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CRUISE REPORT No. 41

RRS *CHARLES DARWIN* CRUISE 141
01 JUN - 11 JUL 2002

Satellite Calibration and Interior Physics of the Indian Ocean: SCIPIO

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2003

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ABSTRACT

RRS *Charles Darwin* Cruise 141, SCIPIO (Satellite Calibration and Interior Physics of the Indian Ocean) provided a multidisciplinary survey of the Mascarene Ridge system in the western Indian Ocean. The principal objectives were to (a) study the flow of water masses through the Ridge system, together with their decadal-timescale variability, (b) assess the energy fluxes and mixing arising from internal waves, (c) collect *in situ* data for the calibration of sea-surface temperature and ocean colour sensors on the ENVISAT satellite, (d) investigate the biogeochemical properties of the water masses, and (e) measure the heat fluxes and winds, and the airflow disturbance around the ship. The survey comprised three sections parallel with the Ridge near 64°, 60° and 57° E, joined by two other sections at 8° and 20°S. The sections comprised CTD, LADCP, and biogeochemistry (nutrients, phytoplankton, zooplankton, biogenic gases, CFC tracers and light levels) stations to full ocean depth, at typical spacings of about 60-80 nm. At several of these the CTD and LADCP were cycled continuously for a semi-diurnal tidal cycle to study the internal waves, and the smaller 12-bottle CTD frame was used throughout (usually with 6 bottles) in order to reduce mixing effects from the trailing wake. Underway measurements were made with the shipboard ADCP, TSG, radiosondes, XBTs, and of surface meteorology, skin surface temperature, and zooplankton. The ship's EM12 swath bathymetry system was operated continuously, and used to study certain key areas in detail. In addition, MMP (a cycling CTD) and bottom-mounted ADCP moorings were successfully laid and recovered near 8°S, 60°E, and a first deployment of the ARGODOT turbulence probe was made near 20°S, 57.5°E.

KEYWORDS

ACOUSTIC DOPPLER CURRENT PROFILER, ADCP, ARGODOT, AUTOFLUX, BIOLOGY, CFC, *CHARLES DARWIN*, CRUISE 141 2002, EM12, INDIAN OCEAN, INTERNAL WAVES, LADCP, LIGHTFISH, LIGHT LEVELS, LOWERED ADCP, MASCARENE RIDGE, METEOROLOGICAL MEASUREMENTS, METHYL HALIDES, MIXING, NUTRIENTS, OXYGEN, PHYTOPLANKTON, PLANT PIGMENTS, RADIOSONDE, SATLANTIC, SCIPIO, SISTeR, SOUTH EQUATORIAL CURRENT, SWATH BATHYMETRY, TRACER CHEMISTRY, TSG, XBT, ZOOPLANKTON

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Babb, Richard	ARGODOT	SOC-OED
Benson, Jeff	CTD, Moorings	SOC-UKORS
Dickie, Brian	Oxygen	SOC-SOES
Duc, Marc-Olivier	Nutrients	SOC-SOES
Duncan, Paul	Computing	SOC-UKORS
Evans, Alan	Swath Bathymetry	SOC-CHD
Green, Chris	Light measurements	SOC-SOES
Marie, Hubin	Observer	Seychelles Coastguard
Moat, Bengamin	Autoflux	SOC-JRD
Nightingale, Timothy	SISTeR	RAL
Smeed, David	VM-ADCP, XBT	SOC-JRD
Smythe-Wright, Denise	Biogas, CFC (PI)	SOC-GDD
Stansfield, Kate	CTD	SOC-JRD
Varney, Mark	Biogas, CFC	SOC-SOES
Wynar, John	Moorings, CTD	SOC-UKORS
Young, Darren	Mechanical Engineer	SOC-UKORS

Key:

CHD: Challenger Division
JRD: James Rennell Division
RAL: Rutherford Appleton Laboratory
SOES: School of Ocean and Earth Sciences
GDD: George Deacon Division
OED: Ocean Engineering Division
SOC: Southampton Oceanography Centre
UKORS: UK Ocean Research Service

SCIENTIFIC PERSONNEL - LEG 2

Name	Role	Affiliation
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Budloo, Sunil	Observer	MMS
Duc, Marc-Olivier	Oxygen, Nutrients	SOC-SOES
Evans, Alan	Swath Bathymetry	SOC-CHD
Gallienne, Chris	Zooplankton	PML
Green, Chris	Light measurements	SOC-SOES
Knight, Gareth	Computing	SOC-UKORS
Moat, Bengamin	Autoflux	SOC-JRD
Nightingale, Timothy	SISTeR	RAL
Smeed, David	VM-ADCP, XBT	SOC-JRD
Smythe-Wright, Denise	Biogas, CFC (PI)	SOC-GDD
Stansfield, Kate	CTD	SOC-JRD
Varney, Mark	Biogas, CFC	SOC-SOES
Weeks, Alison	Light measurements (PI)	SI
Wynar, John	Moorings, CTD	SOC-UKORS
Young, Darren	Mechanical Engineer	SOC-UKORS

Key:

CHD: Challenger Division
JRD: James Rennell Division
PML: Plymouth Marine Laboratory
SOC: Southampton Oceanography Centre
SI: Southampton Institute
GDD: George Deacon Division
MMS: Mauritius Meteorological Services Ltd.
RAL: Rutherford Appleton Laboratory
SOES: School of Ocean and Earth Sciences
UKORS: UK Ocean Research Service

SHIP'S PERSONNEL

Name	Rank
Sarjeant, Peter	Master
Gauld, Phil	Chief Officer
Cope, Andy	2nd Officer
Reynolds, Peter	3rd Officer (Leg 1)
Owoso, Titus	3rd Officer (Leg 2)
McGill, Ian	Chief Engineer
Holt, Martin	2nd Engineer
Healy, Tony	3rd Engineer
Harnett, John	3rd Engineer
Baker, Jeff	ETO
Drayton, Mick	CPO (D)
Harrison, Martin	PO (D)
Dale, John	S1A
Edwards, Timmy	S1A
Johnson, Bob	S1A
Moore, Mark	S1A
Pringle, Keith	ERPO
Perry, Clive	SCM
Haughton, John	Chef
Duncan, Andy	Assistant Chef
Robinson, Peter	Steward

ACKNOWLEDGEMENTS

It is a great pleasure to acknowledge the efficiency and professionalism of the Master, Officers and Crew of the *R.R.S Charles Darwin*, which contributed enormously to the smooth-running of such a multi-disciplinary cruise with many disparate scientific aspects and objectives. I would particularly like to thank the Master, Peter Sarjeant, for providing much-valued advice and guidance on several aspects of the cruise, and also those members of the crew, John Dale, Bob Johnson, Mark Moore, and Timmy Edwards, who took upon themselves the extra responsibilities entailed in operating the CTD winch, thereby allowing extra scientific berths to be made available. I am also much indebted to the whole of the scientific party, without whose dedicated efforts the cruise would have quickly foundered, and whose enthusiasm was greatly appreciated. Of special note is Darren Young, whose tireless attention to the CTD winch during the first few days probably saved the whole cruise from abandon. However, it was the helpful attitude, and willingness to work together to achieve the common objectives, of everyone involved, that deeply impressed, and remains with me.

The cruise was largely funded by the UK Natural Environment Research Council through Southampton Oceanography Centre infrastructure funding, with additional support coming from the James Rennell Division core strategic programmes. It was also partly supported by the Royal Geographical Society (with IBG) - Royal Society *Shoals of Capricorn programme*, western Indian Ocean, 1998-2001. This is *Shoals* Contribution No: R035.

My thanks are also extended to the authorities of the Seychelles, Mauritius, and Reunion, for granting us permission to work in their territorial waters.

1 CRUISE DESCRIPTION

1.1 Cruise Details

Cruise Name: Satellite Calibration and Interior Physics of the Indian Ocean
Designation: RRS *Charles Darwin* Cruise 141
Port Calls: Seychelles to Mauritius (Leg 1), Mauritius to Mauritius (Leg 2)
Cruise Dates: 1-21 June, 2002 (Leg 1), 22 June - 11 July, 2002 (Leg 2)

1.2 Outline and Objectives

SCIPIO (Satellite Calibration and Interior Physics of the Indian Ocean) provided a comprehensive, multidisciplinary oceanographic survey of the Mascarene Ridge (MR) system in the western Indian Ocean (Figure 1.1). It was a collaborative effort between the James Rennell Division (JRD), the George Deacon Division, the Challenger Division, the Ocean Engineering Division and the School of Ocean and Earth Sciences of the Southampton Oceanography Centre (SOC), together with Southampton Institute, Rutherford Appleton Laboratory, and Plymouth Marine Laboratory. The cruise was funded largely by the UK Natural Environment Research Council through SOC infrastructure funding, with additional support coming from the JRD core strategic programmes, and the Royal Geographical Society (with the Institute of British Geographers) through their "Shoals of Capricorn" project.

The objectives of the cruise were as follows:

1. Examination of the structure of the mean flow around and over the Mascarene Ridge.
2. Investigation of the decadal-timescale changes in the water masses in the vicinity of the Mascarene Ridge.
3. Assessment of the energy fluxes, and mixing produced by, internal waves in the vicinity of the Mascarene Ridge.
4. Bathymetric survey of parts of the Mascarene Ridge and surrounding area.
5. Calibration of the ENVISAT satellite sensors measuring the temperature (AATSR) and colour (MERIS) of the ocean surface.
6. Investigation of biogeochemical properties (nutrients, phytoplankton, zooplankton, biogenic gases, CFC tracers and light levels) around the Mascarene Ridge, and their relationship to the structure of the mean flow.
7. Measurement of heat fluxes and winds near the air-sea interface, and the airflow disturbance around the ship.

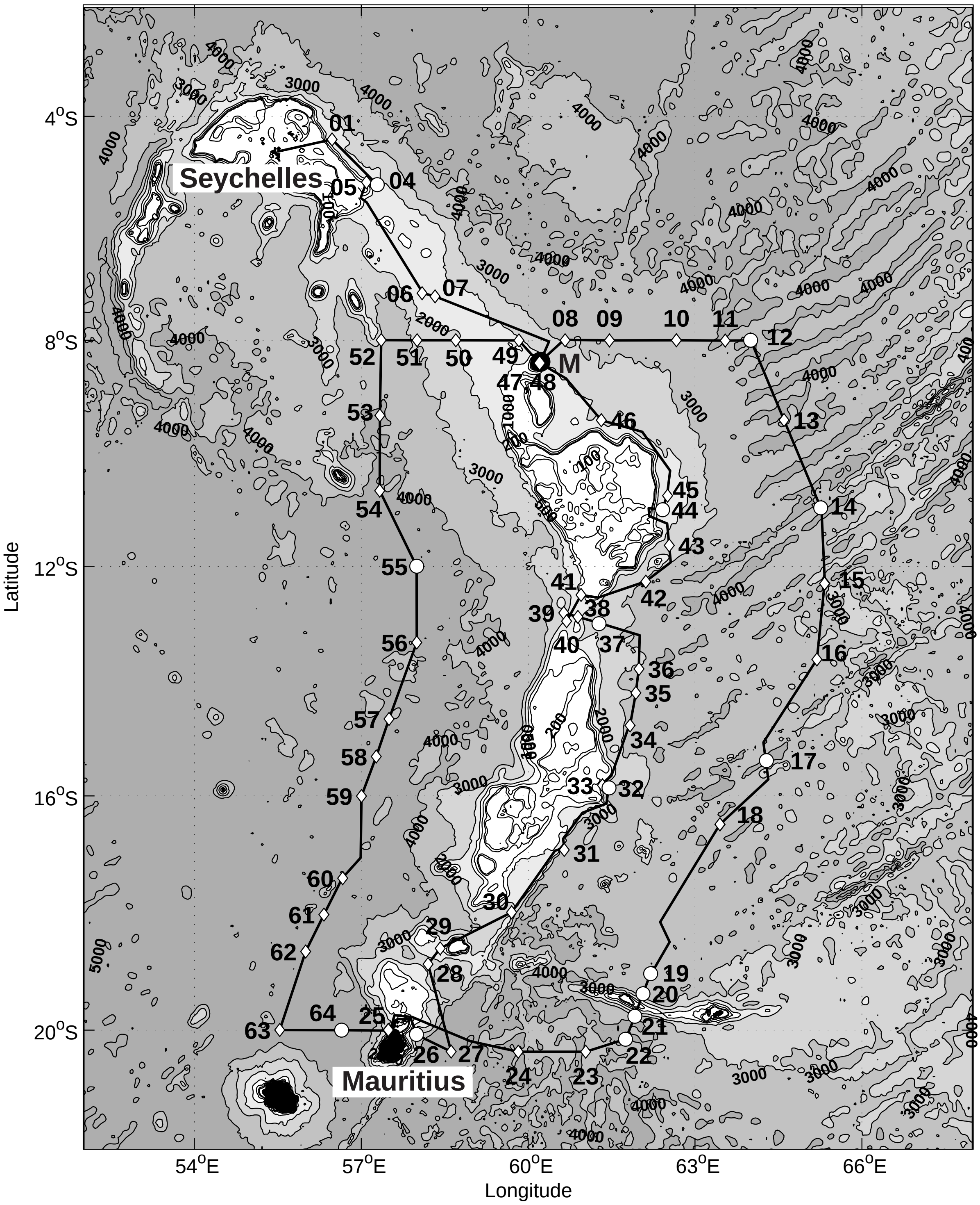

Figure 1.1 Cruise track and bathymetry of the region. CTD station position numbers are indicated, and shown by the diamonds (single-dip CTDs) and the circles (tidal-period yo-yo stations). The moorings are located at M. The bathymetry is from the Sandwell and Smith dataset, and contours are at 100, 200, 500, 1000, 2000, 3000 and 4000 m.

1.3 Cruise Overview

The Mascarene Ridge (MR) is a chain of islands and submarine ridges in the Western Indian Ocean extending between the Seychelles and Mauritius. The South Equatorial Current (SEC), a major current system in the southern Indian Ocean, is know to impact upon the ridge system from the east, but it is not known how it crosses the MR itself. The area is also known from satellite altimetry to be one of large internal tidal waves (generated by the interaction of the astronomical tide with the seafloor topography), but little is known about the structure of these waves, and the mixing that they might cause. The cruise track (Figure 1.1) was designed primarily to examine these issues, and, in order to achieve objective 2, to repeat parts of the WOCE (World Ocean Circulation Experiment) hydrographic lines at (nominally) 8°S (the IO2 section) and at 20°S (the IO3 section).

The cruise therefore comprised sections "upstream" of the MR (the eastern section, stations 12-22), near the Ridge itself (stations 26-49), and "downstream" of the ridge (stations 52-63) to examine how the SEC crosses the Ridge, together with repeats of WOCE lines IO2 (stations 52-12) and IO3 (stations 63-22) to look at decadal-timescale variability. There were also a number of special "tidal-period" stations to examine the internal tides. These were undertaken over the deep "rough" topography of the Central Indian Ridge (stations 12, 14, 17), over deep "flat" topography (station 55), and near both the MR (stations 26, 32, 37, 44 and 64) and the Rodrigues Ridge (stations 19-22). The principal instrument for these stations was the CTD/water sampler/LADCP package, giving profiles of temperature, salinity, oxygen (from the CTD), currents (from the LADCP), and bio-chemical constituents (from the water sampler), through the water column. In addition two moorings were deployed on the MR near 8°S (at M in Figure 1.1) in order to study the changing nature of the flow patterns, and the internal tides, throughout a large part (25 days) of the cruise.

The RRS *Charles Darwin* duly sailed from the Seychelles on the morning of June 1, 2002, in light weather, and proceeded eastwards towards the shelf break for our first intended tidal-period station. However, shortly after deploying the CTD (from the midships gantry), the winching gear failed. This was due to a fracture of the scrollbar, preventing the winch from turning, and was potentially very serious. However, due to heroic efforts from the technical and engineering staff on board, it was possible to effect a working repair which held for the remainder of the cruise. Although approximately 1.5 days was lost from the original work programme because of this, useful science was carried out during this time by steaming back and forth across the shelf break (near station 01) with underway ADCP and XBTs.

With the completion of the winch repair, we proceeded southeastwards along the shelf break to stations 02 and 03 (at the same place as station 04 on Figure 1.1). These were trials of the CTD configuration. When attempting to measure small-scale structures in the water column from a profiling CTD which is also subject to vertical heave from the ship's motion, it has recently become known that spurious temperature (and salinity) "spiking" may occur if the weather conditions are sufficiently rough, due to the turbulent wake behind the CTD frame catching up with, and overtaking, the CTD sensors. Since we wished to make inferences about the mixing in the water column, it was necessary to try to reduce this problem as much as possible. We had two CTD frames available for use, the large 24-bottle frame, and the significantly smaller 12-bottle frame. To reduce the spiking, we decided to use the smaller CTD frame, even though this meant that we would (due to limitations of space) only be able to employ one (downward-looking) of the 300 KHz "Workhorse" LADCPs (lowered ADCP) on the same frame (the larger 150 KHz "Broadband" LADCP only being usable on the 24-way frame). We then undertook tests (stations 02 and 03) both with no water bottles on the 12-way frame, and with a full complement of 12 bottles. These, and subsequent, tests showed that the best compromise, also bearing in mind the need to collect water samples for the chemical and biological objectives, was to use the 12-way frame with just 6 bottles (see section 2 below), and this was actioned subsequent to CTD 18. On each of the full-depth CTD stations, however, we collected 12 water-bottle samples, usually by firing 6 bottles on the main cast in the deeper ocean, and then repeating the upper few hundred metres on a separate cast. The full suite of 12 samples was then analysed for various chemical and biological constituents (nitrate, phosphate, silicate, oxygen, biogenic gases and CFCs). These were usually sufficient to provide a reasonable coverage of all the water masses and variations present in the water column. In addition, the uppermost 6 bottles were sampled for phytoplankton analysis (pigments and species).

Our first tidal-period station (04) was then undertaken on June 3/4. The ship remained on station, and the CTD was continuously "yo-yo"-ed through the full depth of the water column for about 13 hours. We then proceeded southeastwards down the MR, undertaking a bathymetric survey (with the ship's EM12 swath bathymetry system) of the SE corner of the Seychelles shelf (which was found to be about 5-10 nm further west than its supposed position on the charts we had available). After CTD 06, approximately 32 hours were devoted to a special bathymetric survey for the "Shoals of Capricorn" programme, the centre of which was CTD 07. While the ship completed this survey (infilling a box about 25 nm on each side), the surface signatures of plentiful internal waves (alternating rougher and calmer patches) were observed on the sea-surface, and were studied with both the ship's (underway) ADCP, and numerous XBTs.

We then continued southeastwards along the MR and, on June 7, proceeded to lay two moorings in about 750m of water, near 8° S on the north-eastern edge of the Saya da Malha Bank (see M in Figure 1.1). The first mooring comprised a Maclean Moored Profiler (MMP), to record temperature/ salinity (and current) profiles, and the second (about 250m away from the first) was a bottom-mounted ADCP (75 KHz), to provide currents. These moorings successfully provided continuous profiles throughout the duration of their deployment (about 25 days).

We then proceeded eastwards into worsening weather along 8°S to commence our repeat of part of the WOCE line IO2. From about this point on, we were working within the area of reasonably strong winds known as the SE trades (up to 30-40 kts at times), which generally gave much stronger winds and waves than north of 8°S, with worst conditions typically between 12-18° S. CTD station 12 (at 8° 00' S and 64° 00' E) was undertaken on June 8, and marked both the end of the WOCE line, and the commencement of our easternmost leg. We proceeded in a generally southward direction, alternating single-dip CTDs with tidal period stations, but the weather continued to worsen. After CTD 14, we hoped to proceed southeastwards to reach the axial valley of the central Indian Ridge system (at 12° 40'S, 66° 15'E), in order to investigate possible hydrothermal activity. However, this was heading directly into heavy swells and winds, and the ship's speed was reduced to 3.5 kt. Eventually, we were forced in the interests of time to abandon this hope, and turn instead southwards (the ship's speed immediately jumping to 7 kts), making for 12° 18'S, 65° 20'E (station 15), which was in a valley just off the main axial valley. Deep water samples were taken for Manganese (an indicator of hydrothermal activity).

We then proceeded south-southwestwards, completing stations 16-18, but bad weather again interfered and forced us to abandon a planned CTD station near 18° S, 62° 30'E (midway between stations 18 and 19 on Figure 1.1), although several deep XBTs were deployed here. Subsequently, however, we successfully completed four tidal period stations (19-22) across the Rodrigues Ridge, and then, after turning westwards, stations 23 and 24 on the WOCE line IO3, heading for a port call in Mauritius on June 21.

We had been hoping to perform a trial deployment of the "ARGODOT" (an ARGO profiling float modified by the addition of rapidly sampling temperature probes to estimate turbulence and mixing) in the lee of Mauritius (providing calmer conditions for recovery) at the end of the first leg, but problems with the vacuum seal on the float became apparent on June 20, and could not be overcome in time.

The short port call in Mauritius on June 21/22 then allowed the interchange of personnel, so that zooplankton studies could be undertaken on the second leg, at the expense of ARGODOT support. However, suitable instructions were left behind for ARGODOT, and a successful trial deployment of this to 500 m was carried out in the lee of Mauritius, together with CTD 25, as the first action of the second leg.

CTDs 26 and 27 were then undertaken to complete our survey of the line near 20°S (East of Mauritius), and the cruise then proceeded northwards, firstly measuring the structure of the flow through the deep southern channels in the Ridge system (stations 28 and 30), before continuing up the eastern edge of the MR. Special attention (stations 37 to 41) was paid to the region of the Ridge system between 12-13°S, which appears on the GEBCO bathymetric charts as "Somerville Bank" (200-500 m deep), but which in actuality was found to contain a deep (1100 m) channel (10-15 km wide). This appears to be a critical channel in the Ridge system through which a large proportion (initial estimates suggest about 50%) of the transport of the SEC passes. Leaving this area on June 29, the cruise then continued around the eastern side of the Saya da Malha Bank (stations 42 to 46), before successfully recovering both moorings on July 2, a total deployment time a few hours short of 25 days. Immediately following the recovery, CTD station 47 was undertaken on the mooring site, and CTD 48 about 1.5 nm further west, towards the top of the slope (in 400 m water), for comparison purposes.

We then turned westwards along 8°S to complete our portion of WOCE line IO2 (stations 49 to 52), ending at 57° 21.2' E on July 3. We then commenced our southward leg on the western side of the Ridge (stations 52 to 63) on July 4. This was close to the zooplankton (only) survey line undertaken by the SRV "Zuza" for the Shoals of Capricorn progamme in 2001. A new microporous oxygen sensor (developed by R. Pascal) was trialled on CTD 54, but quickly failed due to a water leak in the casing. We then attempted a further tidal-period CTD at station 55, but this had to be cut a little short (to about 11 hours) around midnight on July 5 due to worsening weather. The remainder of the cruise proceeded smoothly (with a small dog-leg in the track near 17°S to avoid entering Tromelin waters), reaching station 63 (55° 32'E, 20° 00'S) on the WOCE line IO3 on July 9, and then turning eastwards towards Mauritius along 20°S. The cruise finished with CTD 64 on WOCE line IO3, which ended at 0630 h on July 10.

Throughout the cruise, we were continuously running the ship's EM12 swath bathymetry system while the ship was underway (except for a few hours of downtime on leg 2), the ship's ADCP (150 KHz) giving currents below the ship to typically 200-300 m (which worked well except for a few days of lost heading information on leg 1), the ship's underway surface sampling instruments (for surface temperature, salinity, fluorescence, and meteorology), the SOC "Autoflux" package, giving detailed meteorological information above the ship's bridge, and (on the second leg) surface zooplankton sampling. In addition, we deployed over 270 XBTs (mostly while the ship was underway) to increase the spatial resolution of the temperature structure (obtained down to 700 m or 1500 m) between the CTDs, and to undertake detailed internal wave studies. This enabled us to typically achieve about 2 to 3 XBTs between each CTD station.

For calibration of the ENVISAT satellite ocean colour sensor (MERIS), it was necessary for the ship to heave-to during times of morning overpasses of the satellite (usually between 1000-1100 h) whenever cloud conditions were moderate or good. At such times, a profile of the light levels in the upper 50 m of the water column was undertaken with the SATLANTIC light profiler, and this would be followed by a shallow (200 m deep) CTD cast to collect water samples for phytoplankton and other pigments affecting the penetration, absorption and reflection of light. On the second leg this would be followed immediately by a vertical haul (up from 150 m) with zooplankton nets, so that the zooplankton could be related to the phytoplankton. (Typically, on the second leg, such zooplankton hauls were obtained once or twice per day.) Furthermore, the shallow CTDs could usually be combined with a regular deep CTD, or by effecting a small break (usually less than an hour) in a tidal-period station. When the ship was specially stopped for a shallow "satellite" CTD in the morning, these would be alternated between heaving-to just *before* the satellite overpass (allowing the light and CTD profiles to be as nearly coincident with the overpasses as possible), and just *after* the overpass, enabling the SISTER radiometer (used for calibrating the ENVISAT surface temperature sensor, AATSR) to sample undisturbed water ahead of any effects from the ship while it was still moving. The SISTER radiometer (measuring the ocean surface skin temperature) was also able to pick up on the nighttime overpasses of the ENVISAT satellite, usually between 2200-2300h, for which the ship did not specially heave-to (though it was sometimes on station for a CTD anyway). In addition, Radiosonde balloons were launched at suitable times throughout the cruise in order to help with the calibration of the AATSR, and there were some successful tows of the "Lightfish" (measuring light levels near the surface while the ship was underway), although the weather was often too rough to allow this latter exercise to be undertaken.

2 CTD DATA ACQUISITION, PROCESSING AND QUALITY

2.1 CTD Configuration and Operation

Here we describe the Conductivity-Temperature-Depth (CTD) configuration and operation on the cruise. For the reasons given in the Overview above, we decided to use the small 12-bottle CTD frame, which had been specially modified for the cruise to carry the LADCP system (see Figure 2.1). In addition, it was decided not to fit the full set of twelve bottles, except when absolutely necessary, but instead to use typically only six bottles, or occasionally none at all.

The CTD package can be seen in Figure 2.1. Conductivity, temperature, and pressure were measured with a UKORS Sea-Bird 911 plus CTD. Chlorophyll fluorescence was measured with a Chelsea Aqua Tracka III fluorometer. Light transmission was measured with 25cm path length Chelsea Alpha Tracka II transmissometer. Light scattering was measured using a Wet Labs Inc. Sea Tech lss6000 m sensor. Dissolved oxygen was measured using an SBE-23 Beckman-type oxygen sensor. Surface photosynthetically active radiation (PAR) was measured at 5 stations with a Biospherical Instruments Light Sensor. An altimeter and an RDI "Workhorse" 300 kHz LADCP were also fitted to the frame. Instrument serial numbers and calibration dates are given in Table 2.1.

The CTD was deployed from the starboard midships gantry of the *Charles Darwin*. Prior to each deployment the Lowered Acoustic Doppler Current Profiler (LADCP) had to be programmed, disconnected from the battery charger and have the blanking plugs installed. Hand lines were used to control the motion of the CTD package once it left the deck of the ship and before entering/leaving the water. The CTD was lowered until it was fully immersed and then left to soak at the sea surface for about two minutes. Soaking ensures that the CTD pumps have been activated, that the system has had time to flush, and also allows time for the instruments to adjust to the water temperature. The CTD was then lowered until it was about 10 m from the sea floor. The lowering and raising rates for these casts were 30 meters/min in the top 400-500 m and the bottom 100 m, and otherwise 60 meters/min. Water samples were taken on the upcast, (using General Oceanics, 10 litre, GO-FLO sampling bottles) after ensuring that the CTD had been stopped for at least 10 seconds before firing the bottle. Once the CTD was back on deck, samples were drawn from the water bottles (where required) and the LADCP data were downloaded and the system put into charge. The CTD and oxygen sensors were flushed with and left to soak in a Triton-X/water solution.

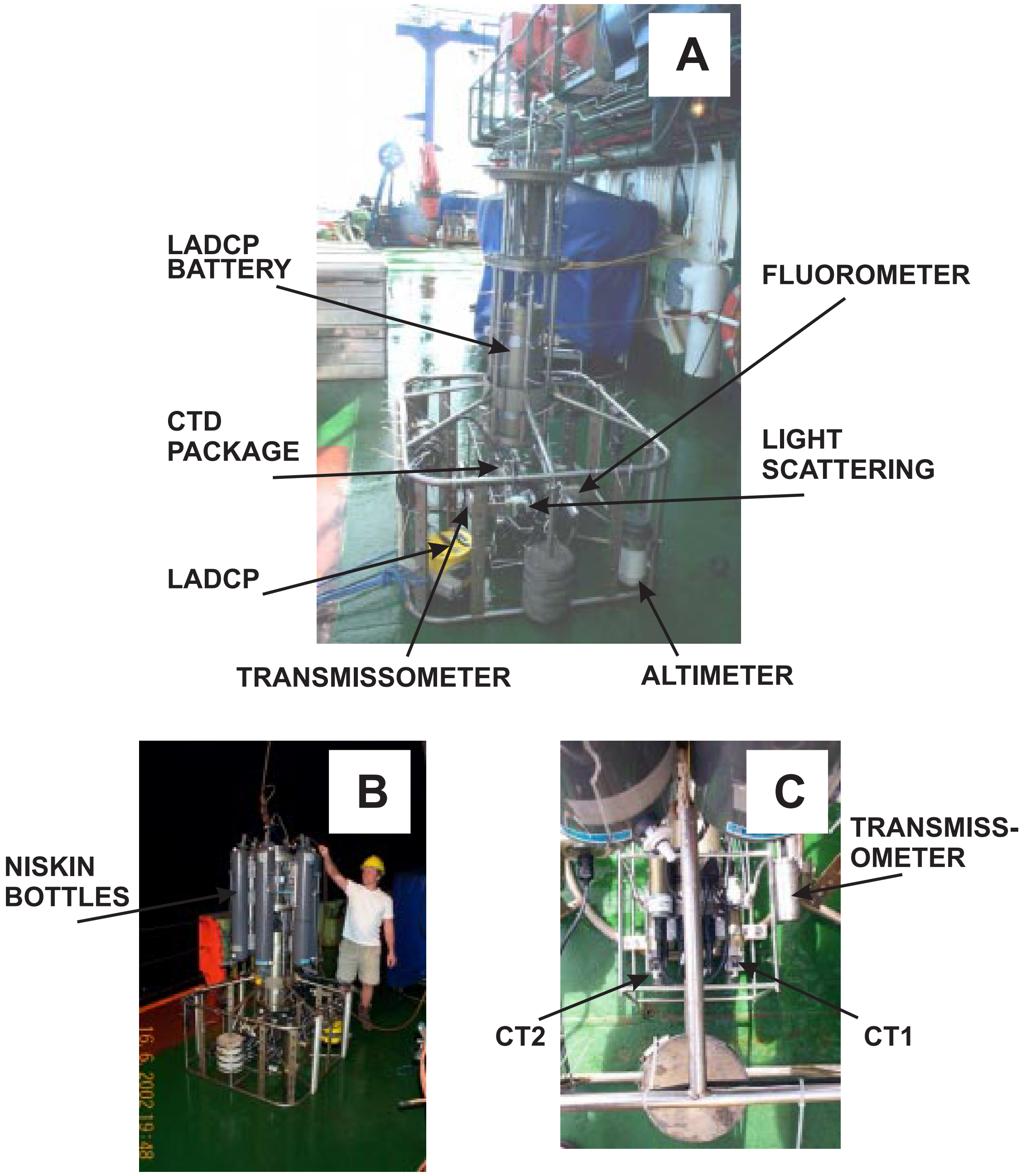

Figure 2.1 Photographs showing the 12-way CTD frame configuration for CD141. a) "Bare bones" configuration. Major system components are identified, b) The 12-way system with 6 water sample bottles, c) Close-up, plan view, of the positioning of the two Conductivity-Temperature sensor units (CT1, CT2) in relation to the frame. The position of the transmissometer is shown for purposes of orientation.

Water sampling was performed with the ship either stationary or (if possible) underway as conditions permitted. The water bottles were not emptied, but left closed and partly full of water between CTD casts to minimise contamination. Where necessary, bottles were added/removed between casts as dictated by the science sampling strategy. Samples were collected on most casts except those that formed part of the tidal period time-series stations. Samples for oxygen and nutrient analysis were drawn from all bottles. Salinity samples were only taken periodically. Samples for biogenic gases, CFCs and phytoplankton analysis were also taken. We encountered problems with several of the magnetically-actuated lanyard releases on the Sea-Bird carousel not-releasing, position number 22 becoming completely jammed by the end of the cruise. In general, careful set-up of the lanyards meant that a full set of bottles were closed on 62 out of the 75 casts where samples were collected. On one cast no water samples were collected as the bottle vents had not been closed prior to deployment. However, we were able to repeat this cast.

Instrument	Type/ Model	Serial Number	Calibration Date
Underwater Unit	SBE 9 plus		-
Deck Unit	SBE 11 plus		-
Conductivity (primary)	SBE 4	2570	07 May 2002
Temperature (primary)	SBE 3 plus	4103	07 May 2002
Conductivity (secondary)	SBE 4	2573	07 May 2002
Temperature (secondary)	SBE 3 plus	4107	07 May 2002
Pressure	Digiquartz	73299	08 May 2002
Fluorometer	Chelsea Aqua Tracka III	088241	28 April 2002
Transmissometer	Chelsea Alpha Tracka II	161048	03 May 2001
Light Scattering Sensor	Sea tech lss6000 m (Wet Labs Inc.)	339	16 April 1997
Oxygen	SBE-23 "Beckman type"	0554	08 May 2002
Photosynthetically Active Radiation	Biospherical Instruments	10	05 May 1999
Altimeter			
Frame			
Pump (primary)			
Pump (secondary)			
LADCP	RDI 300kHz		

Table 2.1. CTD frame instrument details

2.2 Data Acquisition

CTD data was collected at 64 stations with a total of 147 casts. There were three main types of CTD profile collected during the cruise:

- single full depth CTD casts at a particular location (about 40 casts).
- repeated full depth CTD casts at a particular station as part of a tidal period (14 hour) time series (about 90 casts).
- shallow (typically 200 m) CTD casts for surface water samples (about 20 casts).

Dates, times, and positions of all CTD stations and casts are given in Appendix A. Note that because the tidal-period stations usually comprised up to nine individual CTD casts (down and up), the CTD numbering in Appendix A comprises both the station number and the cast number, thus, for example, "ctd00407" refers to the 7th cast at station 04. Further details of the tidal-period stations are listed in Table 2.2 below (in which only the CTD station number is given in the left-most column).

Station Number	**Total no. of Casts**	**Shallow Cast No.s**	**Cast No.s with water samples**	**No.of bottles**	**Comments**
004	9	-	9	0/12	No upcast data on cast 6
012	5	-	5	0/12	CTD inboard to re-position ship on casts 1,3
014	7	1	1,2	0/12	Winch slowed to 30m/min below 2500 m on cast 6
017	5	-	2	0/12	Aux. sensor fouling below 3020 m on 3
019	7	6	5,6,7	6	CTD stopped for 5 mins at 532m on cast 7 (wire angle)
020	6	-	1,6	6	CTD inboard to re-position ship on 4
021	6	-	1,6	6	-
022	5	-	1,2	6	-
026	8	-	7,8	6	Aux. sensor fouling at 850 m on 1,8
032	8	8	7,8	6	-
037	8	-	6	6	CTD inboard to re-position ship on 4
044	9	-	9	6	No useable data on 1,2. Data lost on upcast of 7.
055	5	1	1,5	6	Aborted on 5 due to bad weather
064	5	1,2,4,5	1	0/12	Casts to 2000 m except 3: full depth

Table 2.2. Tidal period time-series stations

The SBE 9 plus CTD was configured for twelve 24-bit words of data sampled at 24 scans per second. Data was acquired using the Sea-Bird SEASAVE-Win32 version 5.22 software which forms part of the SEASOFT c package (SEA-BIRD ELECTRONICS INC., 2001a). This software runs under the Windows 95/98/2000 operating system. The software acquires real-time, raw data (frequencies and voltages) and saves the raw data to the logging computer for later processing. The program also displays selected raw and/or converted (engineering units) real-time or archived data in text and plot displays. The logging PC was attached to the CTD SBE-11 plus deck unit. The instrument configuration and the sensor calibration coefficients were entered using the SEASAVE configure utility. The SEASAVE program also prompts the user for header information, prior to each cast, which is stored with the CTD data. The NMEA-GPS data stream was interfaced to one of the Sea-Bird deck units so that position and time (GMT) were automatically added to the CTD data stream. Logging to the PC was normally started once the CTD was in the water by pressing the power-up (red) switch on the deck unit. The screen was set-up to display a text-read out of the converted, real-time, data as well as plots of temperature, salinity, conductivity, oxygen, potential density, light scattering, light transmission, and fluorescence versus pressure, with a 3-second update. The text display of primary minus secondary temperature and primary minus secondary conductivity (from the duplicate CTD sensors, CT1 and CT2) were extremely useful as a continuous check of data quality. Spot-values of the altimeter reading, CTD pressure and depth were used to guide the CTD package to within 10-m of the bottom. Water bottles were closed using the SEASAVE Fire Bottle utility. Logging was stopped when the CTD reached the surface. The raw data was logged as a binary data file, ctdnnnmm.dat, where nnn was the station number and mm the cast number. Four other files were generated:

- ctdnnnmm.con, which contained the number and type of sensors, the channel assigned to each sensor, and the calibration coefficients;
- ctdnnnmm.hdr, which contained the user-input header information along with system time, instrument type, and serial numbers;
- ctdnnnmm.bl, which contained bottle firing sequence number and position, date, time, and beginning and ending scan numbers for each bottle closure;
- ctdnnnmm.nav, which contained latitude, longitude, time, scan number, and pressure.

The raw data files were then transferred to the data processing PC. For the tidal-period stations each down-up profile pair was treated as a separate cast i.e., logging was stopped, the data file closed and copied to the processing PC before starting the next down-up pair as a separate file. This minimised the chance of losing data due to the PC crashing during the time-series.

A potential source of data loss arose from interfacing the GPS positional data directly with the CTD data. This meant that we were unable to generate a simultaneous automatic back-up of the data as only one of the Sea-Bird deck-units had the correct firmware installed to handle the navigation data. In spite of this we do not believe that we lost any data as a direct result of the navigation interfacing. Data were lost, however, due to i) deterioration of the sea-cable termination, ii) breakage of one of the wires in the winch slip-ring connections, iii) problems with sensor cables (particularly the fluorometer) and connections and iv) operator error.

2.3 Data Processing

The raw binary data files were transferred from the logging PC to the processing PC using a 100 Mbyte zip disk. These zip-disks were not recycled during the course of the cruise but were replaced by a new disk each time one was filled. The full disks served as an initial back up of the raw data files. The files were processed in accordance with the recommendations of Sea-Bird Inc. for SBE-911 plus data with oxygen. The binary files were passed through the following processing routines below which form part of the Sea-Bird SEASAVE-Win32 v5.22 processing package (SEA-BIRD ELECTRONICS INC., 2002). The reader should also refer to the Sea-Bird SEASOFT Win-32 manual for further details (SEA-BIRD ELECTRONICS INC., 2002).

- ***Data Conversion (datacnv)***

This routine converts raw data from an input .dat file to engineering units, and stores the converted data in a .cnv file and (optional) .ros file. Converted data includes: pressure, temperature, and conductivity, dissolved oxygen current and dissolved oxygen temperature and light transmission, etc. (if other auxiliary sensors are part of system).

- ***Align CTD (alignCTD)***

This aligns parameter data in time, relative to pressure, and ensures that calculations of salinity, dissolved oxygen concentration, and other parameters are made using measurements from the same parcel of water. Typically*, Align CTD* is used to align temperature, conductivity, and oxygen measurements relative to pressure (e.g. oxygen needs to be advanced by 6 seconds relative to pressure). When measurements are properly aligned, salinity spiking (and density) errors are minimized, and oxygen data corresponds to the proper pressure (e.g., temperature vs. oxygen plots agree between down and up profiles). For the SBE-911 plus, conductivity must be advanced relative to pressure, the default is by 1.75 scans. This is done in real-time by the deck unit for both the primary and secondary sensors.

- ***Wild Edit (wildedit)***

Marks wild points in the data by replacing the data value with a badflag indicator. The badflag value is documented in the input .cnv header. The *Wild Edit* algorithm requires two passes through the data, using 500 scans per block. The first pass obtains an accurate estimate of the data's true standard deviation, and eliminates wild points using 3 standard deviations (in each block). The second pass re-calculates a new standard deviation from all the data within each block which has not been bad-flagged, and then badflags all data which is more than 10 new standard deviations away from the mean.

- ***Cell Thermal Mass (celltm)***

This uses a recursive filter to remove conductivity cell thermal mass effects from the measured conductivity. The programme uses a thermal anomaly amplitude (α) of 3 and a thermal anomaly time constant of 7 ($1/\beta$). In areas with steep temperature gradients, the thermal mass correction is of the order of 0.005 PSU. In other areas the correction is negligible.

- ***Filter (filter)***

Runs a low-pass filter, with a time constant of 0.15 seconds, on one or more columns of data, e.g. pressure. The filter smooths high-frequency (rapidly changing) data. To produce zero phase (no time shift), the filter is first run forward through the data and then run backwards through the data. This removes any delays caused by the filter.

- ***Derive (derive)***
- Uses data from the input .cnv file (e.g. pressure, temperature, and conductivity) to compute other commonly used oceanographic parameters (e.g. density (in situ density, sigma-theta, sigma-t,

sigma-1, sigma-2, sigma-3, sigma-4), depth (salt water, fresh water), geopotential anomaly, potential temperature (reference pressure = 0.0 decibars) etc.). The programme also computes oxygen from oxygen current, oxygen temperature, temperature, and pressure.

- ***Bin Average (binavg)***

Averages data into desired pressure or depth bins, e.g., 1 db.

- ***Rosette Summary (rossum)***

Reads a .ros file created by "*Data Conversion*" and writes a bottle data summary to a .btl file. The .ros file must contain (as a minimum) temperature, pressure, and conductivity (or salinity). The output .btl file includes: bottle position, optional bottle serial number, date/time, user-selected derived variables (computed for each bottle from mean values of input variables (temperature, pressure, conductivity, etc.)), and user-selected averaged variables (computed for each bottle from input variables). The maximum number of scans processed per bottle is 1440.

In order to process the data through each of the above stages, a batch processing routine was setup as follows: run each software module, entering the desired parameter choices in the File Setup and Data Setup dialog boxes. Upon completing both dialog boxes, press Save or Save As in the File Setup dialog box. The configuration is stored in the Program Setup File (.psu). The following script (saved as e.g. batch.txt) may then be used to process the data files:

```
datcnv /ic:\cd141\raw24hz\%1.dat /cc:\cd141\raw24hz\%1.con /oc:\cd141\cnv24hz
alignCTD /ic:\cd141\cnv24hz\%1.cnv /oc:\cd141\ cnv24hz /f%2
wildedit /ic:\cd141\cnv24hz\%1.cnv /oc:\cd141\cnv24hz /f%2
celltm /ic:\cd141\cnv24hz\%1.cnv /oc:\cd141\cnv24hz /f%2
filter /ic:\cd141\cnv24hz\%1.cnv /oc:\cd141\ cnv24hz /f%2
derive /ic:\cd141\cnv24hz\%1.cnv /cc:\cd141/raw24hz\%1.con /oc:\cd141\cnv24hz /f%2
binavg /ic:\cd141\cnv24hz\%1.cnv /oc:\cd141\1dbraw /f%2/a1m
rossum /ic:\cd141\cnv24hz\%1.ros /cc:\cd141\raw24hz\%1.con /oc:\cd141\cnv24hz /f%2
```

The script can be executed using the Run utility in the Windows Start menu by typing:

sbebatch c:\dirname\batch.txt cast5 test1 (batch filename is c:\dirname\batch.txt; parameter %1 is cast5; parameter %2 is test1)

Once the SEASOFT processing had been completed the data files were transferred to the UNIX machine Darwin3 via ftp. This formed the preliminary back-up for the processed data files and is important as the SEASOFT software only works on PCs. The files were then processed using the following Matlab scripts:

- *cnv2mat_jrd* - converts the .cnv file to a .mat file (matlab format) containing two variables, data and h. Data is an m x n dimensional matrix (where n is the number of variables and m is the number of scans) and h is a "structure" containing header information about the cast.

- *ros2mat* - converts a .ros file to a .mat file (matlab format).

2.4 Sensor Performance and Data Quality

2.4.1 CT sensors

Two manufacturer's laboratory calibrations were performed for the primary and secondary temperature (T1 and T2) and conductivity (C1 and C2) sensors. These were dated 7 May 2002, and 27 July 2002, immediately prior to, and after, the cruise. From these, the manufacturer has supplied the following drifts for the sensors:

Sensor	**Serial No.**	**Drift (°C/year)**	**Drift (psu/month) (at 3.0 S/m)**
T1	O3P4103	-0.00049	
T2	O3P4107	-0.00130	
C1	042570		-0.00200
C2	042573		-0.00120

Table 2.3. Manufacturer Determined Sensor Drifts

Furthermore, over a range of temperatures between -1.5 to 32.5°C, both temperature sensors had residual errors always less than +/- 0.00011 °C, and typically better than +/- 0.00006 °C. Similarly, over a conductivity range of 0 to 6 S/m (Siemens/metre), both conductivity sensors had residual errors always less than +/- 0.00006 S/m, and typically better than +/- 0.00003 S/m. These errors and drifts are pleasingly small.

During the cruise, we were able to investigate, firstly, the relative drifts between the two sets of sensors. Using data coincident with the bottle samples below 2000 metres and ignoring outliers, the differences and relative drifts (over the cruise) between the primary and secondary conductivity and temperature sensors were calculated. The results are shown in Table 2.4.

Quantity	Units	Mean	Standard Deviation	Start difference	End difference	Drift
C2-C1	S/m	-0.00031	0.00007	-0.00039	-0.00024	0.00015
T2-T1	^{o}C	-0.00045	0.00109	-0.00037	-0.00051	-0.00015

Table 2.4. Relative Sensor Drifts

Figure 2.2 (a) shows the difference between the primary and secondary temperature sensors as a

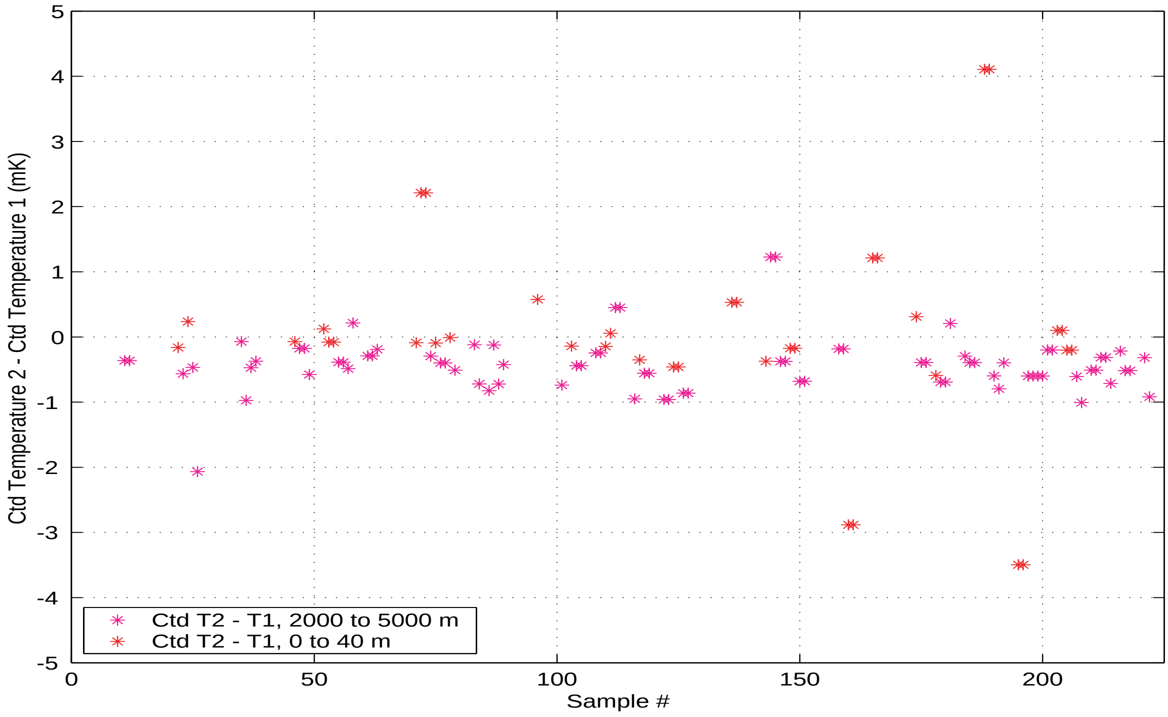

Figure 2.2 (a). CTD primary-secondary temperature differences by sample number.

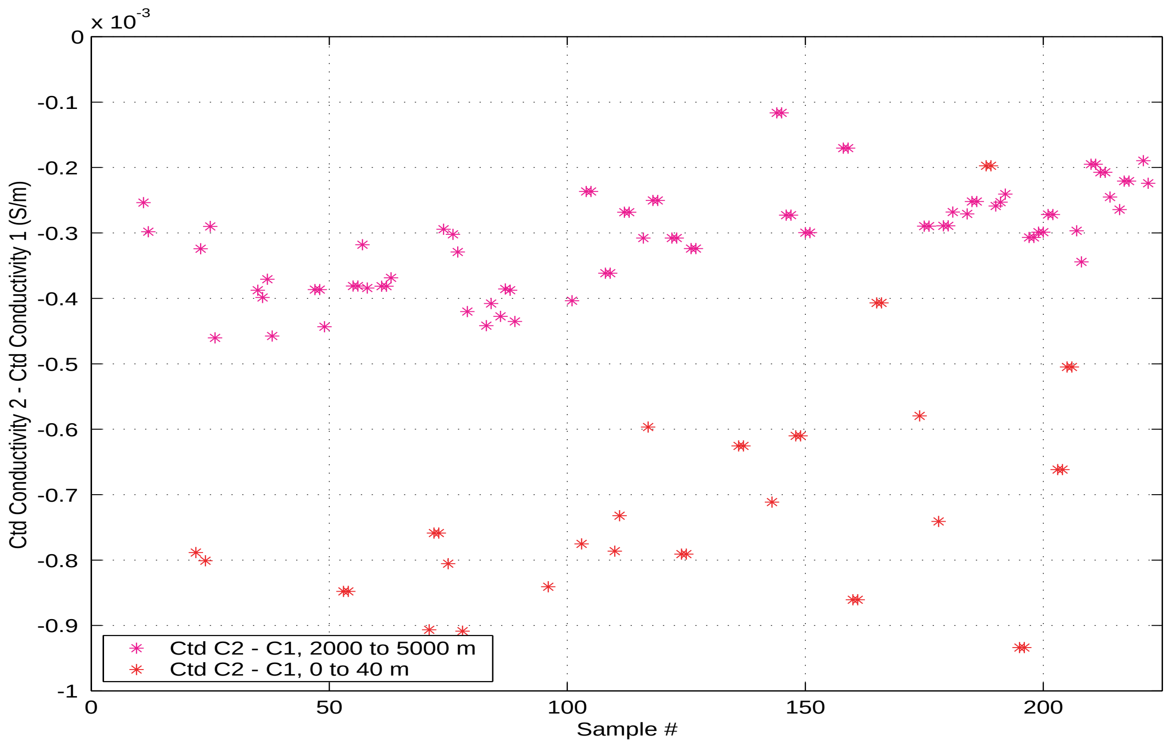

Figure 2.2 (b). CTD primary-secondary conductivity differences by sample number.

function of sample number. The sensors show a virtually constant offset (for those data points below 2000m) of 0.45 milli-degrees over the cruise with a drift of only 0.15 milli-degrees. The secondary sensor reads colder than the primary sensor. Combining these offsets with the manufacturer's inferred drifts for the temperature sensors, we can say that the absolute accuracy of both the temperature sensors is within the manufacturer's specified accuracy of +/- 0.001 °C.

Figure 2.2 (b) shows the difference between the primary and secondary conductivity sensors as a function of sample number. The mean offset (for those data points below 2000m) is -0.00031 S/m with a drift of 0.00015 S/m. This translates to a salinity drift of about 0.002 psu over the cruise for these samples. The secondary sensor reads lower (fresher) than the primary sensor. Comparison with the seawater samples indicates that the secondary sensor is primarily responsible for the offset and that there is a contribution to the drift from both sensors (see section 2.4.2 below).

2.4.2 Salinity Calibration

Shipboard salinity analysis was performed by Tim Nightingale, Chris Green, Adrian New and Kate Stansfield using a Guildline Autosal model 8400B. Water samples for analysis were drawn from selected Niskin bottles into 200 ml glass sample bottles, which were sealed with clean, disposable, stoppers and screw-on caps. Samples were then moved to the Constant Temperature laboratory to equilibrate for a minimum of 24 hours. Typically water samples were taken both from deeper bottles and from bottles in the surface mixed layer to maximise the range of conductivities for calibration. All water samples were thoroughly shaken before analysis. A standard seawater (SSW) sample was run immediately before and immediately after each crate of 24 samples.

To investigate the accuracy of the salinometer, comparisons were undertaken of the differences in the conductivity ratios of standard sea-water (SSW) samples run before and after each crate of 24 CTD salinity samples. The mean value of these conductivity ratio differences was -0.6×10^{-4}, and their standard deviation was 9.8×10^{-5}. In addition, 45 duplicate seawater samples were taken from various individual CTD bottles. These showed a mean salinity difference of 0.0003 psu and a standard deviation of 0.001 with 1 outlier. We conclude that the accuracy of the Guildline Autosal sample analysis is equivalent to +/- 0.001 psu.

The Sea-Bird conductivity sensor usually drifts by changing "span" (the slope of the calibration curve of the error in conductivity versus conductivity), and changes are typically toward lower conductivity readings with time. The offset error in conductivity (i.e. the error at 0 S/m) is usually due to electronics drift,which is typically less than 0.0001S/m per year.Offsets greater than 0.0002S/m are symptomatic of sensor malfunction. Sea-Bird therefore recommends that drift corrections to conductivity should be made by assuming no offset error, unless there is strong evidence to the contrary or a special need (SEA-BIRD ELECTRONICS INC., 2001b).

When correcting for conductivity drift based on salinity bottles taken at-sea, it is important to realize that differences between CTD salinity and hydrographic bottle salinity are due to errors in conductivity, temperature, and pressure measurements (as well as errors in obtaining and analyzing bottle salinity values). All CTD temperature and pressure errors and bottle errors must first be corrected before proceeding with conductivity corrections. The slope correction coefficient, K, for conductivity is then calculated as $K = < C_{btl}/C_{ctd} >$ where C_{btl} is the bottle conductivity, C_{ctd} is the CTD conductivity at the time of the bottle sample and < > denotes the average over all CTDs during the cruise in question. The corrected CTD conductivity is then given by $C_{ctdcor} = K\ C_{ctd}$.

Alternatively, drift corrections can be made by interpolating between pre-cruise and post-cruise manufacturer's laboratory calibrations. For typical Sea-Bird sensors that are calibrated regularly, 70 - 90% of the CTD salinity error is due to conductivity calibration drift, 10 - 30% is due to temperature calibration drift, and only 0 - 10% is due to pressure calibration drift (SEA-BIRD ELECTRONICS INC., 2001b).

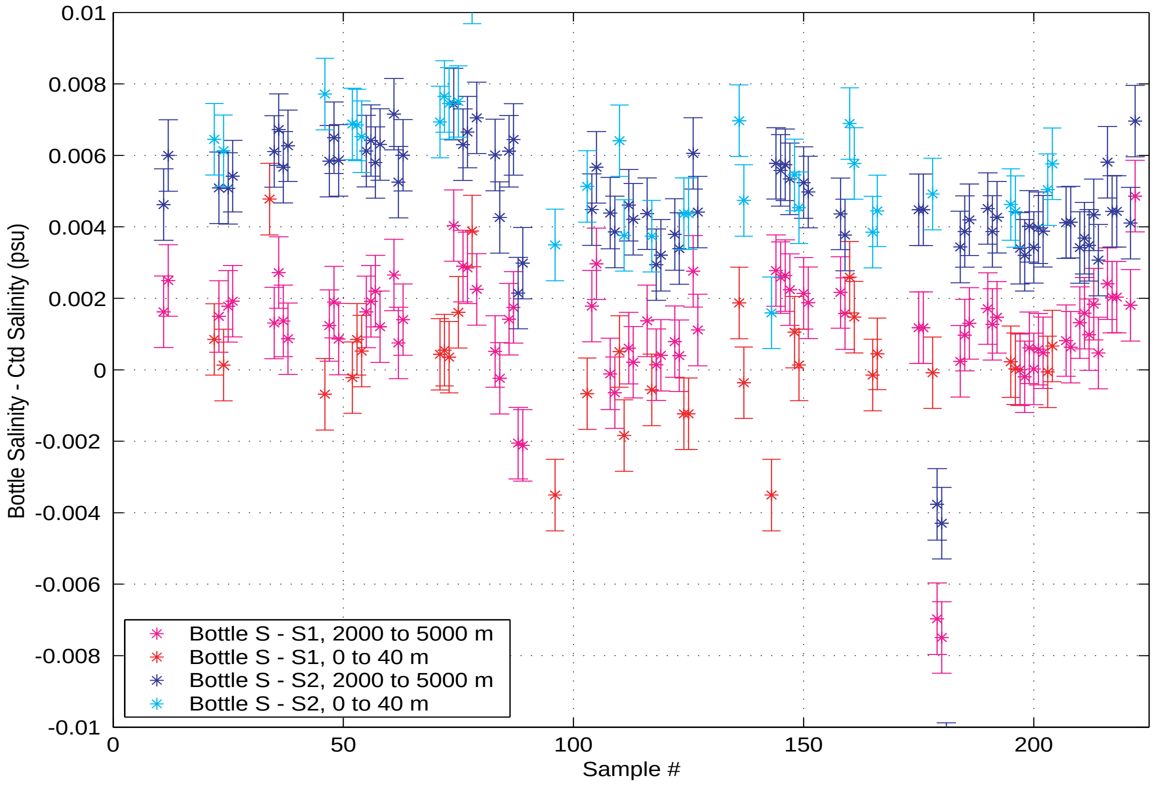

Figure 2.3. Bottle-CTD salinity differences by sample number (sequential).

Figure 2.3 shows a comparison of the bottle and CTD salinities, without (at this time) any offset, slope, or drift corrections having been applied to either set of conductivity data. The error bars are the inferred salinity equivalent error of the bottle samples, +/- 0.001 psu. Ignoring outliers, considering only data below 2000 m and applying a linear fit of the CTD data to the bottle data, the primary sensor showed a start offset of 0.0018 psu a final offset of 0.0003 psu and a drift of -0.0018 psu. The secondary sensor showed a start offset of 0.0065 psu a final offset of 0.0030 psu and a drift of -0.0035 psu, almost twice that of the primary sensor. It should be noted, however, that there appears to be a non-linear component to the drift over the cruise. Because of the large offset and drift of the secondary conductivity sensor, data from the primary sensor are to be preferred. Note also that the salinity drifts inferred during the cruise are of the same sign and magnitude as those determined by the manufacturer's laboratory calibrations (Table 2.3). The salinities from the primary sensor therefore agree with the bottle salinities to typically better than +/- 0.003 psu. Given that the bottle salinities themselves have an accuracy of +/- 0.001 psu, we therefore consider that the overall accuarcy of the CTD salinity observations (from the primary sensor, before any corrections have been made) is +/- 0.004 psu. However, it is apparent from Figure 2.3 that applying a straightforward offset of +0.001 psu to the primary salinities would probably reduce their overall accuracy to +/-0.003 psu.

2.4.3 Oxygen

The SBE 23 dissolved oxygen sensor uses a Beckman style, high-pressure, polarographic oxygen electrode (SEA-BIRD ELECTRONICS INC., 2000). Hysteresis in oxygen measurements is caused by delays in a sensor's response to changing temperature, pressure and oxygen. Slow temperature response and time-mismatch of temperature corrections are responsible for most of the hysteresis in the upper 1000 meters. Hysteresis from pressure cycling remains a factor below 1000 meters.

As described in Section 2.3, CTD oxygens were advanced by 6 seconds relative to the pressure record, and oxygen values in units of μmol/kg and %saturation were computed. For comparison with bottle oxygens, CTD oxygen data from the downcast were used. This was done by matching the temperature (or pressure) at the bottle stop on the upcast to a temperature (or pressure) on the downcast. Including all samples, but disregarding outliers, the mean offset (sample-CTD oxygen) was 6.84 μmol/kg with a standard deviation of 10.63 μmol/kg. The sample oxygens were higher than the CTD oxygens, and there was no significant long-term drift in the differences throughout the cruise, although there was a discontinuity (and slow recovery) near CTD 34 on June 27, as shown in Figure 2.4 (a). (This may have been related to a change in the temperature of the constant temperature (CT) laboratory, in close proximity to the oxygen equipment. This varied between 23-24°C during the early part of the cruise, but jumped to 27-29°C on and after June 27, due to a change in the air-conditioning circulation. This also correlated with a change in the conductivity ratios of the Standard Seawater samples measured on the salinometer in the CT laboratory, which fell from about 2.0005 to 2.0002 at the same time, on June 27.) Figure 2.4 (b) then shows the sample minus CTD oxygen differences plotted against pressure. The residuals show a curve with depth, higher residuals occurring in the top 250 m of the water column. Below this the difference between the bottle and CTD oxygens appears to be smaller and more constant, although there are fewer samples for comparison. As yet, no correction has been applied to the CTD oxygen data.

2.4.4 Package Motion and Wake Considerations

The location of the CT sensor package at the bottom of the CTD frame means that during the downcast the sensors precede the bulk of the package. However, during package decelerations or pressure reversals (arising from the vertical motion of ship), the turbulent wake formed by the sensors, bottles and frame may overtake the leading edge of the package, and the sensors themselves.

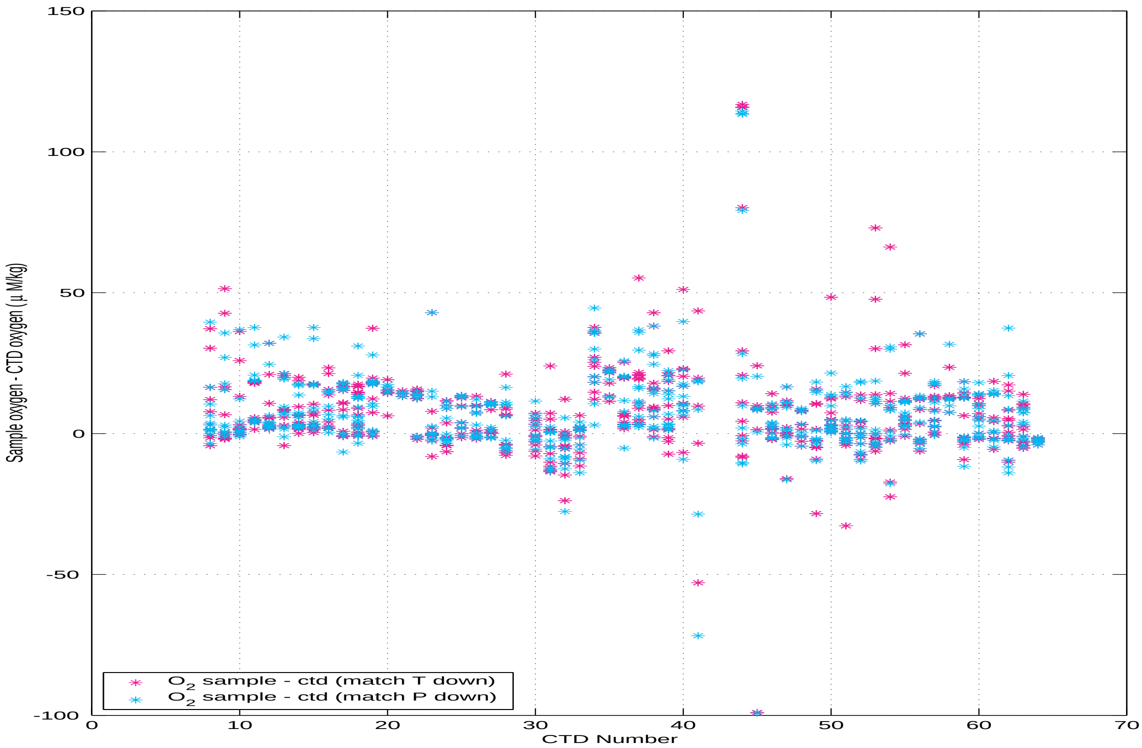

Figure 2.4 (a). Bottle oxygen minus CTD oxygen versus CTD cast number.

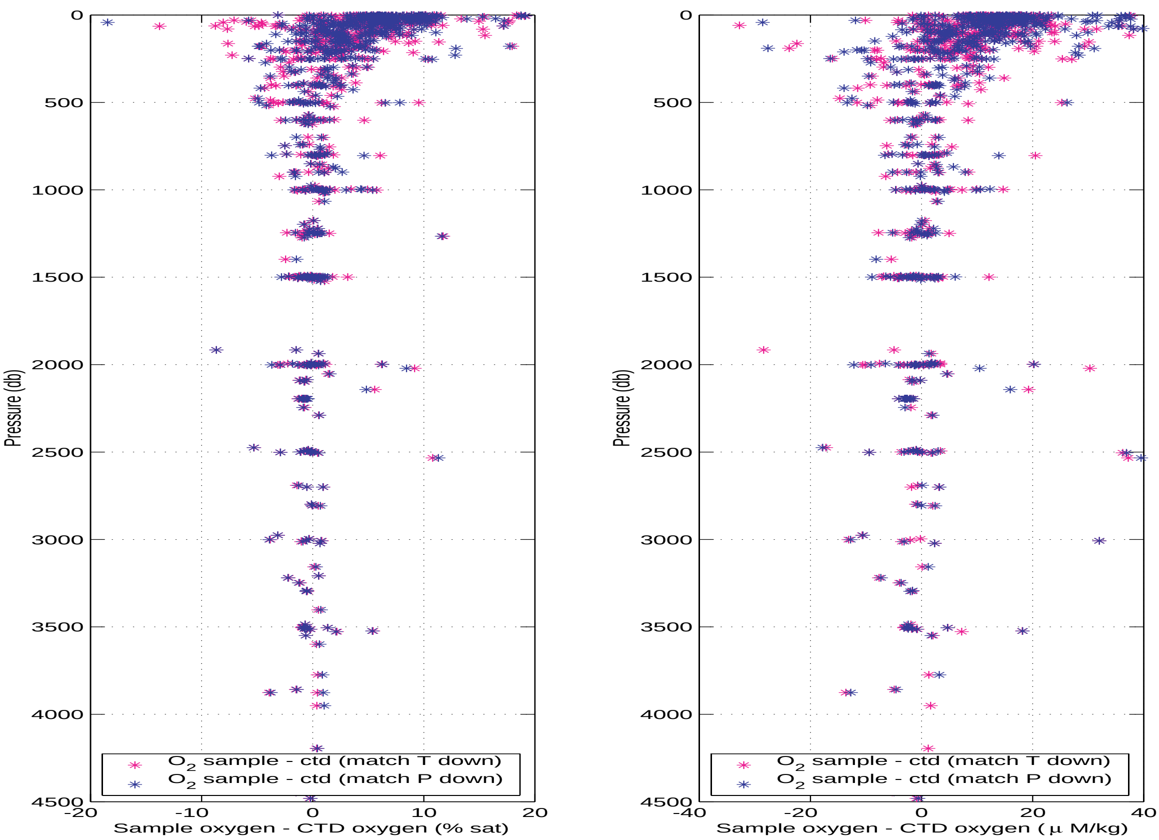

Figure 2.4 (b). Bottle oxygen minus CTD oxygen versus CTD pressure.

This may cause problems when trying to examine the fine-scale structure of the water-column (e.g. when trying to calculate the Thorpe displacement scales). While it is simple to remove data where the package decelerates or reverses, this does not necessarily exclude the problem of data contamination by the wake overtaking the package. Presumably larger packages have larger, more coherent wakes, and thus the potential for more-pronounced wake problems. During the present cruise we tried to do several things to minimise the CTD wake contamination: i) to use a smaller package than is standard, ii) to take care (see Figure 2.1) in locating the CT sensors as far away as possible from parts of the frame or other sensors which could shed wakes or eddies (the frame was NOT specifically designed with this in mind), iii) where possible to minimise the number of sensors and bottles attached to the frame. To try to assess the effect of the number of bottles on the performance of the CT sensors, we initially examined power spectra of the raw, 24 Hz, downcast temperature data for data deeper than 1000 m in the middle of the water column. We compared spectra from casts with 0, 6 and 12 bottles attached to the frame. This showed that there was more energy in the temperature data over a broad-band of frequencies with 12-bottles than with six or no bottles. Although not conclusive, we therefore initially decided, where possible, to run the tidal-period CTD stations with no bottles attached to the frame. However, further spectral analysis during the course of the cruise revealed that although having no bottles attached to the frame appeared to improve the quality of the temperature data in the middle and bottom of the water column, it actually could increase the noise in the temperature signal in the upper part of the water column, compared with having six or 12 bottles. We think that this may be because the decreased weight and drag of the "bare" package means that it is affected more by lateral ship motion than the "full" package in the upper part of the water column. As the best overall compromise, after Station 018, we therefore switched to operating with typically 6 bottles on the frame, alternately spaced around the rosette (see Figure 2.1). (Prior to CTD 018, the tidal-period stations were typically conducted with 12 bottles on for one cast, and then with all bottles removed for the other casts.) The effects of the package motion and the CTD wake on the temperature and conductivity data will require further investigation before Thorpe displacements can be calculated.

2.5 Conclusions

In general, the SBE-911 plus CTD system performed very well. Jeff Benson speculated that some of our sensor cable problems could have been due to the fact that the cables were somewhat more "exposed" on the 12-way frame than they typically are on the 24-way frame. The secondary conductivity showed a larger offset and drift over the duration of the cruise, so data from the primary sensor is to be preferred. Temperature measurements are considered to be more accurate than +/- 0.001 °C, and salinity measurements (from the primary sensor) more accurate than +/- 0.003 psu.

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3 LOWERED ADCP MEASUREMENTS

Two RD Instruments 300 kHz "Workhorse" Lowered Acoustic Doppler Current Profilers (LADCPs) and one RD Instruments 150kHz "Broadband" LADCP were available for use on this cruise. These instruments can be attached to the CTD frames and lowered throughout the water column to provide full-depth profiles of velocity.

However, one of the principal aims of the cruise was to obtain fine-structure temperature measurements from the CTD, in order to estimate rates of mixing via indirect methods. To this end the small (12-bottle) CTD frame was thought essential in order to reduce the turbulent wake of the package through the water, as already described. Unfortunately this frame is incapable of holding the larger 150 kHz instrument or both of the 300 kHz instruments. Consequently, the initial plan at the beginning of the cruise was to use the small frame with one (downward-looking) 300kHz instrument for stations to the east of, and above, the Ridge, but then to use the larger frame with the 150 kHz instrument for a significant number of the stations to the west of the Ridge (where it was thought that the mixing rates would be much lower). However, later in the cruise it was finally decided for the sake of consistency with the earlier measurements, and to save a significant extra workload in transferring to the larger CTD frame, to continue with the same instrument set (i.e. the single downward-looking 300 kHz LADCP and the small CTD frame) for the whole of the cruise, even though the data quality from the 150 kHz LADCP might have been better in the deeper ocean.

The command file used for the 300 kHz Workhorse LADCP on this cruise was identical to that used on cruise CD139 (see the CD139 LADCP cruise report for more details). Slightly different configurations were used on some of the early casts, but these did not improve the results and so were not adopted. The remainder of the LADCP setup (hardware, data download, etc.) was also identical to that on CD139 and so will not be described further. Data were processed using the software developed by Eric Firing at the University of Hawaii, but have not yet been corrected for the compass error due to the surrounding metal on the CTD frame.

Generally, for stations shallower than about 2000 m, or for the upper 1500-2000m on deeper stations, the results from the 300 kHz instrument were reasonable. However, for the deeper stations, the number of available scatterers in the bottom half of the water column was rather small (particularly so in the southernmost half of the cruise). As a consequence, the baroclinic profiles produced were sometimes poorer than hoped for in such cases, with unrealistic shears and bottom velocities. The corresponding barotropic velocities were also contaminated by the low quality water velocities measured by the instrument in these instances.

Figure 3.1 summarises the LADCP data for the early part of the cruise (up to station 17, as an example) along with the station averaged shipboard or vessel-mounted (VM-) ADCP data where available. The LADCP data are the full depth profiles, whereas the VM-ADCP data are the shorter profiles (typically to 300 - 400 m). We note that there is often a very good correspondence between

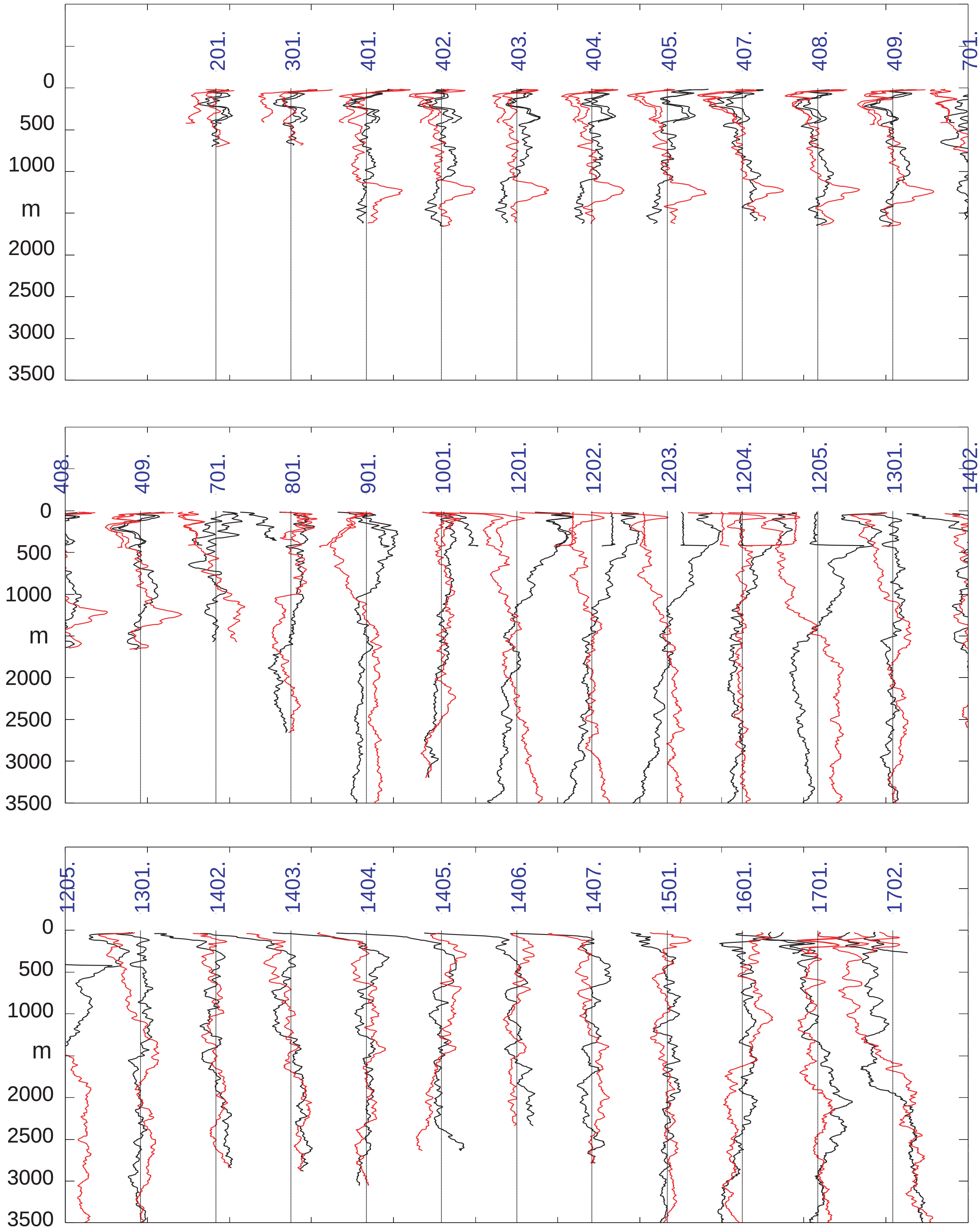

Figure 3.1. LADCP and VM-ADCP current profiles for stations 02 to 17. The vertical scale is metres, and the profiles are marked with NNMM where NN is the station number, and MM the cast number. East-West velocities are black (East is positive), while the North-South component is red (North is positive). A thin black vertical line represents the zero for each station, and the scale is such that 1 m/s separates each such line.

the shear as represented by the LADCP and the VM-ADCP. The absolute values also frequently agree, although there is sometimes an offset apparent between these two sets of data. We also note that the VM-ADCP data between stations 12 and 16 needs further work to recover (due to the loss of heading information), and is not plotted here.

Because of the pronounced nature of some of the features as shown by the LADCP in the region, it is hoped that the data can be useful (particularly if combined with the VM-ADCP). Note in particular the deep slope current between 1000-1500 m at station 04, and the strong surface current at station 14.

Steven Alderson, Jeff Benson, Kate Stansfield, David Smeed

4 VESSEL-MOUNTED ADCP MEASUREMENTS

4.1 Data Processing

During the cruise, data from the vessel-mounted (VM-) 150 kHz RDI broadband ADCP were collected. Real time processing was done using DAS software, the output from DAS being logged on the RVS level A. Data were then read from the RVS datastream "adcp" and converted to pstar format on unix workstations. Data were then merged with navigation data to calculate absolute currents. The data processing was mostly the same as on the previous cruise (CD139), but is described briefly here.

- ***DAS processing***

The parameters were set in the configuration file cd141w.cnf. The most significant parameters in this file were:

- no bottom tracking
- heading compensation
- 120s averaging interval for ensembles
- 64 bins of 8m
- blank beyond transmit was set to 8m.

Thus assuming the transducer to be 5m below the surface the centre of the first bin was at 17m depth. However, the parameters were occasionally changed as follows:

- At the start of the cruise bottom tracking was used whilst steaming over the shelf south east of the Seychelles. This was done to obtain a calibration.
- When the adcpheading was unreliable (see below), heading compensation was switched off, the sampling interval was reduced to 60 seconds and the number of bins reduced to 48.

The user exit program "ue4" was used to input data from the rvs datastream gps_nmea. This ensured that the adcp clock was always synchronised with the navigation time.

- ***PSTAR processing***

The following scripts were used to process the data:

adpexec0 Reads in data from RVS datastream adcp, converts to pstar format, separates into gridded and non-gridded data, scales velocities to centimetres per second, calibrates the backscatter amplitude (x 0.42), subtracts 60s from time (so that the time logged for a particular ensemble refers to the centre of the ensemble). Outputs files:

141adp$JDAY

141bot$JDAY

where $JDAY is the appropriate Julian Day.

adpexec1 Subtracts 45 from heading in file 141bot$JDAY and sets correct absent data value. Renames files to be:

141adp$JDAY.corr

141bot$JDAY.corr

adpexec2 Corrects velocities using the difference between the ashtec and gyro headings (averaged over 2 minutes) from file 141ash01.int. Outputs files:

141adp$JDAY.true

141bot$JDAY.true

adpexec3 Applies user specified calibration (see section 4.2 below) Outputs files:

141adp$JDAY.cal

141bot$JDAY.cal

adpexec4 Merges adcp data with navigation data (file nav141 which is 10 second averaged) and calculates average ship's velocity for each ensemble. Then subtracts ship's velocity from water velocities to get absolute currents. Outputs files:

141adp$JDAY.abs

141bot$JDAY.abs

4.2 Calibration

After leaving the Seychelles, the ship steamed over the shallow shelf on an approximately constant heading for 6 hours and 40 minutes. During this time, bottom tracking was turned on, and a calibration was made by comparing the bottom tracking data with the gps data. The amplitude coefficient was found to be 1.004 and the heading offset was found to be 5.5°. However, during this time, ashtec heading data was not collected. During the first day's collection of ashtec data after this instrument was switched on, the mean difference between the ashtec and the gyro was 0.7°. Therefore a total correction of 6.2° was applied.

4.3 Data Quality

A significant amount of data was lost during the cruise due to incorrect heading information being used by the DAS software. This problem was first manifest at 6:00 GMT on day 156 (June 5). On days 156, 157 and 158 there were several periods of data loss. On each occasion the onset of the problem followed a turn of the ship. The heading received by the DAS software changed continuously during these periods of bad data, although the gyro heading logged by the RVS level A was not affected. After 12:00 GMT on day 160 the problem appeared again. It was eventually fixed at 15:00 GMT on day 164. During days 161-164 data were logged without heading correction. There were several periods during this time when data were not logged at all whilst the problem was investigated. The exact cause of the problem was not identified, but it is most likely associated with the wiring between the gyro repeater and the ADCP. The problem did not re-occur after day 164.

The maximum depth at which data was obtained varied greatly. At the northern end of the survey area good data underway were obtained down to about 400m. But further south, where there were fewer scatterers in the water, data were only obtained down to about 200m.

David Smeed

5 NAVIGATION DATA

Three sources of navigation data were logged during the cruise:

- Trimble 4000 GPS including differential correction from the SeaStar receiver,
- Ashtec ADU-GPS providing heading, pitch and roll information,
- Heading from the ship's gyrocompass.

Processing was mostly the same as on the previous cruise (CD139) though a few changes were made (e.g. additional quality control for the Trimble 4000 data, the additional calculation of distance run, changes to some of the parameters for the quality control of the ashtec data, and changes to the script ashedit.exec so that it was less likely to make mistakes during the editing).

Navigation data was processed daily using the meta-script dailynav1 which executed the following six scripts:

gpsexec0 Reads in data from the RVS datastream gps_nmea. Creates a pstar format file. Edits (i.e. deletes) data outside the range 0 < pdop < 7. It was also found necessary to use pmdian to remove spikes (>.001°) - typically, there were < 5 such spikes in any one day. Outputs files:

$CRUISEgps$JDAY.raw (All data).

Edited data is appended to

$CRUISEgps01

gpsexec1 Averages GPS data in 10 second intervals. Calculates distance run. Input file:

$CRUISEgps01

Output file:

nav$CRUISE

gyroexec0 Reads in data from the RVS datastream gyro_nmea. Creates a pstar format file. Checks heading data is in the range 0-360°. Removes data with duplicate times. Outputs files:

$CRUISEgyr$JDAY.raw (Edited data).

Edited data is appended to

$CRUISEgyr01

ashexec0 Reads in data from the RVS datastream gps_ash. Creates a pstar format file. Outputs file:

$CRUISEash$JDAY.raw

ashexec1 Merges data from the gyro and the ashtec and calculates the difference between the two headings (a-ghdg). Input files:

$CRUISEash$JDAY.raw

$CRUISEgyr$JDAY.raw

Outputs file:

$CRUISEash$JDAY.mrg

ashexec2 Applies quality control by checking limits of parameters. Despikes a-hdg (ashtec heading) using program pmdian. Then creates two minute averages. Applies further editing based on the averaged pitch information (see below). Input files:

$CRUISEash$JDAY.mrg

Outputs files:

$CRUISEash$JDAY.edit

$CRUISEash$JDAY.ave

The limits for the quality control of the 1-second data were changed from values used previously, because good data appeared to be being rejected. For example, on some days the mean roll was up to 1.5° and the standard deviation was over 2.5°. The limits of pitch and roll were changed so that data within 3 standard deviations of the daily mean would not be rejected. The limits of a-ghdg were also increased. Changes are listed below in Table 5.1.

Variable	Previous minimum	Previous maximum	New minimum	New maximum
hdg	0	360	0	360
pitch	-5	5	-10	10
roll	-7	7	-10	10
attf	-0.5	0.5	-0.5	0.5
mrms	0.00001	0.01	0.00001	0.01
brms/	0.00001	0.1	0.00001	0.1
a-ghdg	-5	5	-7	7

Table 5.1: Limits for quality control of 1-second navigation data

Ashexec2 also edits the 2 minute averaged data by removing data outside specified limits of pitch and mrms. It was noted that pitch and roll (averaged over 2 minutes) had standard deviations of 0.5°, and that the headings from the ashtec and the gyro (over a 2 minute period) had standard deviations of about 0.3° (with the difference between them also having a similar spread). The limits were therefore increased from ± 1.5° to ±4.0° for daily mean pitch, and from 0 to 0.004, to 0 to 0.006 for mrms, to reduce the amount of data lost during turns.

Following the above, the averaged ashtec-gyro heading was edited manually to remove spikes using the program plxyed, run from the script ashedit.exec.

Occasionally it was necessary to change the above procedures:

1. On the first day (day 152), the ashtec data logging was not started until 7 hours after sailing.
2. There was a gap in the gps_nmea datastream between 15:37:10 on day 152 and 04:28:21 on day 153. This was patched with data from the gps_4000 datastream. Normally, the position data between these two datastreams differ by less than 1m. The reason for the gap is not known.

David Smeed

6 EXPENDABLE BATHYTHERMOGRAPH MEASUREMENTS

A total of 277 expendable bathythermographs (XBTs) were deployed during the cruise. These had been mostly kindly provided by the Hydrographic Office (MoD) in Taunton on condition that a copy of the data would be returned to them after the cruise for incorporation into their database. In all, there were 44 of the T5 probes (depth rated for 1830 m), and 233 of the T7 probes (depth rated to 780 m). The probes were normally launched from the port or starboard quarter of the aft deck. The data were logged on a PC located in the scientific plot room using the “Seas4” software. This software creates a binary file for each xbt drop, and an ASCII listing of all of the profiles in the data directory can be made using the commands in the “plot and edit” menu. The ASCII listing was used to import the data to PSTAR format.

No existing execs were available for the processing of the XBTs so the following procedure was developed:

- Create an ascii listing of all profiles using seas4.
- Copy to zip disk and then via networked Mac ftp to UNIX.
- Use the c-shell script get_rec to select new drops only from the ascii file.
- Use mk_asc to create an ascii file for each new drop and convert time to seconds from 0000 h on 01/01/02. The output files had 4 columns: drop number, time of drop, depth, and temperature. Output files were stored in the subdirectory "raw".
- Files corresponding to failed drops were deleted.
- Use the programme xbt2pstar to create a single pstar file for each drop. These files were then stored in the directory pfiles.
- Check and edit individual pstar files using the scripts check_all and edit_xbt.
- Append files, merge with navigation, and interpolate to a regular grid using appxbt.

A further check was then performed by comparing the temperature at 4m with that from the TSG.

Appendix B provides a complete listing of the times and positions of all the XBT drops. There are two "Directories", A and B. Directory A contains the first 42 drops. At this point in the cruise all the xbt data were copied off from the pc onto the unix system, and the xbt pc reset its counting algorithm so that the next drop (in reality the 43rd) was relabelled number 1 again. This and the remaining xbts were consequently assigned to Directory B.

David Smeed and Adrian New

7 UNDERWAY DATA

Data from the RVS datastream surfmet, comprising surface meteorology and output from the ships thermosalinograph (TSG), was converted to PSTAR format each day using the script surexec0. The script surexec1 was then used to edit out spikes using pmdian, calculate salinity, and merge the data with navigation. The raw data were added to the file 141sur01, and the processed data were added to the file 141sur02.

Four or five surface salinity water samples were taken from the non-toxic supply each day in order to calibrate the TSG. Samples up to day 184 (July 3) were used to obtain a preliminary calibration of the conductivity. A linear calibration with coefficients: A = 0.2685, B = 0.994044, where $C_{cal} = A + B \times C_{raw}$ gave the best (unweighted least squares after removing outliers) fit to the bottle samples. After calibration the mean and standard deviation of the difference between the sample salinities and the TSG salinities were 0.000 and 0.009 psu respectively. The uncalibrated salinities were on average 0.04 psu higher than the true values.

The lag between the housing temperature and the intake temperature was estimated to be 105 seconds.

The TSG system was cleaned approximately every 5 days. However, between cleans the transmittance showed an almost continuous decline and the fluorescence showed an almost continuous increase. These data are therefore dominated by the accumulation and growth of material within the TSG system, and are not to be relied upon as being accurate.

David Smeed

8 PROFILING ARGO FLOAT (ARGODOT)

On day 173 (June 22) a trial deployment was made of the "ARGODOT" float. This float was built by Richard Babb. Based on a conventional ARGO profiling float, the ARGODOT was specially equipped with two Seabird FP07 fast response thermistors for the measurement of micro-scale temperature, and the inference of rates of mixing. It was also equipped with a hydrodynamic nose-cone to reduce vibrational noise during the profiling of the water column. The ARGODOT probe is shown in Figure 8.1.

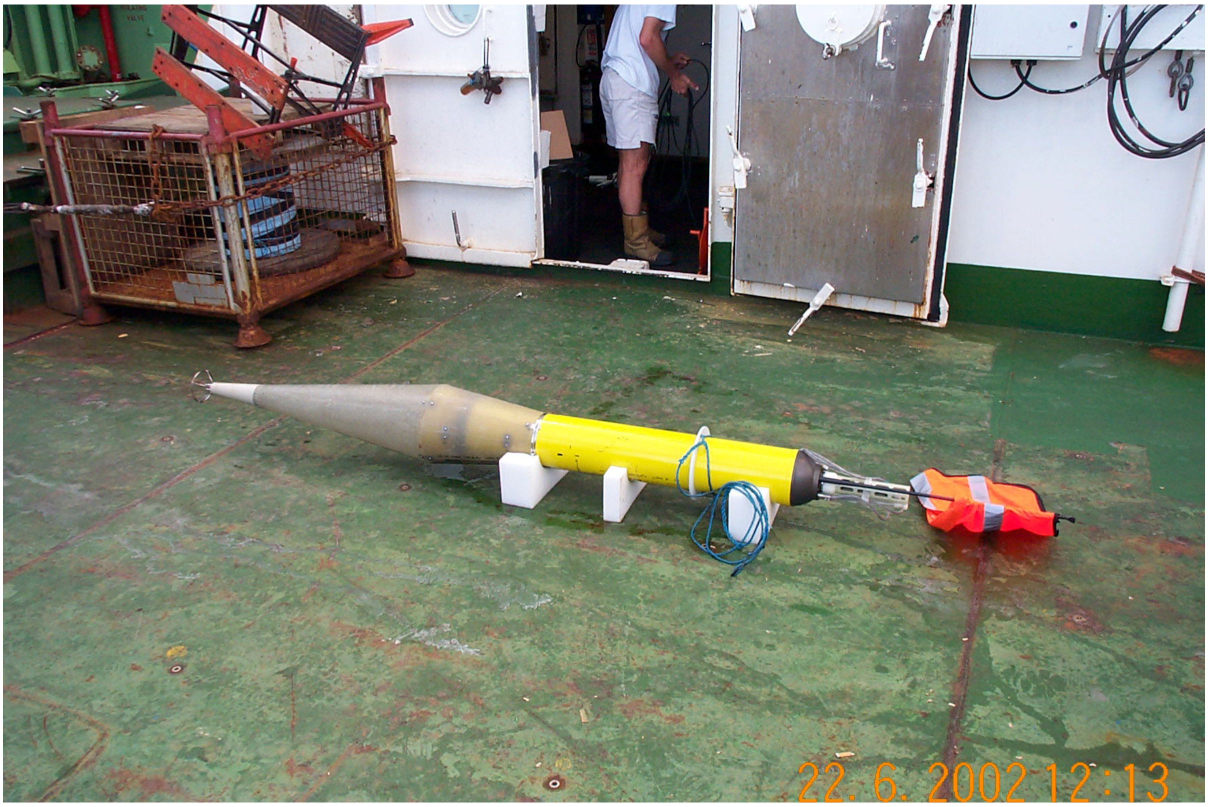

Figure 8.1. The ARGODOT profiling turbulence probe, on deck after a successful deployment off Mauritius.

The float was deployed on June 22 in water close to (in the lee of) Mauritius where the sea state was relatively calm (to assist in the recovery). The float was programmed to make a profile down to 500m and return to the surface (this being the first trial deployment of the instrument). The float was deployed at about 1200 h (local time). At about 1510 h an ARGOS transmission from the float was detected by the Gonio direction finder on the ship. A visual sighting of the float, about 0.75 nm forward of the ship's bow, was made shortly afterwards. Recovery was made by hooking a short trailing line from the side of the ship.

After the deployment of the ARGODOT, the ship had moved about 1 nm away (to the north), and undertook CTD station 25, for purposes of comparison with the ARGODOT data.

CTD data from the ARGODOT was obtained immediately after the recovery of the instrument through the standard ARGOS transmission via satellite, while the float was still on the deck of the ship. This indicated that the float did indeed profile to 500m, and that the temperature was in reasonable agreement with that obtained from CTD 25. The microstucture data, however, were stored on a flash card in the instrument and is only now in the process of being downloaded at SOC. Whilst it is apparent that the data from one of the FP07 thermistors is corrupt, data from the other thermistor is reliable and is yielding good spectral information.

David Smeed and Adrian New

9 MOORINGS

9.1 Introduction

Two moorings were deployed at 8°23' S, 60°13' E (position M in Figure 1.1) in 740-800 m of water on June 7 (day 158). The first mooring comprised a MacLane moored profiler (MMP) equipped with a CTD, an Acoustic Currrent Meter (ACM) and a fluorometer. This had been set to profile continuously over most of the water column, and provided profiles approximately every hour. Two Aanderaa current meters were also fitted to this mooring, just above and below the top and bottom stops (respectively) of the MMP. Close by (about 500m distant), an upward looking 75kHz bottom-mounted ADCP and an Aanderaa tide gauge were deployed on a second mooring. These moorings were designed to provide a time series of hydrographic and internal tide conditions for as long a period as possible. They were both successfully recovered on July 2 (day 183), after a deployment of 25 days, and data were retrieved from all the instruments. An initial inspection indicated that each functioned successfully for the full duration of the deployment. The moorings are illustrated in Figure 9.1.

9.2 Deployment

Deployment of the moorings was scheduled to commence during the morning of June 7, 2002, but due to a more lengthy site survey than originally envisaged (using the EM12 swath system) beforehand, this was delayed until the early afternoon. The weather initially was sunny with 10-15 knot winds, but this gradually worsened during the day with squally showers and the wind speed rising to 20-25 knots. This delay, however, allowed the first mooring to be rigged on deck in plenty of time and checked ready for deployment. Once a decision on the deployment position had been made, arrival on site was at 0803 h GMT (1203 h local time), and final programming of the McLane Moored Profiler could be made. However, communication between the MMP and a portable PC could not be established on deck, thus requiring the removal of the electronics from the pressure tube so that further investigation could be carried out in the main lab. Various approaches were attempted to re-establish communication with the instrument, but eventually success was achieved using another PC. The instrument was programmed on the bench and then returned (in between showers) to it’s housing which had remained under cover on the deck. The MMP was now ready after a delay of approximately one hour, and deployment could proceed as planned.

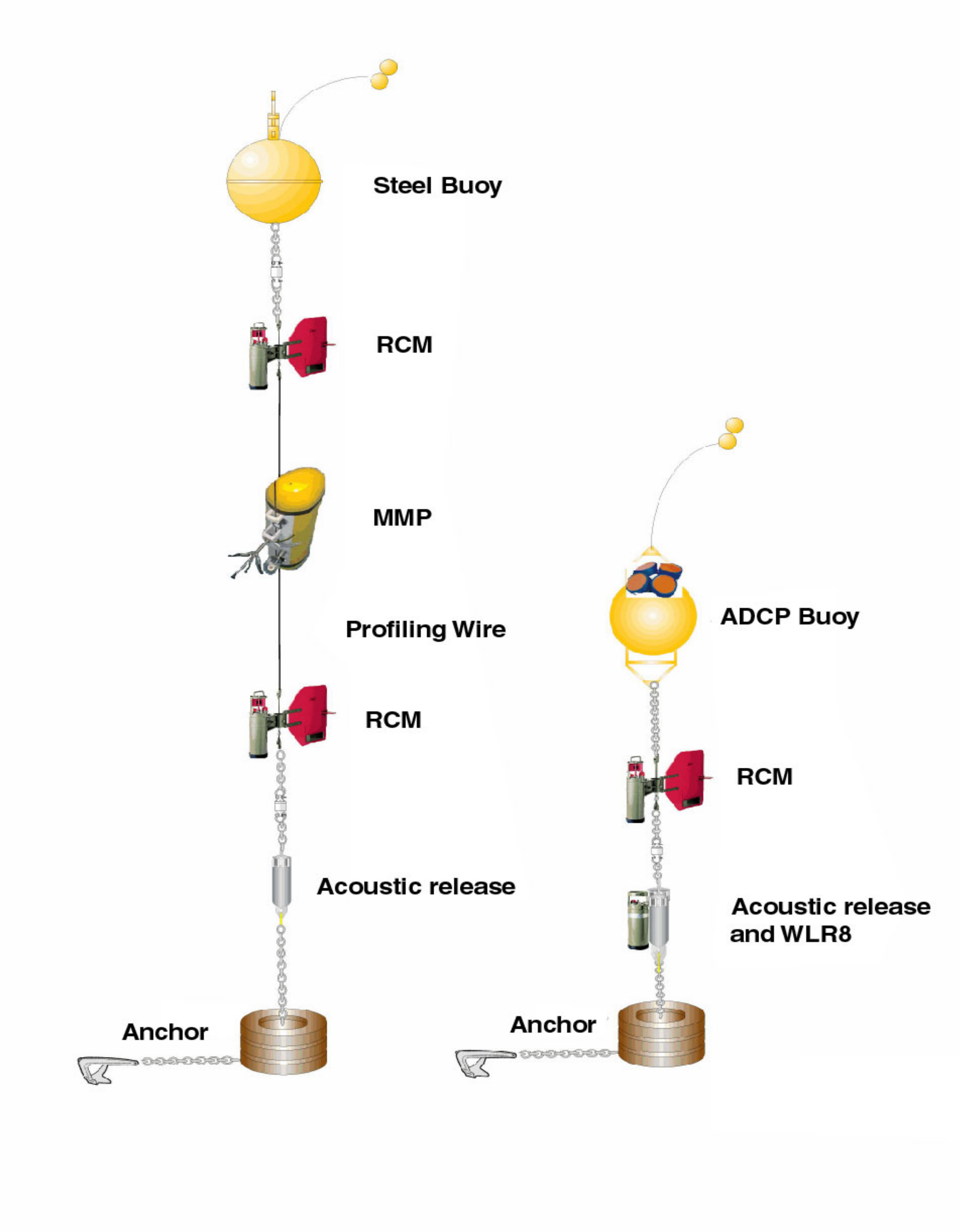

Figure 9.1. Moorings deployed on CD141.

Thanks mainly due to the 1.5-knot current, the ship could hold station almost directly over the deployment site and still allow for streaming of the mooring. This being the case, the 48" sub-surface float for the MMP mooring, with an Argos beacon clamped to it, was lifted over the stern followed by an Aanderaa RCM8 (fitted with CTD). The plastic-coated wire (the main mooring wire, 700 m in length) was then connected and a few metres paid out until the MMP top bumper (or "stop") could be fitted. After some discussion and experimentation, it was decided to fit the MMP at this point and deploy it with the instrument held against the bumper. This method was not without it's problems, but this being done, the package was carefully lowered into the water. The remainder of the jacketed wire was paid out with the lower MMP stop being fitted a few metres from the end. Another RCM8 was connected in below this, followed by an RT661 acoustic release. Finally, this was coupled in to the anchor chain clump, and enhanced in this case with a Bruce anchor because of the steeply-sloping topography. The position and depth were again checked before cutting away the anchor clump at 1227 h GMT.

The vessel maintained position while the sub-surface buoy was being observed to ensure that it became fully submerged and did not subsequently re-emerge. In addition, acoustic ranges were taken using a TT300 deck unit until it was confirmed that the mooring was safely anchored to the sea floor. The ship then steamed round the mooring and several ranges and ship positions were noted. From this, the exact position of the mooring on the sea floor could be fixed. The mooring was calculated as being in a water depth of 800 m and at position 8° 22.84' S, 60° 13.14' E. It was estimated that the lower current meter was 6 m, the profiler bottom stop was 12 m, the profiler upper stop was 701 m, and the upper current meter was 709 m, above the seafloor respectively.

After a break for dinner, deployment of the "Long Ranger" 75kHz ADCP mooring was begun. The ADCP had been programmed before fitting it into a large buoyancy sphere and was already pinging on deck. The buoy was lifted over the stern and lowered into the water followed by the remaining instrumentation, being an RCM7 current meter (fitted with a CT probe), an RT661 acoustic release, and a WLR8 tide gauge. The RT661 was coupled in to the chain clump and Bruce anchor and, when the position was checked, the package was cut away. As before with the first mooring, acoustic ranges were measured to verify the mooring's position and depth on the sea floor. This was calculated to be 8° 22.70' S, and 60° 12.99' E in 740 m water depth. It was estimated that the current meter was 6 m, and the ADCP transducers were 10 m, above the seafloor respectively.

9.3 Recovery

Recovery took place on July 2, 2002, in clear weather and calm seas, the vessel being on site at 0539 h GMT. There was then a short delay before proceeding with recovery while the bridge officers assessed the prevailing conditions. This accomplished, the intention was to recover the MMP mooring first, as this was by far the longer of the two moorings, thus reducing the risk of tangling.

The MMP's acoustic release was interrogated using a TT300 deck unit and several consistent ranges were obtained. The diagnostics revealed that the RT661 acoustic release was vertical and operating correctly and so the release command was transmitted at 0550 h. Although the top of this mooring was only about 80m below the surface, the sub-surface buoy was not spotted visually until 0554 h, coinciding with an Argos transmission detected using a Gonio receiver on the ship at roughly the same time.

The ship manoeuvered alongside the buoy and its trailing line was grappled and connected in to the line from the ship's winch. The buoy and first current meter were hauled on board, the outboard line stopped off, and then the buoyancy and instrument disconnected along with the uppermost MMP bumper. The jacketed wire used for the mooring was then wound onto the winch and observed to be in good condition. Since the MMP cannot support its own weight in air on a mooring wire, it was eventually brought to the surface near the end of the wire and supported by its lower stop. As the instrument was brought inboard, it was lowered into its crate and then extricated from the wire. The bumper was then removed and the last two instruments, an RCM8 and the RT661, were recovered. By 0720 h, recovery was complete and the ship was manoeuvering back into position for recovery of the second mooring.

Interrogation of the second (bottom-mounted ADCP) mooring’s RT661 gave consistent ranges and the diagnostic value showed that it too was vertical. As communication had been established, attempts were then made to release the mooring. After several failed attempts the bridge was asked to stop using the bow thruster while a further attempt was made to send the release command. This time the release command was received and executed, the time being 0740 h. The bridge was then informed and the continued use of the bow thruster for station keeping prevented further communication with the RT661. The sub-surface float was observed on the surface at 0745 h at the same time that an Argos transmission was received on the Gonio receiver.

The initial procedure for recovery was the same as for the MMP mooring, with the ship passing close by the sub-surface buoy while it's trailing line was grappled and then connected into the winch. As this mooring was comparatively short, there was clearance under the stern gantry to lift the buoy/ADCP, RCM7, WLR8 and RT661 all on board together, a line being attached below the buoy to reduce the pendulum motion before lowering it onto the deck.

Recovery now being complete, the equipment was tied down or stowed away and instruments removed for cleaning and data download. All instruments were recovered still functioning and in good condition. The log files from the MMP revealed that during the 25-day deployment it had completed over 600 profiles (approximately one every hour) between 82 dbar and 720 dbar, travelled nearly 365,000 m, and recorded almost 100 Mbytes of data. The MMP had been initially programmed to profile only between its upper stop and 720 dbar (instead of down to its bottom stop), which would have been suitable for the intended target depth of 740 m. However, due to the mooring ending up in water slightly deeper (800 m) than originally anticipated (as it was deployed at the top of a steep slope), this meant that the MMP did not actually profile down to its bottom stop. The ADCP had recorded over 690 Kbytes of data, and the RCM's and WLR8 a combined total of nearly 2.9 Mbytes.

10 EM12 SWATH BATHYMETRY SYSTEM

10.1 Introduction

The Kongsberg Simrad EM12 is a high-resolution 13 KHz multibeam echo sounding system, designed to operate in waters from 500 m to full ocean depth (11000m). The system uses 81 individual echo-sounding beams, and provides the water depth below the ship's track in a "swath" which is typically 3.5 x the water depth in lateral extent. The system was found to be extremely useful for navigating through and recording the complex and partially unknown topography in the area, and for the site survey for the mooring. It was essentially run continuously throughout the cruise while the ship was steaming, but switched off while the ship was on station.

The system is roll- and pitch-stabilized and the advanced signal processing allows the depth to be calculated with an accuracy in the order of 50 to 60 cm or 0.25% of the depth. The system is composed of transmit and receive transducer arrays, a transmitter sub-system, a receiver sub-system (including a beamformer and special digital signal processing), a bottom detector unit and an operator unit with external interfaces for data input and output on a serial line and Ethernet.

The transmitter and receiver sub-systems are physically contained in a preamplifier unit and a transceiver unit. The operator unit is contained in an operator console. Also included with the system is a quality assurance (QA) unit, a sonar imaging unit, a track plotter, recorder/printers and a data storage device. The system is accompanied by the software packages: Mermaid (data logging system), Merlin (real time display system) and Neptune (post-processing system).

The EM12 uses separate transducer arrays for reception and transmission, constructed from individual transducer modules. While the individual ceramic elements are identical, the receive and transmit modules are different due to different scan angle requirements. A single transmit module contains 16 elements in a 4x4 configuration. 24 such modules containing a total of 384 elements make up the transmitter array, which has a total length of 4.8 m. The transmit array is mounted parallel to the keel of the ship and has a beamwidth of 1.8^o in the fore-and-aft direction. The narrow fore-and-aft beamwidth of the transducer array is very important to achieve high accuracy and resolution. 81 beams are transmitted at an equidistant spacing, providing 120^o coverage. Each receive module contains 15 elements in a 3x5 configuration. 14 such modules containing a total of 210 elements make up the reception array, which has a total length of 2.4 m. The receive array is mounted at 90^o to the vessel's keel. It has a beam width of 3.5^o athwartships and 1.8^o in the fore-and-aft direction.

The EM12 implements two depth modes in which different pulse lengths are used. In "shallow" mode (for water depths between 500-1200 m), the pulse length is 2 ms, and for "deep" mode (water depths between 500-11000 m), the pulse length is 10 ms. The swath width is typically 3.5 x water depth in waters up to 4000 m deep, and up to 20 km in deeper waters.

10.2 Data Acquisition

Before commencing survey work the EM12 was calibrated for pitch and roll bias. It was found that there was a +0.44° roll bias, which needed to be accounted for. This was remedied during the Neptune post processing routine, see below. It is normal routine to have acquired a Sound Velocity Profile (SVP, see brief description below) prior to commencing data acquisition. However, during CD141 the SVP-16 probe did not work. An SVP was generated, however, from pressure, temperature and salinity values acquired during a CTD cast (made after the calibration survey was completed and applied to the data during post processing using the Neptune software), using the UNESCO approved algorithm of FOFONOFF & MILLARD (1983).

To optimise the volume and quality of the data acquired by the EM12 it is necessary to ensure that the correct recording parameters are in place on the Bottom Detection Unit (BDU). Depending upon the character of the environment to be surveyed, there are a number of variables which need to be established. These may vary only slightly depending on whether the seafloor morphology varies relatively from one extreme to another, i.e. flat sedimented seafloor to un-sedimented rocky outcrops, or if there is a change in the sea state. Observation of the incoming data was made via the Operator Unit (OU) and Quality Assurance (QA) monitor. The QA application allows real time quality control of position and depth data and watchkeepers were able to keep an eye on the acquisition activity.

There were a number of occasions when the system could not correctly locate the seafloor resulting in spurious acquisition or complete loss of data. It became apparent that most instances, but not all, were when the seafloor topography changed relatively sharply (normal marginal seafloor slopes are in the order of 1^{o} to 5^{o}) and as the ship approached the slope, mostly from shallow water to deep water, at an oblique angle to the shelf trend. Two other causes of data loss were when the EM12 Mermaid software might hang, or when the BDU locked up, resulting in no pings being transmitted. For the former form of data loss there was no alternative but to re-boot the Neptune UNIX workstation and re-start the EM12 mermaid software; for the latter, the BDU would have to be switched off and back on again and a re-set undertaken of all the necessary parameters.

The EM12 system stores the data in files, which increase in number when the line/file number was manually incremented on the OU. This ensures that should the system crash there wouldn't be any more data lost than the amount of data stored on the current file/line number. Data acquired using the parameters set-up on the EM12 console are automatically stored on the Neptune UNIX workstation using the Mermaid software. Once the cruise ID was set up on the EM12 OU, it was necessary to create a directory of the same name in the /data1/raw/ directory on the workstation. This is where all the raw data files were stored.

In order to process the data using the Neptune software, it was necessary to ftp the raw data files from the Neptune UNIX workstation to the Aquavit UNIX workstation (where the Neptune software is kept). Here again it is necessary to set up the directory structure correctly. Create a directory in

/data1/raw/ path, named "cruise ID", and ftp all raw files to this directory. The raw data files may then be accessed.

10.3 Data Processing

Once the data was transferred to the Aquavit UNIX workstation it was possible to begin the process of creating bathymetry grids. There are a number of routines performed before any final grid was created.

The first stage was to create a block of data (a block being a single or a number of EM12 data files identified by the line number) using the "check/replay data" software. Once the raw data has been run through the "check/replay data" software, the block of data generated was stored under /data1/proc/ "block file name".

On starting up the "Neptune" software it will look in the /data1/proc/ directory for the file you have just generated. Once accessed, a +0.44° roll bias needed to be applied using the "Depth Correction" utility. Following this correction the BinStat application was used to create a grid of the selected block of data and a user-defined grid resolution is assigned, creating geographical cells, or rectangles of the seafloor, into which depths are mapped. All depths which fall into a cell are then gathered into a single measurement group (bin).

It is necessary to produce a grid at this stage as the Neptune software requires the data in a gridded format in order to apply certain rules, or cleaning processes, which are used to remove or flag any bad data points. Two rules were applied to most of the data. The Standard Deviation (SD) rule is used to flag out any depth values which deviate from the mean of a block of data. The second rule applied was the Noise rule. This rule flags out any data which deviate from the mean of a cell. The Noise percent is defined by: Noise % = 100*(STD of cell/Mean of cell).

During CD141 a standard deviation value of 1 and a noise rule of 0.75 were most frequently applied (although in shallow waters, i.e. less than 500 m, the SD rule was often not necessary). In practice this meant that any data values which were more than 1% of the mean value of the block were flagged out as bad. Once these automated rules had been applied it was then necessary to manually look through the data in mean cell value or depth difference mode, and remove any spurious bad points that the rules had not flagged as suspect.

Once the raw data had been through its first data cleaning process an ASCII file was exported, and the Generic Mapping Tools software (GMT) was used to produce a provisional grid from which plots of the data were produced. The gridding routine would firstly average the raw data into the individual cells of 150m x 150m (or 100m x 100m depending on the average water depth), which made up the grid. This routine itself smoothes out any erroneous data. This smoothed ASCII data was then used to produce a "surfaced" grid at a resolution of 150m (or 100m). The surfaced grid was then itself used to produce a plot of the data, which was visually checked for any obviously bad data missed during the cleaning process - these would mainly manifest themselves as poorly constructed contours or as obvious colour anomalies on the plot.

If bad data points were seen on the plots, it was then necessary to go back to the Neptune system and again manually remove those bad data points. Once this second clean was complete the data was again exported and used to produce another grid and a second visual check was made. This routine was followed iteratively until a satisfactory grid was produced. All activity related to the EM12, from acquisition to processing, was carefully logged for future reference.

10.4 Data Quality

In general, the quality of the data recorded by the EM12 is directly influenced by the sea conditions. In rough seas and at certain ship speeds, air bubbles and turbulence over the transducers may absorb some of the reflected energy, reducing the signal detected. Also, as mentioned above, the angle of the ship's passage over certain terrain can lead to the loss of data. During CD141, the overall quality of the data was high, and 5100 nm were covered with an average swath width of 3x the water depth. There was very little poor data or data loss. It was, however, observed that in water depths exceeding 4000 m, where the terrain was flat and featureless, the data from the outer beams (0 –10 and 70 –81) were often up to 100 m above/below the mean for that area. These data were removed by manual flagging out during Neptune processing.

Block number	Date	Description	Possible cause
CD141_14	2/6/02	Cannot access data	Corrupt data file
CD141_18_19	4/6/02	Loss of stbd beams	Shelf terrain and A/C
CD141_33_34	6/6/02	Loss of port beams	Terrain alteration
CD141_47_18	8/6/02	No acquisition	Mermaid re-boot required at start of 47.
CD141_69_70_71	14/6/02	Total & port bms loss	BDU failure & terrain alteration
CD141_89(no. not used)	20/6/02	No acquisition	No line 89. Mermaid re-boot
CD141_103_104	24/6/02	Loss of port beams	Altered course (A/C) whilst ↑ depth
CD141_105_106	24/6/02	Loss of port beams	Terrain alteration & sea state
CD141_111	25/6/02	Loss of stbd beams	Oblique approach and sharp ↑ in depth
CD141_112_113	25/6/02	Loss of stbd beams	Continued from line 111
CD141_115_116_117	26/6/02	Loss of stbd beams	Oblique approach
CD141_128_129	29/6/02	Loss of stbd beams	Oblique approach
CD141_135_136	30/6/02	Spurious data	A/C, oblique approach, terrain & sea state.
CD141_140_141_142	1/7/02	No acquisition	Mermaid re-boot required at start of 140.
CD141_174_175_176	6/7/02	Loss of stbd beams	Terrain alteration next to Wormley Smnt
CD141_188_190_191	8/7/02	No acquisition	Mermaid re-boot required at start of 190.
CD141_189	8/7/02	Cannot access data	Corrupt data file

Table 10.1. EM12 data blocks with data loss or corruption

Those data files/lines, which did encounter some problems or data loss are listed above in Table 10.1, along with a possible cause as to why.

In addition to the losses listed above, at 0540 h (GMT) on July 9, during a CTD cast, the ship lost all power (propulsion and electrical). Because of this, the EM12 shut down. It took several hours to resume EM12 activity, as it was discovered that the transceiver unit power supply was damaged and needed replacing. This resulted in approximately 5.5 hrs of ship steaming time where no data was being acquired.

10.5 Sound Velocity Profiles (SVPs)

The SVP-16 sound velocity profiler is a self-contained submersible logging instrument deployed from the starboard-side boat deck using the hydrographic winch, down to a depth of 2000 m (manufacturer's limit). It is designed to measure sound velocity, temperature and pressure of the water column. As it employs a true sound velocity sensor, it measures sound velocity in a more accurate manner than instruments producing calculated values based upon other parameters. Each SVP station requires the ship to heave to, and with the deployment and recovery of the instrument, can last up to 2 hours. Several attempts were made at the beginning of the cruise to acquire an SVP profile using the SVP-16 profiler. However, after every attempt, the error message “Data link failure, check current loop” followed by “No data in probe” would appear when trying to download the data onto the PC. The cause of the error was undetermined.

Once a sound velocity profile from an SVP profiler is acquired, it is usually normal practice to simply convert Expendable BathyThermograph (XBT) information into a sound velocity profile on a daily basis and input this updated SVP when required. However, during CD141, the software required to do the conversion was not available. Instead, all SVPs were generated using data acquired from the CTD casts and manually input into the EM12 system. Table 10.2 below shows from which CTD cast the SVPs were produced.

SVP no.	CTDno./cast no.	Cast Date	Location (lat/lon)	1st line applied to:
SVP1	CTD4/5	4/6/02	-5 13.82 / 57 17.47	CD141_2
SVP2	CTD9/1	8/6/02	-8 00.19 / 61 27.71	CD141_45
SVP3	CTD12/5	9/6/02	-8 00.22 / 63 59.81	Not Used
SVP4	CTD13/1	10/6/02	-9 25.03 / 64 35.99	CD141_61
SVP5	CTD17/1	13/6/02	-15 23.36 / 64 16.95	CD141_75
SVP6	CTD26/5	22/6/02	-20 04.29 / 58 00.00	CD141_100
SVP7	CTD34/1	26/6/02	-14 46.98 / 61 49.80	CD141_119
SVP8	CTD42/1	29/6/02	-12 15.88 / 62 06.78	CD141_132
SVP9	CTD49/1	2/7/02	-8 00.35 / 59 50.20	CD141_149
SVP10	CTD55/3	5/7/02	-11 59.85 / 57 59.65	CD141_170
SVP11	CTD60/1	8/7/02	-17 25.00 / 56 39.80	CD141_184

Table 10.2. CTD stations used for Sound Velocity Profiles

10.6 Benefits of EM12 Swath Data

The EM12 system proved itself to be invaluable to the cruise on many counts, as summarised here. Firstly, as there were problems at the beginning of the cruise with the CTD winch, the EM12 was utilised to fill in the time. During the CTD downtime, the EM12 was used to do a 100% coverage swath survey east of the Seychelles bank (near CTD 01 in Figure 1.1). This bathymetry was acquired to complement the interpretation of ADCP data.

The EM12 was then used to identify accurately the location of the southeast portion of the Seychelles Bank (just south of station 05), as contours identified from the GEBCO data set were somewhat different to information illustrated on the Admiralty charts. It was found that neither dataset was very accurate, thus making this newly acquired swath data of benefit to several sources to correct their datasets and to enhance the safe navigation through this area.

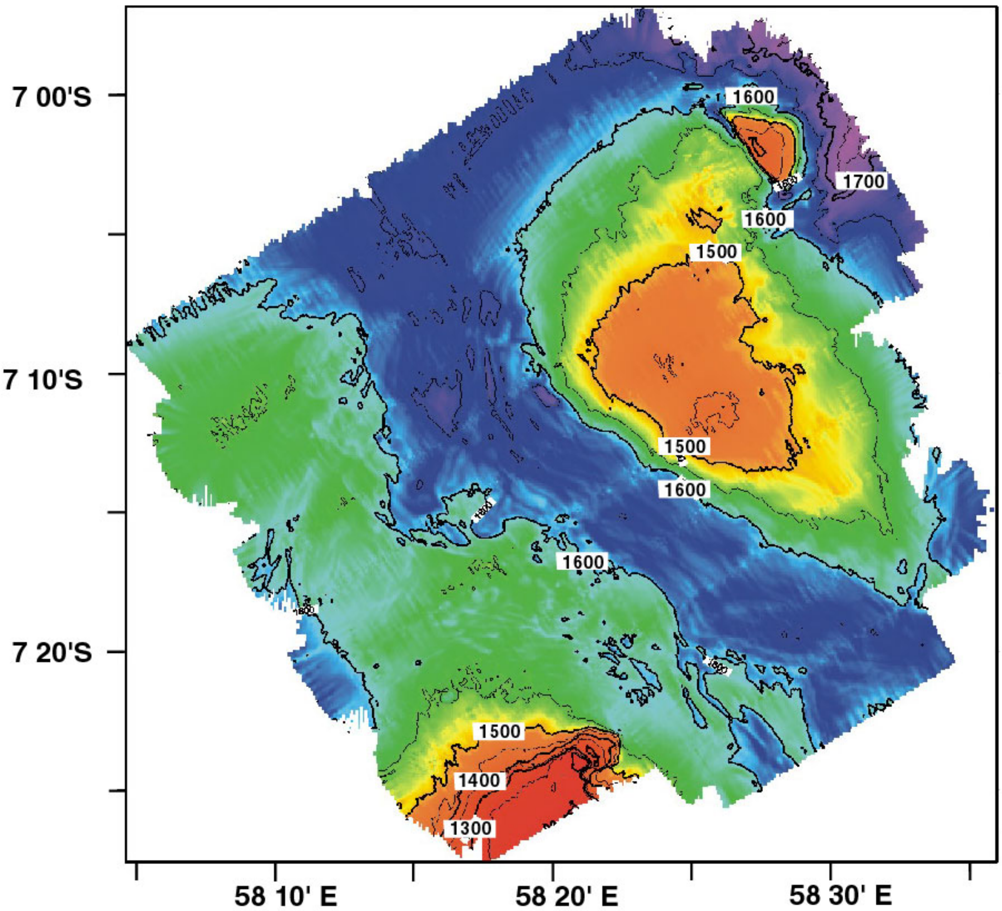

Figure 10.1. Swath survey for the Shoals of Capricorn programme showing seafloor topography (depths are in m).

A detailed survey for the "Shoals of Capricorn" programme was then carried out north west of Ritchie Bank (itself the northernmost offshoot of the Saya De Mahla Bank), centred around CTD station 07, in order to discover if there were any indications of channelling from east to west. The presence of such features could indicate a highway for the migration of water masses, which may have an effect on biological activity in the area. It was found that the survey area did indeed possess such a channel, running north-south, in which clearly marked bedforms indicating the current flow could be seen. Also revealed was a 400 m high sheer cliff face in the northeastern part of the survey, which formed part of what seemed to be a massive "anvil-shaped" rocky outcrop of unidentified geology. The results from this survey are shown in Figure 10.1.

The EM12 was then used to survey the north-east shelf of Ritchie Bank in order to determine the exact topography and depth in order to deploy the moorings (at position M in Figure 1.1). It was necessary to locate an area where the water depth was approximately 750m deep and that would provide useful information for the understanding of internal wave activity. Both objectives were achieved, and were greatly simplified by the EM12 swath survey.

In addition, the EM12 was used to identify whether a channel runs east-west separating the Nazareth Bank to the south, and the Saya De Malha Bank to the north, between 12-13° S. On the GEBCO bathymetric charts, there is no such channel marked, the water depths being no deeper than about 400 m, and the presence of Somerville Bank (a feature less than 100 m deep) is clearly indicated. Conversely, the Sandwell and Smith bathymetry shows the presence of a channel 1700 m deep in this location. The swath survey, however, revealed that the Somerville Bank does not exist (at least in the location stated by GEBCO) with water depths no shallower than 400 m, and that there is indeed a channel between the two major banks, which is 1100 m deep, see Figure 10.2. This channel is a significant discovery as it seems (from the other survey results) that about half of the flow in the South Equatorial Current passes through this gap, flowing from the eastern side to the western side of the Ridge.

Consequently, both the GEBCO and Sandwell and Smith bathymetries are significantly in error in this location. Indeed, this was found to be generally true around the shoals and banks of the Mascarene Ridge. The positions of the rapidly shallowing shelf slopes were often found to be mis-located by the order of 2-5 nm (nautical miles), leading to errors in bathymetric depths often up to, or even exceeding, 500 m. The swath system was correspondingly invaluable for locating and mapping the structure of the shelf slopes, and, consequently, for the placing of the CTD stations (which were carefully chosen in relation to the bathymetry). In addition, the data will filter through to be used as part of a larger dataset to improve the understanding of the bathymetry of the whole area surveyed. As a summary of the data sets obtained, Table 10.3 shows their relation to the Exclusive Economic Zones (EEZs) of the countries in the region.

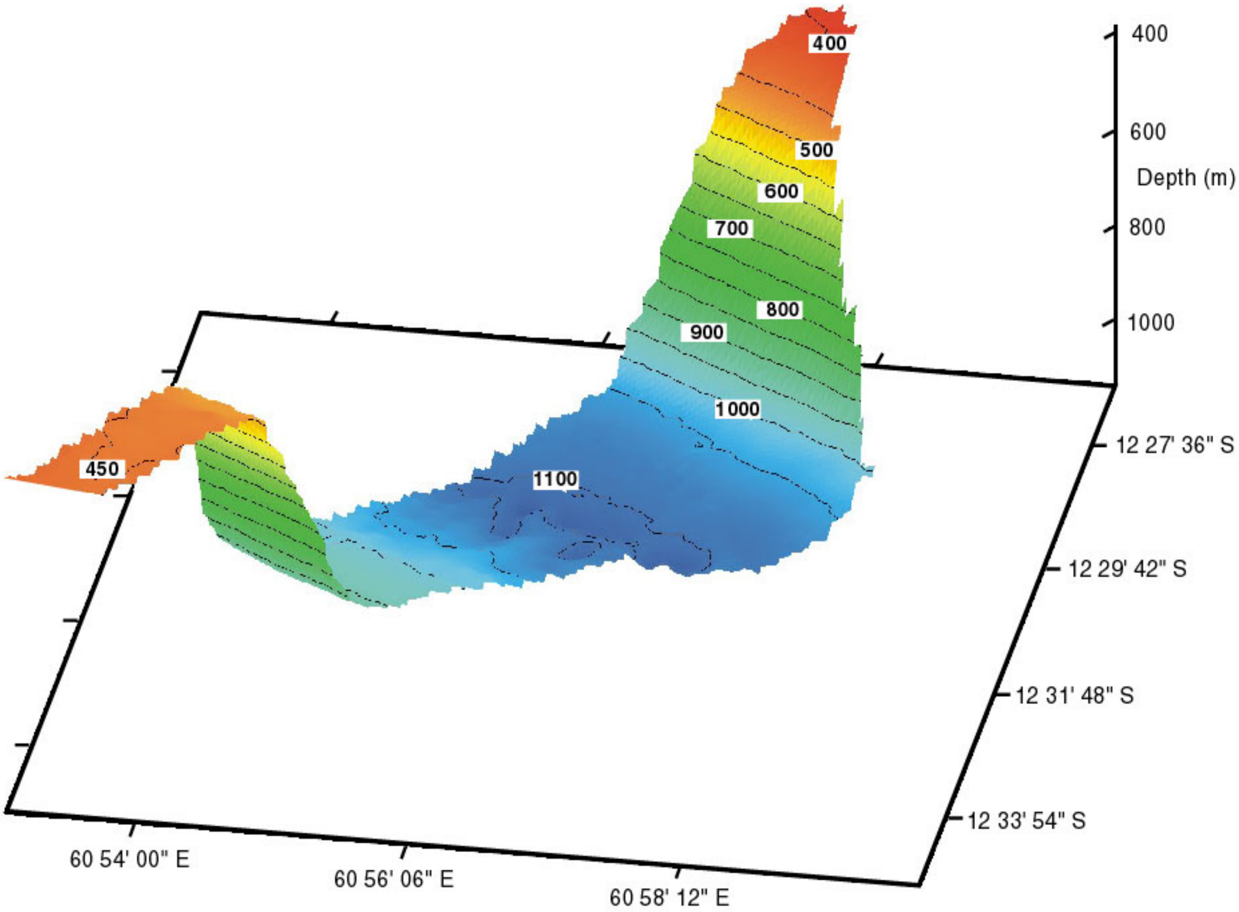

Figure 10.2. Swath survey (perspective view) of the channel between the Nazareth Bank (to the South) and the Saya De Malha Bank (to the North) near 12° 30'S, 60° 56'E (depths in m).

EM12 line no.s	Location	Country
CD141_2_38	Within 200M EEZ	Seychelles
CD141_38_71	International waters	
CD141_72_119	Within 200M EEZ	Mauritius
CD141_120_149	International waters	
CD141_150_158	Within 200M EEZ	Seychelles
CD141_159_188	Within 200M EEZ	Mauritius
CD141_188_191	Within 200M EEZ	Reunion
CD141_192_195	Within 200M EEZ	Mauritius

Table 10.3. EM12 data files in relation to Exclusive Economic Zones (EEZs).

Alan Evans

11 METEOROLOGICAL OBSERVATIONS

11.1 Introduction

For this cruise, several meteorological systems were deployed on the ship in addition to the standing set of meteorological instruments routinely logged as part of the "surfmet" package and described elsewhere. These additional instruments included: the "Autoflux" system, providing near real-time direct measurements of the air-sea fluxes and mean meteorological parameters, a temporary mast instrumented with a number of anemometers to determine the effect of flow distortion by the ship on wind speed measurements, and radiosonde balloons. In addition, hourly observations of the cloud cover and type were made.

11.2 Instrumentation

The SOC Meteorology Team instrumented the *RRS Charles Darwin* with a variety of meteorological sensors prior to cruise CD141 in Freemantle, Australia between May 5-9, 2002. The mean meteorological sensors (Table 11.1) measured air temperature and humidity, air pressure, sea surface temperature (SST), incoming shortwave (300-3000 nm, nanometres) radiation (SW) and incoming longwave (4-50 micron) radiation (LW). The surface fluxes of momentum, heat, CO_2 and moisture (H_2O) and were obtained using the fast-response instruments in Table 11.2. The HS sonic anemometer provided mean wind speed and direction data in addition to the momentum flux estimates. The AutoFlux system used the ship based navigation to obtain ship's position and to correct the wind speed data for ship speed and heading. A temporary mast instrumented with four cup anemometers (Table 11.3), an RS sonic anemometer, and a Windmaster sonic anemometer, was installed on the bridge top to determine the extent of the distortion of airflows over the port and starboard beams of the ship.

The positions of the instruments are indicated in Figures 11.1 and 11.2. Most of the standard AutoFlux instruments were mounted on the ship's foremast in order to obtain the best exposure. The fast response sensors, psychrometers and the SW radiation sensors were all located on the foremast platform. The LW radiation sensors were mounted on top of the foremast extension. The sea surface temperature (SST) "soap" (thermistor) was trailed over the port side of the ship. The heights of the instruments relative to the ship's waterline were:HS sonic anemometer,15.2 m; IFM sensor,14.15m; psychrometers, 14.97 m; shortwave sensors, 14.5 m, and longwave sensors, 17.2 m. The position of the sensors relative to the aft edge of the foremast platform are shown in Figure 11.2 and Table 11.4. The Woods Hole Oceanographic Institution (WHOI) hull contact sensor was located in the engine room on the port side, about 1.0 m below the water line.

Sensor	Channel, variable name	Rhopoint Address	Serial no.	Calibration coefficients	Sensor position and parameter measured
Psychrometer	1 pdp1	$ARD	HS1031 DRY	C0= -0.8056471 C1= 3.846001E-2 C2= 2.15288E-6 C3= -2.502542E-10 C4 = 0.0	Foremast platform. To port of HS sonic. Dry and wet bulb air temperatures and humidity
Psychrometer	2 pwp1	$ERD	HS1031 WET	C0= -0.964358 C1= 3.874771E-2 C2= 1.498676E-6 C3= 2.352717E-10 C4 = 0.0	
Psychrometer	3 pds2	$VRD	HS1029 DRY	C0= -1.076513 C1= 3.8668E-2 C2= 1.65552E-6 C3= 1.535373E-10 C4 = 0.0	Foremast platform. To stbd of HS sonic. Dry and wet bulb air temperatures and humidity
Psychrometer	4 pws2	$WRD	HS1029 WET	C0= -1.016908 C1= 3.89214E-2 C2= 1.787686E-6 C3= -1.058753E-10 C4 = 0.0	
SST "soap"	5 soap sst	$XRD	PD0010/53	C0=44.598964 C1= 1.0258248E-2 C2= -1.5411717E-4 C3= 1.904478E-7 C4= -1.1067	Over port side of forecastle. Sea surface temperature
Eppley LW Dome	6, Td1	$HRD	31170	C1=1 (other coeffs. = 0)	Foremast top aft position. LW.
Body	7, Ts1	$BRD	31170	C1=1	
Thermopile	8, E1	$2RD	31170	C1=1	
Eppley LW Dome	9, Td2	$QRD	31172	C1=1	Foremast top fore position. LW.
Body	10, Ts2	$6RD	31172	C1=1	
Thermopile	11, E2	$CRD	31172	C1=1	
Kipp & Zonen SW	12 SWp	$1RD	903288	C1=0.2132 SEN 4.69	Port foremast platform, SW (LW rhopoint box)
Kipp & Zonen SW	13 SWs	$3RD	903289	C1=0.2045 SEN 4.89	Stbd foremast platform, SW (met rhopoint box)
Vaisala Pressure	14 press	n/a	ptb220	C1 = 1	Scientific plot, air pressure.
WHOI hull sst	sstMEAN	n/a		n/a	Engine room by LT fresh water cooler, SST.

Table 11.1. Mean meteorological sensors. The calibration coefficients for each instrument were applied via the equation $Y = C0 + C1*X + C2*X^2 + C3*X^3+C4*X^4$.

Sensor	Autoflux program	Location	Data Rate	Sections sampled per hour	Derived fluxes
Gill Horizontally Symmetrical Research Ultrasonic Anemometer	gillhs	Port side of foremast platform	20 Hz	64	momentum and heat
R2 sonic anemometer	gillr2ar	Top of the temporary mast	21 Hz	64	momentum
IFM IR H_20/CO_2 sensor	ifmhs	Port side of foremast platform	10 Hz	32	H_2O and CO_2

Table 11.2. Fast response meteorological sensors.

Sensor	Channel, variable name	Address	Serial no.	Calibration coefficients	Sensor position and parameter measured
vector 1	1 ws1	$1RD	rotor with R=45.8	C0= 0.11243 C1= 0.100449252 C2= -1.395633E-5 C3= 1.787436E-8	Above the bridge top. Wind speed
vector 2	2 ws2	$2RD	rotor with R=45.8	C0= 0.11243 C1= 0.100449252 C2= -1.395633E-5 C3= 1.787436E-8	Above the bridge top. wind speed
vector 3	3 ws3	$3RD	rotor with R=45.8	C0= 0.11243 C1= 0.100449252 C2= -1.395633E-5 C3= 1.787436E-8	Above the bridge top. Wind speed
vector 4	4 ws4	$4RD	rotor with R=45.8	C0= 0.11243 C1= 0.100449252 C2= -1.395633E-5 C3= 1.787436E-8	Above the bridge top. Wind speed

Table 11.3. Vector cup anemometers located on the temporary mast above the bridge top. The calibration coefficients for each instrument were applied via the equation $Y = C0 + C1*X + C2*X^2 + C3*X^3$. In addition, the R2 sonic anemometer (in Table 11.2) was mounted at the top of the mast, and a Windmaster sonic anemometer (measuring three components of the wind speed u, v and w on channels 6, 7 and 8) in the middle.

Sensor	Forwards (m)	Port/stbd (m)	Up (m)
HS	1.5	1.83 stbd	2.25 - 2.30
IFM	1.0	2.28 stbd	1.2
Port Psychrometer	0.5	1.48 stbd	2.0
Starboard Psychrometer	0.5	2.18 stbd	2.0

Table 11.4. The positions of the foremast instruments relative to the aft edge of the foremast platform and to port or starboard of the ship's centreline

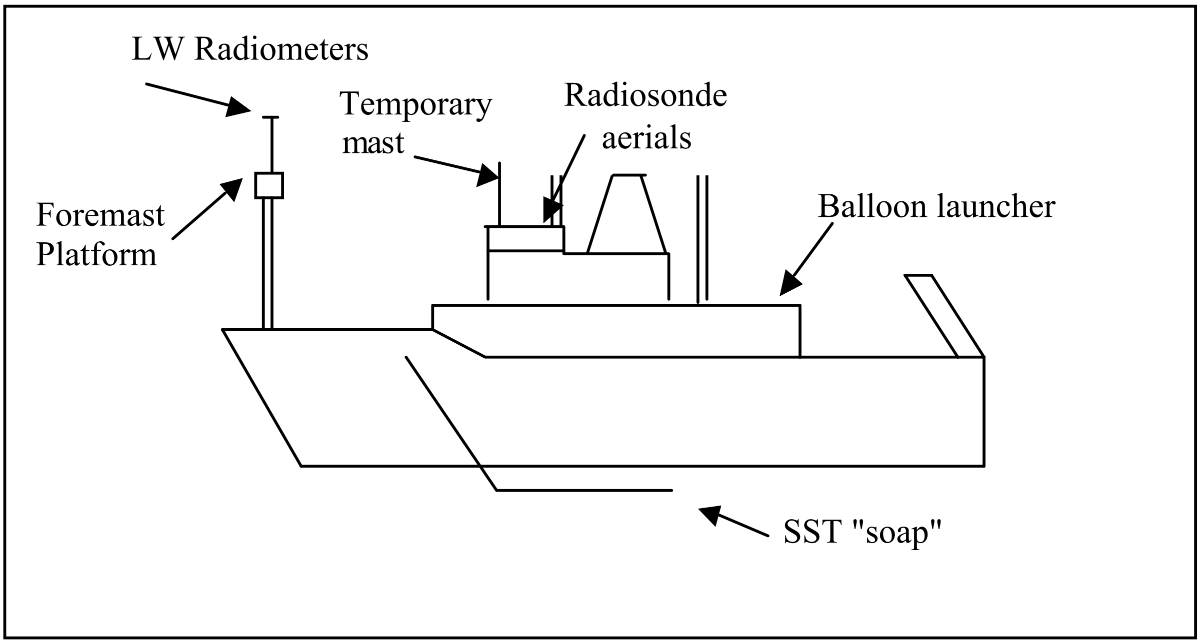

Figure 11.1. Schematic showing the meteorological instrument locations.

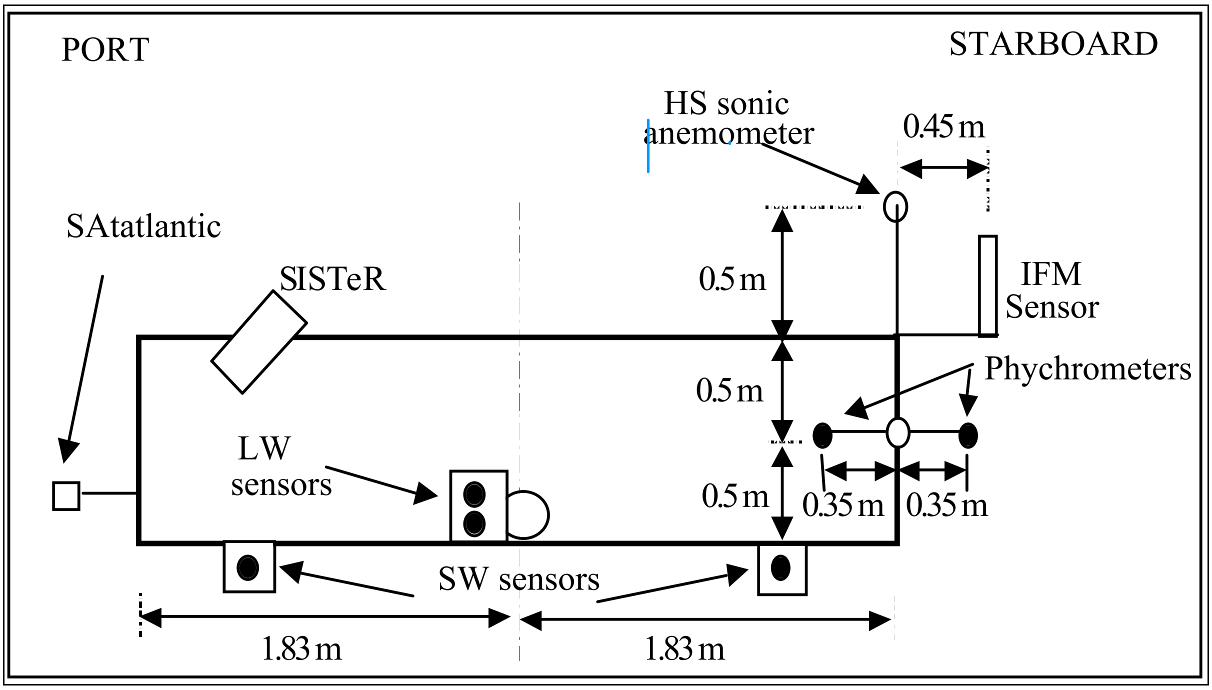

Figure 11.2. Schematic showing a plan view of the foremast platform. Distances are given in meters.

The temporary mast located above the bridge consisted of a 6 m long circular scaffold pole which was securely fixed to the bridge top by a specially designed bracket and held in place by a number of stays. The base of the mast was located 2.77 m in from starboard side, 5.2 m aft of the front edge of the bridge and approximately 13 m above sea level. The anemometers located on the mast measured the wind speeds at a number of heights throughout the cruise. An R2 sonic anemometer was placed at the top of the mast, with the 4 vector cup anemometers, and 1 Windmaster sonic anemometer between them. The heights of the anemometer above the bridge top were: vector 3, 1.57 m; vector 4, 2.57 m; Windmaster sonic, 3.57 m; vector 2, 4.57 m; vector 1, 5.57 m; and the R2 research sonic, 6.72 m. With the exception of the R2 sonic (which was mounted directly on top of the mast), all anemometers were located 1 m forwards of the mast base, i.e. 4.2 m aft of the front edge of the bridge.

For illustrative purposes, a plot of a wide range of the meteorological parameters collected during the first week of the cruise is shown in Figure 11.3. Figures 11.4 and 11.5 then show the wind speed and direction, and the surface temperatures, respectively, over the duration of the whole cruise, to reveal the changing nature of these basic parameters as the ship progressed around its track.

11.3 The Autoflux Logging System

The AutoFlux system provides near real-time direct measurements of the air-sea fluxes of momentum, sensible heat and latent heat in addition to the usual mean meteorological parameters. The fluxes are calculated via the “inertial dissipation” method using data from various fast-response instruments, and the results are emailed to SOC automatically via the ORBCOMM communications system. Most of the instruments utilised by the AutoFlux system have been well proved during IOS/SOC research cruises over the last 15 years, but the system also incorporates a fast response humidity sensor developed during the AutoFlux project (MAST project MAS3-CT97-0108) and a novel sea surface temperature system on loan from Woods Hole Oceanographic Institute.

The logging system utilised one Sunblade 100 UNIX workstation named 'nimbus'. Nimbus was networked, but was independent of the ship's level A system. A second UNIX workstation was also networked and cross mounted to nimbus. Data could then be routinely transferred and analyzed. Data from the mean meteorological sensors were acquired and logged once every 10 seconds by nimbus and stored in hourly files in raw and calibrated format. Navigation data was provided by the ships NMEA output and also logged every 10 seconds. The HS sonic anemometer, R2 sonic anemometer and the IFM H_20/CO_2 sensors logged data at rates of 20 Hz, 21 Hz and 10 Hz respectively. Every hour, 64 sections (32 for the IFM sensor) of data were obtained. Each section contained 1024 data

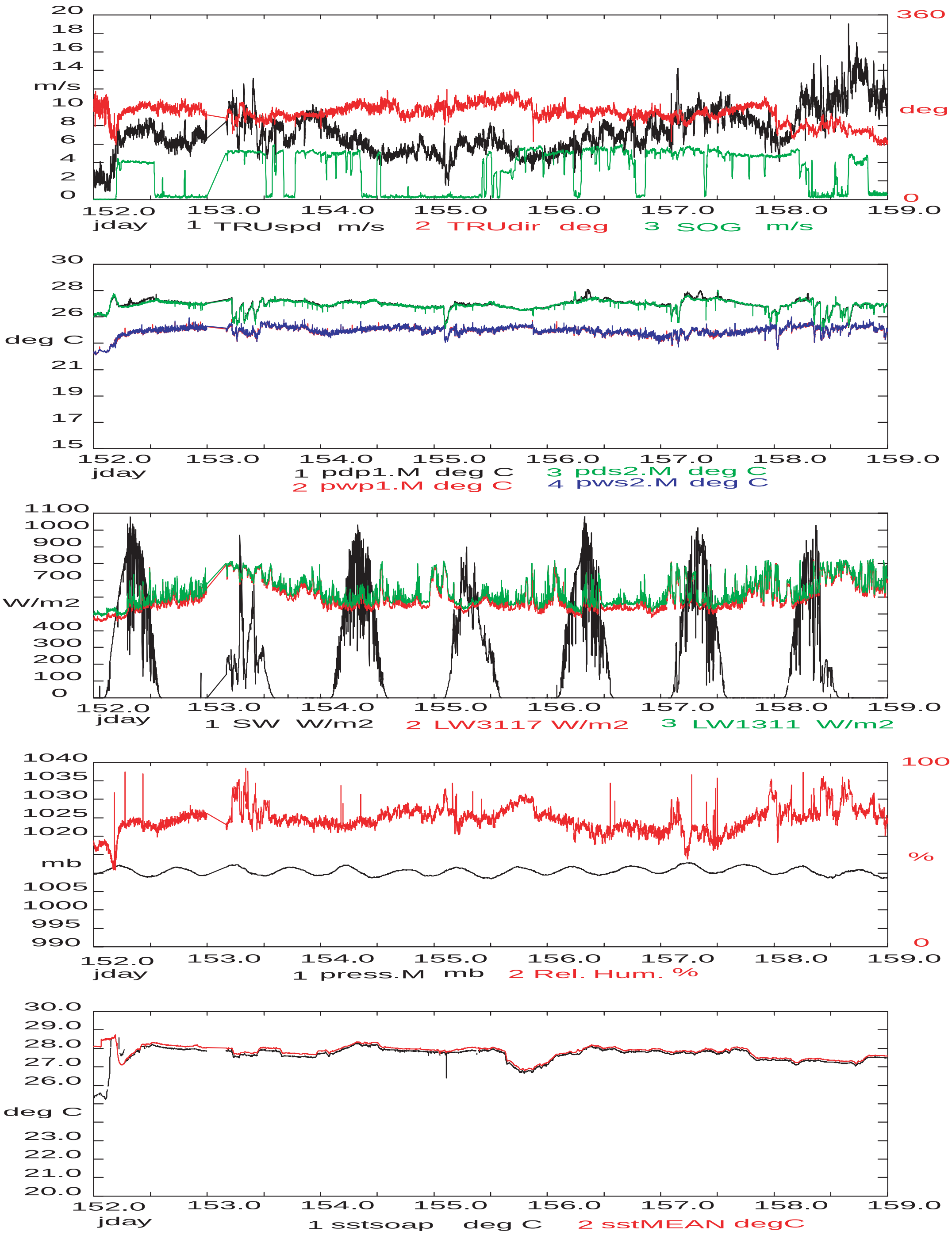

Figure 11.3. Meterological parameters from week 1 of the cruise. First panel shows true wind speed (TRUspd, black, m/s) and direction (TRUdir, red, °), and the ship's speed over the ground (SOG, green, m/s). Second panel shows dry (green/black) and wet (blue/red) bulb air temperatures (°C). Third panel shows Short Wave (SW, black) and LongWave (LW, green/red) heat fluxes (W/m^2). Fourth panel shows relative humidity (Rel. Hum., red, %) and air pressure (black, mbar). Fifth panel shows the soap (sstsoap, black) and WHOI (sstMEAN, red) sea-surface temperatures (°C).

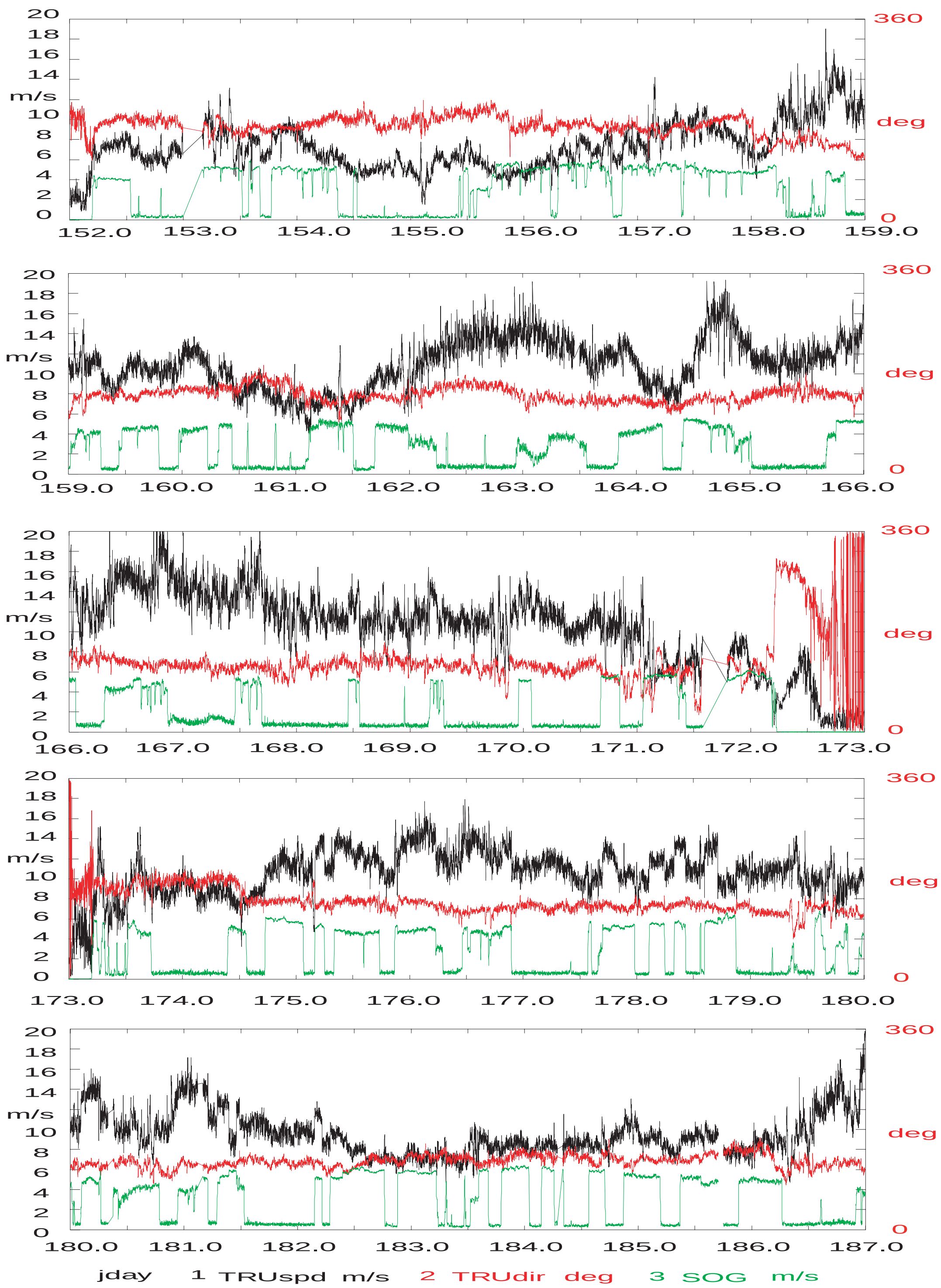

Figure 11.4. True wind speed (TRUspd, black, m/s) and direction (TRUdir, red, °), and the ship's speed over the ground (SOG, green, m/s), for the duration of the cruise.

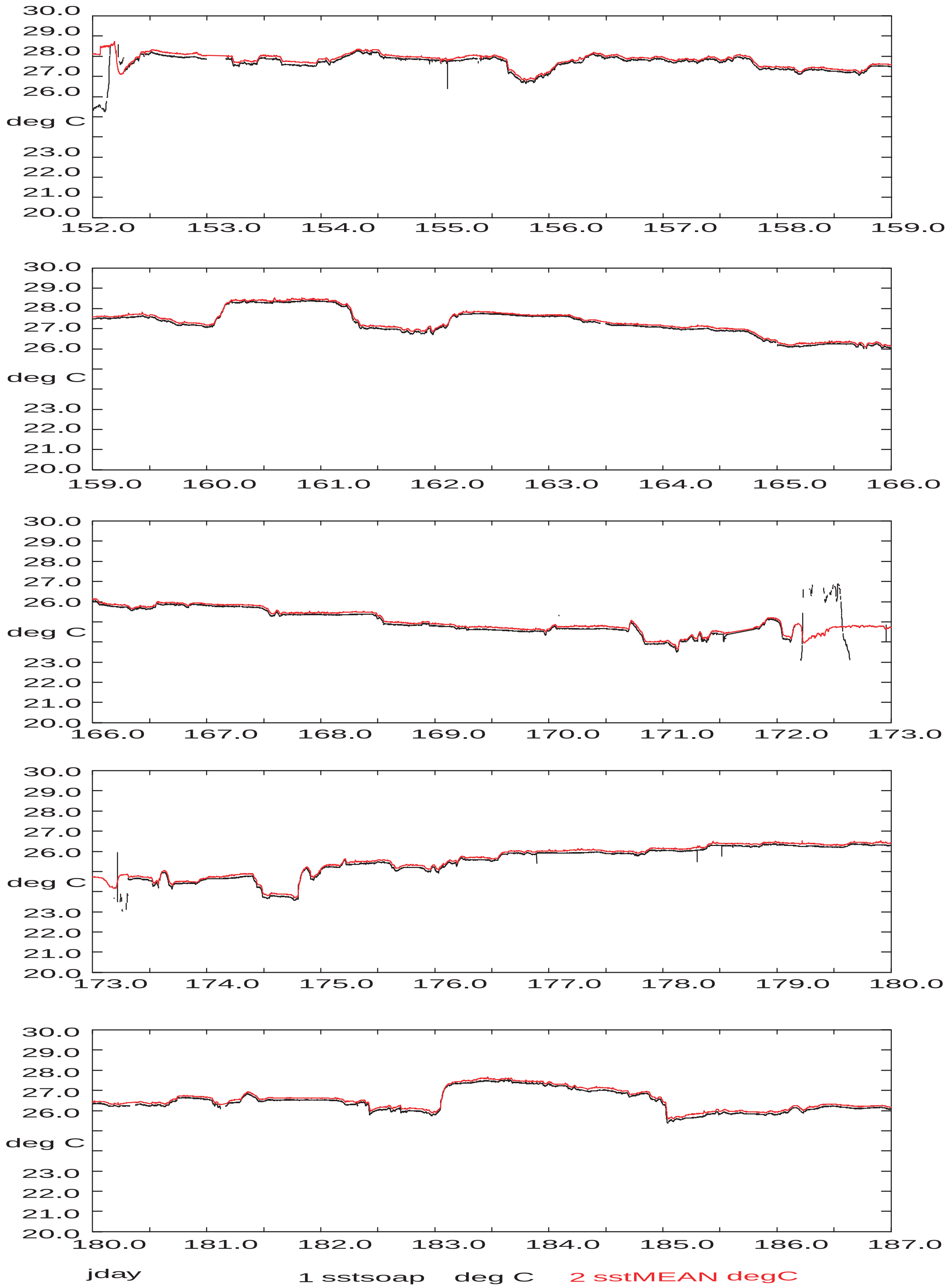

Figure 11.5. Sea-surface temperatures (°C) from the soap (sstsoap, black) and the WHOI sensor (sstMEAN, red), for the duration of the cruise.

samples, and at the end of every hour the data were processed to provide spectra and quality control parameters. The true wind speed, true wind direction, and mean measurements of the H_20 and CO_2 levels over a period of 50 seconds were calculated.

Throughout the cruise the Autoflux workstation performed well, with only one failure at the beginning of day 153 (June 2). It is believed that the power off button on the front of the workstation was inadvertently pressed causing the workstation to power down. The system was rebooted when the next watch started three hours later. During the cruise, the workstation rebooted itself 4 times. As an example, during day 184, the Autoflux display was found to be blank. The command "rup" was used to establish that the machine had only been up 20 minutes. It is speculated that the cause of the reboots may be due to the UPS (uninterruptable power supply), but could not be confirmed on the cruise.

More information on air-sea fluxes and the AutoFlux project in particular can be found under: http://www.soc.soton.ac.uk/JRD/MET/AUTOFLUX.

11.4 Sensor Performance

Comparisons between sensors were routinely made during both legs of the cruise and the following points were observed. Firstly, there were a number of simultaneous drop-outs on each psychrometer which typically lasted 2-3 data cycles (up to 30 seconds). As an example, on jday 162 it was observed that the wet bulb temperatures increased slightly, whilst the dry bulb temperatures reduced dramatically. In general, simultaneous drop-outs were also observed in the SOAP SST data and the short wave measurements, suggesting that the instruments' rhopoint modules, located on the foremast platform, were all being affected at the same time. UHF transmissions and downloading of data via the satellite system could not be traced as the problem and it is unclear why the drop-outs were present. When the drop-outs were removed, though, the mean daily differences in the measured dry bulb air temperatures were below 0.01 °C (with a standard deviation, s.d, of less than 0.004) whilst the wet bulb temperatures agreed to within 0.05 °C (and a s.d. of less than 0.001). The psychrometers and the rhopoint modules were checked on day 171 (June 20). No problems were found, however, so the wet bulb reservoirs were topped up, and it was decided not to change the instruments.

A comparsion of the Kipp and Zonen short-wave sensors showed that both sensors were in good agreement.The daily mean difference in the measured short-wave values was below $5Wm^{-2}$ for 30% of the time and below 20 Wm^{-2} for 64 % of the time. However, both short-wave sensors were prone to shadows cast by the foremast and the psychrometers, blocking out the sunlight at different times of day for each sensor, resulting in some of the larger differences. Due to the effect of the shadows, it is recommended to use the maximum of the two sensors.

Initial comparison of the two longwave radiometers showed good agreement with each other through both legs of the cruise. The daily mean long wave measurements, in general, agreed to within 5 Wm^{-2} of each other with a standard deviation of 2.3 Wm^{-2}. No significant trend due to heating from short wave radiation was seen in the mean longwave difference.

The trailing thermistor (SOAP) sea surface temperature sensor performed well throughout the entire cruise, and when compared to the ship's TSG had a general offset of approximately 0.01 °C. It should be noted that while steaming the soap trails in the top 0.5 m of the water column, but while on station it has a tendency to sink to the depth of the TSG hull intake at 5 m. There was no discernable difference (to within 0.02 °C) between the soap SST and the TSG measured when the ship was steaming and when on station, i.e. the bulk SST at 5 m was the same as that measured in the top 0.5 m. This is thought to be due to the intense mixing in the surface layer. The WHOI mean temperature sensor performed well and on average overestimated the soap by 0.1 °C.

Measurement	**Mean**	**Standard deviation**
LW radiation (3117)	396 (Wm^{-2})	23.6 (Wm^{-2})
LW radiation (1311)	401 (Wm^{-2})	22.2 (Wm^{-2})
SW radiation	356 (Wm^{-2})	267 (Wm^{-2})
Port dry bulb temperatures	25.0 (°C)	1.7 (°C)
Port wet bulb temperatures	22.1 (°C)	2.2 (°C)
Relative humidity	78.0 (%)	7.5 (%)
SOAP SST	26.4 (°C)	1.2 (°C)
WHOI SST	26.5 (°C)	1.2 (°C)
Wind speed (HS)	10 (m/s)	2.8 (m/s)

Table 11.5. Mean values of meteorological parameters during the cruise.

The vector anemometers on the temporary mast performed well throughout the cruise. The windmaster sonic, however, was noted to be at angle of about 10° from the vertical on jday 180. The bolts were tightened and the sonic realigned, but it soon returned back to an angle of 10°. As the instrument did not seem to move further, it was decided to leave it at this angle as only the wind speed magnitude was of priority.

Comparison	Mean	Standard deviation
LW (3117)-LW(1311)	-4.65	2.3
SW1-SW2	28.3	91.6
Port dry - starboard dry	0.03	0.09
Port wet -starboard wet	-0.03	0.04
TSG-SOAP	-0.01	0.04
TSG-WHOI	-0.12	0.04
SOAP-WHOI	-0.108	0.04

Table 11.6. Mean differences of meteorological parameters during the cruise.

The mean values of the mean meteorological parameters throughout the cruise are given in Table 11.5, and the mean differences between the sensors are given in Table 11.6.

11.5 Flow Distortion Study

The presence of the ship distorts the flow of air to any instrument mounted on it by accelerating or decelerating the flow and also displacing it vertically. Hence any wind speed measurement made from a ship-mounted anemometer may be biased. In recent years, Computational Fluid Dynamics (CFD) models have proved successful at quantifying the effects of flow distortion at well exposed anemometer sites on research vessels, but the performance of the models in areas of severe flow distortion has not been investigated. In particular, anemometers on merchant ships are often mounted on a mast above the bridge and are likely to be in a region where the flow is accelerated or decelerated a great deal.

To study such flows, and the performance of the CFD models in reproducing them, the wind speeds measured from the anemometers on the temporary mast were sub-sampled for flows directly over both the port and starboard beams. These were compared to CFD predictions and wind tunnel studies of the flow over a bluff body tanker shape. Initial results showed that for airflows directly over the starboard bow, the measured winds during the cruise agreed well with the CFD predictions.

11.6 Visual Cloud Observations

Two independent sets of visual cloud observations were made every hour by a) the ship staff on the bridge, and b) by the Ben Moat (supplemented by early morning and night observations by Brian Dickie, Kate Stansfield, Chris Green and Alan Evans). For each observation, the amount of low, medium and high cloud and the total cloud cover was recorded in octas (eigths). After the cruise, these results will be used to evaluate the performance of various simple longwave formulae of the type used in ship-based climatological analyses. This study is of particular importance as these formulae have yet to be properly tested using high quality measurements of the longwave flux in the tropics, and it is possible that a significant fraction of the global heat flux imbalance found in many climatological studies is due to a bias in the adopted longwave formulae.

11.7 Radiosondes

Vaisala RS80-15 GPS radiosondes, provided by the UK MET office, were launched to measure the temperature and water vapour structure of the troposphere and provide wind speed and direction profiles. The aim of this was to provide a description of atmospheric conditions during the cruise period and area, which would also be useful for the validation of the AATSR instrument on the ENVISAT satellite via the SISTeR radiometer (see section 12). After each radiosonde profile was completed a TEMP message (WMO message FM35) was generated and sent to Bracknell via IMMARSAT C for weather forecasting purposes.

Data were acquired via an RS232 connection from a PC to a DigiCORA MW15 GPS receiver. The measurements were based on the use of a free-flying balloon-carried radiosonde, transmitting data to the receiving station at a frequency of between 400 - 406 Mhz. Pressure, temperature and humidity were measured by sensors in the radiosonde whilst wind speed and direction were determined by relaying GPS wind finding data to the MW15 receiver. The aerials were mounted on the port side of the bridge top and 200g TOTEX balloons were inflated in the balloon launcher situated on the aft portion (port side) of the boat deck. Provided the relative wind direction was at least 20 degrees off the starboard bow, balloons could be released clear of all obstructions for all wind strengths. A summary of the flight details for each launch is given in Appendix C.

A problem was encountered during the first radiosonde launch, in which the PC was not receiving data from the DigiCORA. The communications port settings in the logging software were changed and the PC successfully logged data for the remainder of the radiosonde launches. All launches except one passed 100 mbars before bursting, whilst only 2 launches (numbers 2 and 13) out of 19 failed to record GPS winds. Data processing was carried out on board. Data from each launch was transferred to a Sun workstation and converted into PSTAR format. Plots of temperature, relative humidity, and wind speed and direction, against pressure, were generated.

Ben Moat (and Tim Nightingale)

12 SISTeR OBSERVATIONS

The Scanning Infrared Sea surface Temperature Radiometer (SISTeR) from the Rutherford Appleton Laboratory (RAL) is a compact, self-calibrating filter radiometer designed to measure the skin temperature of the sea surface. A SISTeR was deployed on the RRS Charles Darwin cruise 141 with support from a small grant from the NERC for the beginning-of-life validation of the AATSR sea surface temperature sensor on the ESA ENVISAT satellite, and the end-of-life validation of the ATSR-2 sensor on ERS-2.

The SISTeR was mounted on the handrails of the port quarter of the ship's foremast platform, immediately inboard of the access ladder and facing outwards over the bow at about 45° from the centre line of the ship (see Figure 11.2). The SISTeR scan mirror was stepped out from the ship at small angular increments and the first clear view to the sea was identified at approximately 20° from nadir. A sea view at 25° was chosen for the standard scanning sequence, along with sky views at 50°, 25° and 0° from zenith. Skin SSTs were calculated from the sea view, with small corrections for reflected sky radiance from the 25° sky view (DONLON & NIGHTINGALE, 2000).

The SISTeR calibration was checked repeatedly against a CASOTS portable black body (DONLON et al., 1999), both before shipping and aboard the Darwin before, during and after the cruise. The CASOTS black body consists of a thin-walled copper cavity immersed in a water bath. The bath temperature was monitored with a Thermometrics AS125 thermistor (S/N 2228), and a Hart Scientific 1504 bridge (S/N A14282). The combined accuracy of the thermistor and bridge was approximately 3 mK at room temperature. The water in the CASOTS water bath was circulated with a 50 W immersible pump, which doubled as a water heater, giving a temperature rise of approximately 3 K (°C) every hour. The initial deviation of the brightness temperature recorded by the SISTeR from the thermometric temperature of the water bath was approximately 10 mK near to ambient temperature, with a slope of –1.5 mK/K over the measurement range. Measurement noise on a 0.8 s sample increased slightly through the cruise from an initial 30 mK or so as the optical surfaces degraded, but the calibration result was reproduced to within the experimental accuracy on each calibration check.

The SISTeR was operated (only possible when it was not raining) for about half of the total cruise time, starting a couple of hours after leaving the Seychelles on the morning of June 1, 2002, and finishing early on the morning of July 10, a day before making port in Mauritius. Skin sea surface temperatures varied between approximately 24°C and 28°C. Poor weather limited observations below approximately 10°S. Scattered cloud was generally present although there were sometimes clear skies, especially at night over the northern part of the cruise track. The cruise track coincided with (i.e. was directly below) the AATSR swath on seventeen occasions (Table 12.1), always near to 10 am or 10 pm local time (0600 h or 1800 h GMT), and with the ATSR-2 swath approximately half an hour later. Of these, four or five fell within the intervals of clear sky and are prospects for validations of both the ATSR instruments. These should be particularly valuable because of the high temperatures (which are not often achieved elsewhere). Balloon GPS radiosondes were also released for the 6am and 6pm UTC (GMT) synoptic times that most closely coincided with the overpasses (see section 11.7).

Overpass	Julian Day UTC	Time UTC	Latitude	Longitude	Across Track Position (km)	Comments
1	152	06:07:59	4°34.12'S	55°36.51'E	189	
2	153	18:08:28	4°17.81'S	56°31.98'E	220	Cloud
3	155	06:13:44	5°14.07'S	57°17.28'E	165	Cloud
4	156	18:13:14	7°12.80'S	58°18.35'E	58	
5	159	05:48:45	8°00.02'S	61°19.86'E	31	Cloud
6	160	17:47:12	8°00.04'S	64°00.79'E	43	
7	163	05:23:56	11°23.91'S	65°19.81'E	212	Cloud
8	163	17:51:38	12°18.29'S	65°19.81'E	147	
9	166	05:31:04	16°29.21'S	63°26.86'E	132	Cloud
10	166	17:55:58	17°49.54'S	62°45.08'E	107	Rain
11	169	05:37:39	19°35.70'S	61°59.89'E	56	Cloud
12	169	18:01:10	19°44.99'S	61°55.44'E	90	Rain
13	175	05:48:56	18°37.85'S	58°23.89'E	155	Cloud
14	175	18:13:06	18°00.00'S	59°42.03'E	19	Cloud
15	178	05:53:13	14°12.81'S	61°55.91'E	257	Cloud
16	182	17:55:28	9°26.06'S	61°24.08'E	126	
17	184	06:03:05	7°59.96'S	58°11.94'E	18	Cloud

Table 12.1. AATSR overpass analysis for CD141. The time and ship's position at overpass is listed, along with the distance of the ship from the centre of the AATSR swath ("across track position"), and a note on the conditions at overpass.

Tim Nightingale

13 OXYGEN AND NUTRIENTS

13.1 Dissolved Oxygen

- ***Sampling***

Sampling for dissolved oxygen was done on every Niskin bottle from the water sampler on all the CTD casts. The samples were drawn from the Niskin bottles into 100 ml calibrated oxygen bottles, and the stopper was carefully placed so as not to trap any air bubbles. The samples were then immediately fixed with 1 ml manganous chloride and 1 ml alkaline iodide, and thoroughly shaken. The fixing temperature was then measured using a spare bottle. Duplicate samples were taken, usually number 2 on 6 bottle casts, and number 3 on 12 bottle casts, except at the beginning of the cruise, where complete sets were taken for initial checks. The crate of samples was filled with non-toxic seawater to keep the samples at a more or less constant temperature (~20°C). It was also covered with its lid to prevent excess light. After 15 to 30 minutes, all bottles were shaken a secondtime to ensure a reduction in flocculent size and an efficient titration. The samples were then left to settle for an hour.

- ***Titration***

The titration was usually completed within 4 to 5 hours after sampling. This was done using an SIS Winkler titration unit with spectrophotometric endpoint detection. The Dissolved Oxygen Analyser software provided the necessary stages of operation, recording and calculation (following the WOCE methodology), as detailed below:

- Bottle record: a complete list of the oxygen sampling bottles used, with number and calibrated volume,
- Blank measurement: checking the reagent normality,
- Standard measurement: checking the thiosulphate titer,
- Titration: oxygen determination,
- Data file record: with entry details and calculated results.

Prior to titration, three sets of reagent blanks were determined, involving three successive 1 ml additions of in-house potassium iodate standard. This was of particular importance whenever reagents were replaced or topped up. Three sets of thiosulphate standardization were also determined. After blanks and standards were done, titration of the samples was carried out. The characteristics of depth, *in situ* sample temperature, fixing temperature and salinity were entered. The sample was then carefully opened. The stir bar and 1 ml of sulphuric acid were added to the solution, and the SIS system fulfilled the thiosulphate addition.

At the end of titration, the titer volume and oxygen concentration (in mg/l, % saturation and µmol/kg) were recorded on the worksheet. An Excel spreadsheet was available for concentration calculations (Dickson method), but was to be completed back at SOC, for validation of the software results. Once all samples were completed, an extra titration of OSI standard was done, to make sure the reagents and titer were not leading to variations. The solutions proved to be stable throughout the cruise. Around 860 samples and duplicates were analysed throughout the cruise.

13.2 Nutrients

- ***Sampling***

Nutrient samples (for nitrate, phosphate and silicate) were drawn from the Niskin bottles after the oxygen samples, into brand new 40ml coulter counter vials, each labelled with cast number and bottle number. Every sample was duplicated. Once sampling was done, the vials were placed in a fridge in the wet lab, until analysis started (usually the same day or within 24hrs).

- ***Analysis***

Analysis was done using a Skalar SanPlus autoanalyser. Reagents were prepared according to modifications derived from Skalar reagent preparations (used by R. Sanders, SOC). Standards were prepared using 3 batches (for nitrate, silicate and phosphate) made at the start of the cruise. These batches were kept in a fridge in the wet lab, and checks were made throughout the cruise against OSI standards, to verify stability.

Standards used in the runs were prepared daily, and some modifications of concentration occurred during the cruise, according to nutrient levels observed.
A distilled water time was allocated at the start of each run. At the end, a 10-20 minute run of distilled water, followed by 10-20 minutes of Decon solution, finished with another distilled water wash were performed to prevent accumulation in the tubing. A distilled solution of alkaline iodide was used (instead of Sodium hydroxide), to run before Decon in the phosphate lines, to clear deposition in the tubing.

Runs were done following Skalar recommendations on Drift and Standard procedures. Resulting files were checked and any mismatched peak was manually positioned to ensure good data. Files were then exported to Excel and processed together with CTD data. Results showed a usual profile of high concentrations at depth, depletion starting generally within about 1000m from the surface, and reaching very low levels in the top 100m or so. Around 900 samples were analysed throughout the cruise.

Marc Duc, Brian Dickie and Chris Green

14 BIOGAS MEASUREMENTS (AND CFC TRACERS)

14.1 Introduction

There were two main aims to the trace gas measurements on the cruise. The first was to investigate the release of biogenic gases ("biogases"), primarily volatile halocarbons eg methyl bromide, methyl chloride and methyl iodide, from identifiable phytoplankton sources. The study involved making extensive biogas measurements together with a detailed survey of phytoplankton and picoplankton. By coupling this work with the zooplankton distribution study and with the optical /satellite calibration and turbulence information, the ultimate aim was to gain an understanding of biogas release in the Indian Ocean and to investigate the use of optical and satellite data as a surrogate for global biogas production. This is the first time that a biogas–satellite link has been investigated.

The second aim was to collect CFC tracer data to WOCE standards for CFC-11, CFC-12, CFC-113 and carbon tetrachloride in order to characterise the water masses of the region and make a study of their spreading, mixing and ventilation rates.

14.2 Sample Collection and Analysis

Samples were drawn from the 10 l Niskin bottles on the CTD frame which had been checked for physical integrity and chemical cleanliness prior to the cruise; no contamination of the bottles developed during the cruise. Samples were drawn first from the rosette/ water sampler, directly into

250 ml ground glass syringes and stored under a continuous flushing stream of surface seawater to keep gas tight. All samples were analysed within 8 hours of collection and most within 4 hours. No evidence of degradation occurred through storage.

Halocarbons (up to molecular weight 253) were analysed using an HP 6890 GC /5973 MSD fitted with a 30 m CB Sil-5CB (0.32 mm id, 5 µm film thickness) coupled to a purge and trap system. The basic principles of the purge and trap system are given in SMYTHE-WRIGHT (2000) and SMYTHE-WRIGHT et al. (2001) and are summarised below. The GC/MS system was set up in the constant temperature laboratory to enhance rapid cool down of the instrument following the chromatographic run. The laboratory temperature was initially set at 25°C but it was subsequently found that operation in fan-only mode was sufficient to keep the laboratory at a temperature below 29°C and the GC/MS cooling optimal.

The trap was a 1/16" stainless steel tube filled with glass beads, cooled using liquid nitrogen and heated using an electric bunsen to 140°C. Drying of the gas stream was achieved using a drying tube filled with anhydrous K_2CO_3. The instrument was set up in SIM (EI) mode to search for 26 halocarbons (see Table 14.1). The chromatographic run time was a balance between high sample throughput and the necessity to sparge for 8 minutes in order to gain good extraction, while having sufficiently long analysis time to cover compounds up to dibromochloromethane with good chromatography. An analysis run time of 12.35 minutes was found to be optimum giving a total analysis time for one sample as 20.35 minutes. However, the actual analysis time was shortened by running the extraction procedure in parallel with the chromatographic run through the GC/MS, giving a sample throughput of approximately one per 15 minutes, allowing for cooling time of the GC/MS system.

Due to a delay in getting the GC/MS fully operational, measurements were made from CTD station 19 onwards. More than half of the stations sampled had 12 depth levels over the full depth of the water column, and the remainder were sampled at 6-8 depths in the top 200 m to focus on biogenic gas release. A total of 46 locations were measured.

14.3 Calibration and Precision

Standardisation was carried out by injection of known quantities of calibrated gas using fixed-volume sample loops (Table 14.2).

Two sources were used, one from a cylinder calibrated by NOAA/CMDL (cylinder number 67707) and the second from a Kin-Tek standards generator, the latter providing calibration of a number of compounds not measured in the NOAA cylinder. The initial intention was to feed the Kin-Tek from

Compound	Formula	Retention Time	Target Ion	Standard Used
HCFC-22	$CHClF_2$	1.95	51	N
CFC-134a	$CH_2F.CF_3$	2.04	69	N
Chloroethene	C_2H_3Cl	2.09	62	N
CFC-12	CCl_2F_2	2.2	85	N
HCFC-142b	$CH_3.CF_2Cl$	2.3	65	N
Methyl Chloride	CH_3Cl	2.62	50	N, K
Methyl Bromide	CH_3Br	2.90	94/96	N, K
CFC-11	CCl_3F	3.56	101	N
HCFC-141b	$CH_3.CCl_2F$	3.57	81	N
Dimethylsulphide	$CH_3.S.CH_3$	3.91	62	K
Methyl Iodide	CH_3I	3.94	142	K
Methylene Chloride	CH_2Cl_2	3.95	84	N, K
Dichloroethene	$C_2H_2Cl_2$	3.97	96	TBC
CFC-113	$CCl_2F.CClF_2$	4.1	101	N, K
Bromochloromethane	CH_2BrCl	5.12	130	K
Chloroform	$CHCl_3$	5.18	83	N, K
Iodoethane	$CH_3.CH_2I$	5.23	156	K
Methyl Chloroform	$CH_3.CCl_3$	5.9	97	N, K
Carbon Tetrachloride	CCl_4	6.6	117	N, K
1-Iodopropane	$CH_3.CH_2.CH_2I$	6.7	127	TBC
Trichloroethylene	$CCl_2.CHCl$	7.1	130	TBC
Bromodichloromethane	$CHBrCl_2$	7.19	83	K
Chloroiodomethame	CH_2ClI	7.65	176	K
Tetrachloroethylene	$CCl_2.CCl_2$	10.0	94	N, K
Bromoform	$CHBr_3$	11.6	174	K
Dibromochloromethane	$CHBr_2Cl$	11.7	127	K

Table 14.1. Compounds measured by the GC/MS. N: "NOAA": Cylinder ALM-67707; K: Kin-Tek Standards Generator; TBC: To be calibrated.

Loop Name	Symbol	Volume
Small Sample Volume	SSV	0.746 ml
Large Sample Volume	LSV	2.918 ml
Very Large Sample Volume	VSV	7.718 ml

Table 14.2. Sample loop volumes.

the ship's nitrogen gas generator. However, this was not adequate for the job, giving only 1 litre per minute of gas, while the Kin-Tek required closer to 5 litres per minute during the injection cycle. Fortunately, there was over capacity in the number of helium gas tanks supplied to the ship and the Kin-Tek was fed from cylinder helium for the entire cruise. Details of the permeation tubes used in the Kin-Tek are given in Table 14.3.

Compound	**Tube number**	**Calibrated rate (ng min $^{-1}$)**
Methyl Chloride	23776	699
Methyl Bromide	30916	13514
Dimethyl sulphide	30919	907
Methyl Iodide	26983	1252
Methylene Chloride	23772	450
Bromochloromethane	23775	132
Chloroform	26987	774
Iodoethane	25274	654
Methyl Chloroform	23766	362
Carbon Tetrachloride	23769	522
Bromodichloromethane	25276	602
Chloriodomethane	25179	854
Tetrachloroethylene	23774	275
Bromoform	23768	145
Dibromochloromethane	23780	22

Table 14.3. *Calibrants used in the Kin-Tek system.*

14.4 Problems

Problems arose from the lack of mobilisation time at the beginning of the cruise and the time it took to get the GC/MS and associated equipment up and running during the early part of the cruise. The main problem was with small but multiple air leaks in the GC/MS and the associated purge and trap system. Unfortunately, these had not been sourced and dealt with prior to the cruise due to health problems. Once these were eliminated, the GC/MS equipment worked perfectly for the entire cruise. The additional problem with the nitrogen gas generator supply, detailed above, was quickly overcome, but necessitated the purchase of extra helium in Mauritius at high cost.

Denise Smythe-Wright and Mark Varney

15 PHYTOPLANKTON AND PIGMENT STUDIES

15.1 Introduction

The principal focus of this work was in support of the biogas, zooplankton, optical and satellite calibration work detailed elsewhere in this report. There is some evidence to suggest that phytoplankton are natural producers of halocarbons which are involved in ozone depletion and greenhouse gas issues. In addition, plant pigments are fundamental contributors to ocean colour. Samples for plant pigment analysis, picoplankton analysis and speciation studies were therefore collected for subsequent analysis at SOC from 55 of the CTD stations along the cruise track, together with 20 plant pigment samples from the shipboard non-toxic (underway) supply, commencing on 26 June, to calibrate the underway fluorometer. Sampling focused on 6-8 depth levels in the top 200 m of the water column.

15.2 Filtered Samples (Pigments)

Following the collection of all other samples from the rosette/ water sampler, water samples for filtration (to assess pigments) were collected into 5 l carboys which were rinsed in the sample prior to being filled. Typically, 6-8 samples were taken from the top 200 m of most CTD stations. These were then subsampled as follows: for each of the 6-8 depth levels, duplicate 2 l water samples were filtered through 25 mm Whatman GF/F filters using a specially developed positive pressure filtration unit. The filter papers were immediately placed in cryovials and stored in liquid nitrogen. The samples were returned to SOC immediately after the cruise in dry shippers and again stored in liquid nitrogen prior to analysis. In all, 57 profiles of pigments were made. These were synchronised to be within 30 minutes of the Satlantic profiles of light, and will be used to calibrate the MERIS ocean colour sensor on the ENVISAT satellite (see section 17). In addition, surface pigment samples were taken from the non-toxic supply on a daily basis from June 26 for calibration of the underway fluorometer (20 samples being taken in total).

15.3 Water Bottle Samples

Water bottle samples were collected both for phytoplankton speciation and picoplankton identification studies. The phytoplankton samples for microscope speciation studies at SOC were taken at the surface, and at the chlorophyll maximum. Two 100 ml amber glass bottles were filled for each depth and preservative agents 1 ml of Lugol's iodine and 2 ml of 4% formaldehyde were added to each.

For the picoplankton identification study, at each of the 6-8 depth levels and in duplicate, 1.8 ml of the bulk water sample was placed in a cryovial and 50 µl of 37% formaldehyde added. The formaldehyde had previously been filtered using in-line filters to remove particles and stored in the 4°C refrigerator. The samples were subsequently stored in the 4°C refrigerator to stabilise and after

24 hours transferred to the –20°C freezer. The samples were returned to SOC in a dry shipper that had previously been cooled to –20°C.

Denise Smythe-Wright, Alison Weeks and Chris Green

16 MESOZOOPLANKTON

16.1 Introduction

The Shoals of Capricorn Programme of the Royal Geographical Society (with the Institute of British Geographers) and the Royal Society conducted marine research around the Mascarene Plateau between 1998 and 2001. As a part of this programme, the 20m sailing research vessel SRV "Zuza" was used to conduct a biological and hydrographic survey of the Mascarene Plateau and Basin between the Seychelles and Mauritius. It was the purpose of that study to investigate to what extent zooplankton biomass may be enhanced by the presence of the Mascarene Ridge in the general westerly flow of the South Equatorial Current, and the assumed associated upwelling of nutrient-rich water around and in the lee of the ridge.

The results from the SRV Zuza cruise showed that zooplankton biomass in the lee of the ridge was very much higher than would be expected in sub-tropical open ocean waters, being more typical of high-energy and well-mixed environments. It was the purpose of the present work to confirm these results at a similar time of the year, and to attempt to relate the enhancement of zooplankton biomass to the physical processes assumed to be driving the increased productivity of this region.

16.2 Materials and methods

Sampling was centred on the use of vertically integrated net hauls, and two Optical Plankton Counters (OPC, HERMAN, 1992) used in vertical profiling and continuous ship-borne mode.

- ***Vertical profiling mode***

Net samples were taken at regular stations, typically once or twice per day, during the second leg of the cruise, using the OPC profiling rig. This device uses a triple net assembly. Two nets (125 µm and 200 µm mesh) were connected to cod ends. On recovery the sample was immediately washed out of the cod ends on to a 150 µm sieve using filtered seawater, and preserved in 4% buffered formaldehyde solution for subsequent analysis. The third (central) net (200 µm mesh) acts as a concentrator for the OPC, yielding a vertical distribution of the larger (>~800 µm ESD) zooplankton. Nets were made from nylon mesh, conical in shape, 1.5m long on a stainless steel ring (57 cm in diameter). A flow meter was installed in the mouth area of the net to enable calculation of volume sampled by the net. Nets were deployed from the hydrographic winch installed in the main CTD gantry, and to a depth of 150 m. Net samples therefore all represent a depth greater than the mixed layer depth (50-100 m during the cruise).

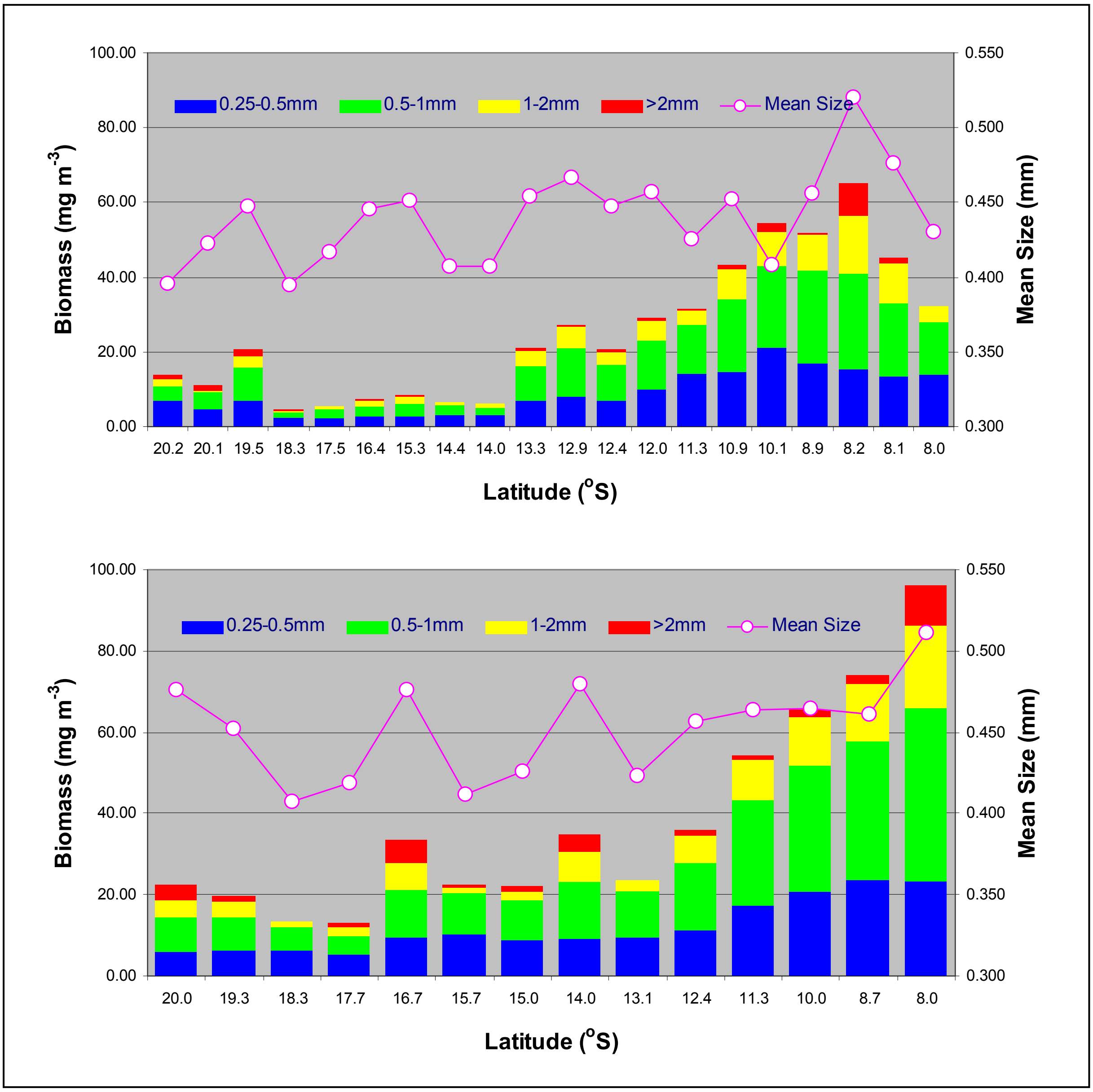

Figure 16.1. Continuous surface zooplankton biomass from OPC-1L in ship-borne surface sampling mode. Biomass in mg m^{-3} for each of four size classes (250-500 µm, 500-1000 µm, 1000-2000 µm and >2000 µm ESD). Mean particle size for each sample also shown. The upper panel is essentially just east of the Ridge, the lower panel is about 200 nm further west.

- ***Continuous ship-borne mode***

A laboratory OPC (OPL-1L) was used (again, during the second leg of the cruise only) to sample surface waters continuously from the ship's uncontaminated (non-toxic) sea water supply. Water from a constant depth (about 6m) was pumped continuously through the OPC. The deployment of the OPC in this mode yields a continuous near-surface size distribution of mesozooplankton biomass across very large spatial scales (GALLIENNE & ROBINS, 1998; GALLIENNE et al., 2001). The

OPC data were validated by taking intermittent samples filtered from the OPC outlet. These samples were preserved as above for subsequent microscopic analysis and comparison to the OPC data.

16.3 Provisional Results

The data from the vertical net hauls will not be available until analysis has been completed at Plymouth Marine Laboratory (PML) after the cruise. Figure 16.1, however, shows the mean continuous surface mesozooplankton biomasses between net sample positions, taken along the transects north from Mauritius to the western edge of Saya de Malha Bank (8°S, 57° 22'E), and from that point southwards back to 20°S, 55° 33'E, near Mauritius (see Figure 1.1). Data are integrated for each run between stations, and shown as biomass in each of four size classes. Units of biomass are given in mg m^{-3}. This is derived from OPC biovolume in ml m^{-3}, assuming a specific gravity for mesozooplankton of 1. Biovolume is calculated as follows (after GALLIENNE & ROBINS, 2001): particle cross-sectional area (CSA) is calculated from OPC digital size (DS) as CSA = 0.0102 * DS. Particle volume is then calculated assuming an ellipsoidal model with a variable length-to-width ratio dependent on body length.

Chris Gallienne

17 OPTICAL OCEANOGRAPHY

17.1 Introduction

The main objective of the optical oceanography carried out during CD141 was to make validation measurements for MERIS, an ocean colour sensor mounted on ESA's ENVISAT satellite. This work comprises part of the validation campaign, which runs for 6 months after the launch of the satellite, which was on May 1 2002. The work requires matchups between satellite overpasses and *in situ* measurements of phytoplankton pigments as well as surface irradiance (Eo), and profiles of downwelling irradiance (Ed) and upwelling radiance (Lu) for which the Satlantic system (profiling the upper 50 m of the water column) has been used. This data will form part of the validation database, to be used to convert the satellite images to chlorophyll (pigment) concentrations. A second objective is to develop an algorithm for pigment concentrations from in situ measurements (Satlantic data) and pigments for the area under study. Finally, the degree of spatial variability, which affects the accuracy of the satellite-derived pigment concentration, was to be ascertained using the towed sub-surface sensor Lightfish and underway fluorescence measurements. It was hoped that a hyper-spectral instrument could have been used for more detailed analysis of the absorption by phytoplankton pigments (SUMOSS) but this instrument did not function during the cruise. SeaWiFs and AVHRR images of the cruise were requested to be sent to the ship from Plymouth Marine Laboratory (PML) regularly throughout the cruise (via email) as a guide to the spatial distribution of phytoplankton and surface temperature, and this proved very useful.

17.2 Measurements

- ***Satlantic***

Measurements of surface irradiance (Eo) were made via a Satlantic sensor mounted on the foremast. Profiles, to about 50 m, of downwelling irradiance (Ed) and upwelling radiance (Lu) were made using a small Satlantic rig deployed from a crane using a slip ring winch on the aft deck from the port side. Measurements were typically made with the sun on the port side to prevent ship shadow affecting the measurements. (During the early part of the cruise, the measurements were made from the starboard side until it was realised that this side of the ship would typically cast a sun shadow over the profiles because the ship's head would be pointing towards the SE, into the trade winds, while on station.)

Daily measurements (from the mast sensor) of the surface downwelling irradiance (Eo) were made throughout the whole cruise. These were generally made during the period from 0800 to 1600 h local time. In addition, 26 water profiles to 50 m (from the profiling instrument) of downwelling irradiance and upwelling radiance were made during the cruise, approximately on a daily basis, when weather allowed, and during satellite overpasses. These were synchronised to be as close as possible (within 30 minutes) of water samples being taken during the upcast of a CTD profile. The Satlantic profile data have been calibrated and scrutinised for quality. A problem with the slip ring winch, which was used to deploy the Satlantic profiler, interrupted the daily pattern of data collection for 2 days, but was rectified. The reference sensor data quality was excellent throughout the cruise.

- ***Pigments***

These are described in section 15 above.

- ***ENVISAT matchups***

14 matchups were made between ENVISAT overpasses, Satlantic profiles and pigment profiles. Of these, it is anticipated that about half will contain too much cloud to obtain good quality MERIS data synchronised with the *in situ* data, but this will not be known until the satellite data can be examined after the cruise.

- ***Lightfish***

8 Lightfish tows were obtained during the cruise, giving information about the sub-pixel scale patchiness of reflectance and fluorescence. This will be combined with the data from the ships underway fluorometer. Poor weather in the southern area of the cruise and rather short periods between CTDs reduced the potential for further Lightfish tows.

- ***SIMBADA radiometer***

Daily measurements were made for the thickness of the aerosol layer using the SIMBADA radiometer, lent by the University of Lille. These measurements were made when the sun was visible, and within 30 minutes of Satlantic profiles and pigment profiles. 24 sets of measurements were made.

- ***Secchi disk depth***

Measurements of Secchi disk depth were made on an almost daily basis at the time of Satlantic profiles, on the second leg of the cruise. In all, 14 Secchi depths were recorded.

- ***Satellite images***

SeaWiFS and AVHRR images were sent to the ship from PML when available. These greatly helped to interpret the surface distribution of phytoplankton and near-surface temperature. The actual data from these images will be available after the cruise. The general distribution of phytoplankton pigments shows higher values in the northern portion of the survey area and close to the Ridge, with some sharp gradients in regions where physical features were found.

Alison Weeks and Chris Green

18 SCIENTIFIC ENGINEERING

All engineering equipment used was found to function satisfactorily throughout the cruise, with the exception of the following items:

18.1 Starboard Gantry

This was used extensively throughout the cruise. Several major leaks were discovered on the hydraulics, but these were rectified by fitting new Dowty sealing washers and tightening several unions. In addition, a crew member received a small electric shock when testing the gantry emergency stop. On investigation, water was found inside the stop box. This was cleaned out and dried, and the box cover was replaced and silicone-sealed up. However, a week or so later another crew member received a shock.

As mentioned previously (on CD127) the gantry judders violently when moving outboard. The control lever must be released and not tried again until the juddering has stopped. This problem has become progressively worse since last year. This is a safety matter, because in marginal weather conditions the CTD must be deployed as quickly as possible to avoid potential damage and injuries from the swinging package. In very rough weather, the gantry made a load thumping sound as the ship rolled. This was traced to the locking dogs on the main gantry support arms. When the gantry was fully inboard and in the stowed position there is excessive wear on the dogs. This allows the gantry to move back and forth against the dogs as the ship rolls. This movement could also be because of air in the main rams, allowing the gantry to move and compress the air trapped in the end of the cylinders. It is recommended that the locking dogs are repaired and that the rams are bled at the next available opportunity.

18.2 CTD Winch and Wire

During the first test deployment of the CTD package a loud bang was heard from the CTD winch. On investigation the chain drive for the scroll shaft had exploded, and the scroll carriage was jammed at one position on the scroll shaft. After retrieval of the CTD and three hundred metres of cable, the main scroll carriage sheave was dropped to allow access to the scroll shaft follower. The follower had to be jacked out of its bush housing. On removal it was apparent that the follower had not seen grease for a long time. This fact had contributed to the scroll jamming. When the follower reached the end of its travel in one direction and was supposed to kick back to travel back along the shaft it could not, and tore a large chunk out of the scroll shaft.

The follower had to be repaired, since no spare could be found onboard. The bent part was ground off and weld added to try to build up the follower to some semblance of the original. The scroll shaft was also weld-repaired and redressed as best it could be. Test dip CTDs were carried out to gain confidence with the repairs, and then the winch was used successfully for the remainder of the first leg. On arrival in Port Louis, Mauritius for change of personnel a new mouse had been sent out. This greatly improved the scrolling and the winch worked well for the remainder of the cruise. Clearly, a new scroll shaft and bearings should be fitted as soon as operationally possible.

The maximum wire out on the CTD winch was 4570 metres, with a maximum tension of 2.05 Tonnes. The cable was terminated at the beginning of the cruise and then re-terminated due to damage a few weeks later. The termination was tested to 1.5 tonnes.

18.3 Main Winch Power Pack

Early in the cruise a load thumping noise could be heard in the starboard forward corner of the main lab, when the CTD winch was in operation. On investigation the thumping noise was being created by the main hydraulic pump on the power pack. The charge pressure gauge could be seen to fluctuate rapidly between 14-18 Bar when veering. A pulsing could be felt on the discharge side of the pump. This pulsing was resonating up the main supply pipes which are fixed to the starboard bulkhead on the outside of the main lab. Supply voltages to the hydrotransmission valve, which controls the pump swash on the pump, were checked when the CTD winch was in use. The voltages at different veer and haul rates were steady with no fluctuations at all. The pulsing was hardly noticeable during veer, but could still be heard in the main laboratory. It did not fluctuate much on the charge pressure gauge (which was only flickering slightly).

However when in haul at a rate of 60m/min the pump was fluctuating with a regular thumping feel/noise present. In the main laboratory the thumping was much more prominent. The voltage to the controller was constant at 4.04 Volts D.C. The charge gauge pulsed rapidly between 14 -18 bar. When the haul rate was increased to 80m/min, the voltage ramped up smoothly to 5.39 Volts. The pulsing on the charge pressure gauge became more erratic, and the gauge needle was a blur between 14-18 bar. There is probable internal damage to the pump. There was a long time difference between when the main pumps and then the motors were sent away for overhaul. The Hydro motor was replaced last year (2001). Then this year (2002) the CTD motor was replaced. All the time the CTD winch was used after the main pumps were overhauled there has been the possibility of contamination in the system from the CTD and Hydro motors to pass around the closed loop circuit and enter the pump. New pipe work replaced in Durban, but not cleaned out and flushed through, could also have contributed to internal damage to the pump. Another problem which could be connected to the above is that the neutral position when driving the CTD winch is very difficult, and sometimes almost impossible, to find. This fault could be caused by a damaged pump or damaged control valve.

It is highly likely that the CTD/HYDRO winch power pack pump has sustained internal damage. All the time (2 years) since the main power pack pumps were overhauled, the HYDRO and CTD winch motors have been breaking up internally. The closed loop hydraulic circuits used to run both winches can facilitate this because the circulating oil in the system does not return to the tank before returning to the suction side of the pump. It is possible that the problem could simply be due to the non-return valves fitted to the main pump, between the charge pump and the main pump. It could, however, be rather worse with internal damage to the main pump. The control valve should be replaced for the CTD system, and the pump should be removed for inspection and overhaul.

18.4 Main Winch Controls and Associated Electrics

The CTD load read out went off the scale during the cruise. On investigation the load cell junction box was found to be half full of water. The box was cleaned, dried out and silicone sealed around the joints. Two weeks later the same problem re-occurred. The box was again cleaned out and silicone sealant applied all around the box and joints. When the Hydro winch was used for the first time after this there were no read-outs at all. After various communications with Mr. Pete Mason at SOC, it seemed the problem lay within the main clam system computer. This fault was to be left until Simon Dodd joined the ship for the next cruise. After a few weeks of using the Hydro winch, however, the clam display returned to normal. Finally, we note that the audible alarm on the starboard winch control unit does not work.

18.5 P.E.S. Davit and Power Pack

This was used several times during the cruise to deploy and recover the P.E.S fish (echo-sounder). It worked well until the final recovery of the fish when the winch drum started shuddering as it turned. The supply line could also be felt to shudder. The brake was checked and it was coming on and off with no problems. It is recommended that the pump be replaced and that the motor be sent away for checking.

Darren Young

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APPENDIX A: CTD STATION INFORMATION

Station	Date	Start Time (GMT)	Latitude (°N)	Longitude (°E)	Water Depth (m)	Max. Depth (m)
ctd00101	01-Jun-02	14:50:07	-4.416667	56.475000	1270.0	298.0
ctd00201	03-Jun-02	13:11:02	-5.228333	57.287500	1688.0	757.0
ctd00202	03-Jun-02	17:24:10	-5.228667	57.290500	1680.0	760.0
ctd00401	03-Jun-02	19:46:01	-5.228833	57.291167	1696.0	1705.0
ctd00402	03-Jun-02	21:02:02	-5.227000	57.296667	1677.0	1707.0
ctd00403	03-Jun-02	22:19:46	-5.232000	57.290667	1658.0	1656.0
ctd00404	03-Jun-02	23:34:26	-5.230500	57.290667	1665.0	1670.0
ctd00405	04-Jun-02	00:46:14	-5.230333	57.290667	1667.0	1673.0
ctd00406	04-Jun-02	01:56:21	-5.230833	57.292833	1667.0	1663.0
ctd00407	04-Jun-02	05:31:36	-5.231000	57.288500	1666.0	1649.0
ctd00408	04-Jun-02	07:08:46	-5.235000	57.290167	1653.0	1657.0
ctd00409	04-Jun-02	08:16:07	-5.232000	57.292333	1659.0	1677.0
ctd00501	04-Jun-02	13:31:07	-5.180833	57.093167	115.0	114.0
ctd00601	05-Jun-02	06:30:18	-7.162000	58.093000	1584.0	207.0
ctd00701	05-Jun-02	18:56:19	-7.219500	58.326667	1639.0	1628.0
ctd00801	07-Jun-02	20:42:31	-7.999833	60.663667	3017.0	3031.0
ctd00901	08-Jun-02	07:44:41	-8.031670	61.461833	3620.0	3665.0
ctd01001	08-Jun-02	19:20:48	-8.003330	62.664833	3440.0	3463.0
ctd01101	09-Jun-02	06:01:30	-8.065000	63.543667	3775.0	204.0
ctd01201	09-Jun-02	11:07:28	-8.036670	63.996833	4112.0	4170.0
ctd01202	09-Jun-02	14:09:34	-7.985167	63.996000	4112.0	4163.0
ctd01203	09-Jun-02	16:50:48	-7.995167	64.083330	4117.0	4177.0
ctd01204	09-Jun-02	20:09:50	-7.989167	63.988000	4107.0	4158.0
ctd01205	09-Jun-02	23:03:56	-7.996500	63.999500	4112.0	4157.0
ctd01301	10-Jun-02	12:54:02	-9.417167	64.599833	4099.0	4137.0
ctd01401	11-Jun-02	06:29:21	-10.967667	65.260500	2990.0	200.0
ctd01402	11-Jun-02	08:25:59	-10.959167	65.279167	2813.0	2914.0
ctd01403	11-Jun-02	11:45:54	-10.965500	65.267167	2868.0	2968.0
ctd01404	11-Jun-02	13:42:21	-10.970000	65.261000	2972.0	3133.0
ctd01405	11-Jun-02	16:26:11	-10.952000	65.275667	2676.0	2712.0
ctd01406	11-Jun-02	18:19:35	-10.955667	65.273167	2698.0	2431.0
ctd01407	11-Jun-02	20:28:28	-10.960500	65.271167	2891.0	2885.0
ctd01501	12-Jun-02	13:47:18	-12.300333	65.334000	3807.0	3994.0
ctd01502	12-Jun-02	18:32:08	-12.303667	65.327833	3901.0	204.0
ctd01601	13-Jun-02	06:03:43	-13.630333	65.192333	3590.0	3638.0
ctd01701	14-Jun-02	00:42:13	-15.387667	64.282000	4144.0	4183.0
ctd01702	14-Jun-02	03:19:50	-15.385500	64.283833	4144.0	4195.0
ctd01703	14-Jun-02	07:56:13	-15.387667	64.281500	4143.0	4195.0
ctd01704	14-Jun-02	10:35:17	-15.387667	64.285167	4143.0	4201.0
ctd01705	14-Jun-02	13:10:22	-15.387000	64.284833	4144.0	4194.0
ctd01801	15-Jun-02	02:11:07	-16.489333	63.449333	3795.0	3847.0
ctd01802	15-Jun-02	05:49:00	-16.489000	63.447000	3795.0	253.0
ctd01901	16-Jun-02	19:56:13	-19.046000	62.202667	3481.0	3472.0
ctd01902	16-Jun-02	22:09:16	-19.044333	62.213167	3435.0	3462.0
ctd01903	17-Jun-02	00:21:07	-19.043833	62.217500	3402.0	3423.0
ctd01904	17-Jun-02	02:25:53	-19.042167	62.218000	3398.0	3436.0
ctd01905	17-Jun-02	04:36:46	-19.039333	62.211500	3425.0	3476.0

APPENDIX A (continued): CTD STATION INFORMATION

Station	Date	Start Time (GMT)	Latitude (°N)	Longitude (°E)	Water Depth (m)	Max Depth (m)
ctd01906	17-Jun-02	07:41:18	-19.037167	62.205833	3433.0	14.0
ctd01907	17-Jun-02	08:05:45	-19.038167	62.202833	3454.0	3502.0
ctd02001	17-Jun-02	13:33:45	-19.382167	62.066333	3509.0	3561.0
ctd02002	17-Jun-02	15:49:03	-19.381333	62.061167	3521.0	3544.0
ctd02003	17-Jun-02	18:07:05	-19.378333	62.060000	3522.0	3596.0
ctd02004	17-Jun-02	20:24:05	-19.368667	62.067833	3522.0	3625.0
ctd02005	17-Jun-02	23:08:21	-19.383167	62.065000	3509.0	3563.0
ctd02006	18-Jun-02	01:21:43	-19.379833	62.062167	3530.0	3576.0
ctd02101	18-Jun-02	08:06:15	-19.764667	61.918167	3616.0	3706.0
ctd02102	18-Jun-02	11:20:49	-19.766167	61.920167	3607.0	3635.0
ctd02103	18-Jun-02	13:35:52	-19.760000	61.922333	3486.0	3572.0
ctd02104	18-Jun-02	15:45:39	-19.755500	61.922667	3448.0	3544.0
ctd02105	18-Jun-02	18:03:37	-19.749833	61.924167	3426.0	3495.0
ctd02106	18-Jun-02	20:27:19	-19.745500	61.931000	3358.0	3363.0
ctd02201	19-Jun-02	02:04:29	-20.152833	61.750667	3740.0	3833.0
ctd02202	19-Jun-02	05:12:34	-20.147667	61.753667	3783.0	3891.0
ctd02203	19-Jun-02	08:36:59	-20.152833	61.756167	3763.0	3845.0
ctd02204	19-Jun-02	11:03:54	-20.150167	61.756500	3740.0	3829.0
ctd02205	19-Jun-02	13:21:17	-20.149833	61.757167	3754.0	3874.0
ctd02301	19-Jun-02	21:20:17	-20.366500	61.033667	3661.0	3795.0
ctd02401	20-Jun-02	10:43:27	-20.365833	59.821000	3946.0	4039.0
ctd02501	22-Jun-02	09:18:45	-20.01000	57.481500	1594.0	205.0
ctd02502	22-Jun-02	10:25:48	-19.998167	57.486000	1594.0	1676.0
ctd02601	22-Jun-02	17:44:06	-20.072833	57.993000	2375.0	2345.0
ctd02602	22-Jun-02	19:23:07	-20.070333	57.981667	2241.0	2306.0
ctd02603	22-Jun-02	20:56:36	-20.074833	57.978167	2320.0	2384.0
ctd02604	22-Jun-02	22:31:01	-20.078000	57.986167	2350.0	2374.0
ctd02605	23-Jun-02	00:04:44	-20.078500	57.993167	2370.0	2558.0
ctd02606	23-Jun-02	01:46:38	-20.083000	57.991667	2458.0	2533.0
ctd02607	23-Jun-02	03:24:16	-20.081667	57.992833	2424.0	2534.0
ctd02608	23-Jun-02	06:00:47	-20.083667	58.06167	2565.0	2674.0
ctd02701	23-Jun-02	13:53:13	-20.363667	58.615333	4522.0	4596.0
ctd02801	24-Jun-02	01:49:37	-18.883333	58.200833	2803.0	2817.0
ctd02901	24-Jun-02	06:14:16	-18.614167	58.419333	1250.0	202.0
ctd03001	24-Jun-02	18:02:06	-17.999167	59.702000	2053.0	2064.0
ctd03101	25-Jun-02	07:16:28	-16.930833	60.649167	3834.0	3877.0
ctd03201	25-Jun-02	21:56:44	-15.862667	61.453667	2938.0	3018.0
ctd03202	26-Jun-02	00:01:56	-15.857000	61.456333	2998.0	3052.0
ctd03203	26-Jun-02	01:53:38	-15.859000	61.451167	2912.0	2969.0
ctd03204	26-Jun-02	03:43:07	-15.861833	61.452000	2911.0	2940.0
ctd03205	26-Jun-02	05:39:08	-15.862833	61.448167	2850.0	2884.0
ctd03206	26-Jun-02	07:31:53	-15.857000	61.451333	2910.0	3003.0
ctd03207	26-Jun-02	10:23:23	-15.864833	61.452500	2918.0	2977.0
ctd03208	26-Jun-02	13:13:16	-15.869667	61.452833	2949.0	203.0
ctd03301	26-Jun-02	14:53:41	-15.817167	61.335667	408.0	420.0
ctd03401	26-Jun-02	23:58:02	-14.780000	61.832167	3495.0	3526.0

APPENDIX A (continued): CTD STATION INFORMATION

Station	Date	Start Time (GMT)	Latitude (°N)	Longitude (°E)	Water Depth (m)	Max Depth (m)
ctd03501	27-Jun-02	06:07:31	-14.214000	61.935167	3664.0	202.0
ctd03601	27-Jun-02	10:41:41	-13.796833	61.994667	3463.0	3529.0
ctd03701	27-Jun-02	22:48:17	-13.01667	61.270167	2125.0	2135.0
ctd03702	28-Jun-02	00:12:36	-12.996500	61.270333	2133.0	2133.0
ctd03703	28-Jun-02	01:36:22	-12.994167	61.265000	2123.0	2131.0
ctd03704	28-Jun-02	03:00:14	-12.993500	61.263333	2125.0	2120.0
ctd03705	28-Jun-02	04:54:58	-13.01333	61.267333	2119.0	2110.0
ctd03706	28-Jun-02	06:24:23	-13.01667	61.257667	2099.0	2088.0
ctd03707	28-Jun-02	09:51:53	-12.996667	61.279000	2160.0	2138.0
ctd03708	28-Jun-02	11:16:03	-12.991500	61.270333	2141.0	2147.0
ctd03801	28-Jun-02	16:12:13	-12.885000	60.895000	457.0	440.0
ctd03901	28-Jun-02	21:02:30	-12.815833	60.639167	1900.0	1939.0
ctd04001	29-Jun-02	01:07:57	-12.962667	60.691000	323.0	340.0
ctd04101	29-Jun-02	06:44:21	-12.501333	60.951500	1106.0	1113.0
ctd04201	29-Jun-02	19:07:57	-12.266833	62.116667	3264.0	3280.0
ctd04301	30-Jun-02	05:34:54	-11.631333	62.536333	2332.0	202.0
ctd04401	30-Jun-02	12:58:26	-11.01167	62.415667	2068.0	2063.0
ctd04402	30-Jun-02	14:20:48	-10.999167	62.414500	2068.0	2071.0
ctd04403	30-Jun-02	16:53:51	-10.998167	62.420833	2079.0	2075.0
ctd04404	30-Jun-02	19:12:39	-10.996667	62.430667	2085.0	2083.0
ctd04405	30-Jun-02	20:39:23	-10.997667	62.436000	2085.0	2084.0
ctd04406	30-Jun-02	22:04:17	-10.995500	62.433000	2085.0	2086.0
ctd04407	30-Jun-02	23:26:26	-10.999333	62.431500	2085.0	2085.0
ctd04408	01-Jul-02	00:45:37	-11.01500	62.430500	2082.0	2083.0
ctd04409	01-Jul-02	02:03:19	-11.01000	62.428333	2082.0	2085.0
ctd04501	01-Jul-02	05:21:35	-10.755000	62.505833	2086.0	202.0
ctd04601	01-Jul-02	18:39:55	-9.419667	61.316667	2075.0	2087.0
ctd04701	02-Jul-02	08:48:46	-8.380500	60.219667	795.0	852.0
ctd04801	02-Jul-02	11:51:50	-8.398333	60.193167	339.0	328.0
ctd04901	02-Jul-02	16:38:54	-8.02500	59.835667	1883.0	1919.0
ctd05001	03-Jul-02	01:19:37	-8.01000	58.698333	2292.0	2291.0
ctd05101	03-Jul-02	11:03:21	-8.00500	58.02333	3004.0	3013.0
ctd05201	03-Jul-02	17:13:33	-7.999000	57.357500	3190.0	3221.0
ctd05301	04-Jul-02	04:57:38	-9.336667	57.334667	3822.0	3860.0
ctd05401	04-Jul-02	17:30:44	-10.666167	57.331167	4144.0	4198.0
ctd05501	05-Jul-02	06:43:08	-11.999333	57.995000	4263.0	201.0
ctd05502	05-Jul-02	09:14:00	-12.03667	57.992667	4264.0	4321.0
ctd05503	05-Jul-02	11:51:11	-11.993333	57.996500	4263.0	4322.0
ctd05504	05-Jul-02	14:54:15	-12.01167	58.00833	4261.0	4320.0
ctd05505	05-Jul-02	17:55:34	-12.05500	57.995833	4264.0	2055.0
ctd05601	06-Jul-02	10:09:49	-13.335167	57.998167	4239.0	4295.0
ctd05701	06-Jul-02	22:12:47	-14.668167	57.500000	4256.0	4323.0
ctd05801	07-Jul-02	05:49:02	-15.319167	57.267833	4324.0	201.0
ctd05901	07-Jul-02	12:11:31	-16.03333	57.02333	4367.0	4429.0
ctd06001	08-Jul-02	00:32:31	-17.416667	56.665333	4344.0	4407.0
ctd06101	08-Jul-02	08:34:01	-18.039500	56.329333	4375.0	699.0

APPENDIX A (continued): CTD STATION INFORMATION

Station	Date	Start Time (GMT)	Latitude (°N)	Longitude (°E)	Water Depth (m)	Max Depth (m)
ctd06201	08-Jul-02	14:27:28	-18.668167	55.999333	4410.0	4482.0
ctd06301	09-Jul-02	02:26:37	-19.999333	55.534667	4381.0	4449.0
ctd06401	09-Jul-02	15:06:27	-20.00333	56.643667	4356.0	2199.0
ctd06402	09-Jul-02	18:24:49	-20.05333	56.632667	4355.0	938.0
ctd06403	09-Jul-02	19:57:34	-20.04167	56.627833	4356.0	4421.0
ctd06404	09-Jul-02	22:39:05	-20.00333	56.638500	4357.0	2213.0
ctd06405	10-Jul-02	00:10:07	-19.999833	56.639667	4357.0	2205.0
ctd06406	10-Jul-02	01:28:48	-20.01333	56.639667	4357.0	2207.0

APPENDIX B: XBT STATION INFORMATION

XBT Directory A

Drop. No.	Probe Type	Date	Time GMT	Latitude (°N)	Longitude (°E)	Comment
1	T7	2/6/2	0920	-4.283	56.642	Format problem?
2	T7	2/6/2	0935?	-4.270	56.658	Bad
3	T7	2/6/2	0952	-4.310	56.590	
4	T7	2/6/2	1027	-4.367	56.497	
5	T7	2/6/2	1110	-4.417	56.408	Bad
6	T7	2/6/2	1117	-4.430	56.370	Bad
7	T7	2/6/2	1122	-4.442	56.365	
8	T7	2/6/2	1455	-4.420	56.342	
9	T7	2/6/2	1526	-4.375	56.417	
10	T7	2/6/2	1555	-4.333	56.488	
11	T7	2/6/2	1855	-4.295	56.537	
12	T7	2/6/2	1931	-4.245	56.640	
13	T7	2/6/2	2011	-4.192	56.730	Bad
14	T7	2/6/2	2014	-4.185	56.743	
15	T7	2/6/2	2050	-4.130	56.770	
16	T7	2/6/2	2124	-4.177	56.242	
17	T7	2/6/2	22 51	-4.233	56.592	
18	T7	2/6/2	2247	-4.288	56.497	
19	T7	2/6/2	2326	-4.348	56.392	
20	T7	2/6/2	2352	-4.385	56.332	
21	T5	3/6/2	0115	-4.417	56.475	
22	T5	3/6/2	0316	-4.605	56.706	
23	T5	3/6/2	0528	-4.822	56.970	
24	T5	3/6/2	0631	-4.917	57.085	
25	T5	3/6/2	0829	-5.117	57.318	
26	T7	4/6/2	1746	-5.508	57.133	
27	T5	4/6/2	1920	-5.750	57.165	
28	T7	4/6/2	2114	-6.033	57.335	
29	T5	4/6/2	2312	-6.317	57.525	
30	T7	5/6/2	0124	-6.600	57.720	
31	T5	5/6/2	0334	-6.592	57.920	
32	T7	5/6/2	0746	-7.120	58.158	
33	T7	5/6/2	0757	-7.098	58.192	
34	T7	5/6/2	0942	-7.005	58.402	
35	T7	5/6/2	0958	-7.047	58.335	
36	T7	5/6/2	1008	-7.070	58.300	
37	T7	5/6/2	1010	-7.090	58.270	
38	T7	5/6/2	1012	-7.110	58.240	To 400m only?
39	T7	5/6/2	1015	-7.130	58.210	
40	T7	5/6/2	1018	-7.150	58.180	
41	T7	5/6/2	1022	-7.170	58.150	
42	T7	5/6/2	1140	-7.197	58.114	

APPENDIX B (continued): XBT STATION INFORMATION

XBT Directory B

Drop. No.	Probe Type	Date	Time GMT	Latitude (°N)	Longitude (°E)	Comment
1	T7	5/6/2	1401	-7.030	58.432	
2	T7	5/6/2	1617	-7.257	58.162	
3	T7	6/6/2	0018	-7.132	59.484	
4	T7	6/6/2	0223	-7.332	58.199	
5	T7	6/6/2	0451	-7.170	58.527	
6	T7	6/6/2	0703	-7.403	58.252	
7	T7	6/6/2	0945	-7.233	58.558	
8	T7	6/6/2	1209	-7.415	58.272	
9	T5	6/6/2	1509	-7.353	58.638	
10	T5	6/6/2	1845	-7.573	59.142	
11	T5	6/6/2	2157	-7.595	59.583	
12	T7	8/6/2	0343	-8.000	61.067	
13	T7	8/6/2	1431	-8.002	62.000	
14	T7	9/6/2	0355	-7.998	63.322	
15	T7	10/6/2	0431	-8.272	64.116	
16	T7	10/6/2	0603	-8.500	64.212	
17	T7	10/6/2	0732	-8.750	64.300	
18	T7	10/6/2	0923	-9.000	64.417	
19	T7	10/6/2	1107	-9.240	64.530	
20	T7	10/6/2	1714	-9.500	64.633	
21	T7	10/6/2	1859	-9.750	64.742	Bad
22	T7	10/6/2	1902	-9.755	64.745	
23	T7	10/6/2	2045	-10.000	64.849	
24	T7	10/6/2	2230	-10.250	64.945	
25	T7	11/6/2	0034	-10.500	65.063	
26	T7	11/6/2	0317	-10.750	65.165	
27	T7	11/6/2	2243	-10.970	65.265	
28	T7	12/6/2	0223	-11.238	65.298	
29	T7	12/6/2	0708	-11.588	65.313	
30	T7	12/6/2	0856	-11.808	65.305	
31	T7	12/6/2	1033	-12.000	65.317	
32	T7	12/6/2	1253	-12.250	65.332	
33	T7	12/6/2	2131	-12.500	65.320	
34	T7	12/6/2	2323	-12.750	65.288	
35	T7	13/6/2	0115	-13.000	65.258	
36	T7	13/6/2	0300	-13.250	65.233	Bad
37	T7	13/6/2	0305	-13.252	65.233	
38	T7	13/6/2	0445	-13.502	65.307	Bad
39	T7	13/6/2	0450	-13.502	65.207	
40	T7	13/6/2	1049	-13.785	65.111	

APPENDIX B (continued): XBT STATION INFORMATION

XBT Directory B

Drop. No.	Probe Type	Date	Time GMT	Latitude (°N)	Longitude (°E)	Comment
41	T7	13/6/2	1211	-14.000	64.978	
42	T7	13/6/2	1223	-14.023	64.960	
43	T7	13/6/2	1327	-14.183	64.860	
44	T7	13/6/2	1434	-14.340	64.755	
45	T7	13/6/2	1546	-14.500	64.650	
46	T7	13/6/2	1725	-14.692	64.528	
47	T7	13/6/2	1835	-14.833	64.432	
48	T7	13/6/2	2007	-15.000	64.313	
49	T7	13/6/2	2210	-15.167	64.275	
50	T7	13/6/2	2345	-15.333	64.280	
51	T7	14/6/2	1710	-15.503	64.305	Aborted?
52	T7	14/6/2	1724	-15.528	64.307	
53	T7	14/6/2	1828	-15.667	64.302	
54	T7	14/6/2	1949	-15.833	64.133	
55	T7	14/6/2	2111	-16.000	63.970	
56	T7	14/6/2	2234	-16.167	63.798	Bad
57	T7	14/6/2	2239	-16.170	63.783	
58	T7	15/6/2	0000	-16.333	63.622	
59	T7	15/6/2	0732	-16.500	63.433	
60	T7	15/6/2	0847	-16.667	63.350	Bad
61	T7	15/6/2	0852	-16.683	63.350	
62	T7	15/6/2	1015	-16.842	63.270	
63	T7	15/6/2	1131	-17.000	63.183	
64	T7	15/6/2	1252	-17.167	63.083	
65	T7	15/6/2	1403	-17.333	63.000	
66	T5	15/6/2	1509	-17.500	62.910	
67	T5	15/6/2	1632	-17.667	62.825	
68	T5	15/6/2	1804	-17.833	62.745	
69	T5	15/6/2	1917	-18.000	62.647	Bad
70	T5	15/6/2	1921	-18.000	62.645	
71	T5	15/6/2	2115	-18.168	62.552	Spike at 1100m
72	T5	16/6/2	0516	-18.250	62.617	
73	T5	16/6/2	0657	-18.305	62.633	
74	T5	16/6/2	0828	-18.358	62.655	Bad
75	T5	16/6/2	0833	-18.358	62.655	
76	T5	16/6/2	1023	-18.395	62.682	
77	T5	16/6/2	1226	-18.580	62.570	
78	T5	16/6/2	1352	-18.750	62.418	
79	T5	16/6/2	1535	-18.917	62.285	
80	T5	16/6/2	1733	-19.048	62.205	

APPENDIX B (continued): XBT STATION INFORMATION

XBT Directory B

Drop. No.	Probe Type	Date	Time GMT	Latitude (°N)	Longitude (°E)	Comment
81	T5	17/6/2	0743	-19.033	62.207	
82	T5	17/6/2	1157	-19.178	62.148	To 1400m only.
83	T5	17/6/2	1237	-19.277	62.110	
84	T5	18/6/2	0459	-19.500	62.017	
85	T7	18/6/2	0518	-19.550	62.017	
86	T7	18/6/2	0537	-19.583	62.000	
87	T7	18/6/2	0602	-19.650	61.983	Bad
88	T5	18/6/2	0613	-19.667	61.983	Bad
89	T5	18/6/2	0618	-19.683	61.967	
90	T5	18/6/2	0622	-19.667	61.862	
91	T5	18/6/2	0702	-19.767	61.920	
92	T7	19/6/2	0005	-19.917	61.867	
93	T7	19/6/2	0114	-20.083	61.783	
94	T7	19/6/2	1712	-20.207	61.605	
95	T7	19/6/2	1817	-20.255	61.413	
96	T7	19/6/2	1924	-20.313	61.207	
97	T7	20/6/2	0131	-20.365	61.000	
98	T7	20/6/2	0319	-20.365	60.667	
99	T7	20/6/2	0504	-20.368	60.334	To 580m only.
100	T7	20/6/2	0658	-20.366	59.959	To 600m only.
101	T7	20/6/2	0830	-20.367	59.667	To 600m only.
102	T7	20/6/2	1522	-20.325	59.670	To 600m only.
103	T7	20/6/2	1525	-20.325	59.670	To 600m only.
104	T7	20/6/2	1708	-20.257	59.337	
105	T7	20/6/2	1902	-20.187	59.000	To 600m only.
106	T7	23/6/2	0905	-20.078	58.022	To 550m only.
107	T7	23/6/2	1143	-20.237	58.353	
108	T7	23/6/2	1328	-20.362	58.617	
109	T7	23/6/2	1921	-20.000	58.512	To 600m only.
110	T7	23/6/2	2111	-19.667	58.413	
111	T7	23/6/2	2255	-19.333	58.333	
112	T7	24/6/2	0048	-19.000	58.233	
113	T7	24/6/2	0539	-18.650	58.383	To 300m only.
114	T7	24/6/2	0544	-18.633	58.375	
115	T7	24/6/2	1025	-18.333	58.657	
116	T7	24/6/2	1417	-18.157	59.217	
117	T7	24/6/2	2055	-18.000	59.692	
118	T7	24/6/2	2331	-17.670	59.870	
119	T7	25/6/2	0215	-17.333	60.150	
120	T7	25/6/2	0502	-17.003	60.446	

APPENDIX B (continued): XBT STATION INFORMATION

XBT Directory B

Drop. No.	Probe Type	Date	Time GMT	Latitude (°N)	Longitude (°E)	Comment
121	T5	25/6/2	1055	-16.944	60.646	
122	T7	25/6/2	1200	-16.821	60.639	
123	T7	25/6/2	1333	-16.663	60.668	
124	T7	25/6/2	1459	-16.505	60.822	
125	T7	25/6/2	1642	-16.333	60.998	
126	T7	25/6/2	1948	-16.165	61.388	
127	T7	25/6/2	2042	-16.000	61.427	No wire in XBT.
128	T7	25/6/2	2046	-16.000	61.430	
129	T7	26/6/2	1801	-15.667	61.528	
130	T7	26/6/2	2009	-15.333	61.672	
131	T7	26/6/2	2214	-15.000	61.768	
132	T7	27/6/2	0330	-14.617	61.860	
133	T7	27/6/2	0517	-14.322	61.911	
134	T7	27/6/2	0911	-14.007	61.963	
135	T7	27/6/2	1455	-13.663	62.000	
136	T7	27/6/2	1640	-13.333	61.998	
137	T7	27/6/2	1728	-13.225	61.933	To 400m only?
138	T7	27/6/2	1737	-13.217	61.900	
139	T7	27/6/2	1752	-13.200	61.858	
140	T7	27/6/2	1758	-13.192	61.838	
141	T7	27/6/2	1806	-13.190	61.820	
142	T7	27/6/2	1813	-13.183	61.800	
143	T7	27/6/2	1821	-13.173	61.772	
144	T7	27/6/2	1828	-13.167	61.750	
145	T7	27/6/2	1837	-13.155	61.727	
146	T7	27/6/2	1843	-13.145	61.700	
147	T7	27/6/2	1851	-13.138	61.675	
148	T7	27/6/2	1857	-13.128	61.653	
149	T7	27/6/2	1904	-13.125	61.633	
150	T7	27/6/2	1912	-13.118	61.612	
151	T7	27/6/2	1925	-13.105	61.572	
152	T7	27/6/2	1943	-13.082	61.508	
153	T7	27/6/2	2003	-13.060	61.448	
154	T7	27/6/2	2027	-13.033	61.367	
155	T7	27/6/2	2041	-13.018	61.318	
156	T7	27/6/2	2056	-13.003	61.268	
157	T7	27/6/2	2114	-13.000	61.267	
158	T7	27/6/2	2125	-13.000	61.267	
159	T7	27/6/2	2144	-13.000	61.267	
160	T7	27/6/2	2201	-13.000	61.267	

APPENDIX B (continued): XBT STATION INFORMATION

XBT Directory B

Drop. No.	Probe Type	Date	Time GMT	Latitude (°N)	Longitude (°E)	Comment
161	T7	27/6/2	2220	-13.000	61.270	
162	T7	27/6/2	2236	-13.000	61.267	
163	T7	28/6/2	1436	-12.942	61.083	
164	T7	28/6/2	1537	-12.895	60.925	
165	T7	28/6/2	1944	-12.837	60.757	
166	T7	29/6/2	0238	-12.925	60.692	
167	T7	29/6/2	0436	-12.643	60.857	
168	T7	29/6/2	0607	-12.455	60.962	
169	T7	29/6/2	1251	-12.533	61.327	
170	T7	29/6/2	1525	-12.422	61.660	
171	T7	29/6/2	1756	-12.308	61.988	
172	T7	30/6/2	0055	-12.098	62.333	
173	T7	30/6/2	0203	-12.000	62.433	
174	T7	30/6/2	0205	-12.000	62.433	To 550m only.
175	T7	30/6/2	0210	-12.000	62.438	To 500m only?
176	T7	30/6/2	0505	-11.641	62.541	Spike at 380m.
177	T7	30/6/2	0514	-11.630	62.538	
178	T7	30/6/2	0856	-11.337	62.542	
179	T7	30/6/2	1151	-11.000	62.282	
180	T5	30/6/2	1549	-10.997	62.415	
181	T7	1/7/2	0831	-10.523	62.573	
182	T7	1/7/2	1126	-10.050	62.422	Bad
183	T7	1/7/2	1129	-10.038	62.408	
184	T7	1/7/2	1351	-9.673	62.128	
185	T7	1/7/2	1605	-9.505	61.743	
186	T7	1/7/2	1803	-9.430	61.392	Bad
187	T7	1/7/2	1807	-9.427	61.370	
188	T7	1/7/2	2213	-9.272	61.212	
189	T7	2/7/2	0033	-8.917	60.928	
190	T7	2/7/2	0322	-8.583	60.536	
191	T7	2/7/2	2008	-7.998	59.673	
192	T7	2/7/2	2148	-8.000	59.333	
193	T7	2/7/2	2332	-8.000	59.000	
194	T7	3/7/2	0344	-8.000	58.667	
195	T7	3/7/2	0532	-7.997	58.303	
196	T7	3/7/2	1547	-8.000	57.580	
197	T7	3/7/2	2014	-7.988	57.372	To 600m only?
198	T7	3/7/2	2259	-8.343	57.352	
199	T7	4/7/2	0050	-8.667	57.343	
200	T7	4/7/2	0244	-9.000	57.340	

APPENDIX B (continued): XBT STATION INFORMATION

XBT Directory B

Drop. No.	Probe Type	Date	Time GMT	Latitude (°N)	Longitude (°E)	Comment
201	T7	4/7/2	0439	-9.318	52.331	
202	T7	4/7/2	1056	-9.673	57.333	Spikes: 500-600m.
203	T7	4/7/2	1257	-9.983	57.160	
204	T7	4/7/2	1503	-10.330	57.338	
205	T7	4/7/2	2057	-10.680	57.340	
206	T7	4/7/2	2323	-11.000	57.490	
207	T7	5/7/2	0147	-11.342	57.667	
208	T7	5/7/2	0407	-11.670	57.833	
209	T5	5/7/2	2028	-12.017	57.987	Bad
210	T5	5/7/2	2031	-12.017	57.987	Failed on launch.
211	T5	5/7/2	2039	-12.017	57.987	Many spikes.
212	T5	5/7/2	2146	-12.027	57.985	Some spikes.
213	T5	5/7/2	2311	-12.160	57.990	
214	T5	6/7/2	0041	-12.302	57.990	Bad
215	T5	6/7/2	0043	-12.300	57.990	Spike at 80m.
216	T5	6/7/2	0211	-12.435	57.993	
217	T7	6/7/2	0346	-12.587	57.997	
218	T7	6/7/2	0604	-12.822	57.998	
219	T7	6/7/2	0847	-13.189	57.999	
220	T7	6/7/2	1411	-13.385	57.982	
221	T7	6/7/2	1547	-13.657	57.877	
222	T7	6/7/2	1744	-13.988	57.752	
223	T7	6/7/2	1943	-14.322	57.625	
224	T7	7/7/2	0331	-15.000	57.383	
225	T7	7/7/2	0807	-15.358	57.273	
226	T7	7/7/2	0957	-15.664	57.139	
227	T7	7/7/2	1746	-16.362	56.998	
228	T7	7/7/2	1926	-16.655	57.000	
229	T7	7/7/2	2127	-17.000	57.000	
230	T7	7/7/2	2338	-17.333	56.763	
231	T7	8/7/2	0616	-17.699	56.515	To 350m only.
232	T7	8/7/2	1220	-18.338	56.171	
233	T7	8/7/2	2014	-19.000	55.880	
234	T7	8/7/2	2224	-19.360	55.752	
235	T7	9/7/2	0014	-19.672	55.652	

APPENDIX C: RADIOSONDE STATION INFORMATION

Flight No.	Jday	Launch time (GMT)	Latitude (°S)	Longitude (°E)	Burst Pressure (mbar)	Comments
1	155	05:10	5°14.03	57°17.27	32	No logging by PC. Temp message contained no humidity.
2	156	16:59	7°14.35	58°15.21	44	No GPS winds. No cap.
3	158	05:06	8°00.00	61°14.04	42	No cap.
4	160	16:57	7°09.80	64°00.50	34.1	
5	163	17:13	12°18.13	65°19.94	34.7	
6	166	05:00	16°29.02	63°26.93	29.1	No cap.
7	166	17:10	17°44.03	62°48.03	31.6	
8b	169	05:43	19°36.39	61°59.77	34	First 2 sondes would not stabilise in lab
9	169	16:53	19°45.07	61°55.41	35.8	
10	175	05:02	18°44.25	58°19.27	44.6	Noisy signal above 100mbar
11	175	17:02	18°01.06	59°37.10	-	Stop detected. PTU data only
12	178	07:05	14°20.08	61°54.54	21.4	
13	182	16:58	09°28.52	61°34.73	68.9	Intermittent GPS winds
14	184	05:10	07°59.80	58°21.90	33.1	No humidity in TEMP message
15						Sonde was defective.
15a	187	05:24	12°45.64	58°00.6		Failed at 800mbar. No cap.
16	189	10:59	18°08.44	56°16.93	28.7	good
17	189	17:10	18°40.36	55°59.60	33.8	good
18	190	11:23	20°00.30	56°08.10	34.0	good
19	190	17:05	19°59.48	56° 40.30	33.9	good