station created in Matlab. If the CTD file is present:

cd proc; cd Rctd and open a Matlab session. Run *m_setup* and the script *mk_ctdfile(nnn).*
cd proc/Pctd; ctd_in(nnn,02) will read the 1Hz CTD data in. *plist=nnn.02; fd* aligns the LADCP and CTD data sets in time.
cd proc; perl –S add_ctd.prl nnn_02 adds the CTD data to the *.blk LADCP files in the scdb directory.
perl –S domerge.prl -c1 nnn_02 merges the single pings into corrected shear profiles. The -c1 option now states that we have included CTD data.
matlab; plist=nnn.02; do_abs; calculates the velocities again with the merged pings.

2.2.2 LDEO Processing

As with the UH processing the LDEO processing can first be carried out without the CTD data to monitor the results and performance of the beams.

cd ladcp; cd ldeo/di1102; and start a Matlab session.
Type *sp* and when prompted enter the station number and the run letter ('noctd' for no CTD data and 'wctd' when CTD data are included).
Next type *lp* and this will run the processing scripts.

The steps above should then be repeated to include the CTD data after it has been processed. The format of the CTD data required is the same for both the LDEO and UH processing paths and when CTD data are available the processing will automatically use it. The LDEO processing extracts the useful bottom track velocities. These velocities were not used to constrain the full velocity profile but existed as a method of verifying the reality of the near bottom velocities calculated by the standard LDEO inverse calculation.

2.3 Mstar Formatting

The data from both processing routes were read into Mstar files. Three Mstar files were created for each station: one for the UH profile, one for the full LDEO profile and one for the LDEO bottom track velocities. An example of a vertical profile from the LADCP on the titanium frame is shown in figure 2.1.

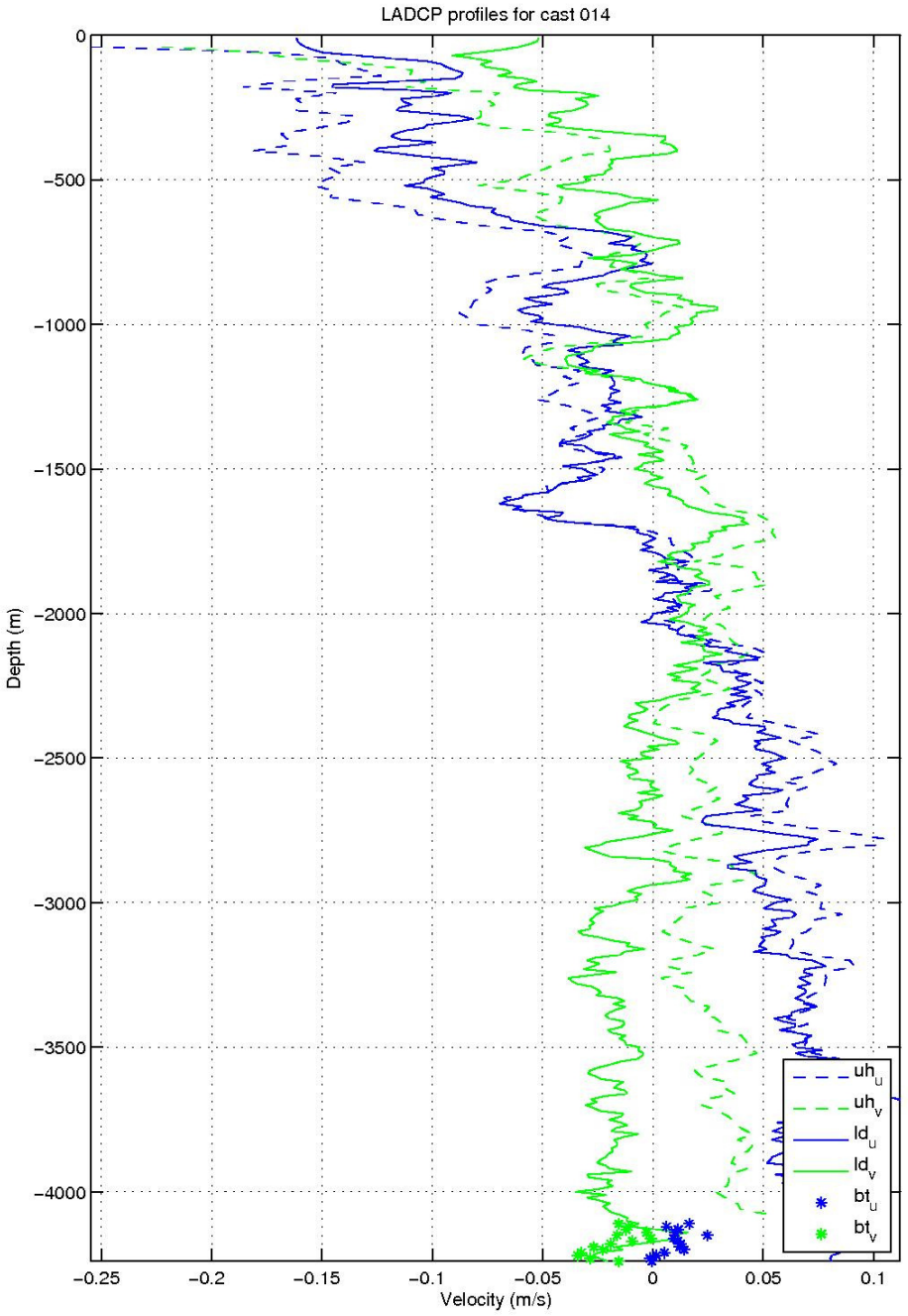


Figure 2.1: LADCP profile from the titanium frame LADCP. Estimates of velocity from University of Hawaii (UH) and Lamont-Doherty (LD) software are both shown. Bottom track data (bt) is also marked.

3 ISW Turbulence Measurements

Alex Forryan and Jonathan Lauderdale

3.1 Summary of turbulence stations on D361

During the RSS Discovery cruise D361 the microstructure profiler MSS90L, serial number 35, was used for microstructure turbulence measurements in the surface ocean. The ISW profiler is an instrument for simultaneous microstructure and precision measurements of physical parameters in marine and limnic waters, it is designed for vertical profiling within the upper 300 m.

From experience analysing turbulence probe data from D306 cruise to the PAP site and D321 cruise to the Iceland Basin it was decided that 10 profiles would be taken per station. This is because the above analysis revealed the turbulent diffusivities to be log-normally distributed (if not worse) with the causative mixing being intermittent.

The ISW profiler was deployed for a two hour period usually at the end of each station. There are only two issues with deployment (1) cable should be fed out sufficiently quickly to ensure that at least two loops are always visible in the top few meters of water (2) the cable has a tendency to catch occasionally, possibly because of salt crystals forming on it. The tendency of the cable to catch during deployment necessitates keeping a 'tickling stick' between spooling out cable (but not touching the cable as there is an outside chance this can induce vibrations that would be recorded as turbulence) and the drum to quickly throw off any loops that catch.

Following the recent rebuild by NMFD the profiler winch and control box, which have caused problems on previous cruises, performed flawlessly. However, there were problems during the cruise with both the PC used for recording the data and with the turbulence profiler itself.

While recording data during the initial casts to check profiler sinking velocity it was noticed that the apparent sinking speed of the profiler was occasionally increasing by up to 0.3 ms^{-1} for a few seconds during a profile. These events coincided with the computer operator entering data in the logging spreadsheet. During recording the blue interface box buffers data from the profiler and signals the PC to read from this buffer when the buffer is half full. The interface box continues to write to the buffer and when the buffer is full the oldest data are overwritten. If this occurs before the PC has read the buffer data are lost and there is no indication of any error from the recording software. On processing the loss of data is noticeable as sudden increases in pressure between samples which is interpreted as an increase in sinking speed. The performance of the PC is such that carrying out any other activity on the PC while recording can result in data loss. On all subsequent casts logging was carried out on paper and after the deployment was finished entered in the profiler spreadsheet log.

Processing a single profile of approximately 250 m depth on the profiler PC takes up to three hours. When the profiler is deployed every day this makes it difficult to analyse the previous days casts in time for the technicians to rectify any problems with the shear sensors before the next deployment. The time taken to process the cast data contributed to the delay in recognising that the initial problems with shear sensor 2 were not due to the shear probe.

Initially the turbulence probe worked well until station 6 when shear probe 2 (SHE2) developed a fault. While recording a cast at the start of station 6 the output from SHE2 displayed by the sst_sda recording software (the raw voltage from the shear probe) was observed to fixed at zero indicating a maximum output voltage of -3V. The output voltage from the ISW profiler is between –3 to 3V which is displayed by the sst_sda recording software as a number between 0 and 65536 where 32768 indicates zero volts. SHE2 was replaced following recovery of the profiler with a new type PNS06 shear sensor. Examination of the data from SHE2 recorded during the next two stations indicated that although SHE2 appeared to be working the voltage output from SHE2 was not high enough. This was initially attributed to the new shear sensor. Following station 9 SHE2 was again replaced but this time with a type PNS03 shear sensor. However, changing the shear sensor had no noticeable effect of the recorded voltages. The profiler continued to be deployed with only one working shear sensor until station 13 when shear sensor 1 (SHE1) began to display readings varying between zero and 65536 on the sst_sda software. An internal examination of the profiler found that the component at the base of the shear probe stalk for SHE1 was badly corroded. This component was replaced prior to station 14. Both shear sensors now appeared to be working. However, the readings displayed on the sst_sda software indicated that the voltages from both shear sensors were too low (displayed values on the sst_sda software only varying by approximately +/- 5 around 32768). This was later confirmed by examination of the recorded data. After two further failed attempts to get SHE1 working (stations 15 and 16) it was decided to continue profiling without either microstructure shear sensor working. Consequently for all subsequent stations (17 onwards) there is no microctructure shear data. A summary of all deployments if the ISW profiler is given below (table 2.1). Example vertical profiles of turbulent diffusivity, recorded while the shear probes were working, are shown in figure 3.1.

Table 3.1: Summary of ISW profiler deployments on cruise D361

Stn. No.	Date	Jday	Lat. (deg:min)	Lon. (deg:min)	Start time (GMT)	Filename (mrd)	Comments
1	16/02/11	47					
			28 18.37 N	16 09.815 W	12:31	d3610001	sinks at 0.6ms^{-1}
			28 18.467 N	16 09.590 W	12:45	d3610002	
			28 18.305 N	16 09.492 W	12:52	d3610003	
3	22/02/11	53					
			12 36.745 N	17 43.051 W	13:24	d3610004	
			12 36.052 N	17 43.271 W	13:33	d3610005	
			12 37.052 N	17 43.352 W	13:43	d3610006	
			12 37.207 N	17 43.409 W	13:52	d3610007	
			12 37.366 N	17 43.389 W	14:02	d3610008	
			12 37.517 N	17 43.424 W	14:15	d3610009	
			12 37.995 N	17 43.478 W	14:24	d3610010	
			12 37.826 N	17 43.529 W	14:34	d3610011	
			12 37.973 N	17 43.589 W	14:43	d3610012	Slight reverse ~ 100 m
			12 38.197 N	17 43.660 W	14:56	d3610013	
4	22/02/11	53					
			12 35.64 N	17 34.049 W	17:56	d3610014	parked on seabed (75m)
			12 35.847 N	17 34.150 W	18:07	d3610015	
			12 35.891 N	17 34.168 W	18:10	d3610016	
			12 35.990 N	17 34.227 W	18:15	d3610017	
			12 36.052 N	17 34.272 W	18:17	d3610018	Position uncertain
			12 36.059 N	17 34.273 W	18:19	d3610019	
			12 36.086 N	17 34.317 W	18:23	d3610020	
			12 36.193 N	17 34.376 W	18:27	d3610021	
			12 36.237 N	17 34.397 W	18:30	d3610022	
			12 36.275 N	17 34.407 W	18:34	d3610023	
6	23/02/11	54					
			12 32.723 N	18 50.347 W	11:03	d3610024	
			12 32.718 N	18 50.362 W	11:14	d3610025	
			12 32.731 N	18 50.363 W	11:25	d3610026	SHE2 reading zero
			12 32.741 N	18 50.371 W	11:38	d3610027	SHE2 reading zero
			12 32.742 N	18 50.353 W	11:48	d3610028	SHE2 reading zero
			12 32.749 N	18 50.342 W	11:59	d3610029	SHE2 reading zero
			12 32.752 N	18 50.338 W	12:10	d3610030	SHE2 reading zero
			12 32.774 N	18 50.339 W	12:22	d3610031	SHE2 reading zero

Stn. No.	Date	Jday	Lat. (deg:min)	Lon. (deg:min)	Start time (GMT)	Filename (mrd)	Comments
			12 32.826 N	18 50.340 W	12:33	d3610032	SHE2 reading zero
			12 32.849 N	18 50.337 W	12:46	d3610033	SHE2 reading zero
SHE 2 replaced with PNS06 shear probe No. 061							
7	24/02/11	55					
			12 34.004 N	21 49.093 W	17:06	d3610034	SHE2 not working
			12 34.135 N	21 49.051 W	17:16	d3610035	SHE2 not working
			12 34.228 N	21 48.983 W	17:29	d3610036	SHE2 not working
			12 34.412 N	21 48.909 W	17:40	d3610037	SHE2 not working
			12 34.537 N	21 48.821 W	17:52	d3610038	SHE2 not working
			12 34.616 N	21 48.712 W	18:03	d3610039	SHE2 not working
			12 34.699 N	21 48.632 W	18:15	d3610040	SHE2 not working
			12 34.709 N	21 48.538 W	18:25	d3610041	SHE2 not working; Slight rewind on cable
			12 34.750 N	21 48.445 W	18:36	d3610042	SHE2 not working
			12 34.845 N	21 48.482 W	18:47	d3610043	SHE2 not working
8	25/02/11	56					
			12 35.469 N	23 35.066 W	17:49	d3610044	SHE2 not working
			12 35.589 N	23 35.053 W	17:59	d3610045	SHE2 not working
			12 35.711 N	23 35.007 W	18:10	d3610046	SHE2 not working
			12 35.835 N	23 34.929 W	18:20	d3610047	SHE2 not working
			12 35.957 N	23 34.864 W	18:29	d3610048	SHE2 not working
			12 36.083 N	23 34.810 W	18:39	d3610049	SHE2 not working
			12 23.235 N	23 34.729 W	18:52	d3610050	SHE2 not working
			12 36.318 N	23 34.713 W	19:04	d3610051	SHE2 not working
			12 36.423 N	23 34.699 W	19:14	d3610052	SHE2 not working
			12 36.490 N	23 34.681 W	19:23	d3610053	SHE2 not working
9	26/02/11	57					
			12 18.063 N	25 10.392 W	12:47	d3610054	SHE2 not working
			12 18.106 N	25 10.421 W	12:55	d3610055	Slight rewind on cable; SHE2 not working
			12 18.142 N	25 10.479 W	13:05	d3610056	Slight rewind on cable; SHE2 not working
			12 18.189 N	25 10.547 W	13:15	d3610057	SHE2 not working
			12 18.209 N	25 10.602 W	13:23	d3610058	SHE2 not working
			12 18.257 N	25 10.690 W	13:33	d3610059	SHE2 not working
			12 18.326 N	25 10.770 W	13:43	d3610060	SHE2 not working
			12 18.363 N	25 10.826 W	13:52	d3610061	SHE2 not working
			12 18.390 N	25 10.864 W	14:02	d3610062	Slight rewind on cable;

Stn. No.	Date	Jday	Lat. (deg:min)	Lon. (deg:min)	Start time (GMT)	Filename (mrd)	Comments
							SHE2 not working
			12 18.432 N	25 10.931 W	14:11	d3610063	SHE2 not working
SHE 2 replaced with PNS03 shear probe No. 6091							
10	04/03/11	63					
			7 11.622 S	25 00.118 W	01:09	d3610064	SHE2 not working
			7 11.614 S	25 00.038 W	01:18	d3610065	SHE2 not working
			7 11.627 S	24 59.924 W	01:28	d3610066	bit of a snag going down; SHE2 not working
			7 11.642 S	24 59.816 W	01:38	d3610067	SHE2 not working
			7 11.669 S	24 59.648 W	01:48	d3610068	SHE2 not working
			7 11.674 S	24 59.523 W	02:02	d3610069	SHE2 not working
			7 11.663 S	24 59.427 W	02:14	d3610070	SHE2 not working
			7 11.658 S	24 59.331 W	02:24	d3610071	SHE2 not working
			7 11.635 S	24 59.219 W	02:35	d3610072	SHE2 not working
			7 11.627 S	24 59.097 W	02:46	d3610073	SHE2 not working
11	05/03/11	64					
			3 14.832 S	25 32.627 W	12:34	d3610074	USB connection flake; SHE2 not working
			3 14.841 S	25 32.738 W	12:49	d3610075	USB port changed; SHE2 not working
			3 14.851 S	25 32.790 W	13:00	d3610076	SHE2 not working
			3 14.872 S	25 32.839 W	13:11	d3610077	SHE2 not working
			3 14.880 S	25 32.881 W	13:21	d3610078	SHE2 not working
			13 14.88 S	25 32.927 W	13:33	d3610079	SHE2 not working
			3 14.874 S	25 32.970 W	13:44	d3610080	SHE2 not working
			3 14.864 S	25 33.021 W	13:55	d3610081	Supply voltage drop 14:00 for a few seconds; SHE2 not working
			3 14.837 S	25 33.064 W	14:06	d3610082	SHE2 not working
			3 14.818 S	25 33.112 W	14:17	d3610083	Rewind on cable ~ 100m; SHE2 not working
12	06/03/11	65					
			1 90.497 S	25 48.139 W	13:20	d3610084	SHE2 not working
			1 09.373 S	25 48.005 W	13:36	d3610085	SHE2 not working
			1 90.247 S	25 47.861 W	13:50	d3610086	SHE2 not working
			1 09.150 S	25 47.741 W	14:01	d3610087	SHE2 not working
			1 90.087 S	25 47.657 W	14:12	d3610088	SHE2 not working

Stn. No.	Date	Jday	Lat. (deg:min)	Lon. (deg:min)	Start time (GMT)	Filename (mrd)	Comments
			1 09.029 S	25 47.585 W	14:24	d3610089	SHE2 not working
			1 08.968 S	25 47.502 W	14:33	d3610090	SHE2 not working
			1 08.879 S	25 47.430 W	14:46	d3610091	SHE2 not working
			1 08.803 S	25 47.361 W	14:56	d3610092	SHE2 not working
			1 08.714 S	25 47.281 W	15:06	d3610093	SHE2 not working
13	07/03/11	66					
			1 10.933 N	26 04.053 W	14:50	d3610094	
Station aborted due to SHE1 failure							
14	08/03/11	67					
			3 22.000 N	26 50.308 W	12:11	d3610095	Neither SHE1 or SHE2 working
			3 22.159 N	26 50.353 W	12:20	d3610096	Neither SHE1 or SHE2 working
			3 22.362 N	26 50.393 W	12:30	d3610097	Neither SHE1 or SHE2 working
			3 22.536 N	26 50.471 W	12:41	d3610098	Neither SHE1 or SHE2 working
			3 22.741 N	26 50.567 W	12:53	d3610099	Neither SHE1 or SHE2 working
			3 22.959 N	26 50.671 W	13:07	d3610100	Neither SHE1 or SHE2 working
			3 23.158 N	26 50.786 W	13:19	d3610101	Neither SHE1 or SHE2 working
			3 23.339 N	26 50.872 W	13:30	d3610102	Neither SHE1 or SHE2 working
			3 23.592 N	26 50.949 W	13:42	d3610103	Neither SHE1 or SHE2 working
			3 23.868 N	26 50.988 W	13:54	d3610104	Neither SHE1 or SHE2 working
15	09/03/11	68					
			5 40.783 N	27 31.642 W	11:50	d3610105	Test to 100 m
Station aborted neither SHE1 or SHE2 working							
16	10/03/11	69					
			8 21.772 N	28 20.847 W	15:25	d3610106	Test to 100 m
Station aborted neither SHE1 or SHE2 working							
17	11/03/11	70					
			10 38.129 N	28 44.992 W	13:16	d3610107	Neither SHE1 or SHE2 working
			10 38.184 N	28 44.915 W	13:25	d3610108	Neither SHE1 or SHE2 working
			10 38.238 N	28 44.809 W	13:34	d3610109	Neither SHE1 or SHE2 working

Stn. No.	Date	Jday	Lat. (deg:min)	Lon. (deg:min)	Start time (GMT)	Filename (mrd)	Comments
			10 38.281 N	28 44.702 W	13:45	d3610110	Neither SHE1 or SHE2 working
			10 38.299 N	28 44.607 W	13:55	d3610111	Neither SHE1 or SHE2 working
			10 38.323 N	28 44.514 W	14:05	d3610112	Neither SHE1 or SHE2 working
			10 38.244 N	28 44.378 W	14:20	d3610113	Neither SHE1 or SHE2 working
			10 38.374 N	28 44.259 W	14:29	d3610114	Neither SHE1 or SHE2 working
			10 38.353 N	28 44.192 W	14:39	d3610114	Neither SHE1 or SHE2 working
			10 38.342 N	28 44.159 W	14:49	d3610116	Neither SHE1 or SHE2 working
18	11/03/11	71					
			12 00.031 N	28 59.521 W	23:51	d3610117	Neither SHE1 or SHE2 working
	12/03/11	72	12 00.144 N	28 59.735 W	00:02	d3610118	Neither SHE1 or SHE2 working
			12 00.215 N	28 59.591 W	00:13	d3610119	Neither SHE1 or SHE2 working
			12 00.285 N	28 59.479 W	00:25	d3610120	Neither SHE1 or SHE2 working
			12 00.387 N	28 59.389 W	00:36	d3610021	Neither SHE1 or SHE2 working
			12 00.542 N	28 59.218 W	00:47	d3610022	Neither SHE1 or SHE2 working
			12 00.629 N	28 59.119 W	00:59	d3610123	Neither SHE1 or SHE2 working
			12 00.799 N	28 59.004 W	01:14	d3610124	Neither SHE1 or SHE2 working
			12 00.960 N	28 58.877 W	01:26	d3610125	Neither SHE1 or SHE2 working
			12 01.083 N	28 58.806 W	01:36	d3610126	Neither SHE1 or SHE2 working
19	13/03/11	73					
			15 29.931 N	28 48.511 W	15:19	d3610127	Neither SHE1 or SHE2 working
			15 29.988 N	28 48.438 W	15:28	d3610128	Neither SHE1 or SHE2 working
			15 30.041 N	28 48.342 W	15:38	d3610129	Neither SHE1 or SHE2 working
			15 30.052 N	28 48.276 W	15:48	d3610130	Neither SHE1 or SHE2 working

Stn. No.	Date	Jday	Lat. (deg:min)	Lon. (deg:min)	Start time (GMT)	Filename (mrd)	Comments
			15 30.048 N	28 48.208 W	15:57	d3610131	Neither SHE1 or SHE2 working
			15 30.084 N	28 48.134 W	16:05	d3610132	Neither SHE1 or SHE2 working
			15 30.121 N	28 48.053 W	16:15	d3610133	Neither SHE1 or SHE2 working
			15 30.125 N	28 47.963 W	16:30	d3610134	Neither SHE1 or SHE2 working
			15 30.103 N	28 47.922 W	16:39	d3610135	Neither SHE1 or SHE2 working
			15 30.083 N	28 47.887 W	16:48	d3610136	Neither SHE1 or SHE2 working
20	14/03/11	74					
			17 24.387 N	28 23.842 W	09:18	d3610137	Neither SHE1 or SHE2 working
			17 24.524 N	28 23.715 W	09:28	d3610138	Neither SHE1 or SHE2 working
			17 24.642 N	17 23.573 W	09:39	d3610139	Neither SHE1 or SHE2 working
			17 24.769 N	28 23.455 W	09:49	d3610140	Neither SHE1 or SHE2 working
			17 24.829 N	28 23.355 W	09:59	d3610141	Neither SHE1 or SHE2 working
			17 24.893 N	28 23.256 W	10:09	d3610142	Neither SHE1 or SHE2 working
			17 24.973 N	28 23.162 W	10:20	d3610143	Neither SHE1 or SHE2 working
			17 25.092 N	28 23.051 W	10:29	d3610144	Neither SHE1 or SHE2 working
			17 25.161 N	28 22.927 W	10:39	d3610145	Neither SHE1 or SHE2 working
			17 25.239 N	28 22.812 W	10:50	d3610146	Neither SHE1 or SHE2 working
21	15/03/11	75					
			19 07.263 N	28 07.953 W	07:54	d3610147	Neither SHE1 or SHE2 working
			19 07.454 N	28 07.938 W	08:03	d3610148	Neither SHE1 or SHE2 working
			19 07.647 N	28 07.875 W	08:14	d3610149	Neither SHE1 or SHE2 working
			19 07.845 N	28 07.783 W	08:24	d3610150	Neither SHE1 or SHE2 working
			19 08.094 N	20 07.665 W	08:38	d3610151	Neither SHE1 or SHE2 working

Stn. No.	Date	Jday	Lat. (deg:min)	Lon. (deg:min)	Start time (GMT)	Filename (mrd)	Comments
			19 08.326 N	20 07.634 W	08:51	d3610152	Neither SHE1 or SHE2 working
			19 08.593 N	28 07.565 W	09:04	d3610153	Neither SHE1 or SHE2 working
			19 09.007 N	28 07.465 W	09:19	d3610154	Neither SHE1 or SHE2 working
			19 09.304 N	28 07.360 W	09:29	d3610155	Neither SHE1 or SHE2 working
			10 09.543 N	28 07.217 W	09:39	d3610156	Neither SHE1 or SHE2 working

3.2 Profiler description

The MSS90L profiler is produced by Sea and Sun Technology GmbH in cooperation with ISW Wassermesstechnik. The main housing of the MSS90L profiler comprises a cylindrical titanium tube of length 1250 mm and diameter 90 mm. The housing is pressure tight to 5 MPa (500m). Weights and buoyancy rings can be added to the top and bottom of the probe respectively which allows the user to tune the sinking velocity by altering the buoyancy. The ISW profiler was equipped with 2 velocity microstructure shear sensors, a microstructure temperature sensor, standard CTD sensors for precision measurements, a vibration control sensor, and a two component tilt sensor (table 3.2). The sampling rate for all sensors is 1024 samples per second, the resolution 16 bit. All sensors are mounted at the measuring head of the profiler (sensor end). The microstructure sensors are placed at the tip of a slim shaft, about 150 mm in front of the CTD sensors. The data are transferred, from the profiler, via electrical cable to an onboard unit which pipes the data to a laptop PC.

Table 3.2: Sensor range, accuracy, and resolution for MSS90L microstructure profiler. Taken from the published specification of MSS90L.

Sensor	Range	Accuracy	Resolution
Microstructure shear (Airfoil lift force sensor)	0 to 6 s^{-1} (Dissipation rate10^{-2} to 10^{-10} W kg^{-1})	not specified	approx. 10^{-3} s^{-1}
Microstructure temperature (FP07)	-2 to +30 °C	± 0.02 °C	500 µC (linear)
Pressure	1 to 50 bar	± 0.1 % fs^{1}	0.002 % fs^{1}
Temperature	-2 to +30 °C	± 0.01 °C	0.0005 °C
Conductivity	0 to 6 mS cm^{-1}	± 0.005 mS cm^{-1}	0.0001 mS cm^{-1}
Acceleration	-1 to +1 ms^2	0.02 ms^2	0.005 ms^2

[1]Full scale pressure range

3.3 Calibration

Calibration of the shear sensors was performed by ISW Wassermesstechnik using a special shear probe calibration system. The probe rotates about its axis of symmetry at 1Hz under an angle of attack in a water jet of constant velocity. At different angles of attack the rms voltage output of the probe is measured. The probe sensitivity is the slope of the regression (best fit of a cubic approximation) of the sensor output versus the angle of attack. The calibration constants for the shear sensors used during cruise D361 are given in table 3.3.

Table 3.3: Calibration constants for shear sensors used during cruise D361

Sensor	Serial	Sensitivity	A0	A1	Type
SHE1	6086	1.12E-004	1.31E-002	2.63E-002	PNS03
SHE2	6090	1.18E-004	1.25E-002	2.49E-002	PNS03
SHE2	61	3.05E-004	4.82E-003	9.65E-003	PNS06
SHE2	6091	1.17E-004	1.26E-002	2.52E-002	PNS03

The calibration of the CTD sensors is to be carried out by Sea & Sun Technology GmbH using standard calibration equipment and procedures for CTD probes post cruise. The vibration control sensor and the tilt sensors were calibrated by ISW Wassermesstechnik using special calibration equipment for both sensors.

3.4 Installation and operation of the microstructure measuring system

3.4.1 Profiler and winch installation

The ISW was operated via a winch SWM1000, mounted on the port stern quarter of the vessel. In addition to the fastening provided by the construction of the mounting plate the plate was further secured to the bulwark with two steel bolts, running through bulwark and plate.. The power cable for the winch and the data cable connecting the PC to the profiler were run along the port side of the vessel and into the deck laboratory through the bosun's locker.

3.4.2 Profiler deployment

For vertical sinking measurements, the profiler was balanced with a negative buoyancy which gave it a sinking velocity of ~0.6 ms^{-1}. During the ISW measurements, the ship was moving with speed ~0.5-1.0 knots with respect to the water against the wind. Disturbing effects caused by cable tension (vibrations) and the ship's movement were minimized by maintaining slack in the cable. As a rule of thumb two' loops' should always be visible just below the sea surface.

In order to take into account the intermittent nature of marine turbulence, repeated ISW measurements were carried out in bursts of 10 profiles per station, with each station lasting up to two hours. The measurement interval was ~12 min for a profile to 250 dbar. A profile depth of 250 dbar was chosen to ensure that both the upper mixed layer, if any, and the region directly below it were covered by each profile.

Profiler deployment can be carried out with a minimum of two people, one to operate the computer and one to drive the winch. However, it is easier to deploy the profiler if three people are involved, the additional person being responsible for managing the cable spooling from the winch and preventing the cable from catching. Should the winch catch and rewind, a large amount of slack cable in the water gives time for the operators to resolve the snag and restart spooling before the profiler is affected. Data processing of the measurements is relatively robust to tension in the cable and only in cases where the profiler is pulled upwards by the cable do the measurements have to be discarded. Nevertheless, fluctuations in profiler sinking velocity increase the error in the shear calculation by an order of four, while cable tension increases the background noise recorded by the shear sensors reducing the recording accuracy of the instrument.

Slack cable in the water means that the profiler will continue to descend even after the winch has started to rewind. As a consequence of this, when deploying in areas where the water depth is close to the desired depth of the profile, it is recommended that the winch be stopped at least 50 dbar short of the target profile depth to allow for the additional depth the profiler sinks before the slack cable can be rewound. Monitoring of the maximum depth achieved by the profiler on each cast then allows the winch stop depth to be fine tuned to achieve a safe maximum profile depth.

3.5 Data collection and archiving

The raw data from the ISW profiler are transmitted via RS485 data link to the on board interface unit of the measuring system. Details relating to each station were noted in an Excel file. For data acquisition, on-line display and storage of data the software package SDA 180 (Sea & Sun Technology GmbH) was used. The icon on the laptop desktop has label `SST_SDA`. The raw data are stored in the MRD (microstructure raw data) binary format.

Raw MRD format data are processed using the MSSpro software package (ISW

Wassermesstechnik) which calculates shear, turbulent kinetic energy dissipation, and turbulent diffusivity. The icon on the desktop has label `Msspro`. The processed data are stored in ASCII (filename extension .TOB) format. Data was processed, using the MSSpro software, according to the procedure for obtaining turbulent diffusivity described in the cruise report on Discovery cruise D321, which is reproduced below.

3.6 Basic guide to processing necessary to obtain turbulent diffusivity (paraphrased from Discovery cruise D321 report).

It is important to set up different directories for the different stages of processing as there is the potential to overwrite files. Note also that the software has to sit directly under `C:` to use the current batch files. For D361 the following directories were used:

`C:\sst_sda\Rawdata`	Storage of raw files as they are generated
`C:\datpro\cutfiles`	Raw files copied here for depth trimming
`C:\datpro\D361\Station<num>`	ASCII processed file for each station
`C:\datpro\D361\Station<num>\Rawdata`	Copies of the raw files for each station

3.6.1 Checking sinking velocity

At the start of the cruise the sinking velocity of the probe should be checked. This should be between 0.5 and 0.7ms^{-1} to give best signal to noise ratio. Only one cast is required to check the sinking velocity. Rather than go through the lengthy processing steps below there is a quicker route:

Copy file to C:\datpro\cutfiles and trim it as in 3. below.

Click Run button in top menu bar, then Batch job.

Choose velocity D361 option

Configure batch job as described below but you may want to set up a new directory e.g. C:\datpro\velocity for doing this test

Click start

Use Datgraf (see below) and the configuration file Velocity to check the vertical velocity profile

3.6.2 Processing steps

Copy files to process from C:\sst_sda\Rawdata to \datpro\cutfiles

Start msspro by double-clicking on icon

Trimming profiles :

Click Utilities Button once, then click once on the Cutgraf option and a new window should appear.
Click on Input files and select required files from cutfiles. Note that this program will overwrite these files once edited which is why they must be copied here from C:\sst_sda\Rawdata
The filenames should appear in the right margin. Double-click on the first file. Move cursor to top of hashed rectangle in lower half of plot such that double-headed arrow appears. Hold down left button and drag the top of the blue hashed rectangle downwards until just above the point at which the pressure starts to decrease again. Press F9 to cut the profile such that data within the remains of the blue hashed rectangle is deleted. The program automatically moves on to the next file. Note: it may be the over-sensitive touch pad but this can be a bit fiddly as if you click even slightly away from the top of the rectangle you instead zoom in (to an area within a red hashed rectangle which will appear). Right click to zoom out again.
Repeat until the end of the file list is reached – then click 'OK' when it tells you this point is reached.

Converting files to ASCII and calculating shear:

In datpro click once on File, then click once on Select input files for file list
In window that appears, navigate to C:\datpro\cutfiles, set type to .mrd and choose required files.
Click once on Run in top menu bar
Select Batch job and choose convert+shear D361 from the options that appear. If they don't appear, navigate to C:\datpro\batch. Note that you must use the batch job configured for the shear sensors that are fitted to the profiler (for those fitted during D361 see above).
A configure batch job window should appear. Set the output directory to C:\datpro\D361Station<num> A window of possible files will appear, but click any single letter into the filename box and hit OK.
Set the output filename prefix in the same window. (Note that the filenames are restricted to 8 characters and that this step will overwrite the relevant leading letters of your initial filename e.g. if the rawfile is called abcdefgh and you choose prefix D361A then the output file will be called D361Afgh. It is therefore important that you choose the structure of your filename and your

prefixes carefully to avoid over-writing files. For D361 the prefix S<num>s was used for this stage leaving the last 3 characters for the sequential profile number.
Click Start job. For 10 profiles of roughly 100m this batch job will take of order 3 hours to run, and much much much longer for profiles of 200m + longer.
It is important to check the last profile of each station to ensure that the shear sensors are still functioning prior to the next station.

Calculating turbulent dissipation rates and Thorpe scale:

1. If you have just done the preceding stage you will first need to clear the input file list. Click on the Input file list button. Select all the files visible. Click once on the File button on the top bar. Click on Reject selected input files.
2. Now load files for this stage of processing. Click on the File button in the top menu bar, then on Select input files.
3. Navigate to C:\datpro\D361\Station<num> and select required files
4. Click once on Run button in top menu bar, then on the Batch job option that appears.
5. Choose epsilon+thorpe – new from options
6. In Configure batch job window that appears set output directory to C:\datpro\D361\Station<num>.
7. For D361 the prefix S<num>e was used for this stage
8. Click Start. This stage will take a couple of hours roughly for 10 profiles to 100m.

Calculate turbulent diffusivity

1. Clear previous input files as above.
2. Now load files for this stage of processing. Click on the File button in the top menu bar, then on Select input files.
3. Navigate to C:\datpro\D361\Station<num> and select required files
4. Click once on Run in top menu bar then on Batch job option that should appear
5. Choose Eddy option
6. In Configure batch job window that appears set output directory to C:\datpro\D361\Station<num>
7. For D361 the prefix S<num>k was used for this stage
8. Click start job. This stage will take only a few minutes for 10 profiles to 100m.

Examining data i.e. dissipation rates:

1. Click once on Utilities button on top menu bar.
2. Click on Datgraf option – a new window should appear.

3. Click on Configure button in Datgraf, then on the Load configuration option.
4. Choose epsilon D361
5. Set work path to C:\datpro\D361\Station<num>
6. Click on the file of interest in the right margin and the data should appear in the adjacent plots. The plot ranges (and parameters plotted) can be adjusted by clicking Configure, then Options, then the Data parameters tab.
7. eps1 and eps2 are the dissipation rates as estimated from the two velocity microstructure probes. They should be pretty similar. If one is systematically much lower than the other or even just systematically different in structure and amplitude it may be an indication that one of the sensors is broken. In this case you need to work out which of the two you trust most. Looking at previous profiles should help in this regard.

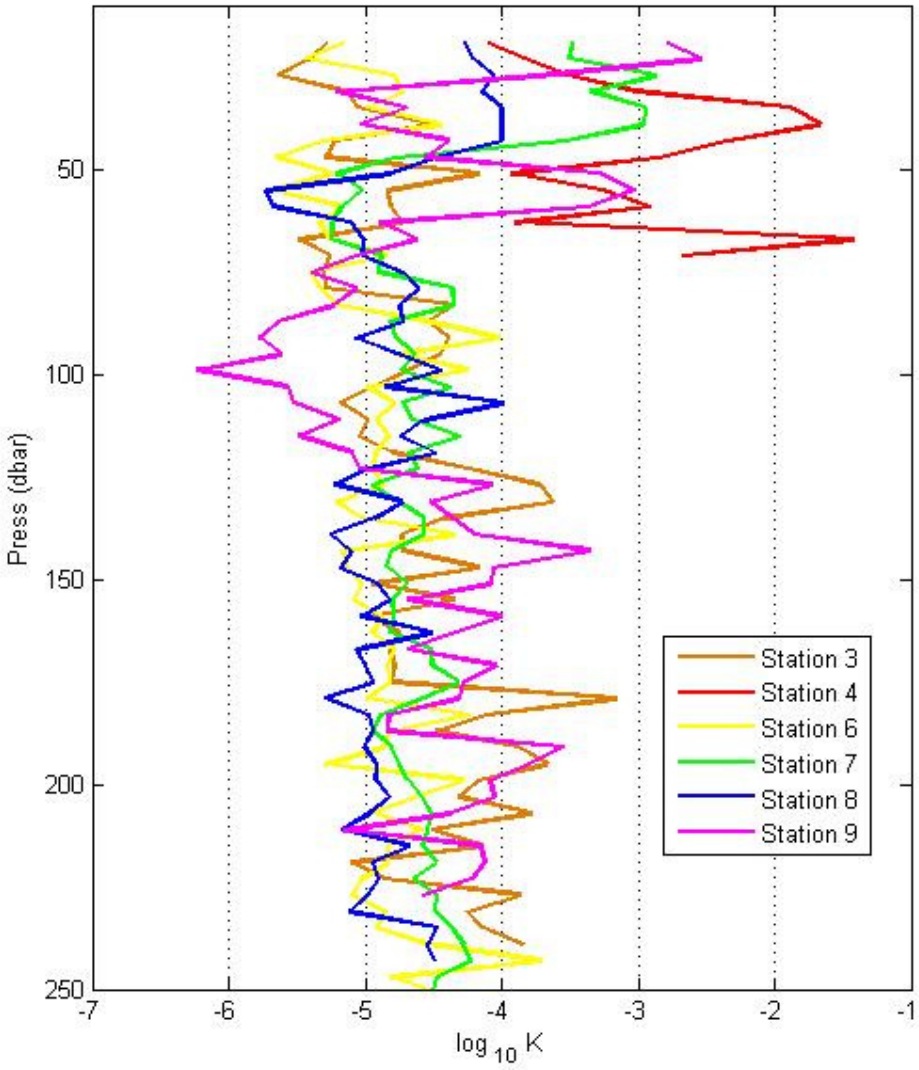


Figure 3.1: Vertical profiles of turbulent diffusivity recorded while the microstructure shear sensors were working on cruise D361

4 CTD Data Processing and Calibration

Alex Forryan and Jonathan Lauderdale

4.1 Summary of CTD deployments

Two CTD frames were used during cruise D361, a standard stainless steel frame and a trace-metal clean titanium frame. The titanium frame was deployed using a non-conducting kevlar cable with an auto-fire unit to trigger the niskin bottles at pre-programmed depths. In total 49 casts were made during the cruise including 5 where the titanium frame niskin bottles did not fire and 4 test casts. Of the successful casts 20 were made using the stainless steel frame to depths of 500 m and 19 full depth casts using the trace-metal clean titanium frame. Water was sampled from all successful casts. Water samples from the stainless steel frame was used for biological analysis and from the titanium frame for trace-metal analysis. All samples take from the stainless steel frame for biological analysis were sampled in the the following order: oxygen, nutrients, DIC/DOC, and everything else. Sampling from the titanium frame was carried out in a trace metal clean lab on the rear deck. Sampling depths were selected on a per-cast basis for all casts. A summary of all CTD casts is given in table 4.1. Examples of vertical profiles of transmittance, oxygen, fluorescence, potential temperature and salinity from a full-depth titanium frame cast (cast 14) are given in figures 4.7 and 4.8.

Table 4.1: Summary of all CTD casts on cruise D361.

No.	Frame Type	Date	Jday	Time (GMT)	Latitude (°N)	Longitude (°E)	Depth (m)	Comments
1	Steel	15/02/11	46	10:14	28.31	-16.12	501	Test 1
2	Titanium	16/02/11	47	10:50	28.32	-16.13	1838	Test 2
3	Titanium	17/02/11	48	14:29	28.24	-16.21	438	Test 3
4	Titanium	18/02/11	49	10:11	27.78	-16.23	600	Test 4
5	Steel	22/02/11	53	01:04	12.59	-17.91	501	
6	Titanium	22/02/11	53	03:22	12.59	-17.92	2627	
7	Steel	22/02/11	53	07:17	12.59	-17.71	500	
8	Titanium	22/02/11	53	12:16	12.61	-17.72	1003	
9	Steel	22/02/11	53	17:00	12.59	-17.57	152	
10	Titanium	22/02/11	53	19:54	12.61	-17.57	49	Misfired
11	Titanium	22/02/11	53	20:36	12.61	-17.57	49	
12	Titanium	22/02/11	53	21:29	12.59	-17.57	108	
13	Steel	23/02/11	54	05:48	12.57	-18.82	501	
14	Titanium	23/02/11	54	08:35	12.55	-18.83	4198	
15	Steel	24/02/11	55	06:57	12.58	-21.82	500	

No.	Frame Type	Date	Jday	Time (GMT)	Latitude (^{o}N)	Longitude (^{o}E)	Depth (m)	Comments
16	Titanium	24/02/11	55					Misfired
17	Titanium	24/02/11	55	14:12	12.57	-21.82	4775	
18	Steel	25/02/11	56	06:53	12.58	-23.56	500	
19	Titanium	25/02/11	56	09:51	12.59	-23.56	4886	Misfired
20	Titanium	25/02/11	56	16:42	12.59	-23.58	1102	
21	Steel	26/02/11	57	06:52	12.3	-25.13	494	
22	Titanium	26/02/11	57	09:54	12.3	-25.15	4925	
23	Steel	03/03/11	62	15:20	-7.22	-24.99	1001	
24	Titanium	03/03/11	62	18:37	-7.22	-25	5498	Paused at 215 m for 15 mins winch overheating
25	Steel	04/03/11	63	03:56	-7.22	-24.99	502	
26	Steel	05/03/11	64	06:48	-3.26	-25.52	488	
27	Titanium	05/03/11	64	09:39	-3.25	-25.54	5485	Misfired
28	Titanium	05/03/11	64	17:25	-2.96	-25.61	2073	
29	Steel	06/03/11	65	09:57	-1.17	-25.79	498	
30	Titanium	06/03/11	65	09:57	-1.16	-25.8	4914	
31	Steel	07/03/11	66	06:51	1.16	-26.05	502	
32	Titanium	07/03/11	66	09:03	1.16	-26.05	3704	
33	Steel	08/03/11	67	06:50	3.33	-26.81	510	
34	Titanium	08/03/11	67	09:26	3.35	-26.83	4213	
35	Steel	09/03/11	68	06:53	5.66	-27.5	496	
36	Titanium	09/03/11	68	09:12	5.67	-27.51	4098	
37	Steel	10/03/11	69	06:48	8.34	-28.33	500	
38	Titanium	10/03/11	69	09:30	8.35	-28.34	4727	
39	Steel	11/03/11	70	06:48	10.63	-28.73	502	
40	Titanium	10/03/11	70	09:44	10.62	-28.73	5591	
41	Titanium	12/03/11	71	04:09	12.03	-28.98	5637	
42	Steel	12/03/11	71	07:29	12.05	-28.98	498	
43	Steel	13/03/11	72	06:48	15.51	-28.79	499	
44	Titanium	13/03/11	72	09:19	15.51	-28.79	5105	
45	Steel	14/03/11	73	07:15	17.4	-28.39	503	Winch failure for 2 mins on downcast
47	Titanium	14/03/11	73	15:36	17.43	-28.39	4575	
48	Steel	15/03/11	74	07:03	19.12	-28.13	501	
49	Steel	15/03/11	74	10:43	19.17	-28.12	1002	

4.2 Initial Processing Using SeaBird Programs

The files output by Seasave have the appendices: .hex, .HDR, .bl and .CON. The .CON files for each cast contain the calibration coefficients for the instrument. The .HDR files contain the information in the header of each cast file. The .hex files are the data files for each cast and are in hex format. The .bl files contain information on the bottle firing of the rosette. Files produced by the autonomous titanium frame unit and the conventional stainless steel frame unit were processed in exactly the same way.

Initial data processing was performed on a PC using the SeaBird processing software SBE Data Processing version 7.21b. The following options were used in the given order :

Data Conversion: turns the raw data into physical units. It takes the .CON files and .hex files. The input files were named D361_nnn.hex where nnn refers to the three-digit station number.

Cell Thermal Mass: takes the .cnv files output from Align CTD and makes corrections for the thermal mass of the cell, in an attempt to minimize salinity spiking in steep vertical gradients due to a temperature/conductivity mismatch. The constants applied were; thermal anomaly amplitude $\alpha = 0.03$; thermal anomaly time constant $1/\beta = 7$.

Wildedit: marks wild points in the data by replacing the data value with badflag. The badflag value is documented in the input .cnv header. Wild Edit's algorithm requires two passes through the data: the first pass obtains an accurate estimate of the data's true standard deviation, while the second pass replaces the appropriate data with badflag.

Bottle_Summary: generates an ASCII summary .bl file of the bottle firing data from the cast .ros file. This must contain the CTD scan number for each bottle firing.

4.3 Mstar CTD Processing

The entire Mstar software suite is written in Matlab and uses NetCDF file format to store all the data. There are four principal types of files:

SAM files: store all information about rosette bottles samples, including upcast CTD data from when the bottles were fired. Data from chemistry samples corresponding with each bottle are uploaded into this file as well. Other information about the station is stored too.

CTD files: store all data from CTD sensors. There are five CTD files: raw, 24Hz, 1Hz, psal and 2db. The program averages and interpolates the raw data until it has 2db resolution.

DCS files: store information necessary to know CTD downcast (for e.g. start, bottom and end points of the cast). It is also used to merge in latitude and longitude.

FIR files: keep information about CTD data in points when each rosette bottle was fired. Also stores information about winch work.

4.4 Processing Procedure Used on D361

After having converted the CTD cast data with the SBE processes, there were two ASCII files to work on: ctd_di361_nnn_ctm.cnv and ctd_di361_nnn.bl. The first one contains all raw CTD data including cast information. The other one contains information about the firing of each bottle on the cast. To start the CTD data processing, m_setup was run in Matlab to add Mstar tools and information needed for the processing. The following scripts were then run:

msam_01: creates an empty sam file to store all information about rosette bottle samples. The set of variables are available in the /templates directory and can be changed according to what it needs to store. This file, named as sam_di361_nnn.nc, stores data for each sample bottle, their flags, and some CTD data at firing time.

mctd_01: reads the raw data (ctd_di361_nnn_ctm.cnv) and stores it in a NetCDF file named ctd_di361_nnn_raw.nc, which becomes write protected.

mctd_02a: copies ctd_di361_nnn_raw.nc into ctd_di361_nnn_24hz.nc renaming the variables for the SBE sensor.

mctd_02b: using 24Hz data (ctd_di361_nnn_24hz.nc), applies oxygen hysteresis correction to variable oxygen_sbe to create new variable oxygen.

mctd_03: using 24Hz data (ctd_di361_nnn_24hz) it averages to 1Hz data. Then, using the 1Hz file (ctd_di361_nnn_1hz) it calculates salinity and potential temperature (ctd_di361_nnn_psal). This script also calls *mctd_sensor_choice.m*, which records the first choice conductivity-temperature sensor pair for each station. First choice sensor data is then stored in the variables *temp* and *cond* (which are subsequently used to calculate variables *potemp* and *psal*).

mdcs_01: creates an empty file named as dcs_di361_nnn to store information about the start, bottom and end of the cast.

mdcs_02: populates dcs_di361_nnn with information from the bottom cast. It takes the highest pressure point as bottom.

mdcs_03: selects and shows surface data < 20db (ctd_di361_nnn_surf) allowing the analyst to choose the positions of the start and end scan numbers. The start is selected by scrolling from the top of data printed out by

mdcs_03. The operator identifies where the CTD went from being on deck (zero/negative pressure) to roughly 10db and then the point where is it was brought back to the surface for the start of the downcast. The scan number at which the pressure begins to increase and temperature, salinity and oxygen data show reasonable values is selected as the start point of the downcast.To find the end of upcast, the data were scrolled up from the bottom to identify where the CTD came back onboard. The operator chooses the last available point where sensor values are reasonable before an abrupt change in measurements occurs as the CTD is lifted out of the water.

mctd_04: using information on dcs_di361_nnn it selects the CTD downcast data from ctd_di361_nnn_psal file and averages it into 2db resolution (ctd_di361_nnn_2db).

mdcs_04: loads position from navigation file and merges it on the cast's points previously defined in mdcs_03, and stores it in dcs_di361_nnn_pos.nc.

mfir_01: extracts information about fired bottles from ctd_di361_nnn.bl and copies them into a new file named fir_di361_nnn_bl.nc.

mfir_02: using fir_di361_nnn_bl and ctd_di361_nnn_1hz it merges the time from the CTD using scan numbers and puts it into a new file (fir_di361_nnn_time.nc).

mfir_03: stores the CTD data at each bottle firing time in fir_di361_nnn_ctd. The CTD data are taken from ctd_di361_nnn_psal and selected according to the firing time information stored in fir_di361_nnn_time.

mfir_04: copies information of each bottle from fir_di361_nnn_ctd onto sam_di361_nnn.

mwin_01: creates a new file named win_di361_nnn.nc to store information about winch working (for e.g. angles, rate and tension).

mwin_03: using time stored in fir_di361_nnn_time, it selects wire-out from win_di361_nnn at each bottle firing location to fir_di361_nnn_winch.

mwin_04: pastes wire-out information from fir_di361_nnn_winch into sam_di361_nnn.nc.

mdcs_05: applies positions from dcs_di361_nnn_pos.nc to all files. If a file on the set doesn't exist yet it won't be uploaded.

4.5 Sample Files

The sample files (sam_di361_nnn.nc) were created whilst processing each CTD station. These were filled with upcast conductivity, temperature, oxygen and pressure from both primary and secondary sensors coincident with bottle firings. Only the results from salinity and oxygen sampling were included in the sample files.

For salinity samples the following scripts were run:

9. *msal_01*: creates a salinity sample file (sal_di361_nnn.nc) to store the results from the salinity sample analysis. It uses a text file (comma separated) named sal_di361_nnn.csv which contains data from the salinometer analysis, the position on the rosette that the sample was taken from and a data quality flag number.
10. *msal_02:* copies the information from the sal_di361_nnn.nc file to the sample file sam_di361_nnn.nc.

For oxygen samples the following scripts were run:

9. *moxy_01:* creates an oxygen sample file (oxy_di361_nnn.nc) to store the results from the oxygen sample analysis. It uses a text file (comma separated) named oxy_di361_nnn.csv which contains data from the oxygen analysis, the position on the rosette that the sample was taken from and a data quality flag. Note the oxygen analysis must include the sample temperature if the analysis is in umol l^{-1} for later conversion to umol kg^{-1}.
10. *moxy_02*: copies the information from oxy_di361_nnn.nc to the sample file sam_di361_nnn.nc.
11. *msam_oxykg:* converts the oxygen concentration measurements from umol l^{-1} to umol kg^{-1} in the sam_di361_nnn.nc file.
12. *moxy_03:* maps the upcast oxygen sample to the appropriate place on the downcast using potential density. This is for calibrating the CTD oxygen sensor (see below).
13. *moxy_04:* Generates a residuals file for the oxygen concentration measurements and the CTD downcast oxygen based on the mapped positions of the oxygen samples. Creates oxy_di361_nnn_oresid.nc

Processed CTD sensor data was viewed using script *mplotxy_ctdck*. This uses *DCS*, *PSAL* and *2db* CTD files to allow the CTD data to be viewed and compared with data from previous casts. CTD data was viewed as soon as possible after each cast to identify any potential problems with the sensors. No issues with the CTD sensors were found during cruise D361.

4.6 Temperature-Conductivity Sensor first choice

The two CTDs used on D361 were equipped with two conductivity sensors each. The primary conductivity-temperature sensor for each frame was attached near the bottom of the frame and the secondary sensor was attached to the fin.

The primary and secondary temperature sensors on the steel frame compared reasonably well (~ 0.016^{o}C difference) with the difference remaining constant on both upcast and downcast. On the titanium frame the primary and secondary sensors were in good agreement (< 0.001^{o}C difference) in all cases.

Primary and secondary conductivity sensors on the steel frame were in good agreement (< 0.001 difference) for all casts. Initially the secondary conductivity sensor on the titanium frame was offset by ~ 4. However, this sensor was damaged on deck and replaced following cast 6. The new secondary conductivity sensor compared well with the primary on all remaining casts (< 0.02 difference).

For both frames the primary conductivity-temperature sensor was used as the first choice sensor for all casts.

4.7 Salinity calibration

Upcast salinity from the first choice sensors present in the *SAM* file at bottle depths as *upsal* was calibrated against salinity derived from bottle samples. This rough calibration was applied using *apply_calibration_di361* to the *2db* and *SAM* files to the *psal* variable (first choice sensor salinity).

Residuals for the bottle – CTD salinity appeared to be stable over time (figure 3.1 and 3.2). Consequently a single calibration of CTD salinity to bottle salinity was carried out for each CTD frame using all casts. A multiplicative correction factor for the CTD salinity was estimated as the mean ratio of bottle salinity and CTD salinity. The mean ratio of bottle salinity and upcast CTD salinity was calculated for each frame. For both steel and titanium frames the ratio for the first choice sensor was near unity (1.0000431 steel frame; 1.000116 titanium frame). Following salinity ratio calibration bottle – CTD salinity residuals showed some structure against pressure. Salinities were further corrected using an additive factor for both CTD frames. The additive factor (Fs) was calculated from a linear fit to bottle – CTD salinity residuals and pressure where :

$Fs_{(itanium)} = 4.197x10^{-7}(pressure) – 0.00054$

and

$Fs_{(steel)} = 1.839x10^{-6}(pressure) – 0.00028$

The effect of applying this calibration to the CTD salinity data was to reduce the mean residuals for the bottle – CTD salinity from ~ 0.0075 to < $1x10^{-5}$ for the titanium frame and from ~ 0.0001 to < $2x10^{-5}$ for the steel frame. A more comprehensive calibration using conductivity measurements will be carried out post-cruise.

4.8 Calibration of the oxygen sensor

The oxygen sensor was attached to the conductivity-temperature sensor on both CTD frames. Residuals for bottle – CTD oxygen appeared to be stable over time (figure 3.3 and 3.4). For both frames bottle oxygen and CTD oxygen showed a clear linear relationship (figure 3.5 and 3.6). A multiplicative correction factor for the CTD oxygen was estimated as the mean ration of the bottle and CTD oxygen values. This factor was calculated using the data from all casts for each frame. For all steel frame casts a factor of 1.2011 was used and for all titanium casts a factor of 10.7633 was used.

After application of this correction bottle – CTD oxygen residuals retained a clear structure against pressure. CTD oxygen was further corrected using an additive correction factor for both CTD frames. The additive factor (Fo) was calculated from a linear fit to bottle – CTD oxygen residuals and pressure where

$Fo_{(steel)} = 0.0002692(\text{pressure}) - 2.2944$

and

$Fo_{(titanium)} = 0.026063(\text{pressure}) - 4.3202$

The effect of applying this calibration to the CTD oxygen data was to reduce the mean residuals for the bottle – CTD oxygen from ~9 um kg^{-1} for the titanium frame and ~ 24 um kg^{-1} for the steel frame to < 2 um kg^{-1} for both frames.

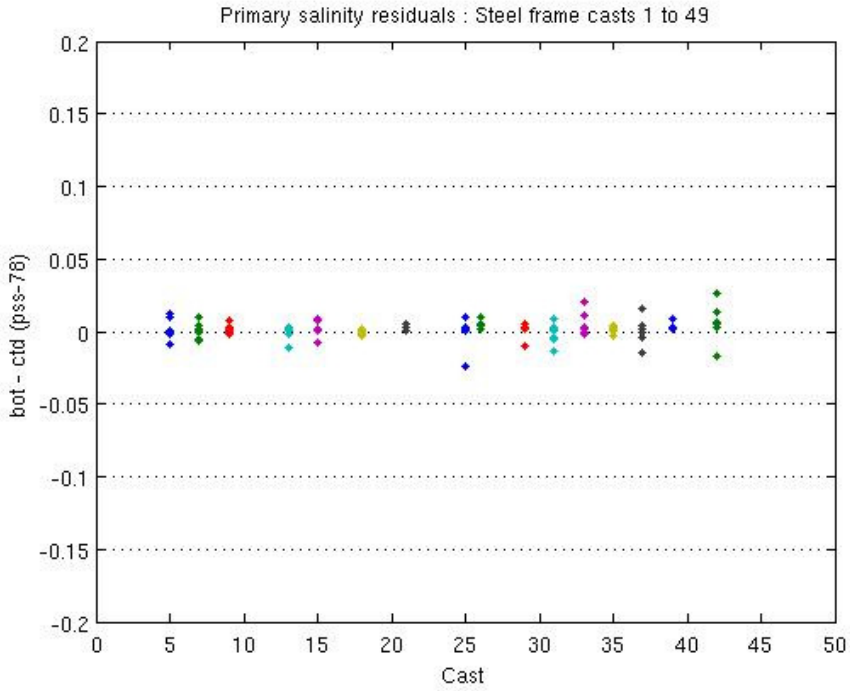


Figure 4.1: Salinity residuals (bottle - CTD salinity) for each steel frame CTD cast on cruise D361.

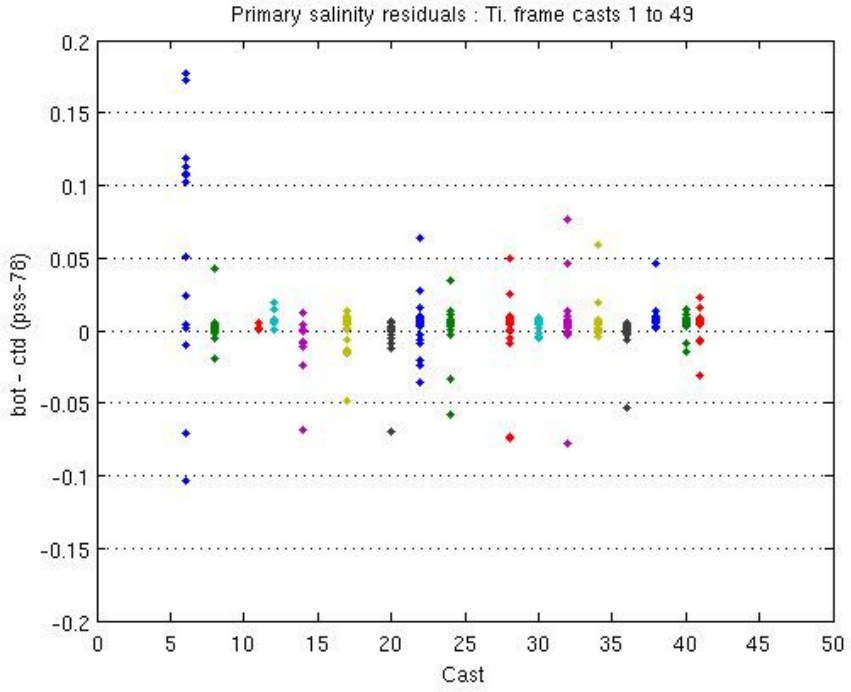


Figure 4.2: Salinity residuals (bottle - CTD salinity) for each titaniuml frame CTD cast on cruise D361.

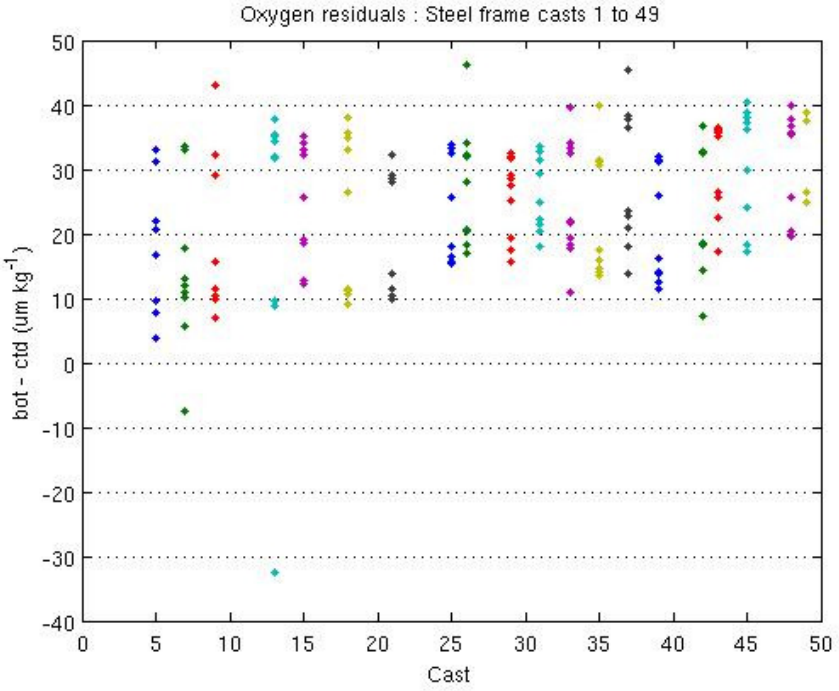


Figure 4.3: Oxygen residuals (bottle - CTD oxygen) for each steel frame CTD cast on cruise D361.

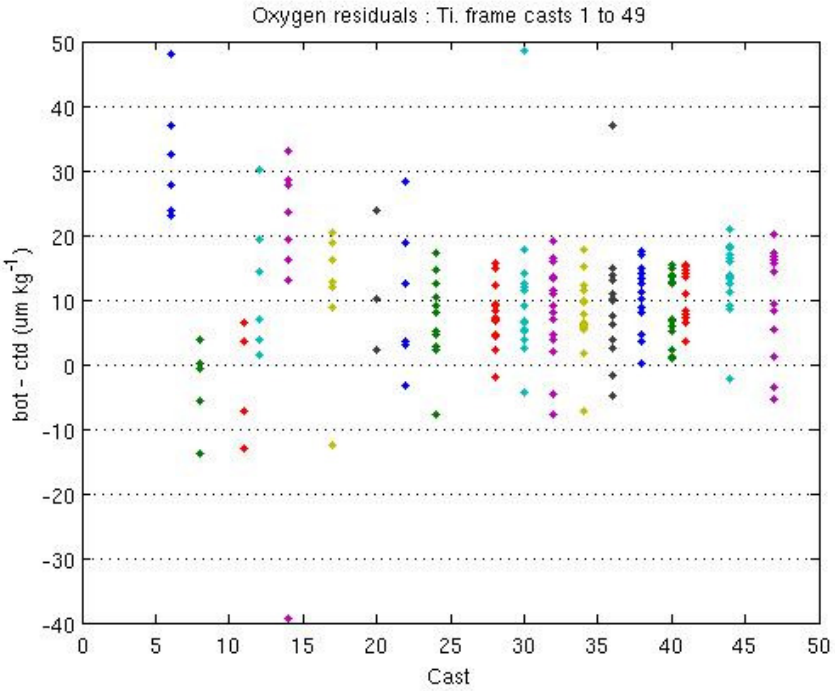


Figure 4.4: Oxygen residuals (bottle - CTD oxygen) for each titanium frame CTD cast on cruise D361.

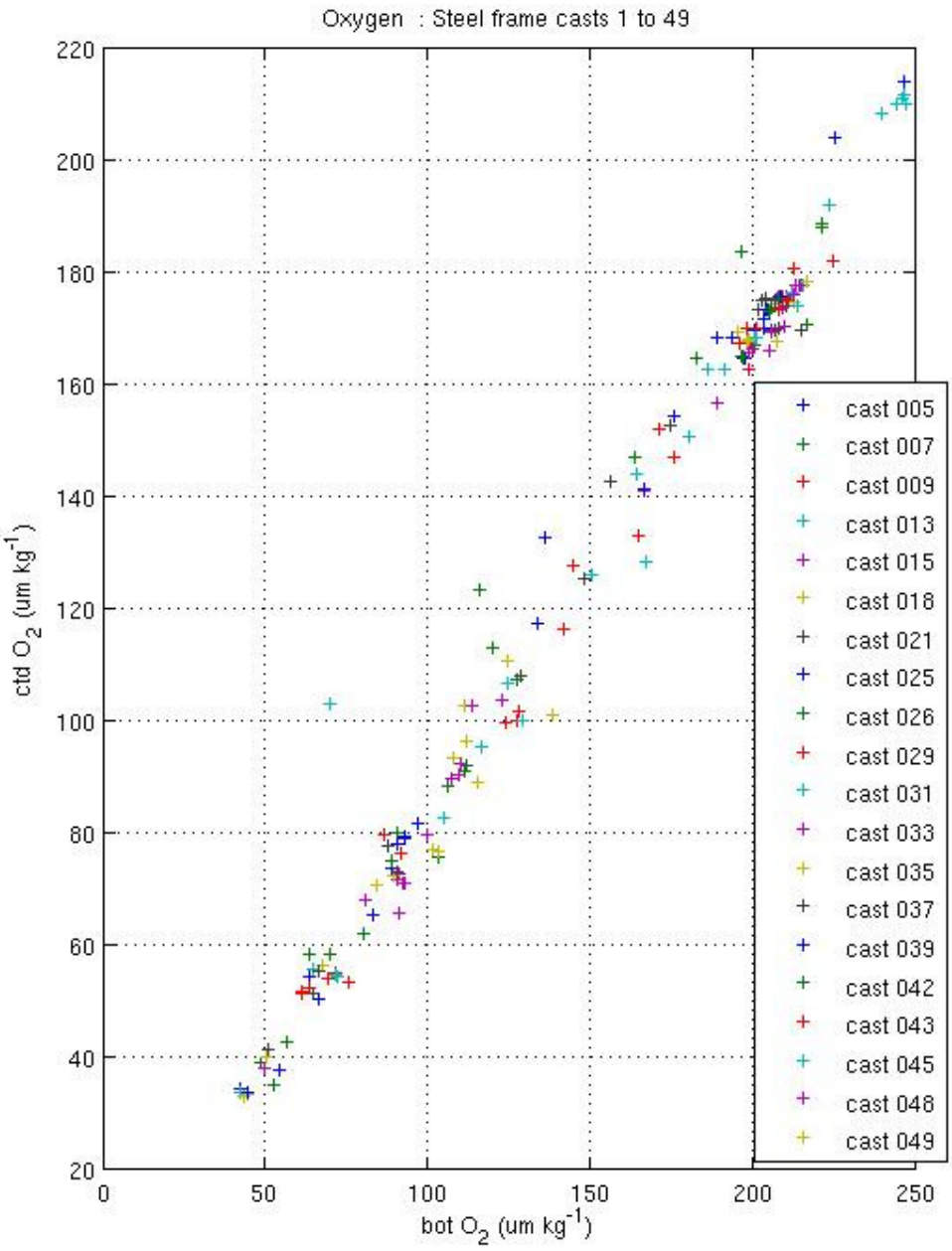


Figure 4.5: Bottle vs CTD oxygen concentration for all steel frame CTD casts on cruise D361.

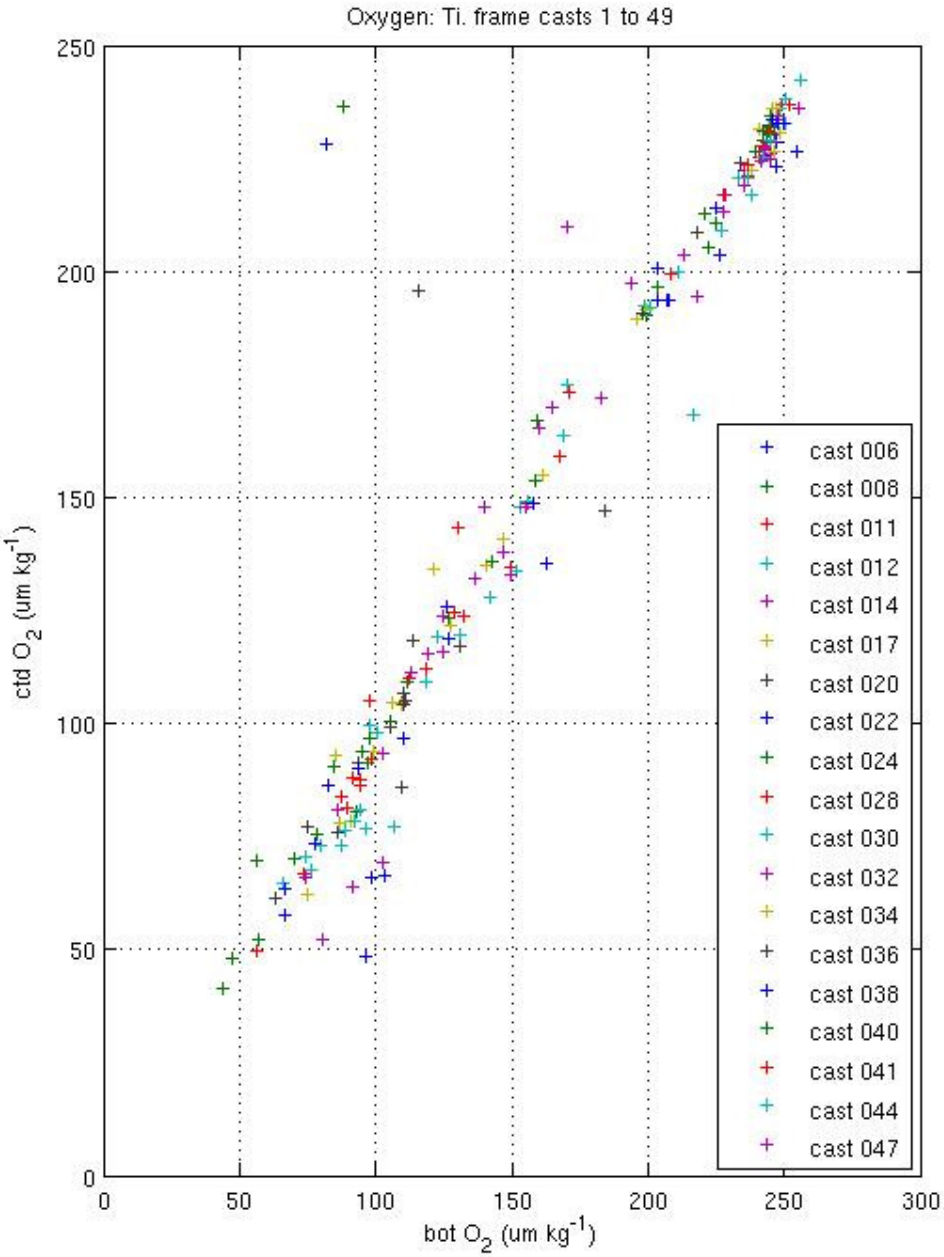


Figure 4.6: Bottle vs CTD oxygen concentration for all titanium frame CTD casts on cruise

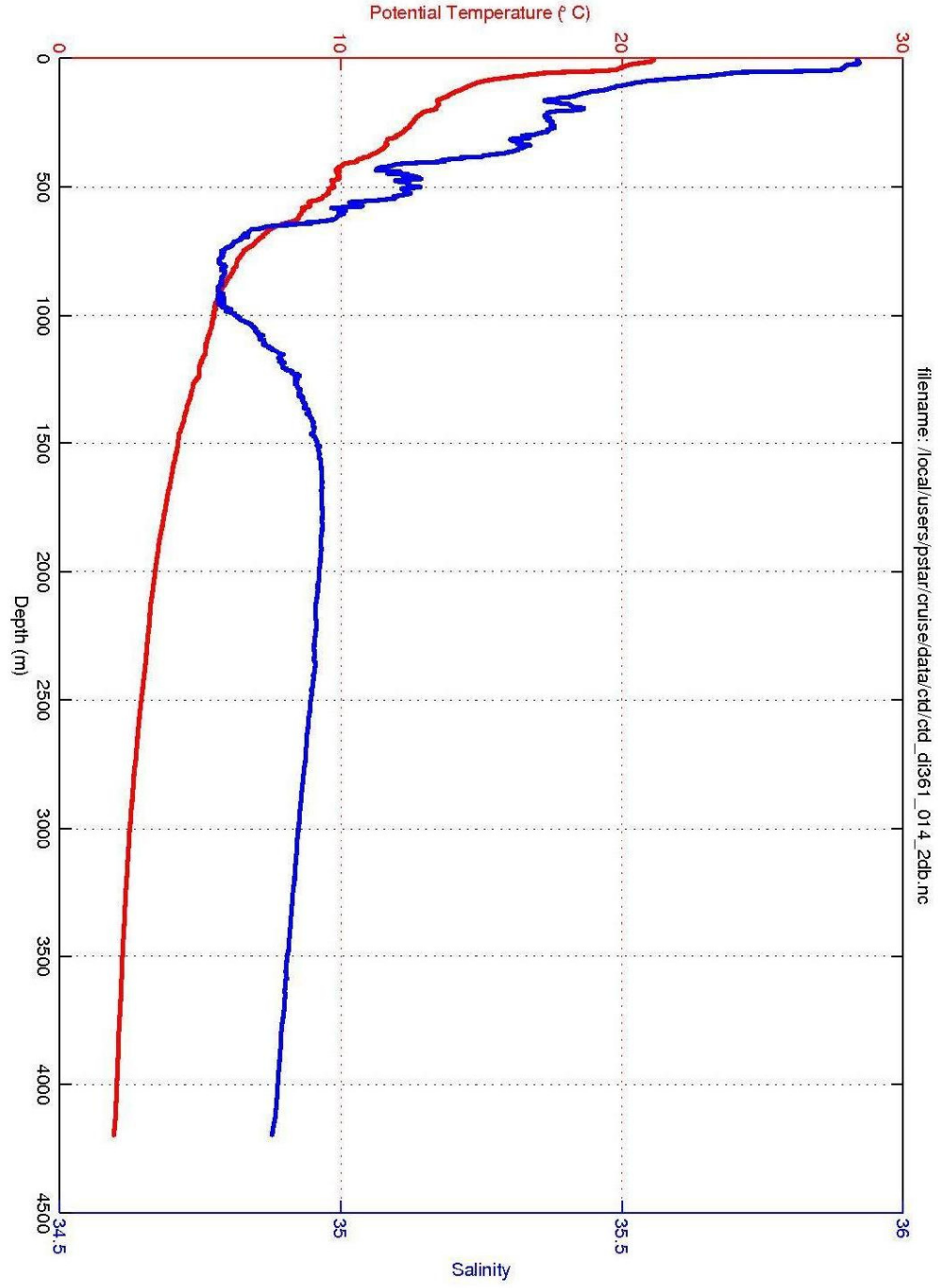


Figure 4.7: Potential temperature and uncalibrated salinity from cast 14 (titanium frame) on cruise D361.

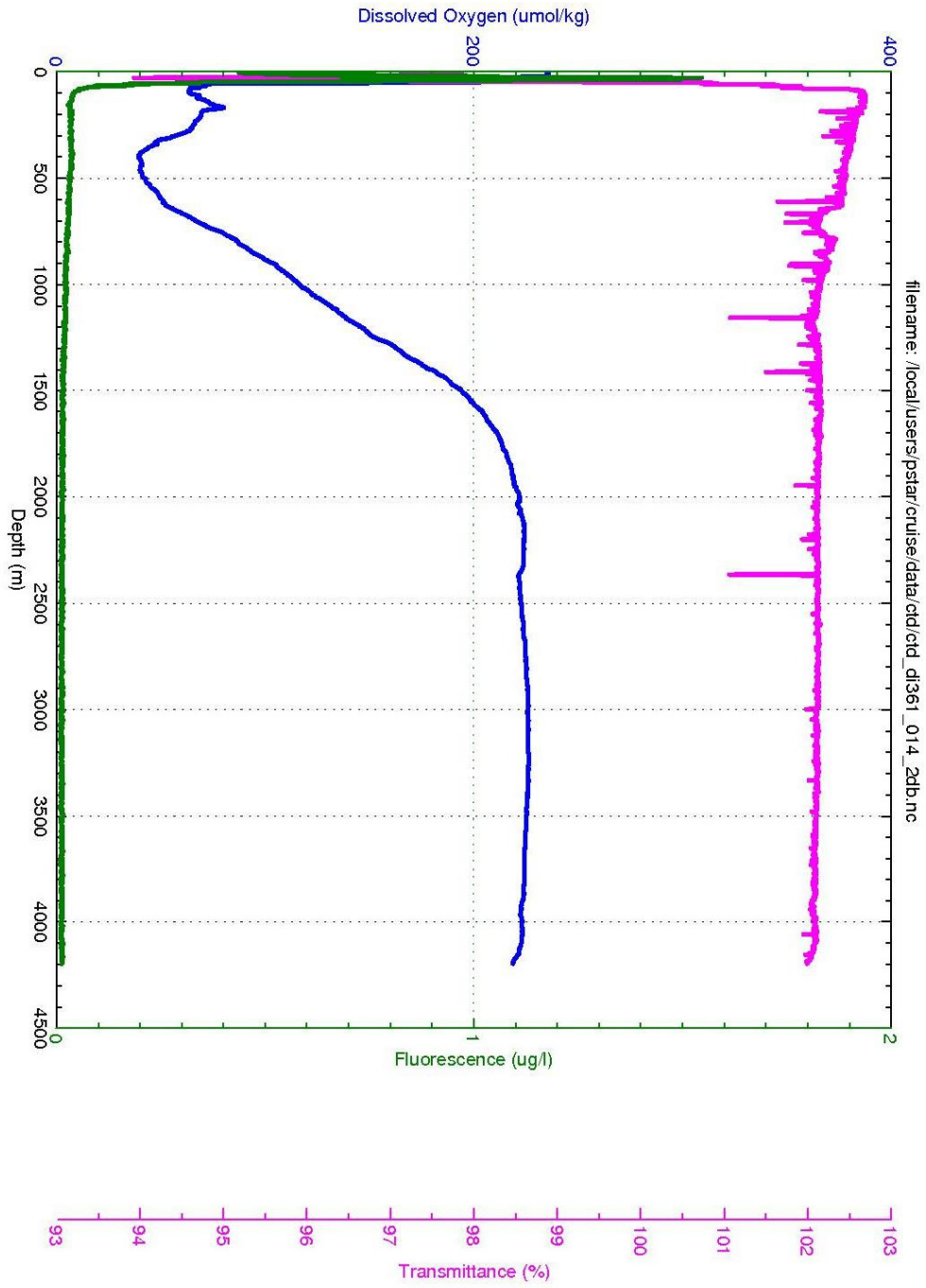


Figure 4.8: Fluorescence, Transmittance and uncalibrated oxygen from cast 14 (titanium frame) on cruise D361.

5 Underway Measurements: Positioning, Meteorology, Sea Surface Properties and Upper Ocean Velocity.

Jonathan Lauderdale

5.1 Computing and Processing Particulars:

As in earlier cruises, primary data logging was performed by IFREMER's TECHSAS data logging system and this provided the main access point from which scientific processing commenced using the recently developed MEXEC software suite (courtesy of Brian King, NOCS). MEXEC is composed of individual MSTAR files written in Matlab that provide tools for interrogating, accessing and modifying oceanographic data. These tools can be combined in sequence, within a wrapper script to allow routine processing of raw data to be easily achieved. Careful records of processing steps are essential for the future understanding of a dataset and each operation automatically writes a description of operations to a file in the history directory with the same name as the processed file. Furthermore, MEXEC employs the “machine independent” NetCDF (network Common Data Form) file format by default, which allows for such comments to be carried within the datafile itself.

The main workhorse for processing was a Sun Microsystems Ultra 40 workstation “e*urus*” running SUSE Enterprise Desktop 10 Linux and Matlab 7.8.0 (R2009a) set up in the “Plot room” adjacent to the Main Lab. On *eurus* were mounted the various *Discovery* file systems to allow access to the different raw data streams. Additionally, an Apple MacMini “b*rianking*” running Mac OS X 10.5.4 was located in the Main Lab and was used to log in to *eurus* via Secure Shell (via Apple’s *Terminal.app* and *X11.app*), allowing processing tasks to be executed by simultaneous operators.

All the data was stored locally on *eurus* in the directory */noc/users/pstar/di361/data/* with a backup to external hard disk performed daily. The parent directory *di361* is symbolically linked in *pstar’s* home directory to “*cruise*” to maintain the same directory structure between cruises.

Once an instance of Matlab has been invoked it was necessary to run the command *m_setup*, which initialises the MEXEC tools and cruise/platform specific information needed to run MSTAR routines. Given the early issues during Di361, it was convenient to make use of a feature enabling the division of accumulated underway data into separate master files (See table 5.1). Initially this required extensive code modification by JML since this feature was previously unused and many of the

MSTAR files had the suffix "*01*" hard coded. However, this was easily remedied by creating a variable "*MSCRIPT_CRUISE_SUFFIX*" set within the *m_setup* procedure. It is intended that the main cruise data set, hence all the plots presented here come from the "*04*" files with parts *01-03* kept for completeness.

Details of each stream and the processing applied will be described below. The raw TECHSAS feed was interrogated by issuing the command "*mtlookd*" which displays the date and time ranges covered by the TECHSAS data and the data stream name.

Table 5.1: Underway data logged during Di361. Note: Main leg began at 1200 hours on JD 49 therefore that day's data appears at the end of part 03 and the start of part 04.

Cruise Part	**Julian Days**	**Comment**
01	33 to 37	In port, Santa Cruz de Tenerife
02	38 to 40	False start, returned to Tenerife
03	41 to 49	Engine trials off Tenerife
04	49 to 78	Main Leg of Di361

Generally "daily" processing follows the same procedure for all variables with a call to the MSTAR routine "*mday_01*" that extracts the relevant chunk of data from the TECHSAS stream and converts it to NetCDF. Stream specific processing steps follow, before a call to the MSTAR script "*mday_02*" that appends these daily files to the master file and merges positions in from the raw master navigation file. Calls to the main daily processing commands follow the form:

>> mday_01(MSTAR_Directory_Key,MSTAR_prefix,RVS_Stream_name,day);

>> mday_02(MSTAR_Directory_Key,MSTAR_prefix,day);

Table 5.2 provides a breakdown of the arguments to "*mday_01*" and "*mday_02*" for the variables of interest during Di361. The MSTAR Directory Key is established when *m_setup* is run and points to the physical locations specified in the final column

of Table 2. For convenience, the two globally applicable tasks are called by single functions "*mday_00_get_all*" and "*mday_02_run_all*", with day-of-year number as an argument, that operate on each data stream automatically. Filenames resulting from *mday_01* generally take the form "*Prefix_Cruise_JDay_raw.nc*", for example a raw navigation file from day 40 would be "*gpsg2_di361_d040_raw.nc*", while the appended master files from mday_02 generally take the form "*Prefix_Cruise_MSCRIPT_CRUISE_SUFFIX.nc*", or "*gpsg2_di361_04.nc*".

The next sections explore in more detail the equipment and data processing applied to the data streams listed in table 5.2.

5.2 Navigational Data

High quality navigation data were necessary to orientate all the measurements made during the cruise. In addition, accurate ship speed and heading are important for making accurate underway measurements of ocean currents as well as wind speed and direction, for example, a heading error of 1 at a ship speed of 10 kts can produce errors of approximately 10 cm s^{-1} in upper ocean velocity perpendicular to the ship, as measured by the Vessel-mounted Acoustic Doppler Current Profiler (VMADCP).

RRS Discovery has three GPS receivers: the Trimble 4000, which is a differential GPS, the GPSG2, which was used as the primary source of navigational data, and the Ashtech 3DF GPS Attitude Detection Unit (ADU5). The ship also possesses a gyrocompass and Chernikeeff Electromagnetic (EM) log to measure ship speed and heading. Data from the Trimble 4000 and GPSG2 streams as well as position and attitude data from the Ashtech GPS and heading information from the gyrocompass were processed daily (table 5.2).

Table 5.2: Arguments to daily processing scripts for the variables of interest during Di361. The primary source of navigation information (referred to as M_POS) was the GPSG2 system, hence its repetition in the table. Also, two thermosalinograph (TSG) streams are recorded - both are supplied with conductivity and temperature from the SBE45 but *met_tsg* additionally contains data from the underway transmissometer and fluorometer (see relevant section of this cruise report.)

Data Stream	MSTAR Directory Key	MSTAR Prefix	RVS Stream Name	Physical File Location (~/cruise/)
GPSG2	M_GPSG2	gpsg2	gpsg2	data/nav/gpsg2
POS (default nav)	M_POS	Pos	gpsg2	data/nav/gpsg2
GPS4000	M_GPS4000	gps4000	gps4000	data/nav/gps4000
Ashtech ADU	M_ASH	Ash	adu5pat	data/nav/ash
Gyrocompass	M_GYR	Gyr	gyro_s	data/nav/gyros
Echosounder	M_SIM	Sim	ea600m	data/sim
Meteorology	M_MET	Met	surfmet	data/met/surfmet
Met Light	M_MET_LIGHT	met_light	surflight	data/met/surflight
TSG	M_TSG	Tsg	SBE45	data/tsg
Met TSG	M_MET_TSG	met_tsg	surftsg	data/met/surftsg
Chernikeeff Log	M_CHF	Chf	log_chf	data/chf

The gyrocompass provides a reliable estimate of the ships' heading that is not dependent on transmissions external to the ship. However, the instrument is subject to latitude- and velocity-dependent errors and has an inherent oscillation following a change of heading. Although the gyrocompass is reliable, the time-dependent errors need to be corrected using the less reliable but more accurate Ashtech ADU. This system comprises four antennae mounted two on top of the Wheelhouse and two on the Boat Deck forming a nearly rectangular array. Every second, the Ashtech calculates ship attitude (heading, pitch and roll) by comparing phase differences between the four incoming satellite signals. This is usually very accurate (to ~0.057), but occasionally the Ashtech unit failed to pick up enough GPS signals to provide an accurate fix. These periods were usually identifiable by spikes in the

heading, pitch and roll data that must be removed to avoid contaminating the ashtech-minus-gyro (a_minus_g) heading correction used in the calculation of the VMADCP velocities. The data for both these systems and the heading correction were calculated in daily segments before being applied to calibrate the VMADCP data.

A comparison of the position data produced by all three GPS streams was carried out (Figure 5.1). The GPSG2 and the GPS4000 agree to a high degree, within 30m, however there is considerably more scatter in the comparisons of both dedicated GPS systems with the Ashtech ADU (the Ashtech is not necessarily designed for such a function). In all three cases there appears to be some heading dependent bias although this is expected due to the different physical locations of the receivers mounted on the ship, the bias is considerably more pronounced in comparisons with the Ashtech system where disagreement is fairly large at ~150m.

At the start of the cruise while moored in Santa Cruz de Tenerife, it was discovered that the Ashtech ADU was producing a heading that was rotated 90 relative to the gyrocompass. Investigation by Martin Bridger, the underway technician, discovered that the ports the GPS receivers were plugged into the ADU had changed but that they were indeed connected to the correct ports. This misalignment was present during the previous cruise (Di360, TECHSAS data available from the 16th January 2011) but presumably not noticed because the heading data was not required. The cruise before that (Di359) made no mention of such a problem. An offset of 90 was thus introduced to the Ashtech configuration software to account for this. The large heading dependent position offsets (figure 5.1c and d) and a possible heading dependence of the ashtech/gyro differences (figure 5.1d) may require a more careful calibration of the system in the near future.

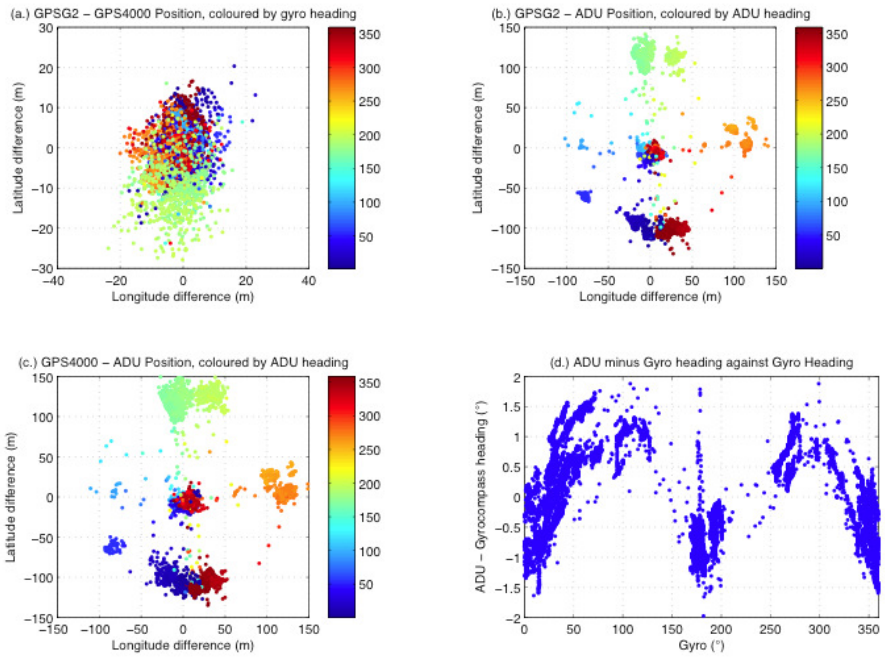


Figure 5.1: Position and heading comparisons between *Discovery's* GPS devices and gyrocompass

The GPSG2 stream was selected as the default navigation source. After extracting the data from TECHSAS using *mday_01* (or *mday_00_get_all*), the gyrocompass data from *gyr_di361_d???_raw.nc* was edited to remove non-monotonic times from the very high frequency output using "*mgyr_01"*, producing the output files *gyr_di361_d???_raw.nc*. Next, "*mash_01*" was run to merged the gyro heading into the Ashtech data file and calculate the Ashtech-gyrocompass heading correction. This script contains a quality control step that calls "*mdatpik*" such that data are removed outside the limits of head_ash (0 to 360), pitch (-5 to 5), roll (-7 to 7), mrms (0.00001 to 0.01), brms (0.00001 to 0.1), head_gyr (0 to 360) and a_minus_g (-7 to 7). Finally *mash_01* calculates two minute temporal averages producing "*ash_di361_d???.nc"* files. Note that the purpose of this process is to provide reliable heading information for VMADCP calculations - the emphasis is on removing bad data spikes and smoothing high-frequency variability. An additional step of manually cleaning the heading information will be carried out back at NOCS using the "*mplotxyed*" tool to blank out bad data points and linearly interpolate missing data. Finally, "*mgpsg2_01*" was used to rename the GPS field "*lon*" to "*long*" through a call to "*mheadr*". Longitude is currently referred to by the abbreviation "*long*" throughout MEXEC, causing Matlab's "undefined function or variable error".

Following concatenation of the navigation files using *mday_02*, the bestnav processing is completed by invoking "*mbest_all*", a convenient wrapper for the "*mbest_01*", "*mbest_02*", "*mbest_03*" and "*mbest_04*" sequence. These scripts run 30-second averaging on the 1Hz positions and gyrocompass data in the master file (to save worrying about day boundaries), producing the file "*pos_di361_ave_0?.nc*", and then calculates speed and ground course from the GPS data (in the file "*pos_di361_spd_0?.nc*"), before merging the GPS and gyro data into the bestnav file "*bst_di361_0?.nc*".

5.3 Echo Sounder Depth and Underway Bathymetry

RRS *Discovery* was equipped with a Simrad EA500 echo sounder (10.2/12.0kHz 'fish' and hull mounted system) to collect accurate depth measurements throughout the cruise. The estimated depth of the hull-mounted transducer was 5.3m while the Precision Echo Sounding (PES) transducer mounted in a "fish" was towed at an estimated depth of 8.5m. The PES fish transducer was used preferentially as it is less susceptible to bubbles and noise generated whilst the ship is steaming. The measured depth was logged by the TECHSAS system, assuming a constant sound velocity of 1500 ms^{-1} and displayed on the Simrad visual display unit, informing decisions to change the preset range and gain of the signal.

During the cruise, the echo sounder sometimes failed to detect the bottom for example if the transmitted ping penetrated thick layers of soft sediment on the sea floor before being reflected by the underlying bedrock, reporting either zeros or spuriously large depths – a particular example occurred during Station 4 off the Senegalese coast during ISW Turbulence profiling where the echo sounder was flipping between reported depths of ~30m, ~60m and ~120m. Tweaking the settings on the Simrad unit settled the depth at 64m.

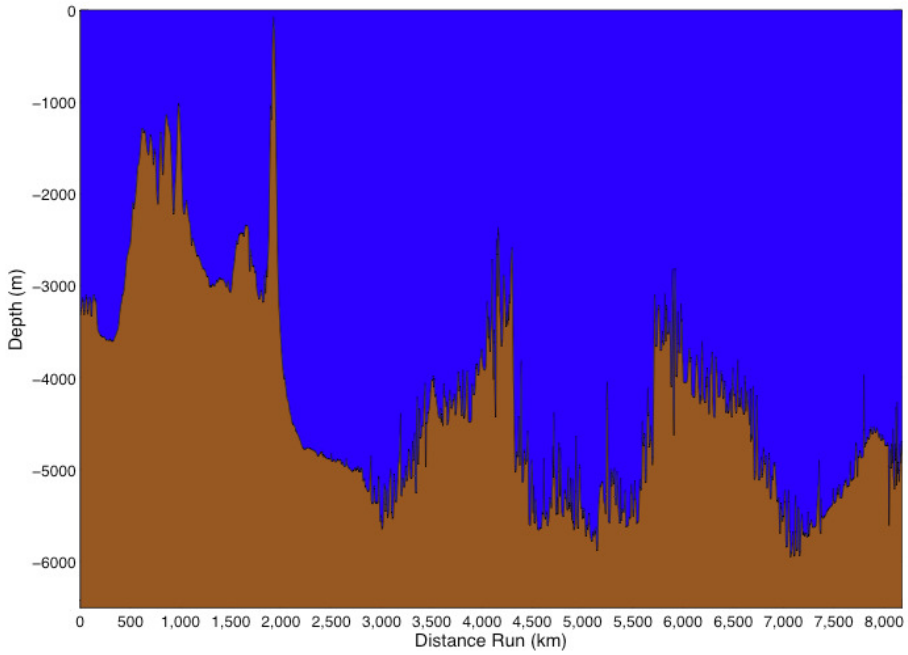


Figure 5.2: Median smoothed, Carter-corrected and 5km binned bathymetry data along the cruise track occupied during Di361.

The Raw echo sounder depths were extracted from the TECHSAS system using the appropriate call to "*mday_01*" (see table 5.2), saved following the form "*sim_di361_d???_raw.nc*" and then appended together with merging of position data during *mday_02*. Periodically, the raw bathymetry files would be refined by rejecting data outside a reasonable range (5 to 10000m), smoothed using a 5-minute median average and correct for the variable speed of sound using Carter table climatologies ("*mcarter*" option using "*mcalc*") using the script "*msim_01*", given a day-of-year with output directed into the file "*sim_di361_d???_smooth.nc*". The adjusted daily files were reappended using "*msim_02*", which takes the arguments of minimum and maximum day numbers to append (so several files can be processed automatically) and the level of processing that has occurred, producing the file "*sim_di361_procstep_0?.nc*". This last argument ("*procstep*") defaults to "*smooth*" to directly accept files produced by "*msim_01*", however once manual despiking and removal of bad data has been performed using "*mplotxyed*" at NOCS, then providing "*edited*" will append those files instead. The final part of "*msim_02*" also bins the bathymetry data into 5km along cruise-track bins producing the files "*sim_di361_procstep_5km_0?.nc*" (see figures 5.2 and 5.3).

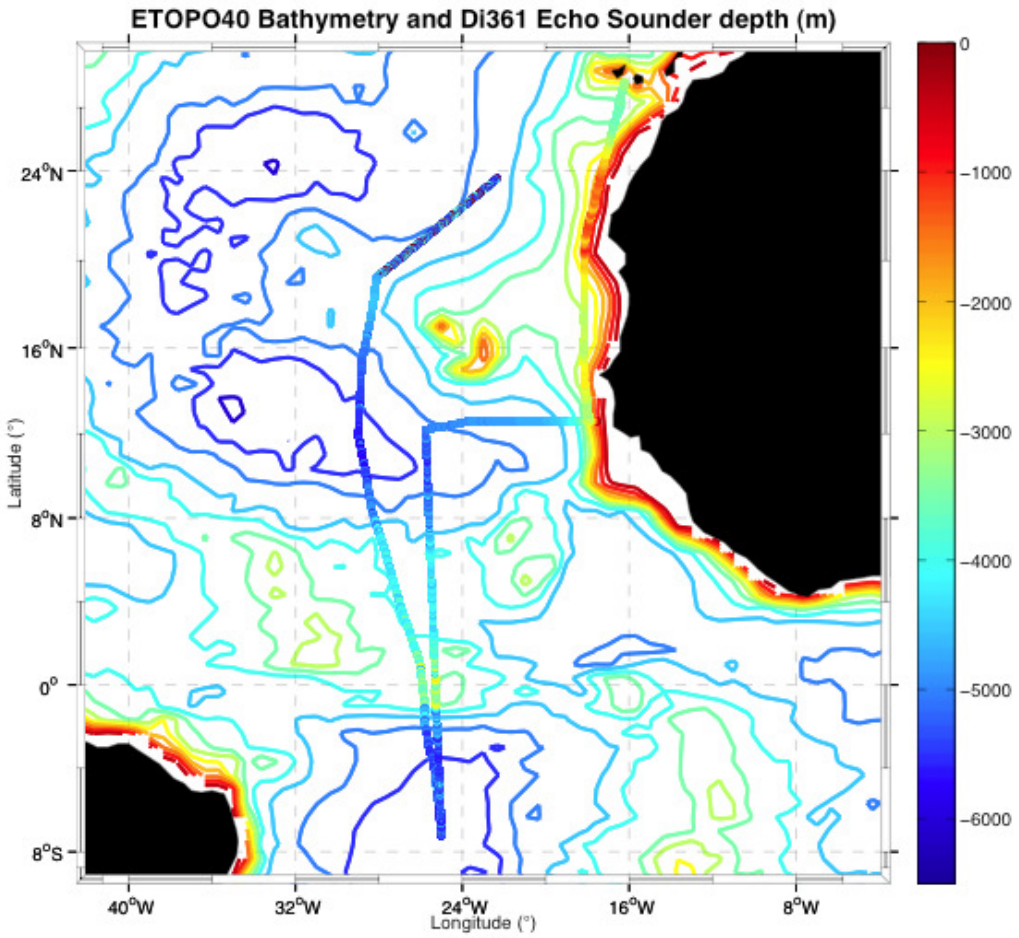


Figure 5.3: Corrected echo sounder depths (m) along the cruise track compared to the 40-minute ETOPO database.

5.4 Surface Meteorological Measurements (SURFMET)

RRS *Discovery* was equipped with a variety of meteorological sensors to measure air temperature and humidity, atmospheric pressure, total irradiance, photosynthetically active radiation, wind speed and wind direction throughout the cruise (see table 3). The radiation and pressure variables were logged in the directory "*cruise/data/met/surflight*" while the remaining data was logged in "*cruise/data/met/surfmet*".

Accumulated meteorological variables were recovered from the TECHSAS logging system using the appropriate call to "*mday_01*" (see table 5.1) and appended to the underway cruise file during "*mday_02*". Once the navigation data had been processed, the true wind speed and direction was computed relative to Earth using

the script "*mtruewind_02.m"* and saved in the files "*met_di361_true_0?.nc*" and "*met_di361_trueav_0?.nc*".

Table 3: Meteorological Instruments installed during Di361. TIR is total irradiance (335-2200nm) while PAR is photosynthetically active radiation (400-700nm).

Variable	Instrument	S/N	Position	Accuracy
Atmospheric Pressure	Vaisala PTB100A barometer	Z4740021	Port Foremast	0.1 hPa
Dry bulb air temp & Humidity	Vaisala HMP45A	E1055002	Port Foremast	Humidity ±1.1% Temp ±0.15 C
Wind speed & direction	Gill sonic anemometer	071123	Port Foremast	Speed ± 0.24 m/s Direction ± 3
TIR	Kipp & Zonen CM6B pyranometer	994133	Port	9.70 V/W/m^2
		962276	Starboard	10.28 V/W/m^2
PAR	Skye SKE510 sensor	28559	Port	11.21 V/W/m^2
		28558	Starboard	10.87 V/W/m^2

Periodically, the raw meteorological data would be refined by applying calibrations to the barometric pressure (linear correction, *c = 0.2884, m=0.9997*), PAR (ratio correction, *pPAR = 11.21 V/W/m^2, sPAR = 10.87 V/W/m^2*) and TIR (ratio correction, *pTIR = 9.70 V/W/m^2, sTIR = 10.28 V/W/m^2*) sensors and smoothing into 1-minute temporal median bins using "*msurfmet_01*", producing the files "*met_light_di361_d???_cal.nc*", "*met_light_di361_d???_smooth.nc*" and "*met_di361_d???_smooth.nc*". The adjusted daily files were reappended using "*msurfmet_02*", which takes the arguments of minimum and maximum day numbers to append (so several files can be processed automatically) and the level of processing that has occurred, producing the file "*met_di361_procstep_0?.nc*" and "*met_light_di361_procstep_0?.nc*". This last argument ("*procstep*") defaults to "*smooth*" to directly accept files produced by "*msurfmet_01*", however once manual despiking and removal of bad data has been performed using "*mplotxyed*" at NOCS, then providing "*edited*" will append those files instead.

During the cruise it was noticed that the barometric pressure was recording a visible diurnal signal that was attributed to atmospheric tides (figure 5.4).

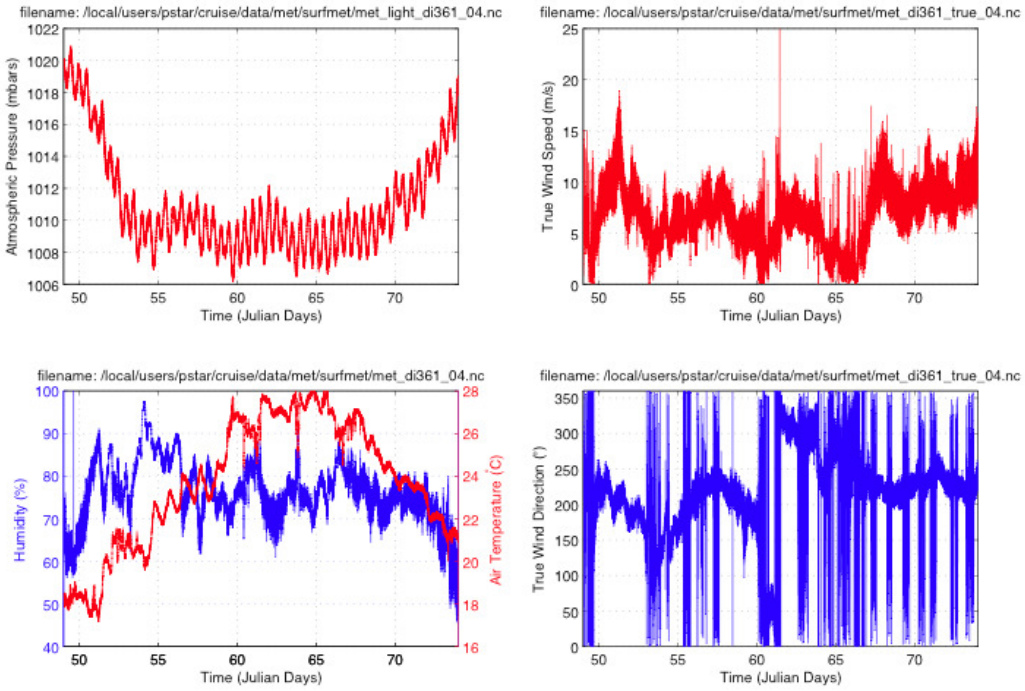


Figure 5.4: Meteorological data collected during Di361 (a.) atmospheric pressure (mbar), (b.) true wind speed (ms^{-1}), (c.) atmospheric temperature (C) and relative humidity (%) and (d.) true wind direction ( )

5.5 Underway Temperature, Salinity, Fluorescence & Transmittance

Near surface temperature, salinity, fluorescence and transmittance were measured throughout the cruise by instruments located in the non-toxic supply. The inlet for this supply is situated on the underside of the hull, close to the bow and surface waters are pumped past a Seabird 38 temperature sensor mounted within a few metres of the inlet, before reaching the fluorometer, transmissometer and thermosalinograph in the water bottle annex (WBA). Details of the instruments are given in Table 5.4.

Files were transferred from the TECHSAS onboard logging system on a daily basis using the relevant calls to "*mday_01*" and "*mday_02*" (see table 5.1). Data from the Seabird TSG was logged in both the "*cruise/data/met/surftsg"* and "*cruise/data/tsg/"* directories, with the additional transmittance and fluorescence data logged in the former location.

Table 5.4: Underway Instruments installed during Di361. WBA is the Water Bottle Annex

Variable	Instrument	S/N	Position
Temperature	SBE45 MicroTSG	229	WBA
	SBE38 Digital Thermometer	0490	Hull intake
Salinity	SBE45 MicroTSG	229	WBA
Transmittance	Wetlabs Tranmissometer	CST-112R	WBA
Fluorescence	Wetlabs Fluorometer	117	WBA

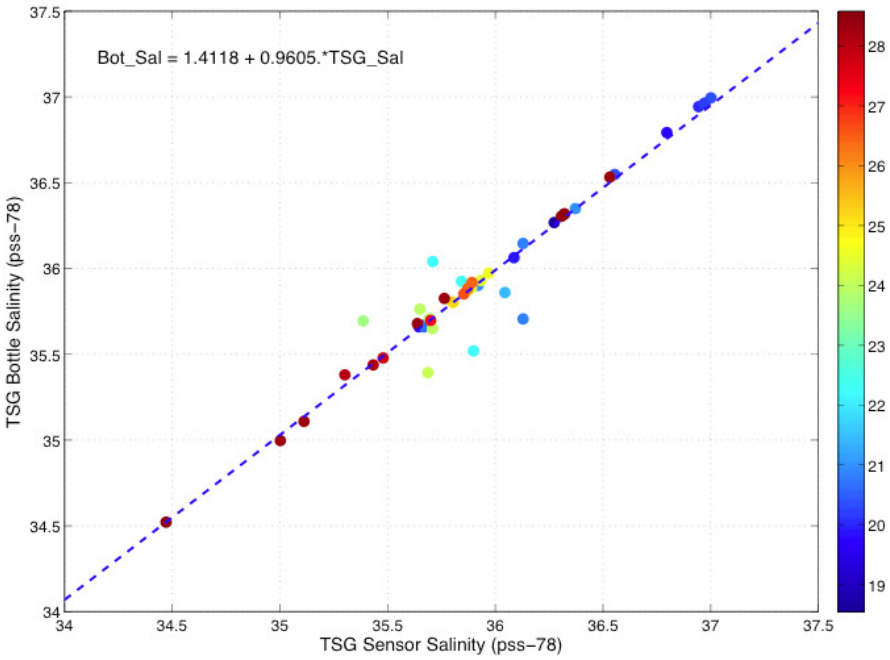


Figure 5.5: Calibration of the TSG Salinity against measured bottle salinity shaded according to *in situ* (intake) temperature (C)

Water samples from the TSG outflow pipe were collected for calibration of the TSG salinity in 200ml flat glass bottles at ~4 hour intervals throughout the cruise. Before each sample was taken, the sample bottles were rinsed thoroughly 3 times with the sample water from the non-toxic supply. Bottles were filled halfway up the shoulder and the necks wiped dry to prevent contamination of the sample by salt crystallisation at the bottle opening and sealed using airtight, single-use plastic inserts before the bottle cap was refitted. The samples were stored in open crates and left in the controlled temperature laboratory for a minimum of 24 hours before analysis, ensuring full adjustment to the ambient temperature of the laboratory. A total of 76 TSG samples were taken during the cruise, although only 48 were available at the time of writing.

The conductivity ratio of each sample was measured using the salinometer, and the corresponding salinity value was calculated using the OSIL salinometer data logger software, and stored in a Microsoft Excel spreadsheet. The measured salinities of the samples were transferred to a text file, along with the date and time of collection. This file was converted to NetCDF format, and the dates and times were converted into seconds since midnight on 1st January 2011 using "*mtsg_01.m*". This script

appends data from successive processed crates to the file "*tsg_di361_bottle_04.nc*". The script "mtsg_02" then extracts the concurrent TSG data and merges with the bottle data using a 10-minute averaging window of the raw 0.5Hz data to account for inaccuracies in the logged sample time. Bottle-TSG salinity pairs were regressed against each other to evaluate a linear calibration to apply to TSG salinity (figure 5.5). Additionally, these data were compared to *in situ* and WBA temperature and with time, revealing no significant biases or drift.

The final calibration, in which bottle salinity is assumed to be "true" salinity, is:

$$Bottle\_Salinity = 1.4118 + 0.9605 \times TSG\_Salinity \qquad \text{Equation (1)}$$

Applying equation (1) to the TSG salinities reduces mean residuals from 0.00674 to roughly zero (-8.734×10^{-15}). This task is carried out by the script "*mtsg_03*" which operates on the daily files calibrating salinity and transmittance if supplied with the relevant slope and offset parameters (salinity) and reference and blocked voltage readings (transmittance) before median averaging the data into 1-minute bins, producing the files "*[met_]tsg_di361_d???_cal.nc*" and "*[met_]tsg_di361_d???_smooth.nc*". Chlorophyll samples from the underway system may also be used to calibrate the fluorometer, although this was not attempted here. Finally, "mtsg_04" appends these daily files together in a similar fashion to "*msim_02*" and "*msurfmet_02*", taking "smooth" as the default processing stage. Manual editing of bad data will be performed at NOCS in the future – the TSG transmissometer was susceptible to bubbles becoming trapped and therefore will require some cleaning of the data. Figures 5.6 and 5.7 show the underway variables collected during Di361.

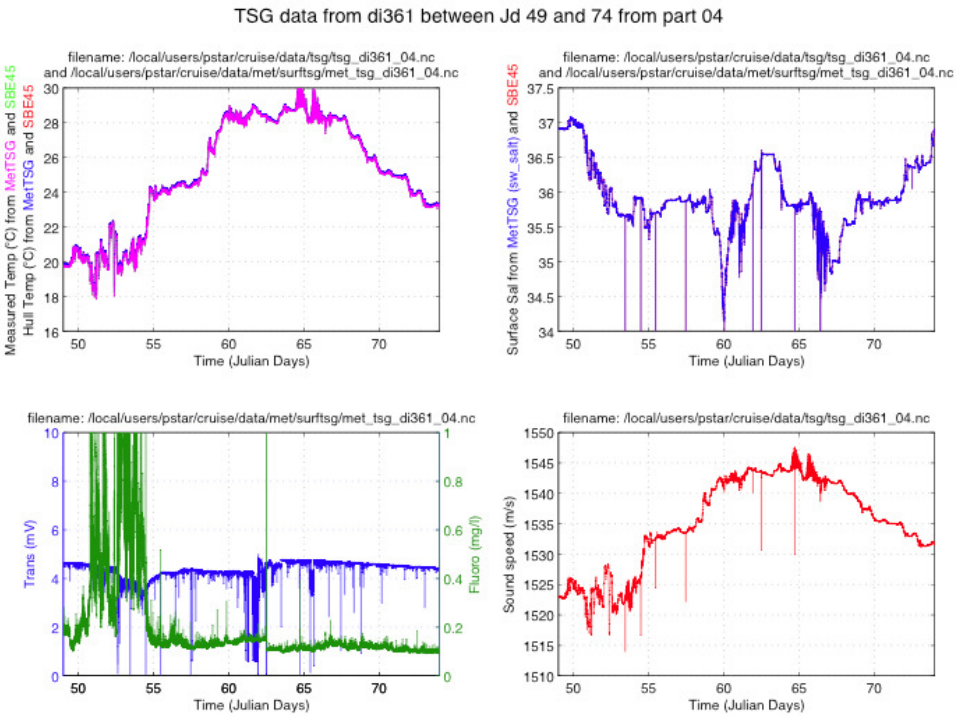


Figure 5.6: Surface ocean data collected during Di361 plotted against time. The large signal in the Fluorescense between days 50 and 55 are collected from along the northwest Africa coast, while the low salinity signals on days 60 and 63 were collected along the equator.

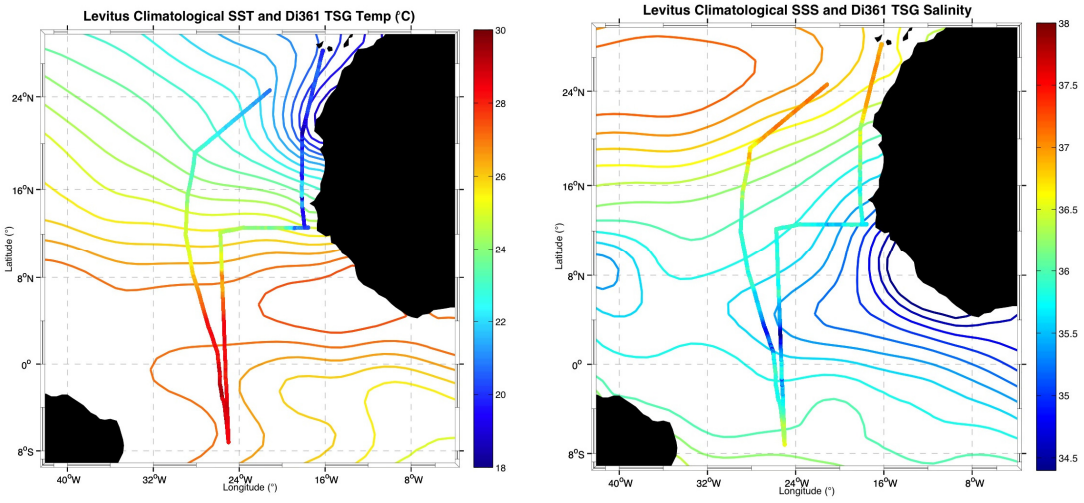


Figure 7: Underway a) temperature and b) salinity along the Di361 cruise track compared to Levitus climatological values. Note the displacement of isotherms/isohalines due to comparison of annual average climatology with boreal winter data.

5.6 Vessel Mounted Acoustic Doppler Current Profiler Upper Ocean Velocity

RRS *Discovery* is fitted with two vessel-mounted Acoustic Doppler Current Profilers (ADCPs) fitted to the hull of the ship to measure the upper ocean horizontal velocity field. Usually one of the Ocean Surveyor (OS) instrument operates at 75kHz (OS75) and the other at 150kHz (OS150), however, on this occasion OS150 was unavailable as it was removed by divers whilst docked in Santa Cruz de Tenerife. The depths of the transducers are 5.3m. Both transducers are of the phased-array type, which means that they are made up of many elements each transmitting in different phase. This is advantageous, because it means that the accuracy of the velocities derived from the Doppler shifted return signals is not affected by speed of sound changes throughout the water column. If the speed of sound changes in the water column or in front of the transducer, the angle of the beam will consequently change in the same ratio as the Doppler shift equation, meaning that a change in the Doppler frequency shift of a particle moving parallel to the face is compensated by the corresponding beam angle shift, cancelling out the change in the speed of sound. However, the range and accuracy is particularly affected by exposure to bubbles especially in rough weather.

OS75 data was acquired using the RD Instruments VmDas software package installed on a dedicated Microsoft Windows XP PC in the main laboratory. The software performs preliminary screening and transformation of the data from beam to Earth coordinates. VmDas is opened from the Start Menu and data acquisition is initiated by clicking on “Collect Data” in the File Menu. Instrument options are set under “Options”, “Edit Data Options” and then set the configurable parameters. In particular, the OS75 was set to measure 65 bins of 16m depth with a transducer depth of 5.3m and a blanking depth of 8m in order to avoid ringing from the transmit pulse. The files are stored in the directory “*C:/RDI/ADCP/DI361_OS75/*” and is exported from Windows XP as a shared folder that is mounted on *eurus* under “*cruise/data/vmadcp/di361_os75/network/*” to allow easy access to the raw data.

Under the ADCP setup tab, the relevant control file (“*di361_os75_??.txt*”, *wt* for water track mode and *bt* for bottom track mode) was selected. It is important each time the ADCP is restarted to increase the number in the recording tab by 1, otherwise VmDas may overwrite previously written files. Recording commences by clicking the blue record button in the top left of the screen and stops by pressing the blue stop recording button in the top left of the screen. Data collection was typically stopped and restarted with a new file number everyday during the cruise (nominally 1200hrs). Leaving it on the same file for too long allows the files to become too large and post-processing becomes slow. The files we produced have names of the form

"*os75_di361nnn_filenumber.ext*", where "*nnn*" is the file sequence number, "*filenumber*" is the number of the file in the sequence and *"ext"* is the extension (see below). We set a new *"filenumber*" to occur every time a file size of 10Mb was reached. The list of files produced is given below:

.ENR files are the binary raw data files.
.ENS files are binary ADCP data after being screened for RSSI and correlation and with navigation data included.
.ENX files are ADCP single ping data and navigation data after having been bin-mapped, transformed to Earth coordinates and screened for error velocity and false targets.
.STA files are binary files of short-term average ADCP data (120s**,** user-specified in VmDas).
.LTA files are binary files of long-term average ADCP data (600s, user-specified in VmDas).
.N1R files are ASCII text files of raw NMEA navigation data from the NMEA1 stream.
.N2R files are ASCII text files of raw NMEA navigation data from the NMEA2 stream.
.NMS files are binary files of navigation data after screening.
.VMO files are ASCII text files specifying the option settings used for the data collection.
.LOG files are ASCII text files logging all output and error messages.

The 'R', 'S' and 'L' tabs on the VmDas menu bar allow you to swap between graphical output from the .ENR, .STA and .LTA files. When in 'R' mode, the raw velocity parallel to each beam is displayed, but this can be difficult to interpret as it is shown in beam coordinates. A more useful plot can be made in either the 'S' or the 'L' mode, displaying average profiles of speed, direction and profiles of percent good returns. The data can also be inspected in real-time using the WinADCP software, which loads the .ENX, .STA or .LTA files and displays the output as contour plots. The Monitor Option should be switched on with a suitable time interval (120s) so the contour plot is regularly updated. Plots of *u* and *v* were routinely examined throughout the cruise to check the data stream.

Throughout Di361, OS75 was operated in narrowband single-ping mode and on the rare occasions where depth permitted, the bottom-tracking feature was enabled to obtain the most accurate phase and amplitude calibrations (~30 minutes sailing out of Tenerife and several hours off the Senegalese coast).

Processing of the raw ADCP velocities from the ENX files was achieved using CODAS (Common Ocean Data Access System) routines provided by the University of Hawaii. This suite of Python, Unix and Matlab programs allows manual inspection and editing of bad profiles and provides best estimates of the required rotation of the data, either from water profiling or bottom tracking. Once loaded into the *rawdata* directory ("*cruise/data/vmadcp/di361_os75/rawdata*"), the shell script "vmadcp_movescript" was run creating a new directory "*rawdata???*" and moves the relevant data to this new location.

The command "*adcptree.py di361???nbenx --datatype enx*" sets up a directory tree for the CODAS dataset and an extensive collection of configuration files, text files and Matlab routines. The main script from hereon is "*quick_adcp.py*", whose function can be controlled by providing text control files with the "*--cntfile*" option. Firstly, "*q_py.cnt*" loads the ADCP velocities into the CODAS database, performs routine editing and processing, averages the data into 5-minute periods and makes estimates of water track and (if available) bottom track calibrations. These values are stored in "*cal/watertrk adcpcal.out*" and "*cal/watertrk/btcaluv.out*" files and are appended each time "*quick_adcp.py*" is run.

The Gautoedit package within CODAS allows the user to review closely the data collected by VmDas and flag any data that is deemed to be bad. These flags can then be passed forward using the "*q_pyedit.cnt*" control file and the data removed. Gautoedit is run for Matlab by entering "*m_setup; codaspaths; gautoedit*" usually after the first "*quick_adcp.py*" step to observe whether the ENX files had processed correctly. The start time of the ENX file was entered in the "*decimal day (start)*" box, the length of the dataset was entered in the "*decimal day step*" box, the "*show amplitude*" and "*use depth as vertical coordinate*" options selected and the "*show now*" button pressed to produce a series of figures. The first displays the absolute east-west (U) velocity component, absolute north-south (V) component and the percentage good parameter. The second figure contains subplots of the ships' track and absolute velocity vectors in the upper 20 bins. Initially, there was bug within this part of the software where Gautoedit crashed during the plotting of the ships' track and velocity vectors. This was due to the Matlab "*m_map*" package not being able to find an initialised map projection, which was easily correct by moving the call to "*m_proj*" up from line 199 to line 194 in "*cruise/sw/uh_adcp/programs/matlab/autoedit/apuv.m*". This initial review of the data allows the user to confirm the direction of steaming, identify the position of on-station and off-station parts of the file and spot any areas with low percentage good.

Gautoedit automatically flags bad data below 50% good signal, which covered most eventualities but more rigorous inspection and rejection of bad data will take place on return to NOCS. The "*del bad times*" command removes entire temporal sections of the data while the "*pzap bins*" command allows the user to flag all data within a defined polygon. Once satisfied with the changes made, the "*List to Disk"* option is selected which creates and updates "*a*.asc*" files in the "*di361???nbenx/edit*" directory. These edit are then applied by issuing the command "*quick_adcp.py --cntfile q_pyedit.cnt*".

A heading correction file was created in Matlab by running the script "*make_g_minus_a(75,???)*" in order to subtract the Ashtech heading from that of the shipboard gyrocompass. In the "*cal/rotate*" directory the "*rotate.tmp*" file was edited to point to the appropriate "*g_minus_a*" file that was created in the previous step (usually "*di361???nbenx/edit/di361???nnx.rot*"). The rotation to the database was applied with "*rotate rotate.tmp*"and using "*quick_adcp.py --cntfile q_pytvrot.cnt*" the time dependant heading correction was then run.

Finally, the invariant amplitude and phase corrections were applied using "*quick_adcp.py --cntfile q_pyrot.cnt*". The best calibration estimates are obtained when the velocity data is collected using the seabed as a reference. Our two bottom-track estimates were recorded early in the cruise and the mean values (phase=-1.6304 , amp=1.00245) were applied throughout. However, comparison of the two passes of the equatorial current system (ECS, the first heading south and the second heading north) revealed considerable red-shift (positive) u velocity, which is equivalent to cross-track velocity, initially and blue-shift (negative) u velocity later (see figure 5.8).

Analysis of the mean water-track phase and amplitude calibrations highlighted significant deviation from the bottom track estimates (figure 5.9) of approximately one degree, which is equivalent to a cross-track velocity error of around 10 cm s^{-1} or roughly the velocity offset that is observed assuming that the ECS is relatively stable. Although there may still be tidal signals contaminating the ADCP measured velocity, this would probably produce a vertically banded signature in time with the ebb and flood, not a constant offset. Given that the only rotational corrections made to the OS75 are associated with heading and also given the heading dependent errors in the Ashtech ADU data compared to the alternative GPS receivers (figure 1) then this could, speculatively, be the cause – at a constant heading (i.e. north or south for the two passes of the ECS), these errors might manifest as a constant rotational offset.

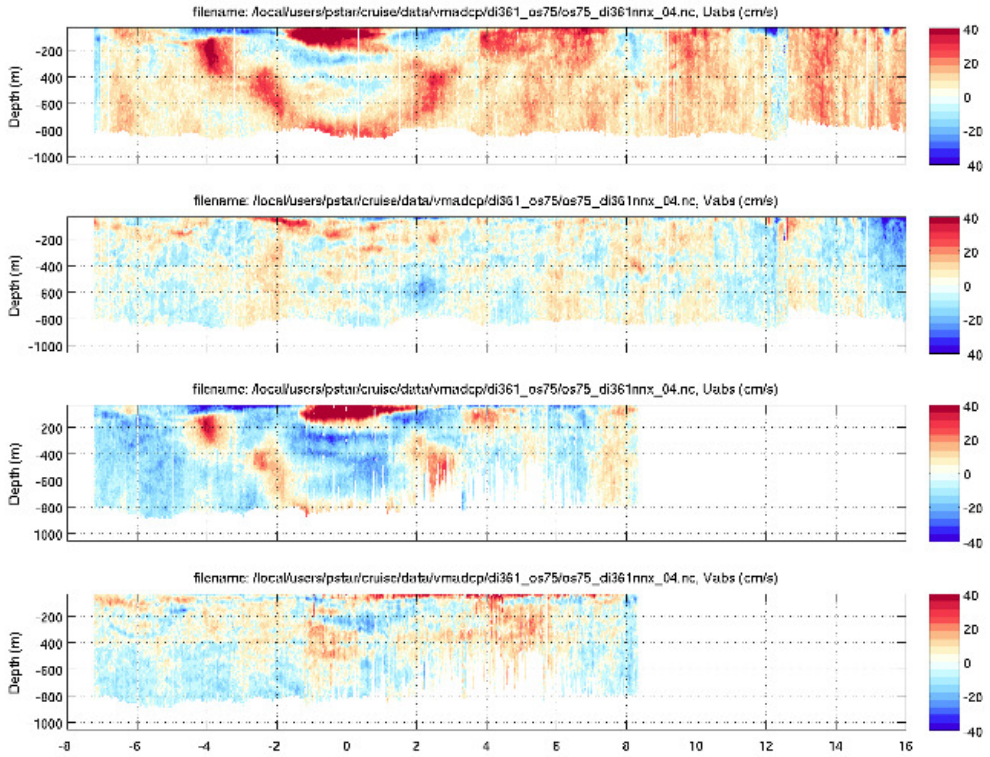


Figure 5.8: Initial sections of upper ocean velocity between 8 S and 16 N for first pass u (top) and v (upper) velocities and second pass u (lower) and v (bottom) velocities. Note the positive bias in zonal velocity for the first pass heading south and the negative bias in zonal velocity for the second pass heading north. Meridional velocities are broadly similar for both passes.

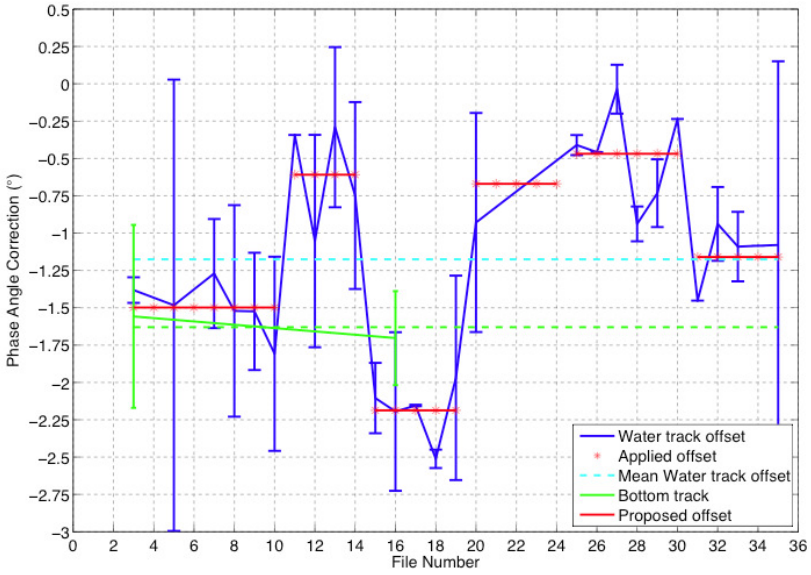


Figure 5.9: VMADCP phase corrections calculated from water-track and bottom-track data (where available) collected during Di361 and the corrections applied within "*q_pyrot.cnf*" to the final ADCP data. File 002 starts from 1200 on JD49.

Applying the average phase correction in each of the observed groups in figure 5.9 indeed removes the ECS cross-track biases for the two passes of the ECS (figure 5.10 and 5.11), although a more rigorous and detailed investigation will be carried out post-cruise. Comparison with CTD Lowered ADCP (LADCP) upper ocean velocity estimates is mostly satisfactory, with the majority of stations producing similar results in both magnitude and vertical structure (figure 5.12).

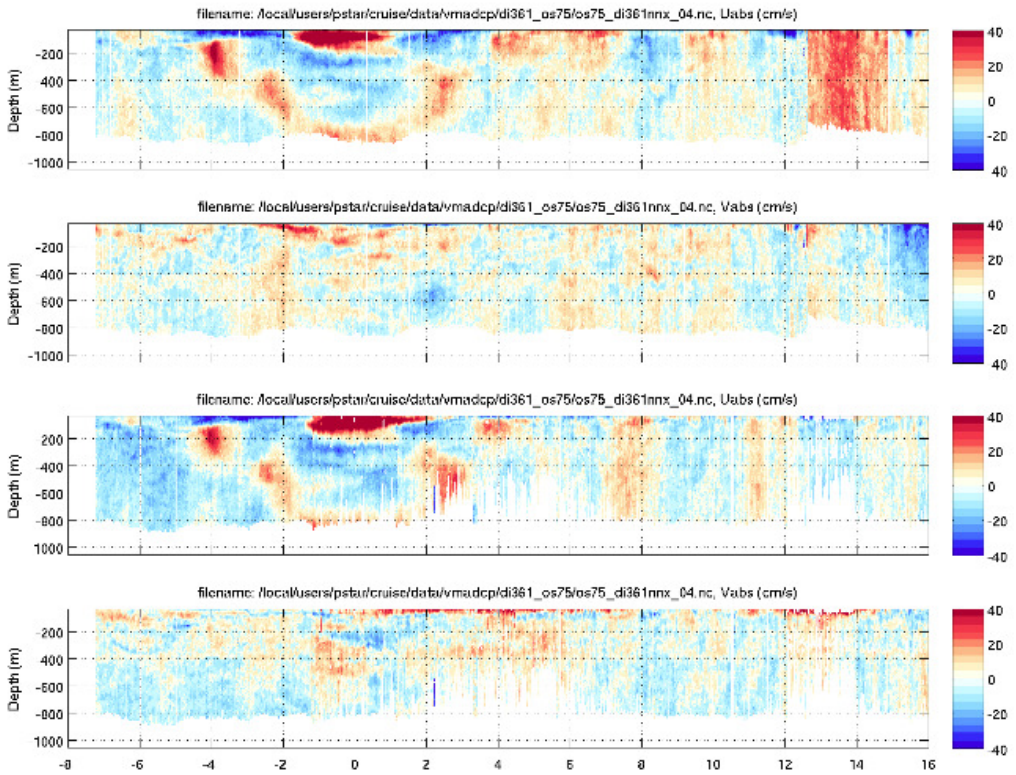


Figure 5.10: Adjusted sections of upper ocean velocity between 8 S and 16 N for first pass u (top) and v (upper) velocities and second pass u (lower) and v (bottom) velocities.

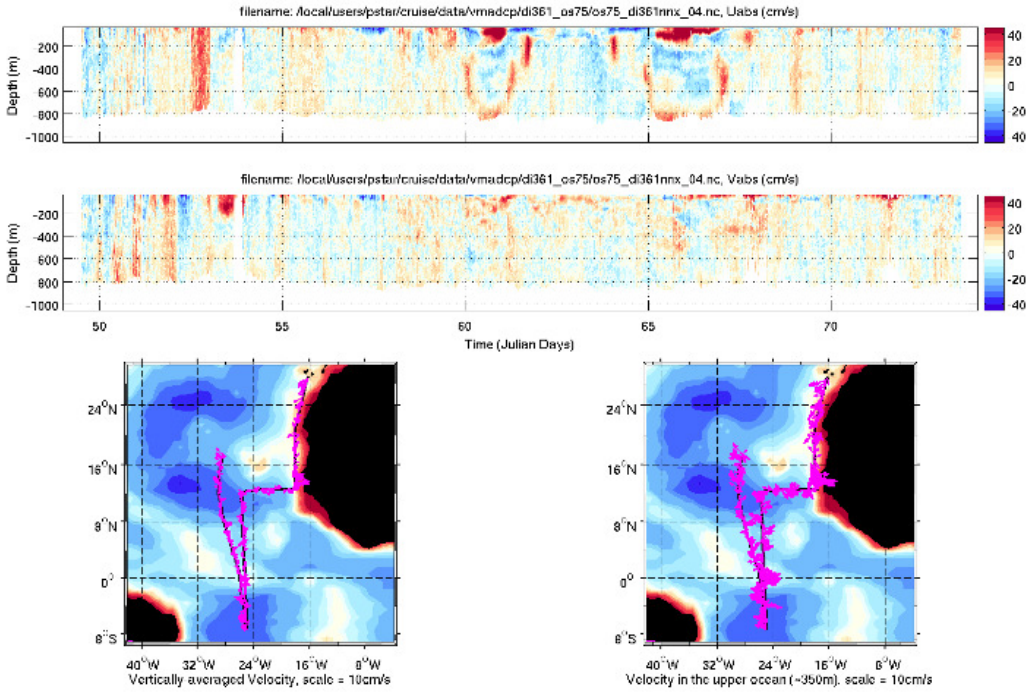


Figure 5.11: Adjusted sections of VMADCP u (top) and v (lower) velocities as a function of time with bottom two panels showing vertically averaged (left) and averaged in velocities the top 350m (right) along the Di361 cruise track.

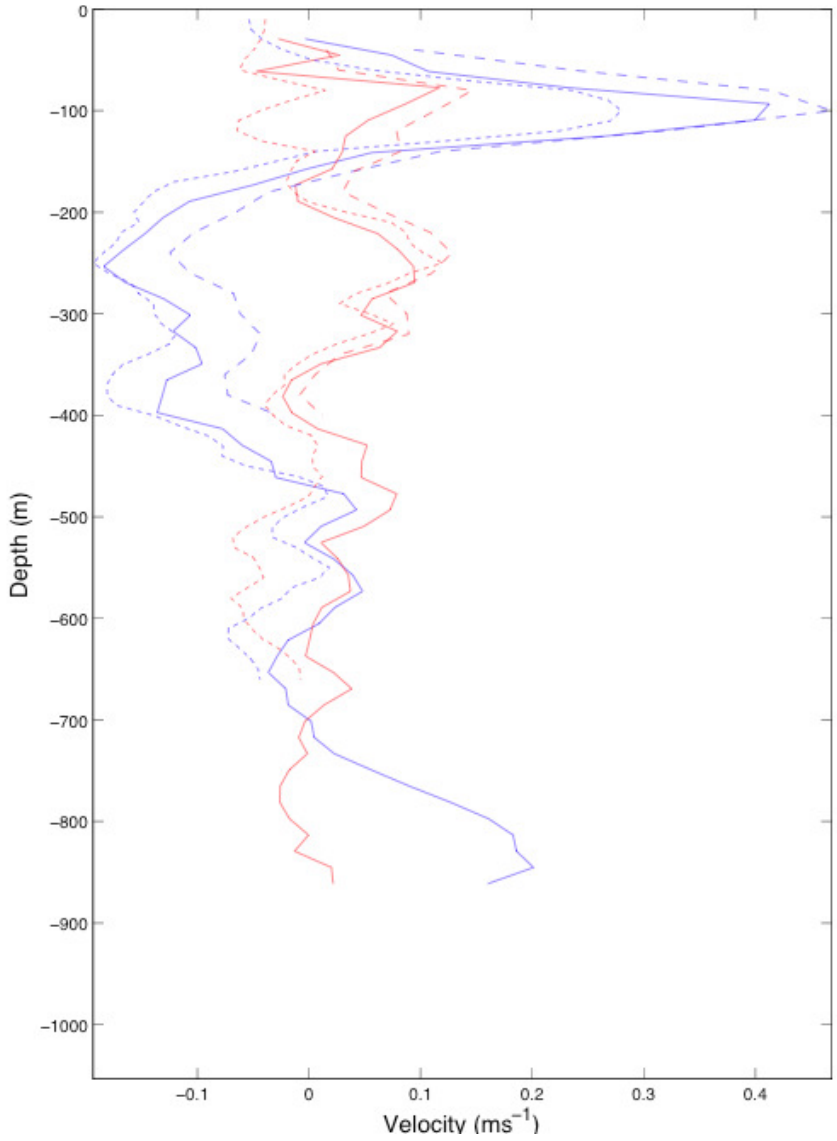


Figure 5.12: Comparison of VMADCP and LADCP velocities at station 29. The blue lines are u velocity (m s^{-1}) and red lines are v velocity (m s^{-1}). VMADCP velocities are the solid lines, LADCP velocities calculated using the University of Hawaii (UH) software are shown as dashed lines and LADCP velocities calculated using the Lamont-Doherty Earth Observatory (LDEO) software are show as dotted lines.

6 NMF-SS Sensors & Moorings Cruise Report

Jeff Benson, Allan Davies

6.1 CTD system configuration

1) Two CTD systems were prepared; the first water sampling arrangement was a NOC 24-way stainless steel frame system, (s/n SBE CTD4 (1415)), and the initial sensor configuration was as follows:

Sea-Bird 9plus underwater unit, s/n 09P-46253-0869

Sea-Bird 3P temperature sensor, s/n 03P-2674, Frequency 0 (primary)

Sea-Bird 4C conductivity sensor, s/n 04C-2231, Frequency 1 (primary)

Digiquartz temperature compensated pressure sensor, s/n 100898, Frequency 2

Sea-Bird 3P temperature sensor, s/n 03P-4872, Frequency 3 (secondary, vane mounted)

Sea-Bird 4C conductivity sensor, s/n 04C-3258, Frequency 4 (secondary, vane mounted)

Sea-Bird 5T submersible pump, s/n 05T-3002, (primary)

Sea-Bird 5T submersible pump, s/n 05T-3088, (secondary, vane mounted)

Sea-Bird 32 Carousel 24 position pylon, s/n 32-37898-0518

Sea-Bird 11plus deck unit, s/n 11P-24680-0587

2) The auxiliary input initial sensor configuration was as follows:

Sea-Bird 43 dissolved oxygen sensor, s/n 43-0709 (V0)

Tritech PA200 altimeter, s/n 6196.118171 (V2)

Chelsea MKIII Aquatracka fluorometer, s/n 88-2050-095 (V3)

Chelsea 2-pi PAR irradiance sensor, UWIRR, s/n PAR 10 (V4)

Chelsea 2-pi PAR irradiance sensor, DWIRR, s/n PAR 09 (V5)

Chelsea MKII 25cm path Alphatracka transmissometer, s/n 161047 (V6)

WETLabs light scattering sensor, red LED, 650nm, s/n BBRTD-167 (V7)

3) Additional instruments:

Ocean Test Equipment 20L ES-120B water samplers, s/n's 27-33, 36-41, 43, 44, 46, 48-59

Sonardyne HF Deep Marker beacon, s/n 245116-001

NOC 10 kHz acoustic bottom finding pinger, s/n B7

TRDI WorkHorse 300kHz LADCP, s/n 13329 (downward-looking)

NOC WorkHorse LADCP battery pack, s/n WH007

4) Sea-Bird 9*plus* configuration file D361_st_NMEA.xmlcon was used for all CTD casts, with D361_st_noNMEA.xmlcon used for the back-up, simultaneous logging desktop computer. Both PAR sensors were removed for any cast deeper than 500 metres. The LADCP command file used for all casts was WHMD361.txt.

5) The second water sampling arrangement was a NOC 24-way titanium frame system, (s/n SBE CTD TITA1), and the initial sensor configuration was as follows:

Sea-Bird 9plus underwater unit, s/n 09P-34173-0758

Sea-Bird 3P temperature sensor, s/n 03P-4383, Frequency 0 (primary)

Sea-Bird 4C conductivity sensor, s/n 04C-3767, Frequency 1 (primary)

Digiquartz temperature compensated pressure sensor, s/n 90074, Frequency 2

Sea-Bird 3P temperature sensor, s/n 03P-4592, Frequency 3 (secondary, vane mounted)

Sea-Bird 4C conductivity sensor, s/n 04C-3768, Frequency 4 (secondary, vane mounted)

Sea-Bird 5T submersible pump, s/n 05T-3085, (primary)

Sea-Bird 5T submersible pump, s/n 05T-3086, (secondary, vane mounted)

Sea-Bird 32 Carousel 24 position pylon, s/n 32-34173-0493

Sea-Bird 11plus deck unit, s/n 11P-19817-0495

6) The auxiliary input initial sensor configuration was as follows:

Sea-Bird 43 dissolved oxygen sensor, s/n 43-0619 (V0)

Benthos PSA-916T altimeter, s/n 874 (V2)

Chelsea MKIII Aquatracka fluorometer, s/n 088244 (V3)

Chelsea 2-pi PAR irradiance sensor, DWIRR, s/n PAR 02 (V4)

Chelsea 2-pi PAR irradiance sensor, DWIRR, s/n PAR 03 (V5)

Chelsea MKII 25cm path Alphatracka transmissometer, s/n 161-2642-002 (V6)

WETLabs light scattering sensor, red LED, 650nm, s/n BBRTD-168 (V7)

7) Additional instruments:

Ocean Test Equipment 10L ES-110B trace metal-free water samplers, s/n's 1 through 29

Sonardyne HF Deep Marker beacon, s/n 234002-002

TRDI WorkHorse 300kHz LADCP, s/n 13399 (downward-looking)

NOC WorkHorse LADCP battery pack, s/n WH008T

8)) Sea-Bird 9*plus* configuration file D361_ti_SEARAM.con was used for the CTD casts. The LADCP command file used for all casts was WHMD361.txt.The PAR sensors were removed for any cast deeper than 500 metres.

6.2 Other instruments

1) Autosal salinometer---One salinometer was configured for salinity analysis, and the instrument details are as below:

Guildline Autosal 8400B, s/n 68958, installed in Stable Laboratory as the primary instrument, Autosal set point 24C, 27C or 30C, depending upon Stable Laboratory temperature variations.

2) Fast Repetition Rate Fluorometer---One FRRF system was installed as follows:

Chelsea MKI, s/n 05-4845-001---Configured for underway sampling, located in Deck Laboratory.

3) Stand Alone Pump System---Three SAPS were deployed up to depth of 530 metres on Kevlar wire, serial numbers as follows:

03-01, 03-04, 03-06 and 03-07

Note A: Technical detail report

S/S CTD

Cast D361035 had only 23 water samplers closed (position 24 was not initiated.)

Cast D361048 had all water samplers closed one position higher than sampler firing number, i.e. sampler 24 was closed in position one, sampler 1 was closed in position two, etc.

Ti CTD

Changed out secondary conductivity sensor s/n 04C-3768 for s/n 04C-2164 beginning cast D361008, as 3768 was damaged when vane impacted against vessel. New configuration file written: D361_ti_1_SEARAM.con.

No water collected as Carousel did not 'fire' samplers cast D361016 (cables from 17P to 9P and SBE 32 incorrectly connected).

Only two samplers 'fired' on cast D361019, as battery voltage below operating limit at 4500m on up cast.

No water collected as Carousel did not ‘fire’ samplers cast D361027 (neither criteria of maximum pressure nor hold at bottom for two minutes met.)

Tubing from SBE pump to SBE secondary sensor pair displaced prior to cast D361032, data from secondary sensors therefore spurious.

Total number of casts -22 S/S frame, 27 Ti frame.

Casts deeper than 500m - 2 S/S frame, 21 Ti frame.

Deepest casts -1005m S/S frame, 5631 Ti frame.

Autosal

Serial number 68958 has significant algae growth in conductivity cell, and in bath. Soaked for 24 hours with 5% Decon, 10% methanol and 85% Milli-Q water; flushed 200ml solution repeatedly through cell, repeated over several days throughout cruise to inhibit further growth and clean cell. Analysis comparison run with s/n 60839 displays comparable values, i.e no drift in s/n 68958.

FRRF

No issues reported

SAPS

S/n 03-06 has malfunctioning (low volume) buzzer.

LADCP’s

Script file corrupted for deployment D361009m; no data collected (s/n 13329).

7 Computing and Ship Systems Report

Martin Bridger

RVS LEVEL C System

Level C - The level C system is a Sun Solaris 10 UNIX Workstation discovery1 also known as ABCGATE. The RVS software suite is available on this machine. This suite of software allows the processing, editing and viewing of all data within the RVS data files. This system also has monitors that allow us to ensure that the level C is receiving data from the level B.

Ifremer Techsas System

The Ifremer data logging system is the system that will inevitably replace the existing Level A + B system while for the most part the Level C will remain as the main system for outputting, viewing and editing the acquired data.

The Techsas software is installed on an industrial based system with a high level of redundancy. The operating system is Red Hat Enterprise Linux Edition Release 3. The system itself logs data on to a RAID 0 disk mirror and is also backed up from the Level C using a 200GB / 400GB LTO 2 Tape Drive. The Techsas interface displays the status of all incoming data streams and provides alerts if the incoming data is lost. The ability exists to broadcast live data across the network via NMEA.

The storage method used for data storage is NetCDF (binary) and also pseudo-NMEA (ASCII). At present there are some issues on some data streams with file consistency between the local and network data sets for the ASCII files. NetCDF is used as the preferred data type as it does not suffer from this issue.

The Techsas data logging system was used to log the following instruments:

1) Trimble GPS 4000 DS Surveyor (converted to RVS format as gps_4000)
2) Chernikeef EM speed log (converted to RVS format as log_chf)
3) Ships Gyrocompass (converted to RVS format as gyro)
4) Simrad EA500 Precision Echo Sounder (ea500)
5) NMFD Surface-water and Meteorology (surfmet) instrument suite
6) ASHTECH ADU-2 Altitude Detection Unit (gps_ash)

7) NMFD Winch Cable Logging And Monitoring CLAM (winch)
8) Fugro Seastar 9200 G2 XP Differential (gps_g2)
9) Seabird SBE45 MicroTSG (seabird)

Fugro Seastar DGPS Receiver

The Fugro Seastar G2 is a Glonass and GPS receiver that is used to provide 10CM accuracy and also receives differential from the Fugro differential system. This signal is then buffered out to multiple systems including the Trimble 4000 DS. The Seastar was purchased as an upgrade to the old Seastar and G12 combination. The system is designed to cope wit the future expected solar activity that is expected to disable part of the existing GPS network. The system is also capable of receiving corrections via Internet if necessary.

NetCDF files for this system s9200G2s-FUGRO.gps

RVS Stream gps_g2

Forms part of the bestnav stream

Trimble 4000 DS Surveyor

The Trimble 4000DS is a single antenna survey-quality advanced GPS receiver with a main-masthead antenna. It uses differential corrections from the Fugro Seastar unit to produce high quality differential GPS (DGPS) fixes. It is the prime source of scientific navigation data aboard RRS Discovery and is used as the data source for Navigation on the ships display system (SSDS). This antenna is directly on top of the mast and suffers from negligible interference from other items on the mast. It is also almost directly at the centre point of the ship making it an ideal navigation system.

The Techsas NetCDF File ends with the following extensions :

Position-4000.gps

Satelliteinfo-4000.hps

RVS Stream gps_4000

Forms part of the bestnav stream

Ashtec ADU-2

This is a four antenna GPS system that can produce attitude data from the relative positions of each antenna and is used to correct the VMADCP for ship motion. Two antennae are on the Bridge Top and two on the boat deck.

The Ashtec system worked reliably throughout the cruise with some gaps that are quite usual with this system due to the amount of calculations necessary. No Large data gaps are present. The ADU-2 forms part of the bestnav system which is an assembly of multiple GPS signals including the gyronmea and emlog stream in order to calculate the best possible position, speed heading pitch and roll of the ship. The Ashtech is not as reliable as the Fugro Seastar G2 and the 4000DS mainly due to its low position on the ship it is hard for this system to maintain locks on satellites when the ship is maneuvering and the bridge and main mast come into its direct line of sight with the satellites.

The Techsas NetCDF File ends with the following extensions :

ADUPOS-PAPOS.gps

gppat-GPPAT.att

RVS Stream gps_ash

Forms part of the bestnav stream

Gyronmea

The Gyronmea is a file that receives its data from the Ships gyro compass located on the bridge. There are two such Gyros on the bridge and we are able to use either one of them as a source of heading. The selected Gyro is logged by the TECHSAS system and is used as part of the bestnav calculation.

The NetCDF File for Techsas ends with gyro-GYRO.gyr

RVS data stream gyro

RDI Ocean Surveyor 75KHz Vessel Mounted ADCP (VMADCP)

The RDI Ocean Surveyor was setup by the science party at the start of the cruise with a bottom track and water track file that is included with the dataset. The configuration was changed when we left the shelf and went to deeper water. The Ocean surveyors are fed with data from the ships GPS, Gyro and ADU systems in order so that the system can calculate true speeds and direction of the currents below the ship.

60 Bins

16 Meter Bin Size

16 meter Blank

5.3 Meter Transducer Depth

Hi Resolution (short Range)

Ping as fast as possible.

RDI 150KHz Vessel Mounted ADCP (VMADCP)

The RDI Ocean Surveyor was setup by the science party at the start of the cruise with a bottom track and water track file that is included with the dataset. The configuration was changed when we left the shelf and went to deeper water. The Ocean surveyors are fed with data from the ships GPS, Gyro and ADU systems in order so that the system can calculate true speeds and direction of the currents below the ship.

100 Bins

4 Meter Bin Size

4 meter Blank

5.3 Meter Transducer Depth

Hi Resolution (short Range)

Ping as fast as possible.

Chernikeef EM log

The Chernikeef EM log is a 2-axis electromagnetic water speed log. It measures both longitudinal (forward-aft) and transverse (port – starboard) ships water sped.

The EM log was not calibrated prior to the cruise and was reading at 0.0 knots when alongside.

The system was logged by the TECHSAS logging system.

DYLog-LOGCHF-DYLog

RVS Stream chernikeef

Simrad EA500 Precision Echo Sounder (PES)

The PES system was used throughout the cruise, with a variation between use of the Fish and use of the hull transducer. The fish is more accurate than the hull transducer as it is capable of being deployed deeper and is also decoupled from the noise of the ship.

The PES outputs its data to a stream called ea500 on the Level C System.

Surfmet System

This is the NMFD surface water and meteorology instrument suite. The surface water component consists of a flow through system with a pumped pickup at approx 5m depth. TSG flow is approx 25 litres per minute whilst fluorometer and transmissometer flow is approx 3 l/min. Flow to instruments is degassed using a debubbler with 40 l/min inflow and 10/l min waste flow.

The meteorology component consists of a suite of sensors mounted on the foremast at a height of approx 10m above the waterline. Parameters measured are wind speed and direction, air temperature, humidity and atmospheric pressure. There is also a pair of optical sensors mounted on gimbals on each side of the ship. These measure total irradiance (TIR) and photo-synthetically active radiation (PAR).

The Non Toxic system was enabled as soon as we were far enough away from land.

The port TIR sensor was changed prior to sailing as it was giving incorrect readings compared to the starboard and spare sensors.

The SBE45 unit was cleaned prior to sailing. Techsas NetCDF Files for Surfmet

Surf-SURFMET.SURFMETv2

MET-SURFMET.SURFMETv2

Light-SURFMET.SURFMETv2

SBE45-SBE45.TSG

Surfmet rvs stream is the raw data captured from the TECHSAS System

The temp_h temp_m and cond data in the surfmet file is a direct copy of the seabird data however it can be delayed in time. For that reason, always use the data from the seabird instead of the surfmet for protsg and salinity calibrations.

These files contain

Temp_h (Housing Temperature from the SBE45 in the wetlab)

Temp_m (Marine Temperature from the Hull intake)

Cond (Conductivity from the SBE45 in the wet lab)

Trans (Raw Voltage from Transmissometer)

Fluo (Raw Voltage from Fluorometer)

Speed (Wind Speed from Gill Windsonic Anemometer)

Direct (Wind Direction from Gill Windsonic Anemometer)

Airtemp (Air Temperature from Vaisala HMP45A)

Humid (Air Temperature from Vaisala HMP45A)

Pressure (Air Pressure from Vaisala PTB100)

PPAR (Photosynthetic Active Radiation from SKE510 PAR Sensor on PORT Gimbal)

SPAR (Photosynthetic Active Radiation from SKE510 PAR Sensor on STBD Gimbal)

PTIR (Total Incidental Radiation from CM6B TIR Sensor on PORT Gimbal)

STIR (Total Incidental Radiation from CM6B TIR Sensor on STBD Gimbal)

Seabird is the raw log of the SBE45 and SBE38 through the SBE45 Junction Box.

Temp_h (Housing Temperature of SBE45 TSG)

Temp_m (Remote or Marine Temperature from Inlet pipe)

Cond (Conductivity in SBE45 TSG)

Salin (Calculated Salinity from Instrument)

Sndspeed (Calculated Sound Velocity from Instrument)

Met Platform Sensors

Wind Speed and Direction

Manufacturer : Gill

Model : Windsonic (Option 3)

Ultrasonic Output Rate	1, 2, 4Hz
Wind Speed	Range 0-60 m/s
Wind Direction Range	0-359 no dead band
Operating Temp Range	-35 ºC to +70 ºC
Moisture Protection	IP65
External Construction	Luran
Digital O/P Options	RS232 / 422 / 485 / SDI-12
NMEA O/P	Yes
Analogue Outputs	2 (optional)
Calibration	Generic

Total Incidental Radiation

Manufacturer : Kipp and Zonen

Model Number : CM6B

Spectral range (50%points)	305...2800 nm
Sensitivity	9...15 µV/Wm-2
Impedance	70...100 Ohm

Response time	1/e 5 s, 99 % 55 s
Non-linearity	<1.5 % (<1000 W/m 2)
Tilt error	<1.5 % at 1000 W/m 2
Operating temperature	-40...+90 _C
Temperature dependence of sensitivity	_2 %
	(-10...+40_C)
Maximum irradiance	2000 W/m2
Directional error	< _20 W/m2 at 1000 W/m2
Weight	0.85 kg
Cable length	10 m

Temperature and Humidity

Manufacturer : Vaisala

Model Number : HMP45A

Relative humidity measurement

HMP45A	
Measurement range	0.8 ... 100 % RH
Accuracy at +20 °C (+68 °F)	± 2 % RH (0 ... 90 % RH)
	± 3 % RH (90 ... 100 % RH)
Sensor	Vaisala HUMICAP® 180

Temperature measurement

HMP45A	
Measurement range	-39.2 ... +60 °C (-38.6 ... +140 °F)
Accuracy +20 °C (+68 °F)	± 0.2 °C (± 0.36 °F)
Sensor	Pt 1000 IEC 751

Operating environment

Temperature	
operation	-40 ... +60 °C (-40 ... +140 °F)
storage	-40 ... +80 °C (-40 ... +176 °F)

Inputs and outputs

Operating Voltage	7 ... 35 VDC
Power consumption	< 4 mA
Output load	> 10 kohm (to ground)
Output scale	-40 ... +60 °C (-40 ... +140 °F) equals to 0...1V
Output signal	resistive 4-wire connection

Photosynthetic Active Radiation

Manufacturer : Skye Instruments

Model Number : SKE 510

Spectral Range	400-700nm
Sensitivity Current	3.5µA/100Wm^2
Sensitivity Voltage	1mV/100Wm^2
Working Range	0 – 5000Wm^2
Linear Error	<0.2%
Absolute Calibration Error	typ <3% max 5%
Cosine Error	3%
Azimuth Error	<1%
Temperature coefficient	+/-0.1%/ºC
Longterm Stability	+/-2%
Response Time	10ns

Internal Resistance	300Ohms
Temperature Range	-35ºC … +70ºC
Humidity Range	0 – 100% RH

Barometric Pressure

Barometric pressure measurement

Pressure range	800 ... 1100 hPa
Accuracy at +20 °C (+68 °F)	±0.3 hPa
Sensor	Vaisala

Operating environment

Temperature range	-5 ... +45 °C (+23 ... +113 °F)
Humidity range	<80 % RH

Inputs and outputs

Operating voltage	9 ... 16 VDC
Power consumption:	
operation mode	2 mA (typical)
shutdown mode	150 µA (typical)
Output voltage	0 … 2.5 VDC

Sea Surface Instruments

Fluorometer

Manufacturer : WetLabs

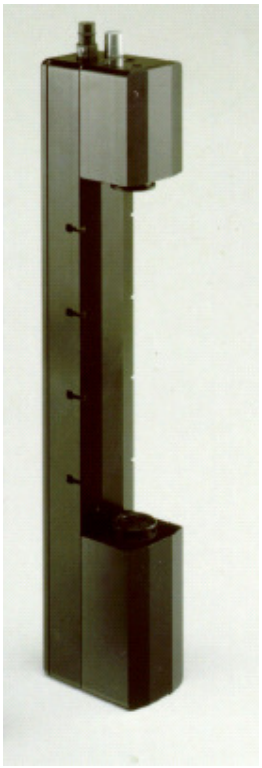
Model Number : WetStar

Temperature Range	0-30 C
Depth Rating	600m
Response time	0.17s
Input Voltage	7-15vdc
Current Draw	< 40 mA
Output	0-5VDC

Transmissometer

Manufacturer : WetLabs

Model Number : CStar



Pathlength	25cm
Wavelength	660nm
Bandwidth	~ 20nm
Rated Depth	600m
Temperature	0-30ºC

Power Input	7-15VDC
Current Draw	< 40mA
Data Output	0-5Volts
Time Constant	0.167 sec
Temperature Error	0.02 percent F.S./deg C

Seabird Micro TSG SBE45

Measurement Range

Conductivity: 0-7 S/m (0-70 mS/cm)

*Temperature *:* -5 to 35 ℃

Initial Accuracy

Conductivity: 0.0003 S/m (0.003 mS/cm)

*Temperature *:* 0.002 ℃

Salinity: 0.005 PSU, typical

Typical Stability *(per month)*

Conductivity: 0.0003 S/m (0.003 mS/cm)

*Temperature *:* 0.0002 ℃

Salinity: 0.003 PSU, typical

Resolution

Conductivity: 0.00001 S/m (0.0001 mS/cm)

*Temperature *:* 0.0001 ℃

Salinity: 0.0002 PSU, typical

Calibration Range

Conductivity: 0-6 S/m (60 mS/cm); physical

calibration 2.6-6 S/m (26-60 mS/cm),

plus zero conductivity (air)

*Temperature *:* +1 to +32 ℃

Time Resolution	1 second
Clock Stability	13 seconds/month
Input Power	8-30 VDC
Acquisition Current	34 mA at 8 VDC; 30 mA at 12-30 VDC
Quiescent Current	10 microamps
Acquisition Rate	1 Hz maximum
Operating Pressure	34.5 decibars (50 psi) maximum
Flow Rate	10 to 30 ml/sec (0.16 to 0.48 gal/min)
Materials	PVC housing
Weight	4.6 kg (10.2 lbs)

Seabird SBE 38 Digital Oceanographic Thermometer

Measurement Range	-5 to +35 ℃
Initial Accuracy	± 0.001 ℃ (1 mK)
Typical Stability	0.001 ℃ (1 mK) in 6 months, certified
Resolution	0.00025 ℃ (0.25 mK)
Calibration	-1 to +32 ℃
Response Time	500 milliseconds
Self-Heating Error	less than 200 µK

RMS Noise

(at temperature

equivalent of 8.5 ℃)

NAvg	**Noise (℃)**
1	0.000673
2	0.000408
4	0.000191
8	0.000133
16	0.000081
32	0.000052

Note:

NAvg = number of A/D cycles per sample.

Interval between samples (seconds)

= (0.133 * **NAvg**) + 0.339

RS-232 (standard):

8 – 15 VDC at 10 milliamps average

External Power	*RS-485 half-duplex (optional):*
	8 – 15 VDC at 6 milliamps average
Materials	Titanium pressure case rated
	at 10,500 meters (34,400 feet)
Weight	In water: 0.5 kg (1.2 lbs)
	In air: 0.9 kg (2.0 lbs)

Processed Data files

Relmov – Relmov is the relative motion file for this cruise. This is generated using the ships gyro and ships Chernikeef Log data to extract a movement in a given direction. This is then used by bestnav when and where necessary to calculate fixes if GPS fixes were not available.

Bestnav – Bestnav uses all 3 GPS Systems logged, gps_4000, gps_g2, gps_ash and creates a best suite stream by providing an as complete account of the ships track as possible. This is done by reading all 3 GPS streams with gps_4000 being primary, gps_g2 as secondary and gps_ash as tertiary. The system looks for gaps of a certain length in the primary and when it finds those gaps it requests that the next gps down fill in the gaps. If no GPS data is available it asks RELMOV to fill in until data is available again. Then the system calculates back over itself to ensure that the extrapolated positions are correct using the GPS data available around the gap.

Bestdrf – Bestdrf is a product of bestnav. When run bestnav uses the relmov data which contains a predicted vn and ve based upon direction and speed through the water. The Bestdrf file is the accurate drift velocity of what actually occurred based on the GPS changes between each record.

Protsg - Protsg is the Processed Thermosalinograph data. The raw data is taken from the seabird stream or seatemp stream if cleaned and then ran through a salinity calculation. The data varies slightly from the raw seabird salin variable as they use a slightly different algorithm for the calculation of salinity.

Pro_wind – This program is designed to remove the relative variables from the wind data logged by surfmet. By removing any fixed offsets in the system and removing the affect of ship motion pro_wind is a true representation of ships wind data.

Intdep – Intdep is a Interpolated data set that extrapolates data where none was logged based on a 2min band pass filter. Intdep is then passed to which takes Carters tables into account.

Prodep – Prodep is an automated process that access the bestnav position fix data and then uses a pre programmed Carters table of corrections and corrects the echo sounder data for that given time.

Network Services

Networking worked well throughout the cruise despite a few hiccups with one of the wireless access points on the Forecastle Deck. A wireless access point was installed in the comms rooms to give network access to the port container slots.

Data Storage

DISCOFS is an advanced Network Attached Storage device. All scientific cruise data was stored on this device under the Disco_Cruises/D361 folder, and organised with a standard template of folders

All cruise data were stored on ths storage area.

All CTD, ADCP and LADCP data was backed up to DISCOFS on acquisition.

Data Backups

Backups of the Level C data were done twice daily as a tar file to LTO tape. Alternating between the standard backup below and a full /rvs backup. The following paths were included in the tar file:

/rvs/raw_data

/rvs/pro_data

/rvs/def7/control

/rvs/users

The LTO2 system was backed up on a daily basis in a rolling 2 tape system.

Data Archiving

The Data archive will be provided on 320GB USB Hard Drives

1 x HDD to BODC, disk to be returned once data extracted.

1 x HDD to PSO

1 x HDD to NOCS held by NMFSS for 6 Months

Additional Information

Surfmet Sensor Information

Ship	RRS Discovery
Cruise	D361
Technician	Martin Bridger
Date	19/03/2011

Manufacturer	Sensor	Serial no	Comments	Calibration Expires
Seabird	SBE45	229	TSG	29/03/11
Seabird	SBE38	0490*	Remote Temperature	17/11/10
Wetlabs	fluorometer	117		24/05/11
Wetlabs	transmissometer	CST-112R		24/05/11
Vaisala	Barometer PTB100A	Z4740021*		23/09/11
Vaisala	Temp/humidity HMP45A	E1055002*		29/09/11
SKYE	PAR SKE510	28559*	PORT	21/07/11
SKYE	PAR SKE510	28558*	STBD	11/06/11
Kipp and Zonen	TIR CMB6	994132*	PORT	08/08/12

Kipp and Zonen	TIR CMB6	962276*	STBD	04/10/12
Sensors without cal				
Seabird	P/N 90402 SBE45 JB	63	Junction Box	
Gill	Windsonic Option 3	071123		

SPARES

Manufacturer	Sensor	Serial no	Comments	Calibration Expires
Seabird	SBE45	0232		24/08/11
Seabird	SBE38	476. 491	Remote Temperature	14/03/11
Wetlabs	fluorometer	WS3S-248		13/12/12
Wetlabs	transmissometer	CST-113R		24/05/11
Vaisala	Barometer PTB100A	S3610008		15/04/11
Vaisala	Temp/humidity HMP45A	B4950011		04/08/11
SKYE	PAR SKE510	28563		11/06/11
SKYE	PAR SKE510	28556+28557		11/02/11
Kipp and Zonen	TIR CMB6	994133	Reading low	08/08/12
Kipp and Zonen	TIR CMB6	962301		18/02/11
Sensors without cal				
Seabird	P/N 90402 SBE45 JB	65	Junction Box	
Gill	Windsonic Option 3	071121		

Sensors marked * were fitted prior to D361

8 Determination of oxygen concentrations in the (sub) tropical Atlantic

Anouska Bailey

8.1 Introduction

In the eastern tropical North Atlantic, there is evidence for high iron concentrations (> 1.5 nM) in the oxygen minimum zone located between 300 and 700 m. Although iron is expected to be high in an OMZ, concentrations in the tropical Atlantic are significantly higher than would be expected from a typical Fe:C ratio of marine organic matter (Bergquist and Boyle, 2006). It is hypothesized that iron may either be advected from the reducing continental sediments on the African margin or accumulate via biological remineralisation of surface derived Fe supplied by the Saharan mineral dust plume. The intensity and depth of the OMZ in the eastern tropical North Atlantic supports the former hypothesis. A goal during D361 was to transect through the OMZ in the eastern tropical Atlantic and determine the gradients in iron and other trace metals and reconcile the primary source of the elevated iron in this region.

In order to accurately identify the oxygen dynamics of the tropical Atlantic, an oxygen sensor was placed on the stainless steel rosette frame and trace-metal clean titanium rosette frame, along with a typical CTD sensor package. Oxygen samples were collected from at least 8 depths per cast in order to verify and calibrate the oxygen concentrations derived from the sensors.

8.2 Methods

Sampling – 125 ml optically-clear glass oxygen bottles triple-rinsed with Milli-Q and stored full of Milli-Q. Each bottle is pre-calibrated for volume and has unique identifying number on shoulder and on stopper. Oxygen samples were drawn first from Niskin as soon as rosette was secured on deck. Silicon tubing was used to fill bottles from Niskin and bottle was overflowed three times to ensure no bubbles. Temperature of each sample was taken immediately then sample was fixed with 1 ml manganese (II) chloride (3 M) and 1 ml alkaline iodide and shaken vigorously for a minimum of 15 seconds. Samples were reshaken prior to storage approximately 15 minutes later. For titanium rosette samples were collected as above by Maeve Lohan then stoppers replaced. These samples were collected by Anouska Bailey immediately after sampling was completed and fixed as above after the temperature was recorded. Triplicate samples were taken from all depths on the test cast and duplicate samples were taken from the stainless steel rosette on several occasions following this, but no duplicates were taken from the titanium rosette.

Sample processing – Samples were stored upright under water in a dark 60 L container in temperature-controlled room until the precipitate had settled. Samples were analysed within 12-48 hours of sampling. Method validation performed onboard D361 confirmed samples to be stable for over 72 hours when stored underwater in a temperature-controlled environment. Prior to analysis 1 ml sulfuric acid (10 N) was added to each sample to dissolve the precipitate.

Analysis – Samples were analysed for dissolved oxygen concentration onboard using the modified Winkler method (Carpenter, 1965) and a PC-controlled potentiometric titration system (Metrohm Titrando 888). Reagent blanks were run using 0.025 N potassium iodate (2.5 ml aliquots) and sodium thiosulphate titrant (0.2 N) was standardized using 5 ml of 0.01 N potassium iodate (CSK 1° standard, Wako Chemicals). Each of these was performed in triplicate (at minimum) prior to analysis of samples each day. Lab temperature was monitored throughout analysis. Calculation of dissolved oxygen concentration was according to HOT protocol (website given below) and Grasshoff (1983). Samples were analysed to produce a dissolved oxygen concentration in µmol l^{-1} and these values were forwarded to the oxygen sensor calibration team for conversion to µmol kg^{-1} and further processing.

8.3 Results

39 profiles were sampled (Table 8.1) in total with all samples being analysed on board. The mean difference between all replicates sampled during the cruise after suspicious results (flagged as bad) were removed was ≤ 0.64 µmol O_2 l^{-1} (mean CV 1.1%). Mean reagent blank was 0.0049 ± 0.0008 mL over the course of the cruise and mean thiosulphate normality was 0.1988 ± 0.0002 N. Oxygen concentrations measured ranged from 43 µmol O_2 l^{-1} to 263 µmol O_2 l^{-1} (Figs 8.1, 8.2).

Table 8.1. List of rosette casts which were sampled for dissolved oxygen (cast number in bold indicates titanium rosette, all others from stainless rosette)

Date	Cast	Lat	Long	Depths(m)
21/2/11	5	12°35.144 N	17°54.699 W	2,10,20,30,40,50,102,200,400,500
22/2/11	**6**	12°35.409 N	17°55.016 W	50,200,500,1100,1700,2625
22/2/11	7	12°35.243 N	17°42.843 W	5,10,20,30,50,70,100,200,400,500
22/2/11	**8**	12°36.565 N	17°43.047 W	50,200,500,700,1000
22/2/11	9	12°35.165 N	17°34.244 W	2,10,20,40,85,100,120,150
22/2/11	**11**	12°36.691 N	17°34.397 W	25,35,40,45
22/2/11	**12**	12°35.22 N	17°34.309 W	27,37,52,67,81,100
23/2/11	13	12°34.323 N	18°49.408 W	2,7,14,20,25,35,50,100,500
23/2/11	**14**	12°35.176 N	18°49.568 W	35,75,200,600,1500,2500,3000,4200
24/2/11	15	12°34.726 N	21°48.990 W	2,20,30,40,50,70,100,200,500
24/2/11	**17**	12°34.457 N	21°49.375 W	50,100,300,750,2000,2700,3500
25/2/11	18	12°35.121 N	23°33.433 W	2,15,30,45,55,65,85,350,400,500
25/2/11	**20**	12°35.104 N	23°34.649 W	55,100,300,750
26/2/11	21	12°18.041 N	25°07.055 W	2,20,30,50,80,90,110,300,500
26/2/11	**22**	12°18.057 N	25°08.504 W	50,110,300,750,2000,2700,3500,4955
3/3/11	**24**	07°13.317 S	24°59.916 W	50,110,200,400,600,900,1500,2000, 2500,3500,4500,5510
4/3/11	25	07°13.229 S	24°59.534 W	2,30,60,80,110,120,252,353,502
5/3/11	26	03°15.773 S	25°30.834 W	1,20,40,60,75,95,120,160,400,500
5/3/11	**28**	02°57.954 S	25°36.477 W	45,60,85,150,300,400,500,600,850, 1100,1500,1700,2000
6/3/11	29	01°10.503 S	25°47.533 W	2,20,40,50,60,70,85,200,275,500
6/3/11	**30**	01°10.109 S	25°47.981 W	25,50,60,100,150,400,500,750,900 1100,2000,2500,2700,3500,4000
7/3/11	31	01°09.387 N	26°02.673 W	1,20,40,50,60,75,90,120,300,500
7/3/11	**32**	01°09.510 N	26°02.984 W	25,60,75,150,200,400,600,750,900,

				1100,1500,1700,2000,2500,3300, 3699
8/3/11	33	03°19.303 N	26°48.207 W	2,20,35,45,55,60,80,140,300,500
8/3/11	**34**	03°20.310 N	26°49.045 W	25,75,100,250,300,500,750,900, 1100,1300,1700,2000,2300,2700, 3500,4209
9/3/11	35	05°39.665 N	27°29.667 W	2,20,30,38,47,70,90,160,300,500
9/3/11	**36**	05°39.904 N	27°30.424 W	25,85,100,200,300,500,750,800,900, 1100,1500,1700,2000,2500,3000, 4092
10/3/11	37	08°20.277 N	28°19.726 W	2,20,30,49,57,70,90,300,500
10/3/11	**38**	08°20.696 N	28°20.092 W	25,40,55,80,100,300,400,500,750, 1100,1500,2000,3000,4000,4723
11/3/11	39	10°37.533 N	28°43.777 W	1,20,30,50,60,80,100,200,340,500
11/3/11	**40**	10°37.573 N	28°43.963 W	25,100,150,200,500,600,750,1100, 2000,2500,3500,4500,5587
12/3/11	**41**	12°00.99 N	28°58.10 W	90,160,325,500,750,1100,1700,2500, 3000,4000,5000
12/3/11	42	12°03.025 N	28°58.795 W	1,20,40,56,68,75,100,300,500
13/3/11	43	15°30.607 N	28°46.875 W	2,20,50,67,78,95,120,300,400,500
13/3/11	**44**	15°30.385 N	28°47.416 W	50,110,150,200,250,500,600,950, 1100,1700,2000,2700,3500,4000, 4500
14/3/11	45	17°23.405 N	28°23.906 W	3,25,54,74,90,105,130,400,500
14/3/11	**47**	17°25.830 N	28°22.632 W	27,85,100,150,400,600,750,1100, 2000,2500,3000,3500,4000
15/3/11	48	19°06.556 N	28°07.781 W	5,20,40,60,75,110,150,280,500
15/3/11	49	19°08.784 N	28°07.534 W	10,200,300,500,750,1000

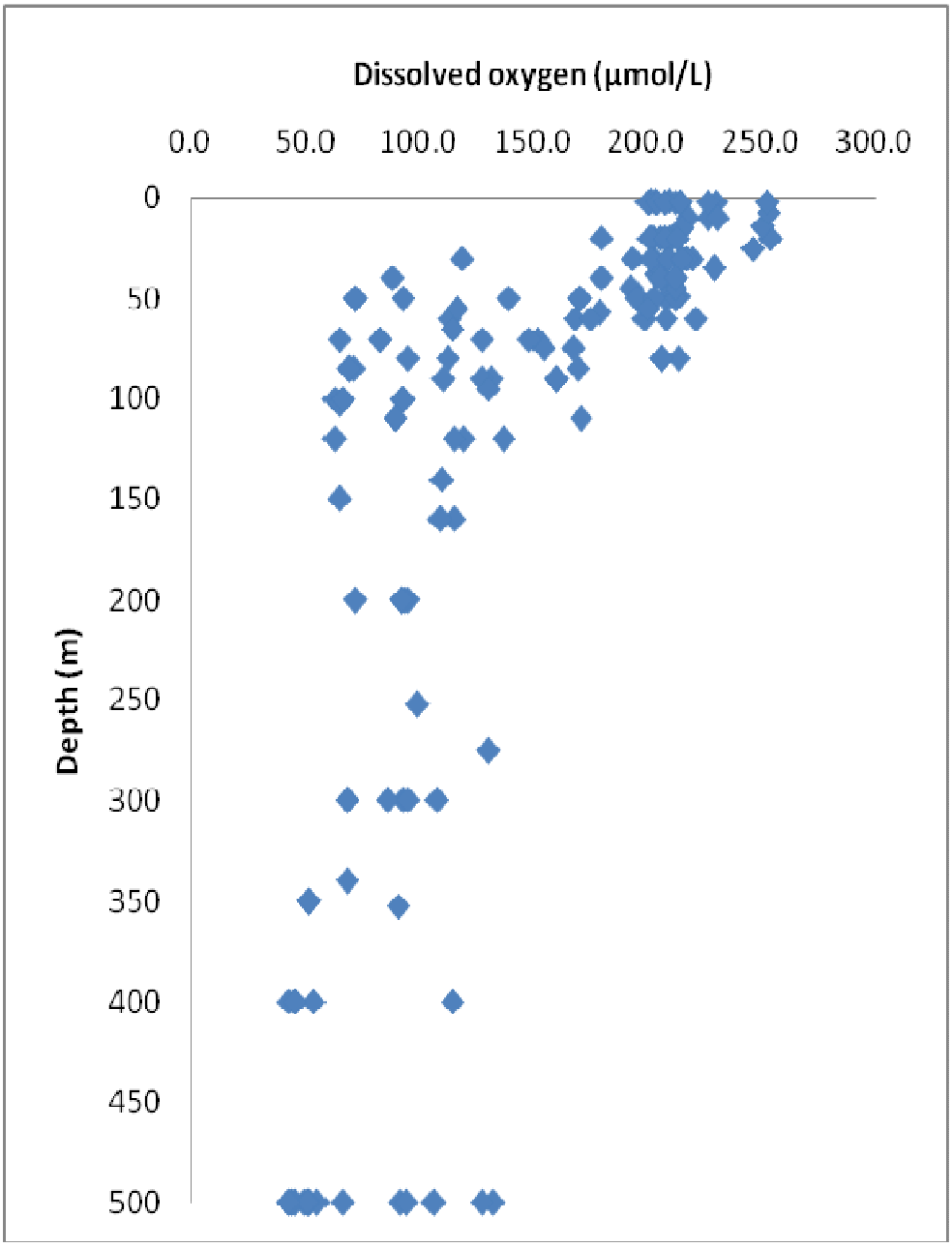


Figure 8.1. Dissolved oxygen profiles (µmol O_2 l^{-1}) from all stainless steel casts.

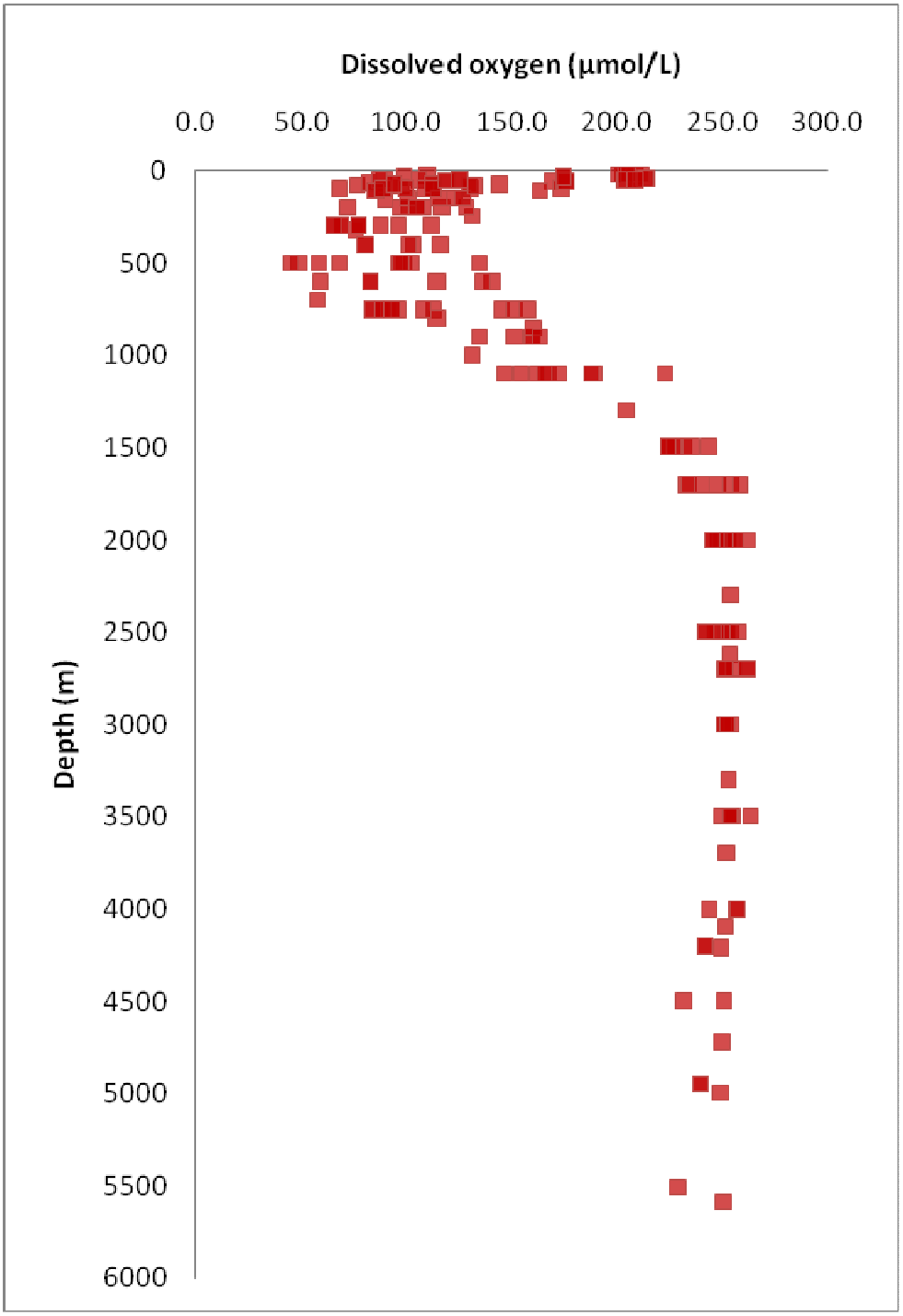


Figure 8.2. Dissolved oxygen profiles (µmol O_2 l^{-1}) from all titanium casts

8.4 References

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9 NUTRIENTS Cruise Report

Malcolm Woodward and Francois-Eric Legiret

Objectives:

To investigate the spatial and temporal variations of the micromolar nutrient species; Nitrate, Nitrite, Silicate, Ammonium and Phosphate during the research cruise from Tenerife, working south and offshore of the upwelling regions of the coasts of Mauritania and Senegal, and where necessary to deploy innovative analytical techniques for nanomolar nutrient concentrations. Following the near shore survey a detailed CTD and surface transect from east to west offshore was carried out from Senegal and south of the Cape Verde Islands. Surface waters were then sampled on a southerly transect to investigate when the nanomolar phosphate concentrations started to increase into the southern gyre where the iron concentrations dropped to trace levels. Once this was established we then commenced a CTD transect to the north west until about 20 North.

Overall the aim was to carry out sampling and analysis according to Go-Ship protocols wherever possible, and to compare results with the certified International Nutrient reference materials provided by KANSO, Japan, this being part of a global programme to improve nutrient analysis data quality world-wide.

9.1 Sampling and Analytical Methodology

The micro-molar analyser used was the PML 5 channel (nitrate, nitrite, phosphate, silicate, ammonium) Bran and Luebbe AAIII segmented flow, colorimetric, autoanalyser, using classical proven analytical techniques.

Nanomolar ammonium was analysed using a method based on the gas diffusion of the ammonia across a Teflon membrane due to a differential pH gradient, and there then followed its reaction with a fluorescent reagent and the subsequent detection by a Jasco fluorimeter.

Nanomolar nitrate, nitrite and phosphate were detected using colorimetric methodologies as with the standard segmented flow analyser, but using 2 metre Liquid waveguides capillary cells as the flow cells.

Water samples were taken from either a 24 x 20 litre stainless steel CTD/Rosette system (SeaBird), or an automatically fired (Sea-Ram system, (SeaBird)) CTD 24 bottle system on a trace metal free titanium rosette system. These samples were processed within the trace metal free sampling laboratory container .The CTD bottles were sub sampled into acid clean, ‘aged’, 60 mls HDPE (nalgene) sample bottles

and analysis for the nutrient samples was in most cases complete within 2-3 hours of sampling.

Clean handling techniques were employed to avoid any contamination of the samples, particularly for the ammonium samples. Gloves used were Dura-Touch, and all people sampling prior to the nutrients from the CTD wore these gloves. Samples were not decanted and kept tightly closed until just before analysis for the ammonium, this to avoid any contamination from external sources.

No water column water samples were frozen or stored in any way.

Table 9.1. CTD samples analysed by AAIII Micromolar, and Nanomolar analysers.

Date	**CTD**	**Position**	**CTD or TM bottle analysed**
15/02/11	Test	$28^0$18.75'N $16^0$07.27'W	1,2,3,4,6,7,8,9,10,11,12,13,14,15,16,17, 18,19, 20, 21, 22, 23, 24.
21/02/11	CTD_005	$12^0$35.14'N $17^0$54.70'W	1,2,3,4,5,6,7,8,9,10,11,12,14,15,16,17, 18,19, 20, 21, 22, 23, 24.
22/02/11	CTD_006	$12^0$35.41'N $17^0$55.02'W	10,11,12,13,14,15,16,17, 18,19, 20, 21, 22, 23, 24.
22/02/11	CTD_007	$12^0$35.24'N $17^0$42.83'W	1,2,3,5,6,7,8,10,11,12,13,14,15,16,17, 18,19, 20, 21, 24.
22/02/11	CTD_008	$12^0$36.56'N $17^0$43.05'W	1,3,5,7,9,11,13,15,17,19, 21, 23.
22/02/11	CTD_009	$12^0$35.16'N $17^0$34.24'W	2,4,6,8,10,12,14,16,18,20, 22,24.
22/02/11	CTD_011	$12^0$36.56'N $17^0$34.34'W	1,7,14,21
22/02/11	CTD_012	$12^0$35.22'N $17^0$34.31'W	1,3,5,7,9,11,13,15,17,19, 21, 23.
23/02/11	CTD_013	$12^0$34.33'N $18^0$49.41'W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19, 20, 21,22,23, 24.
23/02/11	CTD_014	$12^0$33.18'N	1,2,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19, 20,

		$18^0$49.57'W	21,22,23, 24.
24/02/11	CTD_015	$12^0$34.72'N $18^0$49.41'W	1,2,3,4,5,6,7,8,9,10,11,12,14,15,16,17,18,19, 20, 21,22,23, 24.
24/02/11	CTD_017	$12^0$34.46'N $21^0$49.36'W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19, 20, 21,22,23, 24.
25/02/11	CTD_018	$12^0$35.12'N $23^0$33.43'W	1,2,3,4,6,7,8,9,10,11,12,13,14,15,16,17,18,19, 20, 22,23, 24.
25/02/11	CTD_019	$12^0$35.09'N $23^0$33.43'W	1,2,
25/02/11	CTD_020	$12^0$35.10'N $23^0$34.05'W	1,2,3,4,5,6,7,8,9,10,11,12,13
26/02/11	CTD_021	$12^0$18.04'N $25^0$07.05'W	1,3,5,6,8,9,10,11,12,13,15,16,17,18,19, 20,22,23, 24.
26/02/11	CTD_022	$12^0$18.06'N $25^0$08.50'W	1,2,3,4,5,6,7,8,9,10,11,13,14,15,16,17,18,19, 20, 21,22,23, 24.
03/03/11	CTD_023	$07^0$13.38'S $24^0$59.39'W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,16,17,18,19, 20, 21,22,23, 24.
03/03/11	CTD_024	$07^0$13.31'S $24^0$59.92'W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19, 20, 21,22,23, 24.
04/03/11	CTD_025	$07^0$13.12'S $24^0$59.55'W	1,2,3,5,6,7,8,9,10,11,12,13,14,16,17,18,19, 20, 21,22,23, 24.
05/03/11	CTD_026	$03^0$15.77'S $24^0$30.83'W	1,2,3,4,6,7,8,9,10,11,12,13,14,15,16,17,18,19, 20, 21,22,23, 24.
05/03/11	CTD_028	$02^0$57.95'S $25^0$36.48'W	2,3,4,6,7,8,9,10,11,12,13,14,15,16,17,18,19, 20, 21,22,23, 24.
06/03/11	CTD_029	$01^0$10.50'S $24^0$47.53'W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19, 20, 21,22,23, 24.
06/03/11	CTD_030	$01^0$10.10'S $25^0$47.98'W	2,3,4,6,7,8,9,10,11,12,13,14,15,16,17,18,19, 20, 21,22,23, 24.

07/03/11	CTD_031	$01^0$09.38'N $26^0$02.67'W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19, 20, 21,22,23, 24.
07/03/11	CTD_032	$01^0$09.51'N $26^0$02.98'W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19, 20, 21,22,23, 24.
08/03/11	CTD_033	$03^0$19.30'N $26^0$48.21'W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19, 20, 22, 24.
08/03/11	CTD_034	$03^0$20.32'N $26^0$49.04'W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19, 20, 21,22,23, 24.
09/03/11	CTD_035	$05^0$39.66'N $27^0$29.66'W	1,2,3,4,5,6,7,8,9,11,12,13,14,15,16,17,18,19, 20, 21,22,23, 24.
09/03/11	CTD_036	$05^0$39.90'N $27^0$30.42'W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19, 20, 21,22,23, 24.
10/03/11	CTD_037	$08^0$20.28'N $28^0$19.72'W	1,2,3,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19, 20, 21,22,23, 24.
10/03/11	CTD_038	$08^0$20.09'N $28^0$20.09'W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19, 20, 21,22,23, 24.
11/03/11	CTD_039	$10^0$37.53'N $28^0$43.77'W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18, 20, 21,22,23, 24.
11/03/11	CTD_040	$10^0$37.57'N $28^0$43.96'W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19, 20, 21,22,23, 24.
12/03/11	CTD_041	$12^0$00.99'N $28^0$58.10'W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19, 20, 21,22,23, 24.
12/03/11	CTD_042	$12^0$03.02'N $28^0$58.79'W	1,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19, 20, 21,22,23, 24.
13/03/11	CTD_043	$15^0$30.61'N $28^0$46.87'W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19, 20, 21,22,23, 24.
13/03/11	CTD_044	$15^0$30.38'N $28^0$47.41'W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19, 20, 21,22,23, 24.
14/03/11	CTD_045	$17^0$23.91'N	1,2,3,5,7,8,9,10,11,12,13,14,15,16,17,18,19, 20,

		$28^0$29.91'W	22,23, 24.
14/03/11	CTD_047	$17^0$25.83'N $28^0$22.63'W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19, 20, 21,22,23, 24.
15/03/11	CTD_048	$19^0$06.55'N $28^0$07.78'W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,16,17,18,19, 20, 21,22,23, 24.
15/03/11	CTD_049	$19^0$08.78'N $28^0$07.53'W	1,2,3,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19, 20, 21,23, 24.

UNDERWAY SAMPLING from Trace Metal Fish (for details of fish sampling locations, see Appendix B):

Samples taken for nutrients:

20/02/11 : Numbers 004-027 analysed

21/02/11 : Numbers 028-042 analysed

22/02/11 : Numbers 043-044 analysed

23/02/11 : Numbers 045-053 analysed

24/02/11 : Numbers 054-062 analysed

25/02/11 : Numbers 063-067 analysed

26/02/11 : Numbers 068-072 analysed

28/02/11 : Numbers 073-096 analysed

01/03/11 : Numbers 097-151 analysed

05/03/11 : Numbers 152-164 analysed

07/03/11 : Numbers 171-177 analysed

08/03/11 : Numbers 178-185 analysed

09/03/11 : Numbers 186-192 analysed

10/03/11 : Numbers 193-200 analysed

11/03/11 : Numbers 201-207 analysed

12/03/11 : Numbers 208-211 analysed

13/03/11 : Numbers 212-221 analysed

14/03/11 : Numbers 222-227 analysed

15/03/11 : Numbers 228-231 analysed

9.2 Cruise results and summary

The 5-channel autoanalyser worked very well throughout the cruise, all preliminary data handling and work-up was carried out on the cruise.

Some preliminary data was plotted up for the coastal survey south from Tenerife and then the surface nutrient transect with samples from the underway fish (Figure 8.1).

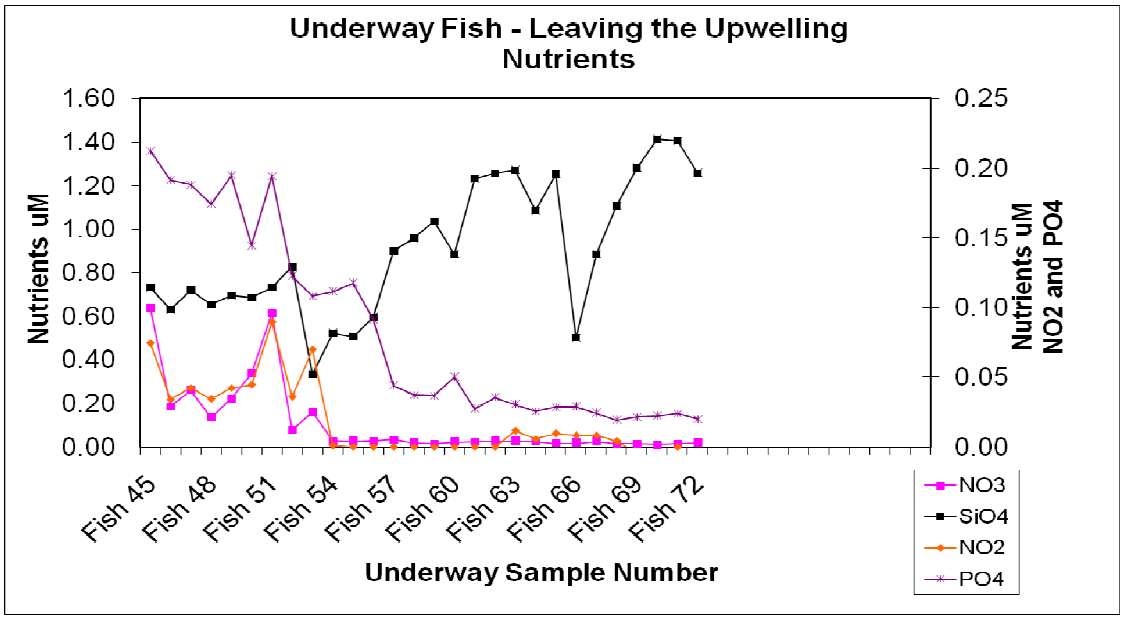

Figure 9.1. Underway surface nutrients for the E-W transect from the Senegal coast

The next results are odv plot for the full depth CTD transect traversing east from the nutrient rich waters of the coast of Senegal to the oligotrophic water of the eastern central Atlantic (Figure 9.2). The different water masses that relate to their different nutrient signatures can be easily observed.

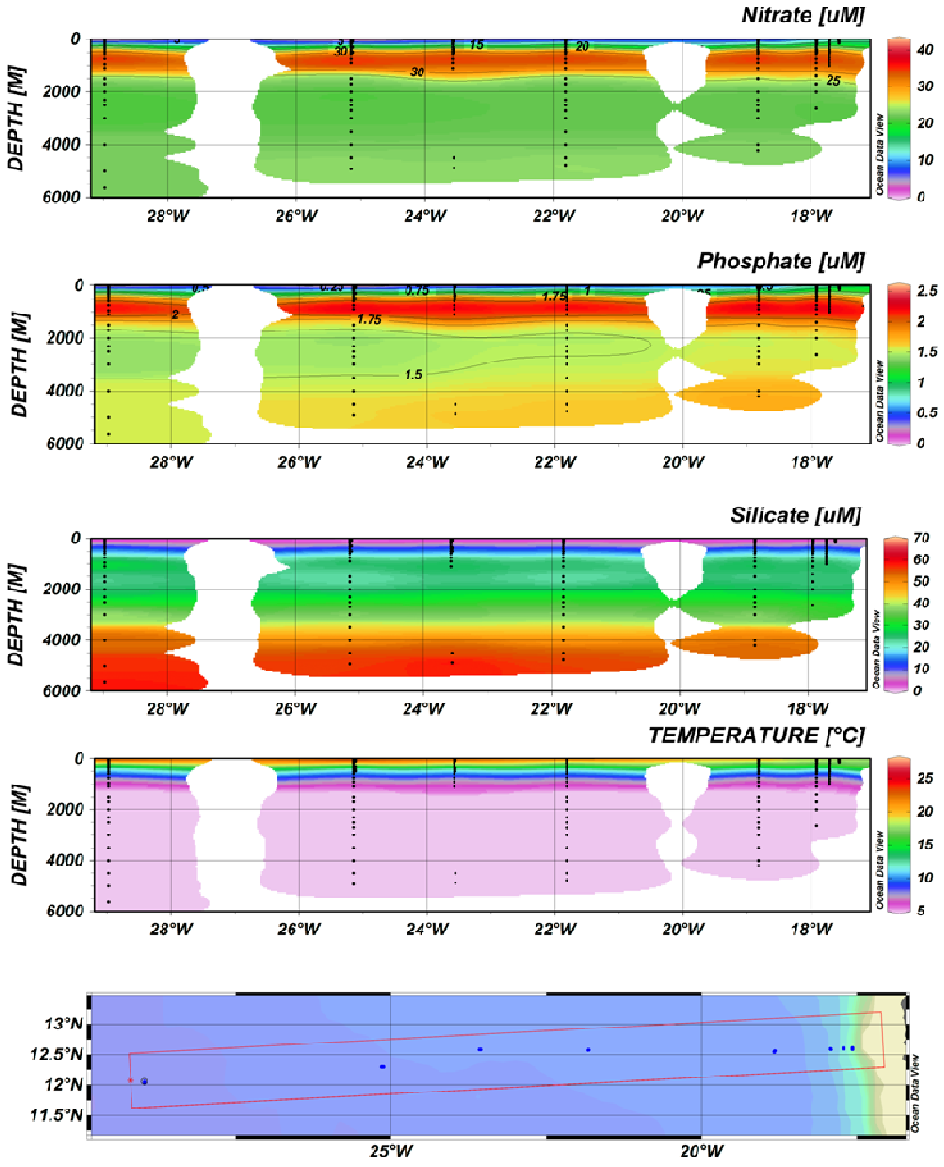

Figure 9.2. Full depth nutrients for the E-W transect from the Senegal coast

More detail of the surface nutrient structures can be seen by plotting the data for the upper 500 metres which is shown in the following two figures (Figure 9.3 and 9.4), this now shows surface structures and the fluorescence maximum zone and the primary nitrite maximum zone where the biological activity generates this nitrite as well as an ammonium maximum area in the water column.

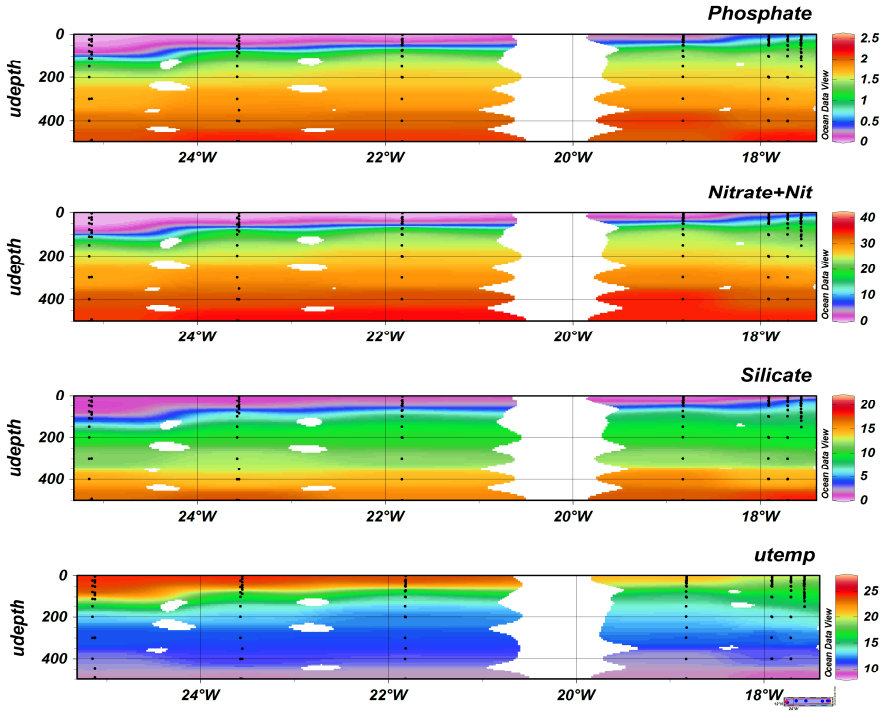

Figure 9.3. Upper 500 m nutrients for the E-W transect from the Senegal coast

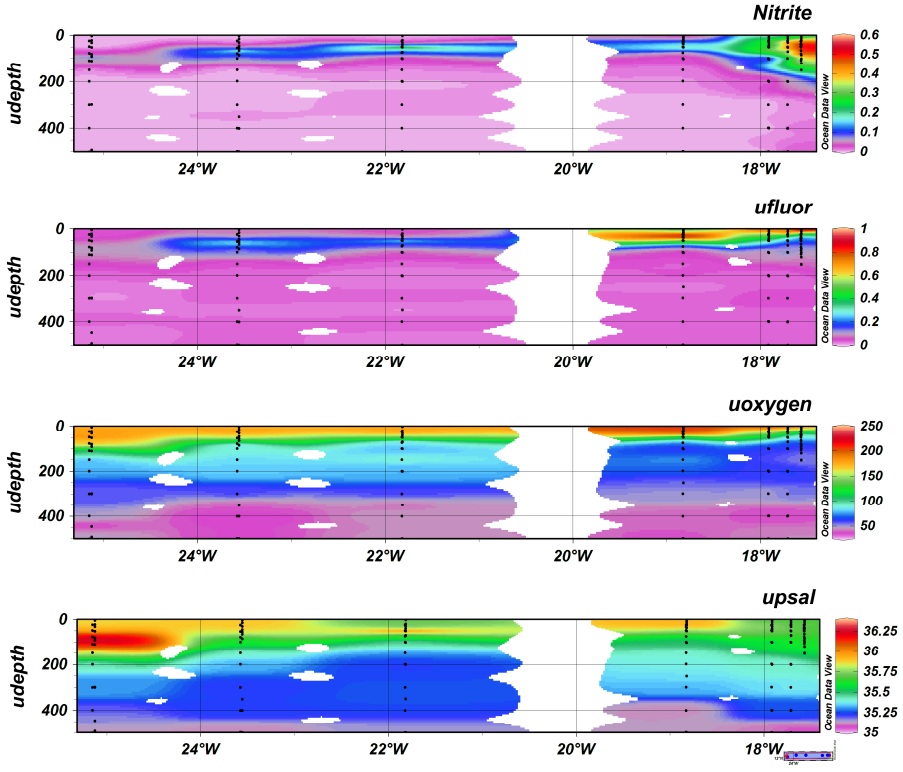

Figure 9.4. Upper 500 m nutrients for the E-W transect from the Senegal coast

THANKS:

To the RRS *Discovery*, her officers, crew, and catering superstars for making it all possible.

Thanks to Director and Science Team at PML for contributing the staff time of EMSW and to the funding from SOES/NOC for the cruise costs.

Special thanks to all the other cruise scientists for making this cruise a pleasure to be a part of, a great team effort.

10 Determination of the carbonate system parameters in the (sub) tropical Atlantic

Eithne Tynan and Elliott Roberts

Objectives:

The objectives on this cruise were to provide high quality carbonate system measurements. Dissolved Inorganic Carbon (DIC) and Total Alkalinity (TA) measurements on the full water column were performed on board as well as underway surface measurements of DIC, TA and pH.

10.1 Introduction

A thorough understanding of the physical and biological processes that determine the carbonate system variability in the present ocean is of particular importance in order to predict future changes associated with ocean acidification and climate change (Feely et al. 2004; Doney et al. 2009), including enhanced ocean temperatures, stratification and increased storminess (Lovenduski et al. 2008; Le Quéré et al. 2007; Bopp et al. 2001).

The region of the sub-tropical and tropical northeast Atlantic Ocean is strongly influenced by the highly productive coastal upwelling system off the Northwest African coast and the oxygen minimum zone (OMZ) south of the Cape Verde Islands (Stramma et al. 2008; Stramma et al. 2005). The OMZ in the tropical northeast Atlantic results from a slow ocean ventilation south of the Cape Verde Islands and degradation of sinking organic matter below the euphotic zone. The OMZ will be sampled from East to West along the south of Cape Verde Islands and results will be compared with existing carbonate system measurements available in this oceanic region (Dumousseaud 2010, Goyet et al 1998, A16N)

10.2 Methods

Sampling protocol – The sampling procedure used for the determination of DIC and TA from the CTD casts followed Dickson et al. (2007). Samples were collected in 250 ml Schott Duran borosilicate glass bottles with glass stopper. Samples were taken as soon as possible after the Niskin bottle was opened (following trace gases, dissolved oxygen and nutrients samples). A piece of silicone tubing was used for the sampling and care was taken to prevent any air bubbles being trapped in the sample. The glass stopper was inserted in the bottle in order to remove the stopper

volume and a head space of 1% (2.5 ml) was allowed for water expansion. Most samples were analysed within 1 day of sampling. The last eight casts had to be poisoned with 50 µl of mercuric chloride for later analysis in the lab.

For underway measurements all samples were taken from the non-toxic water supply at approximately 6m. Samples for TA and DIC were taken through a piece of tygon tubing connected to the sample pump on the Apollo analyser. The pumps were rinsed twice before sample collection. Samples for pH were collected onto 20mL vials with septum tops. After three rinses the sample was collected making sure no air bubbles were present.

Seawater samples (approximately 20 ml) for DOC and TDN concentrations were filtered through combusted (450 ℃, 4-6 h) glass-fibre filters (Whatman, GF/F) into combusted (450 ℃, 4-6 h) glass ampoules and acidified with 30 µl of 50 % (v/v) hydrochloric acid. After acidification, the ampoule was flame-sealed using a propane-butane burner.

Samples collected – Samples for DIC, TA, DOC and TDN were collected from every depth on each Stainless Steel cast, which was generally ten depths. Samples for DIC, TA, DOC and TDN were collected below 500m from every Titanium cast, with an average of 14 depths per cast (see Table 8.1 for the list of bottle numbers sampled from each cast). Stainless Steel rosette samples were collected by Eithne Tynan and Titanium rosette samples were collected by Maeve Lohan. Duplicate samples were taken from the stainless steel rosette on several occasions, but no duplicates were taken from the titanium rosette.

Underway samples were collected between stations, approximately every half hour for TA and every hour for pH. DIC sampling from the underway was automated and was done every five minutes between stations for approximately 25 days (128 in total for TA and 360 for pH). Samples for DIC were collected by Eithne Tynan, samples for TA by Eithne Tynan and Elliott Roberts, and pH samples by Elliott Roberts.

Sample analysis

CTD cast samples – The instrument used for the determination of DIC and TA from the CTD casts was the VINDTA 3C from Marianda (Kiel, Germany) connected with a coulometer (UIC 5011). DIC samples were analysed on board using a coulometric titration. The sample is acidified with phosphoric acid 10% which results in the conversion of total dissolved inorganic carbon ($[CO_2^*] + [HCO_3^-] + [CO_3^{2-}]$; where $[CO_2^*] = [CO_2] + [H_2CO_3]$) to CO_2 gas. The CO_2 generated is carried into the coulometric cell using an inert gas (N_2) and titrated coulometrically.

For the determination of TA, the sample of seawater is titrated with hydrochloric acid 0.1 M. The acid solution is added in small increments until the carbonic acid equivalence point is reached (protonation of carbonate and bicarbonate ions). The total volume added allows the calculation of total alkalinity to be undertaken. A glass electrode/reference electrode system monitors the titration (measurement of the electromotive force).

Repeated measurements on the same batch of seawater (n ≥4) were run every day of analysis, prior to the samples analysis, in order to assess the precision of the method. Certified Reference Materials from A.G. Dickson (Scripps Institution of Oceanography) were used as standards to calibrate the system at the beginning of each day of analysis. Samples from casts 5 to 39 (excluding 32) were analysed on board. Cast 32 and casts 40 to 48 were poisoned and will be analysed at the National Oceanography Centre using the VINDTA 3C system.

Samples for the determination of Dissolved Organic Carbon (DOC) and Total Dissolved Nitrogen (TDN) will be analyzed at the National Oceanography Centre, Southampton, by HTCO (High Temperature Catalytic Oxidation) following Badr et al. (2003). Samples will be analysed within 6 months upon return.

Underway samples – DIC and TA measurements from the underway were carried out using instruments from Apollo SciTech. Measurements of DIC were conducted with the Dissolved Inorganic Carbon Analyzer, Model AS-C3. All dissolved inorganic species are converted to CO2 by addition of 10% phosphoric acid. The resulting CO_2 is then purged out of solution by an inert gas (N_2) and the dried CO_2 concentration is measured with the LI-7000 CO_2 analyzer. A five-point calibration using CRMs from A.G Dickson (Scripps Institution of Oceanography) was performed every day.

Measurements of TA were conducted with Total Alkalinity Titrator, Model AS-ALK2. The working principle of this instrument is the same as that for the VINDTA 3C. A sample of seawater is titrated with 0.1M HCl. The first addition brings the pH to 3.5-4 and then continues in small 0.05ml additions until a pH value under 3.0 is reached. The total volume added allows the calculation of total alkalinity to be undertaken. A Ross Orion combination glass pH electrode monitors the titration (measurement of the electromotive force). The pH electrode was calibrated at the beginning of every day using pH 4, 7 and 10 buffer solutions. The acid concentration was standardized for every new batch made using CRMs from A.G. Dickson (Scripps Institution of Oceanography). Accuracy was checked every ten samples using CRM from the same batch.

pH was determined spectophotometrically using two indicators, thymol blue and m-cresol purple. The procedure for m-cresol purple followed SOPs described in Dickson et al. (2007). An LS-LL tungsten-halogen lamp, connected to the flow cell via a fibre optic cable, was used as the light source. The other end of the fibre cable was connected to a USB 4000 UV-Vis spectrometer. Spectra Suite software was used to determine the absorbance of the dark, reference and sample at the particular wavelengths. The procedure for thymol blue followed the method described by Zhang and Byrne. A similar set up was used but using LED lamps as the light source and a USB 2000 UV-Vis spectrometer were used for the thymol blue method. The flow cells were in a thermostat waterbath at 25C. The sample was drawn from the sample tube into the flow cell using a Masterflex C/L Cole Parmer® pump that extracts the sample at a rate of 60RPM.

Table 10.1. List of rosette casts which were sampled for DIC, TA and DOC (cast number in bold indicates titanium rosette, all others from stainless rosette)

Date	Cast	Lat	Long	Niskin bottle no.
21/2/11	5	12°35.144 N	17°54.699 W	1,2,3,4,6,10,12,16,19,23
22/2/11	**6**	12°35.409 N	17°55.016 W	10,11, 13,14,15,16,17
22/2/11	7	12°35.243 N	17°42.843 W	1,2,3,6,10,12,15,18,24
22/2/11	**8**	12°36.565 N	17°43.047 W	13,14,15,16,17
22/2/11	9	12°35.165 N	17°34.244 W	2,4,6,10,14,18,20,24

22/2/11	**11**	12°36.691 N	17°34.397 W	9,10,11,12
23/2/11	13	12°34.323 N	18°49.408 W	1,3,4,6,10,13,16,19,23
23/2/11	**14**	12°35.176 N	18°49.568 W	1,2,4,5,6,7,8,10,11,12,13,14
24/2/11	15	12°34.726 N	21°48.990 W	1,3,4,6,10,12,16,19,23
24/2/11	**17**	12°34.457 N	21°49.375 W	1,2,3,4,5,6,7,8,9,10,11,12,13,14
25/2/11	18	12°35.121 N	23°33.433 W	1,2,3,4,6,10,13,16,19,23
25/2/11	**20**	12°35.104 N	23°34.649 W	12,13,14
26/2/11	21	12°18.041 N	25°07.055 W	1,3,5,6,10,13,16,19,23
26/2/11	**22**	12°18.057 N	25°08.504 W	1,2,3,4,5,6,7,8,9,10,11,13,14
3/3/11	**24**	07°13.317 S	24°59.916 W	1,2,3,4,5,6,7,8,9,10,11,12,13,14
4/3/11	25	07°13.229 S	24°59.534 W	1,2,3,6,10,13,16,19,23
5/3/11	26	03°15.773 S	25°30.834 W	1,2,3,4,6,10,13,16,19,23
5/3/11	**28**	02°57.954 S	25°36.477 W	2,3,4,5,6,7,8,9,10
6/3/11	29	01°10.503 S	25°47.533 W	1,2,4,5,7,11,14,15,17,24
6/3/11	**30**	01°10.109 S	25°47.981 W	2,3,4,5,6,7,8,9,10,11,12,13
7/3/11	31	01°09.387 N	26°02.673 W	1,2,4,5,7,11,14,15,17,24
7/3/11	**32**	01°09.510 N	26°02.984 W	1,2,3,4,5,6,7,8,9,10,11,12,13,14
8/3/11	33	03°19.303 N	26°48.207 W	1,2,4,5,7,11,14,15,17,24
8/3/11	**34**	03°20.310 N	26°49.045 W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15
9/3/11	35	05°39.665 N	27°29.667 W	1,2,4,5,7,11,14,15,17,23
9/3/11	**36**	05°39.904 N	27°30.424 W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15
10/3/11	37	08°20.277 N	28°19.726 W	1,2,5,7,11,14,15,17,24
10/3/11	**38**	08°20.696 N	28°20.092 W	1,2,3,4,5,6,7,8,9,10,11
11/3/11	39	10°37.533 N	28°43.777 W	1,2,4,5,7,11,14,15,17,24
11/3/11	**40**	10°37.573 N	28°43.963 W	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16
12/3/11	**41**	12°00.99 N	28°58.10 W	1,2,4,5,6,7,8,9,10,11,12,13,14,15
12/3/11	42	12°03.025 N	28°58.795 W	1,4,5,7,11,14,15,17,24
13/3/11	43	15°30.607 N	28°46.875 W	1,2,4,5,7,11,14,15,17,24
13/3/11	**44**	15°30.385 N	28°47.416 W	1,2,3,4,5,6,7,8,9,10,11,12,13,14

14/3/11	45	17°23.405 N	28°23.906 W	1,2,5,7,11,14,15,17,24
14/3/11	**47**	17°25.830 N	28°22.632 W	1,2,3,4,5,6,7,8,9,10,11,12
15/3/11	48	19°06.556 N	28°07.781 W	1,2,4,5,6,11,14,16,17,22

10.3 Preliminary results

Preliminary results for the CTD casts on the East-West transect from the Senegal Coast are shown in Figure 10.1 (not corrected for nutrients, temperature or salinity). These results show the enhanced DIC values (of up to 2250 µmol/kg) expected in the OMZ due to organic matter remineralization. TA values are also slightly lower (ca. 2300 µmol/kg, compared to 2360 µmol/kg in some of the surface waters) in the OMZ. Further analysis are needed to establish the effect of the carbonate pump on the data observed.

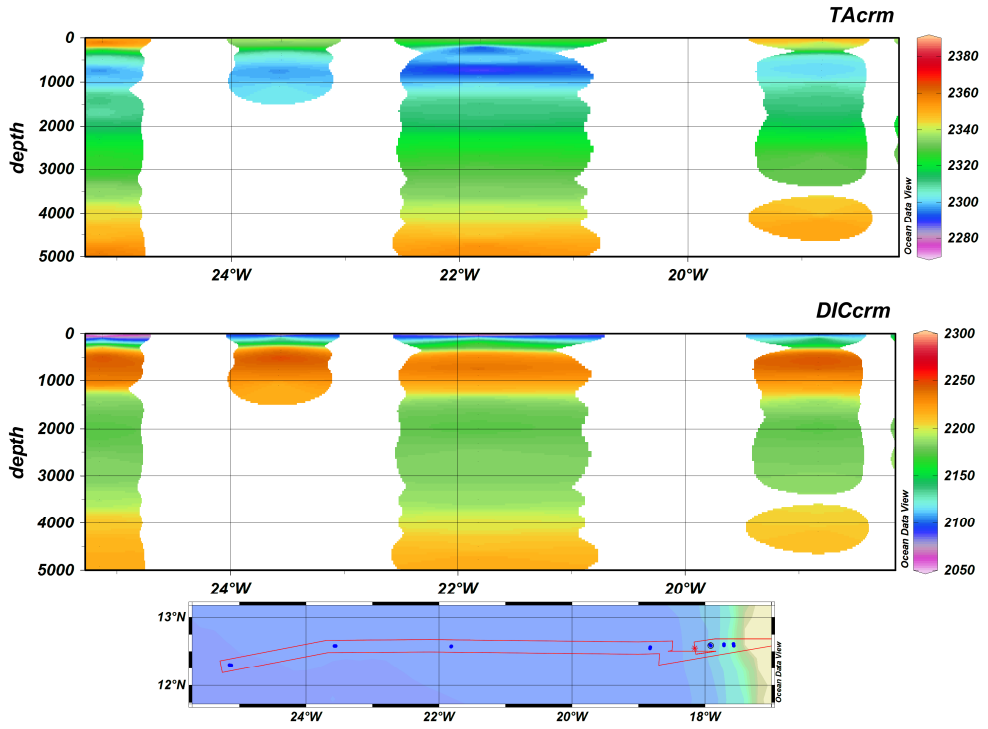

Figure 10.1. Concentrations of TA and DIC in the OMZ

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11 Trace metal sampling, Ti CTD

Sample logs for all Ti CTD casts are in Appendix C. Samples were collected for trace metal work (see sections 12-18). In addition, from all the Ti-CTD casts unfiltered samples were collected for oxygen, alkalinity/DIC, nutrient and salinity analysis onboard ship (see sections 4, 8, 9 and 10). Additionally, unfiltered samples were taken for barium (at all depths), dissolved organic carbon (see section 10), dissolved organic phosphorus (from depths below 500m; see section 30). Filtered samples were collected for nitrate isotopes, rare earth elements and ^{232}Th from all casts (Table 11.1). In addition filtered samples for iron (see section 17), chromium (see section 19), lead, cadmium, protactinium/thorium (^{231}Pa/^{230}Th) and silicon isotopes were collected from selected stations (see Appendix C).

Table 11.1 Samples collected from Ti CTD for additional measurements

Sample	**Responsible**
Barium	Eric Achterberg, University of Southampton
Nitrate isotopes	Mark Moore
Rare earth elements	Gideon Henderson, Oxford University
^{232}Th	Gideon Henderson, Oxford University
Lead and cadmium isotopes	Imperial College, London
^{231}Pa/^{230}Th	Gideon Henderson, Oxford University
Si isotopes	Kate Hendry, WHOI

12 Dissolved cobalt distribution in subtropical Atlantic Ocean-D361

Maeve Lohan, Angela Milne

12.1 Introduction

Cobalt (Co) is an important micronutrient for marine phytoplankton (*Morel et al.,* 1994; *Croft et al*., 2005). While it is widely accepted that iron (Fe) limits phytoplankton growth over large areas of the surface ocean [*e.g. Coale et al*., 1996; *Boyd et* al., 2000], a growing body of evidence suggests that other trace elements such as Co may limit or co-limit algal growth (*Saito et al.,* 2008). Indeed, a number of recent studies have recognised the importance of cobalt in influencing phytoplankton dynamics in the open ocean (*e.g. Saito et al*., 2002; *Bertrand et al*., 2007; *Panzeca et al.,* 2008; *Saito and Goepfert*, 2008).

Cobalt is required for the synthesis of vitamin B_{12} by marine prokaryotes. Vitamin B_{12} is a biologically produced, Co-containing organometallic compound that is only produced by certain bacteria and archaea, thus all eukaryotes must either acquire it from the environment, or possess an alternative metabolism with no vitamin B_{12} requirement (*Bertrand et al*., 2007). Cobalt is also a co-factor in the enzyme carbonic anhydrase (CA), which is required by marine phytoplankton for inorganic carbon acquisition (*Morel et al*., 1994). Some phytoplankton such as centric diatoms are able to substitute Co or cadmium (Cd) for zinc (Zn) in CA, but there are some key phytoplankton genera such as the cyanobacteria *Prochlorococcus* and *Synechococcus* that have an absolute requirement for Co (*Saito et al.,* 2002). Given that *Prochlorochoccus* may be the most abundant autotroph in the ocean (*Partensky et al*., 1999) and may account for a significant proportion of global photosynthesis (*Campbell et al*., 1994), there is a need to understand the potential role of Co in controlling the growth and distribution of this organism.

In addition, there is emerging evidence that some forms of alkaline phosphatase (AP), a metalloenzyme that facilitates acquisition of phosphorus (P) from the dissolved organic phosphorous (DOP) pool, may contain Co as the metal cofactor (*Gong et al*., 2005) rather than Zn (*e.g. Plocke et al.,* 1962). Expression of AP is of particular importance in the North Atlantic Subtropical Gyre, where up to 30% of primary production may be supported by the DOP pool (*Mather et al*., 2008). *Jakuba et al.* (2008) have also provided evidence for important linkages in the biogeochemical cycles of Co, Zn and P in the phosphorous-poor surface waters of the Sargasso Sea. At present, however, the biogeochemical cycling of Co and the

extent to which this trace element may influence phytoplankton growth and species composition in the surface ocean is not well understood.

12.2 Methods

Sampling – Water column samples were collected at 20 stations (up to 24 depths) along the transect (Fig. 1 and Appendix A) using the titanium-frame CTD, which was fitted with trace metal clean 10L OTE (Ocean Technology Equipment) sampling bottles with external springs, modified for trace metal work. The trace metal clean OTE sample bottles were then transferred to a clean van on the back deck for sample processing. In addition, underway samples were collected along the transect using a 'towfish' deployed off the port side of the ship. Near-surface seawater (~2 metre depth) was pumped into the clean van using a teflon diaphragm pump connected to clean oil free compressed air compressor and samples collected every two hours while the ship was in transit.

Sample processing – From the titanium frame rosette bottles, samples for dissolved colbalt were filtered using a 0.2 µm Supor Acropak filter capsule (Pall Corp.) that was pre-rinsed with ~5 L of surface seawater from the 'towfish' followed by several hundred mL of sample into 125mL Nalgene LDPE bottles. These samples were filtered with a low overpressure of 10-50 kPa positive pressure using oxygen-free N_2. Samples were acidified to 0.024 M with ultrapure HCl (UpA Romil).

Analysis – Samples for total dissolved cobalt will be UV-digested prior to analysis using flow injection analysis (Shelley et al., 2010) back at the University of Plymouth.

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13 Particulate Trace metal in subtropical Atlantic Ocean-D361

Maeve Lohan, Angela Milne

13.1 Introduction

Particulate trace metals may occur in several forms, including stable refractory phases or as coatings on surfaces that can be rapidly recycled. Particulate behaviour is metal specific with, for instance, the majority of particulate Fe occurring in refractory phases while Zn is primarily associated with more labile phases (Hurst & Bruland, 2007).

The particulate Fe pool is important for remineralisation, scavenging and export processes in the ocean (Frew et al., 2006). Particulate Fe exists as either biotic (e.g., cellular Fe, detritus) or abiotic/lithogenic (e.g., alumino-silicate clays) material, which may be solubilised for uptake by protozoan (Barbeau et al., 1996) or zooplankton (Hutchins and Bruland, 1994) grazers. Little information exists on the coupling between the biogeochemical cycles of Fe and carbon (C) in the ocean, due to the scarcity of data on the Fe content of suspended or exported particles. Iron/carbon ratios are essential to determining the carbon sequestration efficiency and hence the impact of increased Fe supply on atmospheric carbon dioxide (CO_2) drawdown and global climate in the contemporary ocean (Blain et al., 2007) and in the geological past (Boyd et al., 2007).

Few studies have concurrently measured trace elements in both the dissolved and particulate phases. Furthermore, labile particulate trace metals which are biologically available could be considerably higher than dissolved phase and therefore act as an important source for phytoplankton growth (Berger et al., 2008). Assessment of total biologically available trace elements may thus require the determination of both dissolved and labile particulate metal phases (Lam & Bishop, 2008). A first step towards a quantitative description of the cycling of trace elements between the dissolved and particulate phases required for their realistic incorporation into biogeochemical ocean models is to measure the standing stock of the particulate fraction.

13.2 Methods

Sampling- Water column samples were collected at 20 stations (up to 24 depths) along the transect (Fig. 1 and Appendix A) using the titanium-frame CTD, which was fitted with trace metal clean 10L OTE (Ocean Technology Equipment) sampling bottles with external springs, modified for trace metal work. The trace metal clean OTE sample bottles were then transferred to a clean van on the back deck for sample processing.

Sample processing- After the sampling of oxygen, alkalinity, total dissolved iron and nutrients, 12 OTE bottles were clamped and pressurized with oxygen free N_2 gas. Up to a maximum of 7 L of seawater from the OTE bottles on the Ti rosette was filtered through 25 mm Supor 0.45 µm polyethersulfone filters (Supor; Pall Gelman) housed in acid cleaned Millipore Swinnex filter houses and connected to the OTE bottles using luer lock fittings and acid cleaned Bev-a-line tubing (Cole Parmer).

Following filtration, the filter houses were removed and placed in a laminar flow bench. Using an all-polypropylene syringe attached to the top of the filter holder, residual seawater was forced through the filter using air from within the laminar flow bench. This ensures there is no spillage and loss of particulate material from face of filter when filter holder is opened, and will remove as much seawater as possible in order to reduce the residual seasalt matrix for analytical simplicity after the sample is digested. The filter holders were gently opened and the PES filter was folded in half using acid cleaned plastic tweezers, the filters were then placed in an acid washed 2 ml LDPE vials and frozen at -20^{o}C until analysis.

Only 12 OTE bottles could be pressurised and sampled at one time. Prior to the sampling of the next set of 12, the OTE bottles were inverted three times to gently mix the seawater and re-suspend particulates. Filtration of all twenty-four bottles was completed in approximately seven hours.

Process blanks samples were be obtained using a 0.2µm pore size AcroPak capsule filter on the outlet of the GO-Flo bottle, attaching the loaded filter holder to the capsule filter outlet, and filtering normally to a default volume of 2 L, so that TM-clean 0.2 µm filtered seawater passes through the particle sampling filter. This filter will then be treated thereafter as for normal samples.

Analysis –Samples will be analysed for both labile and refractory particulate Fe, Mn, Al, Co, Zn, Cd, Ba, Ni, Cu, Ti, and potentially other elements using ICP-MS at the

University of Plymouth. For labile particulate trace elements the filter is subjected to a weak acid leach (25% acetic acid at pH 2) with a mild reducing agent (0.02 M hydroxylamine hydrochloride) and a short heating step (10 min 90–95^{o}C). This approach is fully detailed in Berger et al. (2008). After the labile fraction has been determined the refractory trace elements will be determined using methods developed by Robert Sherrell during the Intercalibration effort. Briefly, the filters are placed in Savillex 15 ml vials and 1 ml of 50% HNO3 & 10% HF added and then heated to 130 ^{o}C for 4 hours. This solution is then dried down on a hot plate and 100 micro liters of concentrated HNO3 added and the dry down procedure is repeated. The residue is brought back into solution with 5% HNO3 for analysis by ICP-MS. The samples are then spiked with an internal reference such as In for drift correction.

13.3 References

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14 Dissolved iron(II) and hydrogen peroxide distribution in the Atlantic Ocean during D361

Angela Milne, Maeve Lohan

14.1 Introduction

In much of the open-ocean, primary production by phytoplankton is controlled by the major nutrients (nitrate, phosphate, and silicate), however in up to half of the open ocean from tropical to polar regions, iron has been shown to be growth limiting (Coale et al. 1996; Behrenfeld and Kolber, 1999; Boyd et al. 2000). Our ability to understand the dynamics of marine ecosystems and their role in global climate change is therefore intertwined with our understanding of this essential nutrient, it's determination in seawater is therefore of fundamental importance. Research in this area has focused on the dynamics of iron speciation in seawater along with the mechanisms by which iron is assimilated by marine phytoplankton (Moffet 2001; Sunda 2001). The lower redox state, iron(II), is of particular interest due to its greater solubility and potential bioavailability (Bruland et al. 1991; Rich and Morel, 1990). However, in oxygenated seawater levels of iron(II) are extremely low, existing at low picomolar concentrations, and can be rapidly oxidised by O_2 and reactive oxygen species, such as H_2O_2, to the more thermodynamically favoured iron(III) form (Millero et al. 1987; Moffet and Zika, 1987). Making measurements of this transitory species, without perturbing the redox balance, is therefore extremely difficult. The persistence of iron(II) is due to a combination of factors; photochemical (O'Sullivan et al. 1991; Johnson et al. 1994), thermal, enzymatic, and microbial cycling pathways (Tortell et al. 1999; Croot et al. 2001). Low temperatures retard its oxidation (Millero et al. 1987) and organic complexation may promote iron(III)-ligand photoreduction and thus slow oxidation rates further (Johnson et al. 1994, Croot et al. 2001). Furthermore, atmospheric deposition (Zhuang et al. 1992) and diffusion from reducing sediments (Hong and Kester 1986) may also supply iron(II) to the ocean. The ratio of iron(II) to "total" dissolved iron(II+III) in surface seawater is thus a balance between the strength of the sources of iron(II), rates of reduction and oxidation, and complexation of each redox state by (in)organic ligands.

Reactive oxygen species are ubiquitous in the surface waters of the ocean's and include free radicals and peroxides, of which H_2O_2 is one of the principal species. H_2O_2 is the most stable of the reactive oxygen species, with a half-life that can range from hours to days depending on environmental conditions (Cooper et al. 1994; Petasne and Zika 1997; Yuan and Shiller 2001, 2005). In the open ocean, the concentrations of this species are controlled by a complex set of factors involving aerosol deposition, light intensity, biological production, concentration of organic matter and physical mixing processes. This influences not only the concentration of H_2O_2 but also its distribution through the water column. A typical H_2O_2 profile depicts

a suface maxima followed by depletion with depth (Croot et al. 2004, Yuan and Shiller 2001). Concentrations of less than 10 nM to values greater than 200 nM have been reported in surface waters of the Southern, Atlantic and Pacific Oceans (Sarthou et al. 1997; Zika et al. 1985; Miller & Kester 1994; Yuan & Shiller 2001, 2005; Croot et al. 2004), with the lowest values having been observed in the Southern Ocean. This wide range illustrates the complexity of the processes which contribute to the presence and persistence of H_2O_2 in the ocean. This transient species is highly reactive and can be involved in many chemical interactions, it is of particular importance in redox processes with metal ions (Moffett and Zika, 1987; González-Davila et al. 2005; Millero and Sotolongo 1989).

14.2 Methods

Sampling - Water column profiles were collected from varying depths through the water column using twenty-four 10 L OTE bottles mounted on a Ti rosette. On recovery, the OTE bottles were transferred into a clean container for sampling. Unfiltered samples from selected depths were collected into acid cleaned LDPE bottles which had been previously soaked in ultra high purity water. Bottles and caps were rinsed 3 times with sample before being filled from the bottom up using clean silicon tubing. The collection of 9 samples took approximately 1 h from the time the Ti rosette was recovered from the water. In addition, after the ship's departure from station, occasional unfiltered surface samples (5 m) were collected from the underway tow-fish for H_2O_2 analyses. Samples were stored in a cool box prior to analyses.

Sample processing – No additional processing of samples was required prior to analyses.

Analysis –Flow Injection with Chemiluminescence detection (FI-CL) was used for the determination of both Fe(II) and H_2O_2. Samples for Fe(II) were filtered (0.2 µm PES syringe filter, Nalgene) and buffered (pH 5.5) in-line prior to extraction and pre-concentration using a column filled with 8-HQ chelating resin (Bowie et al. 2002). In contrast, samples for H_2O_2 were run directly without filtration (Milne et al. 2009, Price et al. 1994). Measurements were made on board and started immediately after the collection of samples. Each sample was first analysed for Fe(II) and then transferred to a separate flow injection system for H_2O_2 analysis. Measurement of both parameters took approximately 15 min per sample. All sample handling and analyses took place in a laminar flow bench using clean handling techniques.

14.3 Results

Samples for Fe(II) were collected from 7 Stations (totalling 57 samples) and analysed on board immediately after collection. Due to instrumental difficulties no data could be produced for one station, there are therefore 6 profiles for dissolved Fe(II). Preliminary results indicate that, in general, concentrations through the water column are very low and range between 10-200 pM with the lowest concentrations being observed in surface waters. The distribution of Fe(II) through the water column appears to be strongly correlated with O_2 with the highest Fe(II) levels coinciding with the O_2 minimum. This inverse relationship between Fe(II) and O_2 is illustrated in Figure 14.1 which displays a profile from Station 16. This profile is typical of the profiles collected from Stations 16-20. Higher concentrations of dissolved Fe(II) were observed for Station 9 (100-800 pM), this Station was the final one occupied on the east-west transit of 12^{o}N along the oxygen minimum zone of the North Atlantic.

Samples for H_2O_2 were collected at 12 Stations totalling 111 samples, and again analysed on board. In general, samples were analysed after first being analysed for Fe(II), however, due to instrumental difficulties, at 5 stations (Stations 11-15) H_2O_2 alone was measured. The distribution of H_2O_2 through the water column was typical for this reactive oxygen species, the highest concentrations were observed in surface waters rapidly dropping to below the limit of instrumental detection once clear of the photic zone (approximately below 100-150 m). Surface concentrations were variable and ranged from approximately 20 to > 80 nM, while spatial and temporal differences are likely the main factors to have influenced this concentration range, weather conditions particularly through the ITCZ will also be a factor. The sharp decline in H_2O_2 concentrations to below detection limits incidentally coincided with the increase in observed dissolved Fe(II) concentrations, this was particularly noticeable a Station 9 where the highest Fe(II) levels corresponded to sharp negative peaks in the determination of H_2O_2.

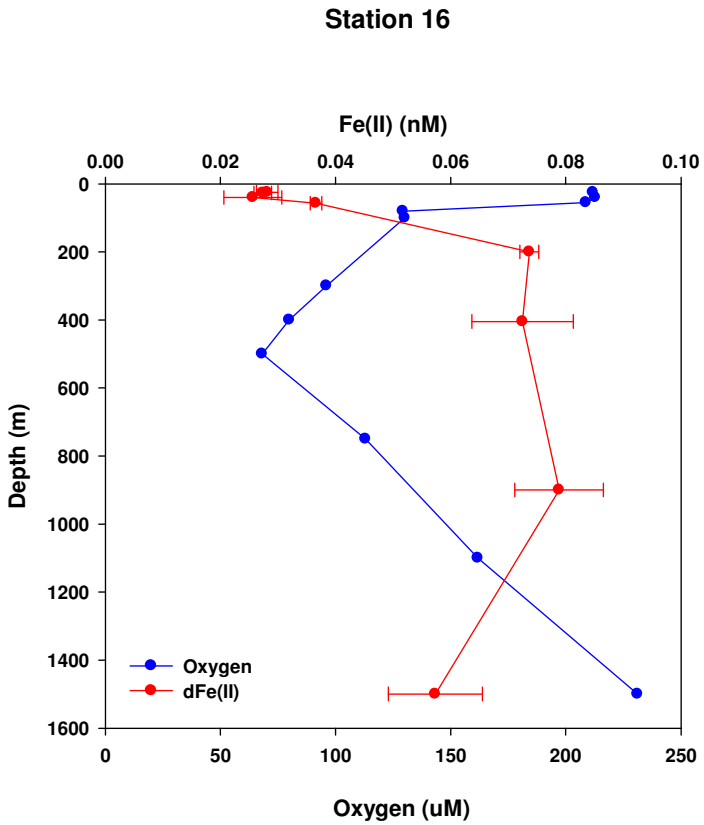

Figure 14.1. Dissolved Fe(II) concentrations (nM) for Station 16.

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15 Dissolved and total dissolvable trace metal distributions and iron speciation

Bronwyn Wake

15.1 Introduction

Iron is well established as a limiting element for phytoplankton growth. The role of other trace elements in the biological cycle is less understood and there is a lack of data for the global ocean on the concentration and distribution of these elements.

The role of iron (Fe) in the ocean is well established but other trace elements are not as extensively studied or understood. Understanding the roles of the various elements, will enable us to determine the sources and sinks in the ocean and gain a greater knowledge of their biogeochemical cycling. Trace elements can be used to track inputs into the ocean, aluminium (Al) is an indicator of aerosol deposition (Tria et al., 2007), and manganese (Mn) can indicate sedimentary or hydrothermal inputs (Johnson et al., 1992; Middag et al., 2011).

The biological role of various trace elements is beginning to be elucidated. Nutrient-like profiles indicate biological utilisation and regeneration, and the metals could be behaving individually or antagonistically (Bruland et al., 1991). Cadmium (Cd), zinc (Zn) and cobalt (Co) can functionally substitute for each other in marine diatoms to achieve optimum growth rate (Price and Morel, 1990); a Cd enzyme has been characterised (Lane et al., 2005). Copper (Cu), at ambient concentrations, can be toxic to some cyanobacteria, whilst diatoms with low Fe requirements are easily limited by it (Morel and Price, 2003).

Lead (Pb) has been antropogenically enhanced in the atmosphere and delivered to the oceans. It's distribution is effected by changing Pb emissions and the movement and subduction of surface waters (Boyle et al., 2005). Silver (Ag) has historical anthropogenic and atmospheric sources to the ocean, very little data existed for this element, but it suggests a link with silicate (Flegal et al., 1995; Ndung'u et al., 2001).

15.2 Methods

Sampling – Water column samples were collected at 20 stations (up to 24 depths) along the transect (Fig. 1.1) using the titanium-frame CTD, which was fitted with

trace metal clean 10L OTE (Ocean Technology Equipment) sampling bottles with external springs, modified for trace metal work. The trace metal clean OTE sample bottles were then transferred to a clean van on the back deck for sample processing. In addition, underway samples were collected along the transect using a 'towfish' deployed off the port side of the ship. Near-surface seawater (~2 metre depth) was pumped into the clean van using a teflon diaphragm pump connected to clean oil free compressed air compressor and samples collected every two hours while the ship was in transit.

Sample processing – From the titanium frame rosette bottles, duplicate samples for dissolved trace metals were filtered using a 0.2 µm Supor Acropak filter capsule (Pall Corp.) that was pre-rinsed with ~5 L of surface seawater from the 'towfish' followed by several hundred mL of sample into 125mL Nalgene LDPE bottles. These samples were filtered with a low overpressure of 10-50 kPa positive pressure using oxygen-free N_2. Total dissolvable metal samples were collected unfiltered. All water samples were acidified to pH~2 using hydrochloric acid (Romil UpA). Unfiltered samples will be left for a minium of 4 months before analysis.

At selected stations, additional samples were collected for Fe speciation and Fe soluble measurements in 250ml Nalgene LDPE bottles. Samples were collected after filtration through 25 mm Supor 0.45 µm polyethersulfone filters (Supor; Pall Gelman) housed in acid cleaned Millipore Swinnex filter houses and connected to the OTE bottles using luer lock fittings and acid cleaned Bev-a-line tubing (Cole Parmer). Fe speciation samples were stored frozen (-20^{o}C) for shore based analysis.

Fe soluble samples were further filtered on-board according to the following protocol (Nishioka et al., 2001; Thuroczy et al., 2010). Tubing was acid rinsed for 30 min before starting, using 10% HCl. Then the hollow fibre filters were placed in the tubing and rinsed with MQ (~220 ml). After rinsing, the sample bottle was introduced. The first 125ml of sample rinsed the filter, the soluble Fe sample bottle and was discarded. The remaining 125ml was collected. After the sample filtration, filter was MQ rinsed again before the new sample was introduced. After the last sample, tubing and filters were MQ back-flushed and 1% HCl rinsed before re-use.

Analysis – One of the filtered water samples was analysed on board for dissolved Fe and dissolved Al via flow injection analysis techniques (for details, see section 14 and section 15). Replicate samples will be analysed for a range of trace metals, e.g.

Fe, Mn, Co, Cd, Zn, Cu, Pb, by inductively coupled plasma mass spectrometry (ICP-MS) back at NOCS (Milne et al., 2010).

Fe speciation samples will be analysed on return to NOCS, by competitive ligand cathodic stripping (Croot and Johansson, 2000).

15.3 Results

The underway samples were analysed on board for DFe and DAl (see section 16 and section 17). All further analysis will be done on return to Southampton. Total dissolvable samples will be analysis after a minimum of 4 months.

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16 Distribution of dissolved and total dissolvable Fe in the water column of the tropical Atlantic Ocean

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16.1 Introduction

While it is established now that iron (Fe) and other trace metals (zinc, cadmium, etc.) can be (co)limiting nutrients for phytoplankton (Boyd, et al., 2000; Coale et al., 2004; Croot et al., 2005), we still know little about the processes by which these trace metals are supplied to the ocean (aeolian dust, resuspension of continental shelf sediments) and what mechanisms govern scavenge/uptake, solubility, mineralization or remineralization of dissolved trace metals. By examining trace metal chemistry in oxygen minimum zones (OMZ) in the tropical Atlantic Ocean as encountered on D361 we can try to complete the overview of the key processes controlling biogeochemistry and mobilization of trace metals to seawater. From this basis we can start to quantify the fluxes involved in each individual process.

16.2 Methods

Sampling –As Fe exists at extremely low levels in seawater, extreme caution is needed in taking samples at sea, because of the potential for contamination from the ubiquitous steel construction of modern research vessels. Thus for the purposes of the present work we employed a variety of techniques for obtaining clean water samples:

(i) Discrete water samples from depth were obtained via Niskin bottles deployed on a titanium frame CTD rosette (Ti-CTD) on a Kevlar line. Dissolved samples were collected after filtration through 0.2 m PES filters with slight N_2 overpressure. All sample collection was carried out under trace metal clean conditions in the sampling container situated on the working deck close to the Kevlar winch. Samples were usually taken between the surface and the sea floor and acidified after collection by adding 140 µL ultra-clean HCl acid into 125 mL sample.

(ii) Surface water samples were collected from the NMF towed fish deployed from a winch on the working deck some 3-4 m from the side of the ship and a depth of 2-3 m. From the fish samples were pumped to the trace metal clean sampling container via a totally enclosed system with suction provided by Teflon pump. Filtered samples were obtained by directly drawing a sample through a 0.2 m cartridge filter (AcroPak®). Sample Bottles were then

filled and acidified by ultra-clean HCl acid. The entire system was self enclosed.

Analysis –Most of the collected seawater samples (18 of 19 profiles and 210 of 250 surface samples) were analyzed already on board for dissolved Fe concentrations using an online flow injection analysis (FIA) systems with a Toyopearl column via luminol chemiluminescence (Klunder et al.in press). SAFe and GeoTraces standard seawaters were analysed every day to validate the measured dissolved Fe concentrations (Table 16.1).

Table 16.1: Results of performed calibration measurements

SAFe S	0.095±0.011	nmol L-1	(n=5)
SAFe D2	0.933±0.035	nmol L-1	(n=5)
GS-23	0.424±0.026	nmol L-1	(n=5)
GD-57	0.940±0.056	nmol L-1	(n=6)

16.3 Preliminary Results

The sampling locations of the surface samples and water column samples are shown in Fig. 1.1 and 1.2. In total, samples from 19 deep Ti-CTD stations and 250 samples of the underway fish sampling system were collected for dissolved and total dissolvable trace metal analysis during this cruise.

Dissolved Fe measurements on surface samples from the towed fish showed Fe concentrations in the dissolved phase between 0.059 and 1.3 nmol L^{-1}, depending from the location (Fig. 16.1). Highest Fe concentrations were measured in the centre of the Intertropical Convergence Zone (ITCZ) (Fish 90 – 110 and Fish 175 – 195). This was explained by rain that washed a reasonable amount of dust out of the air into surface waters. The dust particles were then partly dissolved and the containing Fe was excreted. Lowest Fe concentrations close to the detection limit were measured in the outer northern layer of the Southern Atlantic gyre (Fish 128 – 146).

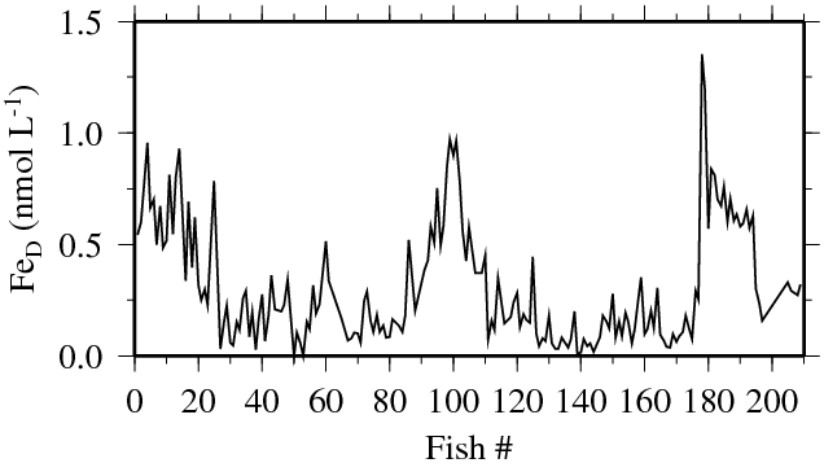

Figure 16.1: Preliminary results of dissolved Fe concentration in surface waters of the tropical Atlantic Ocean.

The results of dissolved Fe measurements of three sampled deep Ti-CTD stations showed enhanced Fe values in the depth of the OMZ core between 200 and 1000 m (Fig. 16.2). The elevated Fe contend in this depth might be caused by overall lower oxygen concentration (~40 µmol L^{-1}) found at these depth and connected to this probably a higher concentration of the better soluble Fe(II) species. A detailed explanation for this behaviour and the overall cycling of trace metals in the tropical Atlantic Ocean will be possible with samples collected for later measurement of total dissolvable Fe and other elements (Al, Cd, Zn, Pb, Cu, Co, etc.) in the laboratory in Southampton.

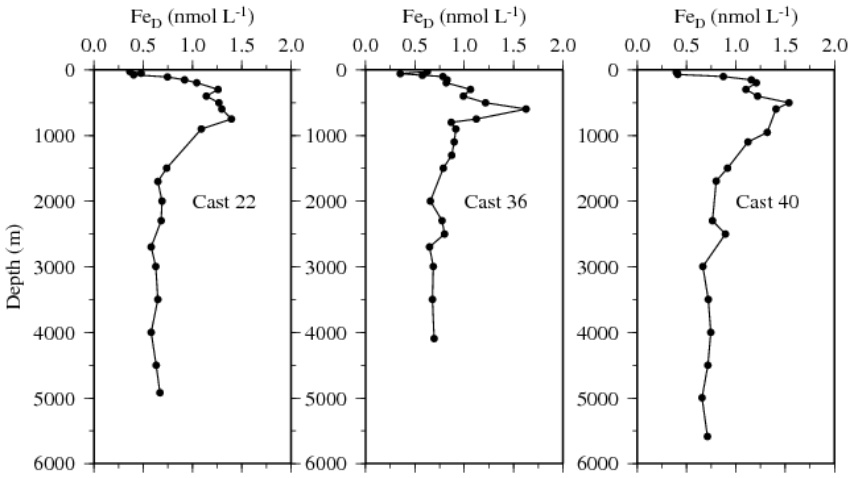

Figure 16.2: Preliminary results of dissolved Fe concentration in the water column at three distinct locations in the OMZ of the tropical Atlantic Ocean.

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17 Dissolved aluminium and iron isotopes distributions in the tropical Atlantic Ocean

Jessica Klar

17.1 Introduction

Al and Fe are major components of the continental crust but are found in trace amounts in oceanic waters. As well as phosphorous, Iron plays a key role in regulating microbial nitrogen fixation (diazotrophy) in the (sub) - tropical Atlantic Ocean (Mills *et al.*, 2004). Fe and P are thought to be mainly supplied to this region through dust transported from the Saharan desert (Bowie *et al.*, 2002, De Jong *et al.*, 2007).

Atmospheric dust deposition can be estimated through dissolved aluminium (dAl) concentrations in surface seawater (Measures and Brown, 1996, Measures and Vink, 2000, Mahowald *et al.*, 2005, Measures *et al.*, 2005). Al is not assimilated by living cells, which makes this element a conservative tracer of dust inputs of Fe and other biolimiting trace metals, such as Zn, Co and Cu. The degree of Fe uptake can be estimated by comparing the Fe:Al ratios in atmospheric dust and dissolved in surface seawater. Furthermore, relative concentrations of aluminium to other metals (V, Pb) in aerosol samples can give information about whether the source of atmospheric inputs is crustal (e.g. dust blown from deserts and other arid regions) or industrial (burning of fossil fuels) (Helmers and Van Der Loeff, 1993).

Further, in this oceanic region, a pronounced Fe maxima is observed in the oxygen minimum zone (OMZ), found in sub-surface waters (Measures *et al.*, 2008). Therefore sub-surface transfer to the upper ocean (through mixing and upwelling) is another potential source of Fe to the diazotrophic community.

In general terms, Fe can be supplied to the euphotic zone through atmospheric dust deposition, upwelling and mixing of deep waters. The origin of this Fe can be from dissolution of continental dust particles, remineralization of sinking biogenic material, anoxic decomposition of biogenic material in sediments, and Fe complexed to organic or inorganic ligands (Boyd and Ellwood, 2010). The relative importance of the different Fe sources to the upper ocean is still poorly understood. It has been discovered that the different sources of Fe have distinctive isotopic compositions (Johnson and Beard, 2005, Radic *et al.*, 2009, Kappler *et al.*, 2010, Rouxel and

Auro, 2010). Therefore, it is curtail to develop methods for the determination of Fe isotopes in the dissolved pool (John and Adkins, 2010, Lacan *et al.*, 2010).

Our aim is to establish the distribution of dissolved aluminium in surface waters and in the water column along the ships transect. Further we want to gain insight in the distribution of iron isotopes in the water column within the oxygen minimum zone in order to establish the source of pronounced Fe concentrations in sub-surface waters.

17.2 Methods

Sampling – 369 Water column samples were collected at 19 CTD stations along the transect using the titanium-frame CTD, which was fitted with trace metal clean 10L OTE (Ocean Technology Equipment) sampling bottles with external springs, modified for trace metal work. At these stations samples were collected at up to 24 depths. The trace metal clean OTE sample bottles were then transferred to a class 100 clean van (sampling container) on the back deck for sample processing (where the OTE bottles stayed until next deployment). OTE bottles were pressurized with oxygen-free nitrogen. In addition, a total of 213 underway samples were collected along the transect using a towfish deployed off the port side of the ship. Near-surface seawater (~2 metre depth) was pumped into the sampling container using a teflon diaphragm pump connected to clean oilfree compressed air compressor and samples collected every two hours while the ship was in transit.

Sample processing; Al – From the titanium frame rosette bottles, filtered seawater samples were collected in 125mL Nalgene LDPE bottles for shipboard determination of Al and Fe. Filtered samples were collected through a 0.2 µm Supor Acropak filter cartridge (Pall Corp.). All water samples were acidified to pH~1.9 using hydrochloric acid (Romil UpA) within twelve hours of collection.

Sample processing; Fe isotopes – From the titanium frame rosette bottles, filtered seawater samples were collected in 1 L Nalgene HDPE bottles. Filtered samples were collected through 0.45 µm polyethersulfone filters (Supor; Pall Gelman) or 0.2 µm Acropak filter cartridges (Supor, Pall Corp.), depending on the available water budget. All water samples were acidified to pH~1.9 using hydrochloric acid (Romil UpA) within twelve hours of collection.

Analysis – Between one hour and one week after acidification all filtered seawater samples were analysed on board for dissolved Al using flow injection analysis developed by (Resing and Measures, 1994) (with modifications from (Brown and Bruland, 2008)), where Al is detected by the fluorescence of a formed chelate by reaction with lumogallion.

Iron isotopes samples have been stored and will be analyzed at NOCS.

17.3 Results

369 profile samples were collected (Fig. 17.2 and 17.3) from the Ti-frame CTD and 213 underway samples (1-234, Fig. 17.1) from the tow-fish. The majority of samples were analysed on board for dAl.

Preliminary analysis showed surface concentrations of approximately 3 to 50 nM dAl, with low concentrations close to the Senegal coast. It is observed that dAl concentrations are especially pronounced between 7° N and 2° N, ranging from 30 to 50 nM. In the southern hemisphere dAl concentrations become lower, down to ~10 nM.

Preliminary analysis of the TiCTD depth profiles showed high dAl at surface (10 to 50 nM) but rapidly decreasing dAl at subsurface. From 1000 m to depth dAl generally ranges from 10 to 20 nM. On the Senegal shelf dAl was lower (below 10 nM) compared to the rest of the profiles. dAl profiles through the OMZ along 12° N are shown in figure 17.2.

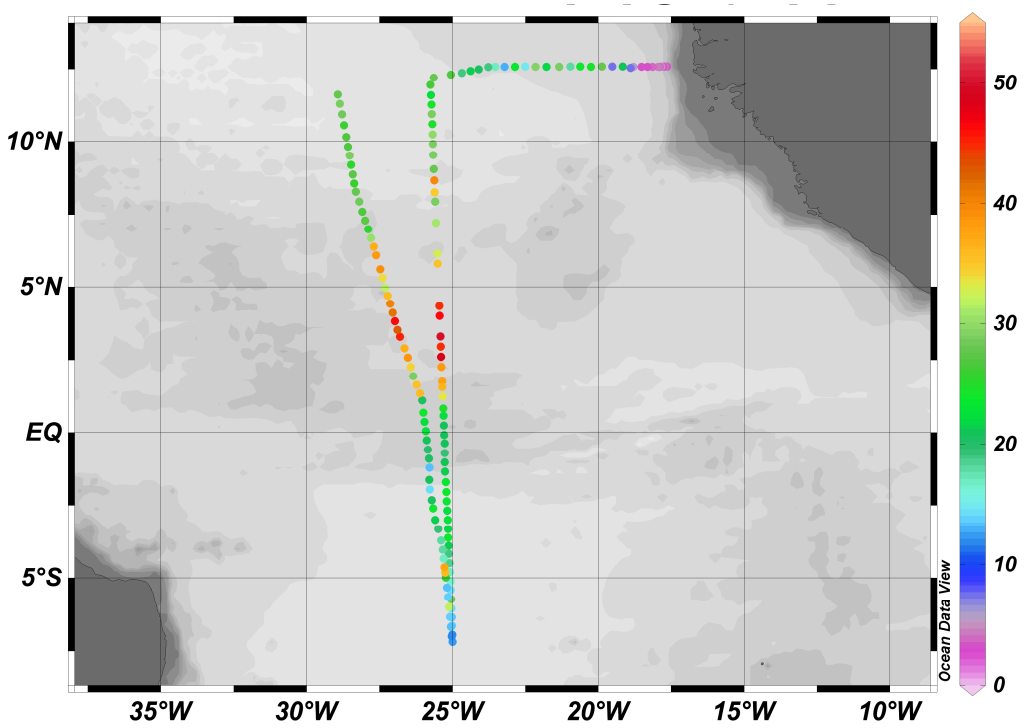

Figure 17.1: Dissolved Al (nM) concentrations in samples collected using underway tow fish (collection every 2h)

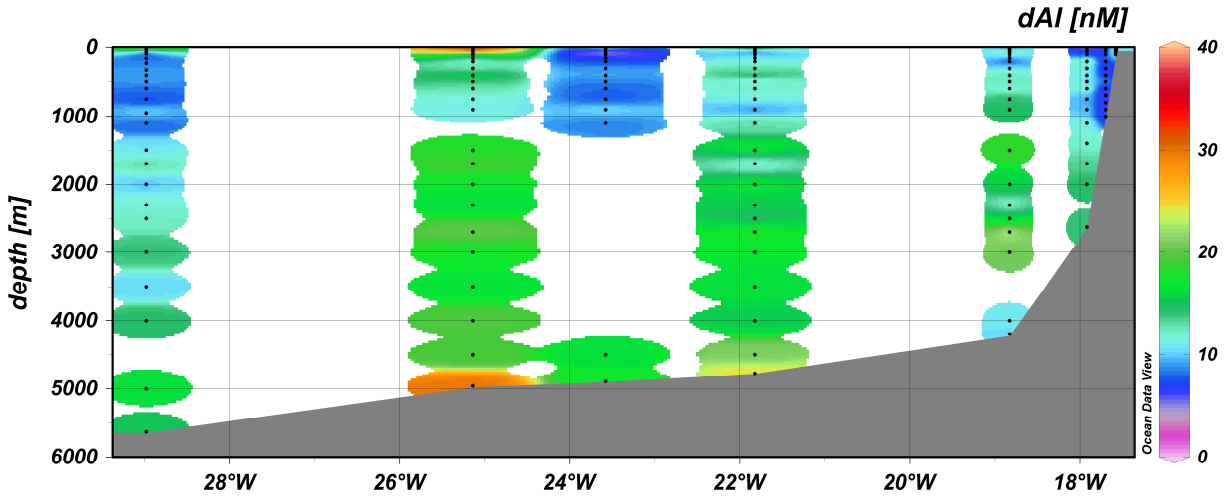

Figure 17.2: Dissolved Al depth profiles from the TiCTD along the transect through the OMZ at 12° N.

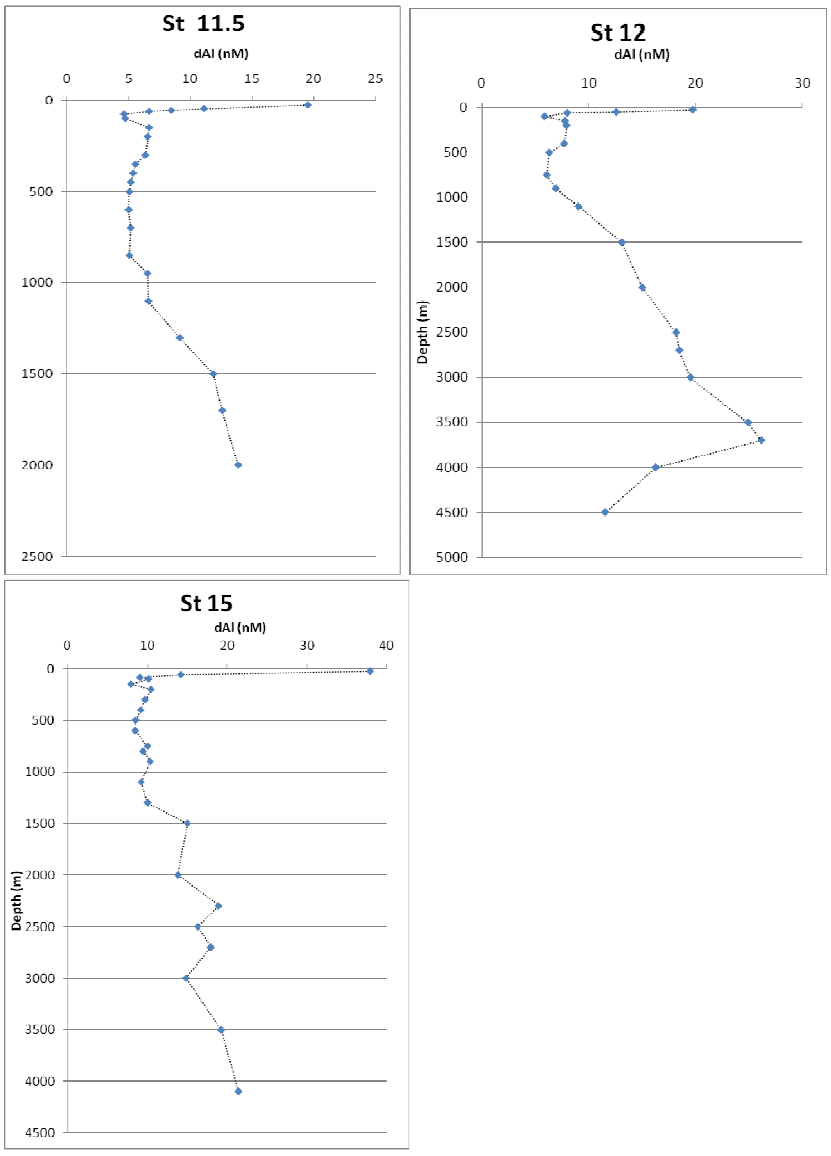

Figure 17.3: Dissolved Al depth profiles from the TiCTD, showing profiles south of the equator (station 11.5 and 12), and north of the equator (station 15).

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18 Seawater sampling for inorganic iodine speciation

Rosie Chance

18.1 Introduction

The majority of iodine dissolved in seawater is found as either iodide (I^-) or iodate (IO_3^-), with respective surface concentrations around 100-200 and 300-400 nM in the tropical Atlantic [1]. Iodine is volatilised from the sea surface to the atmosphere, where it is involved in tropospheric ozone depletion and particle formation, and may thus impact climate. The mechanism of volatilisation may depend on the chemical speciation of the iodine, for example iodide at the sea surface can react with ozone to release molecular iodine (I_2)[2]. However, the controls on dissolved inorganic iodine speciation in surface seawater are not fully understood. Biological productivity and phytoplankton cell senescence have been implicated in iodide formation[3, 4], and iodide has been identified as the dominant fraction in the oxygen minimum zone (OMZ) of the Arabian Sea, occurring in association with nitrite and Mn^{2+} sub-surface maxima [5]. Conversely, upwelling waters typically have a low iodide/high iodate signature characteristic of deep waters [6]. Consequently, the East-West transect through the OMZ extending from the Senegalese coast was considered to be a potentially interesting area to study inorganic iodine speciation, affording insights into whether iodide production was primarily associated with regeneration in the oxygen minimum zone or biological productivity in surface waters.

The on board objective for this work was as follows:

> To collect seawater samples for determination of inorganic iodine speciation (iodide and iodate) from the oxygen minimum zone extending from the West African continental shelf.

18.2 Methods

Sampling protocol – Seawater was collected from both the trace metal clean titanium rosette and, for surface water samples, the trace metal clean FISH. Samples (40 mL) were filtered directly into polycarbonate centrifuge tubes (Corning) through either a polyethersulfone (PES) filter for the rosette casts or an AcroPak^{TM}(Pall) filter capsule for the Fish samples (see Trace metal sampling section for more details). Following collection, samples were frozen upright at -20degC for return to the UK. This storage protocol has been established as sufficient to preserve dissolved iodine speciation [7].

Samples collected – A total of 148 seawater samples were collected during the East-West transect along 12°N from the coast of Senegal. These are summarised in Table 18.1; full sampling details are given in the titanium rosette and fish sampling log tables elsewhere in this cruise report.

Table 18.1. Summary of seawater samples collected for determination of inorganic iodine speciation during cruise D361.

Cast no.	Station	Latitude, N	Longitude, W	Date	Time, UT	No. depths sampled
6	2	12 35.415	17 54.991	22/02/2011	02:15	15 (25 to 2625 m)
8	3	12 36.556	17 43.018	22/02/2011	11:48	12 (25 to 1000 m)
11	4	12 36.50	17 34.344	22/02/2011	19:46	4 (25 to 45 m)
12	5	12 35.228	17 34.309	22/02/2011	21:22	6 (27 to 100 m)
FISH 43	-	12 35.439	17 35.722	22/02/2011	21:50	~surface
FISH 44	-	12 35.378	17 39.195	22/02/2011	22:10	~surface
FISH 45	-	12 35.225	17 42.838	22/02/2011	22:30	~surface
FISH 46	-	12 35.166	17 46.357	22/02/2011	22:50	~surface
FISH 47	-	12 35.141	17 49.880	22/02/2011	23:10	~surface
FISH 48	-	12 35.076	17 53.383	22/02/2011	23:30	~surface
FISH 49	-	12 35.119	17 56.932	22/02/2011	23:50	~surface
FISH 50	-	12 34.987	18 8.459	23/02/2011	00:55	~surface
FISH 51	-	12 34.871	18 18.686	23/02/2011	01:53	~surface
FISH 52	-	12 34.992	18 30.710	23/02/2011	03:02	~surface
FISH 53	-	12 34.851	18 47.644	23/02/2011	04:35	~surface
14	6	12 33.014	18 49.597	23/02/2011	07:02	22 (25 to 4200 m)
FISH 54	-	12 32.562	18 53.611	23/02/2011	13:20	~surface
FISH 62	-	12 34.790	21 46.751	24/02/2011	05:35	~surface
17	7	12 34.455	21 49.377	24/02/2011	12:46	24 (25 to 4770 m)
FISH 67	-	12 34.920	23 31.823	25/02/2011	05:35	~surface
FISH 68	-	12 34.105	23 46.123	25/02/2011	21:00	~surface
FISH 72	-	12 18.495	25 3.408	26/02/2011	05:25	~surface
22	9	12 18.078	25 08.434	26/02/2011	08:06	24 (25 to 4955 m)
FISH 73	-	12 12.223	25 38.555	26/02/2011	17:00	~surface
FISH211	-	11 54.287	28 58.846	11/03/2011	22:55	~surface
41	18	12 00.98	28 58.856	12/03/2011	02:03	23 (20 to 5631 m)

Sample analysis – Samples will be analysed for iodide by cathodic stripping square wave voltammetry [7, 8] and iodate by spectrophotometry[8].

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19 Cr isotope analysis of seawater as part of the study: "Resolving Past Changes in Ocean Oxygenation: Utility of Chromium Isotopes"

Hélène Planquette (NOCS) and Rachael James (NOCS)

19.1 Background information

Dissolved Chromium has a complex redox cycle in seawater (Achterberg and van den Berg, 1997, Connelly et al., 2006) and mainly exists in two forms: Cr(VI) and Cr(III). Cr(VI) forms a relatively stable oxy-anion that can be toxic at elevated concentrations, whilst Cr(III) tends to be removed quite quickly from the oxic water column. Although it is thermodynamically expected that Cr(VI) is the dominant oxidation state in seawater, non negligible concentrations of Cr(III) have been reported in the Sargasso Sea (Connelly et al., 2006) or in the Mediterranean Sea (Achterberg and van den Berg, 1997). Reported concentrations of total Cr in the literature varied from 2 to 5 nM, implying that the measurement of stable Cr isotopes is a real analytical challenge.

Ellis et al. (2002) showed that the lighter isotopes of Cr are preferentially reduced during the reduction of Cr(VI) to Cr(III), having the consequence to enrich the remaining Cr(VI) in the heavier isotopes on the $^{53}Cr/^{52}Cr$ ratio. Therefore it is possible to use Cr isotopes as a tracer for the reduction of Cr(VI) and use them to reconstruct past redox conditions in the ocean (Frei et al., 2009).

The aim of this work is to determine the Cr isotopic composition of both Cr(III) and Cr(VI) in the dissolved phase of seawater throughout the water column, including the oxygen minimum zone. This is part of a wider study that aims to evaluate the present-day Cr isotope budget of the oceans, with a view to using Cr isotopes as a tracer of past seawater oxygenation.

19.2 Sample collection

The initial aim was to collect one water column profile for Cr isotope analysis of seawater in an area with a significant oxygen minimum zone. In total, two profiles have been sampled, one at station 7 and the other one at station 19 (Table 19.1).

Table 19.1: Sampling details for Cr work

Station details	Cast #	Bottle #	Depth (m)	Volume for total Cr "B" (L)	Volume for Cr(III) "A" (L)
7	CTD017	1	4770	2	4
12° 34.455 N		10	1700	2	4
21° 49.377 W		13	900	2	4
24/02/2011		26	400	2	4
Bottom depth *4778m*		20	150	2	4
		24	25	4	-
19	CTD044	13	750	2	4
15° 30.392 N		25	500	2	2
28° 47.347 W		26	300	2	2
13/03/2011		19	200	2	4
Bottom depth *5094m*					

The depths which samples were taken were determined at each station by looking at the dissolved oxygen profile obtained during the descent of the Ti-CTD rosette. In total, 10 samples were collected for total Cr and 9 for Cr(III), covering depths at surface, sub-surface O_2 maximum, in the thermocline, through the O_2 minimum and close to the bottom. Sample volumes varied between 2 and 4L, depending on volume available for other's work, totaling a volume of 54L of seawater.

Upon recovery, individual OTE bottles were transferred in a clean van class 100 container where seawater was filtered through a 0.2µm Pall Acropak capsules directly into 1 L pre acid-cleaned Low Density Poly Ethylene (LDPE) bottles. Bottles were divided in 2 types: "A" for Cr(III) and "B" for Total Cr analyses. In each 1L sample, 100 µL of ^{50}Cr-^{54}Cr isotope spike (initially prepared at NOCS and stored in 6M HCl) was added. Bottles were then shaken and allowed to sit for ~1 hour to equilibrate.

Samples were then conditioned as follows:

- "A" (Cr(III)) bottles: 800 µL of the ammonia solution was added to one 1-L bottle containing 2mM Fe(II) ammonium sulphate solution initially prepared at NOCS. The pH of the solution was checked to be 8-8.5 and adjusted with ammonia when necessary (Cranston and Murray, 1978). 10mL of this solution was then added to each 1L sample. Bottles were shaken and stored in a fridge before shipping back to the UK
- "B" (Total Cr) bottles: 80 µL of ammonia were added to 100ml of 2mM Fe(II) ammonium sulphate solution initially prepared at NOCS in a 125 mL acid cleaned LDPE bottle. 10 mL of this solution were immediately added to each 1L sample (Cranston and Murray, 1978). Bottles were then shaken and stored in a fridge before shipping back to the UK.

At NOCS, Chromium will be separated from the sample matrix using combined cation and anion exchange chromatography and the Cr concentration and isotopic composition will be then determined on a MC-ICP-MS (ThermoFisher Neptune) (Bonnand et al., 2011)

19.3 References

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20 Aerosol and rain sampling

Rosie Chance

20.1 Introduction and Objectives

Atmospheric deposition of Saharan dust is thought to be a significant source of iron and other nutrients to the northern part of the cruise track [1]. These dust inputs may encourage the growth of diazotrophs, and consequently impact carbon sequestration and nitrogen fixation[2]. Atmospheric aerosol and rain was sampled during cruise D361 in order to quantify the supply of micro- and macronutrients to the surface ocean via wet and dry deposition. As dust events are episodic, the atmospheric nutrient source is temporally variable and needed to be studied at the same time as the water sampling and incubation studies took place.

The objectives of the on board work were as follows:

To collect size segregated atmospheric aerosol samples for the determination of trace metals (TM) and major ion (MI) concentrations.

To collect bulk atmospheric aerosol for determination of isotope signatures (ISO).

To collect rain samples for determination of trace metal and major ion concentrations.

To make ship board measurements of aerosol optical depth.

20.2 Sampling protocol

Aerosol – Three high volume aerosol collectors (Andersen) were mounted on the monkey island deck of the ship (figure 20.1). Each sampler was used for a different set of samples (i.e. TM, MI or ISO). To avoid sampling contaminated air from the ships funnel, power supply to the motors was automatically controlled such that sampling only took place when the relative wind direction was between -80 and 145 degrees. The collectors were also manually turned off during routine testing of the life boat engines, which are forward of the monkey island. Air flow through each collector was calibrated at the beginning of the cruise and the mass flow set to 1 m^3 min^{-1}. Aerosol for TM and MI determination were sampled using a two stage Sierra-type cascade impactor (aerodynamic diameter cut offs of ~2.4 and ~1.6 um) with a back-up filter behind, while that for isotopes was sampled in bulk only. Samples were collected onto Whatman 41 paper filters, which for TM and ISO had been acid washed (HCl then HNO_3) before use. The filters were loaded and unloaded from the sampling cassettes under a laminar flow hood; nitrile gloves were

worn and the filters handled by the edges only. Samples were collected over ~12 to 24 hours (TM and MI), dependent on dust loading. ISO samples were collected for ~24 to 48 hours (ISO) such that one ISO sample covered the same period as two sets of TM or MI filters. Exposed filters were folded in half, placed in sealed plastic bags and frozen at -20^{o}C for return to the UK. Three times during the cruise, TM and MI samples were collected using a six stage impactor deployed for 24 to 36 hours. The following blanks were collected for each sample type: Filter blank; Cassette blank; Exposure blank; Motor blank.

Rain – Rain was collected using two 40 cm diameter polypropylene funnels with clean sample bottles attached; a new bottle was used for each rain event. The bottles and funnel for TM rain sampling were acid washed and the bottles stored with very dilute HNO_3 in them, while the bottles and funnel for MI rain sampling were detergent washed and the bottles stored with MilliQ water in them. Both funnels were deployed simultaneously at the front of the monkey island deck during rain events (see figure 20.1 for locations). Following collection, TM samples were acidified using conc. HNO_3 and both samples were frozen at -20^{o}C for return to the UK. Blank samples were prepared by pouring the contents of a cleaned bottle through the funnel and into a second bottle.

Aerosol optical depth – A hand-held sun photometer (Microtops II, Solar Light Co., USA) connected to a GPS was used to measure aerosol optical depth. The instrument was calibrated in advance of the cruise. Readings were taken up to four times a day, where absence of cloud cover allowed.

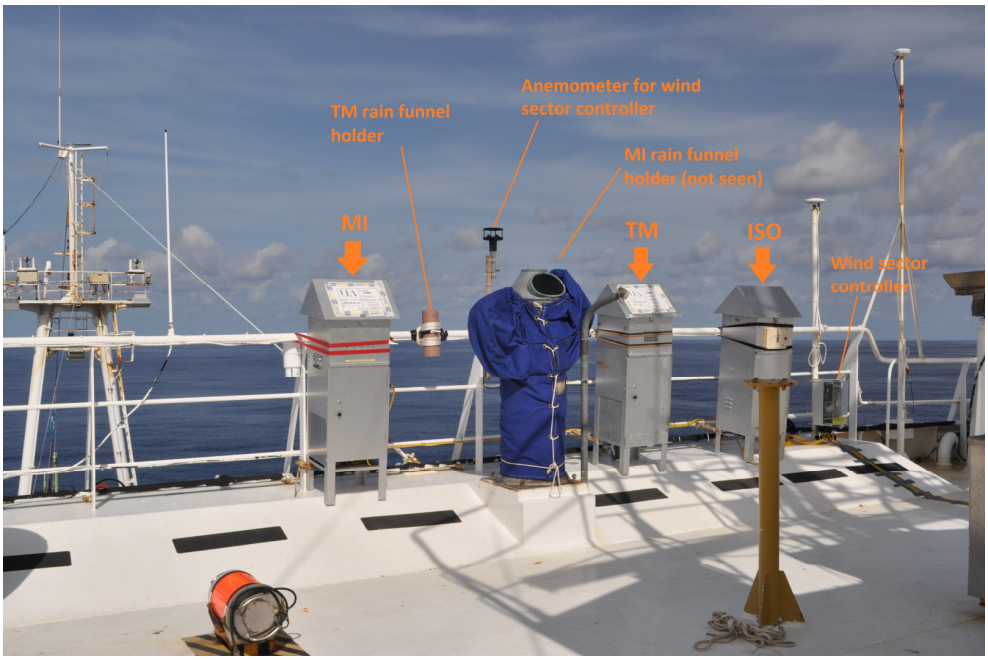

Figure 20.1**.** Location of aerosol and rain sampling equipment on monkey deck of RRS Discovery during cruise D361.

20.3 Samples collected

Aerosol – 30 sets of samples were collected for TM and MI and 20 samples were collected for isotopes, including blanks for each sample type (see Table 20.2 on following page).

Rain – Rain events were rare, but there were some short lived events when crossing the ITCZ. Five sets of rain samples were collected, and a further two sets of blanks prepared (see Table 20.1).

Table 20.1. Summary of rain samples collected during cruise D361

Sample	Type (XX)	Approx. Vol. (mL)	Start time		Start position	
			Date	Time (UT)	Latitude, N	Longitude, W
D361_11_RXX_01	TM, MI	15	01/03/2011	10:00	1 04.30	25 19.77
D361_11_RXX_02	TM, MI	40	02/03/2011	10:21	-2 53.65	25 09.77
D361_11_RXX_03	TM, MI	230 + 120	04/03/2011	16:31	-5 14.25	25 11.96
D361_11_RXX_04	TM, MI	20	07/03/2011	16:20	1 10.03	26 03.52
D361_11_RXX_05	TM, MI	15	07/03/2011	16:46	1 18.47	26 06.30
D361_11_RXX_07.BLK	TM, MI	100	08/03/2011	16:06	3 41.05	26 55.90
D361_11_RXX_09.BLK	TM, MI	90	17/03/2011	12:00	23 21.26	22 43.52

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Aerosol optical depth: A total of 53 measurement events (385 individual scans) were conducted during the cruise, see figure 20.2 for locations of scans taken up to 15/3/11.

Table 20.2. Summary of aerosol samples collected during cruise D361. Note that end time and position refer only to TM and MI samples; ISO samples ran for twice as long, so have the end time and position listed in the row below (except in the case of italicised blanks (*ISO*), which have the end date and position given in the same row

).

Sample id	Type		Start time		Start position		End time		End position	
	(XX)		Date	Time (UT)	Latitude, N	Longitude, W	Date	Time (UT)	Latitude, N	Longitude, W
D361_11_XX_01	TM, MI, *ISO*	motor blk	07/02/2011	13:30	28 29.18	16 13.31	07/02/2011	13:30	28 29.18	16 13.31
D361_11_XX_02	TM, MI, *ISO*	cassette blk	07/02/2011	13:40	28 29.18	16 13.31	08/02/2011	14:35	26 51.84	19 10.80
D361_11_XX_03	TM, MI, ISO	exposure blk	19/02/2011	11:20	23 37.59	17 23.84	20/02/2011	10:15	19 33.30	18 08.97
D361_11_XX_04	TM, MI	sample	20/02/2011	11:25	19 22.09	18 09.26	21/02/2011	19:45	13 25.79	18 00.46
D361_11_XX_05	TM, MI, ISO	sample	21/02/2011	21:24	13 07.66	17 58.45	22/02/2011	18:12	12 35.94	17 34.19
D361_11_XX_06	TM, MI	sample	22/02/2011	18:57	12 36.35	17 34.28	23/02/2011	11:38	12 32.74	18 50.37
D361_11_XX_07	TM, MI, ISO	sample	23/02/2011	13:10	12 32.76	18 51.97	24/02/2011	13:29	12 34.46	21 49.10
D361_11_XX_08	TM, MI, ISO	sample	24/02/2011	14:49	12 34.426	21 49.009	25/02/2011	09:44	12 35.11	23 33.76
D361_11_XX_09	TM, MI	sample	25/02/2011	10:59	12 35.23	23 33.78	25/02/2011	20:57	12 34.16	23 45.89
D361_11_XX_10	TM, MI, ISO	sample	25/02/2011	22:00	12 32.16	23 55.19	26/02/2011	09:58	12 18.07	25 09.20
D361_11_XX_11	TM, MI	sample	26/02/2011	12:26	12 18.12	25 10.17	27/02/2011	10:28	9 27.45	25 39.48
D361_11_XX_12	TM, MI, ISO	sample	27/02/2011	14:59	8 40.12	25 37.48	28/02/2011	11:18	5 01.22	25 28.91
D361_11_XX_13	TM, MI	sample	28/02/2011	12:26	4 48.91	25 28.56	01/03/2011	10:17	1 01.49	25 19.62
D361_11_XX_14	TM, MI, ISO	sample	01/03/2011	11:41	00 47.79	25 18.82	02/03/2011	14:42	-3 33.54	25 09.06
D361_11_XX_15	TM, MI	sample	02/03/2011	15:56	-3 44.43	25 08.32	03/03/2011	13:15	-7 00.03	25 00.03
D361_11_XX_16	TM, MI, ISO	sample	03/03/2011	14:17	-7 09.27	24 59.62	04/03/2011	13:18	-5 57.32	25 07.27
D361_11_XX_17	TM, MI	sample	04/03/2011	14:13	-5 47.88	25 08.46	05/03/2011	11:10	-3 14.81	25 32.31
D361_11_XX_18	TM, *ISO*	motor blk	05/03/2011	13:50	-3 14.87	25 32.99	05/03/2011	13:50	-3 14.87	25 32.99
D361_11_XX_19	TM, MI, ISO	sample	05/03/2011	16:09	-2 59.81	25 35.86	06/03/2011	17:13	-0 52.10	25 48.78
D361_11_XX_20	TM, MI	sample	06/03/2011	17:53	00 45.72	25 49.25	07/03/2011	19:15	1 40.96	26 14.92
D361_11_XX_21	TM, MI, ISO	sample	07/03/2011	20:05	1 48.58	26 17.46	08/03/2011	19:19	4 09.37	27 04.00
D361_11_XX_22	TM, MI	sample	08/03/2011	20:26	4 19.30	27 06.81	09/03/2011	19:24	6 44.34	27 48.25
D361_11_XX_23	TM, MI, ISO	sample	09/03/2011	20:05	6 50.61	27 50.34	10/03/2011	19:24	8 55.58	28 25.70
D361_11_XX_24	TM, MI	sample	10/03/2011	20:00	9 01.47	28 26.72	11/03/2011	19:18	11 18.81	28 51.82
D361_11_XX_25	TM, MI, ISO	sample	11/03/2011	20:07	11 26.79	28 53.44	13/03/2011	10:45	15 30.24	28 47.85
D361_11_XX_26	TM, MI	sample	13/03/2011	11:56	15 30.33	28 48.07	14/03/2011	11:05	17 25.39	28 22.67
D361_11_XX_27	TM, MI	sample	14/03/2011	12:00	17 25.39	28 22.67	15/03/2011	11:09	19 10.52	28 07.05
D361_11_XX_28	TM, MI	sample	15/03/2011	12:11	19 11.06	28 07.56	16/03/2011	12:54	21 11.64	25 33.29
D361_11_XX_29	TM, MI, ISO	sample	16/03/2011	13:46	21 16.17	25 27.23	17/03/2011	12:48	23 24.28	22 39.40
D361_11_XX_30	TM, MI, *ISO*	filter blk	16/03/2011	18:00	21 38.65	24 57.33	16/03/2011	18:00	21 38.65	24 57.33

20.4 Sample analysis

Aerosol samples will be extracted into ultrapure water and the extracts analysed for soluble TM and MI as described below (Table 20.3). Rain samples will be analysed by the same methods. Analysis is expected to take place between summer 2011 and March 2012. Samples will be analysed by at University of East Anglia by Rosie Chance.

Table 20.3. Analytical methods to be used to measure trace metals and nutrients in aerosol and rain samples collected during cruise D361.

Analyte	**Method**
Fe, Al, Mn, V, Zn, Na, Mg, K, Ca	ICP-OES
Co, Cd, Ni, Cu, Pb, and Ag and Th if possible	ICP-MS
Total* Fe, Al, Mn	INAA
*whole filter analysed rather than extract	
Cl^-, NO_3^-, SO_4^{2-}, oxalate, Br^-, plus possibly MSA, formate, acetate	Ion chromatography
NH_4^+	Autoanalyser
PO_4^{3-}	Spectrophotometry
Total soluble N	High temp catalytic oxidation
d15N of NO_3^- and NH_4^+	IRMS

Additional analyses for aerosol isotopes and organic biomarkers (GC-MS and GC-cIRMS) will be carried out by the project partners listed below:

Dominik Weiss (Pb, Nd, Zn and Cd aerosol isotopic signatures)

Imperial College, London

Kate Hendry (Si aerosol isotopic signatures)

Woods Hole Oceanographic Institution (via University of Oxford)

Maite Hernadez (aerosol organic biomarkers)

University of Bristol, email: maite.hernandezsanchez@bristol.ac.uk

Aerosol optical depth data was downloaded from the instrument at regular intervals and emailed to Alexander Smirnov (*Sigma Space Corporation, code 614.4, NASA/Goddard Space Flight Center, Greenbelt, MD 20771. tel.: (301)-614-6626, fax: (301)-614-6695, email: Alexander.Smirnov-1@nasa.gov)* for quality control and processing.

20.5 Preliminary results

No aerosol or rain results are available at this time.

Aerosol optical depth data from the cruise is available at http://aeronet.gsfc.nasa.gov/new_web/maritime_aerosol_network.html and is shown in figure 20.2.

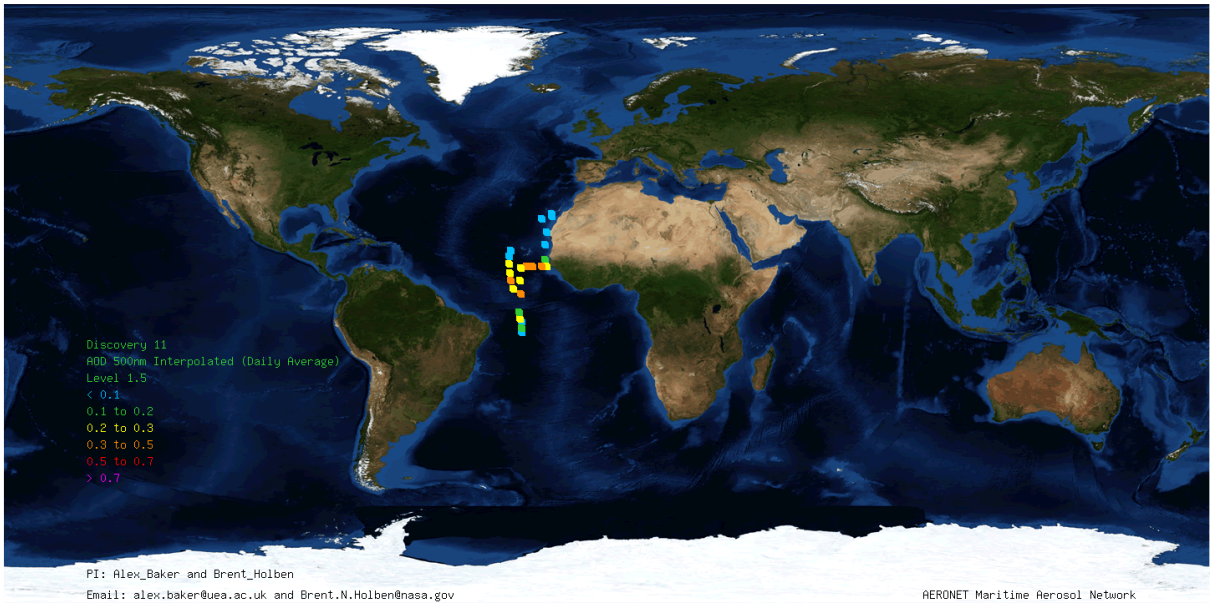


Figure 20.2. Aerosol optical depth measured during cruise D361 between 8/02/11 and 15/03/11.

20.6 References

1. Jickells, T.D., et al., *Global iron connections between desert dust, ocean biogeochemistry, and climate.* Science, 2005. **308**(5718): p. 67-71.
2. Voss, M., et al., *Patterns of nitrogen fixation along 10N in the tropical Atlantic.* Geophysical Research Letters, 2004. **31**(23).

21 Community and Trichodesmium specific iron uptake and turnover

Mark Moore

21.1 Introduction

Iron (Fe) is now thought to play a key role in both controlling phytoplankton production and diazotrophy in many regions of the ocean (e.g. Boyd et al. 2007; Moore et al. 2009). However, despite the importance of this key micronutrient, our understanding of the mechanisms and rates of microbial Fe uptake in the oceans remains poor. In particular, it is still unclear what forms of Fe are accessed by different groups of phytoplankton, with even less understood about the mechanisms for diazotroph groups. The objective of the Fe uptake work within D361 was thus to increase our understanding of microbial Fe uptake and in particular uptake by the key diazotroph group Trichodesmium within a region of contrasting iron availability, from expected high levels within and north of the ITCZ, to lower levels within the South Atlantic gyre.

The rate of iron uptake under ambient concentrations/speciation and hence estimates of biological turnover rates of the ambient DFe pool was thus assessed via a series of incubations performed using carrier free ^{55}Fe.

21.2 Method

Samples were collected pre-dawn using either the trace metal clean tow fish (see appropriate report), trace metal clean CTD casts or using net hauls for uptake specific to the colonial diazotroph Trichodesmium (see Table 21.1). Both filtered and unfiltered trace metal clean seawater was collected from the tow fish into acid washed 2L polycarbonate bottles. Samples for whole community Fe uptake were transferred to acid washed 125ml incubation bottles and immediately placed into a temperature controlled incubator set to sea surface temperature. Samples were then spiked with ~1.3 kBq of carrier free ^{55}Fe, added as weakly acidified (0.3% HCl) Fe(III)Cl. Spiking was performed within 1-2 hours of collection and always just prior to dawn. Samples were immediately returned to the incubator for a 10-12 hour incubation at a light level of 500 umol photons m^{-2} s^{-1}. The ^{55}Fe addition of <1.5 kBq corresponds to an enrichment of the total Fe pool of <3 pM and hence represents a minimal perturbation of ambient conditions. Trichodesmium samples were collected using a nylon 100um mesh phytoplankton net. Individual colonies were picked using either acid washed plastic inoculating hoops or plastic Pasteur pipettes. Colonies were rinsed 3 times in filtered trace metal clean seawater collected from the tow fish, then finally picked into 125 ml of a further clean sample of the same seawater

collection before transfer to the incubator, spiking and incubation as described above.

Uptake of ^{55}Fe was typically measured over a time course with >=3 time points ~every 2-4 hours. At each time step, a measured volume ranging from 40-80ml of sample was placed within the tower of the filtration manifold. A 0.5ml aliquot was removed for measurement of total activity while the remainder was filtered onto 25mm 0.2µm polycarbonate filters under <200 mbar vacuum for whole community uptake, or 1.2µm polycarbonate filters under <100 mbar vacuum for Trichodesmium specific uptake. Uptake into different size fractions was also performed within one of the experiments (see Table 21.1). To differentiate between uptake into cells relative to apparent uptake due to adsorption of ^{55}Fe onto external cell surfaces, subsets of filters and cells were rinsed at the end of the sample filtration with a buffered Ti-EDTA-citrate solution which scavenges adhered ^{55}Fe (Hudson and Morel 1989). Filter samples were then placed in 5ml Ultima Gold before being counted on a liquid scintillation counter (Perkin Elmer TriCarb 3100TR) on board ship.

Table 21.1 Dates and locations of ^{55}Fe uptake experiments performed during D361

Exp	Type	Date	Jday	Station	Sample method	CTD #	Fish #	Net #	Incu temp	Lat	Lon
E1	Community	20/02/2011	51		FISH		23		19	19.891	-18.158
E2	Community	22/02/2011	53	3	CTD	8			20	12.610	-17.716
E3	Community	23/02/2011	54	6	FISH		53		20.9	12.581	-18.794
E4	Community	24/02/2011	55	7	FISH		62		23.9	12.580	-21.779
E6	Community	25/02/2011	56	8	FISH		67		24.3	12.582	-23.530
E9	Community	26/02/2011	57	9	FISH		72		24.3	12.308	-25.057
E10	Community	02/03/2011	61		FISH		116		28.4	-2.365	-25.194
E11	Community	03/03/2011	62		FISH		147		28.4	-6.057	-25.031
E12	Community	04/03/2011	63	10	FISH		152		28	-7.013	-25.025
E13	Community	05/03/2011	64	11	FISH		164		28.6	-3.310	-25.486
E15	Community	06/03/2011	65	12	FISH		170		28.3	-1.216	-25.789
E16	Community	07/03/2011	66	13	FISH		177		28.3	1.108	-26.037
E18	Community	08/03/2011	67	14	FISH		184		28.1	3.288	-26.795
E20	Community	09/03/2011	68	15	FISH		192		27.1	5.612	-27.476
E22	Community	10/03/2011	69	16	FISH		200		25.8	8.279	-28.311

E24	Community	11/03/2011	70	17	FISH		207		25.1	10.563	-28.715
E28	Community	13/03/2011	72	19	FISH		221		23.8	15.454	-28.793
E30	Community	14/03/2011	73	20	FISH		227		23.2	17.368	-28.393
E32	Community	15/03/2011	74	21	FISH		231		23	19.043	-28.139
E7	Trichodesmium	25/02/2011	56	8	NET			8	24.3	12.582	-23.530
E8	Trichodesmium	26/02/2011	57	9	NET			12	24.3	12.308	-25.057
E14	Trichodesmium	05/03/2011	64	11	NET			16	28.6	-3.310	-25.486
E17	Trichodesmium	07/03/2011	66	13	NET			20	28.3	1.108	-26.037
E19	Trichodesmium	08/03/2011	67	14	NET			22	28.1	3.288	-26.795
E21	Trichodesmium	09/03/2011	68	15	NET			24	27.1	5.612	-27.476
E23	Trichodesmium	10/03/2011	69	16	NET			26	25.8	8.279	-28.311
E25	Trichodesmium	11/03/2011	70	17	NET			28	25.1	10.563	-28.715
E27	Trichodesmium	12/03/2011	71	18	NET			30	24.9	12.033	-28.980
E29	Trichodesmium	13/03/2011	72	19	NET			32	23.8	15.454	-28.793
E31	Trichodesmium	14/03/2011	73	20	NET			34	23.2	17.368	-28.393
E26	Community SF	12/03/2011	71	18	CTD	41			24.9	12.033	-28.980

21.3 Initial results

Detailed analysis will only be possible once Fe concentrations are available for all samples. Initial indications suggest that both whole community and Trichodesmium specific uptake rates have been measured. An example of data from 2 whole community experiments is presented in Figure 21.1.

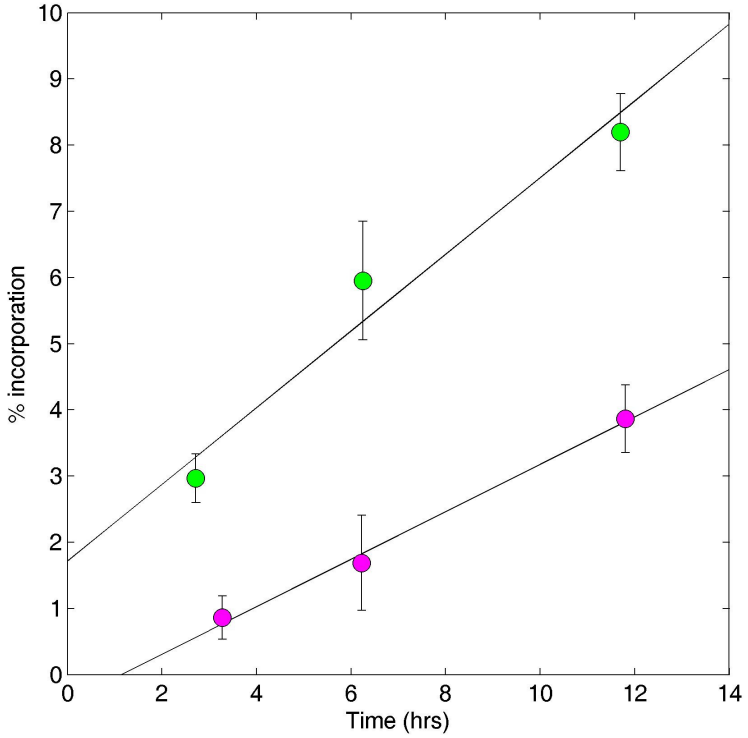


Figure 21.1. Example of the % of initially added ^{55}Fe incorporated into Ti-EDTA-Citrate stable (i.e. intercellular) material at two different stations (station 6 in green, station 9 in pink). The proportional rate of uptake is measured as the slope of the linear regression line.

21.4 References

Boyd et al. 2007 Science 315 612-617
Moore et al. 2009 Nature Geoscience 2 867-871
Hudson and Morel 1989 L&O 34 1113-1120

22 Underway Fast Repetition Rate fluorometry (FRRf).

Joe Snow, Mark Moore

A Chelsea Scientific instruments FASTtrack™ Fast Repetition Rate fluorometer (FRRf) (Kolber et al. 1998) was connected to the ships non-toxic supply within the bottle annex in order to assess and monitor the physiological state of Photosystem II (PSII) within the surface phytoplankton population of the study area.

The FRRf had the following settings when performing measurements (Table 22.1).

Table 22.1: Underway FRRf protocol

6. Acq	0	**F. Sleeptime**	30000
7. Flash seq/acq	16	**G. Gain**	Autoranging, 16
8. Sat	100	**H. Analogue Out**	Disabled
9. Sat Flash Duration	4	**I. Verbose**	Enabled
A. Sat Flash Duration	0	**J. Light Chamber**	Inactive
B. Relax Flash	Enabled	**K. Dark Chamber**	Active
C. Relax Flash/Sequence	20	**L. Logging mode to internal flash**	Enabled
D. Relax Flash/Sequence	4	**M.Autoranging Upper**	85
E. Relax Flash int.	61	**N.Autoranging Lower**	15

The data were stored internally on the instrument and were downloaded between 24 hours and 48 hours intervals throughout D361. The Instrument optics were cleaned whilst the download operation was being carried out and before the protocol was set to run again.

A total of 18 files were collected (Table 22.2) (along with 2 Tenerife test files). Data were then analysed using custom software in a Matlab™ environment. The number of sequences averaged within the recorded files resulted in an average every 20 minutes.

Much of the signal was dominated by marked diel variability in the parameters that can be measured by an FRRf deployed in this mode (F_v'/F_m' and σ_{PSII}'), the data also indicated the presence of a dawn maxima signal before quenching began. Along with this there was a pronounced difference in the data gathered whilst off the Senegalese shelf with that collected in the more open, oligotrophic Atlantic.

22.1 UW FRRF Data

Table 22.2 Underway FRRf files collected during D361.

	UW1	**UW2**	**UW3**	**UW4**	**UW5**	**UW6**	**UW7**	**UW8**	**UW9**
Start Time (GMT)	18th Feb 11:42	19th Feb 12:13	20th Feb 09:42	21st Feb 13:50	23rd Feb 06:05	25th Feb 12:11	25th Feb 19:30	27th Feb 16:02	28th Feb 12:23
	UW10	UW11	UW12	UW13	UW14	UW15	UW16	UW17	UW18
Start Time (GMT)	2nd Mar 13:49	3rd Mar 12:09	5th Mar 17:28	7th Mar 16:01	8th Mar 10:49	9th Mar 19:06	11th Mar 12:12	13th Mar 11:24	15th Mar 17:27
	TEN_1	TEN_2							
Start Time (GMT)		17th Feb 10:59							

23 Biological CTD FRRf.

Joe Snow, Mark Moore

A Chelsea Scientific instruments FAST*track*™ Fast Repetition Rate fluorometer (FRRf) (Kolber et al. 1998) was used to analyse water column samples collected from each of the 6 biological depths of the stainless CTD. This allowed us to assess and monitor the physiological state of Photosystem II (PSII) within the surface phytoplankton population of the study area.

23.1 CTD FRRf Data

The following FRRf files were created for each of the stainless steel CTD casts performed on D361 (Table 23.1).

Table 23.1: List of FRRF CTD files collected during D361.

Cast No.	**CTD005**	**CTD007**	**CTD009**	**CTD013**	**CTD15**	**CTD018**	**CTD021**
File Name (s):	CTD005.fnp	CTD007.fnp	CTD009.fnp	CTD013.fnp	CTD15.fnp	CTD018.fnp	CTD021.fnp
Cast No.	CTD025	CTD026	CTD029	CTD031	CTD033	CTD035	CTD037
File Name (s):	CTD025.fnp	CTD026.fnp	CTD029.fnp	CTD031.fnp	CTD033.fnp	CTD035.fnp	CTD037.fnp CTD037_DCM_RLC.fnp CTD037_surface_RLC.fnp
Cast No.	CTD039	CTD042	CTD043	CTD045	CTD048		
File Name (s):	CTD039.fnp	CTD042.fnp CTD042_surface_RLC_uw.fnp	CTD043.fnp	CTD045.fnp	CTD048.fnp		

24 Trichodesmium Sampling from Plankton Nets

Joe Snow

24.1 Introduction

D361 allowed me to collect the initial samples of my PhD at the National Oceanography Centre, Southampton under the supervision of Dr Mark Moore, Dr Tom Bibby, Prof. Eric Achterberg and Dr Claire Mahaffey (University of Liverpool). The majority of the samples collected were of a colonial, diazotrophic cyanobacterium, which is easily identifiable and pickable from plankton net hauls. These samples have been frozen and will be shipped back to the NOC where I will analyse them for different signs of nutrient limitation.

24.2 Sampling Method

Pre-dawn plankton net tows were deployed at every station to a depth of 10-15m and allowed to collect plankton for 10-15 minutes depending on the assumed level of water column biomass. As well as the pre-dawn net deployment there was a deep net deployment usually performed around 11-1300 GMT that included both surface and DCM nets, Trichodesmium samples were collected from this deployment when present. The collected plankton was then transferred into an acid-cleaned bucket before Trichodesmium colonies were hand picked using a plastic inoculating loop. The samples intended for metal analysis were collected using a clean, predominantly metal free net and stored in a sealed, double bagged, acid cleaned cod end until taken into the clean lab container for picking

24.2.1 Molecular analysis

a. ~50 colonies were filtered onto GF/F's and flash frozen in cryo-vials within 20 minutes of the plankton net arriving back on deck.

b. Frozen samples will be kept in the -80^{o}C freezer until return to Southampton where they will be analysed for expression of genes related to differing nutrient limitations/adaptations.

24.2.2 Metal analysis

a. Under a laminar flow hood approximately 50 colonies were picked onto acid-cleaned 4.0um polycarbonate filters.

b. The filters and biomass were then cleaned using the Oxalate Wash reagent described by Tang and Morel 2006, the filters were submerged in this reagent for 2 ten minute time periods before being washed 15 times with ultra-clean seawater.

c. Collected samples were then flash frozen in liquid nitrogen and will be kept frozen until they can be analysed via ICP-MS for their intracellular metal concentrations.

24.2.3 CHN Samples

a. ~50 colonies were picked onto ashed GF/F's and flash frozen in cryo-vials.

b. The samples will be kept for analysis upon return to Southampton where they will be analysed for carbon and nitrogen composition/concentration.

24.2.4 Phosphate

a. ~50 colonies were picked then filtered onto ashed and then acid-washed GF/Fs, placed into ashed then acid-washed 13mm glass test tubes sealed with tinfoil and parafilm then placed into the -20^{o}C freezer.

24.2.5 Lipid

a. Using minimal plastics, with the exception of the plastic cod end and the plastic inoculating loop.

b. When the biomass collected in the plankton nets was sufficiently high 50 Trichodesmium colonies were picked onto ashed GF/Fs and stored in 13mm glass test tubes, sealed with tinfoil and parafilm. They were then placed into the -20^{o}C for storage

c. They will be kept frozen until return to Southampton where they will be analysed via GC-MS for lipid ratios previously identified by Van Mooy 2006,2009 as indicating phosphate limitation.

24.2.6 Trichodesmium Chlorophyll

5 or 10 colonies were picked into a small volume of seawater, filtered onto a GF/F and the chlorophyll extracted using 8ml of acetone and allowed to sit in the dark at 4 C for 24 hours. They were then analysed by Elizabeth Sargent as per the other underway chlorophyll samples.

24.2.7 Trichodesmium Abundance:

A full 20L surface niskin bottle from the stainless CTD was filtered through a 47mm 10um polycarbonate filter, the collected biomass was resuspended in approximately 50ml of filtered seawater and spiked with ~6ml acid lugol's. These will be analysed upon return to NOCS using light microscopy.

24.2.8 Nitrogen Fixation Incuabtions

Two sets of 50 colonies were picked, placed in 125ml polycarbonate bottles and spiked with 0.5ml ^{15}N gas. A control was set up consisting of 50 colonies in a polycarbonate bottle that were *not* spiked with the ^{15}N gas. The incubations were then placed in the 55% light intensity incubator for 12 hours, meaning they are spiked pre-dawn and processed post-sunset. After 12 hours the entire incubations were filtered onto ashed GF/F filters and placed in a drying oven for 24 hours. They will be analysed upon return to NOCS.

24.2.9 Trichodesmium FRRf

Approximately 15-20 colonies were picked into ~5ml of filtered seawater. This sample was then stored in the dark for +20mins and then processed as per the CTD FRRF protocol listed above.

24.3 List of Samples taken

Below is a table (Table 24.1) of all Trichodesmium samples taken along with information regarding the net deployments such as time of day, depth and deployment duration. See table legend for abbreviations.

Table 24.1: This table lists the differing Trichodesmium samples collected at each station and from each net deployment. Abbreviations include *Stn* – Station, *Net No.* – Net number, *Mol* – Molecular sample, *Met* – Metal sample, *CHN* – CHN sample, Phos – Phosphate sample, *Lip* – Lipid sample, *Chl* – Chlorophyl sample, *Inc* – Nitrogen fixation incubation, *FRRF File* – Fast repetition rate Fluorometer file name, *Abun* – Trichodesmium abundance sample number. In the 'Type' column the letters equate to E – Early (pre-dawn) surface nets, S - ~midday surface net, D - ~midday deep net.

Stn	Net No.	Type	Depth and Duration	Mol	Met	CHN	Phos	Lip	Chl	Inc	FRRF File	Abun
2	NA											05_24
3	5	E	10m, 15mins									
	6	S	10m, 5mins									
	6	D	25m, 10mins									
4	NA											
5	NA											
6	7	E	10m, 15mins								CTD013	13_24
7	8	E	10m, 15mins	X	X	X	X		X		CTD015	15_24
	9	S	10m, 5mins									

	9	D	50m, 10mins									
8	10	E	10m, 15mins	X	X	X	X		X	X	CTD018	
	11	S	10m, 5mins									
	11	D	50m, 10mins									
9	12	E	10m, 15mins	X	X	X	X		X	X	CTD021	21_24
	13	S	10m, 5mins	X								
	13	D	80m, 10mins			X	X	X				
10	14	E	10m, 15mins								CTD25	25_24
	15	S	10m, 5mins									
	15	D	110m	X								
11	16	E	20m, 15mins	X	X	X	X	X	X	X	CTD026	26_24
	17	S	15m, 5mins	X		X	X	X				
	17	D	75m, 10mins	X		X	X	X				
12	18	E	20m, 15mins	X	X	X	X		X	X	CTD029	29_23
	19	S	10m, 5mins					X				
	19	D	60m, 10mins									
13	20	E	10/15m 15mins	X	X	X	X	X	X	X	CTD031	31_23
	21	S	10m, 5mins	X		X	X	X				
	21	D	60m, 10mins									
14	22	E	10/15m 15mins	X	X	X	X	X	10	X	CTD033	33_20
	23	S	10m 3mins	X		X	X	X				
	23	D	55m 7mins	X		X	X	X				
15	24	E	10/15m 15mins	X	X	X	X	X	10	X	CTD035	35_20
	25	S	10m, 2mins									
	25	D	50m, 7mins	X	X	X	X					
16	26	E	10/15m, 10mins	X	X	X	X	X	10	X	CTD037	37_23
	27	S	10m, 2mins									
	27	D	60m, 7mins	X	X	X	X	X				
17	28	E	10/15m 10mins	X	X	X	X	X	10	X	CTD039	39_23
	29	S	10m, 2mins									
	29	D	60m, 7mins	X	X	X	X	X				
18	30	E	10/15m 15mins	X	X	X	X	X	10	X	CTD042	42_23
	31	S	10m, 2mins									
	31	D	70m, 7mins	X	X							
19	32	E	10/15m 15mins	X	X	X	X	X	10	X	CTD044	44_23
	33	S	10m, 2mins									
	33	D	85m, 7mins	X	X	X	X	X				
20	34	E	10/15m 15mins	X	X	X	X	X	10		CTD045	45_23
	35	S	10m, 5mins									
	35	D		X								
21	36	E	10/15m 15mins	X	X	X					CTD048	48_23
	37	S	10m, 5mins									
	37	D										

25 Trichodesmium Sampling from Towed Fish,

Joe Snow, Mark Moore

25.1 Sampling protocol

A 20 µm mesh filter was attached to one of the water outlets of the towed fish and left in place for 30 minutes. There was approximately 5L.min-1 flowing through the mesh through out sampling resulting in a total filtered volume of ~150L. The collected concentrate was re-suspended in a known volume of seawater (~500-1000ml). From this concentrate 50 Trichodesmium colonies were picked for molecular analysis as per the procedure mentioned earlier. Along with this single molecular sample we collected 3 x 100ml bulk concentrate samples, which were filtered onto GF/F's and flash frozen in liquid nitrogen then transferred to the -80^{o}C freezer.

25.2 Samples collected:

Below is a table (Table 25.1) listing all UW Trichodesmium samples collected logged relative to the time they were taken along with the nearest fish sample taken.

Table 25.1: Underway Trichodesmium sampling log, showing the time the sample was taken, the duration of filtering, closest UW sample along with the samples collected and their sample names.

Date	Start time	End time	Closest UW no.	Picked	Bulk 1	Bulk 2	Bulk 3	Vol. (ml)
58 / 27/02/2011	13:30	13:45	Fish 082	2 x 20, 1 x 10 Colonies	-	-	-	
58 / 27/02/2011	16:00	16:30	Fish 084	UWT02 50 Colonies	UWB 02A (100ml)	UWB 02B 100ml	UWT 02C 100ml	
58 / 27/02/2011	17:10	17:35	Fish 085	UWT03 50 Colonies	UWB 03A (100ml)	UW 03B (100ml)	UW 03C (100ml)	
58 / 27/02/2011	18:55	18:25	Fish 086	UWT04 50 Colonies	UWB 04A (100ml)	UWB 04B (100ml)	UWB 04C (100ml)	
58 / 27/02/2011	22:50	23:20	Fish 088	UWT05 50 Colonies	UWB 05A (100ml)	UWB 05B (100ml)	UWB 05C (100ml)	
59 / 28/02/2011	03:02	03:26	Fish 090	UWT06 50 Colonies	UWB 06A (100ml)	UWB 06B (100ml)	UWB 06C (100ml)	
59 / 28/02/2011	07:04	07:35	Fish 092	UWT07 50 Colonies	UWB 07A (100ml)	UWB 07B (100ml)	UWB 07C (100ml)	
59 / 28/02/2011	09:10	09:35	Fish 093	UWT08 50 Colonies	UWB 08A (100ml)	UWB 08B (100ml)	UWB 08C (100ml)	600
59 / 28/02/2011	10:57	11:27	Fish 094	UWT09 50 Colonies	UWB 09A (100ml)	UWB 09B (100ml)	UWB 09C (100ml)	800

59 / 28/02/2011	12:25	12:50	Fish 095	UWT10 50 Colonies	UWB 10A (100ml)	UWB 10B (100ml)	UWB 10C (100ml)	800
59 / 28/02/2011	14:55	15:25	Fish 096	UWT11 50 Colonies	UWB 11A (100ml)	UWB 11B (100ml)	UWB 11C (100ml)	650
59 / 28/02/2011	16:55	17:25	Fish 097	UWT12 50 Colonies	UWB 12A (100ml)	UWB 12B (100ml)	UWB 12C (100ml)	800
59 / 28/02/2011	18:55	19:25	Fish 098	UWT13 15 Colonies	UWB 13A (100ml)	UWB 13B (100ml)	UWB 13C (100ml)	600
59 / 28/02/2011	11:05	11:33	Fish 100	UWT14 30 Colonies	UWB 11A (100ml)	UWB 11B (100ml)	UWB 11C (100ml)	650
60 / 01/03/2011	07:15	07:50	Fish 104	UWT15 20 Colonies	UWB 11A (100ml)	UWB 11B (100ml)	UWB 11C (100ml)	550
60 / 01/03/2011	08:55	09:35	Fish 105	UWT16 50 Colonies	UWB 11A (100ml)	UWB 11B (100ml)	UWB 11C (100ml)	550
60 / 01/03/2011	11:55	12:15	Fish 107	UWT17 45 Colonies	UWB 11A (100ml)	UWB 11B (100ml)	UWB 11C (100ml)	600
60 / 01/03/2011	12:55	13:25	Fish 107	UWT18 50 Colonies	UWB 18A	UWB 18B	UWB 18C	700
60 / 01/03/2011	14:47	15:17	Fish 108	UWT19 50 Colonies	UWB 19A	UWB 19B	UWB 19C	600
60 / 01/03/2011	17:08	17:35	Fish 109	UWT20 15 Colonies	UWB 20A	UWB 20B	UWB 20C	460
60 / 01/03/2011	18:55	19:25	Fish 110	UWT21 50 Colonies	UWB 21A	UWB 21B	UWB 21C	800
60 / 01/03/2011	23:09	23:35	Fish 112	UWT22 50 Colonies	UWB 22A	UWB 22B	UWB 22C	600
60 / 01/03/2011	01:05	01:35	Fish 113	UWT23 50 Colonies	UWB 23A	UWB 23B	UWB 23C	550
61 / 02/03/2011	07:13		Fish 116	UWT24 50 Colonies	UWB 24A	UWB 24B	UWB 24C	460
61 / 02/03/2011	09:07	09:37	Fish 117	UWT25 50 Colonies	UWB 25A	UWB 25B	UWB 25C	600
61 / 02/03/2011	11:25	11:55		UWT26 50 Colonies	UWB 26A	UWB 26B	UWB 26C	530
61 / 02/03/2011	19:09	19:35	Fish 127	UWT27 25 Colonies	UWB 27A	UWB 27B	UWB 27C	350
62 / 03/03/2011	07:30	08:00		UWT28	No Tricho			
63 / 04/03/2011	11:08	11:46	Fish 154	UWT29 0 colonies	No Tricho			
63 / 04/03/2011	12:50	13:20	Fish 155	UWT30 0 colonies	No Tricho			
63 / 04/03/2011	15:05	15:35	Fish 156	UWT31 4 Colonies	UWB 31A	UWB 31B	UWB 31C	650
63 / 04/03/2011	17:05	17:35	Fish 157	UWT32 0 colonies	No Tricho			
63 / 04/03/2011	18:55	19:25	Fish 158	UWT33 0 colonies	No Tricho			
63 / 04/03/2011	22:55	23:25	Fish 160	UWT34 0 colonies	No Tricho			

26 The role of diazotrophs in the export process, assessed by use of CTD water samples, Marine Snow Catcher, Net Tows and SAPS

Elizabeth Sargent

26.1 Introduction:

Until recently, the overwhelming majority of marine nitrogen fixation studies have focused on the non-heterocystous marine cyanobacterium *Trichodesmium*; it is believed to be the most abundant oceanic nitrogen fixer, is widely studied, and is currently the main constituent of global marine nitrogen fixation estimates. More recent data suggests other marine nitrogen fixers, such as the heterocystous cyanobacteria *Richelia intracellularis* and *Calothrix rhizosoleniae*, are likely important contributors to marine nitrogen fixation. *R. intracellularis* and *C. rhizosoleniae* are associated with diatoms as endosymbionts and epiphytes, and are the most widely distributed heterocystous cyanobacteria globally. Information on the physiology, abundance, and distribution of these organisms is lacking, and has been sparsely accumulated over the past two decades; the mechanism for the commencement of the symbiotic relationship has yet to be described, and host-symbiont interactions are poorly understood. Blooms of these diatom-diazotroph associations (DDAs) have been reported seasonally in the Pacific, and episodically in the Atlantic and Indian Oceans. These blooms probably play a significant role in vertical export of organic carbon, nitrogen, and silica to the deep sea, but few have attempted to quantify the role these diazotrophic diatoms play in the export process. Unlike *Trichodesmium,* which is buoyant, diazotrophic diatoms are prone to sinking. DDAs have been reported intact in sediment traps up to 4000m, indicating they are directly involved in the export process. In addition to acting as a mechanism for biogenic silica and carbon export, DDAs also input newly fixed nitrogen into the upper ocean, and help to support further primary production. Quantifying diazotrophic diatom involvement in export will facilitate elucidation of their importance in marine biogeochemical cycles, as well as provide insight into the fate of new nitrogen produced in these organisms.

Objective: Assess the role diazotrophs play in the export process.

26.2 Methods:

Samples were collected via the CTD (A), net tows (B), SAPS (C), and the marine snow catcher (D).

A. CTD

Sampling – Water column samples were collected at all stainless steel CTD stations along the transect. At three depths, the surface, DCM, and below the on the down slope, 4L was filtered onto GF/F filters and flash frozen for proteomics and 0.5L onto 0.8µm polycarbonate filters for BSi. 1L of down slope water was filtered onto 2µm polycarbonate filters for SEM. At SAPS deployment stations, a full biological compliment was taken, where PIC and BSi samples were taken from the 6 depths between the down slope and surface. PIC samples were filtered onto 0.8µm polycarbonate filters and were washed with 10mL alkaline milli-Q (pH adjusted to 10 by adding 160µL of 25% ammonia to 1L of H_20) to remove sodium.

B. Net tows

Sampling – Non-quantitative 20µm plankton nets were deployed to the DCM, which varied in depth between stations, and to 10m for 5 minutes at each station. The concentrate was collected into a 1L cod-end and was then transferred to a large white bucket to aide in visibility for picking. 25, 1mL aliquots were randomly sampled to assess composition using a microscope at 30x magnification. 1, 50mL sample was taken from each net sample for filtration on an ashed GF/F for isotopic nitrogen analysis. 1. An additional 45mL of homogenized sample was preserved in lugol's iodine for microscopic analyses (Table 26.1). When present, the diatoms *Rhizosolenia*, *Hemiaulus*, and *Mastogloia* were isolated and transferred to MET-44 culture media for on board observation.

Table 26.1. Sargent Net Samples

Station	NET#	DCM (m)	Length (m)	Isotopic Nitrogen	Lugol's
St6	NET07	25	5	X X	X X
St7	NET09	50	5	X X	X X
St8	NET11	50	5	X X	X X
St9	NET13	80	5	X X	X X
St10	NET15	110	5	X X	X X
St11	NET17	75	2	X X	X X
St12	NET19	60	5	X X	X X
St13	NET21	60	5	X X	X X

St14	NET23	55	5	X X	X X
St15	NET25	50	2	X X	X X
St16	NET27	60	2	X X	X X
St17	NET29	60	2	X X	X X
St18	NET31	70	2	X X	X X
St19	NET33	85	2	X X	X X
St20	NET35	85	5	X X	X X
St21	NET37	80	5	X X	X X

C. SAPS

Sampling – 5, 250mL concentrated samples from mesh washes were provided by Katsia from each of 7 SAP deployment stations. Each sample was split so as to allow for 3, 50mL filtrations onto GF/F filters that were flash frozen in liquid nitrogen for proteomics, 1, 30mL filtration onto a 2µm polycarbonate filter for SEM, 1, 40mL aliquot for lugol's preservation, and 2, 15mL filtrations onto ashed GF/F filters for isotopic nitrogen from each depth. This resulted in 120 proteomics, 40 SEM, 40 lugol's, and 80 isotopic nitrogen samples as is detailed below (Table 26.2).

Table 26.2. Sargent SAPS sampling

	Depth (m)	Mesh size	Proteomics	SEM	Lugol's	Isoptic nitrogen
SAPS01 Test, not sampled						
SAPS02	60	53µm	3x 50mL	30mL	40mL	2x 15mL
	60	1µm	3x 50mL	30mL	40mL	2x 15mL
	130	53µm	3x 50mL	30mL	40mL	2x 15mL
	130	1µm	3x 50mL	30mL	40mL	2x 15mL
	500	53µm	3x 50mL	30mL	40mL	2x 15mL
SAPS03	65	53µm	3x 50mL	30mL	40mL	2x 15mL
	65	1µm	3x 50mL	30mL	40mL	2x 15mL
	150	53µm	3x 50mL	30mL	40mL	2x 15mL

	150	1µm	3x 50mL	30mL	40mL	2x 15mL
	500	53µm	3x 50mL	30mL	40mL	2x 15mL
SAPS04	70	53µm	3x 50mL	30mL	40mL	2x 15mL
	70	1µm	3x 50mL	30mL	40mL	2x 15mL
	170	53µm	3x 50mL	30mL	40mL	2x 15mL
	170	1µm	3x 50mL	30mL	40mL	2x 15mL
	500	53µm	3x 50mL	30mL	40mL	2x 15mL
SAPS05	70	53µm	3x 50mL	30mL	40mL	2x 15mL
	70	1µm	3x 50mL	30mL	40mL	2x 15mL
	170	53µm	3x 50mL	30mL	40mL	2x 15mL
	170	1µm	3x 50mL	30mL	40mL	2x 15mL
	500	53µm	3x 50mL	30mL	40mL	2x 15mL
SAPS06	70	53µm	3x 50mL	30mL	40mL	2x 15mL
	70	1µm	3x 50mL	30mL	40mL	2x 15mL
	170	53µm	3x 50mL	30mL	40mL	2x 15mL
	170	1µm	3x 50mL	30mL	40mL	2x 15mL
	500	53µm	3x 50mL	30mL	40mL	2x 15mL
SAPS07	85	53µm	3x 50mL	30mL	40mL	2x 15mL
	85	1µm	3x 50mL	30mL	40mL	2x 15mL
	170	53µm	3x 50mL	30mL	40mL	2x 15mL
	170	1µm	3x 50mL	30mL	40mL	2x 15mL
	500	53µm	3x 50mL	30mL	40mL	2x 15mL
SAPS08	140	53µm	3x 50mL	30mL	40mL	2x 15mL
	140	1µm	3x 50mL	30mL	40mL	2x 15mL
	250	53µm	3x 50mL	30mL	40mL	2x 15mL
	250	1µm	3x 50mL	30mL	40mL	2x 15mL
	500	53µm	3x 50mL	30mL	40mL	2x 15mL

D. Marine Snow Catcher

The Marine Snow Catcher (MSC) (fig. 26.1) was successfully deployed to 10m below the deep chlorophyll maximum at 11 stations over the course of the cruise. During deployment, the MSC collects 100L of seawater to capture sinking particles, aggregates, and organisms. The water was allowed to settle inside the MSC on deck for 2 hours, and was then sampled for POC/PON and BSi. 90 of the remaining 95L were then concentrated on a 20µm mesh; the concentrate was resuspended and filtered for scanning electron microscopy (SEM) and was additionally preserved in acid lugol's for composition assessment post cruise. The remaining five liters in the bottom aquarium of the MSC were hand sampled for visible aggregates, which were preserved in either acid lugol's or on polycarbonate filters for SEM. Once all visible aggregates were picked, the aquarium water was filtered for SEM analysis. On two occasions, a time series was conducted to assess relationship between slow and fast sinking particulates; at these stations POC/PON and BSi were sampled from the top 95L every 30 minutes for 3 hours. The D361 MSC sampling resulted in 23 POC/PON, 23 BSi, 24 Lugol's, and 18 SEM samples as is detailed in table 26.3 below.

Table 26.3. Sargent Marine Snow Catcher sampling

Deployment	Time (m)	Source	Volume (L)	POC/PON	BSi	Lugol's	SEM
MSC01 100m	T0	Top	2	X			
	T0	Top	0.5		X		
	T30	Top	2	X			
	T30	Top	0.5		X		
	T60	Top	2	X			
	T60	Top	0.5		X		
	T90	Top	2	X			
	T90	Top	0.5		X		
	T120	Top	2	X			
	T120	Top	0.5		X		
	T150	Top	2	X			
	T150	Top	0.5		X		

	T180	Top	2	X			
	T180	Top	0.5		X		
	T180	Aquarium	0.05			X	
	T180	Aquarium	2				X
MSC02 100m	T0	Top	2	X			
	T0	Top	0.5		X		
	T30	Top	2	X			
	T30	Top	0.5		X		
	T60	Top	2	X			
	T60	Top	0.5		X		
	T90	Top	2	X			
	T90	Top	0.5		X		
	T120	Top	2	X			
	T120	Top	0.5		X		
	T150	Top	2	X			
	T150	Top	0.5		X		
	T180	Top	2	X			
	T180	Top	0.5		X		
	T180	Aquarium	0.05			X	
	T180	Aquarium	2				X
MSC03 35m	T120	Top	2	X			
	T120	Top	0.5		X		
	T120	Aquarium	0.05			X	
	T120	Aquarium	2				X
MSC04 90m	T120	Top	2	X			
	T120	Top	0.5		X		
	T120	Aquarium	0.05			X	
	T120	Aquarium	2				X

MSC05 100m	T120	Top	2	X			
	T120	Top	0.5		X		
	T120	Aquarium	0.05			X	
	T120	Aquarium	2				X
	T120	Hand picked	N/A			X	
MSC06 failed deployment							
MSC07 70m	T120	Top	2	X			
	T120	Top	0.5		X		
	T120	Aquarium	0.05			X	
	T120	Aquarium	2				X
	T120	Concentrate	45			X	
	T120	Concentrate	45				X
	T120	Hand picked	N/A			X	
	T120	Hand picked	N/A				X
MSC08 failed deployment							
MSC09 75m	T120	Top	2	X			
	T120	Top	0.5		X		
	T120	Aquarium	0.05			X	
	T120	Aquarium	45				X
	T120	Concentrate	45			X	
	T120	Concentrate	2				X
	T120	Hand picked	N/A			X	
MSC10 70m	T120	Top	2	X			
	T120	Top	0.5		X		
	T120	Aquarium	0.05			X	
	T120	Aquarium	45				X

	T120	Concentrate	45			X	
	T120	Concentrate	2				X
	T120	Hand picked	N/A			X	
MSC11 80m	T120	Top	2	X			
	T120	Top	0.5		X		
	T120	Aquarium	0.05			X	
	T120	Aquarium	45				X
	T120	Concentrate	45			X	
	T120	Concentrate	2				X
	T120	Hand picked	N/A			X	
MSC12 95m	T120	Top	2	X			
	T120	Top	0.5		X		
	T120	Aquarium	0.05			X	
	T120	Aquarium	45				X
	T120	Concentrate	45			X	
	T120	Concentrate	2				X
	T120	Hand picked	N/A			X	
MSC13 90m	T120	Top	2	X			
	T120	Top	0.5		X		
	T120	Aquarium	0.05			X	
	T120	Aquarium	45				X
	T120	Concentrate	45			X	
	T120	Concentrate	2				X
	T120	Hand picked	N/A			X	

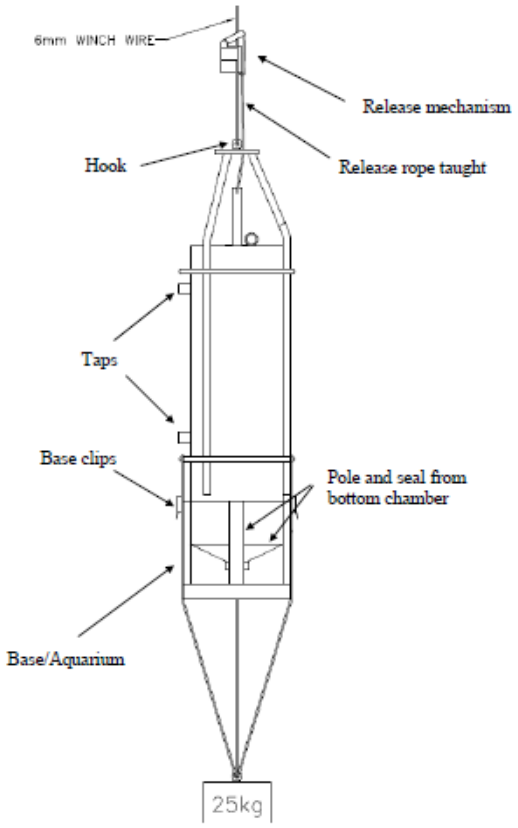


Figure 26.1. External schematics of the marine snow catcher

27 Underway Chlorophyll

Elizabeth Sargent

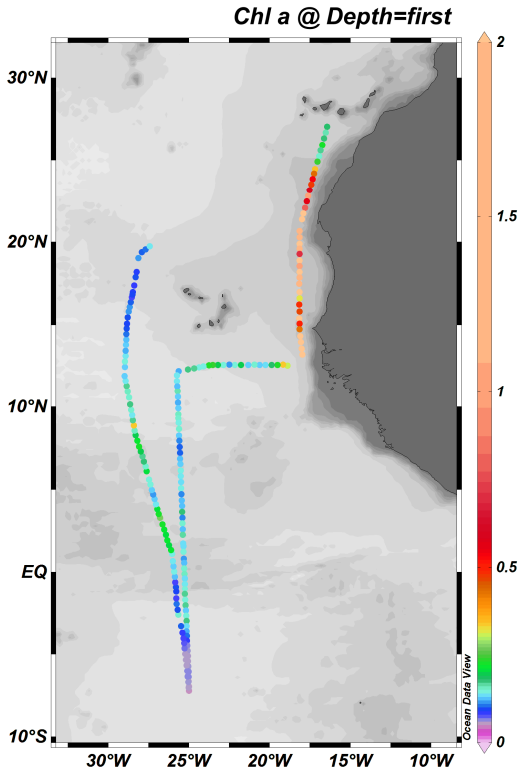
27.1 Methods

Samples were collected along the transect using the towfish (Appendix B). Near-surface seawater was pumped into an on deck clean van where 500mL was transferred to polycarbonate bottles every 2 hours while steaming. 200mL was filtered onto a 25mm GF/F, 0.7µm poresize. The filter was transferred to a cuvette, and 8mL of acetone was added. These samples were then allowed to extract at 4C for 24 hours before chlorophyll concentration was determined the TD-700 fluorometer; the fluorometer was calibrated using an RS Aqua red solid standard at the start and finish of each bulk analysis.

27.2 Preliminary results

Results are shown in Figure 27.1.

Figure 27.1 Surface chlorophyll *a* concentrations for the D361 voyage



28 ^{234}Th derived fluxes of POC, PON, PIC, BSi

Katsiaryna Pabortsava

Objective

Using ^{234}Th:^{238}U disequilibria technique, measure vertical fluxes of particulate organic carbon and nitrogen (POC and PON), particulate inorganic carbon (PIC) and biogenic silica (BSi, opal) fluxes along the transect to estimate how much primary production is exported from the surface of the ocean to its interior.

28.1 Introduction

One way to understand marine particle dynamics in the upper ocean is to use ^{234}Th as a natural tracer of particle formation, transport, and dissolution. ^{234}Th is a naturally occurring isotope, produced by radioactive α-decay of ^{238}U. Unlike conservative ^{238}U ($t_{1/2}$=4.5x10^9 yr), ^{234}Th has a short half-life ($t_{1/2}$=24.1 days) and a strong scavenging affinity, i.e. it is readily scavenged onto particles surfaces and exported with them out of the euphotic zone. In the absence of ^{234}Th uptake onto particles, a secular equilibrium between ^{234}Th and ^{238}U is expected (^{234}Th=^{238}U). Since ^{234}Th is scavenged and then removed from the surface of the ocean as particles descend, a deficiency in ^{234}Th relative to ^{238}U occurs in the upper water column (^{234}Th > ^{238}U, also known as ^{234}Th : ^{238}U disequillibrium) (Santschi, Murray et al. 2006; Verdeny, Masque et al. 2009; Maiti, Benitez-Nelson et al. 2010). An opposite process takes place at depth where particles are solubilized and remineralized supplying ^{234}Th back into the water column and causing ^{234}Th excess relative to ^{238}U (^{234}Th < ^{238}U) (Maiti, Benitez-Nelson et al. 2010).

Assuming steady state of the system (no advective or diffusive turbulent transport), ^{234}Th flux from surface to depth can be calculated from its activity profile integrated from surface to depth z where ^{234}Th and ^{238}U secular equilibrium is reached:

$$Th\ flux = \int_0^z \lambda_{Th}(A_U - A_{Th})\,dz$$

where λ_{Th} is ^{234}Th decay constant ($\lambda_{Th} = 0.20876 d^{-1}$); A_U is ^{238}U activity (dpm m^{-3}) calculated from the salinity; A_{Th} is ^{234}Th activity (dpm m^{-3}) (measured by beta-counting). Detailed description of ^{234}Th analytical procedures is given in Ruetgers van der Loeff *et al.* (2006) (van der Loeff, Sarin et al. 2006).

To derive particulate fluxes, ^{234}Th fluxes are multiplied by the known concentration ratio of a particle-associated element (e.g. C, N, P, etc.) to ^{234}Th on large particles collected with either sediment traps or *in situ* filtration systems (e.g. Stand alone

pumping system (SAPS)). For example, ^{234}Th-derived POC flux (export) is calculated as follows in (van der Loeff, Sarin et al. 2006):

$$POC\ flux = 234Th\ flux * {}^{POC}/_{234Th}$$

28.2 Methods

Determination of ^{234}Th in seawater was performed by scavenging of this nuclide by its co-precipitation with MnO_2 from 4L of seawater collected at 10 different depths on a stainless CTD rosette. This is so called 'small volume technique' modified from 20L-method developed by Ruetgers van der Loeff and Moore (1999). This method not only allowed immediate on-board beta-counting of ^{234}Th activity, but also enhanced both spatial and temporal resolution of particle export.

Within ~1 hour of collection, seawater samples were acidified to pH 1-2 with concentrated HNO_3 at 1.5ml/L to separate ^{234}Th from parental ^{238}U and shaken vigorously. 50µl (0.35Bq/g) of ^{230}Th yield tracer was then added to each sample bottle. The samples were vigorously shaken again and left to equilibrate for 6-8hrs. After equilibration, 7-8ml of HN_4OH was added per sample to bring the pH to 8.0-8.1. To form suspension of MnO_2, 50µl (7.5mg/L) of $KMnO_4$ and 50µl (7.5mg/L) of $MnCl_2$ were subsequently added to seawater samples. The MnO2 precipitate was then allowed to scavenge ^{234}Th for 6-8hrs. The bottles where precipitation of MnO2 took place were then attached to a specially designed filter-holders and the content was precipitated onto ashed 25mm QMA (Whatman) filter. Filter precipitates were dried for 12-24hrs at 60℃ and then mounted onto Risø beta-counter filter holder under layer of Mylar film and Al foil in order to shield alpha-particles and low energy beta-emitters. ^{234}Th was quantified by counting daughter ^{234m}Pa ($t_{1/2}$=1.2min) on a low-level Argon gas-flow 5-sample GM-25 beta-counter manufactured by Risø National Laboratories (Roskilde, Denmark). The counter utilizes an anti-coincidence shield above 25mm-diameter sample windows. The unit is completely surrounded by lead bricks to reduce background count rates. To assess efficiency of beta-counter, 5 NISKIN CTD bottles were sampled simultaneously at a single depth of 1000m in the open ocean. For experimental blank 4L of MilliQ water with all the reagents and spike was filtered. Counting of all the samples was performed till the counting error reached <3% (~1000 counts). The activity of parental ^{238}U was calculated from water salinity according to Chen et al (1997):

$$^{238}U = 0.07081 \times S(‰)$$

Initial counting will be followed by a final background radiation count after >7 half-lives of ^{238}Th decay (~6 months).

After final background count, the MnO_2 filters will be dismounted and prepared for quantification of ^{234}Th recovery by ICP-MS analysis. Mn precipitate will be dissolved in 8M HNO_3/10% H_2O_2 solution followed by addition of ^{229}Th spike. Anion exchange chromatography on AG1-X8 resin will be used to purify Th isotopes. Prior to analyses by ICP-MS, sample elute will be diluted in HNO3 matrix, evaporated in several stages and brought up to volume of 2ml with 10% HNO_3/1%HF solution. Finally, ^{229}Th:^{230}Th ratio will be measured by multicollector ICP-MS (method in Pike et al (2005)).

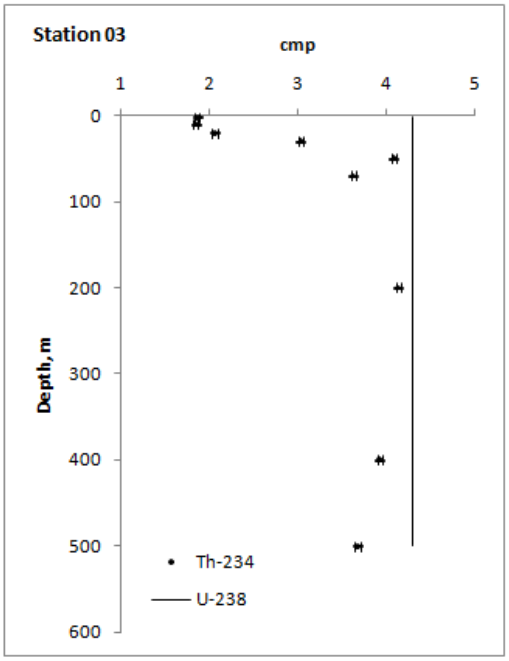
To obtain size fractionated POC/^{234}Th ratio on sinking particles, *in situ* stand alone pumping systems (SAPS) were deployed at three different depths: 10m, 100m and 500m below the base of the mixed layer depth. Sinking particles were collected onto a prefilter (53µm Nitex mesh) and a main filter (1 µm Nitex mesh) with SAPS deployed at 10m and 100m below the base of the mixed layer depth, and onto 53µm Nitex mesh at 500m below the depth of the mixed layer depth. Filter housings and Nitex meshes were acid cleaned prior to deployment of the SAPS. SAPS were set to pump for 90min as a result pumping between 1000-2000 L of seawater. When recovered, particles were rinsed off each of the mesh with exactly 1L of filtered seawater (0.4 µm Polycarbonate filters). Resulting solution was split into four equal parts with Folsom splitter. Four splits were then filtered onto pre-combusted and pre-weighed 25mm GF/F (Whatman) filters for particulate organic carbon and nitrogen (POC(PON)) analysis, onto pre-combusted 25mm QMA (Whatman) filter for Th analysis, and onto 25mm membrane polycarbonate filters for particulate inorganic carbon (PIC) and biogenic silica (BSi, opal) analyses. All filters were then dried for 12-24hrs in the oven at 60℃. Th filters were immediately counted on beta-counter (procedure described above), while POC (PON), PIC and BSi were stored for further analysis in land laboratory. After completing the background radiation count of Th samples, they together with POC (PON) and PIC samples will be fumed with HCl for 24hrs, dried for 24hrs and then analyzed for organic carbon and nitrogen with CHN analyzer, and for Ca (as PIC) with inductively-coupled plasma atomic emission spectroscopy (ICP-AES) after a 24 h leach with 1 M acetic acid. BSi sample will be digested in 0.2 M NaOH for 3 h at 90℃ and measured as Si with an autoanalyzer.

The complete analysis of the samples is expected by the December 2011.

28.3 Preliminary results

Activity of Th-234 was counted approximately three days after sampling. The results (Th-234 counts per minute, cpm) for each station are shown in Figures 28.1-4 below. These values are not calibrated, and will further be corrected for yield, in-growth from U-238 and decay of Th-234.

Figure 28.2: Th -234 counts per minute (cpm) for stations 03 and 08. Error bars represent % error of measured values



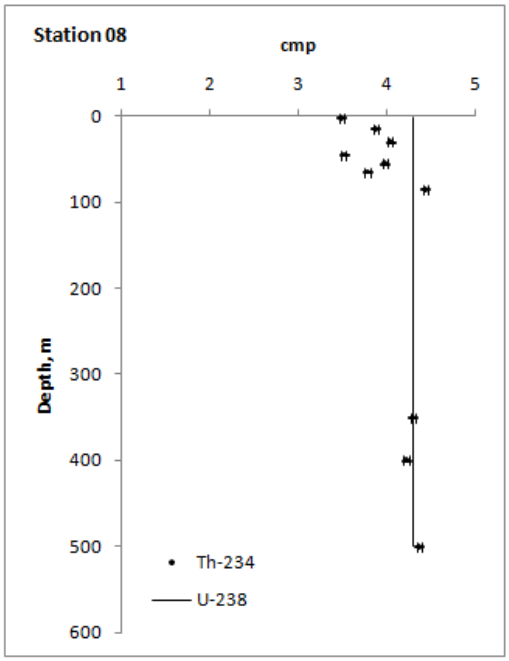
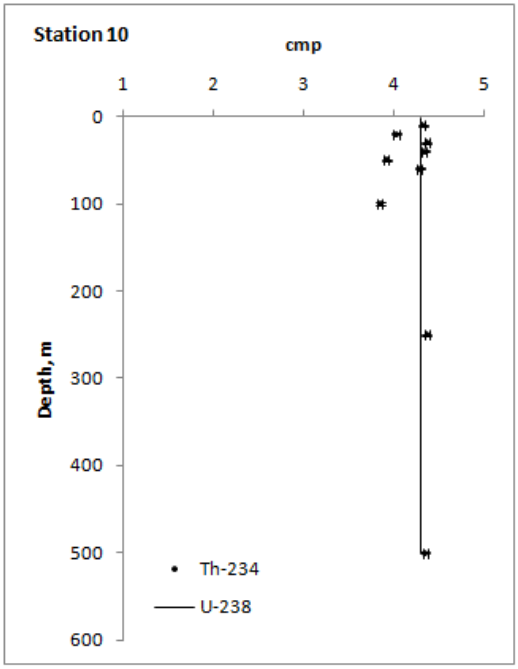


Figure 28.3: Th -234 counts per minute (cpm) for stations 10 and 13. Error bars represent % error of measured values



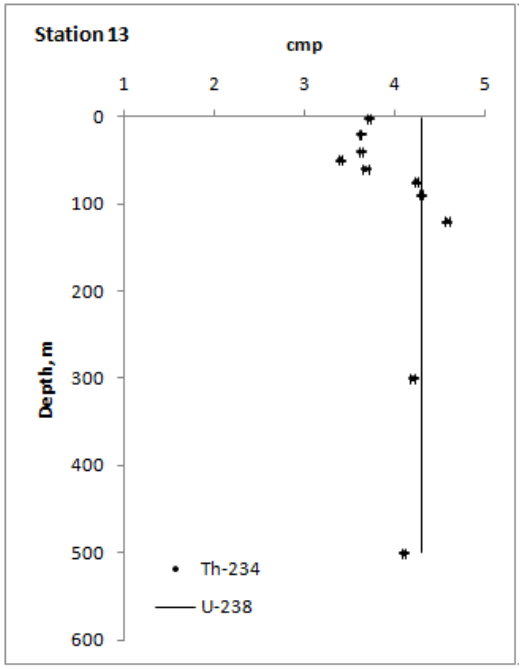


Figure 28.4: Th -234 counts per minute (cpm) for stations 16 and 19. Error bars represent % error of measured values

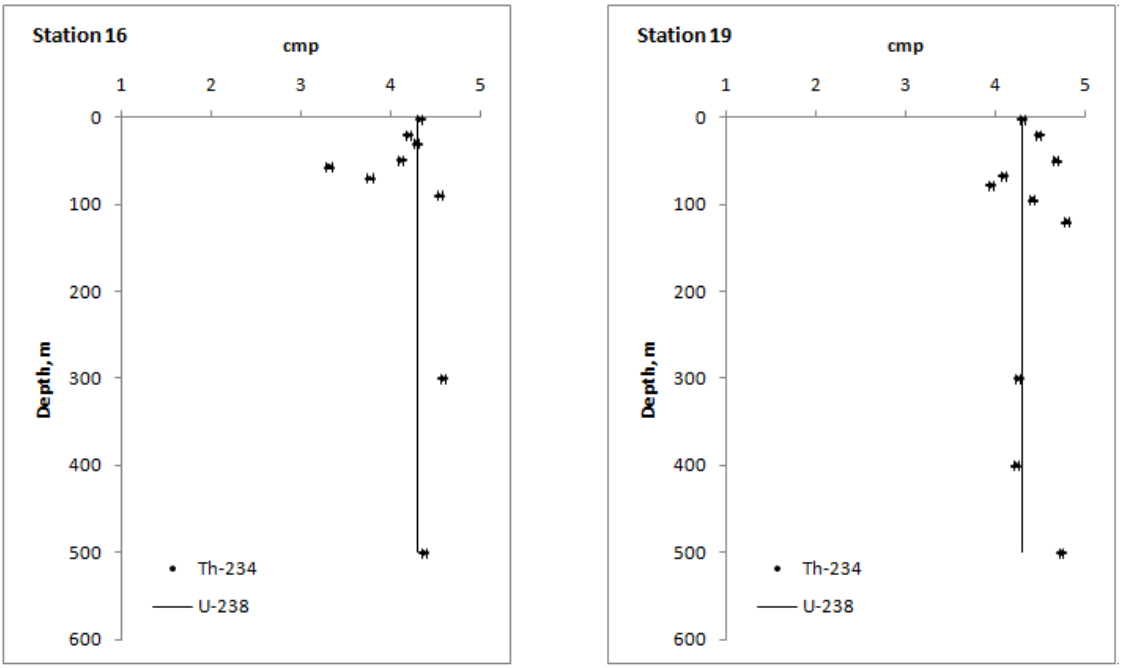
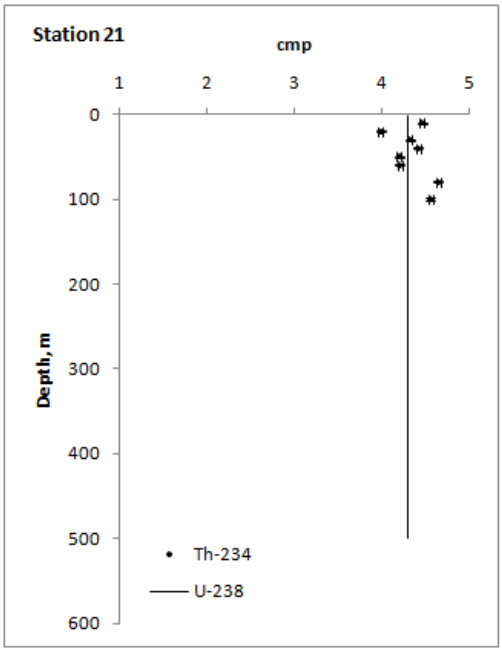


Figure 28.5: Th-234 counts per minute (cpm) for station 21. Error bars represent % error of measured values.



Summary of the sampled CTD stations and deployed SAPS are in the Tables 28.1 and 28.2 below.

Table 28.4: Summary of sampled CTD casts

Station	CTD Cast	Longitude	Latitude	Date	Depths
3	7	12°35'41.25" N	17°42'49.99" W	22.02.2011	2, 10, 20, 30, 50, 70, 200, 400, 500
8	18	12°35'06.139" N	023°33'41.471" W	25.02.2011	2, 15, 30, 45, 55, 65, 85, 350, 400, 500
10	23	07°13'19.25" S	025°59'36.70" W	03.02.2011	10, 20, 30, 40, 50, 60, 100, 250, 500, 1000
13	31	01°09.38642' S	026°02.81276' W	06.03.2011	2, 20, 40, 50, 60, 75, 90, 120, 300, 500
16	37	08°20.47218'N	028°19.96082' W	10.03.2011	2, 20, 30, 49, 57, 70, 90, 300, 500
19	43	15°30'22.87"N	028°47'22.90" W	13.03.2011	2, 20, 50, 67, 78, 95, 120, 300, 400, 500
21	49	19°11.608'N	028°07.881' W	15.03.2011	10, 20, 30, 40, 50, 60, 80, 100, 1000

Table 28.5: Summary of deployed SAPS

Station	SAPS #	Longitude	Latitude	Date	Depths	Mesh size
3	2	12°35'41.25" N	17°42'49.99" W	22.02.2011	60, 130, 560	53, 1 micron
8	3	12°35'06.139" N	023°33'41.471" W	25.02.2011	65, 150, 500	53, 1 micron
10	4	07°13'19.25" S	025°59'36.70" W	03.02.2011	70, 170, 500	53, 1 micron
13	5	01°09.38642' S	026°02.81276' W	06.03.2011	70, 170, 500	53, 1 micron
16	6	08°20.47218' N	028°19.96082' W	10.03.2011	70, 170, 500	53, 1 micron
19	7	15°30'22.87" N	028°47'22.90" W	13.03.2011	85, 170, 500	53, 1 micron
21	8	19°11.608' N	028°07.881' W	15.03.2011	140, 250, 500	53, 1 micron

28.4 References

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29 Heme *b* and nitrogen fixation

David James Honey

29.1 Introduction

Cruise D361 provided an opportunity to sample the tropical North Atlantic - *an area of specific interest to my PhD* - with respect to the influence of iron (Fe) on nitrogen fixation. Having previously collected samples from the sub-tropical North Atlantic (D346), this cruise offered the chance to compare between these two low latitude regions where nitrogen fixation rates are thought to be significant.

Despite the vast abundance of molecular nitrogen (N_2) gas in the atmosphere, fixed sources of nitrogen (nitrates, nitrites, ammonia - i.e. those accessible to living organisms) in the oceans can often be in short supply. N_2 gas is generally not accessible to majority of organisms because of the strong triple bond between the two nitrogen atoms. This can induce a limitation on biological production as nitrogen provides the fundamental building blocks of life, including DNA.

The tropical North Atlantic is an area known to exhibit high levels of nitrogen fixation (transformation of N_2 to fixed nitrogen) by specialised organisms. This has been identified by an excessive nitrate:phosphate ratio (i.e. >16:1) with regards to the expected Redfield ratio in the region (Redfield 1934; Fanning 1992). My project aims to investigate the role Fe has to play in this system. Organisms that are able to biologically fix nitrogen are known as diazotrophs and the most commonly known are from the genus *Trichodesmium*. The enzyme responsible for nitrogen fixation is nitrogenase which has a high Fe requirement. It is believed that the marine diazotrophs provide a significant proportion of fixed nitrogen to the oceans.

The term heme (or haem) refers to the Fe-porphyrin complex that acts as the prosthetic group for a wide range of Fe proteins, also known as the hemoproteins (It should be noted that hemes are not directly involved in the nitrogenase enzyme). There are 3 specific heme structures commonly represented in biology: hemes *a*; *b*; and *c*. Heme *b* (also referred to as protoheme IX) is considered the most versatile form and is associated with globins, cytochrome P_{450}, catalases, peroxidases and *b*-type cytochromes (Caughey 1973). Therefore, hemeoproteins and nitrogenase could potentially highlight the main allocation of Fe within these nitrogen fixing organisms.

Previous research has shown that Fe plays a significant role in mediating phytoplankton blooms and, therefore, potentially influences carbon sequestration to the oceans. However, it has also been argued that the availability of nitrate (NO_3^-, classical 'biological' view) and/or phosphate (PO_4^{3-}, 'geochemical' view) could exclusively or co-limit biological growth and phytoplankton biomass (Smith 1984; Codispoti 1989; Tyrrell 1999). It has also been hypothesised that fluctuations in oceanic nitrogen concentration influence the atmospheric CO_2 concentration over large time scales (i.e. 10^4 years) (McElroy 1983). Therefore, in addition to the obvious interest of climate change, it is interesting to note the significant relationship between Fe (including heme complexes) and the nitrogen cycle.

It is hoped that results collected from cruise D361 will provide an insight regarding the allocation of Fe within diazotrophs in the region, either towards the photosynthetic / respiratory apparatus via hemoproteins, or towards nitrogenase to facilitate the process of nitrogen fixation.

29.2 Methods

29.2.1 Heme b

Samples to measure heme *b* were taken from the stainless CTD at up to 11 depths per cast (between surface and the deep chlorophyll maximum). Up to 4L of seawater was filtered onto GF/F filters (0.7µm pore size, Fisherbrand MF 300). Filters were then folded into eppendorfs and stored in the -80ºC freezer. Analysis will be conducted at NOCS, UK using the High Performance Liquid Chromatography (HPLC) with diode array spectrophotometry technique described by Gledhill (2007). In total, 127 heme *b* samples were collected from 21 CTD casts (see Table 29.1).

29.2.2 POC/PON/t_{zero}

Samples to measure POC/PON/t_{zero} were taken from the stainless CTD at up to 8 depths per cast (between surface and the deep chlorophyll maximum). Up to 4L of seawater was filtered onto pre-ashed (muffle furnace, 450ºC, 24 hours) GF/F filters (0.7µm pore size, Fisherbrand MF 300). Filters were then folded into eppendorfs and stored in the -80ºC freezer. Samples will be sent to PML for analysis using a CHN analyser. In total, 137 POC/PON/t_{zero} samples were collected from 22 CTD casts (see Table 29.1).

29.2.3 Tow FISH sampling

Regular samples were taken from the continuous clean tow FISH supply whilst the ship was steaming between stations. Up to 5L was filtered for heme *b* and POC/PON (see sections 29.2.1 and 29.2.2 for more info on filtering). In total, 79 heme *b* samples and 78 POC/PON samples were collected from the tow FISH (see Appendix B).

29.2.4 Nitrogen fixation incubations

Samples were taken from the stainless CTD at five depths per cast (between surface and the deep chlorophyll maximum) for the preparation of nitrogen fixation incubations. Clear 4½L bottles were filled with seawater (care was taken to ensure no air bubbles remained in the bottle when closing). The bottles were then 'spiked' with 4ml of $^{15}N_2$ gas through a septum closure using a gas-tight syringe. The bottles were then placed in incubators on the aft-deck using water from the non-toxic underway supply, keeping them at surface temperature. Filter film was used to adjust light levels for each incubator to approximately replicate the different depths conditions (80%, 55%, 40%, 10% and 5% on-deck irradiance). After 24 hours, the bottles were removed and their contents filtered onto pre-ashed (muffle furnace, 450°C, 24 hours) GF/F filters (0.7µm pore size, Fisherbrand MF 300). Filters were then folded into eppendorfs and placed in a drying oven (40°C) for a further 24 hours. Once complete, the eppendorfs were stored in a cool, dry place. Analysis will be conducted at NOCS using mass spectrometry. In total, 91 nitrogen fixation incubations were conducted from 16 CTD casts (see Table 29.1).

Table 29.1 CTD Sampling

CTD Cast	Date	CTD Bottle	Depth (m)	N_2-fixation Incubation	Filtering	
					Heme *b*	POC / N / t_{zero}
T001	15/02/2011	23	2	Yes	4L	4L
T001	15/02/2011	19	10	Yes	4L	4L
T001	15/02/2011	16	20	Yes	4L	3.5L
T001	15/02/2011	13	40	Yes	4L	4L
T001	15/02/2011	10	60	Yes	4L	4L

T001	15/02/2011	7	80	Yes	4L	4L
005	22/02/2011	23	2	-	2L	2L
005	22/02/2011	19	10	-	2L	2L
005	22/02/2011	16	21	-	2L	2L
005	22/02/2011	12	31	-	2L	2L
005	22/02/2011	10	41	-	3L	3L
005	22/02/2011	6	50	-	3L	3L
007	22/02/2011	24	2	Yes	2L	2L
007	22/02/2011	18	11	Yes	2L	2L
007	22/02/2011	15	21	Yes	2L	2L
007	22/02/2011	12	31	Yes	2L	2L
007	22/02/2011	10	51	Yes	2L	2L
007	22/02/2011	6	71	-	3L	3L
009	22/02/2011	24	2	-	3L	2L
009	22/02/2011	21	2	-	2L	3 x 2L
009	22/02/2011	20	10	-	3L	2L
009	22/02/2011	18	20	-	3L	2L
009	22/02/2011	14	40	-	3L	3L
009	22/02/2011	10	85	-	3L	3L
013	23/02/2011	23	1	Yes	2L	2L
013	23/02/2011	19	7	Yes	2L	2L
013	23/02/2011	16	14	Yes	2L	2L
013	23/02/2011	13	20	Yes	2L	2L
013	23/02/2011	10	25	Yes	2L	2L
013	23/02/2011	6	35	-	2L	2L
015	24/02/2011	23	2	Yes	4L	3L
015	24/02/2011	19	20	Yes	4L	3L
015	24/02/2011	16	30	Yes	4L	3L

015	24/02/2011	12	40	Yes	4L	3L
015	24/02/2011	10	50	Yes	3L	3L
018	25/02/2011	23	1	Yes	3L	3L
018	25/02/2011	19	15	Yes	3L	3L
018	25/02/2011	16	30	Yes	3L	3L
018	25/02/2011	13	45	Yes	3L	3L
018	25/02/2011	10	55	Yes	3L	3L
021	26/02/2011	23	2	Yes	4L	3L
021	26/02/2011	19	20	Yes	4L	3L
021	26/02/2011	15	30	Yes	-	2L
021	26/02/2011	13	50	Yes	4L	2L
021	26/02/2011	10	80	Yes	4L	3L
021	26/02/2011	6	90	-	-	2L
023	03/03/2011	23	10	-	-	4L
023	03/03/2011	21	20	-	-	4L
023	03/03/2011	20	30	-	-	4L
023	03/03/2011	19	40	-	-	4L
023	03/03/2011	18	50	-	-	4L
023	03/03/2011	17	60	-	-	4L
023	03/03/2011	16	100	-	-	4L
025	04/03/2011	23	2	Yes	4L	4L
025	04/03/2011	19	30	Yes	4L	4L
025	04/03/2011	16	60	Yes	4L	4L
025	04/03/2011	13	80	Yes	4L	4L
025	04/03/2011	10	110	Yes	4L	4L
025	04/03/2011	6	120	-	4L	4L
026	05/03/2011	23	1	Yes	4L	4L
026	05/03/2011	19	20	Yes	4L	4L

026	05/03/2011	16	40	Yes	4L	4L
026	05/03/2011	13	60	Yes	4L	4L
026	05/03/2011	10	75	Yes	4L	4L
026	05/03/2011	4	120	-	4L	4L
029	06/03/2011	24	2	Yes	4L	4L
029	06/03/2011	17	20	Yes	4L	4L
029	06/03/2011	15	40	Yes	4L	4L
029	06/03/2011	14	50	Yes	4L	4L
029	06/03/2011	11	60	Yes	4L	4L
029	06/03/2011	7	70	-	4L	4L
031	07/03/2011	24	1	Yes	4L	4L
031	07/03/2011	17	20	Yes	4L	4L
031	07/03/2011	15	40	Yes	4L	4L
031	07/03/2011	14	50	Yes	4L	4L
031	07/03/2011	11	60	Yes	4L	4L
031	07/03/2011	7	75	-	3.5L	4L
033	08/03/2011	24	2	Yes	4L	4L
033	08/03/2011	17	20	Yes	4L	4L
033	08/03/2011	15	35	Yes	4L	4L
033	08/03/2011	14	45	Yes	4L	4L
033	08/03/2011	11	55	Yes	4L	4L
033	08/03/2011	7	60	-	4L	4L
035	09/03/2011	23	1	Yes	4L	4L
035	09/03/2011	17	20	Yes	4L	4L
035	09/03/2011	15	30	Yes	4L	4L
035	09/03/2011	14	38	Yes	4L	4L
035	09/03/2011	11	47	Yes	4L	4L
035	09/03/2011	7	70	-	4L	4L

037	10/03/2011	24	2	Yes	4L	4L
037	10/03/2011	17	20	Yes	4L	4L
037	10/03/2011	15	30	Yes	4L	4L
037	10/03/2011	14	49	Yes	4L	4L
037	10/03/2011	11	57	Yes	4L	4L
037	10/03/2011	7	70	-	4L	4L
039	11/03/2011	24	1	Yes	4L	4L
039	11/03/2011	17	20	Yes	4L	4L
039	11/03/2011	15	30	Yes	4L	4L
039	11/03/2011	14	50	Yes	4L	4L
039	11/03/2011	11	60	Yes	4L	4L
039	11/03/2011	7	80	-	4L	4L
042	12/03/2011	24	1	Yes	4L	4L
042	12/03/2011	17	20	Yes	4L	4L
042	12/03/2011	15	40	Yes	4L	4L
042	12/03/2011	14	56	Yes	4L	4L
042	12/03/2011	11	68	Yes	4L	4L
042	12/03/2011	7	75	-	4L	4L
043	13/03/2011	24	1	Yes	4L	4L
043	13/03/2011	17	20	Yes	4L	4L
043	13/03/2011	15	50	Yes	4L	4L
043	13/03/2011	14	67	Yes	4L	4L
043	13/03/2011	11	78	Yes	4L	4L
043	13/03/2011	7	95	-	4L	4L
045	14/03/2011	24	3	Yes	4L	4L
045	14/03/2011	17	25	Yes	4L	4L
045	14/03/2011	15	54	Yes	4L	4L
045	14/03/2011	14	74	Yes	4L	4L

045	14/03/2011	11	90	Yes	4L	4L
045	14/03/2011	7	105	-	3.2L	-
045	14/03/2011	5	130	-	3.4L	4L
048	15/03/2011	20	5	Yes	4L	2L
048	15/03/2011	17	20	Yes	4L	4L
048	15/03/2011	16	20	Yes	3.7L	2L
048	15/03/2011	14	40	Yes	4L	4L
048	15/03/2011	11	60	Yes	4L	4L
048	15/03/2011	6	75	-	3.3L	2L
048	15/03/2011	5	110	-	-	4L
049	15/03/2011	24	10	-	4L	4L
049	15/03/2011	23	20	-	-	4L
049	15/03/2011	21	30	-	4L	4L
049	15/03/2011	19	40	-	4L	4L
049	15/03/2011	18	50	-	4L	4L
049	15/03/2011	17	60	-	4L	4L
049	15/03/2011	16	80	-	4L	4L
049	15/03/2011	14	100	-	4L	4L
049	15/03/2011	10	500	-	4L	4L
049	15/03/2011	8	750	-	4L	4L
049	15/03/2011	7	1000	-	4L	4L

29.3 Results

No results from D361 are currently available as all analysis will be conducted once the samples return to the UK. Previous results from cruise D346 have indicated that chlorophyll *a* and heme *b* concentrations show a similar distribution within the surface water column.

29.4 References

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30 Determination of magnitude and cycling of phosphorus in the (sub) tropical Atlantic

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30.1 Introduction

Both direct and geochemical evidence show that nitrogen fixation is more prevalent in the north compared to the south (sub) tropical Atlantic. This has been attributed to the natural fertilization of the North Atlantic with aeolian inputs from the iron-rich dust from the Sahara desert, which supports and periodically enhances growth and activity of iron-demanding nitrogen fixers or diazotrophs. However, diazotrophs are phosphate-demanding and to date, there is no evidence for an equivocal input of phosphorus from aeolian dust inputs. Thus, the source of phosphorus to the N_2 fixing community in the North Atlantic remains a conundrum.

Despite inorganic phosphate concentrations being depleted in the subtropical ocean, there is a large complex pool of dissolved organic-bound phosphorus (DOP) that can be up to two orders of magnitude more abundant than phosphate. Little is known about the source, composition and recycling of DOP. DOP may be produced and recycled within the gyre, or exuded during high biological activity at the flanks of the gyre (e.g. in upwelling or shelf regions) and advected into the gyre through horizontal transport. The DOP pool consists of a series of complex organic molecules of varying lability, with the ester group being one of the more bioavailable. Indeed, DOP can act as an alternative source of phosphorus to both autotrophic and heterotrophic organisms, which have the ability to access DOP via extracellular hydrolytic enzymes, such as alkaline phosphatase and nucleotidase that cleave phosphate from phospho-ester (organic) molecules. However, the concentration of phospho-esters in the (sub) tropical ocean are unknown.

The ubiquitous marine nitrogen fixer, *Trichodesmium* spp., and potentially other members of the N_2 fixing community, are known to produce alkaline phosphatase in response to phosphorus stress, the activity of the enzyme being indicative of relative phosphorus limitation. Some organisms (including *Trichodesmium*) may also use enzymes to access the phosphorus contained in phosphonate bonds (Dyhrman et al. 2006).

The aim of our work on D361 was to (a) determine the relative importance of phosphate and DOP by the whole water microbial community and *Trichodesmium*, (b) determine the variation in DOP production relative to its consumption and (c) identify source regions of DOP. To achieve these aims, we measured the uptake of inorganic phosphate and rate of alkaline phosphatase activity onboard, as well as the rate of DOP production. We collected samples to determine the concentration of DOP, enzyme hydrolysable phosphorus and particulate phosphorus.

30.2 Methods

Samples for dissolved organic phosphorus (DOP) and enzyme hydrolysable phosphorus (EHP) were collected from 10 depths between 0 and 500m from the pre-dawn stainless steel cast. Samples for particulate phosphorus were collected from 6 depths. Rates of phosphate uptake, DOP production and alkaline phosphatase activity were collected from 6 depths between the down slope of the deep chlorophyll maximum (DCM) and the surface. At stations where *Trichodesmium* colonies were found, rates of phosphate uptake and alkaline phosphatase activity were determined on 10-20 colonies.

30.2.1 DOP and EHP

Using an acid-cleaned amber HDPE bottle, 1 L of seawater (triple rinsed with sample prior to sample collection) was collected from 10 depths from the stainless steel rosette frame and CTD deployed at pre-dawn. A clean glass filtration rig was used for filtering samples for determination of DOP and EHP. For DOP, ~100 ml of seawater was vacuum filtered through a combusted and acid washed glass fiber filter and used to rinse both the filter and glass filtration rig prior to the collection of 50 ml of sample in a 60ml HDPE bottle. For collection of seawater for EHP analysis, 250 ml of seawater was vacuum filtered through a Millipore Fast Flow 0.2 m filter and used to rinse the filter and glass filtration rig. A further 250 ml was filtered through the same filter and 175 ml collected in a square HDPE bottle. Samples were frozen upright at -20 C. 183 samples were collected from depth profiles (0-500m) from the stainless steel CTD for determination of DOP and EHP (Table 30.1). Concentrations of DOP will be determined by measurement of phosphate concentrations before and after UV oxidation. Concentrations of EHP will be determined using methods described by Monbet et al., 2007.

Samples for the determination of DOP concentrations were also collected from the titanium CTD (below 500m, 133 samples, Table 30.2). Samples for the determination of DOP and EHP were also collected from the trace metal clean FISH (surface only, 37 samples, Table 30.3).

30.2.2 Particulate phosphate

From 6 depths, 1 L of seawater was collected and filtered onto a 25 mm, combusted and acid washed glass fiber filter using vacuum filtration. The filter was folded, placed in a glass tube, labeled and stored at -20 C until analysis. Analysis will be performed by high temperature combustion and acid digestion. Precision and accuracy of analysis will be verified using an NIST standard (apple leaves).

30.2.3 ^{33}P-phosphate uptake and DO^{33}P production: whole community and Trichodesmium-specific

1 L of seawater was collected from six depths (surface to the downslope of the deep chlorophyll maximum) from the stainless steel CTD cast. To measure ^{33}phosphate uptake, 75 ml of seawater was placed into 2 or 3 125 ml acid cleaned and DIW rinsed polycarbonate bottles and spiked with 3 kBqof ^{33}phosphate. Note that the concentration of phosphate added to incubations was < 0.01 nM. 1ml of spiked seawater was removed immediately and placed in a 7 ml glass scintillation vial (=total activity). A killed control from each depth was also run along side, whereby a 75 ml seawater sample was spiked with 3 kBq of 33P and to this 2.5 ml of gluteraldehyde was added to allow determination of abiotic absorption of phosphate onto the filter and cells. To assess the assimilation of phosphate these bottles were placed in on-deck incubators at varying light levels for 3 hours. After 3 hours, 50 ml of the incubated sample was filtered through a 0.2 m polycarbonate filter. The filter was immediately placed in a 7 ml scintillation vial.

At stations where *Trichodesmium* colonies were found (pre-dawn shallow nets), 20 colonies were placed into 50 ml of underway or filtered seawater in a 125 ml acid and milli-q rinsed polycarbonate bottle. A 3 kBq ^{33}phosphate was introduced and a 1 ml aliquot was immediately removed and placed into a 7 ml scintillation vial to measure for total activity. The sample bottles were placed into an on deck incubator (55% light) for 3 hours after which the whole 50 ml was filtered and the filter placed into a 7 ml scintillation vial.

To determine the production of DO^{33}P, 125 ml of seawater was placed into 2 or 3 125 ml acid cleaned and DIW rinsed polycarbonate bottles and spiked with 20 kBq ^{33}phosphate. 1ml of spiked seawater was removed immediately and placed in a 7 ml glass scintillation vial (=total activity). To determine the production of DOP, sample bottles were placed in on-deck incubators at varying light levels for 8-10 hours. After this time, 50 ml of the incubated sample was filtered though a 0.2 m polycarbonate filter. The filter was retained and placed into a 7 ml glass scintillation vial for phosphate uptake. The filtrate was placed into a 50 ml centrifuge tube, to which 150 µl 1M NaOH was added. The sample was shaken vigorously and centrifuged for one hour at 3500 RPM (MAGIC method (Thomson-Bulldis and Karl, 1998). 1ml of the supernatant was immediately placed in a 7ml glass scintillation vial. To assess the efficiency of the MAGIC method, 2 125 ml seawater sampled were spiked with 20 kBq of ^{33}P and immediately filtered without any incubation time. 50 ml of the filtrate was placed into a 50 ml centrifuge tube, to which 150 µl 1M NaOH was added. The sample was shaken vigorously and centrifuged for one hour at 3500 RPM. 1ml of the supernatant was immediately placed in a 7ml glass scintillation vial.

To each vial containing a filter, sample for total activity or sample of supernatant after precipitation, 5 ml of Ultima Gold Scintillation cocktail was added to each vial. Vials were placed in a Perkin-Elmer Scintillation counter. Quench

standards were analyzed daily. The disintegrations per minute were recorded for each sample and rates of uptake or DOP production calculated using the total activity relative to the post-incubation activity. Calculations for phosphate uptake were similar to those outlined by Bjorkman et al. 2000.

30.2.4 Alkaline phosphatase activity: whole community and Trichodesmium-specific

Alkaline phosphatase activity (APA) was determined using methods described by Ammerman (1993). The principle of the technique involves incubating seawater or *Trichodesmium* colonies with an organic phosphate analog which has little fluorescence when derivatized with phosphate (4-methylumbelliferyl phosphate, MUFP) but is highly fluorescent when not derivatized (4-methylumbelliferone, MUF). Thus, the activity of alkaline phosphatase is determined simply by the increase in fluorescence over time as more phosphate is hydrolyzed by the enzyme, alkaline phosphatase.

Seawater was collected from Niskin bottles attached to the stainless steel CTD frame at 6 depths. 250 ml of seawater was placed in an acid-cleaned 250 ml polycarbonate bottle. The phosphorus substrate, MUF-P was added to seawater to gain a final concentration of 400 nM. Bottles were placed in an on-deck, surface seawater-cooled incubator for a period of at least 12-hours.

Colonies of *Trichodesmium* were collected using a 50 cm (3:1 ratio), 100 m mesh plankton net with a solid cod end deployed to a depth of 10-15 m for 15m. Both “tuff” and “puff” colonial forms were picked using plastic inoculating loops and placed in unfiltered surface seawater. 20 colonies were placed into 125ml acid-cleaned polycarbonate containing 125 ml unfiltered seawater. MUF-P was added to each polycarbonate bottle to yield a final concentration of 800nM. The alkaline phosphatase activity of the unfiltered seawater containing no *Trichodesmium* colonies was also determined. The bottles were placed in an on-deck, surface seawater-cooled incubator for a period of at least 12-hours.

Fluorescence was determined using a Turner 10Au field fluorometer fitted with optical filters with excitation near 365nm and emission near 455nm (Optical kit #10-302R). Upon addition of the MUF-P to either seawater or *Trichodesmium* incubations, 3ml of sample was removed immediately from each bottle to represent the initial fluorescence of the sample (T_{zero}) and added to 1ml of borate buffer (pH > 10.5). Fluorescence measurements were made every 1-2 hours for at least 12 hours.

MUF standards (200, 400, 800 nM), blanks and killed controls (boiled seawater plus 200nM or 400nM MUFP) were incubated each day with seawater or *Trichodesmium* incubations. Fluoresence of MUF standards was determined at T_{zero}

only, but fluorescence of the seawater blank and killed control was monitored throughout the day.

Rates of phosphorus hydrolysis by alkaline phosphatase were determined by calculating the change in fluorescence observed during the incubation time and dividing by the fluorescence of the appropriate MUF standard. Rates were normalized to biomass, either chlorophyll or number of *Trichodesmium* colonies.

Table 30.1. Log of station number, CTD number, Niskin bottle and parameters measured on D361.

Cruise	Date	Station	CTD	Niskin bottle	DOP/EHP	P-uptake	APA	Particulate phosphorus
D361	22/02/2011	2	5	1	x			
D361				2	x			
D361				3	x			
D361				4	x			
D361				5	x	x	x	x
D361				9	x	x	x	x
D361				12	x	x	x	x
D361				15	x	x	x	x
D361				18	x	x	x	x
D361				22	x	x	x	x
D361	22/02/2011	3	7	1	x			
D361				2	x			
D361				3	x			
D361				5	x			
D361				8	x	x	x	x
D361				11	x	x	x	x
D361				14	x	x	x	x

D361				17	x	x	x	x
D361				21	x	x	x	x
D361	22/02/2010	4	9	2	x			
D361				4	x			
D361				6	x			
D361				8				x
D361				10	x			
D361				13				x
D361				14	x			
D361				16				x
D361				18	x			
D361				20	x			
D361				22		x	x	x
D361				24	x			
D361	23/02/2010	6	13	1	x			
D361				3	x			
D361				4	x			
D361				5	x	x	x	x
D361				8	x	x	x	x
D361				12	x	x	x	x
D361				15	x	x	x	x
D361				18	x	x	x	x
D361				22	x	x	x	x
D361	24/02/2011	7	15	1	x			
D361				3	x			

D361				4	x			
D361				6	x	x	x	x
D361				9	x	x	x	x
D361				11	x	x	x	x
D361				15	x	x	x	x
D361				18	x	x	x	x
D361				22	x	x	x	x
D361	25/02/2011	8	18	1	x			
D361				2	x			
D361				3	x			
D361				4	x			
D361				6	x	x	x	x
D361				9	x	x	x	x
D361				12	x	x	x	x
D361				15	x	x	x	x
D361				18	x	x	x	x
D361				22	x	x	x	x
D361	26/02/2011	9	21	1	x			
D361				3	x			
D361				5	x			
D361				6	x	x	x	x
D361				9	x	x	x	x
D361				12	x	x	x	x
D361				15	x	x	x	x
D361				18	x	x	x	x
D361				22	x	x	x	x

D361	04/03/2011	10	25	1	x			
D361				2	x			
D361				3	x			
D361				5	x	x	x	x
D361				9	x	x	x	x
D361				12	x	x	x	x
D361				15	x	x	x	x
D361				18	x	x	x	x
D361				22	x	x	x	x
D361	05/03/2011	11	26	1	x			
D361				2	x			
D361				3	x			
D361				4	x			
D361				6	x	x	x	x
D361				9	x	x	x	x
D361				12	x	x	x	x
D361				15	x	x	x	x
D361				18	x	x	x	x
D361				22	x	x	x	x
D361	06/03/2011	12	29	1	x			
D361				2	x			
D361				3	x			
D361				4	x			
D361				5	x	x	x	x
D361				10	x	x	x	x

D361				13	x	x	x	x
D361				16	x	x	x	x
D361				18	x	x	x	x
D361				22	x	x	x	x
D361	07/03/2011	13	31	1	x			
D361				2	x			
D361				4	x			
D361				5	x			
D361				6	x	x	x	x
D361				10	x	x	x	x
D361				13	x	x	x	x
D361				16	x	x	x	x
D361				18	x	x	x	x
D361				22	x	x	x	x
D361	08/03/2011	14	33	1	x			
D361				2	x			
D361				4	x			
D361				5	x			
D361				6	x	x	x	x
D361				10	x	x	x	x
D361				13	x	x	x	x
D361				16	x	x	x	x
D361				18	x	x	x	x
D361				22	x	x	x	x
D361	09/03/2011	15	35	1	x			

D361				2	x			
D361				4	x			
D361				5	x			
D361				6	x	x	x	x
D361				8	x	x	x	x
D361				13	x	x	x	x
D361				16	x	x	x	x
D361				18	x	x	x	x
D361				22	x	x	x	x
D361	10/03/2011	16	37	1	x			
D361				2	x			
D361				5	x			
D361				6	x	x	x	x
D361				10	x	x	x	x
D361				13	x	x	x	x
D361				16	x	x	x	x
D361				18	x	x	x	x
D361				22	x	x	x	x
D361	11/03/2011	17	39	1	x			
D361				2	x			
D361				4	x			
D361				5	x			
D361				6	x	x	x	x
D361				10	x	x	x	x
D361				13	x	x	x	x
D361				16	x	x	x	x

D361				18	x	x	x	x
D361				22	x	x	x	x
D361	12/03/2011	18	42	1	x			
D361				4	x			
D361				5	x			
D361				6	x	x	x	x
D361				10	x	x	x	x
D361				13	x	x	x	x
D361				16	x	x	x	x
D361				18	x	x	x	x
D361				22	x	x	x	x
D361	13/03/2011	19	43	1	x			
D361				2	x			
D361				4	x			
D361				5	x			
D361				6	x	x	x	x
D361				10	x	x	x	x
D361				13	x	x	x	x
D361				16	x	x	x	x
D361				18	x	x	x	x
D361				22	x	x	x	x
D361	14/03/2011	20	45	1	x			
D361				2	x			
D361				5	x			
D361				7	x	x	x	x

D361				10	x	x	x	x
D361				13	x	x	x	x
D361				16	x	x	x	x
D361				18	x	x	x	x
D361				22	x	x	x	x
D361								
D361	15/03/2011	21	48	1	x			
D361				2	x			
D361				4	x			
D361				5	x			
D361				6	x	x	x	x
D361				10	x	x	x	x
D361				13	x	x	x	x
D361				16	x	x	x	x
D361				18	x	x	x	x
D361				22	x	x	x	x

Table 30.2. Log of samples collected from the surface trace metal clean Fish sampler for determination of DOP and EHP concentrations.

Cruise	**Fish number**	**DOP**	**EHP**
D361	55	x	x
D361	57	x	x
D361	59	x	x
D361	64	x	x

D361	66	x	x
D361	68	x	x
D361	69	x	x
D361	71	x	x
D361	95	x	x
D361	156	x	x
D361	158	x	x
D361	161	x	x
D361	163	x	x
D361	167	x	x
D361	169	x	x
D361	172	x	x
D361	174	x	x
D361	176	x	x
D361	179	x	x
D361	181	x	x
D361	183	x	x
D361	189	x	x
D361	191	x	x
D361	195	x	x
D361	197	x	x
D361	199	x	x
D361	202	x	x
D361	204	x	x
D361	206	x	x
D361	209	x	x
D361	214	x	x
D361	216	x	x

D361	218	x	x
D361	222	x	x
D361	224	x	x
D361	226	x	x
D361	229	x	x

Table 30.3. Log of number of samples collected for determination of DOP concentrations from the titanium CTD.

Cruise	**STN NUMBER**	**No. samples**
D361	2	6
D361	3	5
D361	4	0
D361	5	0
D361	6	13
D361	7	14
D361	8b	4
D361	9	12
D361	10	14
D361	11.5	8
D361	12	12
D361	13	0
D361	14	6
D361	15	7
D361	16	4
D361	17	8
D361	18	7
D361	19	7

D361	20	6
D361	21	0

30.3 References

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31 Abundance and activity of nitrogen fixing bacteria

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31.1 Introduction

Nitrogen fixation is the most important input process of nitrogen into the world's oceans (*1, 2*). The only organisms capable of using atmospheric dinitrogen as an n-source are diazotrophic (nitrogen fixing) bacteria. Cyanobacteria like *Trichodesmium*, *Crocosphaera*, or the recently discovered UCYN-A show the highest abundance in the Tropical North Atlantic Ocean (*3, 4*). These bacteria have a high request of iron for their growth, because both photosynthesis and nitrogen fixation are occurring in the same cell and both processes make use of iron demanding proteins and cofactors. The region has previously been shown to be iron and phosphorous co-limited in terms of diazotrophy (*5*). The dust that enters the surface ocean by episodic storms from the Saharan desert at the eastern margin of the basin plays a key role in supplying new iron and phosphorous to the system. It is our interest to establish the relationship between atmospheric deposition, iron and nutrient loading and the abundance and or dominance of the different diazotrophic phylotypes. Second we would like to establish per area rates of nitrogen fixation of that region. Nitrogen fixation rates have been measured extensively in the past, but a recent development suggested that actual rates might be higher than measured, due to an underestimation of the method in use (*6*). We apply a modified method suggeset by Mohr2010 to establish nitrogen fixation rates. The combined data of abundance of diazotrophs and their activity in terms of nitrogen fixation will be viewed in context with the iron and phosphorous input.

31.2 Methods

For *nifH* gene abundance two liters of seawater were filtered onto 0.22 µm Durapore filters and stored at -80°C. Most Fish stations were sampled and all depths of the stainless steel CTD's 01, 05, 09, 3, 15, 18, 21, 25, 26, 29, 31, 33, 35, 37, 39, 42, 43, 45 and 48. Back in the laboratory the DNA will get extracted using QIAGEN kits and the gene copy number of the dominant diazotrophic phylotypes will be established using qPCR (*4*).

Nitrogen fixation activity was assessed using a modified protocol by Mohr2010. There were three to five depths sampled from the stainless steel CTD's 01, 05, 09, 3, 15, 18, 21, 25, 26, 29, 31, 33, 35, 37, 39, 42, 43, 45 and 48. From each depth triplicates of experimental bottles are taken plus one control. Seawater was filled into 4.5 liter polycarbonate bottles and to each experimental bottle 100 mL of $^{15}N_2$ labelled Seawater (1mL $^{15}N_2$ gas/100mL Seawater) and 1mL of $NaH^{13}CO_3$ (1g/50mL milliq) were added. The control bottles got amended with 100 mL of degassed

seawater that got spiked with 1mL air/ 100mL seawater. Bottles were closed bubble free and stored for 24 hours in on deck incubators covered with light foil to simulate the in situ light conditions. Samples from below the photic zone were stored 24 hours in the constant temperature lab in the dark at 15°C. At the end of the incubation period two liters of each sample were filtered onto precombusted GF/F filters. Filters were dried at 30°C for 24 hours and taken home for further analysis.

Samples will get combusted in an CHN analyser coupled to an isotope ratio mass spectrometer to assess POC and PON content and get the ratios of 15/14N and 13/12C. The uptake of label into biomass and the knowledge of the total biomass and incubation time allows the calculation of nitrogen and carbon fixation rates (*6, 7*).

31.3 Results

In total 354 DNA samples for the quantification of dominant diazotroph phylotypes have been taken both from the FISH and the stainless steel CTD (Figure 1.1, table 31.1). The nitrogen fixation rate measurements sum up to a total of 312 samples, where always 4 are from the same station, same depth, so a total of 78 different locations have been sampled (Table 31.1 and 31.2).

Table 31.1: Sampled stations and amount and type of samples taken

Station	Date	Lat	Lon	Type	Nitrogen fixation	*nifH* gene abundance and diversity
CTD 01	15.02.2011	28.313	-16.12	N2 Profile, DNA	20	9
CTD 05	22.02.2011	12.669	-17.922	N2 Profile, DNA	20	10
CTD 09	22.02.2011	12.669	-17.922	N2 Profile, DNA	16	8
CTD 13	23.02.2011	12.585	-17.978	N2 Profile, DNA	20	9
CTD 15	24.02.2011	12.593	-20.962	N2 Profile, DNA	12	8
CTD 18	25.02.2011	12.585	-22.86	N2 Profile, DNA	16	10
CTD 21	26.02.2011	12.436	-24.375	N2 Profile, DNA	15	9
CTD 23	04.03.2011	-7.2220	-24.9937	N2 Profile, DNA	4	1
CTD 25	04.03.2011	-7.2185	-24.9930	N2 Profile, DNA	12	8
CTD 26	05.03.2011	-3.2612	-25.5204	N2 Profile, DNA	16	9
CTD 29	06.03.2011	-1.1731	-25.7940	N2 Profile, DNA	16	10

CTD 31	07.03.2011	1.1569	-26.0460	N2 Profile, DNA	16	8
CTD 33	08.03.2011	3.3300	-26.8103	N2 Profile, DNA	16	10
CTD 35	09.03.2011	5.6620	-27.4990	N2 Profile, DNA	16	9
CTD 37	10.03.2011	8.3394	-28.3321	N2 Profile, DNA	20	9
CTD 39	11.03.2011	10.6269	-28.7312	N2 Profile, DNA	16	10
CTD 42	12.03.2011	12.0542	-28.9801	N2 Profile, DNA	16	9
CTD 43	13.03.2011	15.5085	-28.7865	N2 Profile, DNA	12	10
CTD 45	14.03.2011	17.3991	-28.3948	N2 Profile, DNA	16	8
CTD 48	15.03.2011	19.1151	-28.1311	N2 Profile, DNA	16	9
FISH 001	08.02.2011	26.9822	-18.8844	DNA		1
FISH 002	08.02.2011	27.0406	-18.6428	DNA		1
FISH 004	18.02.2011	27.038	-16.452	DNA		1
FISH 005	18.02.2011	26.683	-16.535	DNA		1
FISH 006	18.02.2011	26.324	-16.631	DNA		1
FISH 007	18.02.2011	25.933	-16.751	DNA		1
FISH 008	19.02.2011	25.614	-16.843	DNA		1
FISH 009	19.02.2011	25.265	-16.942	DNA		1
FISH 010	19.02.2011	24.923	-17.032	DNA		1
FISH 011	19.02.2011	24.455	-17.182	DNA		1
FISH 012	19.02.2011	24.18	-17.249	DNA		1
FISH 013	19.02.2011	23.848	-17.337	DNA		1
FISH 014	19.02.2011	23.52	-17.424	DNA		1
FISH 015	19.02.2011	23.157	-17.526	DNA		1
FISH 016	19.02.2011	22.806	-17.62	DNA		1
FISH 017	19.02.2011	22.465	-17.71	DNA		1
FISH 018	19.02.2011	22.072	-17.819	DNA		1
FISH 019	19.02.2011	21.736	-17.907	DNA		1
FISH 020	20.02.2011	21.387	-18.006	DNA		1

FISH 021	20.02.2011	20.669	-18.15	DNA	1
FISH 022	20.02.2011	20.284	-18.152	DNA	1
FISH 023	20.02.2011	19.891	-18.158	DNA	1
FISH 024	20.02.2011	19.604	-18.149	DNA	1
FISH 025	20.02.2011	19.287	-18.157	DNA	1
FISH 026	20.02.2011	18.897	-18.161	DNA	1
FISH 027	20.02.2011	18.546	-18.156	DNA	1
FISH 028	20.02.2011	18.198	-18.155	DNA	1
FISH 029	20.02.2011	17.865	-18.154	DNA	1
FISH 030	20.02.2011	17.479	-18.163	DNA	1
FISH 031	21.02.2011	16.989	-18.153	DNA	1
FISH 032	21.02.2011	16.607	-18.148	DNA	1
FISH 033	21.02.2011	16.226	-18.175	DNA	1
FISH 034	21.02.2011	15.798	-18.16	DNA	1
FISH 035	21.02.2011	15.381	-18.166	DNA	1
FISH 036	21.02.2011	15.075	-18.14	DNA	1
FISH 037	21.02.2011	14.73	-18.155	DNA	1
FISH 039	21.02.2011	14.324	-18.115	DNA	1
FISH 040	21.02.2011	13.967	-18.07	DNA	1
FISH 041	21.02.2011	13.569	-18.024	DNA	1
FISH 042	21.02.2011	13.203	-17.981	DNA	1
FISH 049	23.02.2011	12.585	-17.949	DNA	1
FISH 051	23.02.2011	12.581	-18.311	DNA	1
FISH 055	23.02.2011	12.594	-19.165	DNA	1
FISH 056	23.02.2011	12.586	-19.523	DNA	1
FISH 057	23.02.2011	12.586	-19.875	DNA	1
FISH 058	23.02.2011	12.584	-20.253	DNA	1
FISH 061	24.02.2011	12.583	-21.341	DNA	1

FISH 062	24.02.2011	12.58	-21.779	DNA	1
FISH 063	24.02.2011	12.582	-22.153	DNA	1
FISH 064	24.02.2011	12.591	-22.51	DNA	1
FISH 065	25.02.2011	12.584	-22.86	DNA	1
FISH 066	25.02.2011	12.583	-23.213	DNA	1
FISH 067	25.02.2011	12.582	-23.53	DNA	1
FISH 068	25.02.2011	12.568	-23.769	DNA	1
FISH 069	25.02.2011	12.498	-24.097	DNA	1
FISH 070	26.02.2011	12.436	-24.375	DNA	1
FISH 071	26.02.2011	12.373	-24.679	DNA	1
FISH 073	26.02.2011	12.204	-25.643	DNA	1
FISH 074	26.02.2011	11.952	-25.754	DNA	1
FISH 075	26.02.2011	11.603	-25.741	DNA	1
FISH 076	26.02.2011	11.274	-25.723	DNA	1
FISH 077	27.02.2011	10.948	-25.705	DNA	1
FISH 078	27.02.2011	10.601	-25.692	DNA	1
FISH 079	27.02.2011	10.245	-25.68	DNA	1
FISH 080	27.02.2011	9.9136	-25.672	DNA	1
FISH 081	27.02.2011	9.5333	-25.658	DNA	1
FISH 083	27.02.2011	9.0443	-25.64	DNA	1
FISH 084	27.02.2011	8.6658	-25.625	DNA	1
FISH 085	27.02.2011	8.2626	-25.611	DNA	1
FISH 086	27.02.2011	7.9384	-25.596	DNA	1
FISH 087	27.02.2011	7.5717	-25.579	DNA	1
FISH 088	27.02.2011	7.214	-25.565	DNA	1
FISH 089	28.02.2011	6.8668	-25.555	DNA	1
FISH 090	28.02.2011	6.5546	-25.539	DNA	1
FISH 091	28.02.2011	6.1522	-25.521	DNA	1

FISH 092	28.02.2011	5.8054	-25.507	DNA	1
FISH 093	28.02.2011	5.4448	-25.495	DNA	1
FISH 094	28.02.2011	5.0773	-25.483	DNA	1
FISH 095	28.02.2011	4.7264	-25.472	DNA	1
FISH 096	28.02.2011	4.3394	-25.448	DNA	1
FISH 096	28.02.2011	4.3394	-25.448	DNA	1
FISH 097	28.02.2011	4.0025	-25.437	DNA	1
FISH 099	28.02.2011	3.2984	-25.414	DNA	1
FISH 100	28.02.2011	2.9533	-25.4	DNA	1
FISH 101	01.03.2011	2.6068	-25.392	DNA	1
FISH 102	01.03.2011	2.2646	-25.377	DNA	1
FISH 103	01.03.2011	1.7559	-25.353	DNA	1
FISH 104	01.03.2011	1.5712	-25.349	DNA	1
FISH 105	01.03.2011	1.2354	-25.337	DNA	1
FISH 106	01.03.2011	0.8282	-25.315	DNA	1
FISH 107	01.03.2011	0.5789	-25.306	DNA	1
FISH 108	01.03.2011	0.2408	-25.292	DNA	1
FISH 109	01.03.2011	-0.091	-25.281	DNA	1
FISH 110	01.03.2011	-0.3769	-25.263	DNA	1
FISH 111	01.03.2011	-0.7128	-25.263	DNA	1
FISH 112	01.03.2011	-1.0294	-25.268	DNA	1
FISH 113	02.03.2011	-1.3543	-25.254	DNA	1
FISH 114	02.03.2011	-1.7045	-25.228	DNA	1
FISH 115	02.03.2011	-2.0452	-25.211	DNA	1
FISH 116	02.03.2011	-2.3654	-25.194	DNA	1
FISH 117	02.03.2011	-2.6752	-25.175	DNA	1
FISH 118	02.03.2011	-2.9929	-25.157	DNA	1
FISH 119	02.03.2011	-3.311	-25.151	DNA	1

FISH 121	02.03.2011	-3.6089	-25.147	DNA	1
FISH 123	02.03.2011	-3.8958	-25.133	DNA	1
FISH 127	02.03.2011	-4.1753	-25.12	DNA	1
FISH 131	02.03.2011	-4.4886	-25.106	DNA	1
FISH 131	02.03.2011	-4.4886	-25.106	DNA	1
FISH 136	02.03.2011	-4.8006	-25.084	DNA	1
FISH 140	03.03.2011	-5.1107	-25.066	DNA	1
FISH 144	03.03.2011	-5.4154	-25.062	DNA	1
FISH 146	03.03.2011	-5.7431	-25.049	DNA	1
FISH 147	03.03.2011	-6.0567	-25.031	DNA	1
FISH 148	03.03.2011	-6.3558	-25.021	DNA	1
FISH 149	03.03.2011	-6.6467	-25.019	DNA	1
FISH 150	03.03.2011	-6.9561	-25.003	DNA	1
FISH 153	04.03.2011	-6.6847	-25.052	DNA	1
FISH 154	04.03.2011	-6.3426	-25.084	DNA	1
FISH 155	04.03.2011	-6.0074	-25.115	DNA	1
FISH 156	04.03.2011	-5.6677	-25.154	DNA	1
FISH 157	04.03.2011	-5.3317	-25.189	DNA	1
FISH 158	04.03.2011	-4.991	-25.228	DNA	1
FISH 159	04.03.2011	-4.8148	-25.25	DNA	1
FISH 161	04.03.2011	-4.334	-25.3	DNA	1
FISH 162	05.03.2011	-4.0292	-25.336	DNA	1
FISH 163	05.03.2011	-3.7091	-25.396	DNA	1
FISH 166	05.03.2011	-2.605	-25.662	DNA	1
FISH 167	05.03.2011	-2.3243	-25.71	DNA	1
FISH 168	06.03.2011	-1.9592	-25.775	DNA	1
FISH 169	06.03.2011	-1.6323	-25.8	DNA	1
FISH 171	06.03.2011	-0.904	-25.809	DNA	1

FISH 172	06.03.2011	-0.5977	-25.848	DNA	1
FISH 173	06.03.2011	-0.2732	-25.881	DNA	1
FISH 174	06.03.2011	0.0481	-25.914	DNA	1
FISH 175	07.03.2011	0.3661	-25.958	DNA	1
FISH 176	07.03.2011	0.6829	-25.995	DNA	1
FISH 178	07.03.2011	1.3417	-26.116	DNA	1
FISH 179	07.03.2011	1.6439	-26.235	DNA	1
FISH 180	07.03.2011	1.9413	-26.344	DNA	1
FISH 181	07.03.2011	2.2615	-26.429	DNA	1
FISH 182	08.03.2011	2.5764	-26.533	DNA	1
FISH 183	08.03.2011	2.8964	-26.647	DNA	1
FISH 185	08.03.2011	3.5258	-26.885	DNA	1
FISH 186	08.03.2011	3.8208	-26.973	DNA	1
FISH 187	08.03.2011	4.1122	-27.054	DNA	1
FISH 188	08.03.2011	4.4188	-27.14	DNA	1
FISH 189	08.03.2011	4.6954	-27.227	DNA	1
FISH 190	09.03.2011	4.976	-27.309	DNA	1
FISH 191	09.03.2011	5.3104	-27.399	DNA	1
FISH 193	09.03.2011	6.0938	-27.622	DNA	1
FISH 194	09.03.2011	6.3931	-27.695	DNA	1
FISH 196	09.03.2011	6.996	-27.892	DNA	1
FISH 197	09.03.2011	7.2984	-27.992	DNA	1
FISH 198	10.03.2011	7.5985	-28.09	DNA	1
FISH 199	10.03.2011	7.944	-28.193	DNA	1
FISH 201	10.03.2011	8.5577	-28.371	DNA	1
FISH 202	10.03.2011	8.8627	-28.418	DNA	1
FISH 203	10.03.2011	9.1911	-28.473	DNA	1
FISH 204	10.03.2011	9.5077	-28.529	DNA	1

FISH 205	11.03.2011	9.818	-28.583	DNA	1
FISH 206	11.03.2011	10.154	-28.643	DNA	1
FISH 208	11.03.2011	10.934	-28.789	DNA	1
FISH 209	11.03.2011	11.296	-28.86	DNA	1
FISH 210	11.03.2011	11.614	-28.925	DNA	1
FISH 212	12.03.2011	12.449	-28.971	DNA	1
FISH 213	12.03.2011	12.797	-28.96	DNA	1
FISH 214	12.03.2011	13.13	-28.932	DNA	1
FISH 215	12.03.2011	13.448	-28.922	DNA	1
FISH 216	12.03.2011	13.803	-28.902	DNA	1
FISH 217	12.03.2011	14.118	-28.887	DNA	1
FISH 218	12.03.2011	14.446	-28.874	DNA	1
FISH 219	13.03.2011	14.78	-28.854	DNA	1
FISH 220	13.03.2011	15.075	-28.844	DNA	1
FISH 222	13.03.2011	15.808	-28.733	DNA	1
FISH 223	13.03.2011	16.086	-28.665	DNA	1
FISH 224	13.03.2011	16.365	-28.605	DNA	1
FISH 225	14.03.2011	16.661	-28.543	DNA	1
FISH 226	14.03.2011	16.979	-28.475	DNA	1
FISH 228	14.03.2011	17.886	-28.309	DNA	1
FISH 229	14.03.2011	18.193	-28.237	DNA	1
FISH 230	15.03.2011	18.65	-28.15	DNA	1

Table 31.2: CTD bottles that samples for nitrogen fixation rate measurements have been taken from and the corresponding percentage of surface irradiance light shading they were left for 24 hours in

CTD	Niskin	Depth	Light Level (%)
1	24	2	80

1	20	10	55
1	17	20	40
1	14	40	10
1	8	80	0.5
5	8	40	5
5	11	30	10
5	14	20	40
5	17	10	55
5	21	2	80
9	9	85	0.5
9	12	40	10
9	17	20	40
9	23	2	80
13	9	25	5
13	11	20	10
13	14	14	40
13	17	7	55
13	21	2	80
15		50	5
15		20	55
15		2	80
18	8	55	5
18	14	30	40
18	17	15	55
18	24	2	80
21	4	300	0
21	8	80	5
21	15	30	40

21	Underway		80
23	10	300	0
25	8	110	5
25	11	80	10
25	17	30	55
26	8	75	5
26	14	40	40
26	17	20	55
26	21	2	80
29	3	275	0
29	6	60	5
29	19	20	55
29	21	2	80
31	3	300	0
31	9	60	5
31	12	50	10
31	19	20	55
33	3	300	0
33	19	20	55
33	12	45	10
33	9	55	5
35	3	300	0
35	9	47	5
35	19	20	55
35	Underway		80
37	3	300	0
37	9	57	5
37	12	49	10

37	19	20	55
37	20	2	80
39	3	340	0
39	9	60	5
39	12	50	10
39	21	2	80
42	3	300	0
42	9	68	5
42	19	20	55
42	21	2	80
43	9	78	5
43	12	67	10
43	21	2	80
45	3	300	0
45	9	90	5
45	19	25	55
45	Underway		80
48	3	220	0
48	9	75	5
48	19	2	55
48	21	2	80

31.4 References

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Appendix A – RRS Discovery, cruise narrative D361 February 2-March 20 2011

All times in ship's time (GMT – 1 hour)

Thursday 3-2-2011

Arrival at vessel in morning by majority of science party. Off-loading of containers commenced. Installation of instruments in ship's laboratories and container laboratories commenced.

Friday 4-2-2011

Science party continued installing equipment.

Saturday 5-2-2011

Further installation of labs. All going smooth.

Science party stayed on ship at night.

Sunday 6-2-2010

Further installation of instruments and equipment. Airconditioning units in two of the containers were refilled with refrigerant.

Monday 7-2-2011

Departure of vessel delayed due to on-going repair to airconditioning unit in winch cab.

Ship departed at 1500 h. Calm seas. Ship is making good progress.

Tuesday 8-2-2011

Following propulsion problems, it was decided to return to Tenerife to trace problem and undertake repairs

Wednesday 9-2-2011

Return to Tenerife. Divers inspected propeller of vessel, but no rope/nets observed. Contractor from UK flown in to assess/repair vessel.

Thursday 10-2-2011

Contractor arrived, fault finding and repairs commenced. New electrical motor required and sourced.

Friday 11-2-2011

Part to be flown in from UK.

Saturday 12-2-2011

Part arrives and is fitted. Sailing at 1500 h.

Upon leaving port, fault returned and contractor was called back. Trials of engines was continued at sea.

Sunday 13-2-2011

Further repairs and fault finding whilst at sea.

Monday 14-2-2011

Further repairs and fault finding whilst at sea.

Tuesday 15-2-2011

Further repairs and fault finding whilst at sea.

Contractor leaves vessel. New diagnostic instruments ordered in UK.

Whilst the instruments are available from some firms for same day delivery, choice was made by NOC to order from RS Ltd with 3 days delivery time.

Wednesday 16-2-2011

Further fault finding whilst at sea.

Test SS CTD undertaken.

Thursday 17-2-2011

Further fault finding whilst at sea.

Test Ti CTD, nets and snowcatcher deployment undertaken.

Friday 18-2-2011

Further fault finding whilst at sea.

Test Ti CTD undertaken.

At 1136 h message from NOC arrived to inform us that the delivery date for the diagnostic instruments was 23rd February. Decision was made to sail without the instruments.

Saturday 19-2-2011

Transit to first station

Sunday 20-2-2011

Transit to first station

Monday 21-2-2011

Station 2 Senegal Shelf 12º35.00N 17º54.86W; water depth ca. 2650 m

2342 h Stainless CTD (500 m) Cast 05

Tuesday 22-2-2011

0113 h Ti CTD (2500 m) Cast 06

0340 h Depart station 2 for 10 nm steam

Station 3 Senegal Shelf 12º35.00N 17º43W; water depth ca. 1050 m

0526 h Nets 05

0559 h Stainless CTD (500 m) Cast 07

0650 h Deep nets cancelled

0711 h MSC (Marine snow catcher) 02

0750 h SAPS 02

1050 h Ti CTD (1000 m) Cast 08

1218 h Turbulence profiler 02

1412 h Depart station 3 for 7 nm steam

Station 4 Senegal Shelf 12º35.22 N 17º34 .10W; depth ca. 100 m

1547 h Stainless CTD (100 m) Cast 09

1654 h Turbulence profiler 03

Station 4 Senegal Shelf 12º36.75 N 17º34.4 W; depth ca. 50 m

1845 h Ti CTD (50 m) Cast 10 Miss firing of two out of 4 OTE bottles

1930 h Ti CTD (50 m) Cast 11

Strongly changing depths with movement of vessel in currents

Station 5 Senegal Shelf 12º36.22 N 17º34.31 W; depth ca. 150 m

2020 h Ti CTD (120 m) Cast 12

2338 h Depart station 5. Next station pre-dawn on Wednesday

Wednesday 23-2-2011

Station 6 12º34 N 18º50 W; depth ca. 4200 m

0400 h Nets 06

0430 h Stainless CTD (500 m) Cast 13

0600 h Ti CTD (full depth) Cast 14

0930 h Deep nets 07

1000 h Turbulence profiler 04

1200 h Depart

Thursday 24-2-2011

Station 7 12º34 N 21º49 W; depth ca. 4770 m

0500 h Nets 08

0539 h Stainless CTD (500 m) Cast 15

0710 h Ti CTD (full depth) Cast 16 bottles did not fire, operator error.

CTD is repeated

01200 h Ti CTD (full depth) Cast 17

1545 h Deep nets 09

1606 h Turbulence profiler 05

1800 h Depart

Friday 25-2-2011

Station 8 12º35 N 23º34 W; depth ca. 4910 m

0500 h Nets 10

0535 h Stainless CTD (500 m) Cast 18

0637 h Ti CTD (full depth) Cast 19. Only 2 bottles fired.

Cast was repeated to 1100 m depth

1116 h MSC (Marine snow catcher) 03. unsuccessful

1150 h Deep nets 11

1235 h SAPS 03

1511 h Ti CTD Cast 20

1648 h Turbulence profiler 06

1835 h Depart

Saturday 26-2-2011

Station 9 12º18 N 25º07 W; depth ca. 5000 m

0500 h Nets 12

0533 h Stainless CTD (500 m) Cast 21

0635 h Ti CTD (full depth) Cast 22

1100 h MSC (Marine snow catcher) 04. Operation cancelled due to poor fit of top and bottom part of the MSC. This was due to differential heating in the sun of the different parts.

1130 h Deep nets 13

1130 h Turbulence profiler 07

1330 h Depart for 5 days steaming

We have conducted underway sampling during the transect.

Thursday 03-3-2011

Station 10 07º13 S 25º0 W; depth ca. 5488 m

1400 h Stainless CTD (1000 m) Cast 23

1538 h Ti CTD (full depth) Cast 24

2049 h MSC (Marine snow catcher) 05

2100 h SAPS 04

2400 h Turbulence profiler 08

Friday 04-3-2011

0235 h Stainless CTD (500 m) Cast 25

0350 Nets 14 & Deep nets 15

0438 h Depart

The rest of the day we have steamed

We encountered rainstorms in the ITCZ in the early evening

Saturday 05-3-2011

Station 11 03º15 S 25º30 W; depth ca. 5557 m

0500 h Nets 16

0533 h Stainless CTD (500 m) Cast 26

0647 h Ti CTD (full depth) 27. Cast failed to fire. The CTD sensor data was fine. Reason for misfiring not found.

1100 h Deep nets 17

1130 h Turbulence profiler 09

1330 Depart for 2 h steam

1528 h Ti CTD (2000 m) 28. Cast worked well. This has been noted as station 11.5. **02º57 S 25º36 W**

1757 h Depart

Sunday 06-3-2011

Station 12 01º10 S 25º47 W; depth ca. 4930 m

0500 h Nets 18

0534 h Stainless CTD (500 m) Cast 29

0658 h Ti CTD (full depth) 30

1124 h MSC (Marine snow catcher) 06

1212 h Deep nets 19

1220 h Turbulence profiler 10

1420 h Depart

Monday 07-3-2011

Station 13 01º09 N 26º02 W; depth ca. 3700 m

0500 h Nets 20

0536 h Stainless CTD (500 m) Cast 31

0646 h Ti CTD (full depth) Cast 32

1018 h MSC (Marine snow catcher) 07

1032 h Deep nets 21

1050 h SAPS 05

1344 h Turbulence profiler 11 Profiler did not function. Operation aborted.

1445 h Depart

Tuesday 08-3-2011

Station 14 03º19 N 26º48 W; depth ca. 4200 m

0500 h Nets 22

0532 h Stainless CTD (500 m) Cast 33

0646 h Ti CTD (full depth) 34

1048 h Deep nets 23

1110 h Turbulence profiler 12. Operation aborted, as profiler did not function

1308 h Depart

Wednesday 09-3-2011

Station 15 05º39 N 27º30 W; depth ca. 4200 m

0500 h Nets 24

0534 h Stainless CTD (500 m) Cast 35

0651 h Ti CTD (full depth) 36

1026 h Deep nets 25

1050 h Turbulence profiler 13 . Operation aborted, as profiler did not function

1112 h Depart

Thursday 10-3-2011

Station 16 08º20 N 28º20 W; depth ca. 4700 m

0500 h Nets 26

0532 h Stainless CTD (500 m) Cast 37

0647 h Ti CTD (full depth) Cast 38

1100 h MSC (Marine snow catcher) 08

1113 h Deep nets 27

1126 h SAPS 06

1425 h Turbulence profiler 14. Operation aborted due to instrument failure.

1432 h Depart

Friday 11-3-2011

Station 17 10º37 N 28º43 W; depth ca. 5600 m

0500 h Nets 28

0528 h Stainless CTD (500 m) Cast 39

0649 h Ti CTD (full depth) 40

1112 h MSC (Marine snow catcher) 09

1140 h Deep nets 29

1213 h Turbulence profiler 15

1400 h Depart

Friday 11-3-2011

Station 18 12º00 N 29º00 W; depth ca. 5660 m

2250 h Turbulence profiler 16

Saturday 12-3-2011

0105 h Ti CTD (full depth) 41

0543 h Nets 30

0613 h Stainless CTD (500 m) Cast 42

0713 h Deep nets 31

0735 h Depart

Sunday 13-3-2011

Station 19 15º30 N 28º46 W; depth ca. 5000 m

0500 h Nets 32

0532 h Stainless CTD (500 m) Cast 43

0644 h Ti CTD (full depth) Cast 44

1058 h MSC (Marine snow catcher) 10

1110 h Deep nets 33

1130 h SAPS 07

1417 h Turbulence profiler 17

1600 h Depart

Monday 14-3-2011

Station 20 17º23 N 28º23 W; depth ca. 4660 m

0500 h Nets 34

0600 h Stainless CTD (500 m) Cast 45

0714h Ti CTD (full depth) 46. Operation aborted due to winch problems.

0818 h Turbulence profiler 18

1207 h Deep nets 35

1242 h Ti CTD (full depth) 47

1637 h Depart

Tuesday 15-3-2011

Station 21 19º10 N 28º07 W; depth ca. 4600 m

0500 h Nets 36

0537 h Stainless CTD (500 m) Cast 48

0653 h Turbulence profiler 19

0910 h Stainless CTD (1000 m) Cast 49

1040 h MSC 11

1055 h Deep nets 37

1115 h Ti CTD (full depth) 50 cancelled due to winch problems

1120 h SAPS 08

1406 h Depart

Saturday 19-3-2011 – Tenerife

Appendix B – Trace metal towed fish sampling log

Fish #	Date	Julian day	Time (GMT)	lat N	long E	Dis. TM	Total TM	Nuts	Chl a	DNA	IO3	dCo	Pb iso	Cd iso	Fe spp.	DOP/EHP	Mark	Heme/POC/PON	Carboy	Additional
001	08/02/2011	39	08:06:00			x	x	x	x	x										
002	08/02/2011	39	18:23:00			x	x	x	x	x										
003	08/02/2011	39	18:52:00																	
004	18/02/2011	49	16:02:00	27.04	-16.45	x	x	x	x	x										
005	18/02/2011	49	18:00:00	26.68	-16.53	x		x	x	x								x		
006	18/02/2011	49	20:00:00	26.32	-16.63	x	x	x	x	x										
007	18/02/2011	49	22:10:00	25.93	-16.75	x	x	x	x	x								x		
008	19/02/2011	50	00:00:00	25.61	-16.84	x		x	x	x										
009	19/02/2011	50	02:00:00	25.27	-16.94	x	x	x	x	x										
010	19/02/2011	50	03:55:00	24.92	-17.03	x		x	x	x										
011	19/02/2011	50	06:30:00	24.45	-17.18	x	x	x	x	x										
012	19/02/2011	50	08:00:00	24.18	-17.25	x		x	x	x								x		
013	19/02/2011	50	10:05:00	23.85	-17.34	x	x	x	x	x										
014	19/02/2011	50	11:58:00	23.52	-17.42	x		x	x	x								x		
015	19/02/2011	50	14:02:00	23.16	-17.53	x	x	x	x	x										
016	19/02/2011	50	16:00:00	22.81	-17.62	x		x	x	x								x		
017	19/02/2011	50	17:55:00	22.46	-17.71	x	x	x	x	x										
018	19/02/2011	50	20:05:00	22.07	-17.82	x	x	x	x	x								x		
019	19/02/2011	50	21:55:00	21.74	-17.91	x		x	x	x								x		
020	19/02/2011	50	23:56:00	21.39	-18.01	x	x	x	x	x										
021	20/02/2011	51	03:55:00	20.67	-18.15	x		x	x	x										
022	20/02/2011	51	05:57:00	20.28	-18.15	x	x	x	x	x										
023	20/02/2011	51	08:03:00	19.89	-18.16	x		x	x	x								x		
024	20/02/2011	51	10:05:00	19.60	-18.15	x	x	x	x	x										
025	20/02/2011	51	11:54:00	19.29	-18.16	x		x	x	x								x		
026	20/02/2011	51	14:05:00	18.90	-18.16	x	x	x	x	x										
027	20/02/2011	51	16:00:00	18.55	-18.16	x		x	x	x								x		
028	20/02/2011	51	18:00:00	18.20	-18.16	x	x	x	x	x										
029	20/02/2011	51	20:00:00	17.86	-18.15	x		x	x	x								x		
030	20/02/2011	51	22:15:00	17.48	-18.16	x	x	x	x	x								x		
031	21/02/2011	52	01:00:00	16.99	-18.15	x		x	x	x										
032	21/02/2011	52	03:00:00	16.61	-18.15	x	x	x	x	x										
033	21/02/2011	52	04:55:00	16.23	-18.17	x		x	x	x										

034	21/02/2011	52	07:00:00	15.80	-18.16	x	x	x	x	x									
035	21/02/2011	52	09:02:00	15.38	-18.17	x		x	x	x									x
036	21/02/2011	52	11:05:00	15.08	-18.14	x	x	x	x	x									
037	21/02/2011	52	12:53:00	14.73	-18.16	x		x	x	x									x
038	21/02/2011	52	14:26:00	14.43	-18.13	x	x	x	x	x									
039	21/02/2011	52	15:00:00	14.32	-18.11	x	x	x	x	x									
040	21/02/2011	52	16:55:00	13.97	-18.07	x		x	x	x									x
041	21/02/2011	52	19:00:00	13.57	-18.02	x	x	x	x	x									
042	21/02/2011	52	21:00:00	13.20	-17.98	x		x	x	x									x
043	22/02/2011	53	21:50:00	12.59	-17.60	x	x	x			x	x	x						
044	22/02/2011	53	22:10:00	12.59	-17.65	x	x	x			x	x							
045	22/02/2011	53	22:30:00	12.59	-17.71	x	x	x			x	x							
046	22/02/2011	53	22:50:00	12.59	-17.77	x	x	x			x	x							
047	22/02/2011	53	23:10:00	12.59	-17.83	x	x	x			x	x							
048	22/02/2011	53	23:30:00	12.58	-17.89	x	x	x			x	x							
049	22/02/2011	53	23:50:00	12.59	-17.95	x	x	x		x	x	x							
050	23/02/2011	54	00:55:00	12.58	-18.14	x	x	x			x	x							
051	23/02/2011	54	01:53:00	12.58	-18.31	x	x	x	x	x	x	x							
052	23/02/2011	54	03:02:00	12.58	-18.51	x	x	x	x		x	x							
053	23/02/2011	54	04:35:00	12.58	-18.79	x	x	x	x		x	x							
054	23/02/2011	54	13:20:00	12.54	-18.89	x	x	x	x		x	x							
055	23/02/2011	54	15:02:00	12.59	-19.17	x		x	x	x		x				x			x
056	23/02/2011	54	17:03:00	12.59	-19.52	x	x	x	x	x		x							
057	23/02/2011	54	19:00:00	12.59	-19.87	x		x	x	x		x				x			
058	23/02/2011	54	21:05:00	12.58	-20.25	x	x	x	x	x		x							x
059	23/02/2011	54	23:08:00	12.59	-20.62	x		x	x			x				x			
060	24/02/2011	55	00:57:00	12.59	-20.95	x	x	x	x			x							
061	24/02/2011	55	03:05:00	12.58	-21.34	x		x	x	x		x							
062	24/02/2011	55	05:35:00	12.58	-21.78	x	x	x	x	x	x	x			x		1L F, 1L UF		
063	24/02/2011	55	21:01:00	12.58	-22.15	x		x	x	x		x							x
064	24/02/2011	55	23:02:00	12.59	-22.51	x	x	x	x	x		x				x			
065	25/02/2011	56	01:00:00	12.58	-22.86	x		x	x	x		x							
066	25/02/2011	56	03:00:00	12.58	-23.21	x	x	x	x	x		x				x			
067	25/02/2011	56	05:35:00	12.58	-23.53	x	x	x	x	x	x	x			x		1L F, 1L UF		
068	25/02/2011	56	21:00:00	12.57	-23.77	x		x	x	x	x	x				x			x
069	25/02/2011	56	23:10:00	12.50	-24.10	x	x	x	x	x		x				x			
070	26/02/2011	57	01:00:00	12.44	-24.38	x		x	x	x		x							
071	26/02/2011	57	03:00:00	12.37	-24.68	x	x	x	x	x		x				x			

072	26/02/2011	57	05:25:00	12.31	-25.06	x	x	x	x		x	x		x		1L F, 1L UF			
073	26/02/2011	57	17:00:00	12.20	-25.64	x		x	x	x	x	x						x	
074	26/02/2011	57	19:02:00	11.95	-25.75	x	x	x	x	x		x							
075	26/02/2011	57	21:05:00	11.60	-25.74	x		x	x	x		x						x	
076	26/02/2011	57	23:00:00	11.27	-25.72	x	x	x	x	x		x							
077	27/02/2011	58	00:55:00	10.95	-25.71	x		x	x	x		x							
078	27/02/2011	58	02:55:00	10.60	-25.69	x	x	x	x	x									
079	27/02/2011	58	05:00:00	10.24	-25.68	x		x	x	x		x							
080	27/02/2011	58	06:55:00	9.91	-25.67	x	x	x	x	x		x							
081	27/02/2011	58	09:05:00	9.53	-25.66	x		x	x	x								x	
082	27/02/2011	58	11:35:00	9.30	-25.65			x	x			x							
083	27/02/2011	58	13:00:00	9.04	-25.64	x	x	x	x	x		x						x	
084	27/02/2011	58	15:01:00	8.67	-25.62	x		x	x	x		x							
085	27/02/2011	58	17:15:00	8.26	-25.61	x	x	x	x	x		x						x	
086	27/02/2011	58	19:03:00	7.94	-25.60	x		x	x	x		x							
087	27/02/2011	58	21:05:00	7.57	-25.58	x	x	x	x	x		x						x	
088	27/02/2011	58	23:05:00	7.21	-25.57	x		x	x	x		x						x	
089	28/02/2011	59	01:00:00	6.87	-25.56	x	x	x	x	x		x							
090	28/02/2011	59	02:45:00	6.55	-25.54	x		x	x	x		x							
091	28/02/2011	59	05:00:00	6.15	-25.52	x	x	x	x	x		x							
092	28/02/2011	59	06:58:00	5.81	-25.51	x		x	x	x		x							
093	28/02/2011	59	08:58:00	5.44	-25.50	x	x	x	x	x		x						x	
094	28/02/2011	59	11:00:00	5.08	-25.48	x		x	x	x		x							
095	28/02/2011	59	12:56:00	4.73	-25.47	x	x	x	x	x		x			x			x	
096	28/02/2011	59	15:04:00	4.34	-25.45	x		x	x	x		x							
097	28/02/2011	59	16:57:00	4.00	-25.44	x	x	x	x	x		x						x	
098	28/02/2011	59	18:59:00	3.65	-25.43	x		x	x			x							
099	28/02/2011	59	21:00:00	3.30	-25.41	x	x	x	x	x		x						x	
100	28/02/2011	59	23:00:00	2.95	-25.40	x		x	x	x		x						x	
101	01/03/2011	60	01:00:00	2.61	-25.39	x	x	x	x	x		x							
102	01/03/2011	60	02:58:00	2.26	-25.38	x		x	x	x		x							
103	01/03/2011	60	05:55:00	1.76	-25.35	x	x	x	x	x		x							
104	01/03/2011	60	07:00:00	1.57	-25.35	x		x	x	x		x							
105	01/03/2011	60	08:59:00	1.24	-25.34	x	x	x	x	x		x						x	
106	01/03/2011	60	11:30:00	0.83	-25.32	x		x	x	x		x							
107	01/03/2011	60	13:01:00	0.58	-25.31	x	x	x	x	x		x							
108	01/03/2011	60	15:05:00	0.24	-25.29	x		x	x	x		x							
109	01/03/2011	60	17:10:00	-0.09	-25.28	x	x	x	x	x		x							

110	01/03/2011	60	18:58:00	-0.38	-25.26	x		x	x	x	x					
111	01/03/2011	60	21:05:00	-0.71	-25.26	x	x	x	x	x	x					x
112	01/03/2011	60	23:00:00	-1.03	-25.27	x		x	x	x	x					x
113	02/03/2011	61	00:58:00	-1.35	-25.25	x	x	x	x	x	x					x
114	02/03/2011	61	03:02:00	-1.70	-25.23	x		x	x	x	x					
115	02/03/2011	61	05:03:00	-2.05	-25.21	x	x	x	x	x	x					
116	02/03/2011	61	07:00:00	-2.37	-25.19	x		x	x	x	x		x	1 L UF		
117	02/03/2011	61	08:58:00	-2.68	-25.17	x	x	x	x	x	x					x
118	02/03/2011	61	10:59:00	-2.99	-25.16	x		x	x	x	x					
119	02/03/2011	61	13:03:00	-3.31	-25.15	x	x	x	x	x	x					x
120	02/03/2011	61	14:37:00	-3.54	-25.15	60ml										
121	02/03/2011	61	15:03:00	-3.61	-25.15	x + 60 ml		x	x	x	x					
122	02/03/2011	61	16:05:00	-3.76	-25.14	60ml										
123	02/03/2011	61	17:00:00	-3.90	-25.13	x + 60 ml	x	x	x	x	x					x
124	02/03/2011	61	17:30:00	-3.97	-25.13	60 ml										
125	02/03/2011	61	18:02:00	-4.04	-25.13	60 ml										
126	02/03/2011	61	18:32:00	-4.12	-25.12	60 ml										
127	02/03/2011	61	18:55:00	-4.18	-25.12	x + 60 ml		x	x	x	x					x
128	02/03/2011	61	19:30:00	-4.26	-25.12	60 ml										
129	02/03/2011	61	20:01:00	-4.34	-25.11	60 ml										
130	02/03/2011	61	20:32:00	-4.42	-25.11	60 ml										
131	02/03/2011	61	20:58:00	-4.49	-25.11	x + 60 ml	x	x	x	x	x					
132	02/03/2011	61	21:32:00	-4.57	-25.10	60 ml										
133	02/03/2011	61	22:03:00	-4.65	-25.09	60 ml										
134	02/03/2011	61	22:30:00	-4.72	-25.09	60 ml										
135	02/03/2011	61	22:42:00	-4.75	-25.09			x								
136	02/03/2011	61	23:00:00	-4.80	-25.08	x + 60 ml		x	x	x	x					x
137	02/03/2011	61	23:29:00	-4.88	-25.08	60 ml		x								
138	03/03/2011	62	00:00:00	-4.96	-25.07	60 ml		x								
139	03/03/2011	62	00:30:00	-5.03	-25.07	60 ml		x								
140	03/03/2011	62	00:59:00	-5.11	-25.07	x + 60 ml	x	x	x	x	x					
141	03/03/2011	62	01:29:00	-5.19	-25.06	60 ml		x								
142	03/03/2011	62	02:00:00	-5.27	-25.06	60 ml		x								
143	03/03/2011	62	02:30:00	-5.35	-25.06	60 ml		x								
144	03/03/2011	62	02:55:00	-5.42	-25.06	x + 60 ml		x	x	x	x					
145	03/03/2011	62	03:27:00	-5.50	-25.06	60 ml		x								
146	03/03/2011	62	05:01:00	-5.74	-25.05	x + 60 ml	x	x	x	x	x					
147	03/03/2011	62	07:03:00	-6.06	-25.03	x + 60 ml		x	x	x	x		x	1 L UF		

148	03/03/2011	62	09:00:00	-6.36	-25.02	x	x	x	x	x	x							x	
149	03/03/2011	62	10:55:00	-6.65	-25.02	x		x	x	x	x								
150	03/03/2011	62	12:58:00	-6.96	-25.00	x	x	x	x	x	x							x	
151	03/03/2011	62	14:35:00	-7.20	-24.99	x + 60 ml	x	x	x		x							x	
152	04/03/2011	63	07:01:00	-7.01	-25.02	x		x	x		x				x		2L UF	x	NOC
153	04/03/2011	63	08:58:00	-6.68	-25.05	x	x	x	x	x	x							x	2x 25L UoP
154	04/03/2011	63	11:00:00	-6.34	-25.08	x		x	x	x	x								
155	04/03/2011	63	13:00:00	-6.01	-25.12	x	x	x	x	x	x							x	
156	04/03/2011	63	15:00:00	-5.67	-25.15	x		x	x	x	x					x			
157	04/03/2011	63	16:58:00	-5.33	-25.19	x	x	x	x	x	x							x	
158	04/03/2011	63	19:00:00	-4.99	-25.23	x		x	x	x	x					x			
159	04/03/2011	63	20:05:00	-4.81	-25.25	x	x	x		x	x								
160	04/03/2011	63	21:10:00	-4.64	-25.27	x	x	x	x		x							x	
161	04/03/2011	63	23:02:00	-4.33	-25.30	x		x	x	x	x					x			
162	05/03/2011	64	01:00:00	-4.03	-25.34	x	x	x	x	x	x								
163	05/03/2011	64	03:02:00	-3.71	-25.40	x		x	x	x	x					x			
164	05/03/2011	64	05:30:00	-3.31	-25.49	x	x	x	x		x	x	x	x			2L UF, 2L F		
165	05/03/2011	64	16:10:00	-3.00	-25.60	x	x				x								
166	05/03/2011	64	21:14:00	-2.60	-25.66	x			x	x	x							x	
167	05/03/2011	64	22:55:00	-2.32	-25.71	x	x	x	x	x	x					x			
168	06/03/2011	65	01:06:00	-1.96	-25.78	x		x	x	x	x								
169	06/03/2011	65	03:02:00	-1.63	-25.80	x	x	x	x	x	x					x			
170	06/03/2011	65	05:33:00	-1.22	-25.79	x	x	x	x		x	x	x	x			2L UF, 2L F		
171	06/03/2011	65	17:00:00	-0.90	-25.81	x		x	x	x	x							x	
172	06/03/2011	65	18:57:00	-0.60	-25.85	x	x	x	x	x	x					x			
173	06/03/2011	65	21:00:00	-0.27	-25.88	x		x	x	x	x							x	
174	06/03/2011	65	23:00:00	0.05	-25.91	x	x	x	x	x	x					x			
175	07/03/2011	66	00:59:00	0.37	-25.96	x		x	x	x	x								
176	07/03/2011	66	02:55:00	0.68	-26.00	x	x	x	x	x	x					x			
177	07/03/2011	66	05:30:00	1.11	-26.04	x	x	x	x		x				x		2L UF, 2L F		
178	07/03/2011	66	17:00:00	1.34	-26.12	x		x	x	x	x							x	
179	07/03/2011	66	19:00:00	1.64	-26.23	x	x	x	x	x	x					x		x	
180	07/03/2011	66	20:57:00	1.94	-26.34	x		x	x	x	x							x	
181	07/03/2011	66	23:00:00	2.26	-26.43	x	x	x	x	x	x					x			
182	08/03/2011	67	01:00:00	2.58	-26.53	x		x	x	x	x								
183	08/03/2011	67	03:00:00	2.90	-26.65	x	x	x	x	x	x					x			
184	08/03/2011	67	05:30:00	3.29	-26.80	x	x	x	x		x				x		2L UF, 2L F		
185	08/03/2011	67	15:03:00	3.53	-26.88	x		x	x	x	x							x	

186	08/03/2011	67	17:02:00	3.82	-26.97	x	x	x	x	x		x							x		
187	08/03/2011	67	19:01:00	4.11	-27.05	x		x	x	x		x									
188	08/03/2011	67	21:06:00	4.42	-27.14	x	x	x	x	x		x							x		
189	08/03/2011	67	23:00:00	4.70	-27.23	x		x	x	x		x				x					
190	09/03/2011	68	00:57:00	4.98	-27.31	x	x	x	x	x		x									
191	09/03/2011	68	03:20:00	5.31	-27.40	x		x	x	x		x				x					
192	09/03/2011	68	05:30:00	5.61	-27.48	x	x	x	x			x			x		2L UF, 2L F				
193	09/03/2011	68	15:03:00	6.09	-27.62	x		x	x	x		x							x		
194	09/03/2011	68	17:05:00	6.39	-27.70	x	x	x	x	x		x							x		
195	09/03/2011	68	19:05:00	6.69	-27.79	x		x	x			x				x			x		
196	09/03/2011	68	21:05:00	7.00	-27.89	x	x	x	x	x		x							x		
197	09/03/2011	68	23:02:00	7.30	-27.99	x		x	x	x		x				x					
198	10/03/2011	69	00:59:00	7.60	-28.09	x	x	x	x	x		x									
199	10/03/2011	69	03:15:00	7.94	-28.19	x		x	x	x		x				x					
200	10/03/2011	69	05:30:00	8.28	-28.31	x	x	x	x			x	x	x	x		2L UF, 2L F				
201	10/03/2011	69	17:03:00	8.56	-28.37	x		x	x	x		x									
202	10/03/2011	69	19:00:00	8.86	-28.42	x	x	x	x	x		x				x			x		
203	10/03/2011	69	21:03:00	9.19	-28.47	x		x	x	x		x							x		
204	10/03/2011	69	23:02:00	9.51	-28.53	x	x	x	x	x		x				x					
205	11/03/2011	70	00:58:00	9.82	-28.58	x		x	x	x		x									
206	11/03/2011	70	03:00:00	10.15	-28.64	x	x	x	x	x		x				x					
207	11/03/2011	70	05:30:00	10.56	-28.72	x	x	x	x			x			x		2L UF, 2L F				1L F Claire
208	11/03/2011	70	16:58:00	10.93	-28.79	x		x	x	x		x							x		
209	11/03/2011	70	19:12:00	11.30	-28.86	x	x	x	x	x		x				x			x		
210	11/03/2011	70	21:10:00	11.61	-28.93	x		x	x	x		x							x		
211	11/03/2011	70	22:55:00	11.90	-28.98	x	x	x	x	x	x	x	x		x		2L				2L Joe, 1L F Claire
212	12/03/2011	71	10:58:00	12.45	-28.97	x		x	x	x		x							x		
213	12/03/2011	71	13:04:00	12.80	-28.96	x	x	x	x	x		x							x		
214	12/03/2011	71	15:05:00	13.13	-28.93	x		x	x	x		x				x			x		
215	12/03/2011	71	16:59:00	13.45	-28.92	x	x	x	x	x		x							x		
216	12/03/2011	71	19:05:00	13.80	-28.90	x		x	x	x		x				x			x	NOC	
217	12/03/2011	71	21:00:00	14.12	-28.89	x	x	x	x	x		x							x		
218	12/03/2011	71	23:00:00	14.45	-28.87	x		x	x	x		x				x					
219	13/03/2011	72	01:10:00	14.78	-28.85	x	x	x	x	x		x									
220	13/03/2011	72	03:03:00	15.08	-28.84	x		x	x	x		x									
221	13/03/2011	72	05:30:00	15.45	-28.79	x	x	x	x			x			x		2L UF, 2L F				1L F Claire
222	13/03/2011	72	19:10:00	15.81	-28.73	x		x	x	x		x				x			x		
223	13/03/2011	72	21:04:00	16.09	-28.67	x	x	x	x	x		x							x		

224	13/03/2011	72	22:58:00	16.36	-28.60	x		x	x	x	x				x					
225	14/03/2011	73	00:54:00	16.66	-28.54	x	x	x	x	x	x									
226	14/03/2011	73	03:03:00	16.98	-28.48	x		x	x	x	x				x					
227	14/03/2011	73	05:40:00	17.37	-28.39	x	x	x	x		x	x	x	x		2L UF, 2L F				1L F Claire
228	14/03/2011	73	21:01:00	17.89	-28.31	x		x	x	x	x						x			
229	14/03/2011	73	23:15:00	18.19	-28.24	x	x	x	x	x	x				x					
230	15/03/2011	74	02:00:00	18.57	-28.21	x		x	x	x	x									
231	15/03/2011	74	05:25:00	19.04	-28.14	x	x	x	x	x	x			x		2L UF, 2L F				1L F Claire
232	15/03/2011	74	17:05:00	19.38	-27.91	x	x		x								x			
233	15/03/2011	74	19:00:00	19.56	-27.68	x	x		x								x			
234	15/03/2011	74	20:59:00	19.74	-27.44	x			x								x			

Appendix C – Ti CTD sampling log

													Station 2															
Lat:	12o35.415	**CTD no.**	6					**Depth**	2656		**Date:**	22/02/2011																
Long:	17o54.991																											
Bottle no.	**Depth (m)**	**Label ID**	**O2**	**Alk**	**Fe (II)**	**H2O2**	**Nuts**	**Total Diss**	**Ship Al/Fe**	**NOC TM**	**UoP TM**	**Partic TM**	**REE/Th**	**REE**	**N iso**	**Fe iso**	**Pb Iso**	**Cd iso**	**Cr iso**	**Si iso**	**Pa/Th**	**Fe sol**	**Fe Sp**	**DOC**	**DOP**	**Ba**	**IO3**	**Sal**
1																												
2																												
3																												
4																												
5																												
6																												
7																												
8																												
9																												
10	2625	6-10	x				x	x	x	x	x	x		x		x								x	x	x	x	x
11	1999	6-11		x	x	x	x	x	x	x	x	x		x										x	x	x	x	x
12	1699	6-12	x				x	x	x	x	x	x		x		x											x	
13	1399	6-13					x	x	x	x	x	x		x					x				x	x	x	x	x	x
14	1099	6-14	x				x	x	x	x	x	x		x		x							x	x	x	x	x	x
25	900	6-15			x	x	x	x	x	x	x	x		x	x									x	x	x	x	x
16	750	6-16	x		x	x	x	x	x	x	x	x		x		x							x	x	x	x	x	x
26	599	6-17			x	x	x	x	x	x	x	x		x	x				x				x	x	x	x	x	x
18	499	6-18	x		x	x	x	x	x	x	x	x	x			x										x	x	x
19	399	6-19			x	x	x	x	x	x	x	x			x								x			x	x	x
20	299	6-20			x	x	x	x	x	x	x	x				x			x				x			x	x	x
21	198	6-21			x	x	x	x	x	x	x	x	x		x								x			x	x	x
22	99	6-22			x	x	x	x	x	x	x	x	x		x	x							x			x	x	x
23	49	6-23	x		x	x	x	x	x	x	x	x											x			x	x	x
24	24	6-24			x	x	x	x	x	x	x	x	x		x	x			x				x			x	x	x
Notes:																												

													Station 3															
Lat:	12o36.556	**CTD no.**	8					**Depth**	1041		**Date:**	22/02/2011																
Long:	17o43.018																											
Bottle no.	**Depth (m)**	**Label ID**	**O2**	**Alk**	**Fe (II)**	**H2O2**	**Nuts**	**Total Diss**	**Ship Al/Fe**	**NOC TM**	**UoP TM**	**Partic TM**	**REE/Th**	**REE**	**N iso**	**Fe iso**	**Pb Iso**	**Cd iso**	**Cr iso**	**Si iso**	**Pa/Th**	**Fe sol**	**Fe Sp**	**DOC**	**DOP**	**Ba**	**IO3**	**Sal**
1																												
2																												
3																												
4																												
5																												
6																												
7																												
8																												
9																												
10																												
11																												
12																												
13	1002	8-13	x	x			x	x	x	x	x	x		x		x			x				x	x	x	x	x	x
14	899	8-14		x			x	x	x	x	x	x		x		x							x	x	x	x	x	x
25	799	8-15		x			x	x	x	x	x	x		x	x									x	x	x	x	x	x
16	699	8-16	x	x			x	x	x	x	x	x		x		x							x	x	x	x	x	x
26	599	8-17		x			x	x	x	x	x	x		x	x	x			x				x	x	x	x	x	x
18	500	8-18	x				x	x	x	x	x	x	x			x										x	x	x
19	400	8-19					x	x	x	x	x	x			x	x							x			x	x	x
20	300	8-20					x	x	x	x	x	x				x			x				x			x	x	x
21	199	8-21	x				x	x	x	x	x	x	x		x	x							x			x	x	x
22	100	8-22					x	x	x	x	x	x	x		x								x			x	x	x
23	49	8-23	x				x	x	x	x	x	x											x			x	x	x
24	24	8-24					x	x	x	x	x	x	x		x				x				x			x	x	x
Notes:																												

Station 4

Lat:	12o36.50	**CTD no.**	11					**Depth**	51		**Date:**	22/02/2011																		
Long:	17o34.344																													
Bottle no.	**Depth (m)**	**Label ID**	**O2**	**Alk**	**Fe (II)**	**H2O2**	**Nuts**	**Total Diss**	**Ship Al/Fe**	**NOC TM**	**UoP TM**	**Partic TM**	**REE/Th**	**REE**	**N iso**	**Fe iso**	**Pb Iso**	**Cd iso**	**Cr iso**	**Si iso**	**Pa/Th**	**Fe sol**	**Fe Sp**	**DOC**	**DOP**	**Ba**	**IO3**	**Sal**
1																														
2																														
3																														
4																														
5																														
6																														
7																														
8																														
9	49	11-9	x	x			x	x	x	x	x	x	x		x									x			x	x	
10	40	11-10	x	x			x	x	x	x	x	x	x		x									x			x	x	
11	38	11-11	x	x			x	x	x	x	x	x	x		x									x			x	x	
12	25	11-12	x	x			x	x	x	x	x	x	x		x									x			x	x	
13																														
14																														
25																														
16																														
26																														
18																														
19																														
20																														
21																														
22																														
23																														
24																														

Notes:

Station 5

Lat:	12o35.227	**CTD no.**	12					**Depth**	164		**Date:**	22/02/2011																		
Long:	17o34.309																													
Bottle no.	**Depth (m)**	**Label ID**	**O2**	**Alk**	**Fe (II)**	**H2O2**	**Nuts**	**Total Diss**	**Ship Al/Fe**	**NOC TM**	**UoP TM**	**Partic TM**	**REE/Th**	**REE**	**N iso**	**Fe iso**	**Pb Iso**	**Cd iso**	**Cr iso**	**Si iso**	**Pa/Th**	**Fe sol**	**Fe Sp**	**DOC**	**DOP**	**Ba**	**IO3**	**Sal**
1																														
2																														
3																														
4																														
5																														
6																														
7																														
8																														
9																														
10																														
11																														
12																														
13	107	17-13	x				x	x	x	x	x	x	x		x	x											x	x	
14	93	17-14															x	x												
25	80	17-15	x				x	x	x	x	x	x			x	x											x	x	
16	78	17-16															x	x												
26	66	17-17	x				x	x	x	x	x	x			x	x											x	x	
18	64	17-18															x	x												
19	51	17-19					x	x	x	x	x	x	x		x	x											x	x	
20	49	17-20															x	x												
21	36	17-21	x				x	x	x	x	x	x	x		x	x											x	x	
22	34	17-22															x	x												
23	26	17-23	x				x	x	x	x	x	x	x		x	x											x	x	
24	24	17-24															x	x												

Notes:

Station 6

Lat:	12o34.455	**CTD no.**	14					**Depth**	4778		**Date:**	23/02/2011																	
Long:	21o49.377																												
Bottle no.	**Depth (m)**	**Label ID**	**O2**	**Alk**	**Fe (II)**	**H2O2**	**Nuts**	**Total Diss**	**Ship Al/Fe**	**NOC TM**	**UoP TM**	**Partic TM**	**REE/Th**	**REE**	**N iso**	**Fe iso**	**Pb Iso**	**Cd iso**	**Cr iso**	**Si iso**	**Pa/Th**	**Fe sol**	**Fe Sp**	**DOC**	**DOP**	**Ba**	**IO3**	**Sal**
1	4196	14-1	x	x			x	x	x	x	x	x		x	**x**								x	x	**x**	x	x	x
2	4000	14-2		x			x	x	x	x	x	x			x									x	x	x	x	x
3	3498	14-3																										
4	2998	14-4	x	x			x	x	x	x	x	x		x										x	x	x	x	x
5	2699	14-5		x			x	x	x	x	x	x		x	x								x	x	x	x	x	x
6	2500	14-6	x	x			x	x	x	x	x	x		x										x	x	x	x	x
7	2299	14-7		x			x	x				x		x	x								x	x	x	x	x	x
8	1999	14-8		x			x	x	x	x	x	x		x										x	x	x	x	x
9	1699	14-9																										
10	1499	14-10	x	x			x	x	x	x	x	x		x										x	x	x	x	x
11	1098	14-11		x			x	x	x	x	x	x		x	x								x	x	x	x	x	x
12	899	14-12		x	x	x	x	x	x	x	x	x		x										x	x	x	x	x
13	749	14-13		x			x	x	x	x	x	x		x	x									x	x	x	x	x
14	599	14-14	x	x	x	x	x	x	x	x	x	x		x									x	x	x	x	x	
25	498	14-15					x	x	x	x	x	x		x	x									x	x	x	x	x
16	400	14-16			x	x	x	x	x	x	x	x														x	x	x
26	299	14-17					x	x	x	x	x	x			x								x			x	x	x
18	198	14-18	x		x	x	x	x	x	x	x	x			x											x	x	
19	149	14-19			x	x	x	x	x	x	x	x			x								x			x	x	x
20	100	14-20					x	x	x	x	x	x														x	x	x
21	75	14-21	x		x	x	x	x	x	x	x	x			x								x			x	x	x
22	49	14-22					x	x	x	x	x	x	x													x	x	x
23	34	14-23	x				x	x	x	x	x	x			x								x			x	x	x
24	24	14-24			x	x	x	x	x	x	x	x	x													x	x	x

Notes: Bottle 9 did not close
Bottle 3 leaked so was not sampled

Station 7

Lat:	12o34.455	**CTD no.**	17					**Depth**	4778		**Date:**	24/02/2011																	
Long:	21o49.377																												
Bottle no.	**Depth (m)**	**Label ID**	**O2**	**Alk**	**Fe (II)**	**H2O2**	**Nuts**	**Total Diss**	**Ship Al/Fe**	**NOC TM**	**UoP TM**	**Partic TM**	**REE/Th**	**REE**	**N iso**	**Fe iso**	**Pb Iso**	**Cd iso**	**Cr iso**	**Si iso**	**Pa/Th**	**Fe sol**	**Fe Sp**	**DOC**	**DOP**	**Ba**	**IO3**	**Sal**
1	4773	17-1		x			x	x	x	x	x	x		x					x				x	x	**x**	x	x	x
2	4500	17-2		x			x		x	x	x	x		x	x									x	x	x	x	x
3	4000	17-3		x			x	x	x	x	x	x		x										x	x	x	x	x
4	3499	17-4	x	x			x		x	x	x	x		x	x									x	x	x	x	x
5	2999	17-5		x			x	x	x	x	x	x		x									x	x	x	x	x	x
6	2699	17-6	x	x			x		x	x	x	x		x	x									x	x	x	x	x
7	2499	17-7		x			x	x	x	x	x	x		x									x	x	x	x	x	x
8	2300	17-8	x	x			x		x	x	x	x		x	x									x	x	x	x	x
9	1999	17-9	x	x			x	x	x	x	x	x		x									x	x	x	x	x	x
10	1700	17-10		x			x		x	x	x	x		x	x				x					x	x	x	x	x
11	1499	17-11		x			x		x	x	x	x		x									x	x	x	x	x	x
12	1099	17-12		x	x	x	x		x	x	x	x		x	x									x	x	x	x	x
13	899	17-13		x			x	x	x	x	x	x		x					x					x	x	x	x	x
14	749	17-14	x	x	x	x	x		x	x	x	x		x	x								x	x	x	x	x	x
25	599	17-15					x	x	x	x	x	x		x												x	x	x
16	499	17-16			x	x	x		x	x	x	x			x											x	x	x
26	400	17-17					x	x	x	x	x	x							x				x			x	x	x
18	299	17-18	x		x	x	x		x	x	x	x	x		x											x	x	
19	199	17-19			x	x	x	x	x	x	x	x											x			x	x	x
20	149	17-20					x		x	x	x	x	x		x				x							x	x	x
21	100	17-21	x		x	x	x	x	x	x	x	x											x			x	x	x
22	74	17-22					x		x	x	x	x	x		x											x	x	x
23	49	17-23	x				x	x	x	x	x	x											x			x	x	x
24	24	17-24			x	x	x		x	x	x	x	x		x				x							x	x	x

Notes:

Station 8 a

Lat:	12o35.092	**CTD no.**	19					**Depth**	4942		**Date:**	25/02/2011																		
Long:	23o34.628																													
Bottle no.	**Depth (m)**	**Label ID**	**O2**	**Alk**	**Fe (II)**	**H2O2**	**Nuts**	**Total Diss**	**Ship Al/Fe**	**NOC TM**	**UoP TM**	**Partic TM**	**REE/Th**	**REE**	**N iso**	**Fe iso**	**Pb Iso**	**Cd iso**	**Cr iso**	**Si iso**	**Pa/Th**	**Fe sol**	**Fe Sp**	**DOC**	**DOP**	**Ba**	**IO3**	**Sal**
1	4884	19-1					x	x	x	x	x	x		x	**x**													
2	4499	19-2					x	x	x	x	x	x		x														
3																												
4																												
5																												
6																												
7																												
8																												
9																												
10																												
11																												
12																												
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26																												
18																												
19																												
20																												
21																												
22																												
23																												
24																												

Notes: Bottles-3 to 24 did not fire-battery ran out

Station 8 b

Lat:	12o35.092	**CTD no.**	20					**Depth**	4912		**Date:**	25/02/2011																		
Long:	23o34.628																													
Bottle no.	**Depth (m)**	**Label ID**	**O2**	**Alk**	**Fe (II)**	**H2O2**	**Nuts**	**Total Diss**	**Ship Al/Fe**	**NOC TM**	**UoP TM**	**Partic TM**	**REE/Th**	**REE**	**N iso**	**Fe iso**	**Pb Iso**	**Cd iso**	**Cr iso**	**Si iso**	**Pa/Th**	**Fe sol**	**Fe Sp**	**DOC**	**DOP**	**Ba**	**IO3**	**Sal**
1																														
2																														
3																														
4																														
5																														
6																														
7																														
8																														
9																														
10																														
11																														
12	1100	20-12		x	x		x	x	x	x	x	x		x										x	x	x		x		
13	899	20-13		x			x		x	x	x	x		x	x									x	x	x	x	x		
14	750	20-14	x	x	x	x	x	x	x	x	x	x		x										x	x	x	x	x		
25	599	20-15					x		x	x	x	x			x									x	x	x	x	x		
16	499	20-16			x	x	x	x	x	x	x	x		x												x	x	x		
26	400	20-17					x		x	x	x	x	x		x											x	x	x		
18	299	20-18	x		x	x	x	x	x	x	x	x														x	x	x		
19	199	20-19			x	x	x		x	x	x	x	x		x											x	x	x		
20	150	20-20					x	x	x	x	x	x														x	x	x		
21	100	20-21	x		x	x	x		x	x	x	x	x		x											x	x	x		
22	78	20-22					x	x	x	x	x	x														x	x	x		
23	54	20-23	x				x		x	x	x	x			x											x	x	x		
24	24	20-24			x	x	x	x	x	x	x	x	x													x	x	x		

Notes: Bottle 12 did not close

Station 9

Lat:	12o18.078	**CTD no.**	22					**Depth**	5022		**Date:**	26/02/2011																	
Long:	25o08.434																												
Bottle no.	**Depth (m)**	**Label ID**	**O2**	**Alk**	**Fe (II)**	**H2O2**	**Nuts**	**Total Diss**	**Ship Al/Fe**	**NOC TM**	**UoP TM**	**Partic TM**	**REE/Th**	**REE**	**N iso**	**Fe iso**	**Pb Iso**	**Cd iso**	**Cr iso**	**Si iso**	**Pa/Th**	**Fe sol**	**Fe Sp**	**DOC**	**DOP**	**Ba**	**IO3**	**Sal**
1	4923	22-1	x	x			x	x	x	x	x	x		x		x							x	x	**x**	x	x	x
2	4499	22-2		x			x		x	x	x	x		x	x									x	x	x	x	x
3	3999	22-3		x			x	x	x	x	x	x		x										x	x	x	x	x
4	3499	22-4	x	x			x		x	x	x	x		x	x									x	x	x	x	x
5	2998	22-5		x			x	x	x	x	x	x		x		x							x	x	x	x	x	x
6	2698	22-6	x	x			x		x	x	x	x		x	x									x	x	x	x	x
7	2499	22-7		x			x	x				x		x														
8	2298	22-8		x			x		x	x	x	x		x	x									x	x	x	x	
9	1999	22-9	x	x			x	x	x	x	x	x		x		x						x	x	x	x	x	x	x
10	1699	22-10		x			x		x	x	x	x		x	x									x	x	x	x	x
11	1499	22-11		x			x		x	x	x	x		x		x						x	x	x	x	x	x	x
12	1099	22-12													x													
13	899	22-13		x			x	x	x	x	x	x		x										x	x	x	x	x
14	750	22-14	x	x	x	x	x		x	x	x	x		x	x									x	x	x	x	x
25	599	22-15					x	x	x	x	x	x		x		x						x	x			x	x	x
16	500	22-16			x	x	x		x	x	x	x	x		x											x	x	x
26	399	22-17					x	x	x	x	x	x				x						x	x			x	x	x
18	299	22-18	x		x	x	x		x	x	x	x	x		x											x	x	x
19	199	22-19			x	x	x	x	x	x	x	x				x						x	x			x	x	x
20	149	22-20					x		x	x	x	x			x											x	x	x
21	110	22-21	x		x	x	x	x	x	x	x	x	x													x	x	x
22	78	22-22					x		x	x	x	x			x	x						x	x			x	x	x
23	49	22-23	x				x	x	x	x	x	x				x						x	x			x	x	x
24	24	22-24			x	x	x		x	x	x	x	x		x											x	x	x

Notes: Bottle 12 did not close

Station 10

Lat:	-7o13.31	**CTD no.**	24					**Depth**	5537		**Date:**	03/03/2011																	
Long:	24o59.91																												
Bottle no.	**Depth (m)**	**Label ID**	**O2**	**Alk**	**Fe (II)**	**H2O2**	**Nuts**	**Total Diss**	**Ship Al/Fe**	**NOC TM**	**UoP TM**	**Partic TM**	**REE/Th**	**REE**	**N iso**	**Fe iso**	**Pb Iso**	**Cd iso**	**Cr iso**	**Si iso**	**Pa/Th**	**Fe sol**	**Fe Sp**	**DOC**	**DOP**	**Ba**	**IO3**	**Sal**
1	5495	24-1	x	x			x		x	x	x	x		x	x									x				
2	5000	24-2		x			x	x	x	x	x	x		x							x			x	x	x		x
3	4500	24-3	x	x			x		x	x	x	x			x									x	x	x		x
4	3999	24-4		x			x	x	x	x	x	x		x							x			x	x	x		x
5	3500	24-5	x	x			x		x	x	x	x		x	x									x	x	x		x
6	3000	24-6		x			x	x	x	x	x	x		x							x			x	x	x		x
7	2499	24-7	x	x			x		x	x	x	x		x	x						x			x	x	x		x
8	2299	24-8		x			x	x	x	x	x	x												x	x	x		x
9	1999	24-9	x	x			x		x	x	x	x		x	x						x			x	x	x		x
10	1700	24-10		x			x	x	x	x	x	x												x	x	x		x
11	1500	24-11	x	x			x		x	x	x	x		x	x						x			x	x	x		x
12	1099	24-12		x	x	x	x	x	x	x	x	x												x	x	x		x
13	899	24-13	x	x			x		x	x	x	x		x	x									x	x	x		x
14	750	24-14		x	x	x	x	x	x	x	x	x												x	x	x		x
25	599	24-15	x		x	x	x		x	x	x	x		x	x									x	x	x		x
16	499	24-16					x	x	x	x	x	x	x													x		x
26	400	24-17	x		x	x	x		x	x	x	x			x													
18	299	24-18					x	x	x	x	x	x	x													x		x
19	199	24-19	x				x		x	x	x	x			x											x		x
20	150	24-20			x	x	x	x	x	x	x	x														x		x
21	110	24-21	x				x		x	x	x	x	x		x											x		x
22	74	24-22					x	x	x	x	x	x														x		x
23	49	24-23	x				x		x	x	x	x			x											x		x
24	24	24-24			x	x	x	x	x	x	x	x	x													x		x

Notes:

Station 11.5

Lat:	-2o59.965	**CTD no.**	28					**Depth**	5300		**Date:**	05/03/2011																
Long:	25o36.527																											
Bottle no.	**Depth (m)**	**Label ID**	**O2**	**Alk**	**Fe (II)**	**H2O2**	**Nuts**	**Total Diss**	**Ship Al/Fe**	**NOC TM**	**UoP TM**	**Partic TM**	**REE/Th**	**REE**	**N iso**	**Fe iso**	**Pb Iso**	**Cd iso**	**Cr iso**	**Si iso**	**Pa/Th**	**Fe sol**	**Fe Sp**	**DOC**	**DOP**	**Ba**	**IO3**	**Sal**
1	2070	28-1																										
2	2000	28-2	x	x		x	x	x	x	x	x	x		x		x						x	x		x	x		x
3	1699	28-3		x			x	x	x	x	x	x		x	x	x									x	x		x
4	1500	28-4	x	x		x	x		x	x	x	x										x	x		x	x		x
5	1299	28-5		x			x	x	x	x	x	x		x	x	x				x					x	x		x
6	1099	28-6	x	x		x	x		x	x	x	x										x	x	x	x	x		x
7	948	28-7		x			x	x	x	x	x	x		x	x	x				x				x	x	x		x
8	849	28-8	x	x			x		x	x	x	x										x	x	x	x	x		x
9	698	28-9		x		x	x	x	x	x	x	x		x	x	x								x	x	x		x
10	600	28-10	x	x			x		x	x	x	x		x		x				x						x		x
11	499	28-11	x			x	x	x	x	x	x	x														x		x
12	450	28-12					x		x	x	x	x		x	x	x										x		x
13	400	28-13	x			x	x	x	x	x	x	x										x	x			x		x
14	350	28-14					x		x	x	x	x			x					x						x		x
25	300	28-15	x			x	x	x	x	x	x	x	x			x										x		x
16	199	28-16					x		x	x	x	x										x	x			x		x
26	149	28-17	x			x	x	x	x	x	x	x	x		x					x						x		x
18	99	28-18				x	x		x	x	x	x				x						x	x			x		x
19	84	28-19	x			x	x	x	x	x	x	x	x		x											x		x
20	74	28-20				x	x		x	x	x	x				x							x			x		x
21	59	28-21	x				x	x	x	x	x	x										x				x		x
22	54	28-22				x	x		x	x	x	x			x											x		x
23	44	28-23	x				x	x	x	x	x	x			x					x		x				x		x
24	24	28-24				x	x		x	x	x	x	x			x							x			x		x

Notes:Bottle 1 did not fire

Station 12

Lat:	-1o10.113	**CTD no.**	30					**Depth**	4930		**Date:**	06/03/2011																
Long:	25o47.972																											
Bottle no.	**Depth (m)**	**Label ID**	**O2**	**Alk**	**Fe (II)**	**H2O2**	**Nuts**	**Total Diss**	**Ship Al/Fe**	**NOC TM**	**UoP TM**	**Partic TM**	**REE/Th**	**REE**	**N iso**	**Fe iso**	**Pb Iso**	**Cd iso**	**Cr iso**	**Si iso**	**Pa/Th**	**Fe sol**	**Fe Sp**	**DOC**	**DOP**	**Ba**	**IO3**	**Sal**
1	4913	30-1																										
2	4498	30-2		x			x		x	x	x	x		x	x		x							x	x	x		x
3	3999	30-3	x	x			x	x	x	x	x	x						x			x			x	x	x		x
4	3699	30-4		x			x		x	x	x	x		x			x							x	x	x		x
5	3499	30-5	x	x			x	x	x	x	x	x		x				x			x			x	x	x		x
6	2999	30-6		x		x	x		x	x	x	x		x	x		x							x	x	x		x
7	2699	30-7	x	x			x	x	x	x	x	x									x			x	x	x		x
8	2500	30-8	x	x			x		x	x	x	x		x	x		x							x	x	x		x
9	2000	30-9	x	x		x	x	x	x	x	x	x		x							x			x	x	x		x
10	1499	30-10		x		x	x		x	x	x	x		x	x						x			x	x	x		x
11	1100	30-11	x	x			x	x	x	x	x	x		x			x				x			x	x	x		x
12	900	30-12	x	x			x		x	x	x	x						x						x	x	x		x
13	750	30-13	x	x		x	x	x	x	x	x	x		x			x				x			x	x	x		x
14	499	30-14	x				x		x	x	x	x			x											x		x
25	400	30-15	x			x	x	x	x	x	x	x		x							x					x		x
16	395	30-16													x		x	x										
26	200	30-17				x	x	x	x	x	x	x	x								x					x		x
18	150	30-18	x			x	x		x	x	x	x	x													x		x
19	99	30-19	x			x	x		x	x	x	x									x					x		x
20	64	30-20													x		x	x										
21	60	30-21	x			x	x	x	x	x	x	x	x													x		x
22	49	30-22	x			x	x		x	x	x	x	x		x						x					x		x
23	45	30-23				x		x									x	x										
24	24	30-24	x			x	x		x	x	x	x	x		x						x					x		x

Notes:Bottle 1 did not fire

Station 13

Lat:	1o09.511	**CTD no.**	32					**Depth**	4255		**Date:**	07/03/2011																
Long:	26o02.986																											
Bottle no.	**Depth (m)**	**Label ID**	**O2**	**Alk**	**Fe (II)**	**H2O2**	**Nuts**	**Total Diss**	**Ship Al/Fe**	**NOC TM**	**UoP TM**	**Partic TM**	**REE/Th**	**REE**	**N iso**	**Fe iso**	**Pb Iso**	**Cd iso**	**Cr iso**	**Si iso**	**Pa/Th**	**Fe sol**	**Fe Sp**	**DOC**	**DOP**	**Ba**	**IO3**	**Sal**
1	3702	32-1	x	x			x		x	x	x	x		x	x						x			x		x		x
2	3499	32-2	x	x			x	x	x	x	x	x												x		x		x
3	3300	32-3	x	x			x		x	x	x	x		x	x						x			x		x		x
4	2999	32-4		x			x	x	x	x	x	x												x		x		x
5	2499	32-5	x	x			x		x	x	x	x		x							x			x		x		x
6	2300	32-6		x			x	x	x	x	x	x												x		x		x
7	2000	32-7	x	x			x		x	x	x	x		x	x						x			x		x		x
8	1699	32-8	x	x			x	x	x	x	x	x												x		x		x
9	1499	32-9	x	x			x		x	x	x	x		x	x						x			x		x		x
10	1299	32-10		x			x	x	x	x	x	x		x							x			x		x		x
11	1099	32-11	x	x			x		x	x	x	x		x	x						x			x		x		x
12	900	32-12	x	x			x	x	x	x	x	x										x		x		x		x
13	749	32-13	x	x			x		x	x	x	x		x							x			x		x		x
14	599	32-14	x	x			x	x	x	x	x	x										x		x		x		x
25	499	32-15					x		x	x	x	x		x	x						x					x		x
16	400	32-16	x			x	x	x	x	x	x	x										x				x		x
26	300	32-17				x	x		x	x	x	x	x		x						x					x		x
18	199	32-18	x			x	x	x	x	x	x	x										x				x		x
19	150	32-19	x			x	x		x	x	x	x	x								x					x		x
20	100	32-20				x	x		x	x	x	x										x				x		x
21	74	32-21	x			x	x		x	x	x	x	x		x							x				x		x
22	59	32-22	x			x	x	x	x	x	x	x									x					x		x
23	44	32-23				x	x		x	x	x	x			x							x				x		x
24	24	32-24	x			x	x	x	x	x	x	x	x								x					x		x

Notes: Nuts from bottle 14 were filtered by mistake

Station 14

Lat:	3o20.2798	**CTD no.**	34					**Depth**	4255		**Date:**	08/03/2011																
Long:	26o49.03																											
Bottle no.	**Depth (m)**	**Label ID**	**O2**	**Alk**	**Fe (II)**	**H2O2**	**Nuts**	**Total Diss**	**Ship Al/Fe**	**NOC TM**	**UoP TM**	**Partic TM**	**REE/Th**	**REE**	**N iso**	**Fe iso**	**Pb Iso**	**Cd iso**	**Cr iso**	**Si iso**	**Pa/Th**	**Fe sol**	**Fe Sp**	**DOC**	**DOP**	**Ba**	**IO3**	**Sal**
1	4212	34-1	x	x			x		x	x	x	x		x	x						x			x		x		x
2	3998	34-2		x			x	x	x	x	x	x								x					x	x		x
3	3498	34-3	x	x			x		x	x	x	x		x	x						x			x		x		x
4	2997	34-4		x			x	x	x	x	x	x		x							x			x	x	x		x
5	2699	34-5	x	x			x		x	x	x	x		x										x				
6	2497	34-6		x			x	x	x	x	x	x									x			x		x		x
7	2298	34-7	x	x			x		x	x	x	x		x	x									x	x	x		x
8	1999	34-8	x	x			x	x	x	x	x	x									x					x		x
9	1699	34-9	x	x			x		x	x	x	x		x	x					x				x	x	x		x
10	1499	34-10		x			x	x	x	x	x	x		x							x			x		x		x
11	1299	34-11	x	x			x		x	x	x	x		x	x									x		x		x
12	1100	34-12	x	x			x	x	x	x	x	x		x						x	x			x	x	x		x
13	900	34-13	x	x			x		x	x	x	x									x			x		x		x
14	749	34-14	x	x			x	x	x	x	x	x		x										x		x		x
25	599	34-15		x			x		x	x	x	x			x					x				x	x	x		x
16	499	34-16	x				x	x	x	x	x	x	x								x							
26	400	34-17				x	x		x	x	x	x			x											x		x
18	300	34-18	x			x	x	x	x	x	x	x									x					x		x
19	250	34-19	x			x	x		x	x	x	x	x															
20	200	34-20				x	x		x	x	x	x									x							
21	99	34-21	x			x	x		x	x	x	x	x		x					x								
22	74	34-22	x			x	x	x	x	x	x	x									x					x		x
23	53	34-23				x	x		x	x	x	x			x					x						x		x
24	25	34-24	x			x	x	x	x	x	x	x	x								x						x		x

Notes:

Station 15

Lat:	5o39.893	**CTD no.**	36					**Depth**	4115		**Date:**	09/03/2011																	
Long:	27o30.418																												
Bottle no.	**Depth (m)**	**Label ID**	**O2**	**Alk**	**Fe (II)**	**H2O2**	**Nuts**	**Total Diss**	**Ship Al/Fe**	**NOC TM**	**UoP TM**	**Partic TM**	**REE/Th**	**REE**	**N iso**	**Fe iso**	**Pb Iso**	**Cd iso**	**Cr iso**	**Si iso**	**Pa/Th**	**Fe sol**	**Fe Sp**	**DOC**	**DOP**	**Ba**	**IO3**	**Sal**
1	4095	36-1	x	x			x	x	x	x	x	x		x												x		x
2	3499	36-2		x			x		x	x	x	x			x									x				
3	2999	36-3	x	x			x	x	x	x	x	x		x								x	x	x	x	x		
4	2699	36-4		x			x		x	x	x	x		x	x									x		x		
5	2499	36-5	x	x			x	x	x	x	x	x		x	x									x	x	x		
6	2298	36-6		x			x		x	x	x	x											x	x		x		
7	1999	36-7	x	x			x	x	x	x	x	x		x										x	x	x		x
8	1699	36-8	x	x			x					x			x													
9	1499	36-9	x	x			x	x	x	x	x	x												x	x	x		x
10	1298	36-10		x			x		x	x	x	x		x	x							x	x	x		x		x
11	1099	36-11	x	x			x	x	x	x	x	x		x										x	x	x		x
12	899	36-12	x	x			x		x	x	x	x		x	x							x	x	x		x		x
13	800	36-13	x	x			x	x	x	x	x	x												x	x	x		x
14	750	36-14	x	x			x		x	x	x	x		x										x		x		x
25	599	36-15		x		x	x	x	x	x	x	x	x									x	x	x	x	x		x
16	499	36-16	x			x	x		x	x	x	x			x							x	x			x		x
26	400	36-17				x	x	x	x	x	x	x										x	x			x		x
18	300	36-18	x			x	x		x	x	x	x	x		x													
19	199	36-19	x			x	x		x	x	x	x										x	x			x		x
20	150	36-20				x	x		x	x	x	x														x		x
21	100	36-21	x			x	x	x	x	x	x	x	x									x	x			x		x
22	84	36-22	x			x	x		x	x	x	x			x											x		x
23	59	36-23				x	x	x	x	x	x	x										x	x			x		x
24	24	36-24	x			x	x		x	x	x	x	x		x											x		x

Notes:

Station 16

Lat:	8o20.76	**CTD no.**	38					**Depth**	4738		**Date:**	10/03/2011																	
Long:	28o20.112																												
Bottle no.	**Depth (m)**	**Label ID**	**O2**	**Alk**	**Fe (II)**	**H2O2**	**Nuts**	**Total Diss**	**Ship Al/Fe**	**NOC TM**	**UoP TM**	**Partic TM**	**REE/Th**	**REE**	**N iso**	**Fe iso**	**Pb Iso**	**Cd iso**	**Cr iso**	**Si iso**	**Pa/Th**	**Fe sol**	**Fe Sp**	**DOC**	**DOP**	**Ba**	**IO3**	**Sal**
1	4726	38-1	x	x			x	x	x	x	x	x						x						x		x		x
2	4499	38-2		x			x		x	x	x	x		x	x			x						x	x	x		x
3	3999	38-3	x	x			x	x	x	x	x	x					x							x		x		x
4	3499	38-4		x			x		x	x	x	x			x			x								x		x
5	2999	38-5		x			x	x	x	x	x	x		x	x		x									x		x
6	2500	38-6		x			x		x	x	x	x						x								x		x
7	1999	38-7		x			x	x	x	x	x	x					x									x		x
8	1500	38-8	x	x	x	x	x		x	x	x	x		x	x			x						x	x	x		x
9	1099	38-9	x	x			x	x				x		x			x							x				
10	900	38-10		x	x	x	x		x	x	x	x		x	x			x						x	x	x		x
11	750	38-11	x	x			x	x	x	x	x	x		x			x							x		x		x
12	499	38-12	x				x		x	x	x	x			x									x	x	x		x
13	404	38-13			x	x		x									x	x											
14	400	38-14	x				x		x	x	x	x														x		x
25	299	38-15	x				x	x	x	x	x	x	x													x		x
16	199	38-16			x	x	x		x	x	x	x			x											x		x
26	150	38-17					x	x	x	x	x	x														x		x
18	99	38-18	x				x		x	x	x	x	x		x											x		x
19	79	38-19	x				x		x	x	x	x					x	x								x		x
20	56	38-20			x	x											x	x											
21	54	38-21	x				x	x	x	x	x	x	x													x		x
22	39	38-22	x		x	x	x		x	x	x	x			x											x		x
23	26	38-23			x	x											x	x								x		x
24	25	38-24	x		x	x	x		x	x	x	x	x		x											x		x

Notes:

Station 17

Lat:	10o37.55	**CTD no.**	40					**Depth**	5651		**Date:**	11/03/2011																	
Long:	28o43.96																												
Bottle no.	**Depth (m)**	**Label ID**	**O2**	**Alk**	**Fe (II)**	**H2O2**	**Nuts**	**Total Diss**	**Ship Al/Fe**	**NOC TM**	**UoP TM**	**Partic TM**	**REE/Th**	**REE**	**N iso**	**Fe iso**	**Pb Iso**	**Cd iso**	**Cr iso**	**Si iso**	**Pa/Th**	**Fe sol**	**Fe Sp**	**DOC**	**DOP**	**Ba**	**IO3**	**Sal**
1	5590	40-1	x	x			x		x	x	x	x		x	x						x			x	x	x		x
2	4999	40-2		x			x	x	x	x	x	x									x			x		x		x
3	4499	40-3	x	x			x		x	x	x	x									x			x	x	x		x
4	3999	40-4		x			x	x	x	x	x	x		x							x			x		x		x
5	3498	40-5	x	x			x		x	x	x	x		x	x									x	x	x		x
6	2998	40-6		x			x	x	x	x	x	x									x			x		x		x
7	2498	40-7	x	x			x		x	x	x	x		x	x						x			x	x	x		x
8	2298	40-8		x	x	x	x	x	x	x	x	x												x		x		x
9	1998	40-9	x	x			x					x		x	x										x	x		x
10	1697	40-10		x			x	x	x	x	x	x		x										x		x		x
11	1497	40-11		x	x	x	x		x	x	x	x		x	x						x			x	x	x		x
12	1099	40-12	x	x			x	x	x	x	x	x												x		x		x
13	949	40-13		x	x	x	x		x	x	x	x		x	x						x			x	x	x		x
14	750	40-14	x	x			x	x				x														x		x
25	599	40-15	x	x			x		x	x	x	x			x									x	x	x		x
16	499	40-16	x	x	x	x	x	x	x	x	x	x	x								x			x		x		x
26	400	40-17			x	x	x		x	x	x	x			x											x		x
18	299	40-18			x	x	x	x	x	x	x	x	x								x					x		x
19	199	40-19	x				x		x	x	x	x			x						x					x		x
20	150	40-20	x				x	x	x	x	x	x														x		x
21	100	40-21	x				x		x	x	x	x			x											x		x
22	69	40-22			x	x	x	x	x	x	x	x	x								x					x		x
23	39	40-23			x	x	x		x	x	x	x			x											x		x
24	24	40-24	x		x	x	x	x	x	x	x	x	x								x					x		x

Notes:

Station 18

Lat:	12o00.98	**CTD no.**	41					**Depth**	5094		**Date:**	12/03/2011																	
Long:	28o58.856																												
Bottle no.	**Depth (m)**	**Label ID**	**O2**	**Alk**	**Fe (II)**	**H2O2**	**Nuts**	**Total Diss**	**Ship Al/Fe**	**NOC TM**	**UoP TM**	**Partic TM**	**REE/Th**	**REE**	**N iso**	**Fe iso**	**Pb Iso**	**Cd iso**	**Cr iso**	**Si iso**	**Pa/Th**	**Fe sol**	**Fe Sp**	**DOC**	**DOP**	**Ba**	**IO3**	**Sal**
1	5633	41-1		x			x	x	x	x	x	x				x							x	x		x	x	x
2	5000	41-2	x	x			x		x	x	x	x			x									x	x	x	x	x
3	4496	41-3																											
4	3999	41-4	x	x			x		x	x	x	x		x										x	x	x	x	x
5	3499	41-5		x			x	x	x	x	x	x		x		x							x	x		x	x	x
6	2999	41-6	x	x			x		x	x	x	x			x									x	x	x	x	x
7	2500	41-7	x	x			x	x	x	x	x	x		x										x		x	x	x
8	2299	41-8		x	x	x	x		x	x	x	x			x									x	x	x	x	x
9	1999	41-9		x			x	x	x	x	x	x		x		x						x	x	x		x	x	x
10	1700	41-10	x	x			x		x	x	x	x		x	x									x	x	x	x	x
11	1499	41-11		x	x	x	x	x	x	x	x	x		x										x		x	x	x
12	1099	41-12	x	x			x		x	x	x	x			x									x	x	x	x	x
13	950	41-13		x			x	x	x	x	x	x		x		x						x	x	x		x	x	x
14	750	41-14	x	x	x	x	x		x	x	x	x		x	x									x	x	x	x	x
25	599	41-15		x			x	x	x	x	x	x				x						x	x	x		x	x	x
16	498	41-16	x		x	x	x		x	x	x	x	x		x											x	x	x
26	399	41-17			x	x	x	x	x	x	x	x				x						x	x			x	x	x
18	324	41-18	x		x	x	x		x	x	x	x	x		x											x	x	x
19	223	41-19					x	x	x	x	x	x				x						x	x			x	x	x
20	158	41-20	x				x		x	x	x	x			x											x	x	x
21	90	41-21	x				x	x	x	x	x	x				x						x	x			x	x	x
22	64	41-22			x	x	x		x	x	x	x	x		x											x	x	x
23	29	41-23			x	x	x	x	x	x	x	x				x						x	x			x	x	x
24	20	41-24	x		x	x	x		x	x	x	x	x		x											x	x	x

Notes: Bottle 3 tripped in the air
Bottle 5 nutrients are high-check bottle file

Station 19

Lat:	15o30.392	**CTD no.**	44					**Depth**	5136		**Date:**	13/03/2011																	
Long:	28o47.347																												
Bottle no.	**Depth (m)**	**Label ID**	**O2**	**Alk**	**Fe (II)**	**H2O2**	**Nuts**	**Total Diss**	**Ship Al/Fe**	**NOC TM**	**UoP TM**	**Partic TM**	**REE/Th**	**REE**	**N iso**	**Fe iso**	**Pb Iso**	**Cd iso**	**Cr iso**	**Si iso**	**Pa/Th**	**Fe sol**	**Fe Sp**	**DOC**	**DOP**	**Ba**	**IO3**	**Sal**
1	5103	44-1		x			x		x	x	x	x		x	x									x	x	x		x
2	4499	44-2	x	x			x	x	x	x	x	x												x		x		x
3	3999	44-3	x	x			x		x	x	x	x		x	x									x	x	x		x
4	3498	44-4	x	x			x	x	x	x	x	x		x										x		x		x
5	2999	44-5		x			x		x	x	x	x		x	x									x	x	x		x
6	2700	44-6	x	x			x	x	x	x	x	x												x		x		x
7	2499	44-7		x	x	x	x		x	x	x	x		x	x									x	x	x		x
8	2000	44-8	x	x			x	x	x	x	x	x												x		x		x
9	1699	44-9	x	x			x		x	x	x	x		x	x									x	x	x		x
10	1498	44-10		x	x	x	x	x	x	x	x	x		x										x		x		x
11	1099	44-11	x	x			x		x	x	x	x		x	x									x	x	x		x
12	949	44-12	x	x			x	x	x	x	x	x												x		x		x
13	749	44-13		x	x	x	x		x	x	x	x		x	x				x					x	x	x		x
14	599	44-14	x	x			x	x	x	x	x	x		x										x		x		x
25	499	44-15	x				x		x	x	x	x			x				x							x		x
16	399	44-16			x	x	x	x	x	x	x	x	x						x							x		x
26	299	44-17			x	x	x		x	x	x	x			x				x							x		x
18	250	44-18	x		x	x	x	x	x	x	x	x	x													x		x
19	199	44-19	x				x		x	x	x	x			x											x		x
20	149	44-20	x				x	x	x	x	x	x														x		x
21	110	44-21	x				x		x	x	x	x			x											x		x
22	74	44-22			x	x	x	x	x	x	x	x	x													x		x
23	49	44-23	x		x	x	x		x	x	x	x			x											x		x
24	24	44-24			x	x	x	x	x	x	x	x	x													x		x

Notes

Station 20

Lat:	17o 24.272	**CTD no.**	47					**Depth**	4627		**Date:**	14/03/2011																	
Long:	28o23.90																												
Bottle no.	**Depth (m)**	**Label ID**	**O2**	**Alk**	**Fe (II)**	**H2O2**	**Nuts**	**Total Diss**	**Ship Al/Fe**	**NOC TM**	**UoP TM**	**Partic TM**	**REE/Th**	**REE**	**N iso**	**Fe iso**	**Pb Iso**	**Cd iso**	**Cr iso**	**Si iso**	**Pa/Th**	**Fe sol**	**Fe Sp**	**DOC**	**DOP**	**Ba**	**IO3**	**Sal**
1	4573	47-1		x			x	x	x	x	x	x		x				x						x		x		x
2	3999	47-2	x	x			x		x	x	x	x			x		x							x	x	x		x
3	3499	47-3	x	x			x	x	x	x	x	x		x				x						x		x		x
4	3000	47-4	x	x			x		x	x	x	x		x	x		x							x	x	x		x
5	2500	47-5	x	x			x	x	x	x	x	x		x				x						x		x		x
6	2300	47-6		x	x	x	x		x	x	x	x					x							x	x	x		x
7	2000	46-7	x	x			x	x	x	x	x	x		x				x						x		x		x
8	1499	47-8		x	x	x	x		x	x	x	x			x		x							x	x	x		x
9	1099	47-9	x	x			x	x	x	x	x	x		x				x						x		x		x
10	899	47-10		x			x	x	x	x	x	x		x			x							x	x	x		x
11	750	47-11	x	x	x	x	x	x	x	x	x	x						x						x		x		x
12	600	47-12	x	x			x		x	x	x	x		x	x		x							x	x	x		x
13	500	47-13			x	x	x	x	x	x	x	x														x		x
14	405	47-14			x	x											x	x										
25	400	47-15	x				x		x	x	x	x	x		x											x		x
16	299	47-16																										
26	200	47-17			x	x		x	x	x	x	x					x	x										
18	149	47-18	x				x	x	x	x	x	x	x		x											x		x
19	100	47-19	x				x	x	x	x	x	x														x		x
20	86	47-20			x	x											x	x										
21	83	47-21	x				x	x	x	x	x	x			x											x		x
22	49	47-22			x	x	x		x	x	x	x	x		x											x		x
23	26	47-23	x														x	x										
24	24	47-24			x	x	x	x	x	x	x	x	x		x											x		x

Notes: Bottle 16 misfired

Appendix D – SS CTD sampling log

Station	02	CTD No	005	Date	53 / 23 Feb 2011	CTD frame type: SS ■
Latitude	12 35’ 44	Event No		Time I/W (GMT)	0043	
Longitude	17 54’ 69	Depth	2649	Time bottom (GMT)	0104	
Filename		Cast Depth	500	Time O/W (GMT)	0149	
Weather						

Fire Seq	Rosette Pos^{n}	Bot. No.	Depth (m)	Location	Label ID	O2 1 L Anouska	Nuts 0.5 L Malc	DIC 1 L Eith	DOC 0.2 L Eith/Eric	N2 fix 5 L David	Bio 10 L Eliz	Salts 0.2 L Alex	DOP 1 L Claire	P work 10 L Claire	Thorium 5 L Katsia	Total NifH 3 L Tobi	N2 fix 20 L Tobi	Tricho 20 L Joe	Protein 5 L Eliz	Comments
1	1	1	500		05_01	X	X	X	X			X	X			X				
2	2	2	400	O_2 Min	05_02	X	X	X	X			X	X			X				
3	3	3	200		05_03	X	X	X	X			X	X			X				
4	4	4	100		05_04	X	X	X	X			X	X			X				
5	5	5	50	D Slope	05_05		X					X	X	X		X				
6	6	6	50	D Slope	05_06	X	X	X	X		X								X	
7	7	7	40	DCM L05	05_07		X												X	
8	8	8	40	DCM L05	05_08		X										X			
9	9	9	40	DCM L05	05_09		X						X	X		X				
10	10	10	40	DCM L05	05_10	X	X	X	X		X	X								
11	11	11	30	L04	05_11		X										X			
12	12	12	30	L04	05_12	X	X	X	X		X	X	X	X		X				May run out
13	13	13	30	L04	05_13	DID NOT FIRE														DID NOT FIRE
14	14	14	20	L03	05_14		X										X			
15	15	15	20	L03	05_15		X						X	X		X				
16	16	16	20	L03	05_16	X	X	X	X		X	X								
17	17	17	10	L02	05_17		X										X			
18	18	18	10	L02	05_18		X						X	X		X				
19	19	19	10	L02	05_19	X	X	X	X		X	X								
20	20	20	Surface	L01	05_20		X												X	
21	21	21	Surface	L01	05_21		X										X			
22	22	22	Surface	L01	05_22		X						X	X		X				
23	23	23	Surface	L01	05_23	X	X	X	X		X	X								
24	24	24	Surface	L01	05_24		X											X		
				Analyst																
Comments																				

Station	03	CTD No	07	Date	53 / 22 Feb 2011	CTD frame type:
Latitude	12 35.743	Event No		Time I/W (GMT)	0700	
Longitude	17 42.843	Depth	1068	Time bottom (GMT)	0717	SS Y/~~N~~
Filename		Cast Depth	500	Time O/W (GMT)		
Weather						

Fire Seq	Rosette Pos^{n}	Bot. No.	Depth (m)	Location	Label ID	O2 1 L Anouska	Nuts 0.5 L Malc	DIC 1 L Eith	DOC 0.2 L Eith/Eric	N2 fix 5 L David	Bio 10 L Eliz	Salts 0.2 L Alex	DOP 1 L Claire	P work 10 L Claire	Thorium 5 L Katsia	Total NifH 3 L Tobi	N2 fix 20 L Tobi	Tricho 20 L Joe	Protein 5 L Eliz	Comments
1	1	1	500		07_01	X	X	X	X			X	X		X					
2	2	2	400	O_2 Min	07_02	X	X	X	X			X	X		X					
3	3	3	200		07_03	X	X	X	X			X	X		X					
4	4	4	100		07_04	LEAKED														LEAKED
5	5	5	70	D Slope	07_05		X						X	X	X					
6	6	6	70	D slope	07_06	X	X	X	X		X	X							X	
7	7	7	50	L05	07_07		X												X	
8	8	8	50	L05	07_08		X						X	X	X					
9	9	9	50	L05	07_09	DID NOT FIRE														Did Not Fire
10	10	10	50	L05	07_10	X	X	X	X	X	X	X								
11	11	11	30	L04	07_11		X						X	X	X					
12	12	12	30	L04	07_12	X	X	X	X	X	X									
13	13	13	30	L04	07_13		X					X								
14	14	14	20	L03	07_14		X						X	X	X					
15	15	15	20	L03	07_15	X	X	X	X	X	X	X								
16	16	16	20	L03	07_16		X													
17	17	17	10	L02	07_17		X						X	X	X					
18	18	18	10	L02	07_18	X	X	X	X	X	X	X								
19	19	19	10	L02	07_19		X													
20	20	20	Surface	L01	07_20		X								X				X	
21	21	21	Surface	L01	07_21		X					X	X	X						
22	22	22	Surface	L01	07_22	LEAKED														LEAKED
23	23	23	Surface	L01	07_23	LEAKED														LEAKED
24	24	24	Surface	L01	07_24	X	X	X	X	X	X									
				Analyst																
Comments																				

Station	04	CTD No	009	Date	53 / 22nd Feb 2011	CTD frame type:
Latitude	12 35.1645	Event No		Time I/W (GMT)	1647	
Longitude	17 34.2443	Depth	120	Time bottom (GMT)	1700	SS Y/~~N~~
Filename		Cast Depth	160	Time O/W (GMT)		
Weather						

Fire Seq	Rosette Pos^{n}	Bot. No.	Depth (m)	Location	Label ID	O2 1 L Anouska	Nuts 0.5 L Malc	DIC 1 L Eith	DOC 0.2 L Eith/Eric	N2 fix 5 L David	Bio 10 L Eliz	Salts 0.2 L Alex	DOP 1 L Claire	P work 10 L Claire	Thorium 5 L Katsia	Total NifH 3 L Tobi	N2 fix 20 L Tobi	Tricho 20 L Joe	Protein 5 L Eliz	Comments
1	1	1	150		09_01															
2	2	2	150		09_02	X	X	X	X			X	X			X				
3	3	3	120		09_03															
4	4	4	120		09_04	X	X	X	X			X	X			X				
5	5	5	100		09_05															
6	6	6	100		09_06	X	X	X	X			X	X			X				
7	7	7	85		09_07															
8	8	8	85		09_08									X						
9	9	9	85		09_09												X			
10	10	10	85		09_10	X	X	X	X		X	X	X			X				
11	11	11	40		09_11															
12	12	12	40		09_12												X			
13	13	13	40		09_13									X					X	
14	14	14	40		09_14	X	X	X	X		X	X	X			X				
15	15	15	20		09_15															
16	16	16	20		09_16									X					X	
17	17	17	20		09_17												X			
18	18	18	20		09_18	X	X	X	X		X	X	X			X				
19	19	19	10		09_19															
20	20	20	10		09_20	X	X	X	X		X		X			X				
21	21	21	Surface		09_21															
22	22	22	Surface		09_22		X							X					X	
23	23	23	Surface		09_23												X			
24	24	24	Surface		09_24	X	X	X	X		X	X	X			X				
				Analyst																
Comments																				

Station	06	CTD No	13	Date	54 / 23rd Feb 2011
Latitude	12 34.323	Event No		Time I/W (GMT)	0533
Longitude	18 49.408	Depth	4230	Time bottom (GMT)	0548
Filename		Cast Depth	500	Time O/W (GMT)	
Weather					

CTD frame type: SS Y/~~N~~

Fire Seq	Rosette Pos^{n}	Bot. No.	Depth (m)	Location	Label ID	O2 1 L Anouska	Nuts 0.5 L Malc	DIC 1 L Eith	DOC 0.2 L Eith/Eric	N2 fix 5 L David	Bio 10 L Eliz	Salts 0.2 L Alex	DOP 1 L Claire	P work 10 L Claire	Thorium 5 L Katsia	Total NifH 3 L Tobi	N2 fix 20 L Tobi	Tricho 20 L Joe	Protein 5 L Eliz	Comments
1	1	1	500	O_2 Min	13_01	X	X	X				X	X			X				
2	2	2	250		13_02	LEAKED														LEAKED
3	3	3	100		13_03	X	X	X				X	X			X				
4	4	4	50		13_04	X	X	X				X	/			X				
5	5	5	35	D slope	13_05		X					X	/	X		X				
6	6	6	35	D slope	13_06	X	X	X	X		X								X	EMPTY
7	7	7	25	DCM	13_07		X												X	
8	8	8	25	DCM	13_08		X						X	X		X				
9	9	9	25	DCM	13_09		X										X			
10	10	10	25	DCM	13_10	X	X	X	X	X	X	X								
11	11	11	20		13_11		X										X			EMPTY
12	12	12	20		13_12		X					X	X	X		X				
13	13	13	20		13_13	X	X	X	X	X	X									EMPTY
14	14	14	14		13_14		X										X			
15	15	15	14		13_15		X					X	X	X		X				
16	16	16	14		13_16	X	X	X	X	X	X									
17	17	17	7		13_17		X										/			
18	18	18	7		13_18		X					X	X	X		X				
19	19	19	7		13_19	X	X	X	X	X	X									
20	20	20	Surface		13_20		X												X	EMPTY
21	21	21	Surface		13_21		X										/			
22	22	22	Surface		13_22		X					X	X	X		X				
23	23	23	Surface		13_23	X	X	X	X	X	X									EMPTY
24	24	24	Surface		13_24		X											X		
				Analyst																
Comments																				

Station	7	CTD No	015	Date	55 / 24 Feb 2011	CTD frame type:
Latitude	12 34.6 N	Event No		Time I/W (GMT)	0640	SS ☐
Longitude	21 49.1 W	Depth	4775	Time bottom (GMT)	0657	
Filename		Cast Depth	500	Time O/W (GMT)		
Weather						

Fire Seq	Rosette Pos^{n}	Bot. No.	Depth (m)	Location	Label ID	O2 1 L Anouska	Nuts 0.5 L Malc	DIC 1 L Eith	DOC 0.2 L Eith/Eric	N2 fix 5 L David	Bio 10 L Eliz	Salts 0.2 L Alex	DOP 1 L Claire	P work 10 L Claire	Thorium 5 L Katsia	Total NifH 3 L Tobi	N2 fix 20 L Tobi	Tricho 20 L Joe	Protein 5 L Eliz	Comments
1	1	1	500			X	X	X	X			X	X			X				
2	2	2	350	O_2 Min		DID NOT FIRE														DID NOT FIRE
3	3	3	200	O_2 Min		X	X	X	X			X	X			X				
4	4	4	100			X	X	X	X			X	X			X				
5	5	5	70	LDS		DID NOT FIRE														DID NOT FIRE
6	6	6	70	LDS		X	X	X	X				X	X		X			X	EMPTY
7	7	7	50	DCM			X					X							X	
8	8	8	50	DCM			X										X			
9	9	9	50	DCM			X						X	X		X				
10	10	10	50	DCM		X	X	X	X	X	X									
11	11	11	40				X					X	X	X		X				
12	12	12	40			X	X	X	X	X	X									
13	13	13	40			DID NOT FIRE														DID NOT FIRE
14	14	14	30				X					X								
15	15	15	30				X						X	X		X				
16	16	16	30			X	X	X	X	X	X									
17	17	17	20				X										X			EMPTY
18	18	18	20				X					X	X	X		X				
19	19	19	20			X	X	X	X	X	X									
20	20	20	Surface				X												X	
21	21	21	Surface				X										X			
22	22	22	Surface				X						X	X		X				
23	23	23	Surface			X	X	X	X	X	X									EMPTY
24	24	24	Surface				X					X						X		
				Analyst																
Comments																				

Station	8	CTD No	18	Date	56 / 25th Feb 2011	CTD frame type:
Latitude	12 35.12	Event No		Time I/W (GMT)	0637	
Longitude	23 33.43	Depth	4902	Time bottom (GMT)	0653	SS Y/N
Filename		Cast Depth	500	Time O/W (GMT)	0738	
Weather						

Fire Seq	Rosette Pos^{n}	Bot. No.	Depth (m)	Location	Label ID	O2 1 L Anouska	Nuts 0.5 L Malc	DIC 1 L Eith	DOC 0.2 L Eith/Eric	N2 fix 5 L David	Bio 10 L Eliz	Salts 0.2 L Alex	DOP 1 L Claire	P work 10 L Claire	Thorium 5 L Katsia	Total NifH 3 L Tobi	N2 fix 20 L Tobi	Tricho 20 L Joe	Protein 5 L Eliz	Comments
1	1	1	500		18_01	X	X	X	X			X	X		X	X				
2	2	2	400		18_02	X	X	X	X			X	X		X	X				
3	3	3	350		18_03	X	X	X	X			X	X		X	X				
4	4	4	85		18_04	X	X	X	X			X	X		X	X			X	
5	5	5	65		18_05	LEAKED														LEAKED
6	6	6	65		18_06	X	X	X	X				X	X	X	X				
7	7	7	55		18_07		X					X							X	
8	8	8	55		18_08		X										X			
9	9	9	55		18_09		X						X	X	X	X				
10	10	10	55		18_10	X	X	X	X	X	X									
11	11	11	45		18_11		X					X			X					
12	12	12	45		18_12		X						X	X		X				
13	13	13	45		18_13	X	X	X	X	X	X									
14	14	14	30		18_14		X										X			
15	15	15	30		18_15		X					X	X	X	X	X				
16	16	16	30		18_16	X	X	X	X	X	X									
17	17	17	15		18_17		X										X			
18	18	18	15		18_18		X						X	X	X	X				
19	19	19	15		18_19	X	X	X	X	X	X	X								
20	20	20	Surface		18_20		X												X	
21	21	21	Surface		18_21	LEAKED														LEAKED
22	22	22	Surface		18_22		X						X	X	X	X				
23	23	23	Surface		18_23	X	X	X	X	X	X	X								
24	24	24	Surface		18_24		X										X			
				Analyst																
Comments																				

Station	9	CTD No	21	Date	57 26th Feb 2011	CTD frame type:
Latitude	12 18.04 N	Event No		Time I/W (GMT)	0634	
Longitude	25 07.06 W	Depth	4995	Time bottom (GMT)	0652	SS Y/~~N~~
Filename		Cast Depth	500	Time O/W (GMT)	0736	
Weather	Raining steadily, Brightening up later					

Fire Seq	Rosette Pos^{n}	Bot. No.	Depth (m)	Location	Label ID	O2 1 L Anouska	Nuts 0.5 L Malc	DIC 1 L Eith	DOC 0.2 L Eith/Eric	N2 fix 5 L David	Bio 10 L Eliz	Salts 0.2 L Alex	DOP 1 L Claire	P work 10 L Claire	Thorium 5 L Katsia	Total NifH 3 L Tobi	N2 fix 20 L Tobi	Tricho 20 L Joe	Protein 5 L Eliz	Comments
1	1	1	500		21_01	X	X	X	X			X	X			X				
2	2	2	450	O_2 Min	21_02	LEAKED														LEAKED
3	3	3	300		21_03	X	X	X	X			X	X			X				
4	4	4	300		21_04	LEAKED														LEAKED
5	5	5	110		21_05	X	X	X	X			X	X			X				
6	6	6	90	DS DCM	21_06	X	X	X	X		X		X	X		X			X	
7	7	7	90	DS DCM	21_07	LEAKED														LEAKED
8	8	8	80	DCM	21_08		X													
9	9	9	80	DCM	21_09		X					X	X	X		X				
10	10	10	80	DCM	21_10	X	X	X	X	X	X									
11	11	11	80	DCM	21_11		X												X	
12	12	12	50		21_12		X					X	X	X		X				
13	13	13	50		21_13	X	X	X	X	X	X									
14	14	14	30		21_14	LEAKED														LEAKED
15	15	15	30		21_15		X			X	X		X	X						
16	16	16	30		21_16	X	X	X	X											
17	17	17	20		21_17		X									X				
18	18	18	20		21_18		X					X	X	X						
19	19	19	20		21_19	X	X	X	X	X	X					X				
20	20	20	Surface		21_20		X												X	
21	21	21	Surface		21_21	LEAKED														LEAKED
22	22	22	Surface		21_22		X					X	X	X		X				
23	23	23	Surface		21_23	X	X	X	X	X	X									
24	24	24	Surface		21_24		X											X		
				Analyst																
Comments																				

Station	10	CTD No	23	Date	3rd Mar 2011	CTD frame type:
Latitude	07 13.378 S	Event No		Time I/W (GMT)	1458	
Longitude	24 59.378 W	Depth	5846	Time bottom (GMT)	1520	SS Y/~~N~~
Filename		Cast Depth	1000	Time O/W (GMT)	1615	
Weather						

Fire Seq	Rosette Pos^{n}	Bot. No.	Depth (m)	Location	Label ID	Pa/Th Maeve/ Angie	Nuts 0.5 L Malc		Claire	PIC/POC/ Chl/BSi Joe/ David	BIO 4L LIZ				Thorium 5 L Katsia					Comments
1	1	1	1000		23_1		X								X					
2	2	2	1000		23_2		X								X					
3	3	3	1000		23_3		X								X					
4	4	4	1000		23_4		X		X											
5	5	5	1000		23_5		X		X											
6	6	6	1000		23_6	X	X				X									
7	7	7	750		23_7	X	X													
8	8	8	750		23_8		X				X									
9	9	9	500		23_9	X	X				X				X					
10	10	10	300		23_10		X													
11	11	11	300		23_11		X													
12	12	12	250		23_12		X								X					
13	13	13	200		23_13	X	X													
14	14	14	110		23_14	X	X													
15	15	15	110		23_15	LEAKED														LEAKES
16	16	16	100		23_16		X			X					X					
17	17	17	60		23_17		X			X					X					
18	18	18	50		23_18		X			X					X					
19	19	19	40		23_19		X			X					X					
20	20	20	30		23_20		X			X					X					
21	21	21	20		23_21		X			X					X					
22	22	22	20		23_22	X	X													
23	23	23	10		23_23		X			X					X					
24	24	24	10		23_24		X													
				Analyst																
Comments																				

Station	10	CTD No	25	Date	63 / 4th Feb 2011	CTD frame type:
Latitude	7 13.22 S	Event No		Time I/W (GMT)	0336	
Longitude	24 59.54 W	Depth	5491	Time bottom (GMT)	0358	SS Y/~~N~~
Filename		Cast Depth	500m	Time O/W (GMT)		
Weather	Dark, Very dark					

Fire Seq	Rosette Pos^{n}	Bot. No.	Depth (m)	Location	Label ID	O2 1 L Anouska	Nuts 0.5 L Malc	DIC 1 L Eith	DOC 0.2 L Eith/Eric	N2 fix 5 L David	Bio 10 L Eliz	Salts 0.2 L Alex	DOP 1 L Claire	P work 10 L Claire	Thorium 5 L Katsia	Total NifH 3 L Tobi	N2 fix 20 L Tobi	Tricho 20 L Joe	Protein 5 L Eliz	Comments
1	1	1	500		25_1	X	X	X	X			X				X			X	
2	2	2	350		25_2	X	X	X	X			X				X				
3	3	3	250		25_3	X	X	X	X			X				X				
4	4	4	150		25_4	Mis-fired														Mis-fired
5	5	5	120	Ds DCM	25_5		X					X	X	X		X				
6	6	6	120	Ds DCM	25_6	X	X	X	X		X								X	
7	7	7	110	DCM	25_7		X												X	
8	8	8	110	DCM	25_8		X										X			
9	9	9	110	DCM	25_9		X					X	X	X		X				
10	10	10	110	DCM	25_10	X	X	X	X	X	X									
11	11	11	80		25_11		X										X			
12	12	12	80		25_12		X						X	X		X				
13	13	13	80		25_13	X	X	X	X	X	X	X								
14	14	14	60		25_14		X										X			
15	15	15	60		25_15		X						X	X		X				
16	16	16	60		25_16	X	X	X	X	X	X									
17	17	17	30		25_17		X										X			
18	18	18	30		25_18		X					X	X	X		X				
19	19	19	30		25_19	X	X	X	X	X	X									
20	20	20	Surface		25_20	Mis-fired														
21	21	21	Surface		25_21		X												X	
22	22	22	Surface		25_22		X					X	X	X		X				
23	23	23	Surface		25_23	X	X	X	X	X	X									
24	24	24	Surface		25_24		X											X		
				Analyst																
Comments																				

Station	11	CTD No	26	Date	5th Mar 2011	CTD frame type:
Latitude	3 15.8	Event No		Time I/W (GMT)	0636	
Longitude	25 30.5	Depth	5568	Time bottom (GMT)		SS ☐
Filename		Cast Depth	500	Time O/W (GMT)		
Weather						

Fire Seq	Rosette Pos^{n}	Bot. No.	Depth (m)	Location	Label ID	O2 1 L Anouska	Nuts 0.5 L Malc	DIC 1 L Eith	DOC 0.2 L Eith/Eric	N2 fix 5 L David	Bio 10 L Eliz	Salts 0.2 L Alex	DOP 1 L Claire	P work 10 L Claire	Thorium 5 L Katsia	Total NifH 3 L Tobi	N2 fix 20 L Tobi	Tricho 20 L Joe	Protein 5 L Eliz	Comments
1	1	1	500	500m	26_1	X	X	X	X			X		X		X			X	
2	2	2	400		26_2	X	X	X	X			X		X		X				
3	3	3	160		26_3	X	X	X	X			X		X		X				
4	4	4	120	DS+25	26_4	X	X	X	X		X			X		X			X	EMPTY
5	5	5	95	DS	26_5	LEAKED														LEAKED
6	6	6	95	DS	26_6	X	X	X	X			X	X	X		X				
7	7	7	75	DCM	26_7		X												X	
8	8	8	75	DCM	26_8		X										X			
9	9	9	75	DCM	26_9		X						X	X		X				
10	10	10	75	DCM	26_10	X	X	X	X	X	X									EMPTY
11	11	11	60		26_11		X										X			
12	12	12	60		26_12		X					X	X	X		X				
13	13	13	60		26_13	X	X	X	X	X	X									
14	14	14	40		26_14		X										X			
15	15	15	40		26_15		X					X	X	X		X				
16	16	16	40		26_16	X	X	X	X	X	X									
17	17	17	20		26_17		X										X			
18	18	18	20		26_18		X					X	X	X		X				
19	19	19	20		26_19	X	X	X	X	X	X									
20	20	20	2	Surface	26_20		X												X	
21	21	21	2	Surface	26_21		X										X			
22	22	22	2	Surface	26_22		X					X	X	X		X				
23	23	23	2	Surface	26_23	X	X	X	X	X	X									
24	24	24	2	Surface	26_24		X											X		
				Analyst																
Comments																				

Station	12	CTD No	29	Date	6th Mar 2011	CTD frame type: SS ☐
Latitude	1 10.57 S	Event No		Time I/W (GMT)	0633	
Longitude	25 47.5 W	Depth	4930	Time bottom (GMT)	0653	
Filename		Cast Depth	500	Time O/W (GMT)		
Weather	Dark with chances of rain later but otherwise hot and sticky					

Fire Seq	Rosette Pos^{n}	Bot. No.	Depth (m)	Location	Label ID	O2 1 L Anouska	Nuts 0.5 L Malc	DIC 1 L Eith	DOC 0.2 L Eith/Eric	N2 fix 5 L David	Bio 10 L Eliz	Salts 0.2 L Alex	DOP 1 L Claire	P work 10 L Claire	Thorium 5 L Katsia	Total NifH 3 L Tobi	N2 fix 20 L Tobi	Tricho 20 L Joe	Protein 5 L Eliz	Comments
1	1	1	500		29_1	X	X	X	X			X	X			X			X	
2	2	2	275	TOBI	29_2	X	X	X	X			X	X			X				
3	3	3	275	TOBI	29_3		X										X			
4	4	4	200		29_4	X	X	X	X			X	X			X				
5	5	5	85	DS + 25	29_5	X	X	X	X			X	X			X				
6	6	6	70	DS	29_6		X					X	X	X		X				
7	7	7	70	DS	29_7	X	X	X	X		X								X	
8	8	8	60	DCM	29_8		X												X	
9	9	9	60	DCM	29_9		X										X			
10	10	10	60	DCM	29_10		X					X	X	X		X				
11	11	11	60	DCM	29_11	X	X	X	X	X	X									
12	12	12	50	LD4	29_12		X										X			
13	13	13	50	LD4	29_13		X						X	X		X				
14	14	14	50	LD4	29_14	X	X	X	X	X	X									
15	15	15	40	LD3	29_15	X	X	X	X	X	X									
16	16	16	40	LD3	29_16		X						X	X		X				
17	17	17	20	LD2	29_17	X	X	X	X	X	X									
18	18	18	20	LD2	29_18		X					X	X	X		X				
19	19	19	20	LD2	29_19		X										X			
20	20	20	2	Surface	29_20		X												X	
21	21	21	2	Surface	29_21		X										X			
22	22	22	2	Surface	29_22		X						X	X		X				
23	23	23	2	Surface	29_23		X											x		
24	24	24	2	Surface	29_24	X	X	X	X	X	X									
				Analyst																

Comments

Tobi move LD3 to 300m; Anouska 'different bottles'

Station	13	CTD No	31	Date	7th Mar 2011	CTD frame type:
Latitude	01 09.27 N	Event No		Time I/W (GMT)	0636	
Longitude	26 02.6 W	Depth	3685	Time bottom (GMT)	0651	SS ☐
Filename		Cast Depth	500	Time O/W (GMT)		
Weather	Dark and hot, becoming lighter, no doubt hotter later					

Fire Seq	Rosette Pos^{n}	Bot. No.	Depth (m)	Location	Label ID	O2 1 L Anouska	Nuts 0.5 L Malc	DIC 1 L Eith	DOC 0.2 L Eith/Eric	N2 fix 5 L David	Bio 10 L Eliz	Salts 0.2 L Alex	DOP 1 L Claire	P work 10 L Claire	Thorium 5 L Katsia	Total NifH 3 L Tobi	N2 fix 20 L Tobi	Tricho 20 L Joe	Protein 5 L Eliz	Comments
1	1	1	500		31_1	X	X	X	X			X	X		X	X			X	
2	2	2	300		31_2	X	X	X	X			X	X		X	X				
3	3	3	300		31_3		X										X			
4	4	4	120		31_4	X	X	X	X			X	X		X	X				
5	5	5	90	DS+25	31_5	X	X	X	X			X	X		X	X				
6	6	6	75	DS	31_6		X					X	X	X	X					EMPTY
7	7	7	75	DS	31_7	X	X	X	X		X								X	EMPTY
8	8	8	60	DCM	31_8		X												X	
9	9	9	60	DCM	31_9		X										X			
10	10	10	60	DCM	31_10		X						X	X	X	X				
11	11	11	60	DCM	31_11	X	X	X	X	X	X									EMPTY
12	12	12	50	LD4	31_12		X					X					X			
13	13	13	50	LD4	31_13		X						X	X	X	X				
14	14	14	50	LD4	31_14	X	X	X	X	X	X	X								
15	15	15	40	LD3	31_15	X	X	X	X	X	X									
16	16	16	40	LD3	31_16		X						X	X	X	X				
17	17	17	20	LD2	31_17	X	X	X	X	X	X									
18	18	18	20	LD2	31_18		X					X	X	X	X	X				
19	19	19	20	LD2	31_19		X										X			
20	20	20	2	Surface	31_20		X												X	
21	21	21	2	Surface	31_21	LEAKED														LEAKED
22	22	22	2	Surface	31_22		X						X	X	X	X				
23	23	23	2	Surface	31_23		X											X		
24	24	24	2	Surface	31_24	X	X	X	X	X	X									
				Analyst																

Comments

Tobi move LD3 to ~300m; Anouska 'different bottles'

Station	14	CTD No	33	Date	8th Mar 2011	CTD frame type: SS ☐
Latitude	3 19.32 N	Event No		Time I/W (GMT)	0635	
Longitude	26 48.23 W	Depth	4238	Time bottom (GMT)	0650	
Filename		Cast Depth	500	Time O/W (GMT)		
Weather	Raining oddly enough but still dark; Now dry and a little bit greyer; now raining again					

Fire Seq	Rosette Pos^{n}	Bot. No.	Depth (m)	Location	Label ID	O2 1 L Anouska	Nuts 0.5 L Malc	DIC 1 L Eith	DOC 0.2 L Eith/Eric	N2 fix 5 L David	Bio 10 L Eliz	Salts 0.2 L Alex	DOP 1 L Claire	P work 10 L Claire	Thorium 5 L Katsia	Total NifH 3 L Tobi	N2 fix 20 L Tobi	Tricho 20 L Joe	Protein 5 L Eliz	Comments
1	1	1	500	500m	33_1	X	X	X	X			X	X			X			X	
2	2	2	300	TOBI	33_2	X	X	X	X			X	X			X				
3	3	3	300	TOBI	33_3		X										X			
4	4	4	140		33_4	X	X	X	X			X	X			X				
5	5	5	80	DS +25	33_5	X	X	X	X			X	X			X				
6	6	6	60	DS	33_6		X					X	X	X		X				
7	7	7	60	DS	33_7	X	X	X	X		X								X	
8	8	8	55	DCM	33_8		X					X							X	
9	9	9	55	DCM	33_9		X										X			
10	10	10	55	DCM	33_10		X						X	X		X				
11	11	11	55	DCM	33_11	X	X	X	X	X	X									
12	12	12	45	LD4	33_12		X										X			
13	13	13	45	LD4	33_13		X					X	X	X		X				
14	14	14	45	LD4	33_14	X	X	X	X	X	X									
15	15	15	35	LD3	33_15	X	X	X	X	X	X									
16	16	16	35	LD3	33_16		X					X	X	X		X				
17	17	17	20	LD2	33_17	X	X	X	X	X	X									
18	18	18	20	LD2	33_18		X						X	X		X				
19	19	19	20	LD2	33_19		X										X			
20	20	20	2	Surface	33_20		X											X	X	JOE- 5L SHORT
21	21	21	2	Surface	33_21	LEAKED														LEAKED
22	22	22	2	Surface	33_22		X						X	X		X				
23	23	23	2	Surface	33_23	LEAKED														LEAKED
24	24	24	2	Surface	33_24	X	X	X	X	X	X									
				Analyst																

Comments

Tobi @ 300m; Anouska 'Different bottles'

Station	15	CTD No	35	Date	9th Mar 2011	CTD frame type:
Latitude	5 39.66 N	Event No		Time I/W (GMT)	0635	
Longitude	27 29.32	Depth	4472	Time bottom (GMT)	0653	SS ☐
Filename		Cast Depth	500	Time O/W (GMT)		
Weather	Dark with a bit of a nip in the air; maybe sunny later maybe not.					

Fire Seq	Rosette Pos^{n}	Bot. No.	Depth (m)	Location	Label ID	O2 1 L Anouska	Nuts 0.5 L Malc	DIC 1 L Eith	DOC 0.2 L Eith/Eric	N2 fix 5 L David	Bio 10 L Eliz	Salts 0.2 L Alex	DOP 1 L Claire	P work 10 L Claire	Thorium 5 L Katsia	Total NifH 3 L Tobi	N2 fix 20 L Tobi	Tricho 20 L Joe	Protein 5 L Eliz	Comments
1	1	1	500		35_1	X	X	X	X			X	X			X			X	
2	2	2	300	TOBI	35_2	X	X	X	X			X	X			X				
3	3	3	300	TOBI	35_3		X										X			
4	4	4	160		35_4	X	X	X	X			X	X			X				
5	5	5	90		35_5	X	X	X	X			X	X			X				
6	6	6	70	DS	35_6		X					X	X	X		X				
7	7	7	70	DS	35_7	X	X	X	X		X								X	
8	8	8	47	DCM	35_8		X						X	X		X				+LIZ/DAVID
9	9	9	47	DCM	35_9		X										X			
10	10	10	47	DCM	35_10	LEAKED														LEAKED
11	11	11	47	DCM	35_11	X	X	X	X	X	X								X	EMPTY
12	12	12	38	LD4	35_12		X										X			
13	13	13	38	LD4	35_13		X					X	X	X		X				
14	14	14	38	LD4	35_14	X	X	X	X	X	X									
15	15	15	30	LD3	35_15	X	X	X	X	X	X									
16	16	16	30	LD3	35_16		X					X	X	X		X				
17	17	17	20	LD2	35_17	X	X	X	X	X	X									
18	18	18	20	LD2	35_18		X					X	X	X		X				
19	19	19	20	LD2	35_19		X										X			+LIZ/DAVID
20	20	20	2	Surface	35_20		X											X		←
21	21	21	2	Surface	35_21		X										X			LIZ FROM UW
22	22	22	2	Surface	35_22		X						X	X		X				
23	23	23	2	Surface	35_23	X	X	X	X	X	X									
24	24	24	2	Surface	35_24	N/F														N/F
				Analyst																

Comments

Tobi @ 300m; Anouska 'different bottles'.

Station	16	CTD No	37	Date	10-3-11	CTD frame type: SS ☐
Latitude	8 20.3N	Event No		Time I/W (GMT)	06:33	
Longitude	28 19.7 W	Depth	4725	Time bottom (GMT)	06:48	
Filename		Cast Depth	500	Time O/W (GMT)		
Weather	Dark; not so hot; possibly cloudy, but definitely dark					

Fire Seq	Rosette Pos^{n}	Bot. No.	Depth (m)	Location	Label ID	O2 1 L Anouska	Nuts 0.5 L Malc	DIC 1 L Eith	DOC 0.2 L Eith/Eric	N2 fix 5 L David	Bio 10 L Eliz	Salts 0.2 L Alex	DOP 1 L Claire	P work 10 L Claire	Thorium 5 L Katsia	Total NifH 3 L Tobi	N2 fix 20 L Tobi	Tricho 20 L Joe	Protein 5 L Eliz	Comments
1	1	1	500		37_1	X	X	X	X			X	X		X	X			X	
2	2	2	300	I	37_2	X	X	X	X			X	X		X	X				
3	3	3	300		37_3		X										X			
4	4	4	170		37_4	LEAKED														
5	5	5	90	DS +25	37_5	X	X	X	X			X	X		X	X				
6	6	6	70	DS	37_6		X						X	X	X	X				
7	7	7	70	DS	37_7	X	X	X	X		X									EMPTY
8	8	8	57	DCM	37_8		X					X							X	
9	9	9	57	DCM	37_9		X										X		X	
10	10	10	57	DCM	37_10		X						X	X	X	X				
11	11	11	57	DCM	37_11	X	X	X	X	X	X									
12	12	12	49	LD4	37_12		X										X			
13	13	13	49	LD4	37_13		X					X	X	X	X	X				
14	14	14	49	LD4	37_14	X	X	X	X	X	X									
15	15	15	30	LD3	37_15	X	X	X	X	X	X									
16	16	16	30	LD3	37_16		X					X	X	X	X	X				
17	17	17	20	LD2	37_17	X	X	X	X	X	X									
18	18	18	20	LD2	37_18		X						X	X	X	X				
19	19	19	20	LD2	37_19		X										X			
20	20	20	2	Surface	37_20		X										X			
21	21	21	2	Surface	37_21	LEAKED														
22	22	22	2	Surface	37_22		X						X	X	X	X				
23	23	23	2	Surface	37_23	X	X	X	X	X	X							X		
24	24	24	2	Surface	37_24	N/F	N/F												X	
				Analyst																

Comments: Tobi 0 300m

Station	17	CTD No	39	Date	11-3-11	CTD frame type: SS ☐
Latitude	8 37N	Event No		Time I/W (GMT)	06:30	
Longitude	28 43 W	Depth	5593	Time bottom (GMT)	06:48	
Filename		Cast Depth	500	Time O/W (GMT)		
Weather	Have lost the will to look – probably dark again					

Fire Seq	Rosette Pos^{n}	Bot. No.	Depth (m)	Location	Label ID	O2 1 L Anouska	Nuts 0.5 L Malc	DIC 1 L Eith	DOC 0.2 L Eith/Eric	N2 fix 5 L David	Bio 10 L Eliz	Salts 0.2 L Alex	DOP 1 L Claire	P work 10 L Claire	Thorium 5 L Katsia	Total NifH 3 L Tobi	N2 fix 20 L Tobi	Tricho 20 L Joe	Protein 5 L Eliz	Comments
1	1	1	500		39_1	X	X	X	X			X	X			X			X	
2	2	2	340	I	39_2	X	X	X	X			X	X			X				
3	3	3	340		39_3		X										X			
4	4	4	200		39_4	X	X	X	X			X				X				
5	5	5	100	DS +25	39_5	X	X	X	X			X	X			X				
6	6	6	80	DS	39_6		X					X	X	X		X				
7	7	7	80	DS	39_7	X	X	X	X		X								X	
8	8	8	60	DCM	39_8		X					X							X	
9	9	9	60	DCM	39_9		X										X			
10	10	10	60	DCM	39_10		X						X	X		X				
11	11	11	60	DCM	39_11	X	X	X	X	X	X									
12	12	12	50	LD4	39_12		X										X			
13	13	13	50	LD4	39_13		X					X	X	X		X				
14	14	14	50	LD4	39_14	X	X	X	X	X	X									
15	15	15	30	LD3	39_15	X	X	X	X	X	X									
16	16	16	30	LD3	39_16		X						X	X		X				
17	17	17	20	LD2	39_17	X	X	X	X	X	X									
18	18	18	20	LD2	39_18		X					X	X	X		X				
19	19	19	20	LD2	39_19	LEAKED														
20	20	20	2	Surface	39_20		X												X	
21	21	21	2	Surface	39_21		X										X			
22	22	22	2	Surface	39_22		X						X	X	X	X				
23	23	23	2	Surface	39_23	X	X	X	X	X	X							X		
24	24	24	2	Surface	39_24	N/F	N/F													
				Analyst																
Comments																				

Station	18	CTD No	42	Date	12-3-11	CTD frame type: SS ☐
Latitude	12 2.4N	Event No		Time I/W (GMT)		
Longitude	28 58.9W	Depth	5639	Time bottom (GMT)		
Filename		Cast Depth	500	Time O/W (GMT)		
Weather	Dark; cold and dark.					

Fire Seq	Rosette Pos^{n}	Bot. No.	Depth (m)	Location	Label ID	O2 1 L Anouska	Nuts 0.5 L Malc	DIC 1 L Eith	DOC 0.2 L Eith/Eric	N2 fix 5 L David	Bio 10 L Eliz	Salts 0.2 L Alex	DOP 1 L Claire	P work 10 L Claire	Thorium 5 L Katsia	Total NifH 3 L Tobi	N2 fix 20 L Tobi	Tricho 20 L Joe	Protein 5 L Eliz	Comments
1	1	1	500	500	42_1	X	X	X	X			X	X			X			X	
2	2	2	400	02 Min	42_2	LEAKED														
3	3	3	300	Tobi	42_3		X										X			
4	4	4	300	Tobi	42_4	X	X	X	X			X	X			X				
5	5	5	100	DS +25	42_5	X	X	X	X			X	X			X				
6	6	6	75	DS	42_6		X					X	X	X		X				
7	7	7	75	DS	42_7	X	X	X	X		X								X	
8	8	8	68	DCM	42_8		X												X	
9	9	9	68	DCM	42_9		X										X			
10	10	10	68	DCM	42_10		X						X	X		X				
11	11	11	68	DCM	42_11	X	X	X	X	X	X									
12	12	12	56	LD4	42_12		X										X			
13	13	13	56	LD4	42_13		X					X	X	X		X				
14	14	14	56	LD4	42_14	X	X	X	X	X	X									
15	15	15	40	LD3	42_15	X	X	X	X	X	X	X								
16	16	16	40	LD3	42_16		X						X	X		X				
17	17	17	20	LD2	42_17	X	X	X	X	X	X									
18	18	18	20	LD2	42_18		X						X	X		X				
19	19	19	20	LD2	42_19		X										X			
20	20	20	2	Surface	42_20		X												X	
21	21	21	2	Surface	42_21		X										X			
22	22	22	2	Surface	42_22		X						X	X		X				
23	23	23	2	Surface	42_23		X											X		
24	24	24	2	Surface	42_24	X	X	X	X	X	X									
				Analyst																
Comments																				

Station	19	CTD No	43	Date	13 Mar 2011	CTD frame type:
Latitude	15 30.6	Event No		Time I/W (GMT)	06:33	
Longitude	28 46.9	Depth	5069	Time bottom (GMT)	06:48	SS ☐
Filename		Cast Depth	500	Time O/W (GMT)		
Weather						

Fire Seq	Rosette Pos^{n}	Bot. No.	Depth (m)	Location	Label ID	O2 1 L Anouska	Nuts 0.5 L Malc	DIC 1 L Eith	DOC 0.2 L Eith/Eric	N2 fix 5 L David	Bio 10 L Eliz	Salts 0.2 L Alex	DOP 1 L Claire	P work 10 L Claire	Thorium 5 L Katsia	Total NifH 3 L Tobi	N2 fix 20 L Tobi	Tricho 20 L Joe	Protein 5 L Eliz	Comments
1	1	1	500	500m	43_1	X	X	X	X			X	X		X	X				
2	2	2	400	O_2 Min	43_2	X	X	X	X			X	X		X	X				
3	3	3	300	TOBI	43_3	LEAKED														
4	4	4	300	TOBI	43_4	X	X	X	X			X	X		X	X				
5	5	5	120	DS + 25	43_5	X	X	X	X			X	X		X	X				
6	6	6	95	DS	43_6		X					X	X	X	X	X				
7	7	7	95	DS	43_7	X	X	X	X		X									
8	8	8	78	DCM	43_8		X					X								
9	9	9	78	DCM	43_9		X										X			
10	10	10	78	DCM	43_10		X						X	X	X	X				
11	11	11	78	DCM	43_11	X	X	X	X	X	X									
12	12	12	67	LD4	43_12		X										X			
13	13	13	67	LD4	43_13		X					X	X	X	X	X				
14	14	14	67	LD4	43_14	X	X	X	X	X	X									
15	15	15	50	LD3	43_15	X	X	X	X	X	X									
16	16	16	50	LD3	43_16		X						X	X	X	X				
17	17	17	20	LD2	43_17	X	X	X	X	X	X									
18	18	18	20	LD2	43_18		X						X	X	X	X				
19	19	19	20	LD2	43_19	LEAKED														
20	20	20	2	Surface	43_20		X												X	
21	21	21	2	Surface	43_21		X										X			
22	22	22	2	Surface	43_22		X						X	X	X	X				
23	23	23	2	Surface	43_23		X											X		
24	24	24	2	Surface	43_24	X	X	X	X	X	X									
				Analyst																
Comments																				

Station	20	CTD No	45	Date	14 Mar 2011	CTD frame type:
Latitude	17 23.9	Event No		Time I/W (GMT)	07:05	
Longitude	28 23.3	Depth	4644	Time bottom (GMT)	07:15	SS ☐
Filename		Cast Depth	500	Time O/W (GMT)		
Weather	Dark again, dawn approaching; not so hot.					

Fire Seq	Rosette Pos^{n}	Bot. No.	Depth (m)	Location	Label ID	O2 1 L Anouska	Nuts 0.5 L Malc	DIC 1 L Eith	DOC 0.2 L Eith/Eric	N2 fix 5 L David	Bio 10 L Eliz	Salts 0.2 L Alex	DOP 1 L Claire	P work 10 L Claire	Thorium 5 L Katsia	Total NifH 3 L Tobi	N2 fix 20 L Tobi	Tricho 20 L Joe	Protein 5 L Eliz	Comments
1	1	1	500	500m	45_1	X	X	X	X			X	X			X			X	
2	2	2	400	O_2 Min	45_2	X	X	X	X			X	X			X				
3	3	3	300	TOBI	45_3												X			
4	4	4	300	TOBI	45_4	LEAKED														LEAKED
5	5	5	130	DS + 25	45_5	X	X	X	X		X	X	X			X			X	
6	6	6	105	DS	45_6	LEAKED														LEAKED
7	7	7	105	DS	45_7	X	X	X	X				X	X		X			X	
8	8	8	90	DCM	45_8		X												X	
9	9	9	90	DCM	45_9		X										X			
10	10	10	90	DCM	45_10		X					X	X	X		X				
11	11	11	90	DCM	45_11	X	X	X	X	X	X									
12	12	12	74	LD4	45_12		X										X			
13	13	13	74	LD4	45_13		X					X	X	X		X				
14	14	14	74	LD4	45_14	X	X	X	X	X	X									
15	15	15	55	LD3	45_15	X	X	X	X	X	X									
16	16	16	55	LD3	45_16		X					X	X	X		X				
17	17	17	25	LD2	45_17	X	X	X	X	X	X									
18	18	18	25	LD2	45_18		X					X	X	X		X				
19	19	19	25	LD2	45_19		X										X			
20	20	20	2	Surface	45_20		X												X	
21	21	21	2	Surface	45_21	LEAKED														LEAKED
22	22	22	2	Surface	45_22		X						X	X		X				
23	23	23	2	Surface	45_23		X											X		
24	24	24	2	Surface	45_24	X	X	X	X	X	X									
				Analyst																
Comments																				

Station	21	CTD No	48	Date	15 Mar 2011	CTD frame type:
Latitude	19 06.55 N	Event No		Time I/W (GMT)	06:36	
Longitude	28 07.781 W	Depth	4706	Time bottom (GMT)	07:03	SS ☐
Filename		Cast Depth	500	Time O/W (GMT)		
Weather	Dark and Windy.					

Fire Seq	Rosette Pos^{n}	Bot. No.	Depth (m)	Location	Label ID	O2 1 L Anouska	Nuts 0.5 L Malc	DIC 1 L Eith	DOC 0.2 L Eith/Eric	N2 fix 5 L David	Bio 10 L Eliz	Salts 0.2 L Alex	DOP 1 L Claire	P work 10 L Claire	Thorium 5 L Katsia	Total NifH 3 L Tobi	N2 fix 20 L Tobi	Tricho 20 L Joe	Protein 5 L Eliz	Comments
1	1	1	500	280	48_1	X	X	X	X			X	X			X			X	
2	2	2	280	280	48_2	X	X	X	X			X	X			X				
3	3	3	280	220	48_3											X	X			
4	4	4	220	150	48_4	X	X	X	X			X	X			X				
5	5	5	150	110	48_5	X	X	X	X			X	X			X				
6	6	6	110	75	48_6	X	X	X	X		X		X	1L		X			X	
7	7	7	75	75	48_7		X													
8	8	8	75	75	48_8		X												X	
9	9	9	75	75	48_9		X										X			
10	10	10	75	75	48_10		X					X	X	X		X				
11	11	11	75	60	48_11	X	X	X	X	X	X									
12	12	12	60	60	48_12		X										X			
13	13	13	60	60	48_13		X						X	X		X				
14	14	14	60	40	48_14	X	X	X	X	X	X									
15	15	15	40	40	48_15	LEAKED														LEAKED
16	16	16	40	20	48_16	X	X	X	X	X	X		X	1L		X				
17	17	17	20	20	48_17	X	X	X	X	X	X									
18	18	18	20	20	48_18		X						X	X		X				
19	19	19	20	5	48_19		X			X	X						X			
20	20	20	5	5	48_20		X												X	
21	21	21	5	5	48_21		X										X			
22	22	22	5	5	48_22		X						X	X		X				
23	23	23	5	5	48_23		X											X		
24	24	24	5	500	48_24	X	X	X	X	X		X								
				Analyst																

Comments

Bottle 24 fired at 500m, confirmed by temperature and nutrients. Bottles fired at depth above i.e. 1+2 @ 280m, 3 @ 220m, see location for new depth.
Only one bottle fired at DCM

Station	21	CTD No	49	Date	15/03/11	CTD frame type:
Latitude	19 08.784	Event No		Time I/W (GMT)	1008	SS ☐
Longitude	28 07.534	Depth	4667	Time bottom (GMT)	1034	
Filename		Cast Depth	1000	Time O/W (GMT)		
Weather						

Fire Seq	Rosette Pos^{n}	Bot. No.	Depth (m)	Location	Label ID	Pa/Th	Nuts 0.5 L Malc	O2	PIC/POC /CHL/BSI JOE/DA VID	Bio 10 L Eliz	TOBI				Thorium 5 L Katsia	Total NifH 3 L Tobi	N2 fix 20 L Tobi			Comments
1	1	1	1000		49_1		X								X					
2	2	2	1000		49_2		X								X					
3	3	3	1000		49_3		X								X					
4	4	4	1000		49_4	LEAKED														
5	5	5	1000		49_5		X								X					
6	6	6	1000		49_6	X	X													
7	7	7	1000		49_7		X	X		X					X					
8	8	8	750		49_8		X	X		X										
9	9	9	750		49_9	X	X													
10	10	10	500		49_10	X	X	X		X										
11	11	11	500		49_11		X				X									
12	12	12	300		49_12		X	X												
13	13	13	200		49_13	X	X	X												
14	14	14	100		49_14		X		X						X					
15	15	15	100		49_15	X	X													
16	16	16	80		49_16		X		X						X					
17	17	17	60		49_17		X		X						X					
18	18	18	50		49_18		X		X						X					
19	19	19	40		49_19		X		X						X					
20	20	20	40		49_20	X	X				X									
21	21	21	30		49_21		X		X						X					
22	22	22	20		49_22	LEAKED														
23	23	23	20		49_23	X	X		X						X					
24	24	24	10		49_10		X	X	X						X					
				Analyst																
Comments																				