National Oceanography Centre, Southampton

Cruise Report No. 8

RRS *Discovery* Cruise 288

26 JAN – 21 FEB 2005

Madagascar Experiment (MadEx)

Principal Scientist

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2006

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DOCUMENT DATA SHEET

AUTHOR	*PUBLICATION DATE*
QUARTLY, G D et al	2006

TITLE

RRS *Discovery* Cruise 288, 26 Jan - 21 Feb 2005. Madagascar Experiment (MadEx).

REFERENCE

Southampton, UK: National Oceanography Centre, Southampton, 105pp.

(National Oceanography Centre Southampton Cruise Report, No. 8)

ABSTRACT

MadEx (Madagascar Experiment) was a research cruise on *RRS Discovery* with the aims of i) surveying the currents south of Madagascar, ii) deploying moorings, and iii) relating the different biological communities to the physical and chemical conditions (temperature, currents and nutrients). The cruise departed from Durban on 26th January 2005, and returned there on 21st February. An eddy/retroflection signal was seen in ocean colour imagery south of Madagascar, and a "radiator grille" survey pattern adopted. This was achieved with a mixture of SeaSoar tows, CTDs and XBTs, with *Jason* track 196 being occupied at the time of the altimeter overflight. An array of moorings was also laid along this line, with a McLane Moored Profiler placed 120 km further east. A number of surface drifters were also deployed, including the new Pop-up Ocean Drifters.

Numerous underway measurements were made. As well as the shipborne ADCPs and standard instrumentation on the non-toxic supply, surface water samples were taken typically every 2 hours to determine salinity and chlorophyll, and other samples kept for subsequent microscopic and flow cytometry analyses. For zooplankton studies, there were vertical hauls of Bongo nets at half the CTD stations. Extra biological information was provided by the Optical Plankton Counter (OPC), Fast Repetition Rate Fluorometer (FRRF) and the Turner Fluorometer, which were all working well on SeaSoar during the latter part of the cruise.

MadEx II (Discovery cruise D302) recovered the moorings 14 months later, and repeated some of the biological and physical measurements along the mooring line; it is the subject of a separate cruise report.

KEYWORDS

ADCP, cruise 288 2005, CTD, currents, *Discovery*, FRRF, Madagascar, MadEx, moorings, OPC, phytoplankton, SeaSoar, SW Indian Ocean, zooplankton

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OBJECTIVES

MadEx (Madagascar Experiment) was a cruise supported by the James Rennell Division's core strategic programme *Ocean Variability and Climate*. Its overall aim was to look at the variability in the flow south of Madagascar and its effect upon the biology there. The area is important because it provides one of the sources of the Agulhas Current, and thus will have a major bearing on which Indian Ocean water masses are being fed into the South Atlantic through the global thermohaline circulation. There were three specific objectives to this cruise:

- To measure the currents and/or eddy features to the south of Madagascar, preferably coinciding with an altimeter overpass
- To deploy moorings for long-term measurements of currents
- To make two surveys of a feature about a week apart, examining how the biological communities have evolved in that time.

The loss of 5 days working in this area (due to a compassionate evacuation) precluded any effort on the third objective, but did give us a serendipitous section further east than was originally planned.

1. Cruise Narrative

Graham Quartly

Discovery cruise D288, MadEx (Madagascar Experiment) followed on after two CROZEX cruises, which had made a variety of physical, chemical and biological measurements in the area around the Crozet Islands. Being programmed after these cruises meant that less mobilization time was required (as a lot of the equipment was already on board and set up), although there were some last-minute delays, including awaiting a replacement CTD package for the SeaSoar.

The ship eventually set sail from Durban at 12:00 GMT on 26th January 2005 (Julian day, JDay 026). Once we had left the protection of Durban harbour, the vessel headed in a northeasterly direction for several hours to provide a lengthy period of constant velocity over shallow sea-bed in order to provide bottom-tracking data for calibrating the vessel-mounted ADCPs. At 22:30 the ship turned to head east, aiming for a location south of Madagascar.

At ~14:00 on JDay 027 some trial dips of equipment were made — first a shallow dip of the rosette of Niskin bottles, then SeaSoar was deployed vertically off the aft of the ship and recovered, and then the rosette deployed again. The idea was to test the intercalibration of the CTD packages on each. Then the original route was resumed, with another pair of dips 24 hours later, when a different CTD unit had been fitted to the SeaSoar (see section 5.4.2).

Upon reaching 40˚E (at 02:30 on JDay 029) the SeaSoar was deployed again, and later the ship track changed to eastward towards the start point of the chosen "radiator grille" survey pattern (see Fig. 2). The first leg (northward) was commenced at 15:50 on JDay 030. However, there were clear communications problems by 19:00 (halfway up the leg), and SeaSoar had to be recovered in rough conditions. The rest of this leg was then completed using 3 full-depth CTDs.

At 12:40 on JDay 031 we reached the start (northernmost point) of the second leg, did a full-depth CTD, followed by nets, and then deployed SeaSoar (which had been repaired by this time). Unfortunately, only half a leg was run by SeaSoar before it failed again; the leg was completed with shallow (500 m) CTDs, so that we could add the Turner fluorometer, *Cyclops*, (which is not depth-rated below 500 m) to the rosette package. The first XBTs were also used in this line.

The southern point of the third leg was reached at 19:20 on JDay 033, and, as SeaSoar was not then ready, the whole leg was occupied with 7 full depth CTDs, and intermediate XBTs. Bongo nets were also deployed to 200 and/or 800 m at three of these CTD stations. As SeaSoar was still not ready, plans were changed radically, with transit to the northernmost mooring site, with a CTD there prior to mooring work (completed at 12:00 on JDay 034). Then *Discovery* headed north along this key section (leg 7), performing CTDs until the water depth was shallower than 200 m. Care had to be taken, as the area is only moderately-well charted, and there are many sea mounts believed to rise to close to the surface.

After that, we proceeded to the southeast corner of Madagascar, and ran a detailed CTD line out to the mooring site of the McLane Moored Profiler (MMP). The actual bathymetry differed significantly from the database to hand, and on one occasion when depth had increased much more rapidly than envisaged, the ship retraced its route to insert another CTD (sta. 15668) at an intermediate water depth.

Approximately two thirds of the way along this section coincided with the centre of a water mass low in chlorophyll concentration, according to satellite imagery. Onboard ADCP showed a strong southwestward current, confirming that this was the core of the East Madagascar Current (EMC). The four PODs were deployed here, followed by one of the *Clearsat* surface drifters (17:30 On JDay 035).

When this section had been completed, the MMP was deployed (09:00 On JDay 036). By then SeaSoar had been fully repaired, with a new termination to the cable. Then commenced 4 days of continuous SeaSoar surveying, as we traversed the remaining legs of the radiator grille, including northwards along leg 7 on JDay 037, the day of the Jason overpass. The SeaSoar work finished at mooring 1, and another CTD was done there. The plan was to continue southward along leg 7, recording deeper information using CTDs and interspersed XBTs, with the other two moorings being deployed.

However, after the central mooring of the line had been laid, we learnt that one member of the technical team needed to return to the UK to attend an ill relative. We were advised that Réunion was the most appropriate port, with this detour taking up 5 of our remaining 7 working days. Because of haste, the leg to Réunion was done without any CTD or SeaSoar operations. To give people a rest, watch duties were reduced between leaving the mooring site at 14:40 on JDay 041 and reaching Réunion at 04:30 on JDay 044. The boat transfer was effected at 07:00, and then *Discovery* headed back towards the point where operations had been suspended, with regular underway sampling being resumed. (We did not have diplomatic clearance to do any sampling whilst within 200 km of Réunion.)

Having acquired satellite images of the area east of Madagascar, and noted a strong cyclonic feature to the south of the return route (see Fig. 5a), a further change of plan was made. SeaSoar was deployed, now with modifications to the OPC and the Turner fluorometer installed, and a SSW route followed just to the east of the feature's centre. [The track was intended to be along a Jason pass, coincident with a satellite overflight, but was inadvertently 8 km to the west of the satellite nadir track.] The second *Clearsat* buoy was released (03:40 on JDay 046) just to the south of the eddy centre, thus guaranteeing it an initial westward trajectory. Unfortunately time did not permit any CTDs along this interesting section.

On the journey to the final mooring site there was a further dog-leg, so as to reach the centre of an anticyclonic feature identified in further ocean colour imagery. The final mooring was deployed at 12:30 on JDay 047; however, efforts to complete the full CTD section were beset with problems — stormy conditions affecting CTD deployment and retarding progress south, the CTD winch not working, and the air conditioning completely failing leading to high temperature everywhere inside the ship, but of critical importance for the computer room. On top of that, the echo sounder stopped tracking the sea-bed, and feed from the gyro failed.

SeaSoar was deployed for the start of the return leg, and, guided by very recent satellite-derived chlorophyll data, we were able to instigate several sections across an unusual linear feature. SeaSoar was recovered at 10:00 on JDay 049, and all other operations ceased soon after to allow time for the last crate of salts to be done, data to be backed up, and contributions to the cruise report to be written.

We reached Durban some 12 hours earlier than needed, and finally reached harbour at 09:00 on JDay 052. The frozen samples (for HPLC analysis) were packed in dry ice in freezer boxes and collected by courier on the following day.

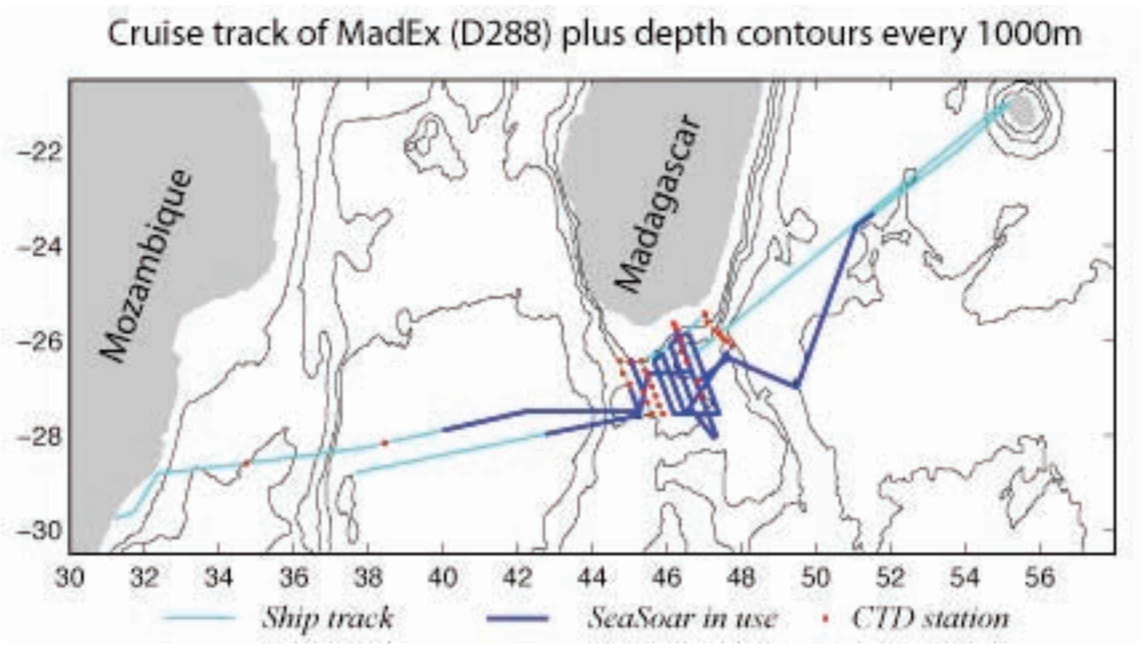

Figure 1 : Actual cruise track, showing CTD and SeaSoar operations.

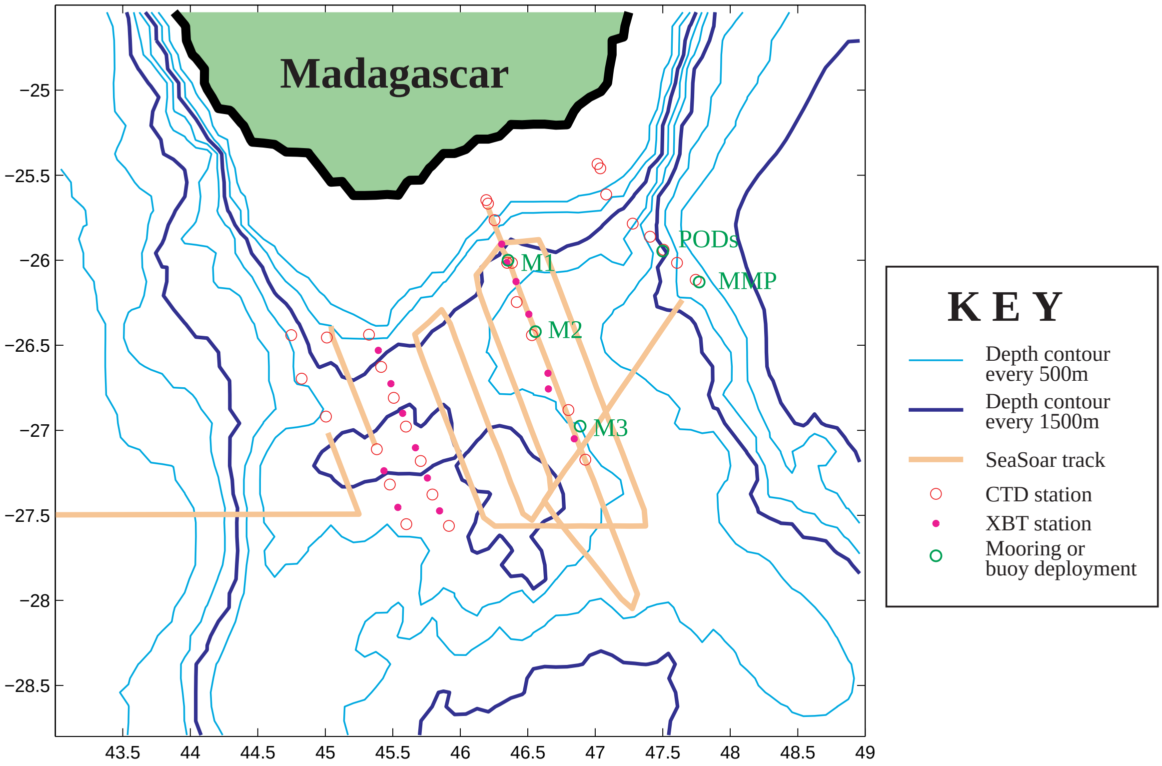

Figure 2 : Detail of survey work south of Madagascar. Final SeaSoar line (heading west from M2) not shown to avoid congestion in plot.

1.1 List of stations

		START			END			
Station No.	**Instrument**	**Date DD/MM/YY**	**Time (GMT) HH:MM**	**Latitude Longitude**	**Date DD/MM/YY**	**Time (GMT) HH:MM**	**Latitude Longitude**	**Comments**
15635 #1	CTD	27/01/05	14:44	28 35.64S 34 34.81E	27/01/05	15:12	28 59.57S 34 73.55E	Trial
15635 #2	SeaSoar	27/01/05	14:08	28 59.54S 34 74.19E	27/01/05	14:46	28 59.58S 34 73.53E	Trial: Vertical dip
15636 #1	CTD	28/01/05	13:35	28 11.02S 38 25.48E	28/01/05	15:03	28 10.84S 38 25.93E	Trial
15637	Seasoar	28/01/05	15:16	28 10.71S 38 26.25E	28/01/05	15:41	28 10.59S 38 26.50E	Trial: Vertical dip
15638	CTD	28/01/05	16:32	28 10.22S 38 26.86E	28/01/05	17:26	28 10.12S 38 26.96E	
15639	SeaSoar	29/01/05	02:31	27 90.38S 40 00.14E	30/01/05	19:56	27 01.52S 45 01.95E	Recovered due to communica-tions failure
15640 #1	CTD	30/01/05	23:12	26 55.07S 45 00.77E	31/01/05	00:53	26 55.17S 45 00.39E	
15640 #2	Bongo nets	31/01/05	01:05	26 55.04S 45 00.19E	31/01/05	01:30	26 54.89S 44 59.90E	200m
15641	CTD	31/01/05	03:30	26 41.48S 44 51.41E	31/01/05	05:30	26 41.85S 44 49.59E	
15642 #1	CTD	31/01/05	08:01	26 26.82S 44 45.08E	31/01/05	09:48	26 26.79S 44 45.15E	
15642 #2	Bongo nets	31/01/05	09:58	26 26.31S 44 44.92E	31/01/05	10:30	26 26.33S 44 49.36E	200 m
15643	CTD	31/01/05	12:40	26 26.89S 45 02.70E	31/01/05	14:00	26 26.96S 45 01.56E	
15643 #2	Bongo nets	31/01/05	14:05	26 27.32S 45 00.57E	31/01/05	14:30	26 27.49S 45 00.20E	200 m
15643 #3	Bongo nets	31/01/05	14:35	26 27.53S 45 00.14E	31/01/05	16:00	26 28.25S 44 59.22E	800 m

15644	Seasoar	31/01/05	20:54	26 38.73S 45 04.27E	01/02/05	05:17	27 05.38S 45 22.25E	Communications failure again
15645	CTD	01/02/05	07:53	27 06.70S 45 22.91E	01/02/05	08:05	27 06.41S 45 23.09E	
15646	XBT	01/02/05	10:00	27 14.32S 45 26.12E				
15647	CTD	01/02/05	11:12	27 19.47S 45 28.67E	01/02/05	12:00	27 19.07S 45 28.75E	
15648	XBT	01/02/05	13:25	27 27.25S 45 32.25E				
15649 #1	CTD	01/02/05	15:02	27 33.47S 45 35.50E	01/02/05	16:00	27 33.08S 45 35.99E	
15649 #2	Bongo nets	01/02/05	16:21	27 32.97S 45 36.20E	01/02/05	16:45	27 32.92S 45 36.44E	200 m
15650 #1	CTD	01/02/05	19:18	27 33.75S 45 53.64E	01/02/05	21:38	27 33.77S 45 54.90E	
15650 #2	Bongo nets	01/02/05	21:56	27 33.86S 45 55.13E	01/02/05	22:09	27 33.88S 45 5.32E	200 m
15650 #3	Bongo nets	01/02/05	22:21	27 33.92S 45 55.44E	01/02/05	23:09	27 34.10S 45 55.57E	800 m
15651	XBT	02/02/05	00:10	27 28.46S 45 50.77E				
15652	CTD	02/02/05	01:00	27 22.63S 45 48.12E	02/02/05	02:53	27 22.66S 45 47.69E	
15653	XBT	02/02/05	03:40	27 16.99S 45 45.52E				
15654	CTD	02/02/05	04:30	27 11.20S 45 42.71E	02/02/05	06:05	27 10.80S 45 42.37E	
15655	XBT	02/02/05	06:45	27 06.15S 45 40.11E				
15656 #1	CTD	02/02/05	07:59	26 59.79S 45 36.71E	02/02/05	09:58	26 58.69S 45 35.85E	
15656 #2	Bongo nets	02/02/05	10:08	26 58.50S 45 35.82E	02/02/05	10:18	26 58.39S 45 35.73E	200 m
15656 #3	Bongo nets	02/02/05	10:25	26 58.34S 45 35.67E	02/02/05	11:07	26 58.18S 45 35.53E	800 m
15657	XBT	02/02/05	11:38	26 54.07S 45 34.37E				
15658	CTD	02/02/05	12:30	26 48.93S 45 31.54E	02/02/05	14:00	26 48.49S 45 30.44E	
15659	XBT	02/02/05	14:41	26 43.57S 45 29.12E				
15660	CTD	02/02/05	15:42	26 37.81S 45 26.10E	02/02/05	17:32	26 37.67S 45 24.82E	
15661	XBT	02/02/05	18:19	26 31.79S 45 23.63E				
15662 #1	CTD	02/02/05	19:10	26 26.47S 45 20.78E	02/02/05	20:40	26 26.18S 45 19.35E	
15662 #2	Bongo nets	02/02/05	20:50	26 26.07S 45 19.16E	02/02/05	21:01	26 26.04S 45 18.98E	200 m
15663	CTD	03/02/05	04:15	26 00.16S 46 21.37E	03/02/05	08:05	26 00.72S 46 23.31E	
15663 #2	Bongo nets	03/02/05	06:38	26 00.16S 46 21.56E	03/02/05	06:52	26 00.29S 46 21.94E	200 m
15663 #3	Bongo nets	03/02/05	07:00	26 00.36S 46 22.14E	03/02/05	06:52	26 00.66S 46 22.91E	800 m
15664	Mooring	03/02/05	10:40	25 59.96S 46 21.18E	03/02/05	12:00	26 00.01S 46 21.18E	ADCP 1
15665 #1	CTD	03/02/05	19:25	25 25.80S 47 00.72E	03/02/05	20:01	25 26.01S 46 21.10E	
15665 #2	Bongo nets	03/02/05	20:11	25 26.04S 47 01.08E	03/02/05	20:22	25 26.06S 47 01.20E	1.1m above bottom
15666	CTD	03/02/05	21:25	25 27.66S 47 02.01E	03/02/05	22:23	25 27.61S 47 02.25E	
15667	CTD	04/02/05	00:24	25 39.38S 47 10.67E	03/02/05	02:30	25 41.36S 47 08.96E	
15668	CTD	04/02/05	03:47	25 35.19S 47 05.94E	04/02/05	05:15	25 36.74S 47 04.78E	
15669 #1	CTD	04/02/05	07:29	25 45.51S 47 18.04E	04/02/05	09:34	25 47.03S 47 16.61E	
15669 #2	Bongo nets	04/02/05	09:44	25 47.15S 47 16.38E	04/02/05	09:55	25 47.26S 47 16.22E	200 m
15669 #3	Bongo nets	04/02/05	10:02	25 47.49S 47 16.22E	04/02/05	10:48	25 48.39S 47 15.90E	800 m

15670	CTD	04/02/05	12:01	25 50.38S 47 24.22E	04/02/05	13:51	25 51.63S 47 24.33E	
15671	CTD	04/02/05	15:00	25 55.25S 47 30.42E	04/02/05	16:47	25 56.25S 47 30.25E	
15671 #2	Bongo nets	04/02/05	16:54	25 56.33S 47 30.22E	04/02/05	17:05	25 56.46S 47 30.16E	200 m
15672	PODs	04/02/05	17:20	25 56.62S 47 30.07E	04/02/05	17:35	25 56.82S 47 30.01E	
15673	CTD	04/02/05	18:54	26 00.49S 47 37.18E	04/02/05	21:52	25 51.22S 47 24.21E	Bottles didn't close
15674 #1	CTD	04/02/05	23:20	26 06.99S 47 44.74E	05/02/05	02:16	26 06.95S 47 44.73E	
15674 #2	Bongo nets	05/02/05	02:30	26 06.96S 47 44.81E	05/02/05	02:41	26 06.95S 47 44.84E	200 m
15675	Mooring	05/02/05	06:17	26 07.71S 47 46.20E	05/02/05	09:00	26 07.60S 47 46.18E	MMP
15676	Seasoar	05/02/05	11:00	26 14.01S 47 38.67E	09/02/05	13:30	25 40.40S 46 15.54E	
15677 #1	CTD	09/02/05	14:53	25 38.77S 46 11.49E	09/02/05	15:25	25 38.83S 46 11.47E	
15677 #2	Bongo nets	09/02/05	15:36	25 38.87S 46 11.52E	09/02/05	15:48	25 38.89S 46 11.47E	~130 m
15678	CTD	09/02/05	16:49	25 39.85S 46 12.20E	09/02/05	17:35	25 39.94S 46 12.36E	
15679	CTD	09/02/05	19:33	25 46.27S 46 14.76E	09/02/05	21:06	25 45.85S 46 15.18E	
15680	XBT	09/02/05	22:10	25 54.30S 46 18.43E				
15681 #1	CTD	09/02/05	23:14	26 01.33S 46 21.72E	10/02/05	00:38	26 00.87S 46 20.82E	
15681 #2	Bongo nets	10/02/05	00:52	26 00.83S 46 20.60E	10/02/05	01:03	26 00.80S 46 20.43E	200 m
15682	XBT	10/02/05	02:05	26 07.53S 46 24.86E				
15683	CTD	10/02/05	02:48	26 13.04S 46 27.35E	10/02/05	05:00	26 14.67S 46 25.15E	
15684	XBT	10/02/05	05:55	26 19.07S 46 30.48E				
15685 #1	CTD	10/02/05	06:46	26 25.26S 46 33.38E	10/02/05	09:18	26 26.40S 46 31.75E	
15685 #2	Bongo nets	10/02/05	09:29	26 26.49S 46 31.54E	10/02/05	09:42	26 26.64S 46 31.21E	200 m
15685 #3	Bongo nets	10/02/05	09:49	26 26.73S 46 31.10E	10/02/05	10:33	26 27.26S 46 30.42E	800 m
15686	Mooring	10/02/05	12:00	26 25.20S 46 33.32E	10/02/05	14:40	26 25.20S 46 33.40E	RCM 2
15687	Seasoar	14/02/05	08:30	23 19.31S 51 32.93E	16/02/05	12:00	26 53.39S 46 46.14E	
15688	Clearsat buoy	15/02/05	03:40	23 43.88S 50 05.27E				
15689 #1	CTD	16/02/05	07:16	26 53.75S 46 47.43E	16/02/05	09:18	26 52.86S 46 47.95E	
15689 #2	Bongo nets	16/02/05	09:25	26 52.80S 46 48.00E	16/02/05	10:34	26 52.19S 46 48.68E	200 and 800 m
15690	Mooring	16/02/05	11:20	26 58.32S 46 53.20E	16/02/05	12:30	26 54.00S 46 47.34E	ADCP 3
15691	XBT	16/02/05	14:10	27 03.01S 46 50.75E				
15692 #1	CTD	16/02/05	15:50	27 11.31S 46 55.46E	16/02/05	17:59	27 10.39S 46 55.62E	
15692 #2	Bongo nets	16/02/05	18:08	27 10.31S 46 55.67E	16/02/05	18:20	27 10.18S 46 55.78E	200 m
15693	XBT	17/02/05	21:53	26 41.21S 45 53.31E				
15694	CTD	17/02/05	03:00			Station abandoned due to winch failure. In addition, echosounder became locked onto multiple signal. RVS gyro feed failed.		
15695	Seasoar	17/02/05	06:28	26 40.00S 46 38.24E	18/02/05	10:00	27 59.13S 42 44.83E	

Table 1 : List of activities, giving station number, date and location.

2. Navigation and ADCP

Fabio Venuti

2.1 Introduction

RRS Discovery is provided with two RDI Vessel-Mounted Acoustic Doppler Current Profilers (VM-ADCPs): the narrowband 150kHz VM-ADCP and a 75 kHz Phased Array instrument (Ocean Surveyor). The vast majority of this report restates that of Penny Holliday and Helen Johnson for D253.

The 150 kHz ADCP is mounted in the hull 1.75 m to port of the keel, 33 m aft of the bow at the waterline and at an approximate depth of 5 m. The 75 kHz ADCP is also mounted in the hull, but in a second well 4.15 m forward and 2.5 m to starboard of the 150 kHz well. This section describes the operation and data processing paths for both ADCPs. The navigation data processing is described first since it is key to the accuracy of the ADCP current data.

2.2 Navigation

The ship's best-determined position was calculated by the RVS process "bestnav" (10-second averaging period). The main data source for D288 was the GPS Trimble 4000 system. This had been determined to be the most accurate system on a number of preceding cruises. The other systems used are Ashtech G12 and Glonass.

Both of these systems had sufficient precision to enable a calculation of ship's velocities to better than 1 cm s^{-1}, and therefore below the instrumental limits of the RDI ADCP systems.

If there were gaps in the GPS4000 data, the bestnav process used other inputs as necessary. These were turned to in the strict preference order: Ashtech G12, GPS Ashtech 3D, GPS Glonass (which uses a combination of Russian and American satellite networks). Or, as a last resort, if no GPS was available the Chernikeef electo-magnetic log velocity data and gyro heading would be used to dead-reckon the ship's position.

Data were transferred every 12 hours from the RVS Level C bestnav stream to the pstar absolute navigation file, abnv2881. The G12, gps-4000, and gyro (gyronmea) data streams were also transferred twice a day; transfer of the gps_glos stream was considered unnecessary.

Scripts:

navexec0: transferred data from the RVS bestnav stream to pstar, calculated the ships velocity, appended onto the absolute (master) navigation file and calculated the distance run from the start of the master file. Output: abnv2881.

gyroexec0: transferred data from the RVS gyronmea stream to pstar, a nominal edit was made for directions outside the 0-360° range before the file was appended to a master file. Output: gyr28801.

gp4exec0: transferred data from the RVS gps_4000 stream to pstar, edited out pdop (position dilution of precision) greater than 5 and appended the new 24 hour file to a master file. Output: gp428801.

gpsexec0: this was identical to gp4exec0 but transferred the RVS gps_g12 data stream to pstar. Output: gps28801.

2.3 Heading

The ship's attitude was determined every second with the ultra short baseline 3D GPS Ashtech ADU2 navigation system. Four antenna, two on the boat deck, two on the bridge top, measured the phase difference between incoming satellite signals from which the ship's heading, pitch and roll were determined. The Ashtech data were used to calibrate the gyro heading information as follows:

ashexec0: transferred data from the RVS gps_ash stream to pstar.

ashexec1: merged the ashtech data from ashexec0 with the gyro data from gyroexec0 and calculated the difference in headings (hdg and gyroHdg); ashtech-gyro (a-ghdg).

ashexec2: edited the data from ashexec1. The heading difference (a-ghdg) was then filtered with a running mean based on 5 data cycles and a maximum difference between median and data of 1 degree. The data were then averaged to 2 minutes and further edited for $-2 < \text{pitch} < 2$ and $0 < \text{mrms} < 0.004$.

The two-minute averages were merged with the gyro data files to obtain spot gyro values. The ships velocity was calculated from position and time, and converted to speed and direction. The resulting a-ghdg should be a smoothly varying trace that can be merged with ADCP data to correct the gyro heading. Diagnostic plots were produced to check this. During ship manoeuvres, bad weather or around data gaps, there were spikes that were edited out manually (plxyed). Ashtech 3D GPS coverage was good: there was only one gap longer than a minute: JDay 049 00:54:07 to 00:58:13 (246 secs).

2.4 150 kHz ADCP

The 150kHz RDI ADCP was logged using RDI Data Acquisition Software (DAS) version 2.48 with profiler firmware 17.20. The instrument was configured to sample over 120-second intervals with 96 bins of 4 m depth, pulse length 4 m and a blank beyond transmit of 4m. The high vertical resolution was chosen to support the remote detection of zooplankton patchiness. Early in the cruise the ADCP was switched to bottom and water track mode over shallow ground to enable calibration. Spot gyro heading data were fed into the transducer deck unit where they were incorporated into the individual ping profiles to correct the velocities to earth co-ordinates before being reduced to a 2-minute ensemble.

Following advice from RDI, the 150 KHz ADCP on *RRS Discovery* had been refitted in dry dock, several years ago, to a heading offset of ~45°. This offset was accounted for in the DAS software configuration on D285. On some previous cruises the ADCP PC clock had been synchronised with the ship's master clock, so removing the tedious need for logging the drift of the PC clock and correcting for it in the processing (adpexec1), but this was not available on D288 and adpexec1 was resurrected. The PC was restarted on day 044 and the clock reset.

The ADCP data were logged continually by the level C computer. From there they were transferred once a day to the pstar data structure and processed using standard processing scripts in pstar; which are presented below.

Data processing:

adpexec0: transferred data from the RVS level C "adcp" data stream to pstar. The data were split into two; "gridded" depth dependent data were placed into "adp" files while "non-gridded" depth independent data were placed into "bot" files. Velocities were scaled to cm/s and amplitude by 0.42 to dB. Nominal edits were made on all the velocity data to remove both bad data and to change the DAS defined absent data value to the pstar value. The depth of each bin was determined from the user supplied information. Output files: adp288##, bot288##

adpexec1: Clock correction applied to both, gridded and non-gridded files. The PC clock was found to have a steady drift, ~ 4 seconds per day, so time checks were made every 12 hours and these offset values were used in adpexec1 to create a clock correction file for calibrating adcp time. Output files: adp288##.corr, bot288##.corr.

adpexec2: this merged the adcp data (both files) with the ashtech a-ghdg created by ashexec2. The adcp velocities were converted to speed and direction so that the heading correction could be applied and then returned to east and north. Note the renaming and ordering of variables. Output files: adp288##.true, bot288##.true.

adpexec3: applied the misalignment angle, ø, and scaling factor, A, to both adcp files. The adcp data were edited to delete all velocities where the percent good variable was 25% or less. Again, variables were renamed and re-ordered to preserve the original raw data. Output files: adp288##.cal, bot288##.cal.

adpexec4: merged the adcp data (both files) with the bestnav navigation file (abnv2881) created by navexec0. Ship's velocity was calculated from spot positions taken from the abnv2881 file and applied to the adcp velocities: the bestnav averaging is now only 10 seconds, and therefore there is no requirement to take spot values from the raw 1-second GPS4000 dataset which still has the occasional spike. The end product is the absolute velocity of the water. The time base of the ADCP profiles was then shifted to the centre of the two-minute ensemble by subtracting 60 seconds and new positions were taken from abnv2881. Output files: adp288##.abs, bot288##.abs.

The calibration parameters of the 150 kHz ADCP used on the previous cruise were A=1.0034 (s.d.=0.064) and tan ϕ = -0.0039 (s.d.=0.0080) implying ϕ = -0.22˚. Towards the end of the D288 cruise these parameters were compared with the new ones obtained by using bottom-tracking data available from our departure across the wide shelf outside Durban. Using long, straight, steady speed sections of standard two minute ensemble profiles we obtained a calibration of A=0.999 (s.d.=0.009) and tan ϕ = -0.040 (s.d.=0.525). These new values are very similar to the previous ones, so the old ones have been used throughout D288.

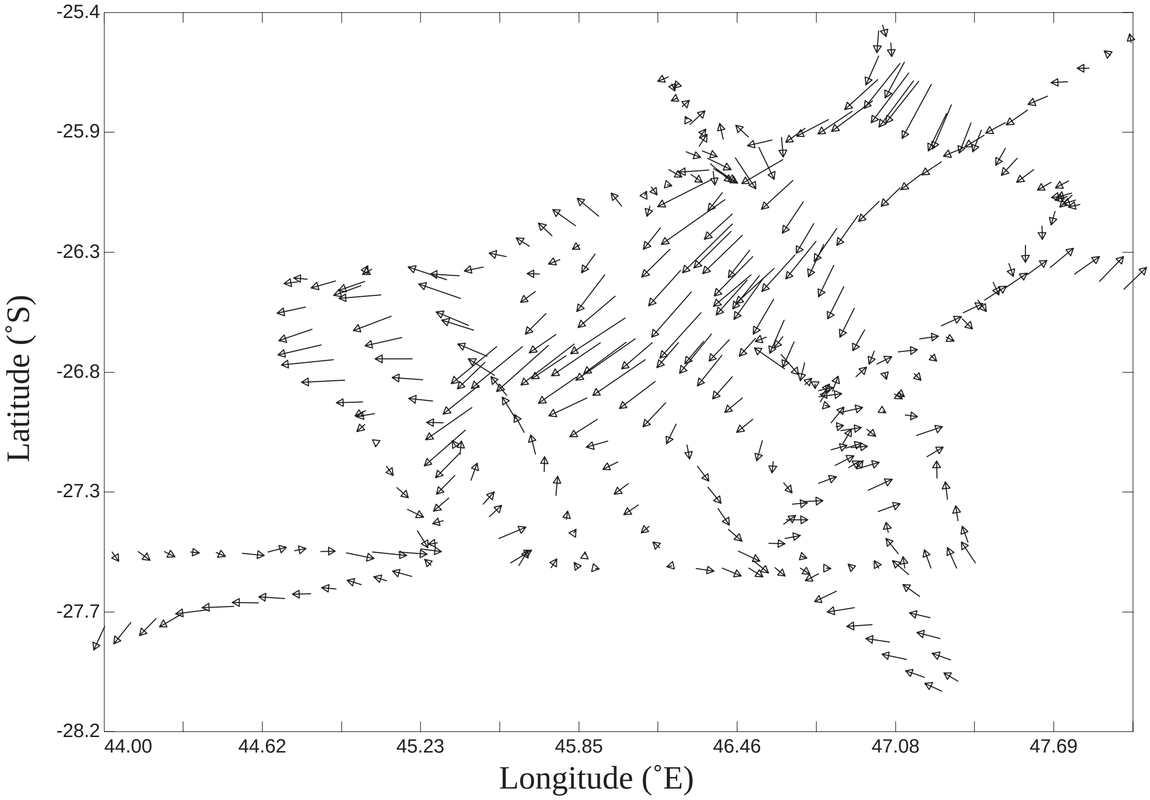

Figure 3 : Synthesis of near-surface flow (23-51m deep) to the south of Madagascar, using the 150 kHz ADCP.

2.5 75 kHz ADCP

The processing path of the RDI Ocean Surveyor 75 kHz Phased Array ADCP set on cruise D253 has been used on cruise D288 as well. The instrument was configured to sample over 120-second intervals with 60 bins of 16 m depth, pulse length 16 m and a blank beyond transmit of 8 m. The instrument is a narrow-band phased-array ADCP with 76.8 kHz frequency and a 30° beam angle. The PC was running RDI software VmDAS v1.3. Gyro heading, and GPS Ashtech heading, location and time were fed as NMEA messages into the software, which was configured to use the Gyro heading for co-ordinate transformation. The software logs the PC clock time, stamps the data (start of each ensemble) with that time, and records the offset of the PC clock from GPS time. This offset was applied to the data in the processing path before merging with navigation. The ADCP was fitted in the forward well as previously noted. It was known to have a heading alignment offset of 60°, this offset was not accounted for in the RDI software configuration. Bottom tracking was switched on early in the cruise for calibration purposes.

The 2-minute averaged data were written to the PC hard disk in files with a .STA extension, e.g. D288005_000000.STA, D288006_00000.STA etc. Sequentially numbered files were created whenever data logging was stopped and re-started. The software was set to close the file once it reached 100MB in size, though on D288 files were closed after ~24 hours, so they never became that large. All files were transferred to the unix directory /data62/os75/raw; .ENX files contain the raw ping by ping profiles ready for averaging and were archived in case they could be useful for looking at deep acoustic backscatter signals. Broadly speaking the new processing path followed the steps outlined for the 150 kHz ADCP. In the following script description, “##” indicates the 12 hours file number.

The calibration parameters set on the previous cruise were A=1.0018 (s.d.=0.0060) and tan ϕ = -1.75089 (s.d.=0.0244) implying ϕ = -60.26˚. As for the 150kHz ADCP, towards the end of the cruise these values were compared with a calibration achieved by using bottom-tracking data available from our departure across the wide shelf outside Durban. Using three 1-hour long, straight, steady speed sections of standard two-minute ensemble profiles (.STA files) we obtained a calibration of A=1.002 (s.d.=0.014) and ϕ = -60.186˚ (s.d.=0.276). These new values are very similar to the previous ones, so the old ones have been used throughout D288.

surexec0: data read into pstar format from RDI binary file (psurvey, program written on D253 by S. Alderson). Water-track velocities written into "sur" file, bottom-track into "sbt" files if in bottom-track mode. Velocities were scaled to cm/s and amplitude by 0.45 to dB. The time variable was corrected to GPS time by combining the PC clock time and the PC-GPS offset. The depth of each bin was determined from the user-supplied information. Output files: sur288##.raw, sbt288##.raw.

surexec1: data edited according to status flags (flag value of 1 indicated bad data). Velocity data replaced with absent data if variable "2+bmbad" was greater than 25% (% of pings with more than one beam bad; therefore no velocity computed). Time of ensemble moved to the end of the ensemble period (120 secs added with pcalib). Output files: sur288##, sbt288##.

surexec2: this merged the adcp data (both files) with the ashtech a-ghdg created by ashexec2. The adcp velocities were converted to speed and direction so that the heading correction could be applied and then returned to east and north. Note the renaming and ordering of variables. Output files: sur288##.true, sbt288##.true.

surexec3: applied the misalignment angle, ø, and scaling factor, A, to both files. Variables were renamed and re-ordered to preserve the original raw data. Output files: sur288##.cal, sbt288##.cal.

surexec4: merged the adcp data (both files) with the bestnav navigation file (abnv2881) created by navexec0. Ship's velocity was calculated from spot positions taken from the abnv2881 file and applied to the adcp velocities: the bestnav averaging is now only 10 seconds, and therefore there is no requirement to take spot values from the raw 1 second GPS4000 dataset which still has the rare spike. The end product is the absolute velocity of the water. The time base of the ADCP profiles was then shifted to the centre of the two-minute ensemble by subtracting 60 seconds and new positions were taken from abnv2881. Output files: sur288##.abs, sbt288##.abs.

3. Satellite Data

Several aspects of the detailed analysis of data from the cruise will involve comparisons with satellite data, or use of them to put observations in context. However, there was also a strong need to have satellite data in near real-time (NRT) to aid with the detailed planning of the cruise. To this end, we made use of 1) directly-broadcast infra-red images received via Dartcomm, and 2) weekly composites of sea surface temperature (SST), sea surface height (SSH) and chlorophyll concentration (CC) provided via email at a few days latency.

3.1 Dartcomm Satellite Ground Station

Rob Lloyd

The satellite pass archive was edited daily to select those passes that covered the cruise area. Those of interest were sampled to produce either false-colour ‘visual’ images or sea surface temperature images using the McClain formula. The naming convention used was DDMMYY[NC][sst][T], where

DDMMYY is the date.

[NC] is the source designator – NOAA or Chinese

[sst] is sea surface temperature

[T] indicates a transformation onto a Mercator grid.

Infrequently the source designator is qualified by a number when more than one daily pass was available. All usable data were archived under /rvs/raw_data/satellite. Those images thought useful for website or other purposes were exported as JPEGs using the conventions above. No facilities exist for masking cloud data on SST images; for this we relied on experts ashore providing data by email.

Note, on 040205 an extra designator (E) was used to extract data from the eastern side of the image to highlight the work area whilst the ship was still in transit.

A number of other satellite datasets were provided to the ship in near real-time via RSDAS in Plymouth or via local contacts at NOCS. The altimetry product used was DUACS produced by AVISO (http://www.aviso.cls.fr). This product contains multi-satellite sea surface height anomalies gridded on a $^1/_3$° Mercator grid. The main source of SST and ocean colour data was MODIS on the NASA satellite, *Aqua*. These data are provided daily on a 0.09° x 0.09° grid. Thirdly, there is MERIS, the ocean colour sensor on ESA's *Envisat* platform.

Ashore, MODIS data were readily available on the web within a day of collection. The altimetry and MERIS data were not generally accessible in NRT. Access to the former was obtained upon submitting a half page proposal; access to ESA data was by comparison very long-winded and cumbersome to obtain.

The MODIS data were collated at RSDAS and composites (typically weekly) made to overcome cloud cover. Then the data for a pre-agreed geographical domain were emailed to the Principal Scientist as a NetCDF attachment. The altimetry data were provided by AVISO as composites; RSDAS reduced these to the agreed area and sent them as NetCDF files. They also provided some MERIS scenes as PNG images. NOCS provided various daily MODIS files and early altimetry composites as .mat files (Matlab datafiles).

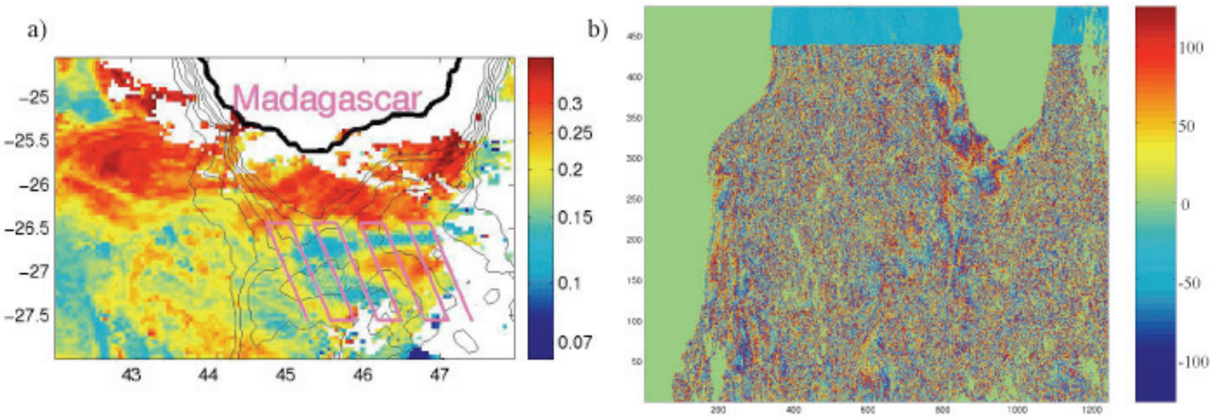

Figure 4 : a) Zoom in on chlorophyll concentration (CC) data south of Madagascar, with depth contours drawn in black, and the planned SeaSoar tracks overlaid in pink. b) Corrupted CC data (expressed as raw data number in range -128 to 127), showing credible values at top of plot only.

Of the files sent, the ocean colour data were the most useful, because they showed features the most clearly. It was definitely advantageous having the data rather than the images, because then we were able to focus in on our area of interest, adjust the contrast to show features more clearly, and easily overlay ship tracks and other information (see Fig. 4a for example). This system failed occasionally, with data being corrupted on transmission (see Fig. 4b). In the future, possibly both data and a quick look image should be sent.

Special thanks are due to NOCS and RSDAS for a quick response to a plea for coverage of an extended region, when the compassionate evacuation via Réunion had been agreed, necessitating recent satellite data from further east. Figure 5a shows the route options considered for the return from Réunion (the pink line was the one followed), and Fig. 5b shows the last directed collection of data (SeaSoar and ADCP) whilst running transects across the unusual feature that had been revealed in ocean colour imagery.

a)

b)

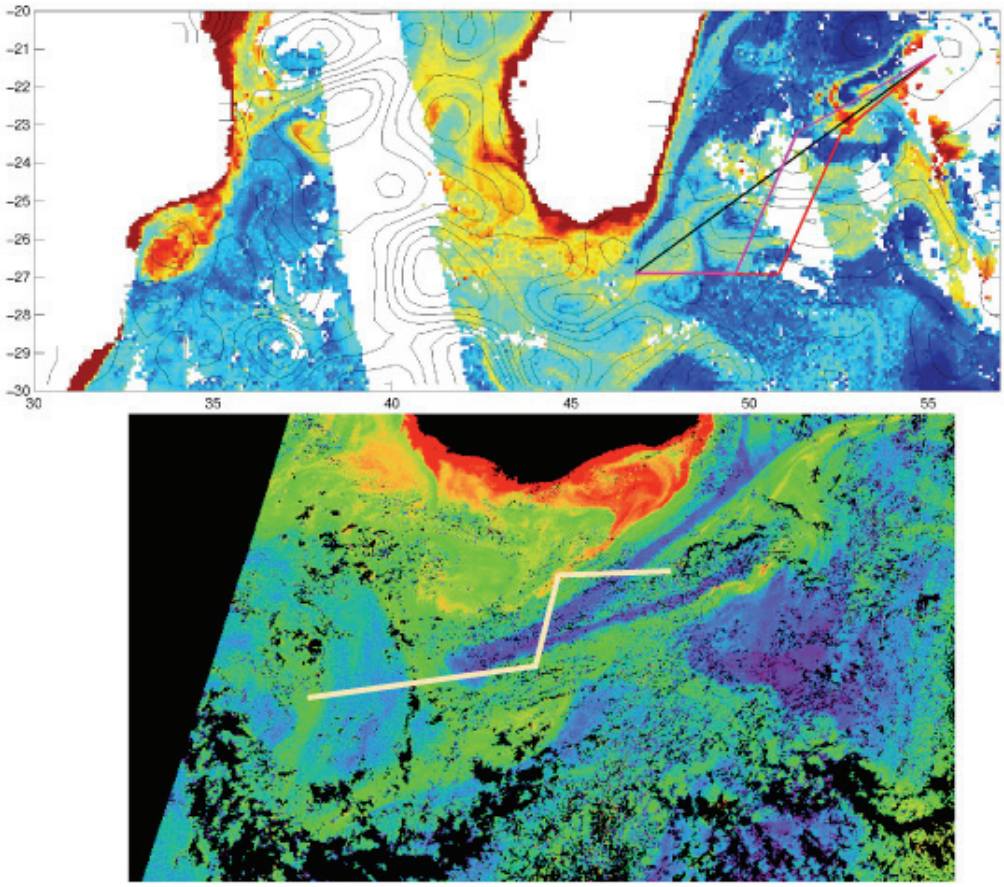

Figure 5 : a) MODIS chlorophyll data with altimetry overlaid (thin contour lines). The thick black line shows the direct route from Réunion to mooring #2, with pink and red showing alternative routes to better sample the eddy field. The route in pink was the one adopted. b) MERIS data for 14th Feb., showing a strong linear feature to the south of Madagascar, of which two transects were made during our last SeaSoar leg (shown by cream line).

4. Meteorology: AutoFlux

Meric Srokosz

AutoFlux is an autonomous, stand-alone system, which obtains direct, near real-time (2 hours) measurements of the air-sea turbulent fluxes of momentum and sensible and latent heat in addition to various mean meteorological parameters. A detailed description of the system may be found in the D285 cruise report (see also the AutoFlux web site at http://www.noc.soton.ac.uk/JRD/MET/AUTOFLUX). The same system was operational on D288. At the beginning of D288 the ORBCOMM system for transmitting data back to the Southampton Oceanography Centre (SOC) was not working and the spare that had been flown out from the UK had to be fitted. This was done on 25th January 2005 (JDay 025) and thereafter the system successfully transmitted data back to SOC.

Despite being "an autonomous, stand-alone system" AutoFlux proved to require a certain amount of "mothering" during the cruise. The AutoFlux UPS (uninterruptible power supply) failed on 29th January (JDay 029) and the power was switched to the mains. The system (xpowerchute programme) was providing information on the UPS such as "battery discharged / low battery / bad battery". A spare UPS was fitted on 2nd February (JDay 033) and the system rebooted. The day after this, 3rd February (JDay 034) it was noticed that the R3 sonic was not logging. A check of the wiring revealed that it had been disturbed when the UPS had been replaced. This was corrected and thereafter the R3 sonic logged without problems.

On 12th February (JDay 043) it was noted that the mean met display window was "hanging" and not displaying data. Attempts to fix this by rebooting *nimbus* and / or by killing the gmet2 programme failed to correct the problem. After some investigation it was found, on 15th February (JDay 046), that loose wiring seemed to be the problem (this cannot be determined with certainty as various "fixes" were tried). Thereafter the mean met appeared to return to normal operation. It is possible that the wiring had been disturbed during the replacement of the UPS, but why it should take 10 days for the problem to manifest itself was unclear (perhaps the ship's motion over that time loosened the wiring to the point where the contact failed).

A recent SOC Technology Innovation Fund proposal will provide funding for system improvements and development. This will include replacement of some of the more antiquated parts (e.g. new UPS) and a better housing for the interfaces, power supplies and associated wiring. In addition, satellite communications will be provided via an IRIDIUM system instead of the current ORBCOMM system since the latter has proved unreliable on more than one occasion.

Full data backups were made automatically once a day to an external hard disk on *nimbus*. Since the AutoFlux data were of interest to cruise participants, copies of the daily files of results were also transferred to a second workstation, *cirrus*. This allowed access to the data without risking interference to the acquisition and processing system on *nimbus*. In order to do this, *cirrus* had to be manually mounted on *nimbus* every time the system was rebooted (using the command "mount cirrus:/local /mnt" in a terminal window on *nimbus*). This had to be done several times during D288 when fixing other problems with AutoFlux. Due to the way *nimbus* and *cirrus* are configured it does not seem possible to make this procedure automatic.

The data transmitted hourly via ORBCOMM to SOC included mean meteorological variables, initial flux results, navigation data and housekeeping information. Plots of these data were displayed on the AutoFlux web site. For example, Fig. 6 shows the cruise track since deployment of AutoFlux on the 3rd November 2004 (JDay 308) and Fig. 7 shows a time series of the air and sea temperatures. In addition, the AutoFlux ORBCOMM data were made available to other users at SOC and were displayed on both the MadEx and the Oceans4schools web pages.

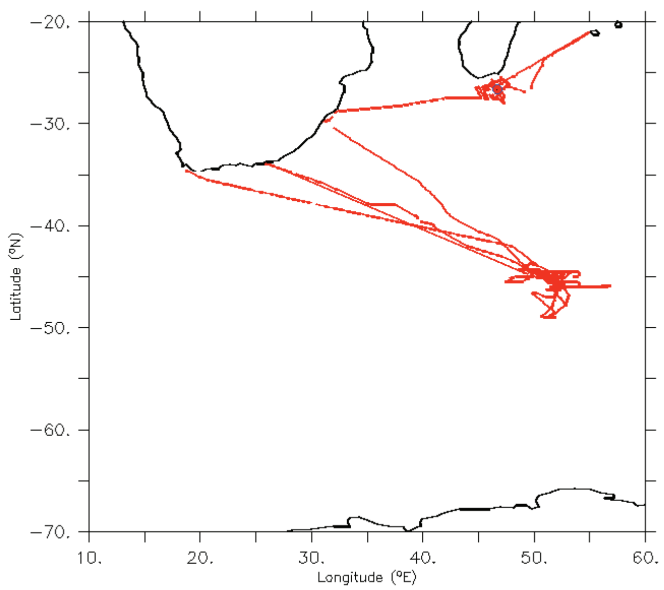

Figure 6 : Ship track from 3rd November 2004 to 17th February 2005.

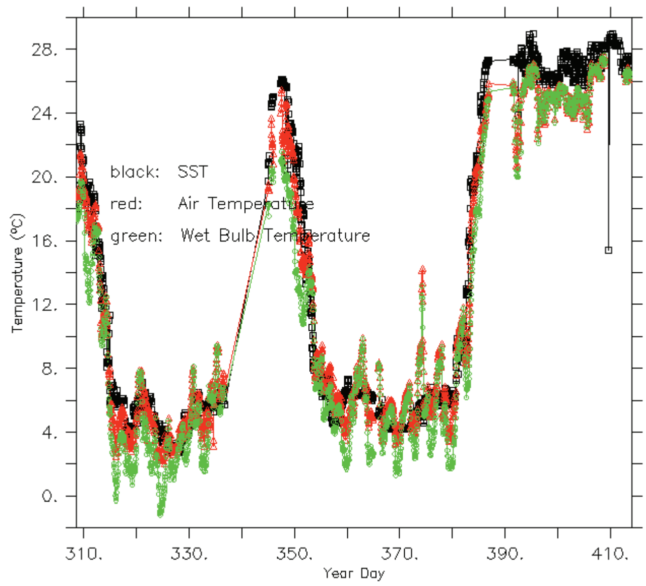

Figure 7 : Time series of air and sea temperatures from 3rd November 2004 to 17th February 2005. The gap around day 340 was due to an unexplained failure of the ORBCOMM transmitter unit towards the end of cruise D285.

Data from the AutoFlux system were backed up onto DLT by Vic Cornell at the beginning and end of D288.

5. Hydrography

The MadEx cruise made use of many of the standard tools available to hydrographers. The CTDs (section 5.1) were normally full-depth, providing profiles of temperature, salinity, oxygen concentration and chlorophyll fluorescence; there were also a few shallow CTDs (500 m) to utilise a new fluorometer giving profiles of phycoerythrin. XBTs (section 5.2) were interspersed with CTDs to give improved horizontal resolution of the temperature in the top 760 m. The LADCP (section 5.3) measures the current profile at each of the CTD stations. Such direct point measurements can be contrasted with the geostrophic flow calculated from the water properties determined at CTD stations and the continuous current profile over the top 800 m provided by the vessel-mounted ADCPs (see Fig. 16)

The undulating vehicle, SeaSoar (section 5.4), was used to record temperature and salinity in the top 300 m at a much finer horizontal resolution (5 km equivalent) than can be achieved by CTD stations. A number of other sensors are fitted to the SeaSoar platform, giving biological measurements that are discussed later (section 7).

The last two subsections cover the underway measurements via TSG and other instrumentation in the water bottle annex (section 5.6) and the salinity analysis of discrete samples with a salinometer (section 5.7) — both straightforward routine operations, but important for the cross-calibration and stability of the other measurements.

5.1 CTD Operations and Processing

Mikis Tsimplis Steven Alderson, Dave Teare, Kevin Smith, Peter Mason & Chris Hunter

5.1.1 Configuration

During cruise D288 35 stations were occupied (see Table 1), with water samples usually taken all the way from the bottom to the surface; the exception being a few early casts to only 500 m. On occasions the Niskin bottles did not close properly — the depths from which useful samples were acquired are illustrated in Fig, 8. The instrumentation on the lowered frame was:

Seabird 9/11 CTD with two sensors of temperature and conductivity. The primary sensors were positioned on a wing protruding outside the frame of the CTD package while the secondary sensors were positioned in the usual position near the lower end of the package.

Seabird Rosette Pylon with 24 bottles.

Chelsea Instruments Fluorometer .

Chelsea Instruments, Aquatrack MKII 660nm Transmissometer.

Turner Fluorometer ("Cyclops") was fitted for casts shallower than 500 m.

Tritech PA200 altimeter.

2 LADCPs one upward and one downward looking operating as slave and master; the LADCP data are reported separately (section 5.3).

One Seabird Electronics 43 oxygen sensor.

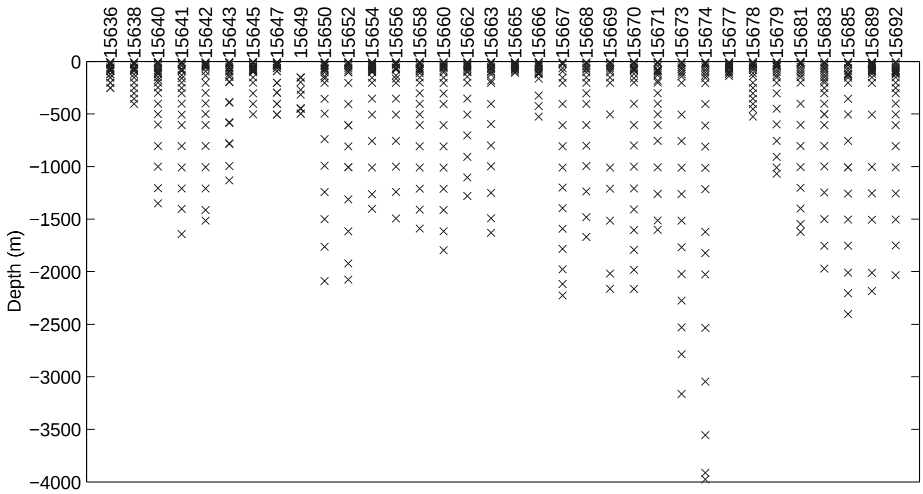

Figure 8 : Depths of samples at each CTD station.

5.1.2 Data acquisition and processing

All CTD data acquired from the Seabird deck unit was logged on two PCs. The file containing the times of bottle firing was only logged on one computer. After the cast was finished the data were transferred electronically (using ftp) to the RVS server from where they were copied to another PC on which the Seabird processing package was installed. Four files were produced for each cast:

stationname.con file containing the configuration and the calibration parameters for the CTD

stationname.dat file containing the data

stationname.HDR dfile containg the header of the file which included the deployment details (date/time/location etc.)

stationname.bl file containing the times of bottle firing.

The Seabird software was then used with the following script:

```
Datcnv /iC:\D288\%1.DAT /cC:\D288\%1.con /pC:\D288\DatCnv.psu /oC:\D288\
Rossum /ic:\D288\%1.ROS /cc:\D288\%1.con /pc:\D288\RosSum.psu /oc:\D288\output1\
Alignctd /ic:\D288\%1.cnv /pc:\D288\AlignCTD1.psu /aa /oc:\D288\output1\
Loopedit /ic:\D288\output1/%1a.cnv /pc:\D288\LoopEdit.psu /al /oC:\D288\output1
Wildedit /ic:\D288\output1\%1al.cnv /pc:\D288\WildEdit.psu /aw /oc:\D288\output1\
Wildedit /ic:\D288\output1\%1alw.cnv /pc:\D288\WildEdit.psu /aw /oc:\D288\output1\
```

Datcnv converted the raw data in to engineering units using information in associated stationname.CON and also produced a stationname.ros water bottle file containing data for each scan associated with a bottle firing, and data for the 2 seconds before and after each bottle firing.

Rossum produced from the stationname.ros file a summary of the values at the times of the firing of the bottles plus their standard deviations.

Alignctd was used to advance the time series of oxygen voltage by 10 sec.

Loopedit marks scans as bad by setting the flag value associated with the scan to badflag for files that have pressure slowdowns or reversals. A minimum velocity of 0.25 m s^{-1} for the CTD was required for data to pass this quality test.

Wildedit was used to mark as bad values those which deviated more than 2 standard deviations from the median over 400 scans. The command was run twice each time forwards and backwards.

The output files stationname.cnv and stationname.btl were then transferred (via ftp) to a Unix workstation for processing with pexec. The data were read into pstar format through **ctd0** command script which produced a stationname.24hz file. This file was copied to a (stationname)e.24hz file which was edited through **pedita** to exclude unreasonable values in the various fields. Then any remaining spikes were manually removed by **plxyed**. Only the pressure, the primary and secondary temperature and conductivity, the oxygen and the fluorometer data were edited this way. The script **ctd1** was then used to produce a (stationname)e.1hz file, which was then run through **ctd2** to produce a (stationname)e.2db and a (stationname)e.ctu file. The data of the .1hz file were routinely plotted versus depth and as T-S plots.

The bottle data were copied into relevant (sam) files by using four execs: **pre-sam**, **sam0**, **sam1** and **passam**.

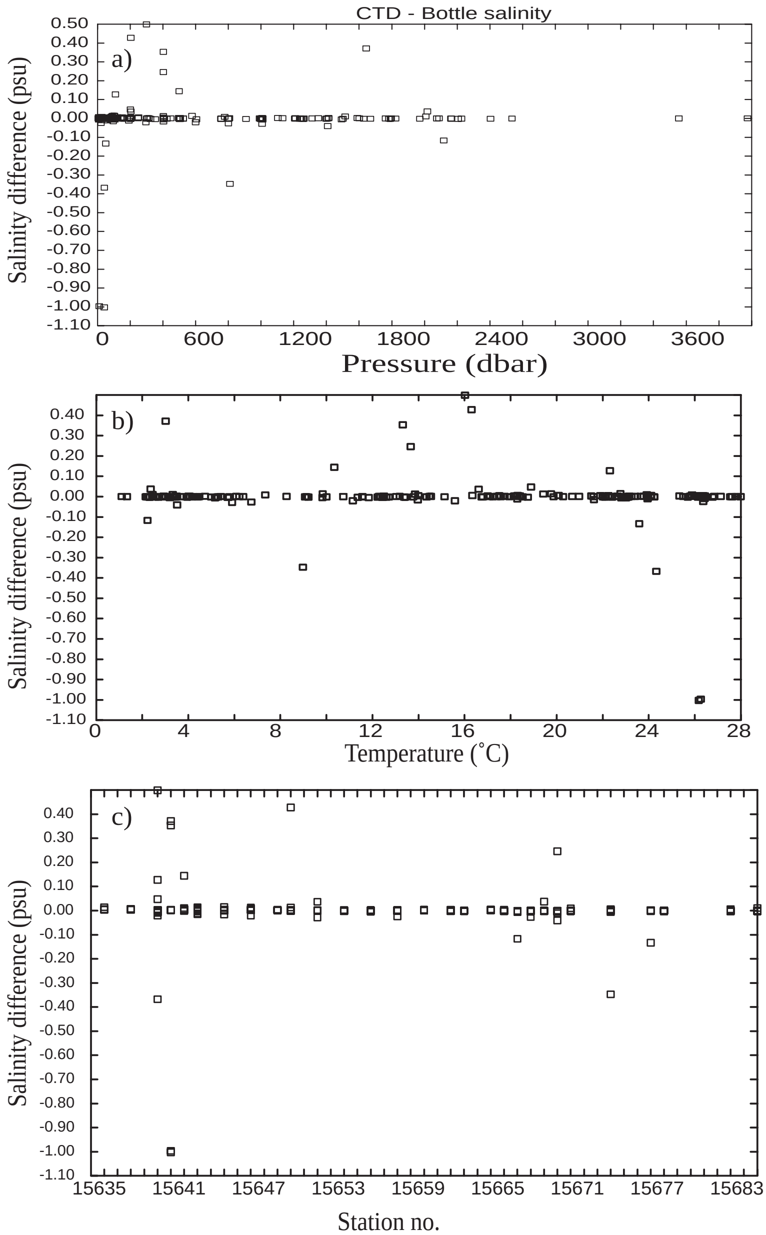

Figure 9 : Difference in salinities (CTD values - bottle sample at that depth) for all casts, as a function of   a) Pressure, b) Temperature, c) Station no.

5.1.3. Quality of conductivity and salinity measurements

The CTD salinity and conductivity values of the primary sensor were compared with the salinities derived from bottle samples. The bottle salinities were also used to calculate the conductivity corresponding to the pressure and in-situ temperature. The salinities were compared as differences between the CTD and bottle salinity and the conductivities as ratios. The results of the comparison are shown in Figures 9 and 10.

Figure 9 shows the distribution of salinity differences with pressure (Fig 9a), temperature (Fig.9b) and station number (Fig. 9c). The mean difference for the 209 samples analysed in all but the last two stations was –0.0036 psu and the SD was 0.1218 psu. However, when outliers were excluded the remaining 196 values had a mean difference of 0.0002 psu and the SD 0.008 psu. The pressure and temperature trends were not statistically significant at the 95% level and therefore were not explored further. Thus the salinity measurements of the primary sensor were not in need of any correction and the calibration of the CTD appeared excellent.

The same conclusions are reached if the conductivity ratio for the primary instrument over the bottle conductivity is examined (Fig. 10). Thus, no statistically significant trends of the conductivity ratio are detectable with temperature, pressure or during the cruise (with station number). The mean value for all the 209 points was 0.9999 with a standard deviation of 0.0031 while when the best 200 points (or less) were considered the mean was 1.0 and the standard deviation 0.0005.

5.1.4 Quality of oxygen measurements

The oxygen measurements did not show much spiking. However the stability of the oxygen sensor is questionable. Figure 11a-d show the distribution of oxygen concentration differences between the CTD at bottle depth and the measured oxygen content from bottle samples versus pressure, temperature and salinity. Although no trend is apparent in any of these three plots, there is significant scattering of the oxygen concentration differences which appear to cluster into two groups one around +10 μmol/kg the other at around –10 μmol/kg. This becomes clearer when the oxygen differences are plotted against station number (Fig 11d). It appears that the oxygen differences are stable around +10 μmol/kg from the beginning of the cruise until station 15653. From then on there are two stations exhibiting large scatter of values while the other stations exhibit scatter that is of the same magnitude as station 15636-15653. However, the offset appears to change from station to station. There were several difficulties with the sampling of oxygen as (a) new people started sampling (b) the computer doing the titration had problems, and (c) there were changes in the configuration of the containers of the chemicals used in sampling. Thus, it is unclear whether the errors are due to the above-mentioned difficulties or due to degradation of the performance of the oxygen sensor.

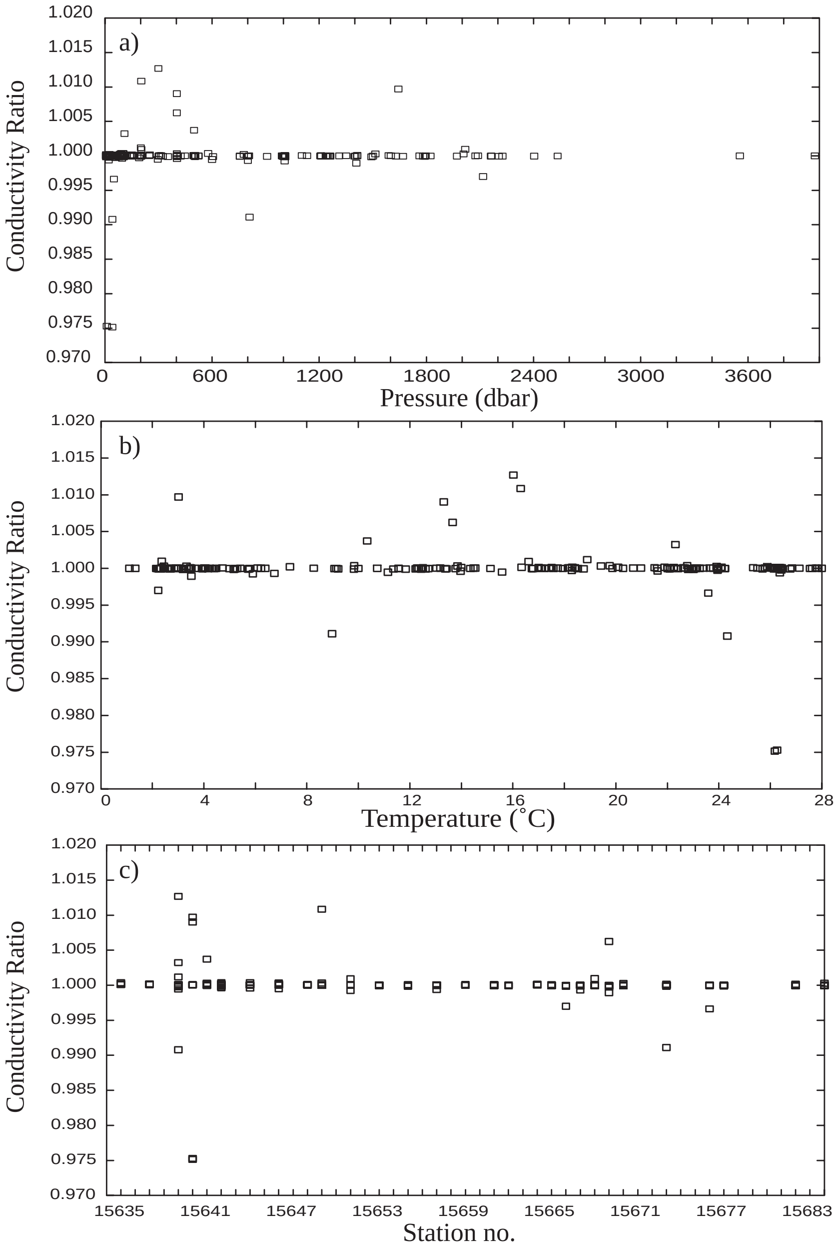

Figure 10 : Conductivity ratio (CTD / bottles) versus a) Pressure, b) Temperature, c) Station no.

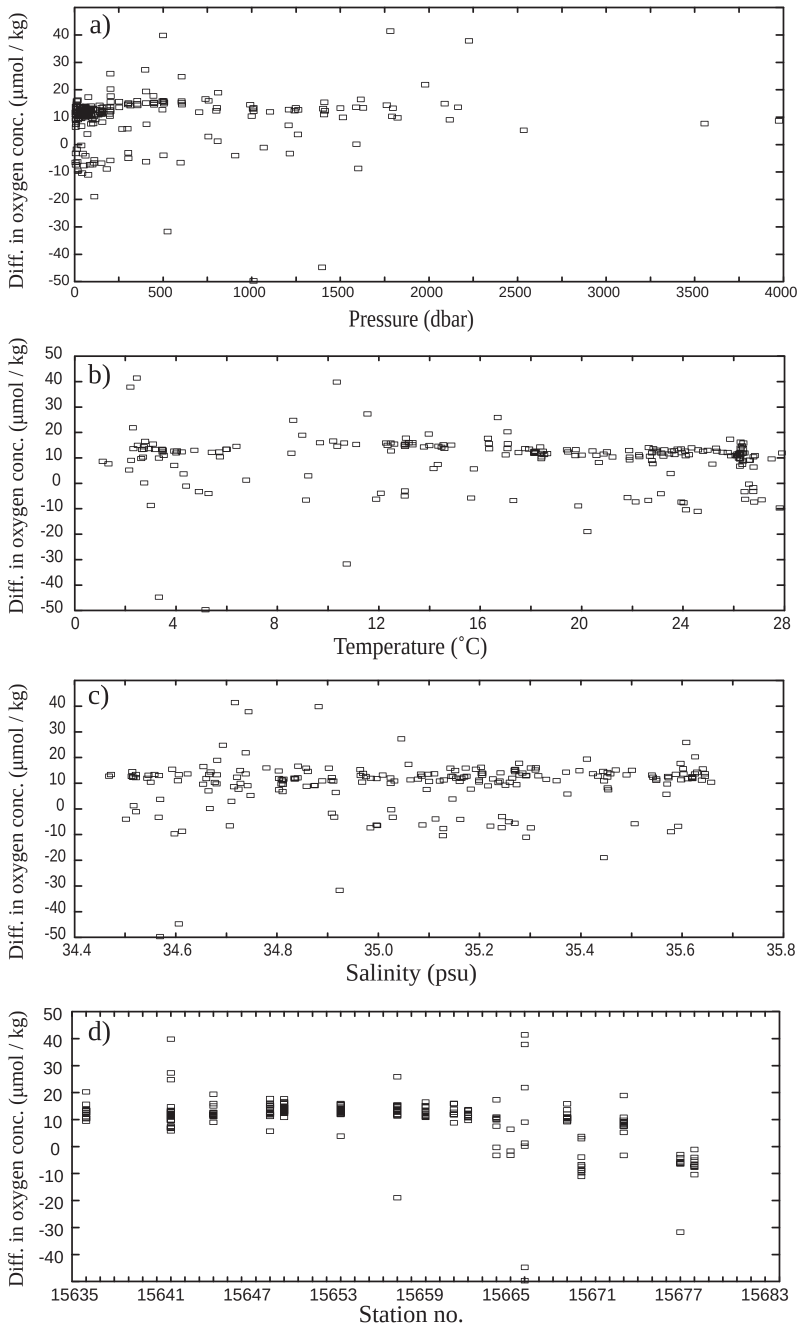

Figure 11 : Oxygen differences between the sensor and bottle versus a) Pressure, b) Temperature, c) Salinity, d) Station no.

We make three more observations in relation to the oxygen concentration differences. First, that there is a slight dependency of the discrepancy on the oxygen concentrations themselves (Fig. 12). Nevertheless this is small and not related to the scatter of values discussed earlier. Second, the offset of about 12-16 μmol/kg apparent in Fig. 11d for most of the stations corresponds to more than 10% of the lowest measured values; therefore any correction must be applied to all stations, else it can affect the locations of oxygen minima. Finally, the large scatter observed may be due to leakage from the Niskin bottles. Indeed, as can be seen in Fig. 13 where the differences in oxygen concentration are plotted against salinity differences, there are a few samples that appear as wild points in both parameters, thus indicating that there was a problem with that particular bottle. How widespread this problem is cannot be assessed from Fig. 13 because salinity samples were not taken from all bottles for which oxygen samples were taken.

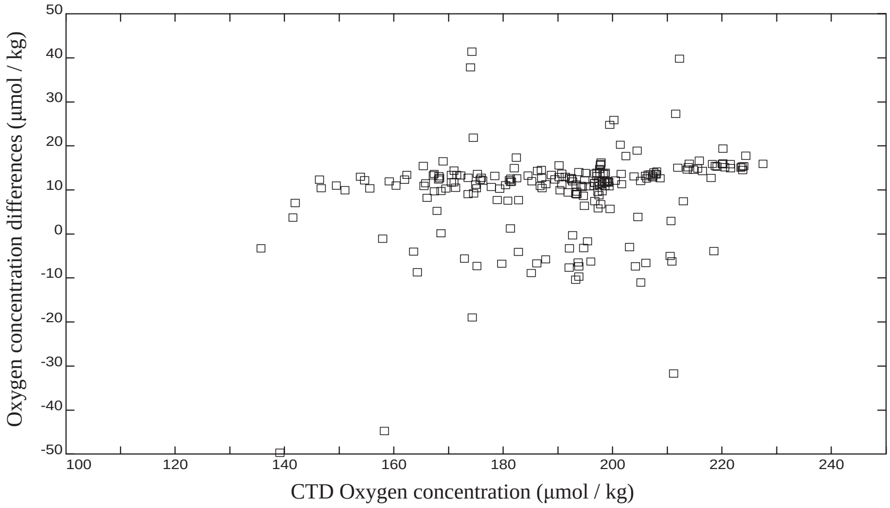

Figure 12 : Oxygen concentration differences versus CTD oxygen concentrations.

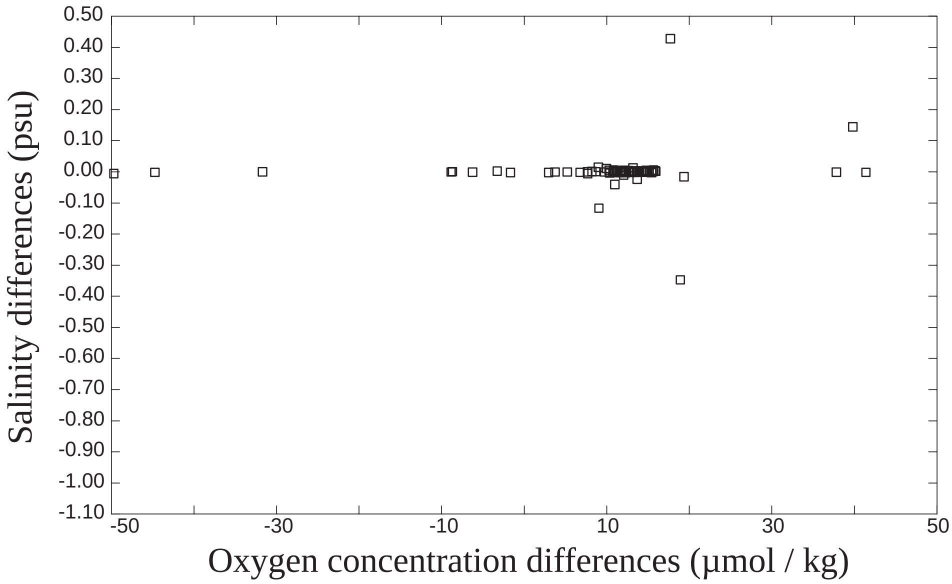

Figure 13 : Salinity differences between CTD and bottle measurements versus oxygen concentration differences between CTD and bottles.

Because of the above complications we chose not to correct the oxygen data but to detail the problem and suggest solutions. The small trend that can be seen in the major cluster of points on Fig. 12 is Δ(oxy) =2.04+ 5.361(oxygen). The mean difference in Fig. 11d excluding stations 15665, 15666, 15671, 15678 and 15679 is 12.5 μmol/kg with SD of 2.6 μmol/kg. The mean for stations 15671, 15678 and 15679 is –5.7 μmol/kg with SD of 3.6 μmol/kg. The two other stations do not have statistically significant means due to the large scatter.

Thus the following options are available:

1) fix all the oxygen concentrations on the basis of the linear trend described above
2) fix the stations in groups on the basis of the above stated means
3) first fix the stations by use of the trend and then recalculate the mean differences and adjust accordingly.

5.1.5 Problems

The secondary sensors for temperature and salinity had offsets and a small delay when compared with the primary ones (see Fig. 14). The primary sensors exhibited many small-scale features, which could occasionally be seen in the secondary instrument records but with much reduced amplitudes.

The altimeter was problematic and unreliable most of the time. On station 15689 the CTD package came on board with noticeable traces of mud on the taps of the bottles on one side of the frame (bottles 20-1) and inside some of these bottles. There was no trace of mud or other sediment on the frame or on the instruments inside the CTD frame. The only other change was that the wing was bent away from the side where the bottles that had mud were located. The operator of the CTD reported that the downcast was stopped, in accordance with the altimeter, at about 10 m above the bottom. The wire tension file was unavailable because the PC that logged this data stream had crashed during the cast and the data had not started being logged. The assessment is that the CTD package touched the ocean bottom on one side because there is no other explanation for the contamination inside the bottles as these had been washed, closed and kept covered for 6 days, with the cover removed and bottles primed only 10 minutes before the cast. After the incident the bottles were washed thoroughly with water from the non-toxic supply as well as with fresh water before the next cast. No damage was apparent in any of the instruments. A separate report was submitted to the PSO on the day of the incident.

No termination problems occurred, but the winch stopped operating at the end of the cruise (JDay 048) and we consequently lost one day of CTD sampling.

There were occasional cases where the bottles did not close properly. Some of them were detected and noted on the CTD logsheets, while others cases were identified by plotting oxygen differences between the oxygen sensor and the oxygen from bottle samples against respective salinity differences (Fig 13).

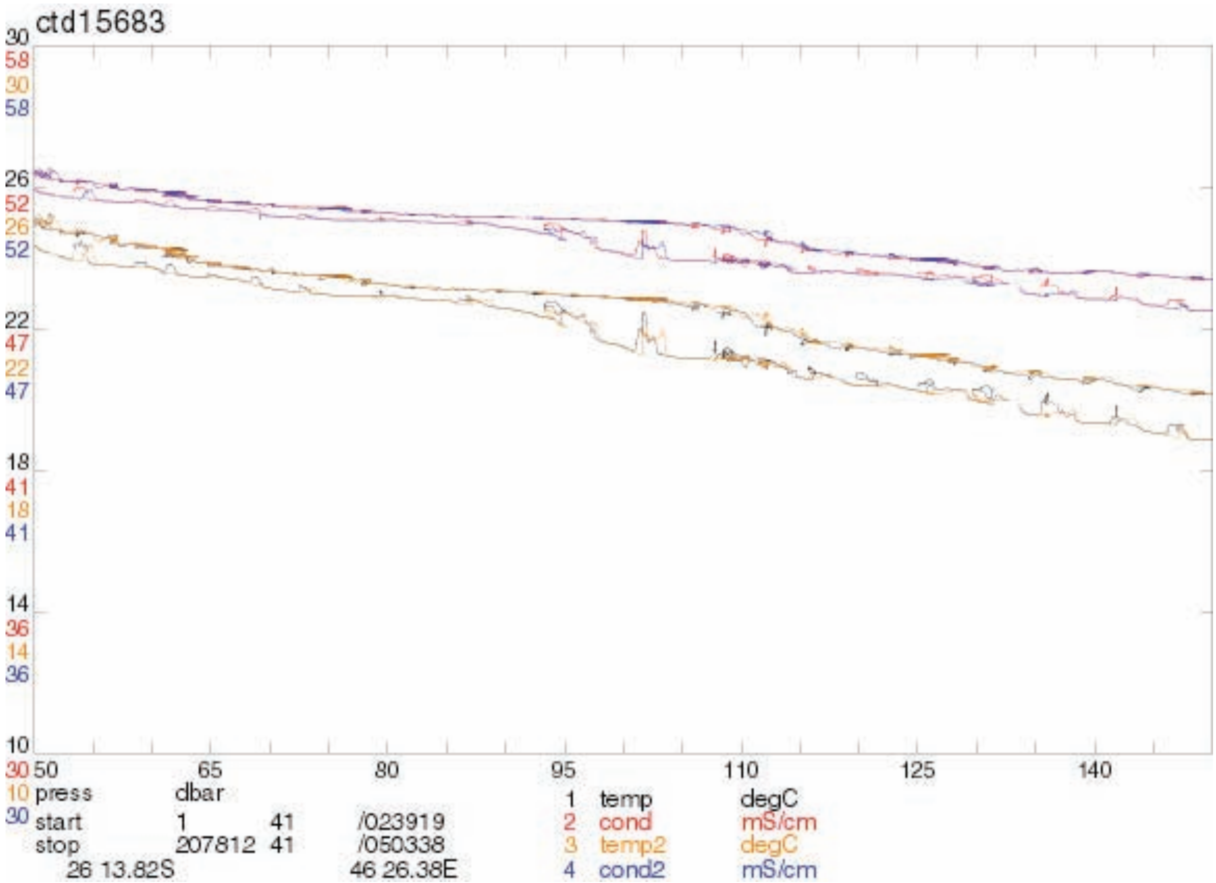

Figure 14 : A part of the 24Hz file for CTD cast 15683. The small-scale features are usually sharper on the primary instruments while at the secondary instruments they have different shape.

5.2.1 Operational issues

During D288 fourteen XBT-5 Bathythermograph probes (Spartan Co Ltd Canada) were deployed. These are designed to return temperature data throughout the top 1500 m of the water column. The probes were launched using a Sippican Corp LM3A hand launcher from the aft port side, while the vessel was underway at approximately 8 knots. Radio communication was maintained with the bridge and the laboratory for the exact location of the launch site and to monitor the descent of the probe. One XBT was deployed while on CTD station 15681. All the data files were exported and converted from RDF format and saved in the EDF format. A short python script was used to reformat the ASCII, and PASCIN was used to produce corresponding PSTAR files.

Station	Latitude	Longitude
15646	27º 15.52 S	45º 26.75 E
15648	27º 27.00 S	45º 32.10 E
15651	27º 28.20 S	45º 50.00 E
15653	27º 17.00 S	45º 45.90 E
15657	26º 05.80 S	45º 40.40 E
15659	26º 44.50 S	45º 29.50 E
15661	25º 44.50 S	46º 99.50 E
15680	26º 52.00 S	46º 17.85 E
15681	26º 00.85 S	46º 20.70 E
15682	26º 07.20 S	46º 23.50 E
15684	26º 18.00 S	46º 30.00 E
15691	27º 02.50 S	46º 52.00 E
15693	26º 46.05 S	46º 38.31 E
15694	26º 39.71 S	46º 38.92 E

Table 2 : Station numbers and locations of XBT-5 Bathythermograph probes launches (see Table 1 for timings).

5.2.2 Comparison of XBT with CTD temperatures

At station 15681 after the CTD and the net casts were finished an XBT was deployed. Figure 15a shows the profile from the XBT and the primary (24 Hz) CTD temperature, while Fig. 15b shows the difference between the two profiles. The overall agreement is good with a mean difference of about 0.18˚C. Nevertheless, due to the sharp temperature gradients in the upper waters, large differences of around 4˚C can be produced. The results can be improved by shifting the XBT records upwards, thus indicating that the speed used in calculating the XBT depth needs slight adjustment.

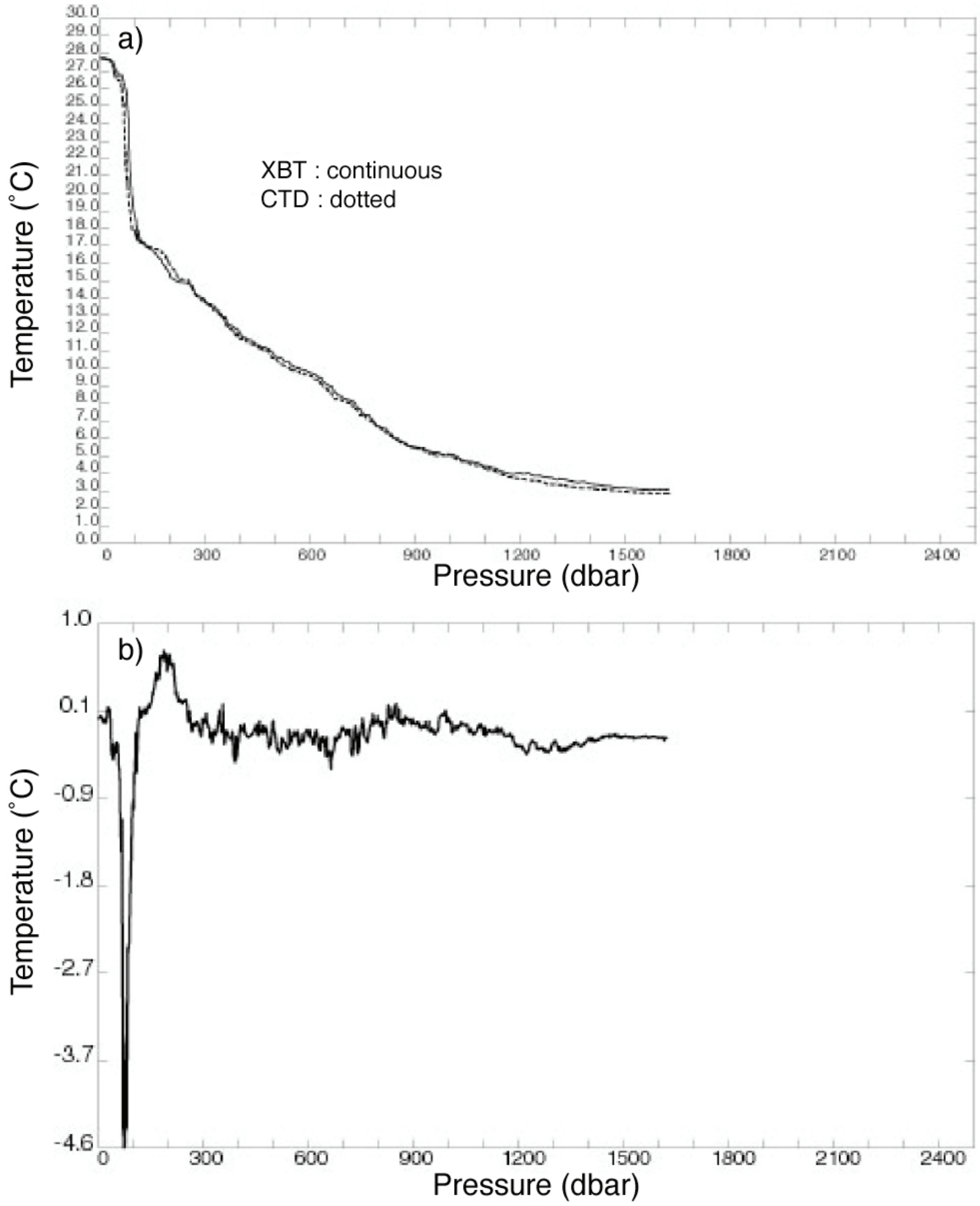

Figure 15 : a) The temperature profiles from the XBT and CTD down cast as station 15681. b) The difference between these profiles.

5.3 LADCP

Steven Alderson, Mikis Tsimplis, Dave Teare,
Peter Mason, Kevin Smith & Chris Hunter

5.3.1 Instrumentation specification and methodology

Two RD Instruments 300 kHz Workhorse (WH) Lowered Acoustic Doppler Current Profilers (LADCP) were attached to a modified frame for simultaneous deployment throughout the cruise. One of the instruments was mounted at the centre of the frame as the down-looking or master Workhorse. The second was mounted at the top of the frame on a special bracket to the side of the rosette. This second Workhorse was denoted the up-looking or slave instrument. The battery pack for both instruments was mounted in the frame at the level of the CTD. The slave was programmed to ping synchronously with the master to prevent interference. Both instruments functioned well. Problems arose twice during the cruise because the battery pack was not properly charged. One dataset from the master was also lost for unknown reasons.

Before each cast the instruments were set up with the following steps:

- test the battery voltage;
- check on board data storage space remaining, and delete old casts if necessary;
- check current time against GMT and adjust if more than a few seconds adrift;
- run a diagnostic check on each instrument;
- download configuration file to each instrument starting with the slave - this configuration requires the slave to listen for the master pinging before it can begin;
- save the diagnostic checks and configuration information in a station-related text file;
- note the time of deployment of the master (i.e. the start of pinging);
- disconnect leads (it's embarrassing otherwise!).

The instruments record to their own internal memory. On recovery the last data file in the memory of each instrument was downloaded to a PC before ftp transfer to a UNIX workstation for processing. Occasionally the cast resulted in more than one file in memory. The correct file was usually significantly larger than the others and has the station time associated with it. The download procedure also involved checking the number of bytes and frames in the file as well as the time of the first frame: information that could be used to pin down the correct data file.

5.3.2 Processing

The LADCP provides a profile of ocean current relative to the CTD package as it descends. Software is required to convert this to an absolute current relative to the ground. The code of Martin Visbeck was used exclusively on this cruise (Visbeck, 2002). This solves a large inverse problem for the water velocities. It allows for the use of other velocity information to act as constraints on the LADCP data. Although shipboard ADCP data can be used in this regard, on this cruise bottom-track velocities alone were used, with default weighting.

Two scripts used on the previous cruise (D287) were used to construct input data files for the processing:

doctdasc: copy time, pressure, temperature and salinity data from pstar to ascii format in columnar form

donavpro: extract time, latitude and longitude data from the pstar version of the bestnav navigation file

In addition a top level matlab m-file for the Visbeck code had to be generated. A generic m-file was created with place holders for cast specific information. A script called domaster then edited in the information into a copy.

domaster: create a cast specific m-file

5.3.3 Results

Results are encouraging. Figure 16 shows a comparison of the LADCP absolute velocities with those from the onboard ADCP's (150 kHz and 75 kHz). Mean absolute difference between the LADCP and each of the other two instruments is calculated over the overlap in depth of their results. Generally, averaged over all stations, differences are of the order of 2-3 cm/s.

5.3.4 Problems

The velocities for station 15641 exhibit a barotropic offset from the shipboard ADCP data for reasons that are not currently understood.

Station 15652 returned no data from the master instrument. It is not apparent from the software how to proceed with only the upward looking instrument. However, supplying the slave data as though it was the downward looking data produced a solution.

The battery pack repeatedly ran down in periods when the system was not in use and the charger was turned off. This may be due to the age of the battery. It is possible that one of the instruments auto-starts and is inadvertently pinging, thereby flattening the battery.

Therefore, it is strongly recommended that the battery pack for the LADCP's should be replaced regularly to avoid recharging problems, and the auto-start facility of the instruments checked and modified if necessary.

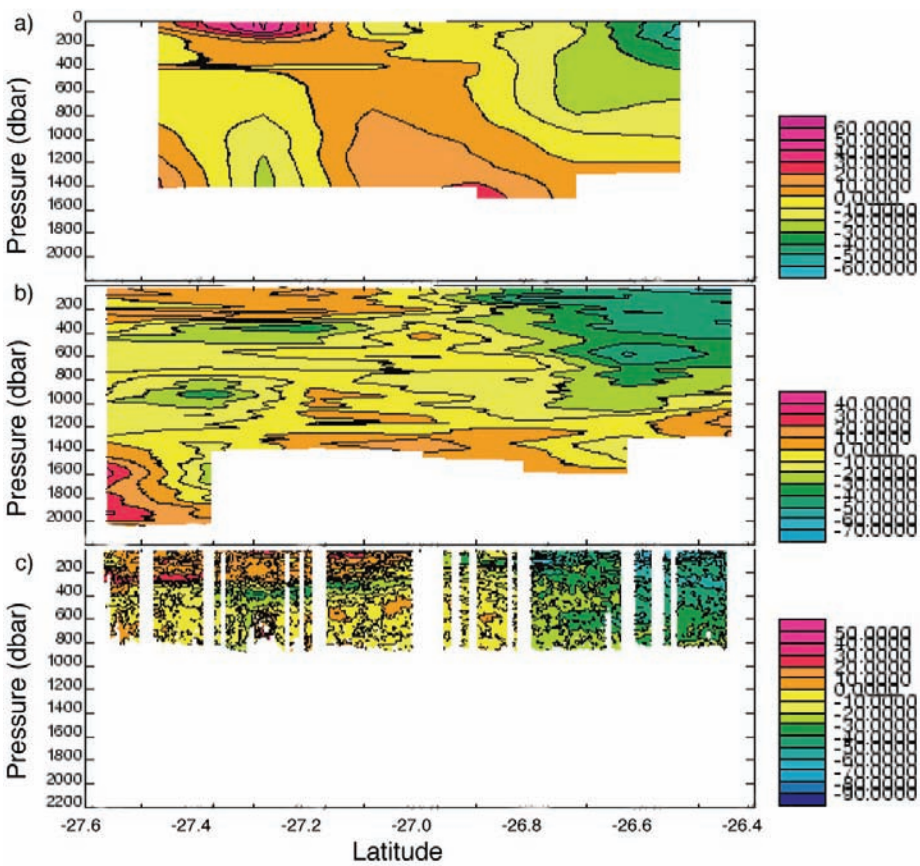

Figure 16 : Comparison of calculated velocities across leg 3 (positive flow is towards ENE) as determined from three different sets of measurements a) CTD, b) LADCP, c) 75 kHz ADCP (Ocean Surveyor).

5.4.1 Station summary

Station No	START		END		Duration	Distance run			Notes
	JDay	GMT	JDay	GMT		start (km)	end (km)	total (km)	
15635 #2	027	14:08	027	14:46	0d 0h 38 m				vertical dip for calibration purposes only (Minipack 210012 fitted)
15637	028	15:16	028	15:41	0d 0h 25 m				vertical dip for calibration purposes only (Minipack 210035 fitted)
15639	029	02:31	030	19:56	1d 17h 25 m	932	1513	581	Line in to survey area and start of first survey leg. Recovered due to termination failure
15644	031	20:54	032	05:17	0d 8h 23 m	1661	1731	70	Begin second leg of survey. Recovered due to termination failure.
15676	036	11:00	040	15:25	4d 4h 25 m	2494	3927	1433	Completed survey from the eastern end
15687	045	08:30	047	06:20	1d 21h 50 m	5596	6360	764	Return from Réunion to third mooring location
15695	048	06:28	049	10:00	1d 3h 32 m	6522	7000	478	Exit from area, across linear feature (see Fig. 5b)
				Total	**9d 8h 38 m**			**3326**	

Table 3 : Overview of SeaSoar deployments.

5.4.2 Instrument specification and calibration

The "C21" SeaSoar system (Allen et al., 2002), used for the first time on D253 (May/June 2001), carries a Chelsea Technologies Group (CTG) MiniPack CTDF (Conductivity, Temperature, Depth and Fluorescence) instrument which is considerably more compact than the Neil Brown CTD instrument that had traditionally been carried in SeaSoar.

The two MiniPack CTDs taken on D285/6 suffered major problems that are discussed in the relevant cruise report (Pollard and Sanders, 2006). MiniPack 210035 was sent back to CTG after D285 for repair; it was returned to RRS Discovery just in time for D288 (MadEx), fully repaired but uncalibrated!

During SeaSoar deployments data were recovered, in real time, from the PENGUIN data handling system on SeaSoar by ftp to create identical data files on the EMPEROR Linux PC in the main lab. Thus data were logged in three files, one containing the CTDF measurements, and two other files for FRRF (Fast Repetition Fate Fluorimeter) and OPC (Optical Plankton Counter) data. The OPC and FRRF data are dealt with elsewhere in this report (sections 7.3 & 7.4).

All of the variables provided by the MiniPack CTDF are "calibrated" using pre-set coefficients stored in the instrument firmware. The sensors sample at 16 Hz, but the output variables are one-second averages. The standard output variables are:

Conductivity (mS cm^{-1})

Temperature (°C)

Pressure (dbar)

ΔT (°C s^{-1}) — temperature change over the one second averaging period

Chlorophyll (mg m^{-3})

For the last two SeaSoar deployments on D288 (15687 and 15695), a Turner "cyclops" fluorimeter was attached to analogue input channel 10 of the MiniPack. This instrument was mounted in a nylon block on the SeaSoar's upper tailplane. The light source has a wavelength in the range 550-600 nm that is particularly effective for detecting the pigment phycoerythrin common to cyanobacteria.

Each of these variables were output at one-second intervals and a time/date stamp was added by the DAPS handling software on PENGUIN. The time-rate of change of temperature, ΔT (°C s^{-1}) was the difference between the first and the last sample in the one-second average of temperature. Firmware calibration coefficients for the two CTDs carried on D288 (MadEx) were as follows:

MiniPack serial no. 210012, calibration date 30/01/04,

$$press. = \left(-1.85335 \times 10^{-9} \times bits^2\right) + \left(9.46170 \times 10^{-3} \times bits\right) - 10.2313$$

$$temp. = \left(5.15065 \times 10^{-11} \times bits^2\right) + \left(5.99447 \times 10^{-4} \times bits\right) - 3.5094$$

$$cond. = \left(-7.16162 \times 10^{-11} \times bits^2\right) + \left(1.11034 \times 10^{-3} \times bits\right) - 0.9619$$

$$chl.conc. = \left(0.00208 \times bits\right) - 3.694.$$

MiniPack serial no. 210035, calibration date 10/12/04,

$$press. = \left(-1.43239 \times 10^{-9} \times bits^2\right) + \left(9.41950 \times 10^{-3} \times bits\right) - 9.4446$$

$$temp. = \left(5.48513 \times 10^{-11} \times bits^2\right) + \left(6.02014 \times 10^{-4} \times bits\right) - 2.9999$$

$$cond. = \left(-1.02301 \times 10^{-10} \times bits^2\right) + \left(1.12546 \times 10^{-3} \times bits\right) - 0.9859$$

$$chl.conc. = \left(0.00223 \times bits\right) - 4.338.$$

$$Ana.Chan.10 = \left(0.000073 \times bits\right) + 0.000606$$

Following the problems encountered on the previous cruises, MiniPack CTDF 210035 was used throughout D288 and behaved reasonably well. Although the instrument had not been calibrated by CTG both temperature and conductivity appeared reasonably well behaved with the existing calibration parameters. Nevertheless, a post-cruise full calibration is urgently required. A recommended cruise calibration was obtained for the data before the end of D288 and is discussed later; this calibration was not applied, however, awaiting rather the outcome of the post-cruise laboratory calibration. The values below are the post-cruise calibration, which have not been used for the plots and analysis shown in this report.

MiniPack serial no. 210035, calibration date 15/04/05,

$$press. = \left(-1.58509 \times 10^{-9} \times bits^2\right) + \left(9.42338 \times 10^{-3} \times bits\right) - 9.7370$$

$$temp. = \left(5.32727 \times 10^{-11} \times bits^2\right) + \left(6.00936 \times 10^{-4} \times bits\right) - 2.9345$$

$$cond. = \left(-7.40091 \times 10^{-11} \times bits^2\right) + \left(1.12464 \times 10^{-3} \times bits\right) - 0.9227$$

$$chl.conc. = \left(0.00186 \times bits\right) - 3.450.$$

5.4.3 Processing steps

The following processing route was followed every 12 hours during SeaSoar tows:

The DAPS data file on EMPEROR was stopped and a new one started every 12 hours, at which time the PENGUIN clock was checked for large drifts and later clock correction if required. As on the immediately preceding cruises, the PENGUIN clock was found to gain, but at the higher ambient temperatures experienced on D288, the PENGUIN clock only gained ~ 3 seconds each 12 hour period. The PENGUIN clock was programmed to reset to the EMPEROR clock time each time it was booted. The latest 12 hour DAPS data files were copied from the EMPEROR PC to the shipboard SUN UNIX system over the ship's ethernet.

pgexec0

Read the raw DAPS data into PSTAR format and added information to the PSTAR header. In addition time in seconds was calculated from the Jday variable used by DAPS. Note that it was necessary to use the -square command line option for the pexec program **pxtime**. Unless this option was specified pxtime rounded the time to the nearest second occasionally giving rise to two records having the same time.

pgexec0a

Used for deployments 15687 and 15695, this variant on pgexec0 read in column 17 of the DAPS MiniPack ascii file; which corresponded to the phycoerythrin fluorimeter discussed earlier.

pgexec1

With the MiniPack set to output variables in physical units it is not necessary to use the pexec program **ctdcal**, and so this script was written to replace **ssexec1** by D. Smeed during D253. We may review this for temperature during D286, following the drifting temperature problem with MiniPack 210012 during D285. The main steps are

a) **pcalc** to apply temperature lag correction
b) **pintrp** to interpolate pressure across gaps in the data. Typically less than 0.3% of the data had to be interpolated
c) **peos83** to calculate salinity and density.

Pedita was then used to remove the worst surface salinity spiking and rare fluorometer spikes. Further editing for spikes, and salinity offsets due to high vehicle dive rates was carried out by inspection with **plpred**.

Subsequently, 12-hour files were merged to produce a single file for each survey, which was then merged with the navigation data. The data were interpolated to a 5 km by 8 dbar regular grid using **pgrids**.

5.4.4 Temperature corrections

It is necessary to make a correction for the small delay in the response of the CTD temperature sensor for two reasons. Firstly, to obtain a more accurate determination of temperature for points in space and time. Second, more importantly, to obtain the correct temperature corresponding to conductivity measurements, so that an accurate calculation of salinity can be made.

Surprisingly, according to the MiniPack users manual, the time response of the temperature and conductivity cells should have been the same. However, a lag in temperature is apparent in the data in two ways. There is a difference between up and down profiles of temperature (and hence salinity) because the time rate of change of temperature has opposite signs on the up and down casts. The second manifestation is the "spiking" of salinity as the sensors traverse maxima in the gradients of temperature and salinity. The rate of ascent and descent of SeaSoar is greater (up to 2-4 ms^{-1} at the beginning of descent and ascent) than that of a lowered CTD package, thus the effects of the temperature lag are more pronounced. Thus, the following correction was applied to the temperature during pgexec1 before evaluating the salinity:

$$T_{corr} = T_{raw} + \tau \, \Delta T$$

where ΔT is defined above and τ is a constant.

The best value of τ was chosen so as to minimise the difference between up and down casts and to reduce noise in the salinity profile. Initially the best value was found to be τ =0.35 s, but this noticeably drifted during the first towed deployment (stn. 15639) to a value of τ =1.30 s. This agreed with the large lag needed on D285/6 and indeed D253, but it is still somewhat concerning and needs to be discussed further with Chelsea Instruments. During the remainder of the D288 the best value was found to reduce slightly until, by the end of stn 15695, a value of τ =0.75 s provided the cleanest profiles and the best fit between up and down profiles.

The waters south of Madagascar are characterised by intense temperature stratification of up to 26 °C in the upper 300 metres. Maximum stratification frequently exceeded 4 °C in 20-25 metres. Very careful tuning of the vehicles flight parameters was therefore required to try to minimise dive and climb rates. However, the complex cable/vehicle interaction of SeaSoar has fundamental dynamic modes that can only be tuned to a limited extent. A considerable number of down profiles required the deletion of derived salinity somewhere over the depth range 20-100 m; this was easily observed by a clear "bulging" of the profile to lower salinities as the conductivity was correlated with too high a temperature. Occasionally, but rarely, both up and down trajectories were too fast and the salinity values were not deleted as up and down "bulges" in the profiles were such as to cancel out, leaving a reasonable mean T/S curve.

5.4.5 Calibration

We had two tools for the calibration of the MiniPack CTD data, the underway thermosalinograph (TSG) connected to the ship's non-toxic supply and the well-constrained T/S profiles from the traditional vertical CTD (SeaBird) stations. Unlike the preceding cruises, D285/6, it was clear from early comparisons with SeaBird CTD data (vertical trials 15635/7) that the temperature sensor on 210035 MiniPack was reasonably well calibrated and no further calibration would be required pending a post-cruise laboratory calibration.

Sadly the comparison with underway bottle samples showed that the TSG salinity (see section 5.6) was not as stable during D288 as it had been during D285/6. Nevertheless, once this had been calibrated by using constant and linear offsets with time, the SeaSoar data were compared to it by extracting data within the depth range of 3-5 m.

The MiniPack 210035 appeared to be 0.04 low in salinity within an accuracy of 0.20-0.25. Expanding the above plot for each individual survey allows offsets to vary between 0.03 and 0.05 but with a similar accuracy and it was difficult to identify whether this variation came from true shifts in the MiniPack data or imperfections in the TSG calibration. So we are left with the comparison with the well-constrained T/S profiles from the CTD stations:

SeaSoar tow 15639

The end of this tow was matched with ctd15640 that suggested that the MiniPack salinity was low by 0.05 ± 0.01.

SeaSoar tow 15644

The end of this tow was matched with ctd15645 that suggested that the MiniPack salinity was low by 0.04 ± 0.01.

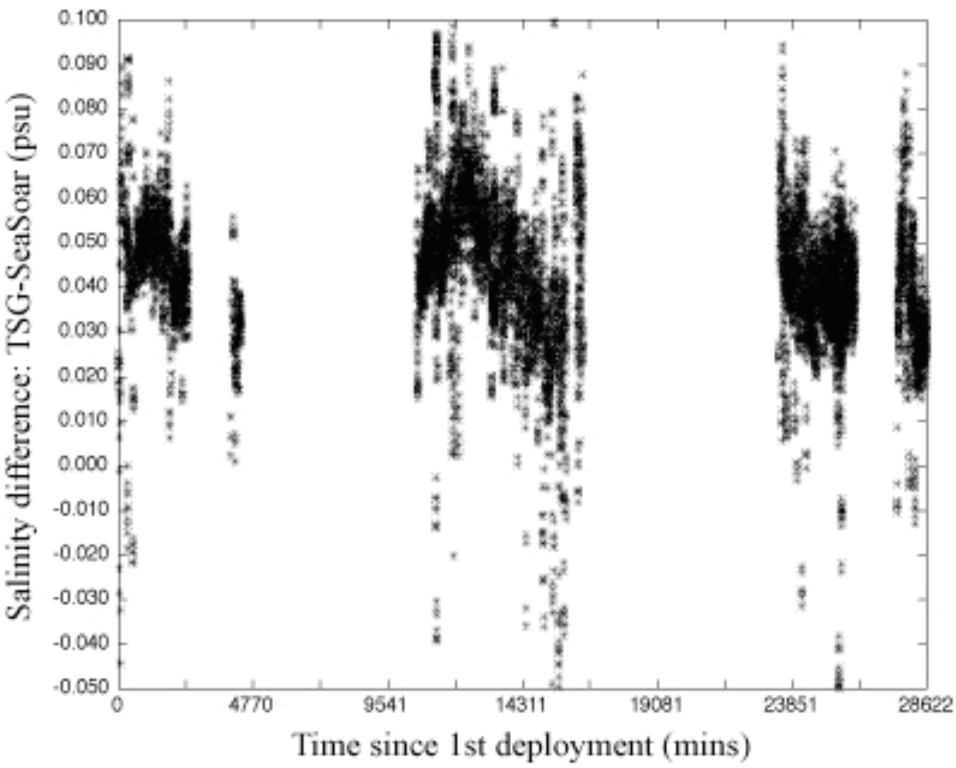

Figure 17 : Salinity difference in near-surface waters (3-5 m) between TSG and SeaSoar.

SeaSoar tow 15676

The beginning of this tow was matched with ctd15674 that suggested that the MiniPack salinity was low by 0.03 ± 0.01. The end of this tow was matched with ctd15677, ctd15678 and ctd15679; a poor match was obtained with ctd15677 and ctd15678 that suggested that the MiniPack salinity was 0.02 low, but a good match with ctd15679 suggested that the MiniPack was low by 0.03 ± 0.01. In addition, SeaSoar T/S profiles were compared at two points where the survey tracks crossed over each other in space but at different times. At these points the T/S profiles appeared to be self-consistent, and the salinities consistent to within 0.01 psu, indicating little drift in the temperature and conductivity sensors.

SeaSoar tow 15687

The end of this tow was matched with ctd15689 that suggested that the MiniPack salinity was low by 0.03 ± 0.01.

All of the above comparisons agreed that the MiniPack salinity was low by ~0.04 ± 0.01-0.02. And with such a large temperature stratification an accuracy of 0.02 may well be all that can be achieved. However, with such a relatively small offset suggested, no final cruise calibration was applied pending the outcome of the post-cruise laboratory calibration.

5.4.6 Summary

As found on D253, a great advantage of the inductive conductivity cell used in the CTG MiniPack is that the occurrence of spikes and offsets due to biological fouling is virtually nil. Thus it was entirely feasible for all the SeaSoar processing to be undertaken by just one scientist.

However, the stability of the instrument's electronics or temperature sensor is clearly a concern as indicated by the need to change the temperature-lag compensation by such a large amount during and between deployments. In 2001, this instrument was one of the first of the modern miniaturised CTD instruments on the market; however, there now exists considerable choice in the market place including instruments from SeaBird, the company that currently holds the standard in lowered CTD accuracy. However it is noted that the tight replication between T/S profiles that are achieved, once a suitable temperature correction is determined, might be hard to beat.

During the cruise PENGUIN was operated in accordance with the documentation provided by Paul Duncan of RSU. Generally PENGUIN performed well and several long tows were completed. There were however issues with the OPC which are documented below and in the section of the report for that instrument (section 7.3). Also the operation of PEGUIN on this cruise has highlighted some issues, which need to be addressed. These are laid out below.

5.5.1 Operational issues

Whilst PENGUIN can be considered a success, many areas of its operation are still not well established. The documentation written by Paul Duncan goes a long way towards addressing these problems, but is really predicated on the assumption that PENGUIN will operate without problems. However, PENGUIN is still a development system. As a result of the wise decision to re-engineer, the PSU is more mature now than at the handover to UKORS but much still needs to be done to maintain its current level of functionality and more should be done to extend its use into other areas. Those areas which must be addressed in order to assure continued operation are:

- Resolution of controllable power supply problems with OPC – see section 7.3.2 for details.
- Resolution of DAPS logging errors for OPC — see section 7.3.1 for details.
- More spare hard disks. These should be ready-imaged with O/S and DAPS.
- A development system should always be on board, capable of supporting two hard disks and with support for a CDROM. It should also have a PSU board with I2C device control and sea-cable connectors so that instruments can be tested on the bench. This would greatly facilitate development, testing, hard disk rebuilds and software installs.
- End-cap modifications – the current Impulse connectors are causing considerable problems during plug/unplug and should be replaced with smaller versions.
- The spare end-cap should be refurbished with new internal connectors to fit Seamap PENGUIN boards. Current spare is not modified and is thus of little use.

- More spares need to be carried on board – especially cables/connectors.
- The current software installation is probably the area which has had the least development since the original system. It needs completely tidying up with the removal of old files and unnecessary software.
- PENGUIN badly needs a new LINUX install – or at least a new custom kernel to support a journalled file system. I suggest ReiserFS as being more robust than ext3.
- Documentation: The docs written by Paul Duncan are a good start but as the operation is being constantly refined this should be ongoing and exhaustive – and on CDROM. Paper documentation does not survive well at sea.

5.5.2 Comments on MadEx deployment

Voltages and Cables:

90 volts with all instruments powered up has been used on this trip and with this cable. It would be very useful to be able to measure the voltage being received by the PENGUIN PSU. This varies considerably between cables and can be critical. It would also probably be good to wire up the sea cable so that the ADSL conductors are not adjacent as this probably reduces the S/N margin.

Modems:

It might be useful to reset the ADSL modems after launch as the characteristics of the cable will change after it has been removed from the winch drum.

Useful X200 Command: show modem

This will show a number of parameters for the ADSL connection including signal to noise margin. Remember that because of the way we have setup the modems the 'downstream' stats refer to the data flowing from PENGUIN to EMPEROR.

At one point on the tow from Reunion the S/N ratio fell below 2dB, with the data rate at that point being insufficient to keep up with capture. In order to improve this I manually set the data rate to 2Mbit/s,. and then reset the top-end modem. Since PENGUIN was running **watchscr**, it also reset the bottom-end modem. This reset the link, and when it came back up the S/N margin was 23dB! The necessary commands to be sent via the modem are specified in Appendix 2.

5.5.3 The Future of PENGUIN

Penguin is a powerful tool for remote data acquisition and has shown this on more than 5 cruises. It uses no novel technology, is composed of "off the shelf" components, is not suitable for development as a research project and counts all of these as strengths. The object of PENGUIN deployment is to meet oceanographic goals rather than those of instrumental research. For this reason I believe that it should be developed within UKORS as an infrastructure component – with the extra resources that this implies being supplied. The best analogy for PENGUIN in past NERC developments would be the level ABC system. PENGUIN needs to be a part of data-collection infrastructure, offering services to developers of instrumentation and survey methods.

PENGUIN has many more potential uses:

- As a data multiplexer for Deep CTDs.
- As an essential part of any SeaSoar expansion.
- As a non-networked data acquisition system on co-ax cabled systems like plankton recorders where only power is carried on the cable.
- Auxiliary Data Acquisition on the ROV.

Future Enhancements for PENGUIN:

- A flash file system for booting with an option to log to flash memory, network or to hard disk.
- An extra serial controller instead of, or in addition to, A/D.
- Up-to-date drivers for currently installed analogue to digital PC104 card.
- An upgrade to the latest PC104 card which would facilitate the above.
- It might be best to switch to one of the embedded LINUX distributions. These offer lower latency and better support for devices.
- A GUI front-end would make for easy monitoring of data transfer rates, signal quality, pressure signal and disk activity.

- Full ocean depth version of PENGUIN.
- Cable voltage/condition monitoring.
- SeaSoar flight control software on-board?
- Fibre optic transceiver version of PENGUIN would enable it to make use of the new fibre optic cables – probably combined with full ocean depth version.

5.6 Thermosalinograph and SurfMet data Stephanie Henson & Meric Srokosz

The Thermosalinograph (TSG) draws water from a non-toxic supply intake, located at a depth of ~5 m on the ship's hull. A temperature and conductivity sensor, as well as a fluorometer and transmissometer are connected to the supply in the water bottle annex. Data were logged continuously throughout the cruise on a SunBlade workstation powered by a UPS. A pstar format file of the form TSGD285.ddd was produced daily at midnight (note that we were not able to change the cruise number to D288). The time is logged as decimal days, however in order to assist merging the data with navigational and other data the time was converted to seconds. Also the header information contained an incorrect start time (should be 01/01/2005) and had to be corrected before merging with other data. A script **tsgtime** was written to perform these steps, requiring the user to input only the day number. Each day's data were appended on to the file tsg288.all. The TSG file was merged with positional data from the abnv file and then averaged into 1 minute (tsg288.1min) and 15 minute (tsg288.15min) files. Bottle salinity and chlorophyll-a samples were taken either hourly (whilst SeaSoaring) or every 2 hours from the non-toxic supply in order to calibrate the TSG salinity and fluorescence respectively.

Interruptions to the continuous data occurred twice: On JDay 039 at ~ 18:30 GMT the fluorometer was disconnected and cleaned after it was noted that the fluorescence values had been continually rising for a couple of days. Biofouling of the sensor was suspected and following cleaning the fluorescence dropped back to reasonable levels. On JDay 041 at ~ 08:00 GMT the conductivity cell was removed and replaced with a spare, after considerable drift in the TSG salinity values was observed. However, the spare cell was found to be even worse than the original, which was then reinstalled. In addition the transmissometer was reading a constant value of 0 V and was replaced with a spare at the same time.

5.6.1 Salinity calibration of underway data

A text file containing salinity sample number, time of sample and salinity was read into pstar, the time changed to seconds and the header information changed so that the start time was 01/01/2005. The data were then merged with position and TSG salinity. A script **compsal** was written to automate these steps. **Datpik** was used to remove 4 outliers from the bottle salinities. An obvious drift was observed in the TSG salinity (see Figure 18 which shows the difference between bottle and TSG salinity against sample number). Even more strangely, after rising continuously for several days the TSG salinity then dropped again, and over a period of several days began to rise again. No explanation could be found for this behaviour. Simple corrections to TSG salinities are specified in Table 4. Figure 19 shows how of three of these surface properties (temperature, salinity and chlorophyll concentration) varied during the cruise.

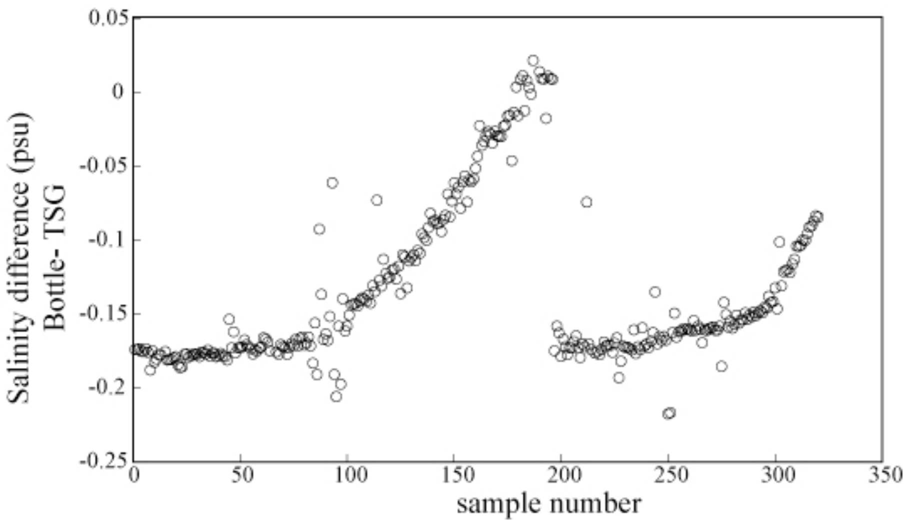

Figure 18 : Change in salinity bias of TSG as a function of underway sample no. (time).

JDay & Time	**tsg - bot (psu)**
after 028 03:00	-0.1751
after 034 12:00	1.5987 - 0.03998 * decimal_day
after 039 23:00	-0.1608
after 046 22:00	1.6658 - 0.032144 * decimal_day

Table 4 : Biases in salinity recorded by TSG relative to bottle samples.

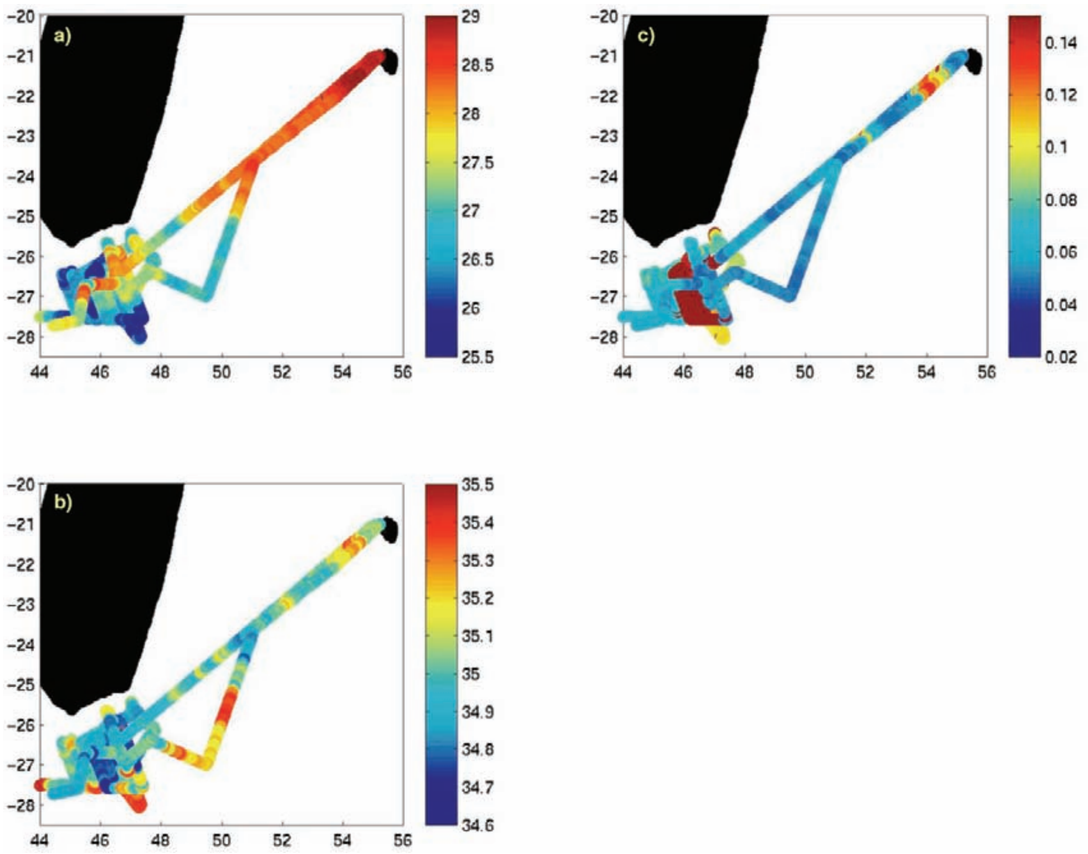

Figure 19 : Spatial variations of a) Temperature, b) Salinity, and c) Fluorescence during detailed survey and detour to Réunion. Note, during the detailed survey south of Madagascar, the fluorometer suffered from biofouling, leading to ever-increasing values; this problem was sorted out prior to the trip to Réunion.

5.7 Salinity bottle samples **Meric Srokosz**

Salinometerists: Steven Alderson, Emma Guirey, Stephanie Henson, Meric Srokosz

Salinity samples were drawn from the Niskin bottles mounted on the CTD rosette and from the non-toxic supply. Samples were taken using 200 ml glass sample bottles; these were rinsed three times in the sample, filled to the shoulder and sealed with a disposable plastic insert and the bottle's screw cap. Non-toxic supply samples were taken hourly from, the Thermosalinograph (TSG) outflow in the water bottle annex and then for some of the time from the SUV-6 (nitrate sensor) outflow to calibrate the continuous TSG measurements. When on station for a CTD or mooring deployment this hourly sampling was suspended, or varied to include a sample midway between stations. Underway sampling was reduced to once every two hours during the detour to Réunion (JDay 041 to 046). Once a crate of sample bottles had been filled they were moved into the stable laboratory to acclimatise for 24 hours prior to analysis.

The salinometer (Autosal 8400B, serial no. 65764) that was used to analyse the bottle samples was situated in the stable laboratory. The laboratory maintained a fairly stable temperature of ~26-27˚C (checked hourly), except towards the end of the cruise after the ship's air-conditioning failed, when the temperature rose to 28˚C. The salinometer water bath temperature was set to 30˚C. The salinometer was fitted with a peristaltic pump, to aid flow-through. Additionally, it was connected to a PC running Softsal (ver. 1.2) that recorded the conductivity readings (3 taken for each sample) and automatically calculated the salinity. The salinometer was standardised prior to the processing of each crate of bottle samples using OSIL IAPSO standard seawater (batch P144, K_{15} = 0.99987, salinity 34.995). The salinometer appeared to remain stable during the cruise (use of the Softsal software which requires standardisation for each analysis cycle means that the usual checks for stability cannot be done).

One problem noted with the Softsal software was that it warns the operator if the suppression is set too high, but not if the suppression is set too low. In the latter case it still gives a salinity value if the operator is not vigilant enough to change the suppression. During the early part of the cruise a few anomalously low salinity values were obtained for this reason (subsequently discarded). Once the operators had got used to using Softsal, and to this particular peculiarity, the problem did not recur.

Softsal saved the measured salinity values in .DAT files that were subsequently transferred to the shipboard system on a floppy disk. The files for the underway measurements were labelled D288UWnn.DAT, where nn increased sequentially from 01.

The CTD files were labelled CTnnnnn.DAT, where nnnnn was the station number associated with the first bottle sample in the crate being analysed. The files were merged with information from the TSG and CTD log sheets in Excel and tab-delimited .TXT files produced (same labelling convention). For use in processing with pexec, these text files were "cleaned up" with the script **cleanexcel**. This produced .TXT files with the identifier "sal" appended at the beginning of the file names.

6. Chemistry

A number of chemical measurements were made during MadEx. Both underway and CTD casts were sampled and routinely analysed for nutrients (nitrate, phosphate and silicate). Samples from the CTD bottles were also analysed for concentration of dissolved oxygen, to act as a validation for the output of the SBE oxygen sensor on the CTD frame. We also had an experimental instrument (SUV-6) for determining nitrate concentration in near real-time through its effect on UV light absorption at specific frequencies. It had been hoped to include that on the SeaSoar, but that required too many modifications; instead it was attached to the underway supply, but then suffered from bubbles in the flow giving a much stronger signal than that for nitrate (which would be weak in the surface layer due to the low nutrient concentrations there).

6.1 Inorganic nutrients

Mark Stinchcombe

6.1.1 Methodology

Analysis for nitrate and nitrite (hereinafter nitrate), phosphate and silicate was undertaken on a Skalar sanplus autoanalyser following methods described by Kirkwood and Aminot (1994), with the exception that the pump rates through the phosphate line are increased by a factor of 1.5, which improves reproducibility and peak shape. Samples were drawn from Niskin bottles on the CTD or from the underway non-toxic supply into 25ml sterilin coulter counter vials and kept refrigerated at 4˚C until analysis, which commenced within 24 hours. Stations were run in batches of 1 to 4 with most runs containing 2 or 3 stations. Overall 29 runs were undertaken. An artificial seawater matrix (ASW) of 40g/l sodium chloride was used as the intersample wash and standard matrix. The nutrient-free status of this solution was checked by running Ocean Scientific International (OSI) nutrient-free seawater on every run. A single set of mixed standards were made up by diluting 5 mM solutions made from weighed dried salts in 1 litre of ASW into plastic 1 litre volumetric flasks that had been cleaned by soaking for 6 weeks in milli-Q water. This was in an effort to minimise the run-to-run variability in concentrations observed on previous cruises. Data were transferred to another computer via memory stick. This enabled data work-up within a few hours of sample analysis, except during the busiest CTD period when the time until data work-up was 48 hours. Data processing was undertaken using Skalar proprietary software. The wash time and sample time were 75 seconds; the lines were washed daily with 0.25M sodium hydroxide (P) and 10% Decon (N, Si).

6.1.2 Instrumental problems

1) During the middle of the cruise the sampler stopped working. It didn't switch on as a run was attempted. This sampler was therefore switched for the spare, which then also stopped working halfway through a run. This resulted in the loss of some data as the machine spilt the samples. With both samplers down no analysis for inorganic nutrients were made for a couple of days. Chris Hunter had a look at the problematic samplers and managed to get one working again. All samples in the intervening period were frozen at -20˚C. This included stations 15652, 15658, 15660, 15663, 15665, 15666, 15667, 15668, 15669, 15670, 15671 and underway samples 101 to 124. They were then thoroughly thawed out by being kept in a cool cupboard and then the fridge until they were ready to be analysed.

2) Throughout the cruise there were problems with what looked like contamination in the phosphate line. During a run the phosphate would suddenly increase dramatically and become very noisy. This would slowly settle down to the normal baseline value again after 15 to 20 minutes. The result though would be a loss in the samples that were being analysed during the time the phosphate line was elevated. The actual cause is unknown: changing reagents, thorough cleaning of the lines, and changing of tubes all had no effect; however, it didn't happen during every run and it seemed to get less common as the cruise went on.

6.1.3 Analyser performance and data quality

The performance of the analyser is monitored via the following parameters: baseline value, calibration curve slope, regression coefficient of the calibration curve, nitrate reduction efficiency. Time series of these parameters are shown in the following figures.

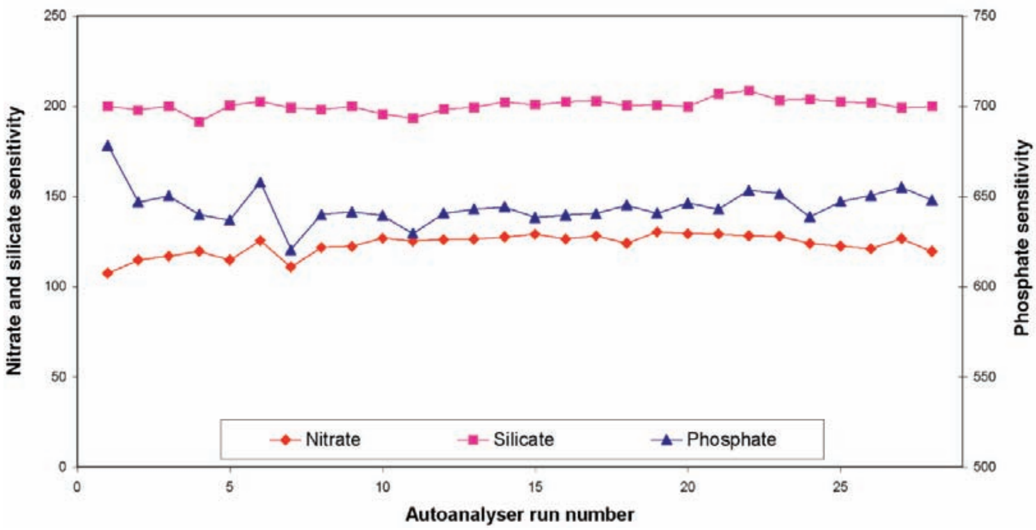

Figure 20 : Time series of instrument sensitivity (bits per micromole).

The instrument sensitivity for nitrate and silicate varied by no more than 5% over the course of the cruise (Fig. 20). The phosphate line was more variable at the start of the cruise, with sensitivity changing by 10 to 15%, but it settled down later, possibly in line with the problems with the phosphate baseline as described above.

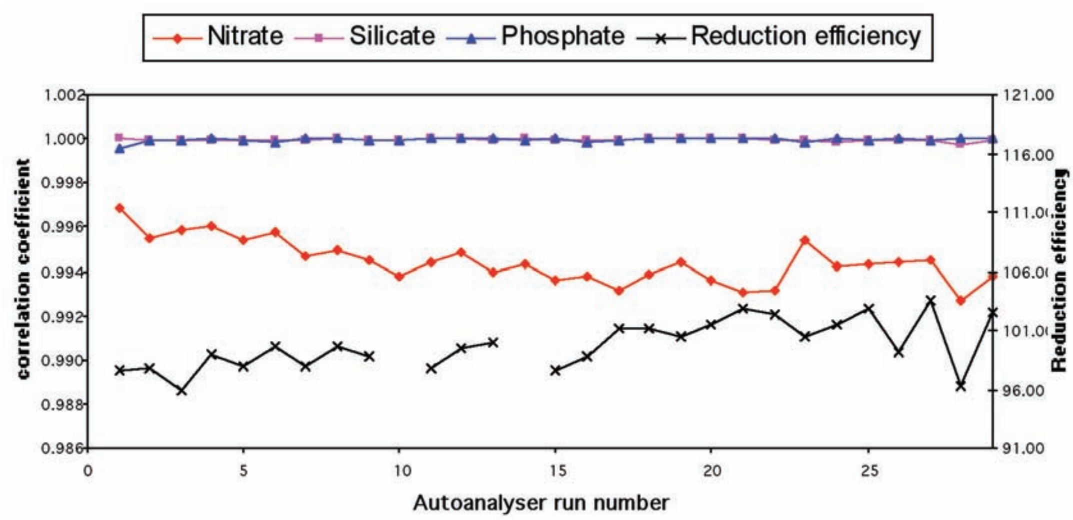

Figure 21 : Time series of regression coefficients of calibration curves and of reduction efficiency.

The quality of the calibration curves was generally good with all of the silicate and phosphate regression coefficients being greater than 0.999 (see Fig. 21). The nitrate was slightly lower but still nearly all the regression coefficients were higher than 0.993. The reduction efficiency of the cadmium column, i.e. its ability to convert nitrate into nitrite, was greater than 95% for the whole of the cruise, but with the majority of values over 98%. The efficiency generally increased over the course of the cruise.

The baselines of the three inorganic nutrients barely changed throughout the cruise (Fig. 22). The exception was two anomalously high baselines for nitrates, which occurred in runs when the baseline showed some level of drifting, with the implication that the runs were put on too early before the baseline had settled. However, the drift samples and wash samples allowed the Skalar software to take this drifting into account, so that there should be no effects in the final analysis.

The short-term precision of the measurements was evaluated by running at least 1 duplicate sample per run. The difference between the two duplicates was calculated and plotted (Fig. 23); the differences were all less than 3%, with the majority being below 2%.

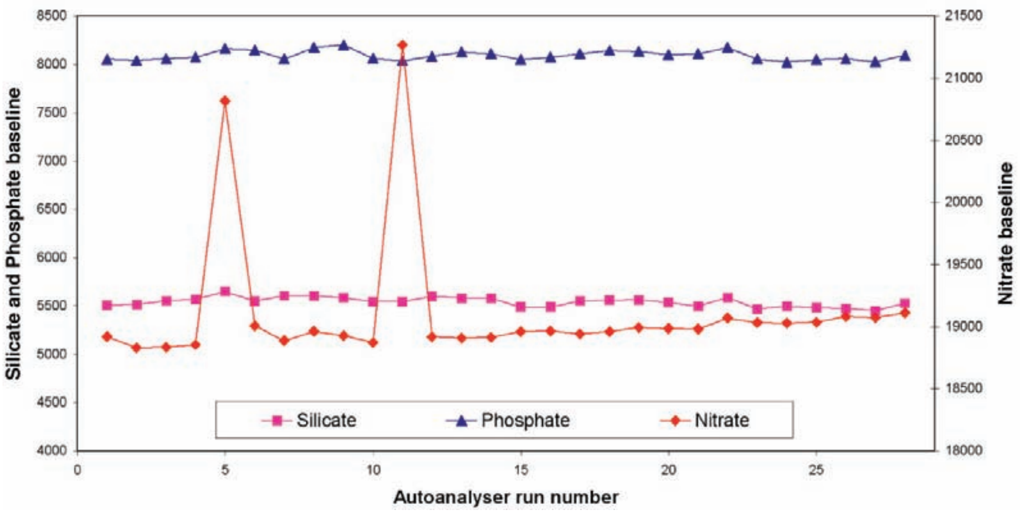

Figure 22 : Time series of baseline values.

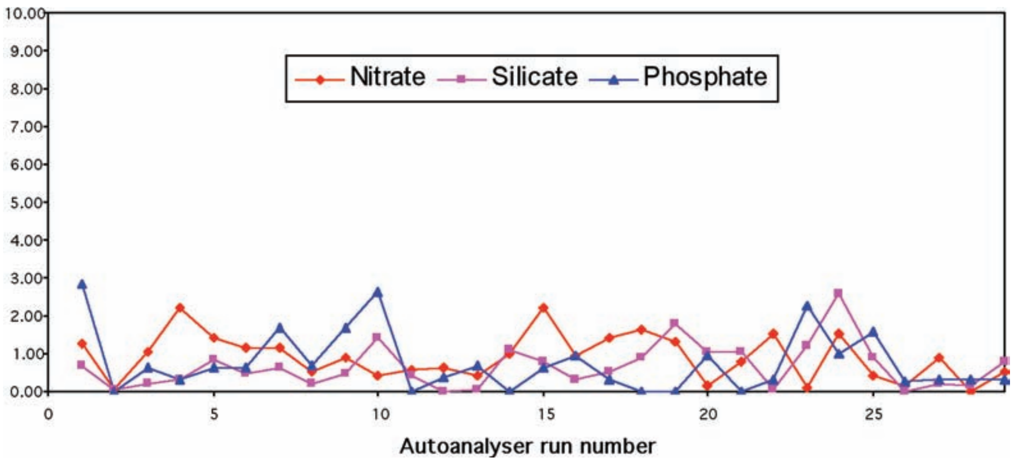

Figure 23 : Percentage difference between analyses of duplicates as a function of run number (time).

6.2.1 Methodology

Water samples for analysis for dissolved oxygen were only taken from the CTD casts. They were the first samples to be drawn from the Niskin bottles. At the start of the cruise one oxygen sample was taken from each Niskin bottle that had been fired and then one repeat bottle was done. This was the case up until station 15658. After this station only 10 to 12 samples were taken from each CTD cast. This change in sampling was done so as to allow there to be sufficient oxygen bottles and analysis time to analyse most of the stations. The samples were drawn through short pieces of silicon tubing into clear, pre-calibrated, wide-necked glass bottles. The temperature of the sample water at the time of sampling was measured, using an electronic thermometer probe, so that we could calculate any temperature-dependent changes in the sample bottle volumes. Each sample was fixed immediately using 1 ml of manganese chloride and alkaline iodide, and then the sample was shaken thoroughly and left to settle for a few hours before analysis.

The samples were analysed in the deck laboratory following the procedure outlined in Holley and Hydes (1995). The samples were acidified using 1ml of sulphuric acid immediately before titration and stirred using a magnetic stirrer. We determined the oxygen concentration using the Winkler whole bottle titration method with amperometric end-point detection (Culberson and Huang, 1987), using equipment supplied by Metrohm.

The normality of the sodium thiosulphate titrant was checked using a potassium iodate standard. This was done a number of times throughout the cruise, though the first two times were with a different standard and when the potassium iodate was changed the sodium thiosulphate also had to be changed. Thiosulphate standardisation was carried out by adding the iodate solution after the other reagents had been added to a water sample in reverse order. Figure 24 shows that there was little degradation of the sodium thiosulphate over the length of the cruise.

The number of duplicates and the ratio between the duplicate values (Fig. 25) can also be seen to show that there was good reproducibility between samples. The lowest sample ratio was 0.95. All the others were 0.98 or above.

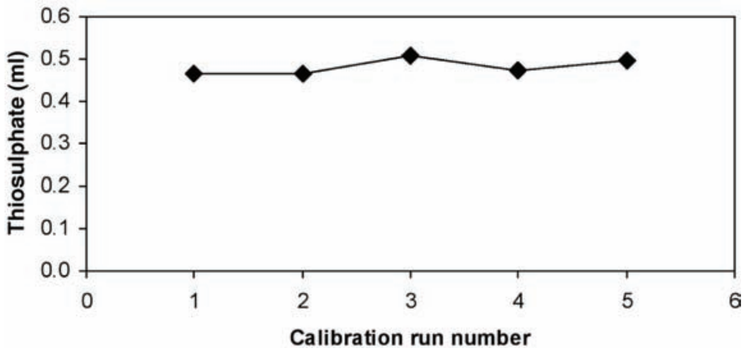

Figure 24 : Repeated assessment (throughout cruise) of normality of thiosuphate solution.

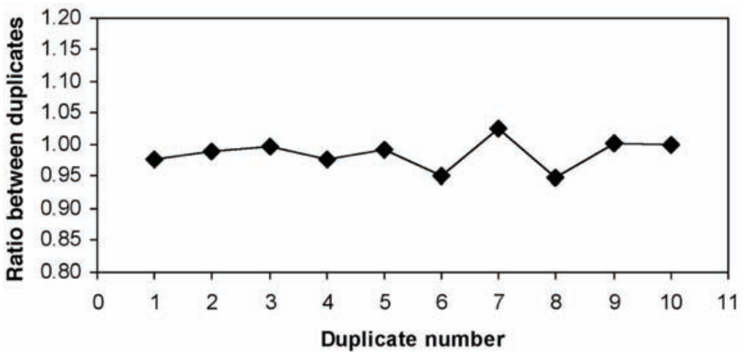

Figure 25 : Ratio between oxygen concentrations determined from duplicate samples.

6.2.2 Instrumental Problems

There were no problems with the taking of the samples and there were no general problems with the analysis equipment. At one point there was a problem with the laptop used to run the analysis equipment. The two machines stopped talking to each other. This problem was investigated and eventually communication was restored, although the actual cause of the problem was not discovered.

The main problem comes from the lack of duplicates made. When switching to only doing half the number of bottles for each station to increase the number of stations sampled, there were few spare oxygen bottles for duplicates. Fortunately, the duplicates actually analysed showed high reproducibility, and there was a good correlation with the oxygen sensor mounted on the CTD frame.

6.3 SUV-6 Nitrate sensor **Emma Guirey, Stephanie Henson & Meric Srokosz**

The SUV-6 nitrate sensor was set up in a special flow-through system and attached to the non-toxic water supply in the water bottle annex. The data were logged onto a PC situated nearby. The only way to transfer data from the PC to the shipboard computing system was by floppy disk. Unfortunately the daily files produced by the SUV-6 are too large to fit on a floppy disk. The programme logging the data started writing a new file at 00:00GMT. To enable data transfer on a floppy, the logging programme was interrupted at approximately 12:00 GMT each day and restarted. This produced two data files per day of around 3Mbytes, each of which could be zipped to around 840 Kbytes and so transferred by floppy. The PC clock was found to differ from and drift slowly relative to ship's time and this difference was noted down each day. Over the period of the cruise when the sensor was operational the time difference (shiptime – PCtime) changed from 4 minutes (JDay 035) to 6 minutes (JDay 049).

It became apparent fairly quickly that the system was not producing sensible measurements and investigation showed that there were bubbles in the non-toxic supply to the SUV-6. After seeking advice from Ralf Prien (SOC) by e-mail, it was decided to test the SUV-6. It was removed from the flow-through housing and readings were taken in air, in a bucket of distilled water and in a bucket of seawater. These showed that the SUV-6 was operating correctly, clearly indicating that it was the flow-through system that was the problem. Further investigation by Kevin Smith (UKORS) found that the sealing O-ring was too narrow and a replacement was fitted. The flow-through system was then connected to the non-toxic supply and, with a sufficiently high flow rate, no bubbles were observed and the SUV-6 gave readings that matched the seawater bucket test.

The SUV-6 became operational on JDay 035 (4th February 2005) and data were collected thereafter until JDay 049 (18th February 2005). The data files are labelled Rdddhhmm.txt where ddd is the integer Julian day, hh the hour and mm the minutes when that data file started being written (hhmm in GMT). The data files are structured:

YY JDAY CH1 CH2 CH3 CH4 CH5 CH6 CH7

where YY is the year (05), JDAY is the decimal Julian day, CH1 to CH6 are the measurements from the 6 channels (see below), and CH7 is a duplicate of CH6. The data are logged once per second and every 60 seconds contains 45 measurements and 15 internal calibration loop measurements.

It was noted that when the flow rate past the sensor was reduced accidentally on one occasion, the readings dropped significantly. Restoring the flow rate to its original value restored the SUV-6 readings. Increasing the flow rate even further made no difference to the readings. This suggests that tests need to be carried out on the flow-through system to determine the optimal flow rate needed for good measurements to be obtained from the SUV-6.

The SUV-6 produces measurements in 6 UV channels (205, 220, 235, 250, 265, 280 nm) and the nitrate measurement is made from the relative absorbance in the 220 nm and 280 nm channels. The 205 nm channel is sensitive to salinity. The data were analysed using Matlab code provided by Ralf Prien (SOC), amended to fix a problem with array indexing. The code is provided in Appendix1. When running the code it occasionally failed for two reasons. First, the raw data files had the occasional glitch where a line of data was either too long or too short (i.e. failed to match the expected data format). This was cured easily by editing out the offending lines from the data files. Second, the code did not run correctly if the data file did not end with a calibration measurement (see above). This too was cured easily by editing out a few lines at the end of the data files to ensure that the last line consisted of calibration data.

The Matlab code produced a time plot of nitrate concentration for each file. Since these plots indicated negative nitrate concentrations (of order –1 μmol l^{-1}), something was clearly wrong either with the measurements or the equation used for calibration of the measurements. See the Matlab code (appendix 1) for the calibration equation, which uses the absorbance in the 220 nm channel with respect to the 280 nm channel. It is possible that the formula was developed under particular temperature and salinity conditions which differ greatly from those experienced on the current cruise, making it unsuitable for calibration of the current data. The nitrate values in the cruise region are particularly low (usually <0.3 μmol l^{-1}), which may not have been the case during formulation of the calibration equation. Additionally, the SUV-6 may not be sensitive enough to accurately measure such low nitrate concentrations. Further investigation of these possibilities will continue ashore.

For comparison with underway data, the Matlab code was amended to output the Nitrate concentrations to file. The files were labelled as Nitr_Rdddhhmm.mat (see above) in the format JDAY N, where N is the nitrate concentration in μmol l^{-1}.

The SUV-6 nitrate values were compared with discrete surface samples taken hourly from the non-toxic supply and measured with a SanPlus autoanalyser. There was no apparent correlation between the SUV-6 and sample nitrate values. Indeed the data did not even vary in the same sense – instead it was noted that the SUV-6 output was somewhat negatively correlated with TSG salinity. In these very low nitrate waters it may be that the SUV-6 sensor is simply responding to changes in salinity, rather than nitrate. This will need to be investigated further post-cruise.

7. Biology

An important aspect of MadEx was to look at the biological productivity, the community structure and its variability. The plan had been to survey an eddy, complete the mooring work, and then re-examine the feature once more, a week or so later. The 5-day detour to Réunion upset this plan, but did enable coverage of a wider range of conditions, including a section across the part of the southwest Indian Ocean where the so-called Plankton Wave (Srokosz et al., 2004) occurs.

For phytoplankton analysis regular samples were taken from the underway supply and from Niskin bottles on CTD casts. The methodology for sample collection for microscope and flow cytometer analyses are detailed in sections 7.1.3 and 7.1.2 respectively. Large volumes of water were also filtered (section 7.1.5) so that they could be returned for HPLC analysis to look at the pigments present. This work was complemented by one of the first operational trials of a fluorometer designed to measure levels of the pigment phycoerythrin (section 7.1.4).

A direct determination of the zooplankton was performed by vertical hauls of Bongo nets at about half of the CTD stations (section 7.2). Finer resolution records of surface water concentrations of both phytoplankton and zooplankton were determined by the use of an OPC and a FRRF on SeaSoar (sections 7.3 & 7.4 respectively). Finally, in order to relate *in situ* measurements to satellite data (section 3.2), we complemented the work on identifying and quantifying phytoplankton and collection of samples for pigment analysis, with local measurements of ocean colour (water-leaving radiance) using hyperspectral radiometers (section 7.5).

7.1.1 Total and size-fractionated chlorophyll-a measurements

Measurements of total chlorophyll-a were made routinely from either the underway supply (every 1 or 2 hrs) or CTD deployments (typically 9 – 10 depths). Water samples (250 ml) were filtered through Whatman GF/F (pore size 0.7 μm) glassfibre filters, then extracted in 10 ml 90% acetone for 20 – 24 hrs in the dark and cold (4˚C) and read fluorometrically on a TD700 laboratory fluorometer with a 90% acetone blank. The TD700 was equipped with Welschmeyer (1994) filters for chlorophyll-a measurement in the presence of high chlorophyll-b and chlorophyll-a_2 (divinyl chlorophyll-a) concentrations. The chlorophyll-a concentration was calculated as:

$$\text{Chla (mg m}^{-3}) = (F – B) \times RF \times (V_1/V_2)$$

where, F is fluorescence reading of sample, B is fluorescence of the blank, RF is response factor (0.139), V_1 is volume of acetone (10 ml) and V_2 is volume filtered (250 ml).

The TD700 fluorometer was calibrated using a dilution series of pure chlorophyll-a standard (Sigma, UK). The response factor (0.136; r^2 = 0.996) from this calibration was compared with that of several previous cruises (D285, 0.132 16/9/04; D286, 0.144 10/12/04; D287, 0.135 15/12/04) that used the TD700 and a mean value (0.139) applied to the MadEx measurements. A slight drift did occur in the fluorescence of the acetone blank and this is likely to be due to temperature fluctuations in the deck lab: all measurements were corrected for variable blanks. A dilute chlorophyll-a standard (nominally 21.2 ng ml^{-1} = 21.2 mg m^{-3}) was also measured during each set of analysis and drift in this measurement was also likely to be due to temperature fluctuations, as well as degradation of the chlorophyll standard. However, drift in the fluorescence of the chlorophyll standard was small. Aliquots of the chlorophyll-a standard on the ship and replicate measurements of underway chlorophyll-a were frozen for return to the UK and cross-checking. Replicate chlorophyll-a measurements (mg m^{-3}) were made on samples from the underway (UW) supply, and for pairs of Niskin bottles i.e. those closed near the surface (5m depth) and those at the fluorescence maximum (90 m); mean UW chla was 0.10 ± 0.003, mean 5 m CTD chla was 0.09 ± 0.002, and mean 90 m chla was 0.29 ± 0.015.

Size-fractionated chlorophyll-a measurements were made by sequentially filtering 250 ml of seawater through 5 μm, 2 μm and 0.2 μm polycarbonate filters (Filedar filtersystems, UK). Filters were extracted and read fluorometrically as with total chlorophyll-a measurements. Total and summed size-fractionated chlorophyll-a measurements were found to be in good agreement; Model II y = 0.86, a = 0.01 , r2 = 0.89 , n = 78.

7.1.2 Flow cytometry: picoplankton

Flow cytometry samples were collected from the underway supply (every 1 or 2 hrs) or from the CTD deployments (typically 9 – 10 depths). Water samples were collected in 50 ml plastic centrifuge tubes, transferred to the laboratory and 1.6 ml of seawater was fixed in 45 µl of 37% molecular grade formaldehyde. The formaldehyde (20 ml) was pre-filtered (0.2 µm) every 4 days from the original stock solution and dispensed into 2 ml plastic vials. After fixing, samples were placed in a fridge for 1 – 2 hrs and then into a –80˚C freezer (observed temperatures range from –50˚ to - 70˚C). Frozen samples were returned to the UK in dry ice and further storage was at –80˚C.

7.1.3 Light microscope samples: nanoplankton and netplankton

Water samples for light microscope analysis of nanoplankton species were collected from the underway supply (every 2 – 6 hrs) or from CTD Niskin bottles (near-surface and at fluorescence maximum). Duplicate 200 ml water samples were placed in 200 ml brown glass bottles and fixed with either 4% acidic Lugols solution or 10% calcium carbonate buffered formaldehyde. Samples were stored at room temperature and out of direct sunlight. Lugols samples are to be analysed for diatom, dinoflagellate and microzooplankton abundance and species composition, while formaldehyde samples are analysed for coccolithophore abundance and species composition. Large volume water samples (10 litres) were also collected from the underway or CTD Niskin bottles (near-surface and at fluorescence maximum) and were concentrated down to 20 ml by removal of water through a 50 µm nylon mesh and preserved with acidic Lugols solution.

7.1.4 Cyclops-7 fluorometer and estimation of phycoerythrin concentrations

During the cruise on shallow (<600 m) CTD profiles a Cyclops-7 fluorometer (Turner Designs^{TM}) set for the detection of the cyanobacterial pigment (phycobilipigment) phycoerythrin (PE) was deployed (see Table 5 for CTD numbers). The Cyclops-7 fluorometer was also deployed on the Seasoar deployment between Réunion Island (JDay 045) and the Madagascar Ridge (JDay 047) and at the end of the cruise (JDau 048-049). Gain settings were fixed on x100 and a solid standard provided by Turner was fitted periodically to calibrate the voltage output (for CTDs 15677 and 15678 voltage was 3.48 V for 3.35 mg m^{-3} phycoerythrin, equivalent to 0.96 V per 1 mg m^{-3}). During Cyclops-7 deployment on the Seasoar, 2-hourly water samples for analysis of particle absorption were taken from the underway (5 m) supply and 4.2 litres filtered through Whatman GF/F glassfibre filters (pore size 0.7 µm). Particle absorption samples were stored flat in plastic petri-dishes and frozen in the –80˚C freezer. On analysis, the absorption (chlorophyll-normalised) at the phycobilipigment wavelengths (488 nm, 550 – 600 nm) will be compared with *in-situ* Cyclops-7 data.

Station	**Latitude**	**Longtitude**	**Chla:PE**	**Notes**
15638	28.17 ˚S	38.44 ˚E	~1	Offshore
15645	27.11 ˚S	45.38 ˚E	~2.5	Offshore
15647	27.32 ˚S	45.48 ˚E	~3 – 8	Offshore
15665	25.43 ˚S	47.01 ˚E	~3 - 4	Coastal
15666	25.46 ˚S	47.35 ˚E	~2 – 3	Coastal

Table 5. Stations where Cyclops-7 fluorometer was deployed during MadEx cruise.

7.1.5 Phytoplankton Pigments

Samples for phytoplankton pigment analysis were collected from both the underway supply (every 2 – 6 hr) or CTD Niskin bottles (near-surface and at fluorescence maximum). Water samples (4.2 litres) were filtered onto Whatman GF/F glassfibre filters (pore size 0.7 µm) and stored in cryovials in the –80˚C freezer. On return to the UK, the samples will be analysed by High-Performance-Liquid-Chromotography (HPLC) following the Barlow (1997a, b) method.

7.1.6 Scientific Highlights

In-situ measurements of chlorophyll-a in waters around the southern tip of Madagascar and across the Madagascar Ridge are in general agreement with MODIS measurements.

Variability of chlorophyll-a size-structure with increases in the percentage contribution and absolute concentration of the >5 μm fraction within elevated chlorophyll-a waters.

Observation of significant *Trichodesmium* numbers (colonies and trichomes) at most CTD stations occupied, especially in the vicinity of the first mooring (25.59.96˚S, 46.21.18˚E). These are the most southerly observations of *Trichodesmium* in the Indian Ocean.

Successful deployment of Cyclops-7 phycoerythrin (PE) fluorometer on both the CTD and Seasoar providing estimates of PE concentrations of 0.10 – 0.20 mg m^{-3} in coastal stations and 0.05 – 0.10 mg m^{-3} in offshore stations (Chla:PE ~2 - 8). These are the first *in situ* measurements of PE in the Indian Ocean.

7.2.1 Equipment

Paired Bongo nets (200 µm mesh size)
Flowmeter
375 ml honey jars
40% Formaldehyde (buffered with $CaCO_3$, pH 7)
Ethanol (99.9 %, A. R. grade)
200 µm mesh sieve + concentrator
2 x wash bottles
Dissecting microscope

7.2.2 Methodology

Zooplankton were sampled using Bongo nets fitted with a calibrated flowmeter. When on station, the CTD was deployed first, and after it was brought back on board, the nets were deployed. Net-sampling was carried out only on stations where the CTD was deployed, with a keen interest on stations spanning across hydrographic features (e.g. eddies). The nets were cast from the starboard deck winch (towing speed of 20 m min^{-1}). During daytime sampling, the nets were vertically hauled firstly from 200 m, and then from 800 m – to cater for downward migration by zooplankton. At night only 200 m hauls were taken. Where depth was less than 200 m (Table 6), bottom depth was determined using a 10 kHz Acoustic pinger, which was attached to the Bongo net weight (see Fig. 26). This required monitoring the direct and bottom-reflected acoustic signals via the *Waterfall* equipment. When nets were on deck, the cod-end buckets were removed and placed in 10 litre buckets. The samples were then passed through a 200 µm mesh sieve, and washed with seawater into honey jars. Formaldehyde (14 ml) was then added to each sample.

At selected stations (see Table 6) samples for genetic analysis were also collected in addition to the regular net samples. The only difference in method was that samples were washed into honey jars using ethanol, and the samples were fixed and preserved strictly in ethanol (i.e. no seawater). After 24 hours ethanol in the sample jars was replaced with fresh ethanol. This was done every 24 hours until the samples remained visibly clear.

Figure 26 : Bongo nets being lowered from starboard side, with pinger attached to bottom bar.

7.2.3 Observations

A brief look under an on-board microscope revealed that the stations were characterised by zooplankton communities dominated by copepods. Large calanoid copepods belonging to the genera *Calanus, Metridia, Rhincalanus* (mostly at 15650) and *Eucalanus*, were found at almost all sites; however, the stations were dominated by small copepod species, which included *Oithona*, *Oncaea* (dominant at 15689), *Paracalanus, Acartia* (15685) and others. Other zooplankton groups were also present in the samples, e.g. euphausiids (most abundant at 15649), harpacticoids (15643, 15662), chaetognaths (abundant at all stations), ctenophores (abundant mostly at 15643), siphonophores (abundant mostly at 15643), polychaetes (present in all samples), pteropods (15685), crab megalopa and zoea (15663 & 15674), other long and thin stalked-eyed decapods (15665), amphipods (present occasionally), fish larvae (mostly at 15656 & 15665). An interesting *Rhincalanus* species with an unusual rostrum shape was found in some samples. Only small copepods were found at 15656, 15677 and 15685, and where high primary production was indicated by ocean colour, small copepods were most abundant (possibly an indication of the presence of small size class phytoplankton?).

JDay	Station	Time	Longitude	Latitude	Depth (m)
031	15640	01:05	45.0063	26.9195	200
031	15642	09:58	44.7525	26.4465	200
031	15643	14:05	45.0260	26.4494	200
031	15643*	14:35	45.0260	26.4494	800
032	15649	16:21	45.5909	27.5585	200
032	15650	21:56	45.8923	27.5627	200
032	15650	22:21	45.8923	27.5627	800
033	15656	10:08	45.6039	26.9871	200
033	15656	10:25	45.6039	26.9871	800
033	15662	20:50	45.3370	26.4398	200
034	15663	06:38	46.3833	26.0017	200
034	15663	07:00	46.3833	26.0017	800
034	15665	20:11	47.0140	25.4311	109
035	15669	09:44	47.2939	25.7730	200
035	15669	10:02	47.2939	25.7730	800
035	15671	16:54	47.5071	25.9214	200
036	15674	02:30	47.7445	26.1167	200
040	15677	15:36	46.1916	25.6464	130
041	15681*	00:52	46.3549	26.0183	200
041	15685	09:29	46.3250	26.2540	200
041	15685*	09:49	46.3250	26.2540	800
047	15689	09:25	46.4730	26.5320	200
047	15689	09:45	46.4730	26.5320	800
047	15692	18:08	46.5520	27.1050	200

*Table 6 : Summary of stations sampled using vertically towed, paired Bongo nets. * indicates stations at which samples were collected for genetic analysis.*

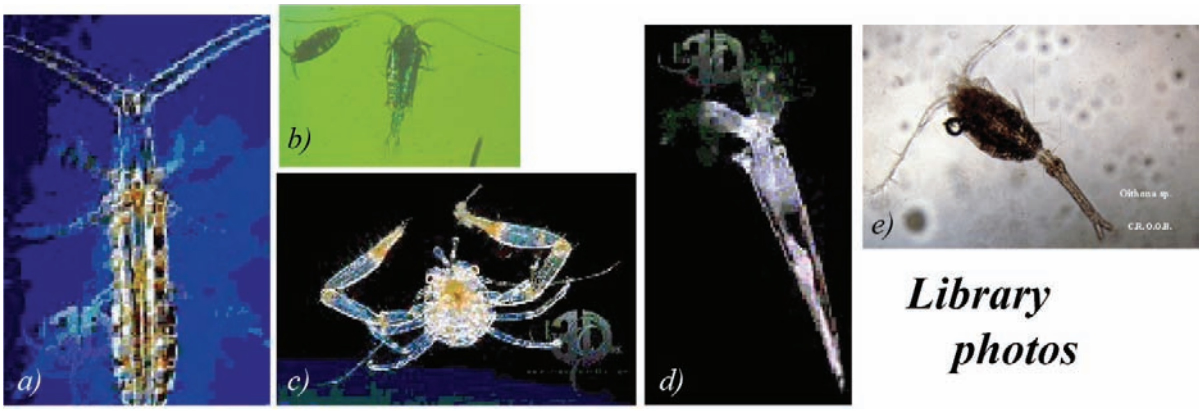

Figure 27 : Example micrographs of species that have been seen in MadEx samples a) Rhinocalanus, b) Centropages, c) Crab zoea, d) Pteropod, e) Oithona.

7.2.4 Problems

Bongo nets are usually fitted with a U4 system that gives an electronic on board readout of net depth and flow-rate. This system was not available on this cruise. Therefore net depth could only be estimated using the length of the cable. For instance, the targeted depth was reached when the 200 m mark on the cable touched the surface of the water.

In the beginning stages of sampling, a 3.5 cm tear and a 1.5 cm tear (in the upper end of the cylindrical net section) were noticed and repaired using needle and thread. After station 15692 a part of the cod-end had to be glued together and reinforced.

Net sampling was terminated after station 15692 due to CTD winch failure.

7.3.1 Operations

The operation of the OPC has been problematic throughout the series of cruises 286,287,288. From Paul Duncan's report (cruise 286),

> "*The OPC problem was solved by making sure we only switched it on in water* (see 'Software' below). *Even then, it sometimes still did not log properly immediately, and had to be shut down for thirty seconds – this would not have been possible with the prototype system*."

At some time during the Crozet cruises the shallow water OPC was replaced with the deep OPC despite its unsuitability for SeaSoar attachment. During the tow from Durban we had problems getting the OPC to start and had to leave it switched off in the water for periods of hours before trying it again. In the subsequent "radiator grille" tow the OPC refused to start at all. When it did start the data were incorrect both in content and periodicity.

It was decided to attempt to analyze the problem on the bench and so we wired up the deep OPC to a bench power supply and a laptop for RS232 analysis. After considerable fiddling we decoded the data stream and discovered that rather than receiving a four-byte data string at 2 Hz composed of two data words (a timer and an attenuance value) we were getting an 8-byte string with two extra data words with headers that corresponded to flow and depth. We then decided to attach the OPC to the spare PENGUIN unit in order to gauge the effect of these extra data on the DAPS software.

The OPC data logged by PENGUIN with the OPC attached looked reasonable but there were some anomalies. Extra timer and attenuance values were occasionally logged into the data stream. The reason for this is as follows:

An OPC data word is two bytes split into 4 nibbles:

H D1	D2 D3

Nibble H is the "header nibble" value 0 - 15 and denotes which kind of data.

1 Particle
2 Attenuance
3 Timer

Nibbles D1-D3 are interpreted as one unsigned 12-bit integer to contain the data value 0 - 4095

The DAPS software makes the assumption that all data words will be of type 1, 2 or 3. When it reads a header nibble that is not one of these it assumes that it has lost synchronization and skips to the next byte. However the OPC can be configured to present data from other, optional sensors including depth, flow etc. These have their own header values.

When we looked at the data stream from the deep OPC we discovered that it was sending not only timer and attenuance values at 2 Hz, but also a depth and a flow value – header numbers 5 and 8. The effect of these would be to introduce spurious readings in the data – but I show below that these would not be too much of a problem.

If we assume an 8-byte data string – split into 16 nibbles that looks like this:

2 5	e 3	**3** a	4 f	**8** 3	1 f	**5** 4	3 b

As you can see we have an attenuance value, a timer value, a depth and a flow value, denoted by a 2,3,8 and 5 in their header nibbles respectively.

DAPS will read the first four bytes correctly giving an attenuance of 1507 and a timer value of 2639. However, when it comes to the next byte it will read an 8 in the header nibble and assume it has lost synchronization. It will then skip to the next byte and read a 1 in the header nibble. This it will assume is a particle and it will read the next byte as the second data byte of the data word giving a count value of 3924 as below.

2 5	e 3	**3** a	4 f	8 3	**1** f	5 4	**3** b	....

You can also see that the next byte – which has a header nibble of 3 will also be interpreted as a timer value and will corrupt the data word which comes after it.

In practice I don't think the above is very common. Corruption will only occur where the flow or depth contains a 1,2 or 3 in the first nibble of their data byte. If it is a 2 or 3 then there will be little impact, as we do not use either of these values for routine processing. Some counts may be lost as a result of their header bytes being read as the data byte of an incorrectly identified data word, but given the large counts that we typically get with the OPC this would probably be lost in the signal – especially for small particle sizes. For larger sizes where numbers are small a few large particles could significantly affect the overall result and might affect things like total biomass calculations.

7.3.2 PENGUIN PSU Problems

While the OPC was connected to the spare PENGUIN unit we noticed some problems with the PSU. Whilst trying to simulate particles in the OPC by passing a length of cable in front of the sensor, we noticed that if we blocked the light path for more than a few seconds the OPC would fail, giving a random series of data values. When we looked at the voltage being generated by the PENGUIN PSU during this period we could see that any interruption of the light path caused a drop in voltage. If this was transitory then the voltage would recover. If however the path were blocked for more than, say, two seconds the voltage would start to decay until it fell to zero. It would then recover back to 15V but with a rapid (4-5 Hz) series of spikes back to zero. The OPC then gave the same type of data we had seen from a failed OPC in the water. This behaviour was consistent across a number of tests.

On connecting the OPC to a bench PSU this behaviour could not be replicated. When we examined the current being drawn by the OPC from the bench PSU we found that it rose from approx 220 mA to a peak of 280 mA when the light path was blocked. This current was not reached using the PEGUIN PSU. Pete Mason conjectured that the limiting factor in this case was the circuitry associated with the I2C power control. By bypassing these components with a fused wire direct from the 15 V PSU supply we were able to achieve stable OPC functioning. This solution was tested in a 40-hour SeaSoar tow where the OPC was fully functional and stable both on deck and in the water.

7.3.3 OPC Data processing

The OPC data from Penguin was transferred at twelve hour intervals onto the Solaris system and placed into /data62/seasoar. These twelve-hour sections were concatenated (in the correct order) using *cat* and then processed using three scripts that provided parameters to pstar programs.

Script 1: **opc1v**

Use **grep** to extract lines with particle data in them.

Run **pascin** to convert the resultant ASCII data to pstar format

Use **pcopya** to add an extra jday variable and then run **ptime** to convert that to a time variable in seconds. Note that on the Solaris 9 system ptime is the name of a system program so that we had to use the full path for ptime.

Run **pmerge** to merge OPC data with the corresponding Seasoar 1-second file to get pressure and distrun. Files at this stage are named opc????.mrg

Script 2: **opc2v**

Run **gropc4** to grid OPC data into 5 km bins and the following size classes for contour plots and further analysis.

99.0676 - 247.4949 µm

247.4949 - 497.8647 µm

497.8647 - 1000.5470 µm

1000.5470 - 1999.3565 µm

1999.3565 - 3999.5676 µm

3999.5676 - 8000.4155 µm

Merge gridded file with the navigation data to get latitude and longitude. Files at this stage are named opc????nav.spd

After this script had been run – the data for the 4 most interesting size classes – 250-500, 500-1000, 1000-2000, 2000-4000 µm were extracted as separate files and plotted using **ucontr**.

Script 3: **opc2m**

It was thought useful to look at the size spectra of abundance for each size class that the OPC classifies. In order to do this for a gridded file a version of opc2v was created which passed parameters to gropc4 to produce a 5 km bin gridded file with an entry in each bin for each size class. These files are named opc????.szs.

These produced some interesting results, which require further analysis. However two main points are worth mentioning. It appears that the OPC's ability to recognize particles is diminished below a value of 300µm rather than the 250µm mentioned in the documentation. Also we notice that the slope of the size spectra changes with depth - possibly indicating changes in the nature of the populations.

Details on plotting output are provided in Appendix 3.

7.4 Fast Repetition Rate Fluorimeter (FRRF) on SeaSoar

Emma Guirey & Meric Srokosz

7.4.1 Introduction

FRRF is an active fluorescence instrument that provides *in situ* measurements of phytoplankton photosynthetic parameters with high temporal resolution. These parameters may be employed to estimate primary production with the aid of biophysical models.

MadEx employed only one FRRF instrument, flown on the SeaSoar undulating towed body and powered by the PENGUIN underwater data-handling unit, also mounted on SeaSoar. Another FRRF instrument was available and it was hoped to attach this to the continuous non-toxic underway supply on the ship. Unfortunately, this instrument was not working and attempts to fix it failed.

7.4.2 Data Processing

Matlab code SSFRRFproc.m, as written by Mark Moore, was used to process FRRF data from SeaSoar recorded by PENGUIN. Input files are of the format nnnnn-mm.frrf, where nnnnn is the station number and mm increases sequentially as sections of data are downloaded during each deployment. Accompanying each *.frrf file is a *.minipack file containing conductivity, temperature, depth and fluorescence from the Chelsea Instruments MiniPack CTDF instrument on SeaSoar. After processing, the FRRF data were merged with the MiniPack data. This stage was also carried out in Matlab.

The fitting routine cannot always constrain the data and so frequently returns unusable values. After communication with Mark Moore via e-mail it was decided to remove all values with relative errors greater than 20% and all data in the top 3m, since surface data tend to be particularly noisy.

Finally, plots with depth of SeaSoar recorded temperature, fluorescence, irradiance (PAR) and the FRRF parameters Fv/Fm (photochemical efficiency) and σPSII (functional absorption cross section) were generated using Matlab code **nogrid_plot2d.m** and **nogridbar.m**. As plotting the data took considerable processing time, only a subset of the data were examined during the cruise. An example of the data obtained on the final SeaSoar tow is shown in Fig. 28.

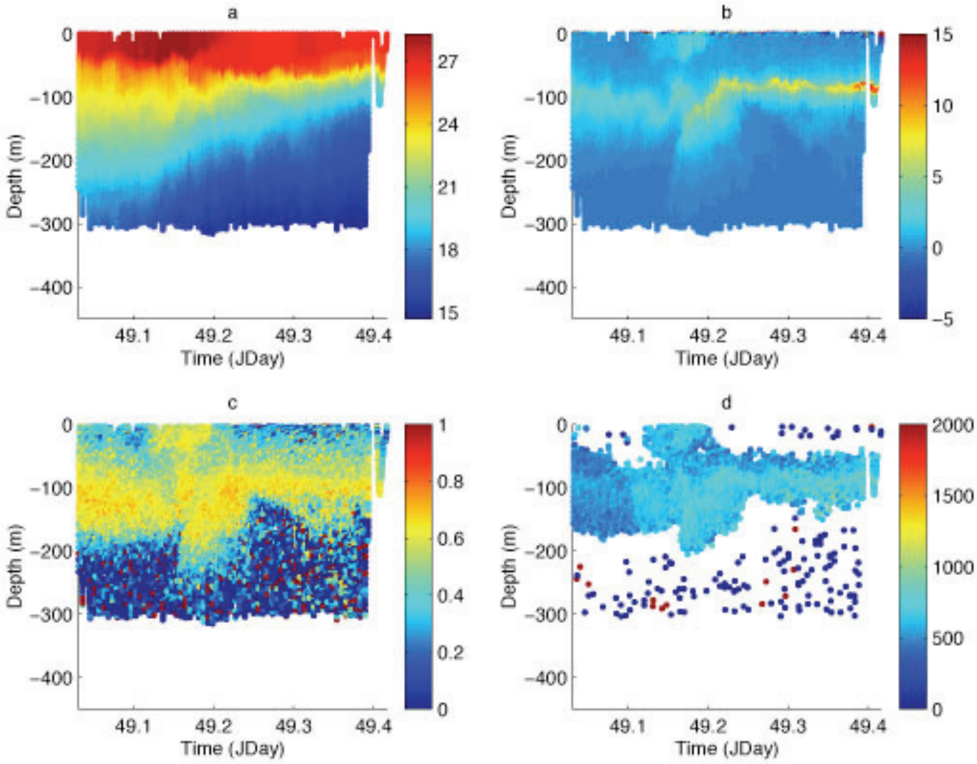

Figure 28 : Data from SeaSoar section 15695-03, as a function of Julian day, showing: a) temperature (˚C), b) fluorescence, c) Fv/Fm and d) σPSII (10-20 m^2 $quanta^{-1}$). For the FRRF parameters, Fv/Fm (photochemical efficiency) and σPSII (functional absorption cross section), all values with relative errors greater than 20% and all data from the top 3m have been removed.

7.5.1 Instruments and set-up

To make *in situ* measurements of ocean colour two hyperspectral radiometers were fitted on the starboard side of Monkey Island (see Fig. 29). The radiometers are of two different designs — the one looking directly upwards is to get an average down-welling radiation, and has a cosine filter to give the correct weighting to all parts of the sky; the other, pointing down at about 40˚ from the vertical, is focussed on a patch of the sea that should be ahead of the ship's wake and thus be undisturbed water. A reel of two-core cable was taken to the ship and two 25 m stretches used to run down from the Monkey Island to the PSO's office (three floors below) where the data control unit and computer lay.

Figure 29 : Hyperspectral radiometers were attached to the starboard side of Monkey Island on RRS Discovery, giving the downward-looking one a clear view of the water ahead of the ship's wake.

7.5.2 Problems

1) The software package on the computer was a proprietary one for these instruments, but was not intuitive and was hard to use (especially for those familiar with Macs). Consequently for several days it seemed impossible to achieve regular sampling.

2) The PC clock was not stable, and so its time had to be noted regularly against the ship clock to allow correction of the data records to GMT.

Recommendations from this cruise (and its successor, MadEx II) are to acquire a reasonable-quality lap-top, with good time-keeping, and ideally allow a cruise participant a week's experience on logging, transferring and interpreting data prior to such equipment being taken to sea again.

8. Moorings and Drifters

Most of the cruise work only gives an idea as to the currents, chemistry and biology during the time that *RRS Discovery* was in the region. To put such measurements in a larger context, three moorings were installed along a line to the south of Madagascar to monitor the flow across the Madagascar Ridge. The moorings were located along the sub-satellite track of the Jason altimeter, so that time variations in the flow detected by the moorings can be compared to those derived from altimetry. A fourth mooring, involving the relatively new McLane Moored Profiler, was located roughly perpendicular to the main line of moorings and about 120 km further east to help assess the propagation rate of features (eddies or current meanders).

It had been hoped to maintain these mooring sites for three years, with one servicing cruise halfway through the exercise. This would have complemented the long occupation of the Mozambique Channel achieved by NIOZ; however, changes in UK priorities for marine research have limited this to a 12-month occupation. Each deployment was accompanied by a CTD station for calibration of the sensors.

Also, two varieties of surface drifters were deployed. These are used for following water bodies, enabling short-term tracking of features identified during the cruise (until the drifter exits the feature), and inferences of velocities associated with some temperature and chlorophyll fronts visible in satellite imagery taken after the cruise.

8.1 Moorings

Ian Waddiington, John Wynar

Four moorings were deployed on this cruise. Each mooring was deployed buoy first - anchor last by streaming from aft using the DBC winch system and ships port aft crane. Procedures followed SOC techniques and all operations went smoothly.

Mooring 1 (Fig. 30)

The mooring comprises an ADCP 75 kHz housed in a syntactic buoy with wire and polyester mooring line. Wire was used above 1000 metres depth to combat possible fish bite.

There are two self-recording current meters at 1000 metres and 1500 metres. An acoustic release is located beneath the 1500 m current meter for acoustic relocation and recovery.

Mooring 2 (Fig. 31)

Mooring 2 is a conventional moored instrument string, comprising buoyancy and discrete self-recording current meters. The mooring is a wire and polyester mooring line. The main buoyancy is a steel sphere with fin to assist stability with ARGOS emergency location beacon built in.

Mooring 3 (Fig. 32)

The mooring comprises an ADCP 75 kHz housed in a syntactic buoy with wire and polyester mooring line. Wire was used above 1000 metres depth to combat possible fish bite. There are two self-recording current meters at 1000 metres and 1500 metres. An acoustic release is located beneath the 1500 m current meter for acoustic location and recovery.

Mooring MMP (Fig. 33)

This mooring is a McLane Moored Profiler (MMP), which is attached to a continuous mooring wire supported at each end by buoyancy. The main buoyancy is a steel sphere with fin to assist stability and fitted with ARGOS emergency location beacon built in.

The vertical mooring wire acts as the guide and drive wire for the MMP. A recording current meter is located at the top of the mooring to record current and CTD data. The MMP records a profile of current speed and direction and CTD as it travels up and down the wire. All data should be logged internally.

	UKORS No.	Longitude	Latitude	Depth	Date
Mooring 1:ADCP	2005/03	46 21.10 E	26 00.01S	1610 m	3rd Feb 2005
Mooring 2:RCM	2005/05	46 33.4E	26 25.2S	2408 m	10th Feb 2005
Mooring 3:ADCP	2005/06	46 47.34E	26 54.00S	2163 m	16th Feb 2005
Mooring MMP	2005/04	47 46.18 E	26 07.6S	3915 m	5th Feb 2005

Table 7 : Locations and dates of MadEx mooring deployments.

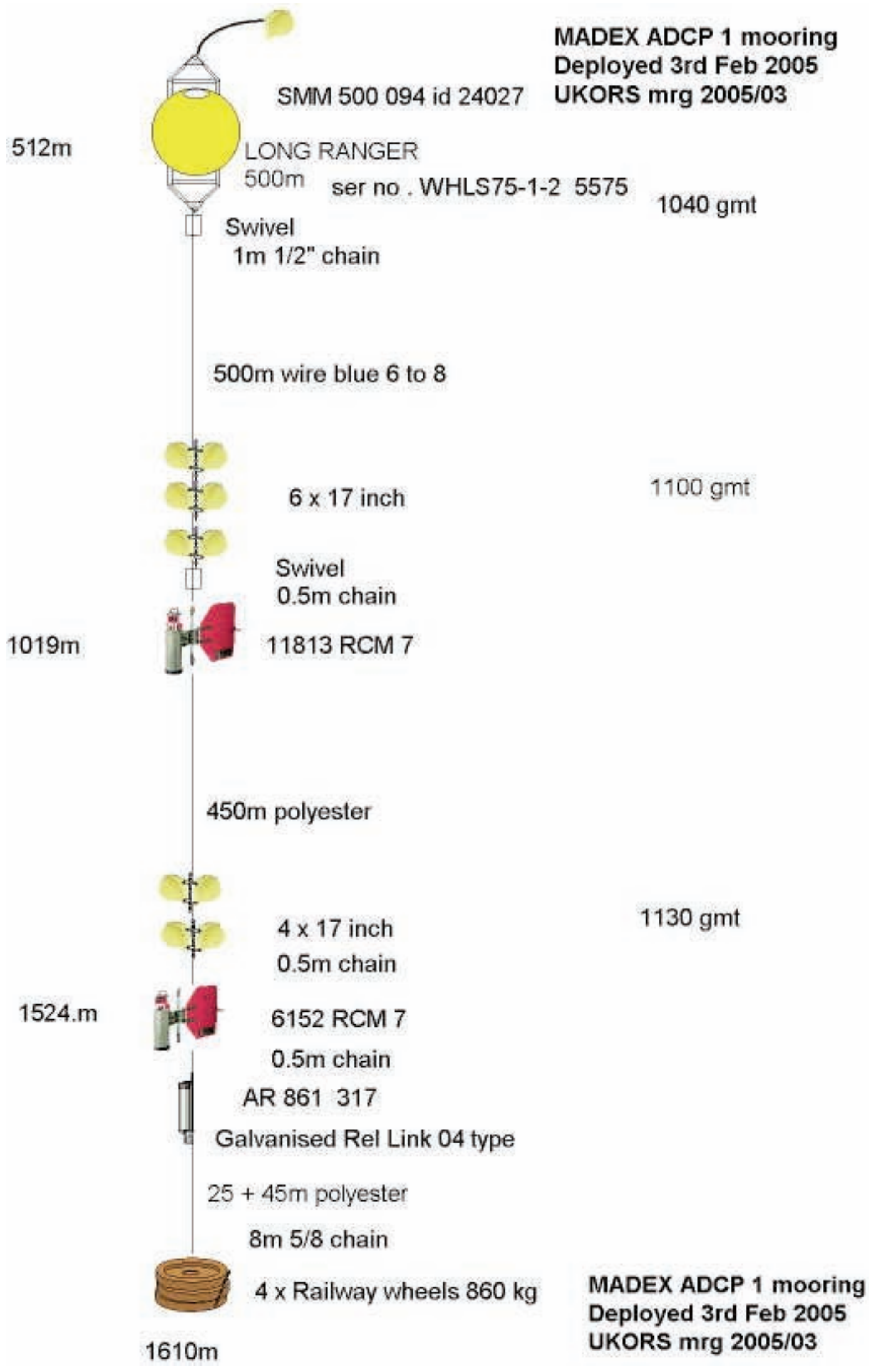

Figure 30 : Schematic for mooring UKORS 2005/03.

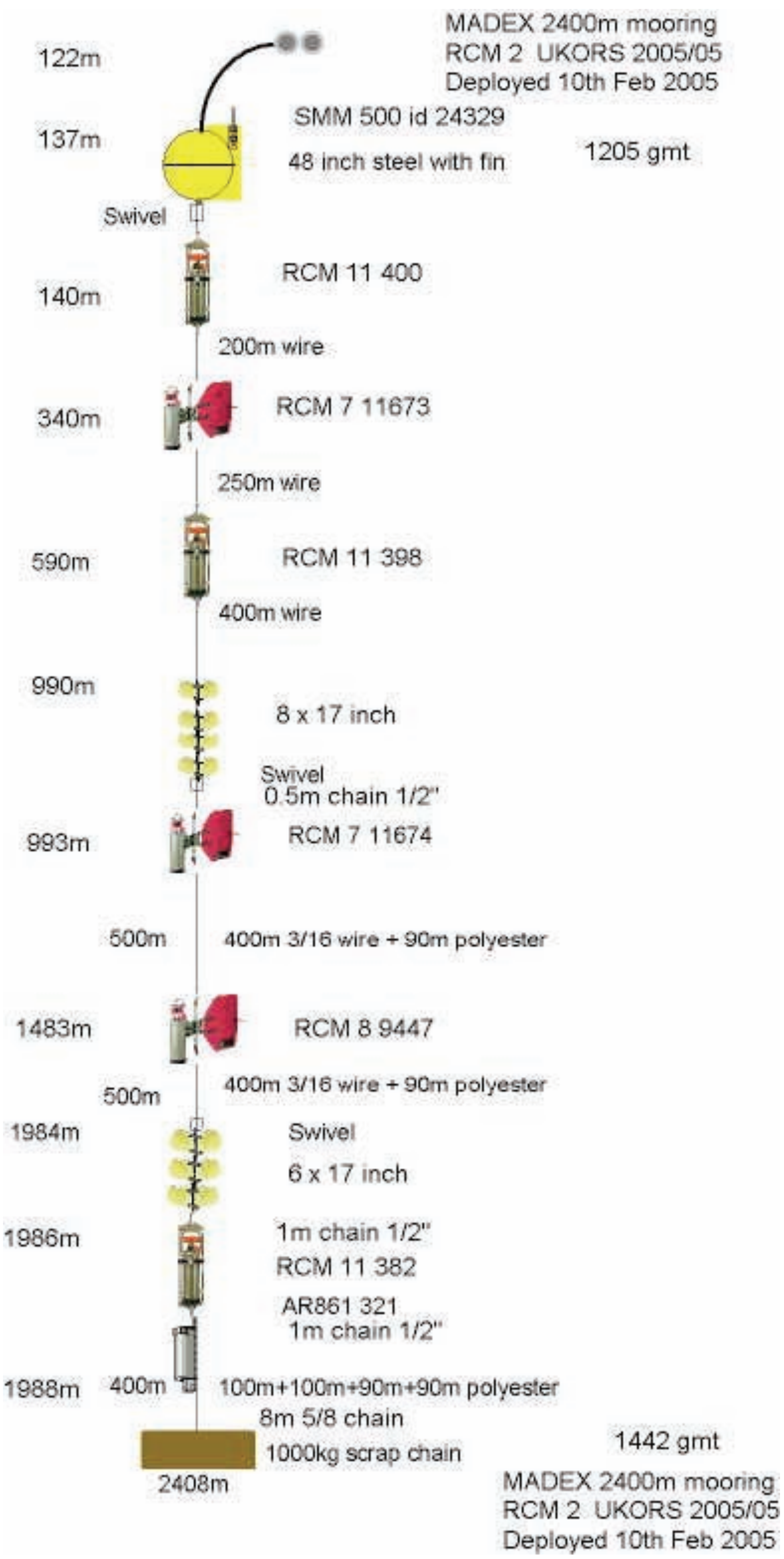

Figure 31 : Schematic for mooring UKORS 2005/05.

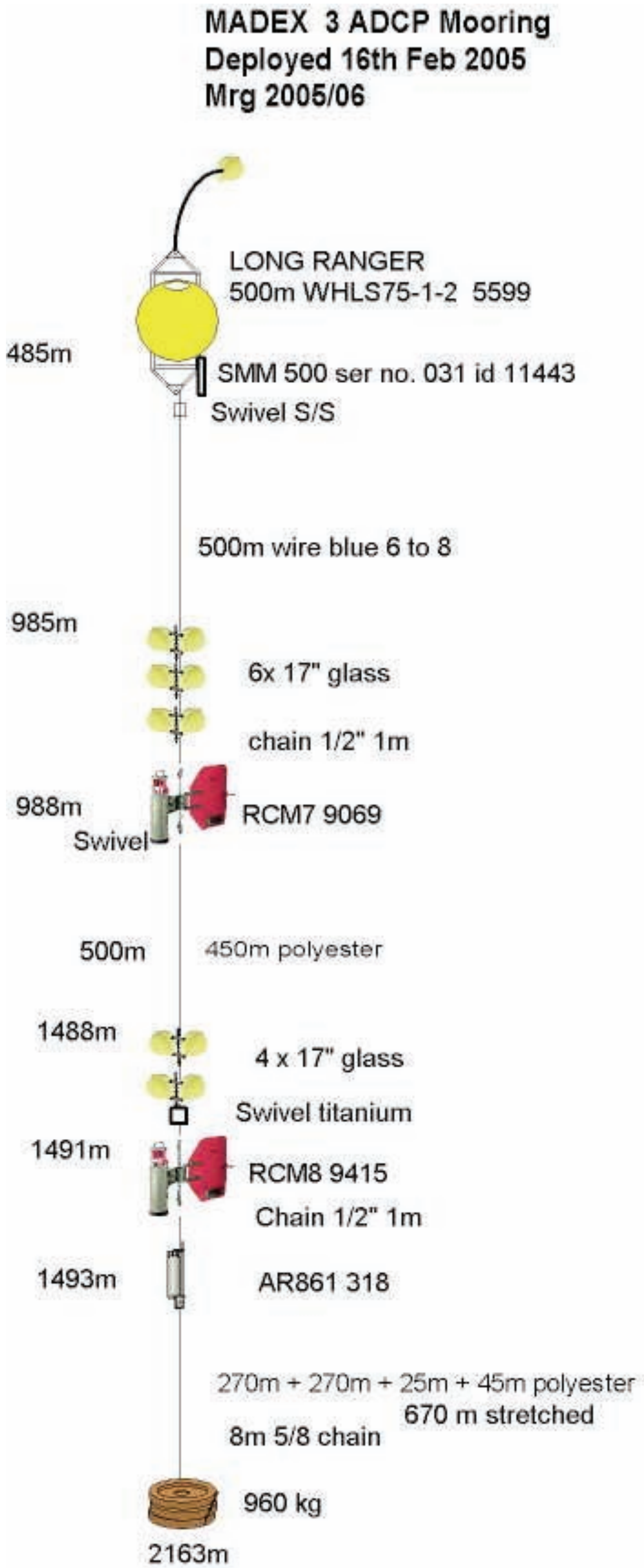

Figure 32 : Schematic for mooring UKORS 2005/06.

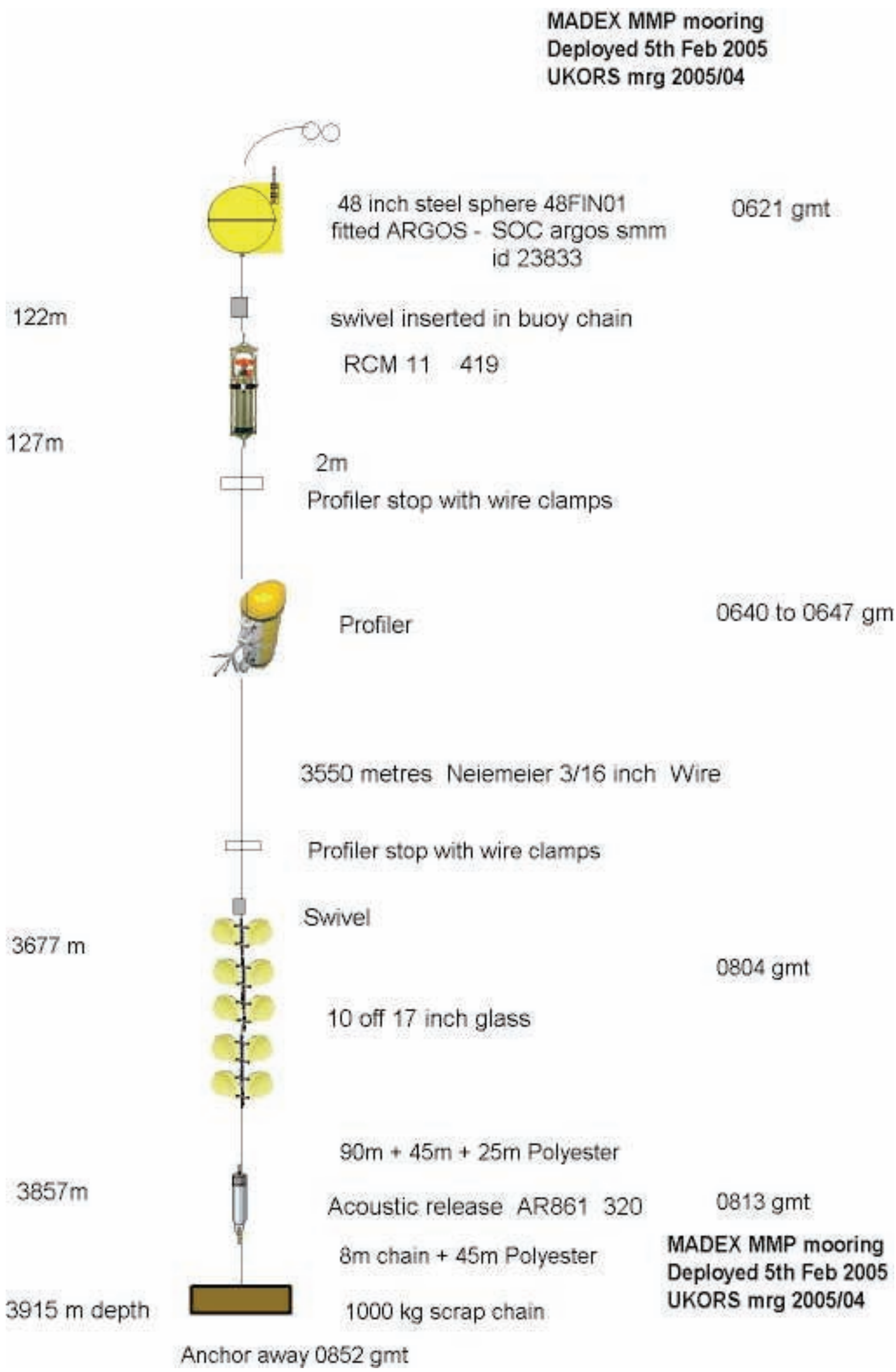

Figure 33 : Schematic for mooring UKORS 2005/04 (McLane Moored Profiler).

8.2 Clearsat drifters

Graham Quartly

Two surface drifters produced by Clearsat were deployed, one on JDay 035 at 25˚57'S 47˚30'E, within the main core of East Madagascar Current, and the second on JDay 046 at 23˚44'S, 50˚05'E within the cyclonic eddy traversed on the return from Réunion. Each drifter has a surface unit with GPS receiver, air and sea temperature sensors plus an ARGOS transmitter. Both were enabled several days before deployment, and the ARGOS transmissions were successful even when the buoys were in the hangar of the ship.

The buoys were easily deployed by putting over the side (2 people required); the second buoy was deployed whilst SeaSoar was out — the controls on the latter were used to keep it down for a few minutes whilst the drifter was left behind.

8.3 PODs

Graham Quartly

The cruise also saw the first full trial of PODs (Pop-up Ocean Drifters) developed under SOC's Technology Innovation Fund. The concept is to allow a unit to fall to the sea-bed; after a pre-programmed time a fizzlink is used to release a latch holding the anchor weight, allowing the buoy component to float to the surface. It should then operate as a free-floating drifter, with drogue and telemetry, that had has a delayed release at a point.

The latch systems on the drifters had to be reworked on the ship, because the higher temperatures in the Indian Ocean compared to Southampton had made the latches loose. Four systems (with delays of 12, 24, 36, & 48 days) were deployed at 25˚57'S 47˚30'E to complement the first Clearsat buoy (effectively a drifter with 0 days delay).

For both Clearsat buoys and PODs data relay was via ARGOS to NOCS. There, data were automatically added to an SQL database, and (for a limited time) summary emails were generated every 6 hours and sent to the ship detailing the buoys' locations. Only 2 of the 4 PODs surfaced close to their specified time, and as neither was before the end of the cruise, only Clearsat data were in practice sent to the ship.

Figure 35 shows the trajectories followed by these drifters in the 7 months after the cruise; a thrid POD eventually made the surface in Dec. 2005, and transmitted for 55 days.

a) b)

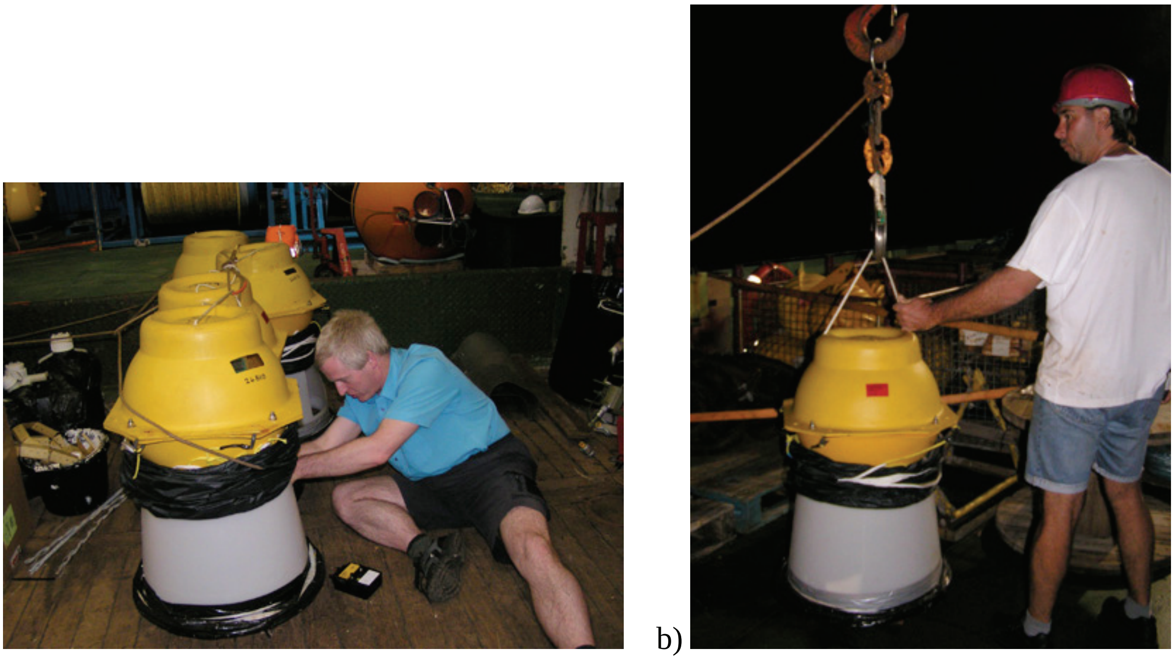

Figure 34 : a) The units were programmed via a simple hand unit. b) Release via a Pelican hook.

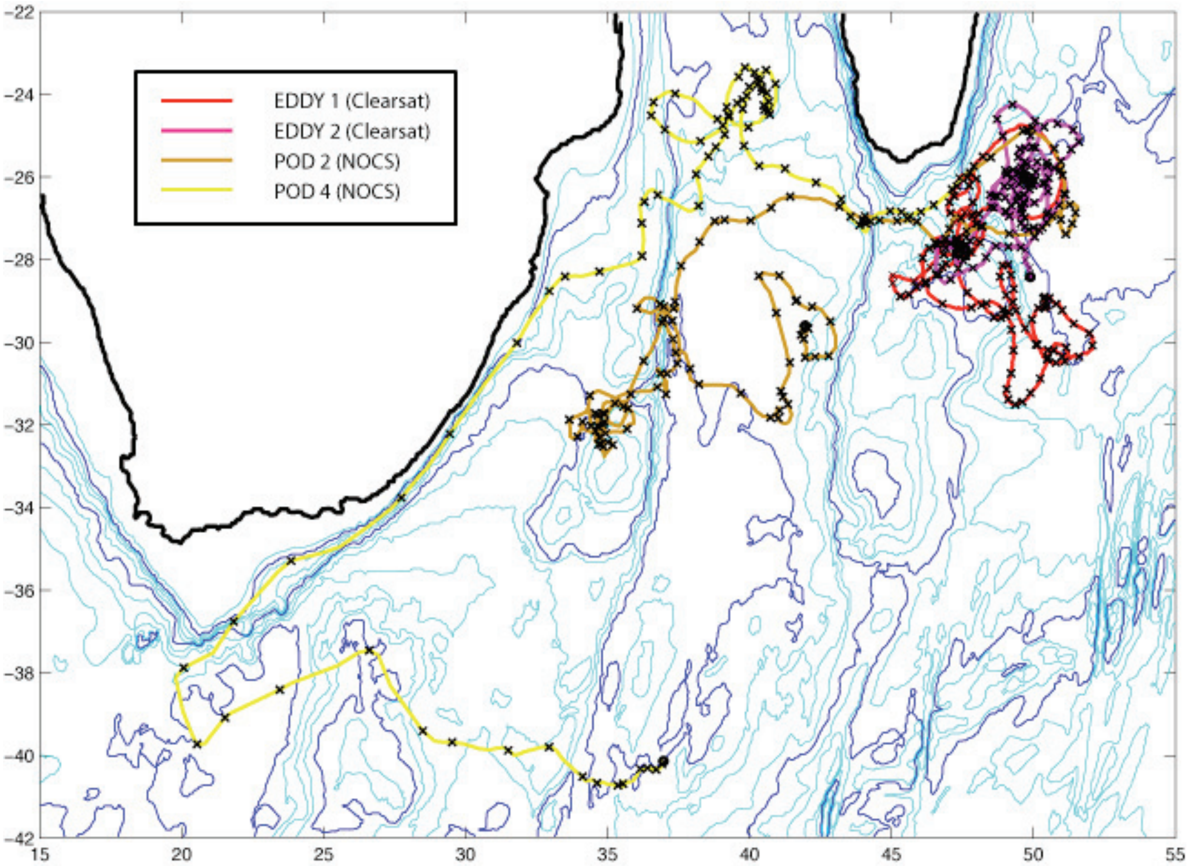

Figure 35 : Buoy trajectories as of 14th September 2005 (black crosses every two days). Individual tracks can also be seen in Near Real-Time at http://www.noc.soton.ac.uk/ops/pod.php

9. Summary

This was an ambitious cruise programme, making physical, chemical and biological measurements, plus placing moorings and drifters in an area where the bathymetry and current structure were poorly known beforehand, as there had been few research cruises in the area. It did seem unfortunately plagued with problems — the necessary 5-day detour to Réunion destroyed any chance of fulfilling one of the cruise objectives, namely that of physical and biological resampling of an eddy to see how it evolved. It was also a great disappointment that SeaSoar had so many problems early on, although it did show its considerable value later on when we achieved 3 days' continuous towing, and then later, finally started getting regular useful data from the OPC. Combined with the FRRF and Turner fluorometer ("Cyclops"), this should prove to have recorded some very useful transects of the biology. The other great disappointment was the failure of the CTD winch towards the end of the cruise, as we tried to complete the full CTD section along the key survey line.

One key facet of the cruise operation was the use of satellite data provided by RSDAS, not merely to put past measurements into perspective, but to direct the future sampling strategy. It was hugely beneficial to have the numerical data rather than just images, as the former gave greater flexibility in detecting details of the flow, although there were a few occasions when data were corrupted upon transmission.

There were 4 items of non-standard technology taken on the cruise, and these had mixed levels of success. The hyperspectral radiometers, intended as a near-autonomous recording unit for ocean colour, proved to require significant effort, and the data collection was irregular. The SUV-6 automatic nitrate sensor was difficult to use in a continuous manner on the underway supply, because the presence of bubbles in the flow led to completely spurious results. On the other hand, the Turner fluorometer, which detects the pigment phycoerythrin, gave credible results on both the CTD and SeaSoar platforms. Finally, the PODs, developed as SOC-built prototypes using Technology Innovation Funds, did demonstrate their potential, although there were lessons learnt concerning both latch mechanisms and the need for appropriate ballasting.

As a result of the SeaSoar problems, many more CTD/LADCP stations were done than had been originally envisaged. This includes three complete sections across the current to the south of Madagascar, with two of the sections being in to the 200 m isobath. An initial examination of the data shows a deep countercurrent (eastward flow) of Red Sea Water at depth along the slope.

The radiator grille survey pattern, informed by satellite imagery, covered a large eddy-like feature to the south of Madagascar. As both shipborne ADCPs were in continuous operation, they gave an interesting insight into this feature: the westward flow was deep (being fairly uniform over the top 800 m surveyed by the 75 kHz ADCP), whereas the eastward return further south was concentrated in the top 150-300 m.

Much of the biological data are still to be worked up, but several interesting species of zooplankton were identified, and *Trichodesmium*, which are nitrogen-fixing bacteria, were found in copious quantities but sporadically — these being the furthest south observations of the species in the Indian Ocean.

Acknowledgements

I am grateful to Roger Chamberlain, the captain of *RRS Discovery*, his crew, and all the UKORS personnel for their effort and ability to adapt to changing circumstances, particularly in addressing all the problems with SeaSoar. The cruise was reliant on the provision of satellite data by RSDAS, who made rapid changes in their procedures in response to our detour to Réunion. Paolo Cipollini and Lisa Marsh also helped with the provision of other data. Friends and colleagues at home were kept informed of progress of the cruise by Oceans4Schools (http://www.oceans4schools.com), which was co-ordinated by Val Byfield; I am grateful to the many people on the cruise who shared their perspective of "life at sea" and their particular rôle in the science via the online "*Cruise Diary*".

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Appendices

A1. Matlab code to analyse SUV-6 output

Emma Guirey

Appendix – Matlab code to anaylse SUV-6 output

```
% suv6dat2nitr.m - Matlab file to convert suv6 rawdata to nitrate values
% R. Prien - 27.01.2005 – modified by E. Guirey on D288

% NB Program assumes data file to have calibration values for at least the last
%    three rows. Edit files to ensure this. EJG 12.02.05

clear
close all

files = [
'R0480000.TXT' % Your filename goes in here
];
nrem = 3;                              % number of points to remove at the flipping edges
colors = ['m','b','c','g','y','r','k'];   % colors for channels
symbs = ['+','.','o'];                  % symbols used
thres = 2000;  % threshold to determine flipping
calch = 1;     % channel for detection of flipping

ind = find(files(1,:)=='.');
eval(['load ',files(1,:)])
eval(['I = ',files(1,1:ind-1),';'])
eval(['clear ',files(1,1:ind-1)])

% for the files taken with Jon Campbells software the first two columns
% are year and Julian day with fraction which gives the time
year = I(:,1);
jdaytime = I(:,2);
I = I(:,3:8);   %%<<<<<<< remove the day and time columns

% for debugging only:
%year = ones(size(I,1)).*05;
%jdaytime = 27.6 + (1:length(I))./24./3600;
sec = (jdaytime - jdaytime(1)).*24.*3600;

figure(1) % plot cal-channel raw data and detected flips
set(gcf,'Name','raw cal chan');
subplot(2,1,1)
plot(sec,I(:,calch),[num2str(colors(2))])
tit = [files(1,:),': ','raw data, ch. ',num2str(calch)];
title(tit)
ylabel('I / counts'),xlabel('time / s ')
hold on

% remove nrem values next to edges
% falling edges
```

```
miin = find((I(1:length(I)-1,calch)>thres)&(I(2:length(I),calch)<thres));
ind=1:length(miin);
plot(sec(miin(ind)+1),I(miin(ind)+1,calch),'k+') % show detected falling edge
 subplot(2,1,2)
 plot(diff(sec(miin(ind)+1)),'b') % show timing of detected falling edges
 hold on
 % remove values next to edge
 for j=1:length(ind)
  I(miin(ind(j))+1:miin(ind(j))+nrem(1)+1,:)=NaN;
  sec(miin(ind(j))+1:miin(ind(j))+nrem(1)+1)=NaN;
 end
 ind=find(isnan(I(:,1)));
 I(ind,:) = [];
 ind=find(isnan(sec));
 sec(ind) = [];

 % rising edge
 mout = find((I(1:length(I)-1,calch)<thres)&(I(2:length(I),calch)>thres));
 ind=1:length(mout);
 subplot(2,1,1)
 plot(sec(mout(ind)+1),I(mout(ind)+1,calch),'ko') % show detected rising edge
 subplot(2,1,2)
 plot(diff(sec(mout(ind)+1))+0.01,'r') % show timing of rising edges
 xlabel('flip No.'),ylabel('time / s')
 title('Time between flips')
 legend('falling','rising')
 for j=1:length(ind)
   if( (mout(ind(j))-nrem(1)+1) > 0)
    I(mout(ind(j))-nrem(1)+1:mout(ind(j))+1,:)=NaN;
    sec(mout(ind(j))-nrem(1)+1:mout(ind(j))+1)=NaN;
   end
 end
 ind=find(isnan(I(:,1)));
 I(ind,:) = [];
 ind=find(isnan(sec));
 sec(ind) = [];

 subplot(2,1,1)
 plot(sec,I(:,calch),'m') % show the raw-data after removal of values at edges

 miin = find(I(:,calch)>thres); % time values with mirror in the path
 mout = find(I(:,calch)<thres); % time values with mirror out of path
Imin = I(miin,:);    % all values with mirror in the path (i.e. internal calibration)
 Imout = I(mout,:);   % all values with mirror out of the path (i.e. measurement)

%% Fig. 2 line-graphs for the two 'flip' positions
figure(2)
 set(gcf,'PaperUnits','centimeters');
 set(gcf,'PaperPosition',[0 0 30 21]);
 set(gcf,'PaperOrientation','landscape');
 set(gcf,'Name','raw all chan.');
```

```
subplot(2,1,1)
t = sec(miin)./60;    % time in min for internal calibration values
h = plot(t,Imin,'-');
for ii=1:6
   set(h(ii),'Color',num2str(colors(ii)))
end
title([files(1,:),': int. path'])
ylabel('I / counts'),xlabel('time / min ')
legend('205','220','235','250','265','280')
grid

subplot(2,1,2)
t = sec(mout)./60;    % time in min for measurement values
h = plot(t,Imout,'-');
for ii=1:6
   set(h(ii),'Color',num2str(colors(ii)))
end
ylabel('I / counts'),xlabel('time / min ')
title([files(1,:),': ext. path'])
legend('205','220','235','250','265','280')
grid
eval(['print -dpsc ',files(1,1:length(files(1,:))-4),'_raw.ps'])

 % Let's find the mean values and standard deviations for all periods (in and out)
% First for int. cal. position
t = sec(miin); % time in secs again for int. cal. position
ind = find( diff(t) > 10);
% this finds indices 28 56 84 etc. (for nrem = 3) which are the last indices of an interval
ind = [1; ind+1 ;size(t,1)+1];
% Now the indices are starts of intervals, only the last one is last index of series +1
Iminmean(length(ind)-1,6)=0; % create matrix of means
Iminstd(length(ind)-1,6)=0;  % and standard deviations
for j=1:length(ind)-1
 Iminmean(j,1) = mean( Imin(ind(j):ind(j+1)-1,1) );
 Iminstd(j,1) = std(Imin(ind(j):ind(j+1)-1,1) );
 Iminmean(j,2) = mean( Imin(ind(j):ind(j+1)-1,2) );
 Iminstd(j,2) = std(Imin(ind(j):ind(j+1)-1,2) );
 Iminmean(j,3) = mean( Imin(ind(j):ind(j+1)-1,3) );
 Iminstd(j,3) = std(Imin(ind(j):ind(j+1)-1,3) );
 Iminmean(j,4) = mean( Imin(ind(j):ind(j+1)-1,4) );
 Iminstd(j,4) = std(Imin(ind(j):ind(j+1)-1,4) );
 Iminmean(j,5) = mean( Imin(ind(j):ind(j+1)-1,5) );
 Iminstd(j,5) = std(Imin(ind(j):ind(j+1)-1,5) );
 Iminmean(j,6) = mean( Imin(ind(j):ind(j+1)-1,6) );
 Iminstd(j,6) = std(Imin(ind(j):ind(j+1)-1,6) );
 tminmean(j) = mean( t(ind(j):ind(j+1)-1) );
end

% Second for the measurement position:
t = sec(mout); % time in secs again
```

```
 ind = find( diff(t) > 8); % this finds the last indices of an interval
 ind = [1; ind+1 ;size(t,1)+1];
% Now the indices are starts of intervals, only last one is last index of series

 Imoutmean(length(ind)-1,6)=0; % create matrix of means
 Imoutstd(length(ind)-1,6)=0; % and standard deviations
 Imoutrelstd(length(ind)-1,6)=0;
 Imoutrel(size(t,1),6) = 0;
% create matrix of ext. path values normalized with following int. path interval
 Imoutrelmean(size(t,1),6) = 0;
 for j=1:length(ind)-1
  Imoutmean(j,1) = mean( Imout(ind(j):ind(j+1)-1,1) );
  Imoutrel(ind(j):ind(j+1)-1,1) = Imout(ind(j):ind(j+1)-1,1)./Iminmean(j,1);
  Imoutrelmean(j,1) = mean( Imoutrel(ind(j):ind(j+1)-1,1));
  Imoutstd(j,1) = std( Imout(ind(j):ind(j+1)-1,1));
  Imoutrelstd(j,1) = std( Imoutrel(ind(j):ind(j+1)-1,1));
  Imoutmean(j,2) = mean( Imout(ind(j):ind(j+1)-1,2) );
  Imoutrel(ind(j):ind(j+1)-1,2) = Imout(ind(j):ind(j+1)-1,2)./Iminmean(j,2);
  Imoutrelmean(j,2) = mean( Imoutrel(ind(j):ind(j+1)-1,2));
  Imoutstd(j,2) = std( Imout(ind(j):ind(j+1)-1,2));
  Imoutrelstd(j,2) = std( Imoutrel(ind(j):ind(j+1)-1,2));
  Imoutmean(j,3) = mean( Imout(ind(j):ind(j+1)-1,3) );
  Imoutrel(ind(j):ind(j+1)-1,3) = Imout(ind(j):ind(j+1)-1,3)./Iminmean(j,3);
  Imoutrelmean(j,3) = mean( Imoutrel(ind(j):ind(j+1)-1,3));
  Imoutstd(j,3) = std( Imout(ind(j):ind(j+1)-1,3));
  Imoutrelstd(j,3) = std( Imoutrel(ind(j):ind(j+1)-1,3));
  Imoutmean(j,4) = mean( Imout(ind(j):ind(j+1)-1,4) );
  Imoutrel(ind(j):ind(j+1)-1,4) = Imout(ind(j):ind(j+1)-1,4)./Iminmean(j,4);
  Imoutrelmean(j,4) = mean( Imoutrel(ind(j):ind(j+1)-1,4));
  Imoutstd(j,4) = std( Imout(ind(j):ind(j+1)-1,4));
  Imoutrelstd(j,4) = std( Imoutrel(ind(j):ind(j+1)-1,4));
  Imoutmean(j,5) = mean( Imout(ind(j):ind(j+1)-1,5) );
  Imoutrel(ind(j):ind(j+1)-1,5) = Imout(ind(j):ind(j+1)-1,5)./Iminmean(j,5);
  Imoutrelmean(j,5) = mean( Imoutrel(ind(j):ind(j+1)-1,5));
  Imoutstd(j,5) = std( Imout(ind(j):ind(j+1)-1,5));
  Imoutrelstd(j,5) = std( Imoutrel(ind(j):ind(j+1)-1,5));
  Imoutmean(j,6) = mean( Imout(ind(j):ind(j+1)-1,6) );
  Imoutrel(ind(j):ind(j+1)-1,6) = Imout(ind(j):ind(j+1)-1,6)./Iminmean(j,6);
  Imoutrelmean(j,6) = mean( Imoutrel(ind(j):ind(j+1)-1,6));
  Imoutstd(j,6) = std( Imout(ind(j):ind(j+1)-1,6));
  Imoutrelstd(j,6) = std( Imoutrel(ind(j):ind(j+1)-1,6));
  tmoutmean(j) = mean( t(ind(j):ind(j+1)-1) );
 end
```

%% Fig.4: ext. path values normalized with following int. path interval

```
figure(4)
 set(gcf,'PaperUnits','centimeters');
 set(gcf,'PaperPosition',[0 0 30 21]);
 set(gcf,'PaperOrientation','landscape');
 set(gcf,'Name','normalized ext. path');
```

```
t = sec(mout)./60;    % time in min for mirror out values
h = plot(t,Imoutrel,'-');
for ii=1:6
   set(h(ii),'Color',num2str(colors(ii)))
end
ylabel('I_{ext} / I_{int}'),xlabel('time / min ')
title([files(1,:),': ext. path, calibration in LNS'])
legend('205','220','235','250','265','280')
grid
eval(['print -dpsc ',files(1,1:length(files(1,:))-4),'_extnorm.ps'])
```

%% Fig.5: means and standard deviation as error bars for each interval

```
figure(5)
set(gcf,'PaperUnits','centimeters');
set(gcf,'PaperPosition',[0 0 30 21]);
set(gcf,'PaperOrientation','landscape');
set(gcf,'Name','means + std dev');

% first for int. path (upper panel)
subplot(2,1,1), hold on
[dum tminmat] = meshgrid(1:6,tminmean);
h = errorbar(tminmat./60,Iminmean,Iminstd);
for ii=1:6
    set(h(ii),'Color',num2str(colors(ii)))
    set(h(ii+6),'Color',num2str(colors(ii)))
end
legend('205','220','235','250','265','280')
grid
ylabel('mean {I(\lambda)} / counts'),xlabel('time / min')
title([files(1,:),': int. path'])
ax = axis;   ax(1)=0;   axis(ax);

% then for ext. path (lower panel)
subplot(2,1,2)
[dum tmoutmat] = meshgrid(1:6,tmoutmean);
hold on
h = errorbar(tmoutmat./60,Imoutmean,Imoutstd);
for ii=1:6
   set(h(ii),'Color',num2str(colors(ii)))
   set(h(ii+6),'Color',num2str(colors(ii)))
end
legend('205','220','235','250','265','280')
ax = axis;
ax(1)=0;
axis(ax);

grid
ylabel('mean {I(\lambda)} / counts'),xlabel('time / min')
title([files(1,:),': ext. path'])
eval(['print -dpsc ',files(1,1:length(files(1,:))-4),'_means.ps'])
```

```
% if(length(tmoutmat)>length(tminmat))
%     tmoutmat(length(tmoutmat),:) = [];
%     Imoutmean(length(Imoutmean),:) = [];
%     Imoutstd(length(Imoutstd),:) = [];
% end
% if(length(tminmat)>length(tmoutmat))
%     tminmat(length(tminmat),:) = [];
%     Iminmean(length(Iminmean),:) = [];
%     Iminstd(length(Iminstd),:) = [];
% end

% from the lab calibration:
Ioff1 = 1000 .* [0.73723096989466   0.93689932661418   2.47702213544662  ...
                 2.32764682034082   2.74370449575342];
Ioff2 = [1.04467450289282   0.33928188910878   0.82393639046140 ...
               0.78263023349615   0.92605517522418];
p2 = [ 38.20596460696951 -13.78382751978668];
ab2 = -log((Imoutrel(:,2)./Imoutrel(:,6)-Ioff2(2))); %absorbance of 220 nm channel

figure(9)
 set(gcf,'PaperUnits','centimeters');
 set(gcf,'PaperPosition',[0 2 21 25]);
 set(gcf,'PaperOrientation','portrait');
 set(gcf,'Name','conc. appl. cal.');

%save time as jday
timereal=(sec(mout)/(60*60*24))+jdaytime(1);

h = plot(sec(mout)./60,polyval(p2,ab2),'b');
title(['Concentration calculated from calibration (220 nm channel)'],'FontSize',14)
xlabel('time / min','FontSize',14),ylabel('concentration / \mu mol l^{-1}','FontSize',14)
set(gca,'FontSize',14)
grid

figure(10)
h = plot(timereal,polyval(p2,ab2),'b');
title(['Concentration calculated from calibration (220 nm channel)'],'FontSize',14)
xlabel('time / min','FontSize',14),ylabel('concentration / \mu mol l^{-1}','FontSize',14)
set(gca,'FontSize',14)
grid

eval(['print -dpsc ',files(1,1:length(files(1,:))-4),'_linregbc.ps'])

%save 6 channel data
eval(['channels_',files(1,1:length(files(1,:))-4),'=[timereal Imoutrel];'])
eval(['save channels_',files(1,1:length(files(1,:))-4)]);

% save nitrate values
eval(['Nitr_',files(1,1:length(files(1,:))-4),'= [timereal polyval(p2,ab2)];'])
eval(['save Nitr_',files(1,1:length(files(1,:))-4)]);
```

A2. Commands to reset S/N ratio on link to PENGUIN

Vic Cornell

At one point on the tow from Reunion the S/N ratio fell below 2dB, with the data rate at that point being insufficient to keep up with capture. In order to improve this I manually set the data rate to 2Mbit/s. and then reset the top end modem. Since PENGUIN was running **watchscr** it also reset the bottom end modem. This reset the link and, when it came back up the S/N margin was 23dB!

To do this I logged into the end modem:

```
telnet endmodem
Trying 139.166.250.19...
Connected to endmodem.
Escape character is '^]'.


Welcome to Dce ...

 ** Aware Inc. ** ADSL CO ** Copyright 1997-2003 ** www.aware.com **

Login: su
Password:
(the password is adsl)
Dce> config
Dce\config> modem
Dce\config\modem> speed downstream 2048

Dce\config\modem> view
modem
   mode adaptive
   speed upstream 1024
   speed downstream 2048
   margin upstream 6
   margin downstream 6
   coding on
   latency downstream 64
   latency upstream 64
   path interleaved
   trellis off
   framing-mode 3
   conceal-id-t1 disable
   utopia tx 1
   utopia rx 1
   phymode multi
   advanced use no
!
Dce\config\modem>
```

mplotAT100m – this is bit of a kludge but useful. Graham Quartly wanted a plot which showed what was happening at 100m. So I wrote a little python program – 100m.py which pulls out the data between 99 and 100 and writes it out on stdout.

```
#!/usr/bin/python
import sys
f=open(sys.argv[1])
lines = f.readlines()
f.close()
lines = [line.split() for line in lines]
#data = [ line for line in lines if (99.0<line[10]<100.0)]
for line in lines:
	if 61.0  > float(line[9]) > 59.0:
		print line[0],' ',float(line[8]),' ',float(line[10])
```

We then run the script below which calls 100m.py and then plots the output.

```
#!/bin/csh
set delay = 20
set th = `mktemp /tmp/plot100XXXXXX`
while 1
#Find the latest file.
set file = `ls -rt /local/users/daps/emperor/penguin/data/cruise | grep minipack| tail -1`
100m.py $file > $th
gnuplot -geometry 1280x400+0+410 -bg cornsilk << !
#set yrange [23:26]
#set y2range [1:0]
plot "$th" using 1:2 axes x1y1 title "Temp" with lines , "$th" using 1:3 axes x1y2 title "Fluor" with lines
show xlabel
pause $delay
!
end
rm -f $th
```