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CRUISE REPORT No. 12

RRS *DISCOVERY* CRUISE 227
15 APR-16 MAY 1997

Plankton patchiness studies by ship and satellite
P^2S^3

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1997

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ABSTRACT

This report describes RRS *Discovery* Cruise No. 227, which was carried out to measure plankton patchiness in the eastern North Atlantic (in the area of 16-20°W, 47-49°N), during the period 15 April to 16 May 1997 (the time of the spring bloom). Meteorological, physical, optical, chemical and biological measurements were made using a combination of underway sampling (MultiMet, ADCP, TSG, fluorimeter, nutrients), towed instrumentation (SeaSoar, OPC, Lightfish, LHPR) and on station sampling (CTD, nitrate sensor, water bottles, Satlantic light sensors, vertical nets). Two large scale surveys, and three small scale surveys were carried out during the cruise. Patchiness in both the phytoplankton (measured by the SeaSoar fluorimeter) and the zooplankton (measured by the OPC) distributions was observed. Satellite SST data (from AVHRR) were received in near real time during the cruise, which aided the interpretation of the ship-based observations. Data acquired during the cruise were assimilated into a coupled bio-physical model, which was run on the ship, in an attempt to provide near real time forecasts of the ocean biology and physics in the survey area.

KEYWORDS

ADCP, ALGAL BLOOM, AVHRR, BIO-OPTICS, BIOLOGICAL-PHYSICAL INTERACTIONS, CRUISE 227 1997, CTD, CURRENTS, DATA ASSIMILATION, *DISCOVERY*/RRS, EASTERN NORTH ATLANTIC, INFRA-RED IMAGERY, METEOROLOGY, NEAR REAL TIME MODELLING, NITRATE SENSOR, NUTRIENTS, OCEAN COLOUR, OPC, PLANKTON PATCHINESS, SATELLITE ALTIMETRY, SATELLITE DATA, SEASOAR, SURFACE TEMPERATURE, VERTICAL NETS

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Key

GDD = George Deacon Division

JRD = James Rennell Division

RSADU = Remote Sensing Applications Development Unit

RVS = Research Vessel Services

SOC = Southampton Oceanography Centre

SHIP'S PERSONNEL

AVERY Keith	Master
LEATHER Ceri	First officer
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MORSE Terry	Second officer
DONALDSON Brian	Radio officer
MOSS Sam	Chief engineer
MACDONALD Bernie	Second engineer
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THOMPSON Cathy	Mess steward
ORSBORN Jeff	Steward
ROBINSON Peter	Steward

LIST OF ABBREVIATIONS AND ACRONYMS

ADCP = Acoustic Doppler Current Profiler

ADEOS = ADvanced Earth Observation Satellite, launched by NASDA

AVHRR = Advanced Very High Resolution Radiometer

CTD = Conductivity, Temperature and Depth sensor

ERS-2 = Earth Remote Sensing satellite - 2, launched by ESA

ESA = European Space Agency

FNOC = Fleet Numerical Oceanographic Centre (USA)

FSI = Falmouth Scientific Inc.

GDD = George Deacon Division (of SOC)

GLONASS = Russian equivalent of GPS

GPS = Global Positioning System

HPLC = High Pressure Liquid Chromatography

HSD = High Speed Data link

JRD = James Rennell Division (of SOC)

LHPR = Longhurst-Hardy Plankton Recorder

MOS = Modular Optoelectronic Scanner

NASDA = National Space Development Agency of Japan

NOAA = National Oceanographic and Atmospheric Administration (USA)

OCTS = Ocean Colour and Temperature Sensor, on ADEOS

OPC = Optical Plankton Counter

OSI = Ocean Scientific International

OTD = Ocean Technology Division (of SOC)

PAR = Photosynthetically Active Radiation

PES = Precision Echo Sounder

PEXEC = in-house suite of programmes for cruise data analysis

PML = Plymouth Marine Laboratory

PSTAR = in-house cruise data format

RSADU = Remote Sensing Applications Development Unit

RSDAS = Remote Sensing Data Analysis Service

RVS = Research Vessel Services

SBWR = ShipBorne Wave Recorder

SeaWiFS = Sea-viewing Wide Field-of-view Sensor

SEG = Scientific Engineering Group (of RVS)

SOC = Southampton Oceanography Centre

SST = Sea Surface Temperature

Topex/Poseidon = joint US/French radar altimeter mission

TSG = ThermoSalinoGraph

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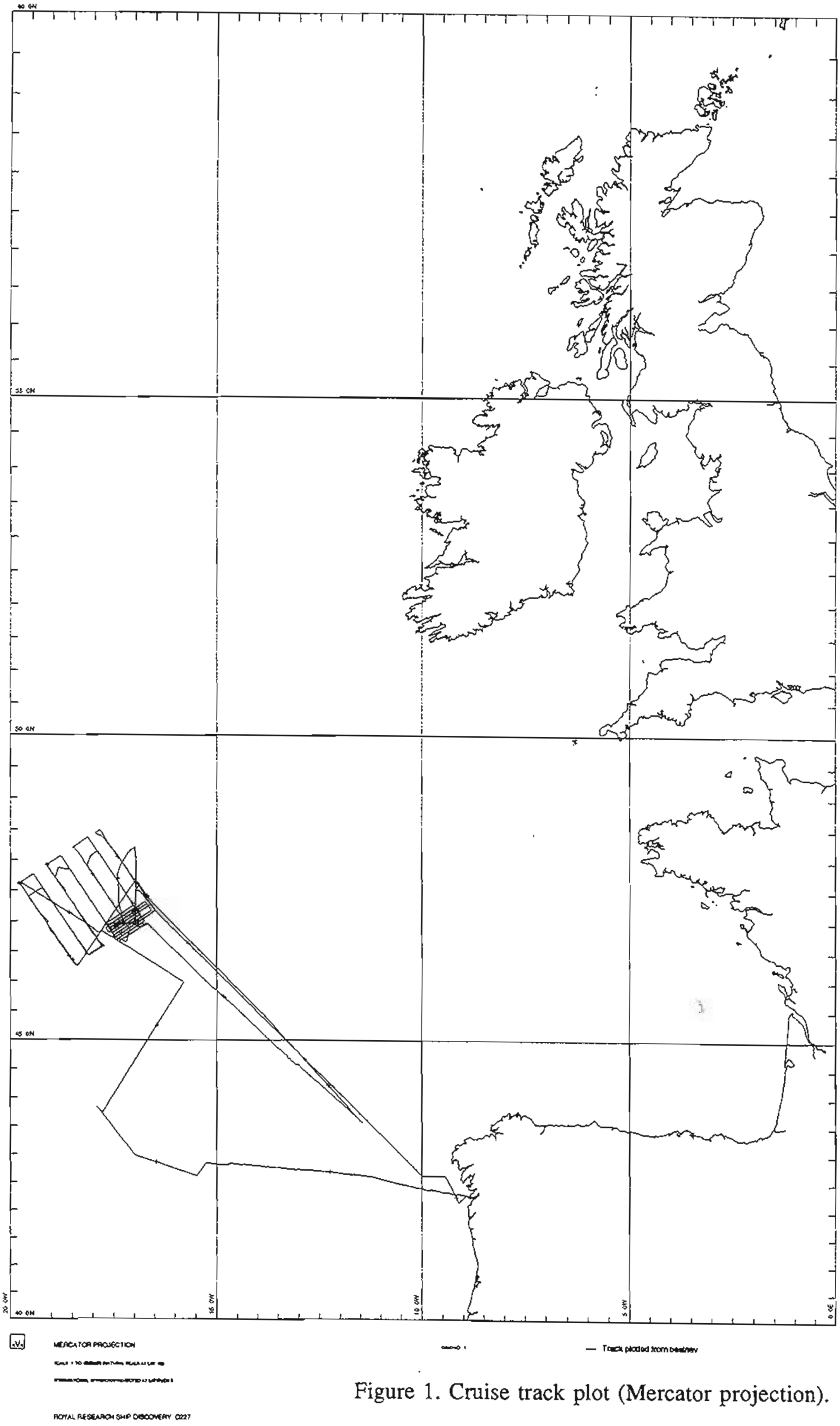

Figure 1. Cruise track plot (Mercator projection).

1. SCIENTIFIC OBJECTIVES

The primary objective of the cruise, as stated in the original cruise proposal, was:

> *"To study the spatial (horizontal) and temporal variability of biological activity ("plankton patchiness") in the upper layers of the ocean, and its relationship to the physical processes occurring there, using a combination of shipborne and satellite measurements."*

The aim was to study plankton patchiness during the development of the spring bloom in April / May, at a frontal region in the North East Atlantic west of Spain and Portugal (centred on 17°W, 43°N; see Figure 1). This was to be done by carrying out a number of repeated detailed upper ocean surveys of a small region (of order 50^2 km^2) using towed (SeaSoar, Lightfish, Longhurst-Hardy plankton recorder) and shipborne (Multimet, ADCP, thermosalinograph, flow-through fluorimeter, nitrate sensor and transmissometer) instrumentation to measure physical and biological parameters. In combination with satellite ocean colour, sea surface topography (height), wind field and sea surface temperature (SST) measurements, this would enable the spatial and temporal structure of the patchiness to be determined and its relationship to the underlying biological and physical processes to be studied. In order to set the physical "context" for the biological patchiness an initial larger scale survey (of order $200^2 km^2$) was to be carried out using a combination of SeaSoar tows and 2000m CTD stations (see section 3). This would also provide data for the initialisation of the Harvard model (see section 10). Along with the CTD stations, vertical nets and optical measurements (Satlantic profiler) would be made. The CTD would also carry a nitrate sensor.

Specific objectives of the cruise were:

- Using a combination of ship and satellite based observation, to study the phenomenon of plankton patchiness, during the development of the spring bloom, by sampling the phytoplankton and zooplankton on the same time and space scales as the physical processes.
- To elucidate the interactions of the physical and biological factors controlling plankton patchiness.
- Using the bio-optical data acquired, to develop and improve satellite ocean colour algorithms for chlorophyll and primary production.
- To relate the satellite observations of sea surface topography (from radar altimetry) and SST (from infrared radiometers) to *in situ* measurements of sub-surface hydrography and dynamics.
- To use the data acquired as an input to improving the modelling of bio-physical interactions.

Originally, the cruise was planned to take advantage of data from the US ocean colour sensor SeaWiFS, but due to delays in its launch this was not possible. Fortunately, the Japanese space agency NASDA had launched an earth observing satellite ADEOS on 17 August 1996, which carried the Ocean Colour and Temperature Sensor (OCTS). This provided an alternative source of ocean colour data (cloud cover permitting)[1]. In addition, an experimental German imaging spectrometer MOS had been launched on an Indian satellite which potentially could also provide ocean colour data (though its narrower swath - 200km as against the 1400km of OCTS - gave more restricted coverage of the cruise area). In neither case were the data available in near real time, which complicated location of the spring bloom (see narrative below - SeaWiFS would have provided near real time data). Despite this lack of near real time ocean colour data, the cruise objectives were achieved in terms of the *in situ* measurements of plankton patchiness obtained.

MAS

2. NARRATIVE

The *RRS Discovery* sailed from Vigo, Spain, on the morning of Tuesday 15th April 1997 (**day 105**, 0730 GMT, 0930 local time; all subsequent times will be given by day number and GMT). The objectives of the cruise had determined the area of operation for which the ship was headed, namely the vicinity of 43°N, 17°W.

At 0820 the ship's speed was decreased to 8 knots for an Acoustic Doppler Current Profiler (ADCP) calibration run, in bottom-tracking mode, across the shelf. At 1200 the 4 hours on, 8 hours off, watch system was started and the non-toxic water supply turned on to allow underway sampling to be carried out. The meteorological measurement system had been acquiring data from the time of sailing, as had the GPS and GLONASS positioning system.

Once off the shelf, a further zigzag (6 legs of 20 minutes duration each, with a 90° turn between each leg) ADCP calibration run was carried out, in water-tracking mode, from 1114 to 1314. Unfortunately, due to problems with the Ashtech GPS system, both this and the earlier bottom-tracked calibration run proved unsuccessful. At the end of the run the ship slowed to allow deployment of the Precision Echo Sounder (PES) fish. A course was then set for the Galicia Bank, in the hope of repeating the bottom-tracked calibration of the ADCP.

The Galicia Bank was reached at 1947, and the ship's speed reduced again to 8 knots for a further bottom-tracking ADCP calibration run. However, the ADCP did not acquire the bottom successfully, the water over the bank being mostly greater than 500m deep, so this calibration run proved unsuccessful too. Course was resumed for the working area and the ship's speed increased.

A scientists' briefing was held at 1700 in the plot. Overnight the ship's clocks were retarded one hour to GMT+1.

Day 106 began rainy and overcast, but by the afternoon the weather was sunny with a few clouds in the sky. A pull test was carried out on the CTD cable. Once outside the 200m mile limit, the *Discovery* hove to for shallow, 120m, (*Discovery* station number 13079 - station details are listed

[1] Unfortunately, subsequent to the time of the cruise, the ADEOS satellite ceased to operate on 30 June 1997.

in Appendix II, and in the following narrative only the station number is given) and deep, 2000m (13080), CTD casts to test the equipment. At the same position a vertical net was deployed to 200m from the aft A-frame (13081). The net had two 200mm and one 53mm compartment. The 53mm mesh ripped on recovery, possibly because of excessive strain due to the pitching motion of the stern, and had to be replaced by a 200mm mesh (no replacement 53mm mesh being available). Subsequently, the vertical net was deployed from an auxiliary winch mid-ships, and no further problems were experienced.

Course for work area was resumed until 1728, when the ship slowed for a SeaSoar test deployment (13082). SeaSoar was recovered at 1943 and *Discovery* continued on course to 43°N, 17°W.

During the day a cruise briefing meeting was held in the plot for the officers and crew, at 1200. Overnight the ship's clock's were retarded one hour to GMT.

The work area (43°N, 17°W) was reached at 0214 on **day 107**. However, indications from underway sampling (particularly surface nitrate values) suggested that the spring bloom had already occurred in this area (due to good weather conditions), so the decision was made to head for a Topex radar altimeter satellite ground track (no. 087, see Figure A.1), deploy SeaSoar and follow the track to the north-east, in order to find where the bloom was beginning. On reaching the track at 0947, SeaSoar was deployed (13083). Prior to deployment, the PAR sensor had been replaced, as on the test run it had not been working. In the afternoon, at 1431, Lightfish was deployed for testing (13084), and recovered at 1834. No problems were experienced with towing both SeaSoar and Lightfish. Overnight *Discovery* continued on course following the satellite track.

In the morning, **day 108** at 0700, a 90° turn to port was made to run towards the next Topex track to the north-west (no. 011, see Figure A.1). At this point, the surface nitrate values were still low, so the search for the spring bloom continued. At 1900, on reaching the Topex track, a further 90° turn to port was made to run south west down the track. Over a period of 20 minutes *Discovery* developed an excessive rolling motion due to the swell, and the new course had to be abandoned and the previous course resumed for safety. In retrospect this proved fortuitous, as overnight the ship passed through an area of higher mesoscale variability and higher surface nitrate concentrations.

The following morning, at 0717 **day 109**, on intersecting Topex track no. 122 (see Figure A.1), *Discovery* altered course to run approximately south-east along the track, at a fairly acute angle to the overnight heading. The data obtained along this track confirmed the observations made overnight and the decision was taken to carry out the large scale survey between this Topex track and the next one to the north-east (no. 198; see Figure A.1). The SeaSoar was recovered at 1946, and *Discovery* was on station for the first CTD (13085) of the line at 2035. The survey (designated Survey B; the initial search pattern being Survey A, see Figure A.2) was to be carried out by alternating lines of CTD stations (at 30km spacing, to 2000m) with lines of SeaSoar tows, with a 30km spacing between lines (see Figure A.3). The overall dimensions of the survey area being 180^2 km^2.

Day 110 was spent working the CTD stations (13086, 13087, 13089, 13093, 13094, 13095) along the satellite track, together with Satlantic light sensor rig dips (to 60m, 13088, 13090, 13092), and a vertical net (to 200m, 13091). A radiosonde balloon was successfully launched at 1138. The weather was generally overcast, with some sunshine and calm seas.

After completion of a vertical net (13096), SeaSoar was deployed in the early hours, 0300, of **day 111** (13097) to carry out the next line of the survey. Once it was light, the Lightfish was also deployed (at 0727; 13098) and no problems were experienced with towing both instruments. Lightfish was recovered, at 1707, prior to the turn toward the next CTD line to avoid tangling cables. As light levels were low by this time of the day, this meant that little was lost in terms of data acquisition. A similar procedure was adopted on the other lines of the survey. SeaSoar continued to be towed until the next CTD line was reached, when it was recovered at 2043. The first of the new line of CTDs was carried out (13099), together with a vertical net (13100). It was decided to keep the ship speed between stations to below 9 knots to improve the quality of the underway ADCP data being acquired.

During **day 112** weather conditions were bright, but cloudy, with relatively low seas. This enabled six CTD stations to be successfully occupied (13101, 13102, 13105, 13109, 13110, 13111), and three Satlantic dips (13104, 13107, 13108) and a vertical net (13106) to be made, thus making good progress on the survey. The final vertical net of the line (13112) was made in the early hours of the next day.

Overnight, weather conditions worsened slightly, and during **day 113** they continued to deteriorate. SeaSoar was deployed at 0311 (13113) during the night and Lightfish at 0729 (13114) in the morning. As a weather front passed through the area, the sea became rougher and the Lightfish cable was shortened to avoid "knitting" it with that of the SeaSoar. Eventually, at 1455, the Lightfish was recovered, earlier than intended, to avoid damage to it. Some concern over the tension on the SeaSoar cable due to the rougher seas, and doubts over the working of the strain gauge, led to the replacement of the strain gauge. The new gauge was calibrated with a pull test and once in place showed that the tension in the SeaSoar cable was acceptable for operations to continue. As the seas were sufficiently rough to make recovering SeaSoar a marginal operation, and possibly too rough carry out CTD stations, the decision was taken to skip the next CTD line. Therefore *Discovery* travelled on to carry out the next SeaSoar line, with the aim of returning to do the CTD line in the morning (see Figure A.3). During this period SeaSoar was only reaching depths of around 280m, rather than the 320m achieved earlier in the cruise.

Day 114 began with sunshine and blues skies, with a few clouds, and relatively calm seas (which should have allowed ADEOS to acquire a good OCTS image). Lightfish was deployed at 0731 (13115), and SeaSoar continued to be towed overnight. During the night the hard disk on the SeaSoar controller PC had become full, leading to a system crash. This was quickly fixed, and SeaSoar operations were only briefly interrupted. At 1007 Lightfish was recovered, prior to a turn to port. SeaSoar was recovered at 1348, after running through the position of the next CTD station, to allow comparison of data between the two instruments. On station (13116) for CTD at 1427. Two further CTD stations (13119, 13120) carried out during the rest of the day, plus a Satlantic light sensor dip (13117) and a vertical net (13118).

During the day the non-toxic water supply was disconnected in order to clean the system. Due to an oversight it was not switched on immediately after cleaning, so some underway data were lost.

The line of CTD stations (13121, 13123, 13125, 13127) was completed on **day 115**, together with Satlantic dips (13124, 13126) and vertical nets (13122, 13128). The day began dull, with calm seas, but the weather worsened during the morning, with rain and stronger winds occurring, but this did not impede operations. During the afternoon the weather brightened. SeaSoar was deployed at 2220 (13129). Prior to deployment, the hydraulic unit was replaced in an attempt to solve the problems experienced in going deeper than 280m. The new hydraulic unit made no difference to the SeaSoar depth performance.

At 0500 on **day 116**, SeaSoar began to experience problems, so it was recovered at 0600 for repairs. Overnight *Discovery* had turned onto the final survey line, so the decision was made to return to the start of the line and carry out CTDs along the line. The CTD was deployed at 0824 (13130) but a short circuit prevented it acquiring data, so it was brought back on deck for a re-termination. The ship remained hove to, and a vertical net (13131) was deployed. Small holes were found in one compartment, possibly due to the net scraping the side of the ship. These were repaired before further deployments. Weather conditions were dull and overcast, with the swell increasing during the day. The CTD was deployed again at 1512 (13132), and after moving along the survey line again at 2016 (13133). During the latter deployment the swell increased to reach a significant wave height of over 6m (based on SBWR readings), making operations difficult. The CTD wire kinked during recovery, and the decision was made to heave to for the night.

On the morning of **day 117** the swell had reduced to 3m making CTD operations possible. 300m of CTD wire was removed from the winch and discarded, and the CTD wire re-terminated. CTD operations were resumed at 1116, and during the day three stations along the survey line were occupied (13134, 13138, 13139). A vertical net (13136) and two Satlantic dips (13135, 13137) were also made. By evening the swell had reduced to 2m, making CTD operations easier. Examination of the underway nitrate sensor data revealed a drift in the instrument, making it difficult to calibrate (and the data possibly meaningless).

The last CTD stations (13140, 13142) in the large scale survey were carried out on **day 118**, together with Satlantic dips (13141, 13143) and a vertical net (13144). At 1343 the SeaSoar (13145) and the Lightfish (13146) were deployed for a run back down the Topex ground track (no. 198, see Figures A.1 and A.3). At this time SeaSoar was only cycling to approximately 270m depth, for unknown reasons.

During the day concern had grown over the condition of one of the scientists (David Cromwell) who was unwell. Consultation by the second officer with doctors at the Royal Naval hospital in Haslar, suggested suspected appendicitis, and the advice given was to get David to hospital as soon as possible. Therefore at 2208, the SeaSoar, the Lightfish, the soap-on-a-rope thermistor and the PES were brought on board, and *Discovery* headed for Vigo at full speed.

During **day 119**, arrangements were made via RVS Operations and the ship's agent in Vigo (Estanislao Duran è Hijos, SA) to have David evacuated from the ship by helicopter, once the *Discovery* was within helicopter range of land. David's condition had stabilised during the night, due to the administration of antibiotics by the second officer. The ship continued at full speed towards Vigo.

At 0525 on **day 120**, *Discovery* rendezvoused with a Spanish air-sea rescue helicopter at 43° 36.9'N, 11° 31.9'W. A diver landed on the afterdeck with a stretcher, and David was winched on board the helicopter in the stretcher. The whole operation was completed by 0536, when *Discovery* set course back to the survey area. Subsequently, we were informed that David had been operated on, his appendix removed, and that he was recovering well. As principal scientist I would like to take this opportunity to express my appreciation of, and admiration for, the way a very difficult situation was handled by the ship's officers (particularly the second officer, in his role as medical officer for the ship) and crew, RVS Operations, the ship's agent in Vigo and the Spanish air-sea rescue helicopter crew.

On the way back towards the survey area, the soap-on-a-rope was deployed again. At 1121 a radiosonde balloon was launched. In the afternoon, between 1400 and 1600, the ship's speed was reduced to 8 knots and a series of 6 legs of 20 minutes duration each, with 90° turns between each leg, was carried out to calibrate the ADCP in water-tracking mode (as the original calibration zigzag on day 105 had not been successful; in fact, this calibration run proved unsuccessful too, for similar reasons). Full speed was then resumed for the survey area. During the afternoon, at 1500, a second briefing for the scientists was held in the plot, to discuss the strategy for the second half of the cruise. This was to consist of repeated small scale surveys of two parts of the large scale survey area; one that was biologically interesting, the second containing an eddy feature. The weather during the day had been sunny with clear skies, and small waves.

The PES was deployed at 0522 on **day 121**, and the SeaSoar shortly thereafter (13147), on the approach to the survey area. Two attempts were made to deploy the Lightfish (13148, 13149), but there were problems with the data stream, due to the failure of the termination. The Lightfish was brought back on board and re-terminated, ready for use on the following day. A successful radiosonde balloon launch was made at 1133. The small scale survey pattern was commenced at 1219 (survey C; see Figure A.4). Each leg of the pattern took about 4 hours to run, so the SeaSoar and OPC data were processed leg by leg, so that a decision could be made rapidly as to which patch of plankton in the survey area to re-survey in more detail with shallow CTDs (300m), vertical nets and LHPR tows. The weather during the day was dull, overcast, with a low swell.

Day 122 began dull, grey and foggy, with a low swell. SeaSoar survey C continued, with some interesting biological patches being found overnight. The Lightfish was deployed during daylight hours (13150). Over the course of the day the weather became brighter with sunshine in the afternoon and a few clouds, but turned duller in the early evening.

Survey C was completed early on **day 123**, and a SeaSoar track was run across the diagonal of the survey area to re-locate the patch with the maximum biological activity. Not surprisingly, the patch had moved. SeaSoar was recovered at 0924 and a shallow (300m) CTD station was made (13151), together with two Satlantic sensor dips (13152, 13154) and a vertical net (13153). The sea was too rough to deploy either the LHPR or SeaSoar, so a search pattern was followed using only underway sampling to try to locate the patch.

Early on **day 124** the search for the biological patch was curtailed, as it wasn't clear whether it had been located. During the day a number of shallow CTD stations (13155, 13159, 13163), Satlantic dips (13156, 13158, 13160, 13162, 13165, 13166) and vertical nets (13157, 13161, 13164) were made, in the vicinity of the supposed location of the patch. It was decided to repeat six lines of the small scale survey with SeaSoar (Survey D; see Figure A.5), which was deployed at 1745 (13167). Weather reports indicated that conditions might deteriorate, but it was thought that it would still be possible to carry out the survey.

Overnight the SeaSoar survey continued (two and a half of the six lines were completed), but in the early hours of **day 125** the weather conditions worsened and *Discovery* was rolling badly (although SeaSoar continued to perform well). It was decided to turn into the waves and to move ahead at low speed in order to stream SeaSoar behind the ship. During the morning the termination on the SeaSoar slowly deteriorated due to strain on the cable, as evidenced by the increasingly poor data return. Unfortunately the weather conditions were too bad to recover SeaSoar at this point. The significant waveheight peaked at about 10m (20m crest-to-trough) during this period, as measured by the SBWR.

During the morning of **day 126** the weather conditions improved somewhat and the significant waveheight was down to around 4m. The decision was taken to recover SeaSoar, which operation was successfully carried out despite the poor weather conditions. The wire was kinked badly near the termination, and during the day the wire was re-terminated and the SeaSoar checked over ready for re-deployment. In the afternoon the weather moderated sufficiently to run south, to be in position to repeat part of the first small scale survey (C; see Figure A.4).

SeaSoar was deployed at 0526 on **day 127** (13168), with the intention of repeating six of the nine lines of survey C (designated Survey E; see Figure A.6). By the evening it became apparent from the OPC data that some interesting patchiness was present. It was decided to stop the survey after the fifth line (in the early hours of the next morning) and to try to identify the boundaries of a patch with SeaSoar. Once identified, the patch would be investigated using a combination of LHPR, CTDs, vertical nets, and Satlantic sensor dips.

Day 128 began well with the successful identification of the patchiness using SeaSoar. At 0750 SeaSoar was recovered and the *Discovery* took up position for the first CTD station to 2000m (13169). Unfortunately the weather deteriorated rapidly during the time taken to do this station, and the CTD wire kinked on recovery, necessitating re-termination. The conditions also prevented the deployment of vertical nets and the Satlantic sensor. So the *Discovery* remained hove to. Later in the afternoon the conditions improved and with the CTD re-terminated the line of vertical nets (13170, 13172, 13174, 13176) and shallow (300m) CTDs (13171, 13173, 13175) was resumed.

Working overnight, the line was completed on **day 129**, with further shallow (13177), and deep (13179) CTDs, together with vertical nets (13178, 13182) and two Satlantic sensor dips (13180, 13181). As the weather conditions were favourable, it was decided to carry out further biological sampling with a LHPR tow. Preparations were made to do this in the morning, but the 20T winch controls failed to operate, and the *Discovery* remained hove to while the problem was investigated. During the late morning some rain bands passed through the area, but the wind and swell conditions remained unchanged. The LHPR was eventually deployed at 1518 (13183), but towing had to be suspended when a problem arose with the tensioner on the winch. Once fixed towing was resumed, at which point the PC logging the data from the LHPR ceased to log data (for reasons unknown). The LHPR was towed in and recovered. Approximately 40 samples had been collected but no ancillary information (for example, depth and temperature) had been recorded. No further use of the LHPR was made on the cruise.

By this stage the delays due to the weather and equipment problems meant that the intended small scale surveys of the eddy were not feasible (given the time remaining and the low probability of locating it). Therefore, it was decided to carry out a second large scale (Survey F; see Figure A.7). This was to be a partial repeat of the first large scale survey (Survey B; see Figure A.2), covering an area of 150^2 km^2, with lines again spaced at 30km, but this time using only SeaSoar. At 2119, SeaSoar was deployed (13184) and the survey commenced, with the ship moving at 8 knots.

During **day 130** the survey continued. The long lines of the survey (see Figure A.7) were run alternatively against and with the swell (significant waveheight 3-4m), which was approximately from the north-west. When running into the swell it was found that the ADCP data quality was severely reduced. At the ends of the lines it proved difficult to run across the swell as *Discovery* rolled badly, so these legs were "dog-legged" to reduce the rolling motion. Lightfish was deployed during daylight hours (13185).

Early on **day 131** the *Discovery* encountered some larger swell waves and experienced a degree of slamming motion, so the ship's speed had to be reduced to 5 knots for a while. Later the swell died down somewhat and the ship's speed was brought back up to 8 knots. Lightfish was deployed in the morning (13186), recovered for the period of the turns from one line to the next in the survey, and re-deployed in the afternoon (13187).

On **day 132** survey F continued. Lightfish was deployed during the day (13188). The waves were lower, so there was no need to "dog-leg" when running across the swell. It was noted that SeaSoar was towing to one side of the ship (the port side) irrespective of the direction of travel with respect to the waves and currents. Whatever was causing this could also be responsible for its inability to dive deeper than about 280m.

During the night the last line of Survey F was completed, and in the early hours of **day 133** the course was changed to run along the Topex track (no. 011) across the survey area (see Figures A.1 and A.7). Lightfish was deployed in the morning (13189), but had to be recovered when the termination failed. It was re-terminated and re-deployed in the afternoon (13190), after *Discovery* turned towards Vigo, and recovered at the end of the day. The weather continued to improve. The ship's clocks went forward one hour overnight to GMT+1.

Lightfish was re-deployed for the morning of day **134** (13191), and it and SeaSoar were recovered after lunch. The final CTD station, to 3000m, was made in the afternoon (13192). This was primarily to carry out further tests on the nitrate sensor. It also provided the opportunity to re-wind the cable onto the drum, as it was not laid down correctly from a previous cruise (earlier CTDs had only been to 2000m, which had not spooled out sufficient cable). Following the CTD station *Discovery* set course for Vigo. The ship's clocks went forward one hour overnight to GMT+2.

Day 135 was spent heading towards Vigo. During the day backups and archiving of the cruise data from the onboard computer system was carried out. Packing up of equipment and clearing up of laboratory spaces was also undertaken.

After carrying out a bottom-tracking ADCP calibration run over the continental shelf overnight, *Discovery* docked in Vigo on **day 136** (Friday, 16th May, 1997) at 0700 (0900 local time).

MAS

3. SURVEY PATTERNS

The aims of the cruise (see objectives in section 1) required a number of repeat surveys to be carried out. As can be seen from the narrative (section 2) the lack of a spring bloom in the initial survey area, the medical emergency and the (at times) poor weather necessitated some revision of the original plans. This section, for ease of reference, summarises the surveys carried out during the cruise and briefly describes their patterns and the numbering scheme employed (the overall cruise track is shown in Figure 1; the survey pattern plots are in Appendix I). In addition, Figure A.1 shows the Topex/Poseidon ground tracks, and numbers, in the region of the surveys, as the large scale surveys were oriented so that some of the survey lines coincided with these tracks (see below).

During the cruise six survey were made, labelled A to F (see also stations list, Appendix II):

Survey A - Figure A.2, days 107 to 109 - this was the initial search for the spring bloom using SeaSoar, moving to the north and west of the centre of the originally planned survey region at 43°N, 17°W. Line B0 of the following survey (see below) is equivalent to the last 180km of line A3.

Survey B - Figure A.3, days 109 to 118 - the first large scale survey (180^2km^2), consisting of alternating lines of SeaSoar (B0, B3, B7, B11, B13) and CTD (B1, B5, B9, B14) measurements. The lines were spaced at 30km, with CTD stations every 30km along the CTD lines. The initial and final lines of the survey lay along Topex/Poseidon ground tracks, and were surveyed both with SeaSoar and CTDs (B0 and B1, B13 and B14). Due to weather and equipment problems the sequence of survey lines was B0, B1, B2, B3, B4, B5, B6, B7, B8, B11, B10, B9, B12, B14, B13 (note that B2, B4, B6 are all SeaSoar lines of 30km length, while B8 and B12 are SeaSoar lines of 60km length, but with a 30km overlap).

Survey C - Figure A.4, days 121 to 123 - the first of the small scale SeaSoar surveys to look at the biological patchiness. Nine lines (C1 to C9) of 60km length, spaced 5km apart; together with a diagonal line across the survey area (C10) were run. Lines C1 to C9 lying at 90° to, and between, lines B7 and B11, with line C3 repeating line B8.

Survey D - Figure A.5, days 124 to 125 - the second small scale SeaSoar survey. Lines D1 to D3 repeating lines C8 to C6, but abandoned during line D3 due to adverse weather conditions.

Survey E - Figure A.6, days 127 to 129 - the third small scale SeaSoar survey. Lines E1 to E5 repeating lines C8 to C4. At the end of this survey, an attempt was made to sample the biological patchiness in more detail using CTDs and vertical nets, plus an LHPR tow along E3.

Survey F - Figure A.7, days 129 to 134 - the second large scale survey using only SeaSoar (150^2km^2). Due to time and weather constraints it was decided to repeat only part of survey B, thus lines F1, F3, F5, F7, F9 and F11 repeat parts of lines B11, B9, B7, B5, B3 and B1/B0. The lines surveyed were of 150km length, spaced at 30km. As the weather had moderated, and sufficient time was available at the end of this survey, line F12 was run along the Topex/Poseidon track that lay diagonally across the survey area, before heading back to Vigo.

In addition to the surveys detailed above, on days 123 and 124 an attempt was made to locate a biological "patch" using underway instrumentation, and to sample it with vertical nets and CTDs. This was not entirely successful, so the SeaSoar was re-deployed for Survey D.

MAS

Navigation

A best estimate of the ship's position was made from a combination of GPS and GLONASS data (called bestnav). The navigation data from bestnav were processed regularly without any event or problems. The navigation data were placed in two files, for ease of handling; in abnv2271 prior to 0543, day 120, and for the rest of the cruise in abnv2272. These navigation data were merged with various data sets to tie them into the ship's position, as required.

BT

4. TECHNICAL SUPPORT

OTD CTD and SeaSoar Support

CTD operations

The CTD equipment used during the cruise consisted of a Neil Brown MkIIIc CTD (Deep03), Falmouth Scientific 24 bottle rosette pylon, Chelsea MKIII Aquatraka (fluorimeter sn88/2690163), Chelsea MKII Alphatraka (25cm transmissometer sn161/2642/002), nitrate sensor, reversing thermometers/pressure sensors and 15 Ocean Test Equipment 10 litre Niskin bottles.

During the cruise 41 CTD casts were completed (and one abandoned) and apart from a few minor problems (see the list below) the system worked perfectly. The sea cable was re-terminated on three occasions, when the cable became kinked or damaged due to the rough sea conditions experienced during the cruise.

Failure list:

1) Two reversing thermometers flooded and the batteries failed in all but one of the others (no spares were packed!).

2) The Falmouth Scientific Inc. (FSI) pylon gave 100% confirmation of bottle firing. However, due to an interrupt problem on the PC, data were not always logged to the bottles level A. An interrupt conflict occurred in the MS Windows set-up. Once resolved no further problems were encountered.

3) After chemical analyses (nitrate, oxygen) two bottles were found to have closed at the wrong depth. The most likely causes are either operator error or lanyards slipping. (99.7% success rate).

4) One Niskin bottle end cap snapped off and was replaced.

SW

SeaSoar operations

The SeaSoar equipment used during this cruise consisted of a Neil Brown MkIIIb CTD (with two conductivity cells; Shall01), Chelsea MKIII Alphatraka, PML PAR light meter, Focal Systems Optical Plankton Counter (OPC, borrowed from PML), and the OTD vertical winch with 420m of faired cable.

Ten separate deployments (totalling ~303 hours , ~40% of the cruise!) were made and generally the system worked very well. However, the maximum depth achieved was only 300m and often the SeaSoar only managed to get to 250m. This did not improve after the hydraulic unit was replaced, the wings adjusted and the sea cable re-terminated (after failing). Again, as for the CTD, problems were caused by the bad weather:

1) During the second recovery, the vehicle hit the aft end causing slight damage to the OPC tube and shearing two mounting bolts. Fortunately the instrument still appeared to give good data. However, it should be returned to Focal for checking and re-calibration.

2) On the fourth run gale force winds forced the ship to heave to, and it was considered safer to leave the SeaSoar deployed. However the termination failed after 6 hours and eventually (30 hours later) the vehicle was recovered. The sea cable was kinked near the termination, but no damage was caused to the vehicle itself.

3) The PAR light meter borrowed from PML failed and was replaced with a spare SOC one.

The winch worked well throughout the cruise and only a few meters of fairing were lost. No time was lost due to mechanical or instrumentation breakdowns.

B(A)W, SW

RVS Scientific Engineering Support

RVS SEG (scientific engineering group) equipment and technical support was required for the following scientific operations during the D227 cruise:

1) SeaSoar towing deployments
2) CTD deployments
3) Lightfish deployments
4) Satlantic light profiler deployments
5) Zooplankton net sampling
6) Echo sounder deployments
7) Non-toxic water supply
8) Milli-pore (MilliQ) pure water system
9) LHPR deployments

The following SEG equipment was in service throughout the cruise to facilitate scientific operations:

1) Main 10T traction winch system and cable haulers
2) Main 20T traction winch system and cable haulers

3) Starboard gantry system and auxiliary pennant winches
4) Stern gantry system
5) Mid-ships/aft main hydraulic power pack and deck distribution system
6) Deck mounted portable winches
7) Stern mounted 30TM ACTA cranes

SeaSoar deployments

OTD SeaSoar operations were carried out throughout the cruise with deployment times ranging from approximately 24 - 72 hours. SeaSoar was deployed using the OTD portable deck mounted winch via a block suspended from the stern gantry pendulum. During deployment problems were encountered with the stern gantry local control console. The fault was identified as water contamination in the local control box sited on the port pedestal. The problem has been rectified, but the control console requires stripping and a number of the electrical components changing.

CTD deployments

CTD operations were conducted with the OTD frame and 15 water bottles. Deployment depths ranged between 300m and 2000m, with a final nitrate sensor calibration drop of 3000m. Sea conditions during the cruise were generally marginal for operation of the OTD frame, due to its high drag characteristics. This resulted in the CTD "floating" as the ship rolled to starboard, and inducing high snatch loads on the cable and termination as the ship rolled to port. During the cruise a total of 450m of cable was removed to enable terminations to be re-made.

Lightfish and Satlantic profiler

The Lightfish was towed from a portable deck mounted slip ring winch via the port airgun boom. Ideally the fish should be towed further away from the ship to keep it out of the ship's wake, and clear of any additional towed vehicles. This point should be considered for future operations. All deployments were carried out successfully.

Zooplankton nets

The first net deployment was carried out over the stern, this resulted in damage to one of the nets due to the ship's pitching motion. Subsequently 400m of 6mm hydro cable was wound on to the starboard gantry auxiliary winches for further deployments. All operations were carried out to a depth of 200m.

PES fish and winch

The PES was used throughout the cruise, deployments and recoveries were carried out without problem.

Non-toxic and MilliQ water systems

Both these systems were utilised during the cruise, operating without problem. There are some minor leaks on the non-toxic distribution pipes in the deck lab. This is to be addressed during the 1997 refit.

LHPR deployment

Due to adverse weather conditions only one LHPR deployment was carried out during the cruise. Prior to the deployment a fault developed on the 20T 37kW power pack, delaying the LHPR operation. It was found the TCS unit did not power up, thus preventing the storage drum hydraulic pressure being set. The faulty unit was replaced with the unit from the 10T system to allow the deployment to continue. On completion of the operation the TCS unit was refitted in the 10T system. A replacement TCS unit is now required for the 20T winch.

CD, JSc

RVS Data Logging

Data acquired on the cruise were logged on the RVS system. The following problems should be borne in mind when processing data post-cruise:

1) LOG_CHF - The athwartships component of the em log is currently unreliable. When deriving 'bestnav' it was ignored.

2) GYROSYNC - The gyro was observed to read 1.5° low. This was corrected before use in 'bestnav'.

3) GLONASS - The data stream contains erroneous time stamps around midnight.

4) GRHOMET - Prior to day 106 2044 the atemp, baro and ch18 data are incorrect.

5) NUTRI2 - The logging of this underway nutrient sensor data was not fully implemented until day 107 1000. Data prior to this may be valid, but with the wrong polarity.

6) At about day 109 0731 all raw data files may contain some duplicate records. This was due to malfunction of the Level B disc. The disc was marked bad and the running spare used for the rest of the cruise.

Recent additions to ship's equipment

A High Speed Datalink (HSD) via a 64Kb satellite link enabled a (prototype) e-mail system to be used. In addition to ship management and scientific traffic, private use was permitted (for a small charge). The transfer of large volumes of remotely sensed and other data, both to and from the ship, contributed to the science, whilst private traffic was valuable for morale.

A GSM digital cellphone was permanently installed in the computer room for RVS Scientific use. The marine aerial was mounted above the Bridge. The aim of this system is to reduce costs and our dependence on RVS Marine facilities. Note also that received calls in foreign ports attract a significant surcharge.

RL

5. METEOROLOGICAL OBSERVATIONS

Surface Meteorology

The aims of the surface meteorological measurements during the cruise included:

i) Determination of the heat fluxes and momentum transfer (wind stress) between the ocean and atmosphere in the experiment area to aid numerical modelling of the upper ocean structure.

ii) To test parametrisations for determining the incoming longwave and shortwave radiative fluxes from cloud observations.

The suite of meteorological sensors deployed allowed estimation of all the different components of the air-sea heat flux. In addition, a sonic anemometer system provided data for wind stress determination using the inertial dissipation method.

Sensors deployed

Mean Meteorology

The GrhoMet meteorological instrumentation system which has been installed on *Discovery* since cruise D223 uses the RVS Rhopoint network for connection to foremast, hull and laboratory sensors. In addition to the normal RVS instrument suite, further sensors were mounted on the foremast and connected into the logging system. A total of 18 sensors were logged (Appendix III and Figure 2). These measured air temperature, air pressure, wind speed, wind direction, downward longwave, shortwave, and photosynthetically active radiation (PAR). The system acquired data at 5 second sampling rate and generated data files in raw and calibrated format, which were written to the PC's hard disk. The GrhoMet system also output raw (uncalibrated) data via an RS232 link to the level '**B**' in SMP format, where the data were logged by the RVS computer system. The scientific clock was read through a serial port and used to update the PC clock once every 6 hours when a new data file was opened.

Wind stress

A Gill Instruments Solent Sonic Anemometer (R2 Asymmetric Model) was mounted on the starboard side of the foremast platform. The anemometer was operated in Mode 1 and the 21 Hz sampled data were logged using a PC system situated in the Plot. This recorded the raw data stream on optical disk and also calculated and recorded wind speed spectra and spectral levels. These were based on an about 12 minutes sampling period starting each quarter hour.

Cloud Observations

Cloud observations (total cover and amount and type of low, middle and high altitude cloud) were made at hourly intervals in the daylight period (during which more reliable observations could be made) between 0600 and 2000. As well as providing a description of the typical weather experienced, these data will be used in evaluating radiation parametrisation formulae.

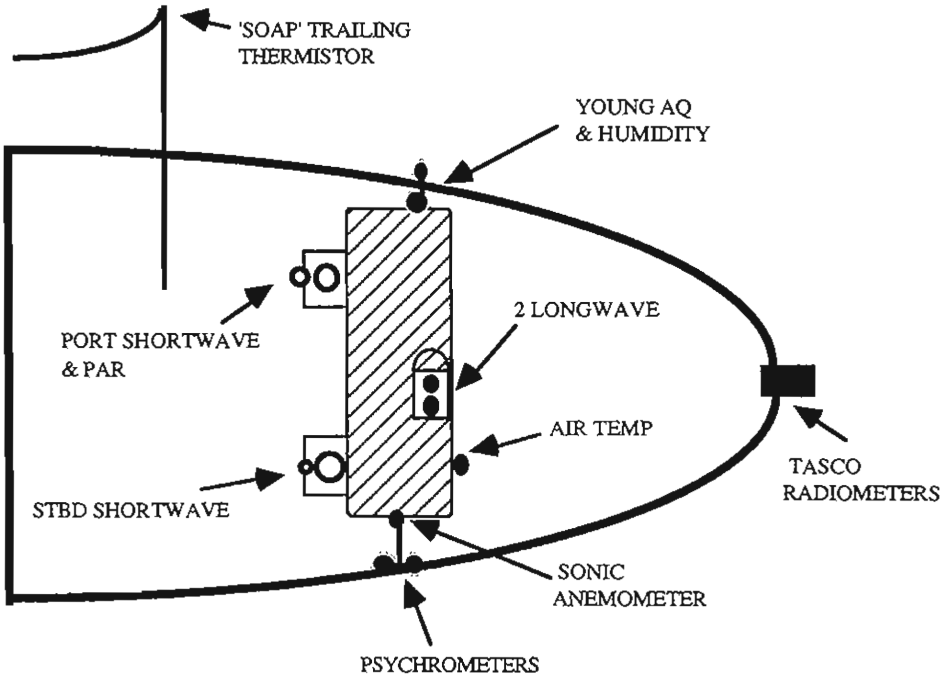

Figure 2. Plan view of the bow of the *Discovery* showing meteorological sensor positions for cruise 227.

Sensor Performance

Air temperature and humidity

Four sensors provided dry bulb air temperature data: two psychrometers, the RVS air temperature sensor, and the temperature signal from the RVS humidity sensor. Of these the RVS air temperature sensor was less affected by solar radiation. In comparison the psychrometers read high by 0.1 to 0.15°C for downward solar radiation greater than 500 Wm^{-2}. These psychrometer dry bulb readings also exhibited an intermittent cold bias. Tests on *RRS Charles Darwin* Cruise 104 have suggested that this error is caused by dripping from the wet bulb wicks. Nevertheless, taken over the whole cruise, the agreement between these temperature sensors was good; the mean difference was 0.03 ± 0.12°C or better. In contrast, the humidity sensor temperature signal was biased cold by 0.9 ± 0.15°C. This offset was approximately constant throughout the cruise and could be removed if required.

The RVS humidity sensor failed at the start of the cruise, but the wet and dry bulb psychrometers provided a reliable humidity estimate. The mean difference between the wet bulb temperature values from the two psychrometers was negligible (-0.01 ± 0.05°C).

Radiative fluxes

Before the start of the cruise a large (about 30 Wm^{-2}) negative bias was noted in the starboard solarimeter reading; after sailing this changed to a positive bias of about 5Wm^{-2}. In contrast the port solarimeter showed a bias of 9Wm^{-2} on the first night of the cruise and 3Wm^{-2} on the second.

These problems, coupled with lack of signal from the port PAR sensor, were investigated by removing the radiometer amplifier at 1445, day 106, it being replaced after modification at 1620 day 107. After this time the port solarimeter bias was $2Wm^{-2}$ or less; the starboard sensor bias remained between 4 to $6Wm^{-2}$. Unfortunately, neither of the PAR sensors now worked; indeed inspection showed that both appeared to have been in service for an excessively long time. A spare PAR sensor of the type used on the SeaSoar was substituted from about 1530, day 109. This was attached to the port solarimeter mount, but was not gimballed.

One problem noted during the cruise was that the various masts and other items situated above the level of the solarimeters meant that both could be in shadow at the same time. Thus, taking the maximum of the two solarimeter readings will not always remove shadowing effects and the downwards short wave will tend to be underestimated. One solution might be to retain the two gimballed units, and to mount a third non-gimballed unit at the top of the foremast extension.

The comparison between the two longwave sensors was similar to that noted on cruises D223 and D224. The two instruments agree well at high values of downward longwave radiation (cloudy conditions), but longwave sensor 1 reads higher for clear skies. From past instrument comparisons, longwave sensor 2 is believed to be the more accurate.

Wind velocity and wind stress

Mean wind speeds from the two wind velocity sensors, the R.M. Young propeller-vane and the Solent Sonic anemometer, were in good agreement. For 12 minute mean winds (corresponding to the wind stress measurement periods) the mean wind speed difference was $-0.1 \pm 0.8ms^{-1}$. This is better than might be expected given the separation of the instruments on either side of the foremast platform. Mean wind speed during the cruise was about $9ms^{-1}$; the maximum mean wind speed observed was about 20 ms^{-1}.

The wind stress estimates obtained from the sonic anemometer corresponded to drag coefficient values similar to those found on previous cruises. An apparently anomalous period of high wind stress was recorded on day 113, but this was associated with larger than normal flow tilt angles at the sonic anemometer. It is believed that the effect of wind and swell was causing the ship to heel and thus causing the erroneous readings.

Sea surface temperature

The sensors used for measuring sea surface temperature are shown in Table 1. Bulk sea surface temperature was measured by the hull contact sensor, the thermosalinograph (TSG), and the trailing thermistor ("soap"). The mean difference (soap - TSG) apparently varied with sea temperature being about -0.07 at 13°C and -0.03 at 15°C; the mean value was -0.061 ± 0.001°C. These differences did not appear to be related to the air-sea fluxes and the accuracy of either instrument would seem adequate to determine the bulk SST temperature. In contrast, the hull temperature sensor read too low and drifted with time. The (hull - TSG) difference was about

0.4°C at the start of the cruise and about 0.7°C towards the end. A bias of this order in the hull sensor readings was also noted on D224; however, on that cruise the bias remained constant to within 0.1°C.

Sensor	Position	Measurement	Logging system
Hull	Forward hold	bulk at ~ 3.5m	GrhoMet
Trailing thermistor	Port bow	bulk at ~ 0.5 m	GrhoMet
Thermosalinograph	Intake pipe in forward hold	bulk at ~ 5.0m	RVS underway sensors
Tasco radiometers	Above bowplate	skin + sky	PC system

Table 1. SST sensors deployed during the cruise.

Air-Sea Flux Calculation

On this cruise a special effort was made to estimate the air-sea heat fluxes on a day to day basis and hence estimate the integrated heating or cooling of the ocean. These data clearly showed a contrast between conditions early and late in the cruise. From day 109 to 124 a relatively warm, moist air flow resulted in small turbulent fluxes and net heating of the ocean (Figure 3). From day 125 onwards, stronger winds and a flow of cold, dry air from north of the area resulted in enhanced latent and sensible heat fluxes. These cancelled the solar heating so that the net change in ocean heat content during the later part of the experiment was small.

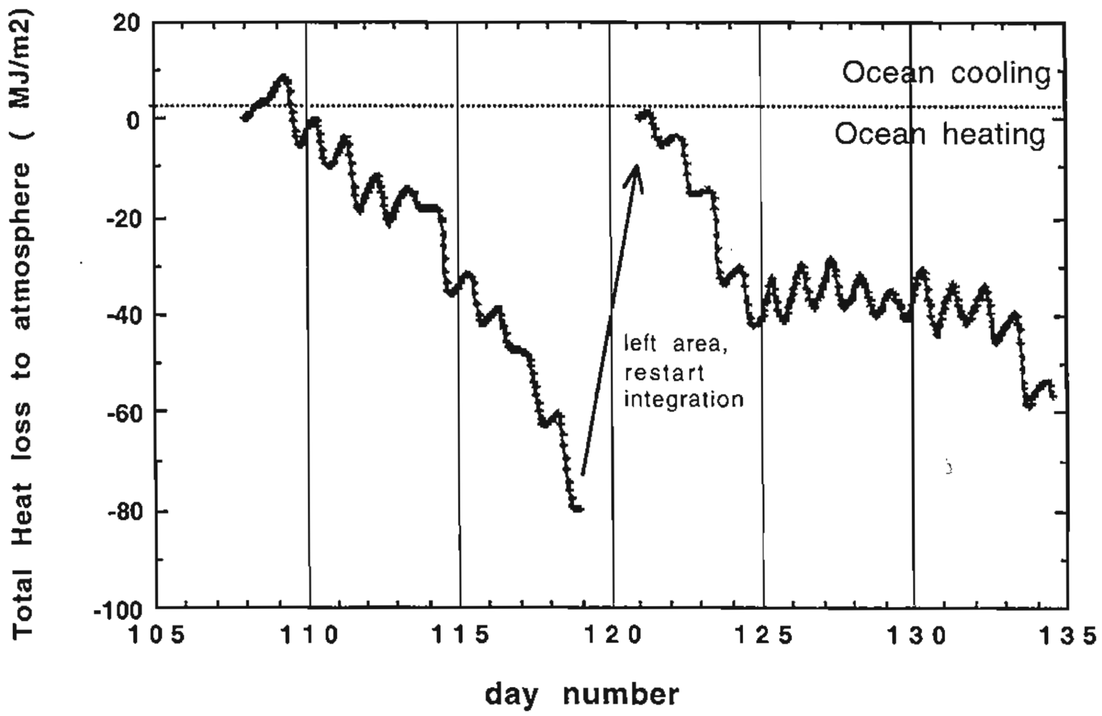

Figure 3. Total integrated heating or cooling of the ocean during the cruise. The amount of heat gained by the ocean increased up to day 125. There was little net heat gain or loss after that day. (The gap in the integration is due to *Discovery* leaving the survey area during the medical emergency.)

Upper air - radiosondes

The aim was to obtain profiles of the tropospheric temperature and humidity structure to aid interpretation of surface colour observations from the ADEOS satellite.

Radiosondes were launched from the top of the winch control cabin. This launch site represents the best available but is far from ideal. Since the last cruise on which radiosondes were used (D224), railings have been placed around the 75TM ACTA crane preventing easy access to the port side of the ship. Thus radiosonde launches are now difficult, if not impossible when the wind is on the starboard side. Insertion of a gate in these railings would help on future cruises.

Twenty-six launches were performed (Appendix IV) using the Vaisala "PTU" sonde RS80-15, which gives profiles of temperature and humidity as a function of pressure. The launch time was chosen to correspond approximately to the overpass time of the ADEOS satellite. Fortunately, because of the generally light to moderate winds experienced, only 1 launch was unsuccessful.

The data were transferred to the UNIX system and processed to 5mb resolution de-spiked profiles formatted as a gridded PSTAR file.

Radiative sea surface temperature

The aim was to obtain measurements of the ocean surface skin temperature in order to improve our knowledge of the surface skin effect for the interpretation of satellite derived SST data.

For measuring the radiative sea surface temperature four Tasco THI-500L infra-red thermometers were mounted on a pole extending forward of the ship's bow. Angled mirrors, manufactured on the ship from aluminium rod, were used to point the measurement beam in different directions. At any time, one or more of the thermometers was pointed upward to measure the radiative sky temperature and the others were pointed downward at the sea surface. Multiple thermometers were used both to determine the reliability of the measurement and, by pointing the instruments at different angles, to check the correction for the non-black body behaviour of the sea surface. The instrument was only deployed for restricted periods in order to minimise contamination of the thermometer lenses by spray; the mirrors and lenses being cleaned before and after each deployment. The periods for which the instrument was deployed are shown in Appendix V. On day 120 failure of a joint in the signal cable caused the RS232/RS485 converter to fail. By day 121 a new version of the logging system was implemented by Simon Watts using an RVS PC fitted with a RS485 interface card. This system operated for the rest of the cruise.

ShipBorne Wave Recorder (SBWR)

The aim was to provide data suitable for ERS-2 altimeter wave measurement validation and for interpretation of the wind stress data.

The MK IV version of the ShipBorne Wave Recorder (SBWR), developed through a collaborative programme between Ocean Technology Division (OTD) of SOC and W.S. Ocean Systems Ltd., has been installed on *Discovery* since cruise 224. The electronic control and processing unit of the MK III system has been replaced by a PC running an application developed using LabWindows CVI. This converts pressure and accelerometer signals into a wave height value, which is periodically processed to produce a wave energy spectrum. The new system had been evaluated on cruise 224, with particular emphasis on testing the communications between the SBWR and the ship computing system.

On this cruise routine data processing methods were established both for the data logged by the level B system and for the data files stored on the SBWR PC. For the latter a script (scrp1.pcwr) and program (pcsbwr.F) were written to automatically recognise and process the four different types of files: RAW files containing wave height data, SPC files of spectral data, PAR files with mean parameter data, and INF files containing housekeeping data. The RAW, SPC and PAR files were converted to PSTAR format and appended files of spectral and mean parameter data created for the cruise.

PKT

6. HYDROGRAPHIC AND CURRENT MEASUREMENTS

SeaSoar data processing and calibration

SeaSoar data were logged via the RVS Level ABC computer system, and then transferred into PSTAR format. Standard PEXEC command files were modified from previous cruises and used to process the data in 4-hour sections, in keeping with the watch system. After initial calibration, the data were examined for spikes and offsets caused by biological fouling of the conductivity cells. The SeaSoar had two conductivity cells fitted, with the additional cell being on a slightly longer arm than the original cell. The original one was selected as the primary cell. It was later noted that the primary cell suffered fewer data spikes than the other. Fouling events were clearly identified by comparing the difference between the two cells. Most fouling events in salinity could be recovered by swapping from the primary cell data to the secondary cell data. Where this was not possible, because both cells were fouled, a corrective offset could be applied to the data to recover it to match the data before and after the fouling event. Occasionally both cells were fouled, and were gradually drifting back to normal values. In these cases the data were irrecoverable.

It is usual practice to compare the SeaSoar salinities with CTD data early on in the survey, to select a modified conductivity ratio. On this cruise, we did not do this due to volume of work, and continued to use the laboratory calibration values for the conductivity ratio. This had the effect that we had to apply a relatively large correction to salinity measurements to bring them into line with the CTD and discrete salinity sample data.

At the end of each survey leg, the 4-hour sections were appended, merged with navigation data and contour plots produced. The survey section data were then converted to ASCII format and passed electronically to the Harvard group for ingestion to their models.

AIM, SGA, PC

CTD data processing and calibration

A total of 42 CTD stations were carried out, and these are detailed in the station list (see Appendix II). Two test stations (13079, shallow, and 13080, deep) were taken on the way to the survey area, 28 deep stations (to 2000m) were taken during survey B (and one station that had to be abandoned, 13130), 4 shallow (to 300m) in survey D and 2 deep and 4 shallow as part of survey E. A final 3000m deep station was taken at the end of the cruise (13192). This deep station was taken to test the nitrate sensor.

The data were logged onto the RVS system. With the exception of the PAR sensor all instruments worked satisfactorily. On a number of occasions (stations 13079, 13080, 13086, 13095, 13099) the times of the bottle firing were not recorded and a system for inferring this from the winch data was devised by Steven Alderson.

Temperature Calibration

The temperature sensor on the CTD was calibrated according to the following formula:

$$T = 1.0372955e\text{-}12\ T_{raw}^2 + 0.000495577\ T_{raw} - 2.1232033$$

The calibration constants were supplied by OTD. All temperatures quoted are on the ITS-90 scale.

Pressure Calibration

The pressure sensor was calibrated with the following formula supplied by OTD:

$$P = 4.840857e\text{-}10\ P_{raw}^2 + 0.1074491\ P_{raw} - 38.893228$$

Salinity Calibration

Initial calibration of the conductivity measurement was made using the following formula supplied by OTD:

$$C = 3.242363e\text{-}11\ C_{raw}^2 + 0.94441544e\text{-}3\ C_{raw} - 0.062996414$$

This was changed after station 13094 (once an improved conductivity ratio was obtained) to:

$$C = 3.245930e\text{-}11\ C_{raw}^2 + 0.945454e\text{-}3\ C_{raw} - 0.063066$$

The value was also corrected for temperature and pressure using the equation (Crease et al., 1988 - a correction for conductivity cell distortion due to changes in T and P):

$$C_{new} = C_{old}\ (1 - 6.5e\text{-}6\ (T\text{-}15) + 1.5e\text{-}8\ P)$$

C_{new} was then converted to salinity using the PEXEC programme peos83.

Measurements of *in situ* salinity were taken from Niskin bottles at depths of 2000 (x2), 1500, 1000, 500 (x2), 100, 70, 50, 20 m and surface (x2) on the deep casts[2], and 300 (x2), 200, 100, 50 and 10 m on the shallow. These measurements were used to refine the salinity calibrations via an empirical fit. Duplicate measurements were not included in the calculation.

At each station the conductivity from the CTD measurement was compared with the conductivity derived from the bottle salinity. (In fact, both conductivities were derived using the equation of state 83 (using peos83) because the PSTAR sam file does not contain the original conductivity value). These conductivities were related via a linear model of the form:

$$\mathrm{Cond(CTD)}_i = \alpha\ \mathrm{Cond(bottle)}_i + \beta + \varepsilon_i$$

where i denotes the bottle and the ε_i are i.i.d. Normal random variables, with zero mean and constant variance. This equation was then inverted to give a calibration equation:

$$\mathrm{Cond(new)} = \alpha'\ \mathrm{Cond(CTD)} + \beta'$$

where $\alpha' = 1/\alpha$ and $\beta' = -\beta/\alpha$.

In order to give better calibrated data to the Harvard group before the bottle data had been analysed the equation was fitted to all the data from the first line of CTDs (B1) producing a single set of calibration constants

$$\alpha' = 0.99874017 \qquad \beta' = 0.03948040$$

These were used for stations 13132 to 13142 before being replaced with the correct values later. Due to a clerical error (*mea culpa* - PC) some of the data passed over to the Harvard group had incorrect calibrations applied. This error was detected and corrected on day 126, the problem started on day 121 with station 13105.

PC, SGA, AIM

Salinity sampling

On each of the 32 successful deep CTD casts, fifteen bottles were fired, of which nine were sampled, and duplicate samples were taken from three of these. On the 8 shallow CTD casts (except shallow test cast), five bottles were sampled and one duplicate taken (see above for depths at which samples were taken on the deep and shallow casts). These discrete salinity samples were used to calibrate the CTD salinity measurements. Further discrete salinity samples were collected from the non-toxic supply in the hangar, in order to calibrate the thermosalinograph salinity measurements, and SeaSoar near-surface measurements. These samples were made approximately hourly during SeaSoar sections and less regularly while on-station for CTD casts. In total, sixteen crates of 24 samples from the non-toxic supply were analysed.

A Guildline Autosal (Model 8400B) salinometer, belonging to the James Rennell Division at SOC, was used routinely throughout the cruise to measure the salinity of samples drawn from the thermosalinograph and from most CTD casts. The salinometer was located in a temperature

[2] 3000m cast (13192) sampled at 3000 (x2), 2000, 1500, 1000 (x2), 800, 500, 100, 50 m, and surface (x2).

controlled laboratory which was kept at around 20°C. The salinometer was operated at 21°C and proved to be fairly stable. Standard sea water ampoules (batch P131) were used to standardise at the beginning and end of each crate of 24 samples. A set of Microsoft Excel spreadsheet macros were used to generate salinities from hand-recorded conductivity ratios.

Around day 117, problems were experienced in filling the conductivity cell with sample fluid. After checking that the tubing was not blocked at any point, methanolic Decon 90 was flushed through the cell, and left in place for 24 hours. This seemed to clear up the problem, and few other difficulties were encountered during the cruise.

AJM, SGA, DJJ, DDC, MAS

Thermosalinograph (TSG) [including underway fluorimeter and transmissometer]

The TSG consists of a FSI temperature sensor mounted near non-toxic supply intake, at a depth of about 5m on the hull, and FSI conductivity and temperature sensors mounted in a non-toxic water supply tank in the hangar. Data from it were logged continuously, together with data from both the fluorimeter and the transmissometer (located in another non-toxic water supply tank in the hangar). The fluorimeter was a Chelsea Instruments sensor, the transmissometer was a SeaTech Instrument. RVS staff handled regular tank cleaning and calibration checks. The system was fully operational within 12 hours of leaving port and in use during the entire cruise.

The data from the TSG were processed in near real time, in order to assist in locating surface features associated with sub-surface eddies, and hence potentially interesting bio-physical environments. Both temperature and salinity records were logged with minimal occurrence of problems. The temperature records were accepted as is. The conductivity values were converted to salinity using PEXEC programme peos83, and then de-spiked. The data were then averaged to 1 minute values and merged with the bestnav navigation data. On each watch, regular water samples were taken (hourly) for salinity and chlorophyll analysis. Once the salinity bottles had been processed a corrected salinity calibration was applied to the data. This was an interim calibration based on a regression of water bottle salinities against TSG conductivity and housing temperature (the tank temperature measurement - see Topliss, 1997, for details). An improved salinity calibration will be carried out post-cruise.

The chlorophyll calibration for the fluorimeter was determined by Mike Fasham, using night-time data only (see p. 47, section 8). During daylight hours the fluorescence signal exhibited marked "surface quenching" effects, which remain to be corrected. The fluorescence and transmissometer records occasionally exhibited large "platform spikes" mostly, but not always, due to disturbances when the tanks were checked. These bad data were replaced with missing values. The transmissometer records suffered the greatest number of such disturbances, typically either not returning to its original value and/or taking a considerable period of time to return to a stable signal. These additional poor data also had to be removed.

BT

Acoustic Doppler Current Profiler (ADCP)

The *RRS Discovery* has a 150kHz RDI ADCP unit mounted in the hull. The instrument was used in "water track" mode, except for the periods over the shelf on departure from, and approach to, Vigo when "bottom track" mode was employed. In both modes, the data were recorded as two minute ensembles in 64 x 8m bins.

As well as the main processing in water track mode, a number of calibrations were attempted. On the passage from Vigo over the shelf a bottom track calibration was tried, but poor quality Ashtech 3DF GPS data during the period meant this was not successful. A zigzag calibration was unproductive for similar reasons, both on the initial passage from Vigo and on the return to the survey site on day 120.

On this cruise, the ship's absolute velocity (used for the conversion of relative current velocities to absolute velocities) was determined using the Russian GLONASS positioning system, together with GPS. This is the first time the GLONASS system has been used on *Discovery*, though it had previously been used on the *RRS James Clark Ross* during a Drake Passage cruise. The system started logging during the time in dock in Vigo, before the start of the cruise, in order to test its accuracy. These data showed that the rms position accuracy for GPS and GLONASS plus GPS to be 25m and 13m, respectively, for a 2 minute average (see Figure 4; for a 10 minute average, the figures were 15.7m and 11.5m, respectively). This difference in accuracy is due to the selective availability of GPS, which leads to increased position error.

The ADCP processing was carried out according to a standard sequence of operations using the set of PEXEC programmes, as follows:

a) The ADCP time stamp is provided by a software clock which drifts by approximately 24 seconds per day relative to the ship's master clock. An hourly log of the time difference was kept, and used to correct for this drift.

b) Information about the pitch, roll and heading of the ship was obtained from the Ashtech 3DF GPS and the ship's gyro. The ship's gyro is known to oscillate through a few degrees, particularly after changes in heading. During the small scale surveys changes in heading were frequent and so this was a significant problem. The difference between the Ashtech and gyro headings averaged over two minute intervals were edited by hand. The resulting gaps were interpolated using a model devised by Griffiths (1994). When these tasks had been completed, the time-corrected ADCP data were merged with the heading and attitude information.

c) The ADCP data were then merged with information about the ship's velocity to get the absolute velocities of the currents relative to the earth. The ship's velocity information was obtained using the GPS plus GLONASS positioning system.

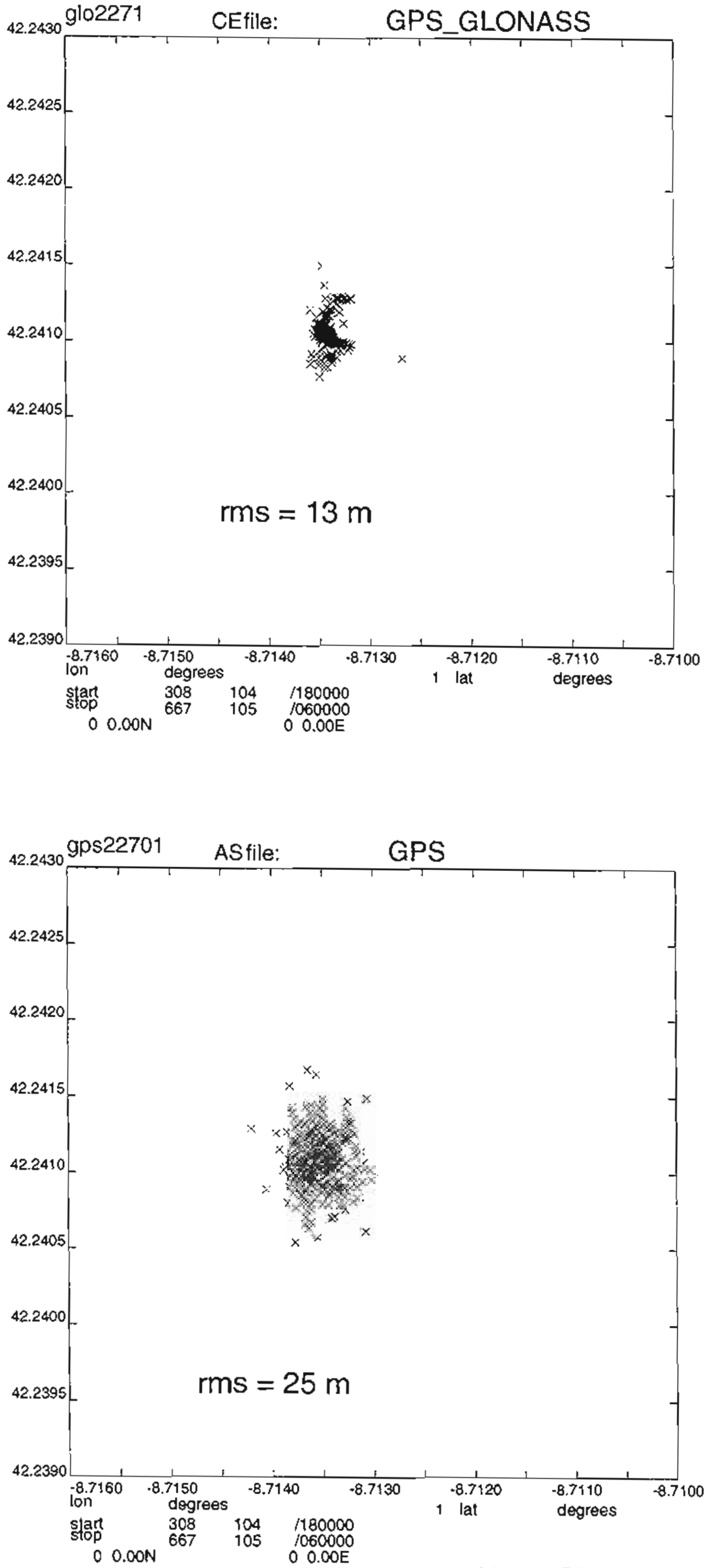

Figure 4. Comparison of position estimates for *Discovery*, while in Vigo, using GLONASS plus GPS (upper plot), and GPS alone (lower plot). The rms values are based on two minute averages over a 12 hour period (1800 day 104 to 0600 day 105). The reason for the crescent-shape of GLONASS plus GPS plot is unknown.

As well as absolute current velocities, the amplitude of the backscatter was also examined. The calampl routine was used. The resulting plots clearly showed the diurnal migration of zooplankton between the surface (where they feed at night) and around 300m depth (where they shelter during the hours of daylight). Because there is as yet no means of converting backscatter amplitude to zooplankton biomass, the plots were primarily of qualitative use.

IT, DDC, SGA

7. OPTICAL MEASUREMENTS

Two optical instrumentation systems were used on D227. The subsurface underway towed sensor, Lightfish, was used to obtain highly spatially resolved measurements of spectral reflectance. The Satlantic radiance and irradiance discrete band sensors (7 wavelengths) were used to obtain depth profiles of measurements, which were used to calculate the diffuse attenuation coefficient. The measurements will also be used to calculate surface reflectance for calibration algorithm development to interpret the data from satellite ocean colour sensors (OCTS, MOS). Samples were taken for the identification of the major plant pigments (HPLC) at each Satlantic cast (surface) and during the Lightfish transects. Phytoplankton samples were also taken for identification of the major taxonomic groups. These data will be used to interpret the optical information from the two systems used.

Lightfish

The spectral wavelengths of the upwelling and downwelling irradiance sensors were 410, 443, 490, 520, 550, 632 nm (bandwidth 20nm). The data from the Lightfish was sampled by the Level A, along with other underway parameters, providing a set of readings every 30 seconds. Calibration constants were applied to the data, following pre-cruise calibration at Plymouth Marine Laboratory. The processing on the cruise consisted of screening the data for spikes, calculating reflectance and examining the relationship between reflectance ratios (typically R443/R550 and R490/R550) with underway chlorophyll, taken from the underway fluorimeter and calibrated with discrete samples.

Lightfish was deployed for 11 tows during the cruise, at the same time as SeaSoar. The depth of the sensor was 3m below the surface. It was deployed using a slip ring winch, which allowed easy adjustment of the cable length. The position and operation of the deployment was not ideal because a 2.5m davit at the stern of the ship was the only available deployment option, even though an alternative was requested and discussed with RVS prior to the cruise. On previous cruises Lightfish has been deployed from one of the stern cranes, but as they are not now used for towing, this option was not available. The davit, which was close to the stern, was far from ideal because the Lightfish tended to be drawn into the wake of the ship, adding noise to the data. Also transferring the weight of the Lightfish from crane to davit, immediately prior to deployment and on retrieval proved awkward. The termination of Lightfish failed on day 121, and on day 132, and RVS technicians re-terminated it.

Comparisons of the reflectance ratios (R443/R550 and R490/R550) showed an inverse relationship compared with underway fluorescence, which was expected. However, a time lag was observed between the fluorescence and the reflectance ratios of about 8 minutes. It is concluded that this is caused by the residence time of the pumped water from the intake at 3m since it is held in a header tank, and also in the tank where the instruments are situated.

Satlantic

Satlantic radiance (Lu) and irradiance (Ed) sensors (411, 443, 490, 510, 556, 670 and 682nm, 20 nm bandwidth) were mounted on a profiling rig, along with the data acquisition unit. The data were recorded on a PC, although the intention had been to record via a Level A. However, as the instrument format had been changed when last calibrated by the manufacturers, it was no longer compatible with the Level A. Instead, the data were logged onto a PC using the Satlantic software (Proview) and the manufacturer's calibration was applied. The data were then processed using the UNIX system on board ship.

Deployment was carried out by means of either the port or starboard cranes on the stern of the ship. A wire from a small winch was used to take the load of the system, and the conducting core cable was paid out as the instrument was lowered. As the depth required was only 60m, this method of deployment was successful.

23 Satlantic casts were made, immediately following CTD stations. 18 of these casts were made with the sensors configured to measure upwelling radiance and downwelling irradiance, so that the remote sensing reflectance ratio could be calculated. During these casts a sample of sub-surface water from the pumped supply was filtered through Whatman GF/F glass fibre filter papers and the filters were frozen in liquid nitrogen so that the pigment composition could be analysed by High Pressure Liquid Chromatography (HPLC). 5 casts were made of downwelling radiance and irradiance, to calculate the Q factor (irradiance / radiance ratio) for different illuminations and water types. A series of deck measurements were also made for comparison between the Satlantic sensors and the mast-mounted PAR sensor.

The data was processed via PEXEC programmes. Firstly, spikes were removed from the data; these were few, typically one or two on the pressure channel per cast. Then Kd and Ku (the downwelling and upwelling diffuse attenuation coefficients) were calculated over the range of the depths where ln(Ed) and ln(Lu) were linear. Kd for all the stations was compared with the chlorophyll values for the first 4 depths of the previous CTD cast, which gave greater than 70% correlation. This comparison will be made later with the pigment samples taken at exactly the same time as the cast.

We wish to thank RVS technicians for their assistance in the deployment of Lightfish and Satlantic.

ARW, DL-J

SeaSoar PAR sensor

Initially a PAR sensor borrowed from PML was fitted to SeaSoar but, as this did not work on the test deployment, it was replaced by a spare SOC one. This worked successfully for the rest of the cruise, and data from it were processed using the OTD supplied calibration.

MAS

CTD transmissometer

Transmissometer data were acquired on all the CTD casts made during the cruise. These data remain to be processed after the cruise.

MAS

8. CHEMICAL AND BIOLOGICAL OBSERVATIONS

Sample dissolved oxygen analysis

Dissolved oxygen samples were the first samples to be taken on deck from the CTD rosette. Samples were drawn from each Niskin bottle on the 32 deep (31 x 2000m, 1 x 3000m) CTD casts and from a standard selection of depths on the 9 shallow (1 x 120m, 8 x 300m) casts. Between one and four duplicate samples were taken on each cast, from the deepest bottles. The samples were drawn through short pieces of silicon rubber tubing into clear, pre-calibrated, wide necked glass bottles and were fixed immediately on deck with manganese chloride and alkaline iodide dispensed using precise repeat Anachem bottle top dispensers. Samples were shaken on deck for approximately half a minute, and if any bubbles were detected at this stage, a new sample was drawn. The samples were transferred to the constant temperature laboratory (set to 20°C), shaken again thirty minutes after sampling and stored under water until analysis.

The temperature of duplicate samples from all depths was measured using a hand held electronic thermometer probe. The temperatures were used to calculate any temperature dependent changes in the sample bottle volumes.

Samples were analysed in the constant temperature laboratory starting between two and six hours after collection. The average storage time was three hours. The samples were acidified immediately prior to titration and stirred, using a magnetic stir bar set at a constant spin speed. The Winkler whole bottle titration method with amperometric endpoint detection (Culberson & Huang, 1987) was used with equipment supplied by Metrohm. The spin on the stir bar was frequently disturbed by the movement of the ship and by the uneven bases of some of the sample bottles, leading to less effective stirring of the sample and thus longer titration times, although this probably did not affect the accuracy of the endpoint detection. The Anachem dispensers have caused problems on previous cruises due to the corrosive nature of the reagents, so to avoid this they were washed out with de-ionised water each time the reagents were topped up.

The normality of the thiosulphate titrant was checked against an in-house potassium iodate standard of 0.01N at 20°C at the beginning of each analytical run and incorporated into the calculations. Blank measurements were also determined at the start of each run to account for the introduction of oxygen with the reagents and impurities in the manganese chloride, as described in the WOCE Manual of Operations and Methods (Culberson, 1991). Tests were carried out at the start of the cruise to determine the most accurate and consistent method of thiosulphate standardisation and it was concluded that the iodate would be added after the other reagents and following on directly from the blank measurements, in the same flask, as on cruise D223. The thiosulphate normality during the cruise (Figure 5) decreased as the batch aged, and was changed prior to run 25. Some variability occurred when the iodate batch was changed, and this will be discussed further in a later report on data quality. The mean (± sd) thiosulphate normality during the cruise was 0.10089 ± 0.0008.

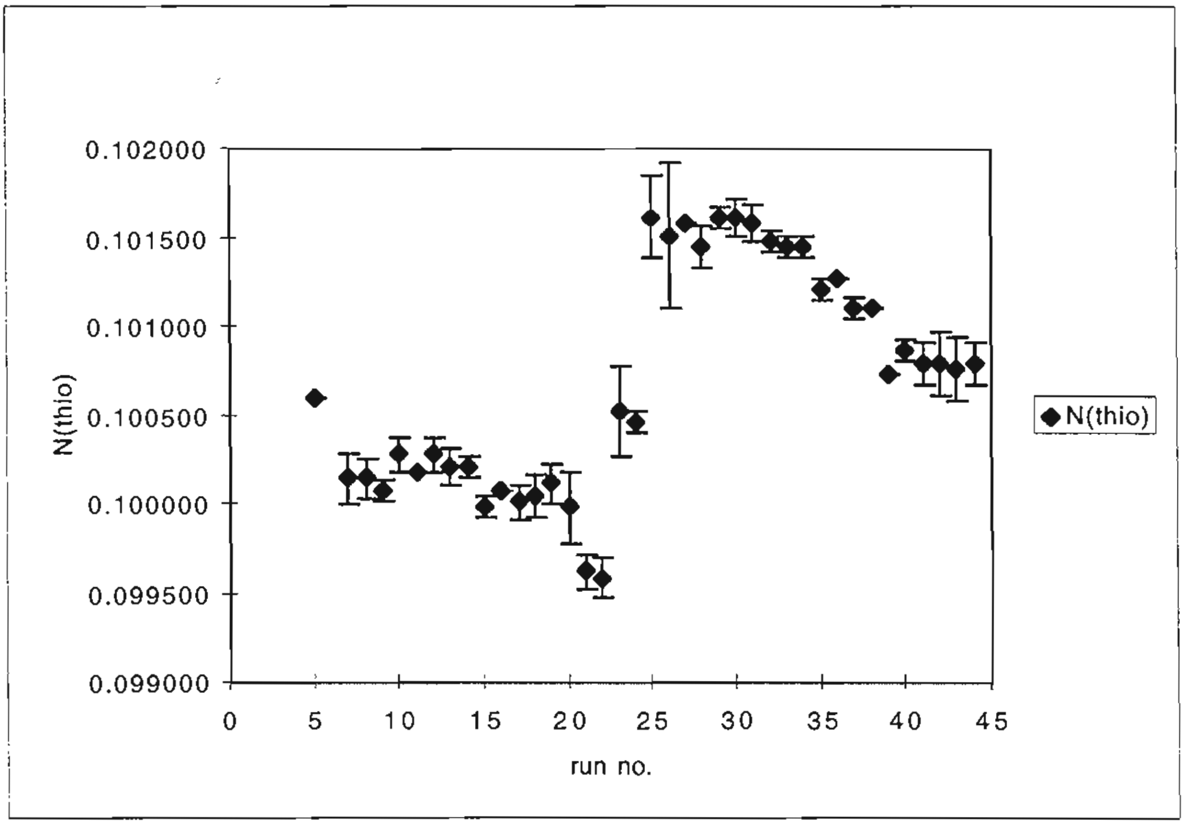

Figure 5. Thiosulphate normality during the cruise. The first few runs of the series were for test purposes and the results are not shown.

Overall the mean (± sd) duplicate difference in dissolved oxygen values across the cruise was 0.763 (± 0.661) µmol/l, for a sample size of 119 pairs of duplicate measurements, and precision remained steady throughout the cruise. Duplicate differences > 1.0 µmol/l accounted for 32% of these duplicate pairs and ignoring these high duplicate differences the mean (± sd) duplicate difference improved to 0.411 (± 0.268) µmol/l. The duplicate difference achieved was not related to the individual calibrated sample bottles used and high duplicate differences seemed to occur at random.

CP, JC, SH

CTD oxygen measurement calibration

Dissolved oxygen concentrations were calculated according to the formula:

$$Oxygen = oxsat(T,S) \times rho \times (oxyc + c) \times \exp(\alpha.oxtemp + \beta.p)$$

where *oxsat(T, S)* is the saturated oxygen value for a given temperature and salinity, *oxyc* is the oxygen sensor current reading, *oxtemp* is the CTD-measured temperature (n.b. sensor temperature reading was not available), *p* is the CTD-measured pressure. Coefficients *rho*, α, β and offset *c* were selected by fitting the continuous data to the discrete bottle sample data and minimising the residual at each station.

The firing of each Niskin affects the upcast oxygen measurement, so it is necessary to calibrate the downcast oxygen measurements with the bottle sample data. These were extracted by selecting the data cycle with the closest matching potential density. A least squares fitting algorithm was used to find the coefficients, and individual samples (up to 15 were available) were excluded manually from the fit as necessary to ensure a sensible fit was achieved.

AIM, SGA

Nutrient Analysis

Sampling

Discrete samples were analysed for dissolved inorganic nutrients: silicate (sio3), nitrate plus nitrite (referred to as nitrate or no2+3) and phosphate (po4) using the SOC Chemlab Autoanalyser. Samples were taken from every Niskin bottle on each cast, following sampling for oxygen (and salinity, when sampled). All samples were taken into 30ml 'diluvial' sample cups, washed 3 times with sample before filling, then analysed immediately in duplicate. Where immediate analysis was not possible, samples were stored in the refrigerator for up to 10 hours. As an indication of precision of the sample measurements the standard deviations of the duplicate differences were 0.54µmol/l for silicate, 0.75µmol/l for nitrate and 0.17µmol/l for phosphate.

Samples were also taken hourly from the non toxic supply near the TSG (increased to every half hour while the SeaSoar was flying). They were stored in the refrigerator and analysed as soon as there were sufficient for an analytical run (named uway01-uway43, with identical file names, and appended as unutbt227). The underway nutrient samples were taken for correlation with the chlorophyll data and for calibrations of the underway nitrate sensor set up in the TSG tank. (Thanks are due to Brenda, Dafydd, David, Mario and Ian for taking these samples.) Aliquots of distilled water and sea water samples from the salinity calibrations of both the underway nitrate sensor and the CTD nitrate sensor on deck were also analysed.

Methods

The sensitivity of the analyser was adjusted to the expected concentrations by changing the gains, flow cells and concentrations of the calibration standards. The silicate and nitrate data can be divided into 3 batches on the basis of these changes:

a) batch 1, up to 40µmol/l, runs 1-41 (stations 13080-142, uway01-22);

b) batch 2, up to 10µmol/l silicate and 15µmol/l nitrate, runs 42-57 (stations 13151-163; uway 23-35) with increased gain settings;

c) batch 3, up to 40µmol/l, runs 58-68 (stations 13169-192, uway36-43).

The changes made and problems encountered are summarised below, and in the calibration section, with details of each method used.

a) Silicate

Silicate analysis followed the standard AAII molybdate-ascorbic acid method with the addition of a 33°C heating bath (Hydes, 1984). For maximum sensitivity an 820nm filter was used and, initially, a 15mm flow cell. The flow cell became blocked and was replaced on run 43 (uway24). A decrease in response over 3 analytical runs after this was traced to the silicate detector and the line was re-routed through a spare detector and 50mm flow cell, to increase the response, on run 48 (station 13151). Low silicate results from runs 62 - 66 were multiplied by a factor (1.34), reflecting the low values in the quality control samples.

b) Nitrate

The standard AAII method using sulphanilamide and naphtylethylenediamine-dihydrochloride was used for nitrate analysis with a glass cadmium filled reduction column. A 15mm flow cell and 540nm filter was used throughout. A nitrite standard, diluted from an Ocean Scientific (OSI) stock standard with Low Nutrient Seawater (LNSW), was used as a quality (QC) sample for nitrate analysis and to check on the reduction power of the Cd column, which was only changed once on run 46 (uway27).

c) Phosphate

For phosphate analysis the standard AAII method was used (Hydes, 1984), which follows the method of Murphy & Riley (1962). A 50mm flow cell, 880nm filter and constant gain setting were used to measure up to 2.5µmol/l. There was a large amount of noise on this channel and the stations with good data are patchy and therefore difficult to contour. This was thought to be due to the age of the photometer, as it had become increasingly sensitive to changes in ambient light. A smooth baseline could be achieved if the line was re-routed through the silicate detector and flow cell, indicating a problem with the phosphate detector on the colorimeter. However changing the colorimeters over resulted in an increase in noise on the other two channels. As phosphate data was of a lower priority it was sacrificed, and no further measurements were made after run 40 (station 13142).

All measurements were made in the deck laboratory. Other than the problems described above the analyser performed well with regular cleaning and maintenance. The tubing on the peristaltic pump was fully replaced after runs 7, 24 and 46 with further periodic changes of individual tubes as necessary.

Calibration

The primary standards were prepared from 0.9598g sodium hexaflurosilicate, 0.510g potassium nitrate and 0.681g potassium dihydrogen phosphate (which had been dried at 110°C for 2 hours and cooled in a desiccator before weighing). Diluting to 500ml with MilliQ de-ionised water resulted in a stock standard of approximately 10μmol/l. The standard concentrations were corrected for weight, and the calibration of the 500ml flask used, to acquire the exact primary stock concentration.

A range of 4 mixed working standards were prepared daily in 100ml plastic volumetric flasks (using 40g/l NaCl). Applying a further correction for the 100ml flask calibrations would have resulted in a uniform decrease in nitrate values by up to 0.2% (and up to a 0.2% decrease for silicate concentrations of over 3μmol/l) for batches 1 and 3. The shallow CTD samples (and underway surface samples) in batch 2 were analysed using standards that had been corrected for the 100ml flasks. The change in standards may have some affect on the calibration coefficients which were monitored for each analytical run. The calibration information will be given in a further detailed report (Peckett & Holley, 1997).

Quality control

Two quality control (QC) samples (prepared from 2 different batches of OSI nutrient standard stocks, diluted using LNSW) were analysed at the start and end of each analytical run. These were named QC2 and QC4 as they were prepared to produce the same concentrations as the second and fourth in-house standards (e.g.: 30 and 10μmol/l for batch 1 and 3 nitrate and silicate samples). This gives us some idea of the precision (and accuracy) of the results (further details in Peckett & Holley, 1997). The silicate OSI QC samples read consistently high by 1μmol/l. However, this offset is not seen in the comparisons with historical data (described in the next section).

Historical data comparisons

Historical data comparisons provide an additional estimate on the accuracy of the results. The TTO (Bainbridge *et al.*, 1980) station 118 (49° 44'N, 21° 60'W) and Vivaldi (Pollard *et al.*, 1991) station 11008 (48° 14'N, 15° 59'W) were selected, as they were close to station 13139 (48° 03'N, 17° 24'W). Despite the fact that the CTD casts were not full depth on D227, the nutrient, and dissolved oxygen, data shows a close agreement between all three cruises (further details in Peckett & Holley, 1997).

SH, CP, JC

Nitrate sensors

Two versions of the experimental UV nitrate sensor were taken on D227. The aim was to collect data from the sensors and to correlate with data from the chemical analysis of sea water. One sensor was attached to the CTD frame, the other placed in the surface non-toxic water supply tank. The sensors measure the absorbance of sea water at three wavelengths. The 300nm channel is a reference channel, the 240nm a function of salinity, nitrate and organic matter and the 220nm channel is related to the nitrate concentration. The sensor 220nm voltage output is converted into absorbance (which is directly proportional to the nitrate concentration) using the equation

$$Abs = \ln (Vo/Vreading)$$

where Vo is the voltage reading in distilled water. This reading was checked before each CTD cast and indicates the stability of the sensor with time. On the CTD sensor Vo drifted down over the first five readings and was then stable before drifting again towards the end of the cruise (this is shown in Figure 6), a mean value of 2.055 for Vo was used in the calculation of all 220nm absorbance values.

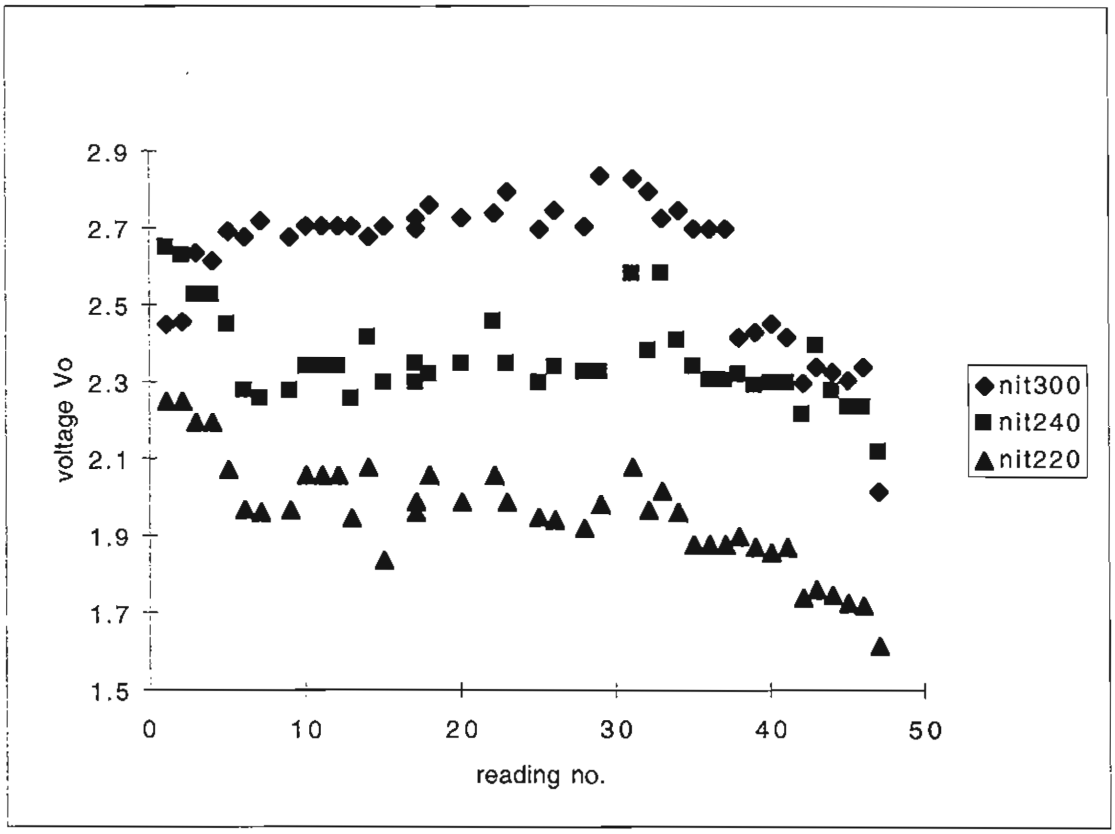

Figure 6. Variation in the CTD nitrate sensor Vo values for the three channels (220, 240 and 300nm) during the cruise.

The Vo of the underway sensor was checked periodically and showed a linear decrease during the cruise, which made it difficult to correlate with the surface nitrate. All three channels on the underway sensor showed a decrease in response, and also a decrease in noise, from day 110 - the cause for this remains to be established. Underway samples have been analysed for nitrate and an attempt will be made to calibrate the sensor from these at a later date.

Calibrations of the sensors were carried out using known nitrate concentrations, assessed by chemical analysis. From these, curves of absorption were constructed to convert absorbance to nitrate concentration. These were carried out in distilled water, standard sea water and water of varying salinity. The results, which confirm the stability of the CTD sensor and the decrease in response from the underway sensor, will be useful background data to judge the effect of salinity on the sensor.

The Niskin bottle samples from each CTD cast were analysed for nitrate (as detailed in the report of nutrient measurements above) and the results used to construct absorbance curves for the sensor. Preliminary processing of the CTD sensor data to apply the calibrations and convert the absorbance to nitrate concentration was carried out. A linear fit of the discrete samples to the CTD upcast 220nm results was preferred, with an R^2 better than 0.92 (a mean value of 0.95). This was calculated for each station and the equations were found to be significantly different. The average equation was:

$$y = 96.33x - 54.66$$

where y is the nitrate concentration and x is the 220nm upcast absorbance.

The equations were applied using 'exnitcal', a script written for this purpose and the calculated nitrate results were compared with the bottle data in terms of concentration and water column structure. The CTD nitrate sensor allows much more vertical resolution of the nitrate features throughout the water column, than the bottle data, and shows promising results despite the experimental nature of this sensor.

The sensor hysteresis was monitored throughout the cruise. The up cast produced a consistently smaller voltage reading than the down cast. It is still apparent on the shallow casts, but of smaller magnitude. It does not appear to be correlated to real water column changes as indicated by the other sensors (temperature, salinity and chlorophyll measurements). On four of the deep CTD casts (13080, 13169, 13179 and 13192) the nitrate sensor was held at full depth for 20 - 30 minutes and shows a 3.5% to 11% change in the voltage reading over this period. When the sensor is held at depth a second order fit of the readings to the nitrate data is more appropriate. This hysteresis is possibly a temperature effect and requires further study.

JC, SH, CP

Chlorophyll and fluorescence

Calibrations

a) Turner Designs TD-700 Bench Fluorimeter

1 mg of Sigma Chemical chlorophyll *a* (*Anacystis nidulans*) was dissolved in 1 ltr of 90% acetone for the main standard. This gave a nominal standard concentration of 1000µg/l. The standard was then measured accurately using the Camspec spectrophotometer to give a concentration of 1015µg/l. A sub-standard was then made up by adding 10ml of the standard to a flask and adding acetone to make up 200ml; the sub-standard concentration was therefore 50.75µg/l. Both standard and sub-standard were wrapped in foil and kept in the refrigerator. On day 106 a sample of the sub-standard was used to calibrate the TD-700 using the Raw Fluorescence Calibration method and the standard acidification procedure for calculating the concentration of chlorophyll

a and phaeophytin. The measured acidification ratio was 1.9932 and the calibration constant 0.1288. This calibration was used throughout the cruise and the concentration of the sub-standard was measured at regular intervals. The results were as follows:

Day	110	114	123	125	129	130	133
Sub-standard conc. (μg/l)	50.13	53.60	48.11	49.07	48.69	47.58	46.77

Table 2. Variation in sub-standard chlorophyll concentration used for calibration during the cruise. The drift on these values is of the same order as the inherent accuracy of the method.

Throughout the cruise, samples (taken both from the non-toxic supply and from Niskin bottles) for chlorophyll analysis were obtained by filtering 100ml of water onto GF/F filters. 10ml of 90% acetone was added to a vial containing the filter and the samples kept for at least 24 hours in a refrigerator before being measured on the TD-700.

b) Tank Chelsea fluorimeter

During most of the SeaSoar operations samples of the pumped sea water supply were taken every hour for chlorophyll analysis. The night samples between 105/1145 and 108/0830 were used to calibrate the tank fluorimeter. The resulting calibration was

$$\ln(\text{chl } a) = -2.3596 + 0.794 * \text{Fvolts}$$

where Fvolts is the output of the fluorimeter in volts. The R^2 of the regression was 77%. To avoid possible confusion in processing due to changing calibrations, this initial calibration was used throughout the rest of the cruise.

c) SeaSoar Chelsea fluorimeter

The SeaSoar fluorimeter was calibrated against the tank fluorimeter, rather than directly against chlorophyll samples. Values of the SeaSoar fluorimeter voltage for the first 2 days of SeaSoar sampling were extracted for night-time cases, where the SeaSoar pressure gave a depth between 3 and 9m. Values for the tank fluorimeter voltage were determined for the same times, allowing for the time lag between the ship and the SeaSoar (150s) and the delay in pumping water from the surface (90s). This allowed us to determine a relationship between SeaSoar and tank fluorimeter voltages for a range of *in situ* chlorophyll concentrations (R^2 = 94%). The resulting SeaSoar fluorimeter calibration was

$$\ln(\text{chl } a) = -2.9948 + 1.4292 * \text{Fvolts}$$

d) CTD Chelsea fluorimeter

The CTD fluorimeter was calibrated using bottle samples from stations 13079, 13085-87, 13089-90, and 13093-95. The resulting calibration equation (R^2 = 97%) was

$$\ln(\text{chl } a) = -5.188 + 2.6821 * \text{Fvolts} .$$

This calibration was used throughout the cruise and no attempt was made to determine individual dip calibrations.

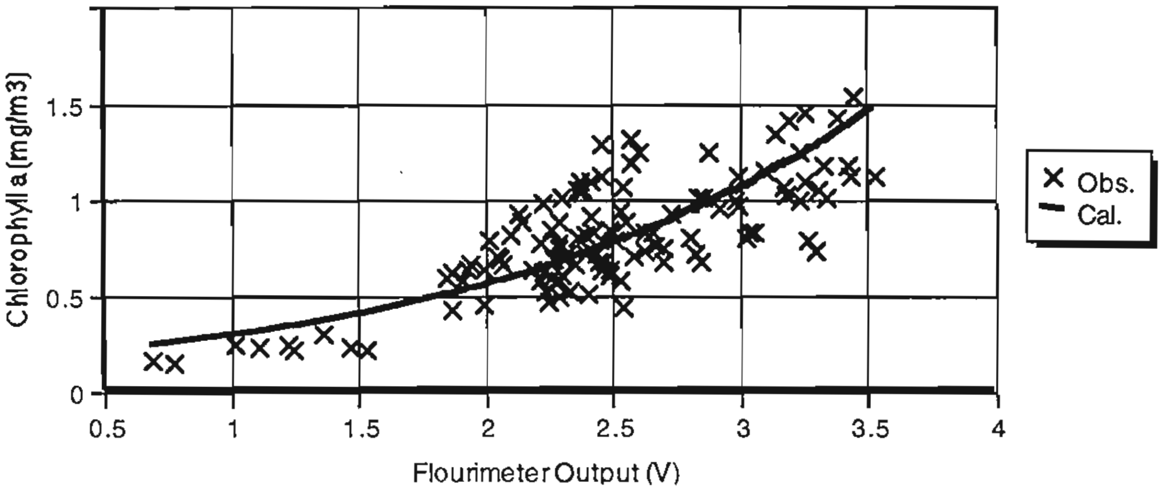

Figure 7. This figure shows the calibration curve for the tank fluorimeter compared to the night samples collected from the beginning of the cruise up until day 125 (this differs somewhat from the equation above, as more data were used here). It is clear that there were a number of samples in the centre part of the curve for which the calibration underestimated the chlorophyll concentration, implying a lower fluorescence yield of the phytoplankton. Most of these cases were found in the north and east of the survey B area. An improved calibration will be performed, using all the sample data, post-cruise.

General Observations

Over 900 chlorophyll samples were taken on the cruise. There was not a large range of mixed layer chlorophyll concentrations. On the run northwards from Vigo, the surface chlorophyll values were generally < 0.3 mg m^{-3} and the two CTDs carried out in this area (13079-80) showed a sub-mixed layer chlorophyll maximum. Once within the main survey area the highest chlorophyll values were always found in the mixed layer and ranged from 0.4-1.6 mg m^{-3}.

There was a lot of spatial patchiness in the survey area that was generally inversely correlated with nutrients. Despite this patchiness a general increase in chlorophyll between days 108 and 123 can be discerned (see Figure 8). The severe storms experienced on days 124-126 resulted in the mixed layer being mixed down to as much as 90m, and this diluted the surface chlorophyll concentrations by almost a half.

Day-time fluorescent quenching was observed throughout the cruise, down to 35m on the brightest days. It was also noticed that during the day-time there was a small, but repeatable, difference between the fluorescence readings on the up and down paths of the SeaSoar, with the up readings being higher. This may be caused by the difference in the angle of the SeaSoar path on the up and down tracks.

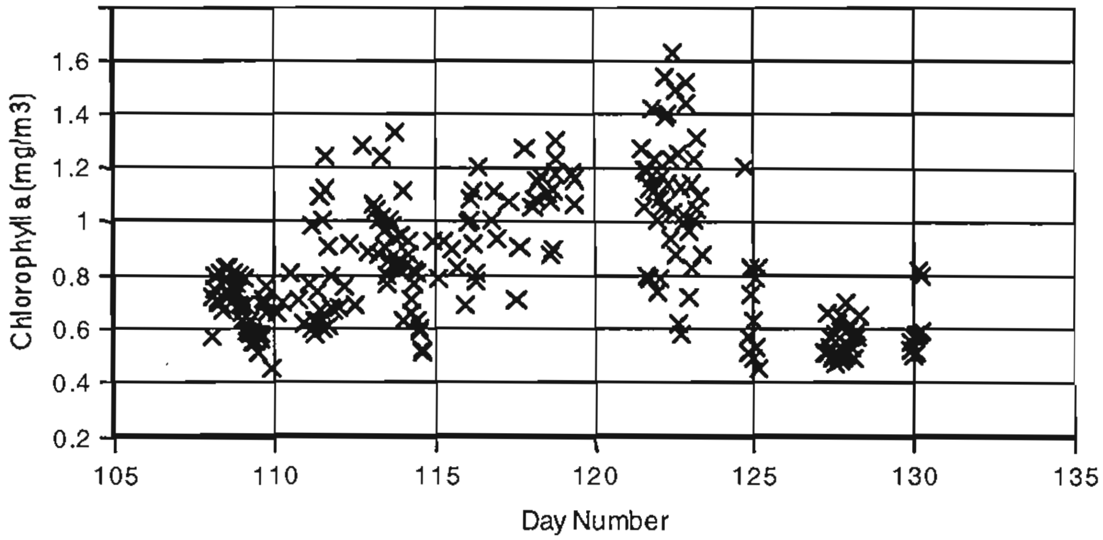

Figure 8. Surface chlorophyll values in the main survey area during the cruise.

An attempt was made to derive a relationship for the degree of quenching as a function of ambient PAR by comparing the SeaSoar fluorescence values when the SeaSoar was near the surface and interpolated values of measured chlorophyll concentrations from the surface pumped water sampling. The function representing the proportional quenching seemed to be of the form

$$Q_{factor} = Q_{min} + (1 - Q_{min}) \exp(-b\ PAR) .$$

Using data from day 111 we obtained values of $Q_{min} = 0.23$ and $b = 0.0187$ for PAR measured in W m^{-2}. Applying this correction to the observed fluorescence profiles did for the quenching correct to some extent, but could not remove it completely.

MJRF, IT

Phytoplankton and pigment sampling

Water samples were taken for phytoplankton identification, preserving two (~200ml) sub-samples in Lugol's and formalin (the latter for identification of coccolithophores). Near surface samples were taken throughout the cruise from the non-toxic supply, typically every 2 hours, but occasionally hourly (in and around interesting plankton patches). The samples will be analysed post-cruise to determine the spatial and temporal distribution of phytoplankton species.

During the deployment of the optical sensors (Lightfish and Satlantic), near surface water samples were also collected for post-cruise photosynthetic pigment analysis. Sampling was every 2 hours during Lightfish deployment, and at every Satlantic station. The water (~2ltr for each sample) was filtered through GF/F glass fibre filters and these were preserved in liquid nitrogen. Once analysed, they will help in understanding the optical properties of the water.

ARW

Primary production and photosynthesis-irradiance curves

The aim of this work is to characterise the vertical variability in the photosynthetic parameters of the phytoplankton assemblages in relation to the environmental conditions.

Methods

Water samples were collected from the Niskin bottles on one CTD station per survey line at five depths in the mixed layer, for the measurement of different rates. The samples were taken at only one CTD station per line due to the large time needed for primary production incubations.

1. Rates of size-fractionated photosynthesis

Triplicate water samples for the determination of primary production were contained in 70 ml polycarbonate bottles, spiked with 6.25 mCi $NaH^{14}CO_3$ and incubated in an on-deck incubator. The incubator was equipped with a set of filters providing a range of seven irradiances from 55% to 1% of I_o. Each sample was incubated at an irradiance level close to the original irradiance experienced by phytoplankton cells. At two depths, additional dark incubations were carried out.

Incubations typically started in the morning (ca. 30 minutes after sampling) and lasted for 7-8 hours. At the end of the incubation, the contents of each bottle were sequentially filtered through 5 mm polycarbonate filters and GF/F filters. Filters were then exposed overnight to concentrated HCl fumes for removal of inorganic ^{14}C. Finally, filters were placed in scintillation vials, 3.5 ml scintillation cocktail added to each vial for later determination of radioactivity using a liquid scintillation counter.

2. Photosynthetic parameters (photosynthesis-irradiance experiments)

At three depths on one CTD station per line (surface, chlorophyll-a maximum and an intermediate depth) additional water samples were collected for photosynthesis-irradiance experiments. Each experiment involved incubation of 70 ml water samples on a bench incubator equipped with an 100W halogen lamp which provided a range of light intensities from approximately 5-2500 $\mu E\ m^{-2}\ s^{-1}$. The samples were cooled using surface water and the incubations lasted for 2.5-3 hours. At the end of the incubation, each sample was filtered through GF/F filters. Decontamination and counting of the filters will be conducted as described above.

Sampling stations

Water samples were collected on the CTD stations listed below in Table 3.

CTD stations	Latitude	Longitude	Sampled depths (m) for	
			Primary production	P-I curves
13089	46° 57.02 N	19° 06.50 W	4, 14, 24, 34, 44	4, 14, 34
13102	47° 01.67 N	18° 13.93 W	5, 10, 20, 30, 40	5, 20, 30
13123	47° 19.40 N	17° 34.37 W	5, 14, 24, 34, 44	5, 24, 34
13123	47° 19.40 N	17° 34.37 W	5, 14, 24, 34, 44	5, 24, 34
13142	48° 29.98 N	17° 51.72 W	2, 15, 25, 34, 46	2, 15, 34
13151	46° 57.75 N	17° 02.78 W	2, 15, 24, 35, 43	2, 15, 24
13155	47° 04.46 N	17° 03.19 W	6, 12, 25, 34, 44	6, 12, 25
13169	46° 59.26 N	17° 15.07 W	surface, 16, 26, 36, 46	surface, 16, 36
13179	46° 50.23 N	17° 34.35 W	6, 13, 24, 32, 44	6, 13, 32

Table 3. Locations and depths of samples collected for primary production and P-I analysis.

RB

Meso- and microzooplankton sampling

The sampling procedures were planned to assess the horizontal and (where possible) vertical variability in meso- and microzooplankton communities and biomass, and their relationship with environmental variables. A secondary aim was to describe horizontal variability in the abundance and composition of rare microzooplanktonic organisms, as potential tracers of different water patches. It was also an objective for this cruise to carry out some water incubations to determine microzooplankton grazing rates at the chlorophyll maximum depth.

Mesozooplankton sampling

Mesozooplankton sampling during the large-scale survey B was carried out using a triple WP2 net, fitted with 200μm mesh. Eleven vertical nets were done during this survey, always at the beginning, the mid point and the end of every CTD line of the large scale survey (except for the first CTD station because of a rip in the net).

One of the collectors was used to make coarse biomass estimates from the freshly taken sample, using the following equation: $log_{10} DV = 1.069\ log_{10} C - 2.209$ (Roman *et al.*, 1985), where *DV* is "displaced volume" in ml and *C* is "carbon" in mg C m^{-3}. The sample from the second collector was size-fractionated (200-500; 500-1000; >1000 μm), filtered through pre-weighted GF/A filters, and then the filters were frozen to be dried and weighted in the laboratory onshore. CNH analysis of the dried samples will be done in order to obtain the proper *dry weight-carbon* relationship. The remaining sample was also size-fractionated and fixed in 4% formalin solution, and stored in 125 ml plastic bottles for subsequent taxonomic analysis.

Mesozooplankton sampling during the small-scale surveys was carried out in the same way as in the large-scale survey, with a triple vertical net at every CTD station (except for the first small-scale CTD station, because of the rough weather). Nine vertical nets were done, six of them along the last CTD line through the patch. Samples will be processed as above. A LHPR was deployed at the patch, but due to a failure in the LHPR system while the net was being towed (see below), samples from LHPR could not be used as a precise tool to ascertain vertical distribution of mesozooplankton. Nevertheless, the samples will be analysed in a coarse way (not at high taxonomic and numerical level).

CTD ST.	NET	LINE	JD	HOUR	LAT N	LONG W	T. biomass (mg C m^{-2})	% >1000µm
13089	13091	B1	110	13:12	46 58.90	19 05.30	3274	_
13095	13096	B1	111	01:45	47 37.60	19 45.90	3580	_
13099	13100	B5	111	23:37	46 34.99	17 47.37	2030	_
13105	13106	B5	112	12:30	47 14.70	18 26.50	2030	_
13111	13112	B5	113	02:15	47 55.90	19 06.70	5618	_
13116	13118	B9	114	17:02	48 12.49	18 27.81	3274	72
13121	13122	B9	115	06:36	47 32.96	17 42.21	3302	52
13127	13128	B9	115	21:25	46 52.44	17 08.90	2963	90
13132	13131	B14	116	09:15	47 10.59	16 29.33	2967	68
13138	13136	B14	117	16:51	47 50.26	17 10.15	3579	57
13142	13144	B14	118	12:20	48 28.10	17 52.30	4483	59
13155	13157	in C	124	09:02	47 04.34	17 03.64	4779	36
13159	13161	in C	124	12:08	47 06.00	17 01.10	3274	32
13163	13164	in C	124	15:27	47 08.20	17 04.40	2657	52
13169	13170	on E3	128	16:20	46 59.10	17 15.17	4178	17
13171	13172	on E3	128	19:16	46 57.69	17 18.76	3274	42
13173	13174	on E3	128	21:27	46 55.58	17 22.93	5968	45
13175	13176	on E3	128	23:44	46 53.76	17 26.83	7908	_
13177	13178	on E3	129	02:40	46 51.70	17 30.70	9270	_
13179	13182	on E3	129	09:26	46 49.69	17 35.70	4485	_

Table 4. Mesozooplankton biomass coarse estimate - preliminary results. (For details of survey lines and patterns see section 3 and Appendix I.)

Microzooplankton sampling

Microzooplankton samples during large-scale survey B were taken from Niskin bottles at 5 depths, using the same pattern described above (first, mid-point and last CTD stations of every CTD line). One of the sampling depths was always selected as the depth of chl-*a* maximum, while the others remained fixed throughout the cruise. 500 ml water samples were fixed in 2.5% acid Lugol solution and stored dark in the cold room for subsequent analysis using Uthermol sedimentation technique, an inverted microscope and a video-image analysis system. Underway microzooplankton samples were also taken at the same stations: 10-15 ltr of water from the underway non-toxic supply were filtered through a 30 μm mesh. Mesh content was fixed in 3% formalin solution and stored in 40ml glass vials for subsequent microscope analysis .

During the small-scale surveys microzooplankton samples were taken as, described above for the large-scale survey, at seven CTD stations, four of them in the last CTD line.

Microzooplankton grazing

Three incubations to determine microzooplankton grazing were done following the standard dilution method (Landry, 1993), but due to the scarcity of CTD water from the chlorophyll-maximum depth just the last of the three incubations was carried out in the correct manner; that is, using water only from the Chl-*a* maximum depth. Unfortunately, the incubator became damaged before the small-scale surveys, where shallow CTDs would have allowed more incubations to be carried out.

MQ

Longhurst-Hardy Plankton Recorder (LHPR)

The LHPR is used to take plankton samples over fine depth ranges, a few tens of metres, to provide ground truthing for the OPC and ADCP measurements, and to give qualitative and quantitative measurements of localised plankton populations. The instrument used was borrowed from PML, and towed on the conducting cable connected to an SOC owned computer. Due to the age of the equipment its use was limited to reasonably calm conditions, less than force five wind and a sea state lower than four. Unfortunately this severely restricted its use on this cruise.

In the end, only one tow proved to be possible and, unfortunately, this failed to produce any useful samples. After about forty minutes of seemingly normal sampling the control program crashed and no data was recorded to disk. Some samples were obtained, but with no depth or flow rate records. Subsequent testing produced the same fault and no real clues as to the cause. Discussions with Steve Coombs of PML led us to believe that there is a fault somewhere in the control computer and alternatives will have to be tested before this unit, or the SOC owned one, are used at sea again.

One potential problem with the ship's equipment also came to light during this cruise. The TOBI termination on the conducting cable has the hole for the locating pin in a different position to that on the *RRS Charles Darwin*. These terminations are individually drilled on fitting, but are all designed for similar swivels, so it should be possible to fix on a standard position.

BB

Optical Plankton Counter (OPC)

Data were collected with a Focal Technologies Incorporated OPC-1T Optical Plankton Counter, which had been borrowed from the Plymouth Marine Laboratory (PML). This was mounted underneath the SeaSoar in place of the usual "bomb" weight, and there was no detectable effect on the stability of the SeaSoar when being towed. The OPC was fitted with an acrylic insert which reduced the cross-section of the sensor tunnel to $0.001m^2$ (see Focal, 1995, for more details). Data were collected via an OPC-2D deck unit and logged onto a PC running a version of the Focal Technologies software, modified to introduce an RVS time stamp into the data stream. Logged data were transferred periodically to a Sun workstation for further processing and analysis.

Initial analysis of the data with existing PEXEC programmes showed features consistent with other SeaSoar measurements (for example, chlorophyll) and was thought to be coherent. However, subsequent, more detailed, analysis showed that the quality of the processed data was poor and contained a number of anomalous features. A simple program written in C (opcp) to examine the raw data showed that, unexpectedly, pressure data from the OPC were present in the data stream and that misinterpretation of this was causing the problems encountered. The PEXEC programmes had been originally written for the SOC OPC, which did not have a pressure sensor, and were unable to cope with the pressure data from the PML OPC, leading to erroneous data handling. It was decided to expand and enhance opcp to provide the initial conversion of the data from raw to PSTAR format, since the existing FORTRAN code proved somewhat impenetrable. The program opcp provides the following products at roughly one second intervals - that is, at each resolvable RVS clock tick:

1) Time in seconds since file start.
2) Per second count of particles in the size range 200-1000μm ESD (equivalent spherical diameter).
3) Per second count of all particles encountered.
4) Carbon in mg C m^{-3} calculated using the Wiebe (1988) equation.
5) Relative pressure from the OPC in the range 0 - 4095.
6) "Base-line" attenuance from the OPC in the range 0 - 4096.

Data processed through opcp revealed a variety of plankton patchiness features, which showed interesting relationships with the SeaSoar chlorophyll measurements.

During the cruise it was thought that the Focal Technologies OPC software, for handling the data, could be improved on. Simon Watts (OTD) was able to show that LabView could handle the data stream, and was able to use LabView to put together a display of the data. An interesting development would be to time the arrival of the OPC counts, to obtain the inter-event distance (the OPC does not attach time tags to the counts, but sends a 0.5 second time marker). This could be done in LabView using the PC clock. The statistics of the inter-event distance would give more information on the patchiness, and the encounter probabilities for various zooplankton size classes. This in turn would help with the modelling of feeding in zooplankton. Another interesting thing to try would be to attach the OPC to the LHPR, in order to compare the OPC measured zooplankton distribution with the actual zooplankton caught by the LHPR.

VCC, MAS

9. SATELLITE DATA

Sea Surface Temperature

Sea Surface Temperature (SST) data from the AVHRR instruments aboard the NOAA satellites were collected by NERC's Satellite Receiving Station in Dundee and processed by NERC's Remote Sensing Data Analysis Service in Plymouth. When an image contained a significant area of cloud-free sea surface within the survey region, the processed data were forwarded to the ship by e-mail as compressed GIF files.

There were three useful images from the weeks prior to the cruise (5, 10 and 11 April), and six further images from during the cruise (16, 24, 25, 27 April and 2, 3 May). By combining the images, mosaics were constructed which gave a clearer overview of the SST patterns over the whole region. The pre-cruise imagery indicated that there were interesting surface features occurring within the proposed survey region, and these appeared to persist over a period of a week or more. The images received during the cruise showed an eddy-like surface warm feature in the west of the large-scale survey region, and a warm water intrusion in the eastern corner of the survey region, which were confirmed by the ship-borne surface temperature data gathered during the surveys (see Figure A.8). These images provided extra information that was useful in deciding the location of the fine-scale surveys.

AIM

Sea surface topography

Near real time (within 2-3 days of acquisition) Topex/Poseidon and ERS-2 radar altimeter residual height data were transmitted to the *Discovery* from SOC, via the satellite data link, for those ground tracks in the vicinity of the survey area. The original aim was that these would be assimilated into the Harvard model (see section 10 below), but this proved not to be feasible during the cruise (it may be done post-cruise). Four of the cruise survey lines (see Figures A.1, A.2, A.3 and A.7) lie along Topex/Poseidon ground tracks and will be useful for studying links between the altimetric sea surface topography and the subsurface dynamics, as measured *in situ*.

MAS

Ocean colour

Unfortunately it was not possible to obtain near real time ocean colour data during the cruise, as

SeaWiFS had not yet been launched[3]. Ocean colour data from OCTS and MOS were not available in near real time, but will be available for analysis subsequent to the cruise.

MAS

10. MODELLING AND DATA ASSIMILATION

Harvard University scientists provided near real-time analyses and forecasts of physical and biological fields via three-dimensional modelling simulations. The primary objectives were:

i) to provide real-time nowcasts and forecasts of physical and biological features in order to provide guidance for efficient adaptive sampling,

ii) to demonstrate the concept of coupled biological and physical real-time shipboard nowcasts and forecasts, and

iii) to develop, test and demonstrate a methodology for efficient, co-operative, real-time nowcasting and forecasting between ship and shore.

The Harvard Ocean Prediction System's (HOPS) hierarchy of dynamical, statistical, and analysis models were used for the onboard, real-time analysis, nowcast and forecast exercise. A parallel and extended real-time analysis and forecast effort was carried out at Harvard. The set of models and associated software employed were as follow:

a) A primitive equation (PE) open ocean regional model.

b) A five-component (nitrate, phytoplankton, zooplankton, ammonium and detritus) biological model. Both coupled to PE model and as a stand-alone 1-D model.

c) A multivariate Objective Analysis (OA) package for the optimal estimation of fields from observational data of various types.

d) An intermittent, Optimal Interpolation (OI), data-assimilation scheme for the PE model.

e) Various support software used for data treatment and the initialisation and updating of the above models.

f) Display software to plot the two- and three-dimensional fields.

The data used to initialise the PE model, and keep it on track through assimilation, were:

- temperature and salinity from CTD and SeaSoar
- nitrate from bottles and surface
- chlorophyll from CTD, SeaSoar and surface
- zooplankton from OPC
- wind stress, net heat flux, evaporation-precipitation and short wave radiation from FNOC analyses and forecasts

The model domain was centred on the original large scale survey (B, see Figure A.3) with a 30km buffer zone around the planned tracks and a horizontal resolution of 5km. A hybrid co-ordinate system was used in the vertical with 53 flat levels overlaying 9 σ-levels, giving resolutions of 5m near the surface to 400m near the bottom. The original plans called for a higher resolution sub-

[3] SeaWiFS was successfully launched (well after the cruise ended) on 1 August 1997.

domain to be designed around the small scale survey and run in two-way nested mode, with information being passed between them. These plans were abandoned due to undiagnosed problems in the simulations (which lead to unrealistic velocities) and the computational requirements of such runs, which greatly exceeded pre-cruise estimates. A useful diagnostic tool would have been coarsened versions of the models, to speed the turn-around time for debugging.

The PE model also seems to have been sensitive to initial discrepancies between the salinities provided by the CTDs and the SeaSoar. A temporal oscillation in the surface velocities, initially attributed to an unknown fault in the surface flux portion of the codes, was no longer present when corrections were applied to the SeaSoar salinities. Some post cruise analysis will have to be done to confirm or deny a cause and effect relation.

The forecasts done for the re-survey of the large domain were accomplished by mapping initial fields from the B survey data, weighted to the last day of the survey, and assimilation fields from the small surveys. The model forecast the previously observed eddy to be sheared to the east. The model, however, has this structure shifted 40km north of a similar structure observed in the data. Another eddy-like structure in the data may be related to a structure the model has shifted 50km to the south, along the model boundary. An intrusion of fresh water from the north-east, predicted by the model, can be seen in the data, although the upper salinity values in the model are significantly too low. Post cruise work will include assessing the model's performance and assimilating the data from survey F into the simulations.

Regarding the biological measurements, two distinct periods were observed. The first was a period of rapid growth between day 108 and day 125, with surface nitrate concentrations decreasing from 6μM to 1μM, mixed-layer phytoplankton concentrations increasing from 0.3μM N to 1.6μM N, and zooplankton biomass increasing from 0.1μM N to 0.5μM N. This period was ended by a storm on day 125, which deepened the mixed layer from 40-50m to 70-80m; surface nitrate increased to 3-4μM, and phytoplankton values decreased to 0.8μM N. The second, post-storm period was then characterised by little change in surface nitrate or phytoplankton concentrations, but with zooplankton biomass continuing to increase to 1.3μM N by day 133. In the model simulations, growth is underestimated during the first period, with less nitrate uptake, phytoplankton growth and zooplankton growth than observed. Consequently, the mixed-layer deepening on day 125 is not as much of a setback as observed, and significant phytoplankton growth continues in the post-storm period. At the end of the simulation (day 133), nitrate and phytoplankton concentrations are in general agreement with observations, although their time rate of change is most likely overestimated. Zooplankton values (0.3 μM N) are much lower than observed. Post-cruise simulations will be carried out to fine tune the biological model parameters to bring the simulation into better agreement with the observations.

PJH, LAA

11. LESSONS LEARNED AND INITIAL RESULTS

Some lessons learned in carrying out this cruise were:

a) the combined use of SeaSoar and OPC gave interesting results on plankton patchiness, due to the ability to simultaneously measure phytoplankton (chlorophyll) and zooplankton, respectively. If, as originally intended, a nitrate sensor had been mounted on SeaSoar too, the additional nutrient data would have given even more insight into the patchiness.

b) if the OPC data, in terms of "events", can be time-tagged using LabView, this would provide further useful information for modelling the behaviour of zooplankton.

c) the interpretation of OPC "counts" in terms of the zooplankton present in the water is non-trivial. This might be addressed by mounting the OPC on an LHPR to make simultaneous observations.

d) the reason for the poorer depth performance of the SeaSoar during the cruise is unclear. One possible explanation is that replacing the "bomb" weight with the OPC alters the hydrodynamic characteristics, preventing SeaSoar from diving to as great a depth as normal.

e) by using balloons inflated to a smaller size, it was possible to achieve successful radiosonde launches, in windy conditions, despite the less than satisfactory position of the balloon launcher on the ship.

f) the new high speed data link (via satellite), recently installed on *Discovery*, proved very useful for the transfer of data to and from the ship, particularly for the Harvard near real time model and for AVHRR imagery (despite some teething problems).

Some initial results from the cruise are:

a) a variety of patchiness phenomena were observed using the combination of SeaSoar and OPC:

- chlorophyll "holes" with concurrent high zooplankton abundance, where grazing seemed to have occurred,
- concurrent higher values of chlorophyll and zooplankton, where (presumably) the zooplankton had migrated to graze, but not yet exhausted the supply of phytoplankton,
- higher zooplankton concentrations at the edge of higher chlorophyll patches, where grazing seemed to be beginning.

All these phenomena were on horizontal scales of a few kilometres upwards.

b) some of the observed patchiness structure was related to the physical structures observed, but not obviously so in other cases, suggesting that these were primarily due to biological interactions.

c) *in situ* data gathered on the cruise were successfully assimilated, in near real time, into the Harvard coupled bio-physical model. The initial results suggest that the physical predictions made by the model are somewhat better than the biological ones, but further post-cruise analysis is required to examine this.

d) comparing OPC and ADCP backscatter data shows interesting results on the vertical migration of zooplankton. Different migration depths can be seen in the two data sets on some occasions, presumably because the instruments respond to different sizes of zooplankton which migrate to different depths. This appears to be a new observation from this combination of instruments (similar effects ought to be observable using multi-frequency acoustic instruments).

Overall, the *in situ* measurements should provide insights into the problem of plankton patchiness. In combination with the ocean colour data from OCTS (once available), this provides a good data set with which to study the plankton patchiness problem, in accordance with the aims of the original cruise proposal (see section 1).

MAS

ACKNOWLEDGEMENTS

As Principal Scientist there are numerous people to thank for the successful execution of the cruise, not least the Master, officers and crew of the *Discovery*. I benefited immensely from the advice of the more experienced sea-going scientists and technicians during the cruise, and hopefully made better decisions as a result (though the responsibility for the poor ones remains mine). Prior to the cruise, the help and advice of Rob Bonner (GDD) and Sue Scrowston, Andy Louch and Andy Hill (RVS Ops) enabled me to organise the cruise. Robin Pascal's (OTD), John Smithers'(OTD) and Paul Wright's (GDD) help in setting up equipment on-board *Discovery* in Vigo was invaluable. Steve Groom and the staff of RSDAS, Helen Snaith (JRD) and Graham Quartly (RSADU) were all involved in sending satellite data, or related information, to the ship while we were at sea. Louise Allen (JRD) made many of the travel arrangements, to and from Vigo, which saved me a lot of hassle. Many thanks are due to all these people. In addition, particular thanks are due to Anne Morrison (RSADU) for help in producing this report. Finally, the success of the cruise is a reflection of the hard work of all the participants, for which I am very grateful!

MAS

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APPENDIX I - Topex/Poseidon ground track and survey pattern plots, plus AVHRR image

Figure A.1 Topex/Poseidon ground tracks in the vicinity of the survey area. Track numbers are given at the edges of the plot. Survey line A1 ran along track 087, survey lines A3, B0, B1 and F11 along track 122, survey lines B13 and B14 along track 198, and survey line F12 along track 011 (see Figures A.2, A.3 and A.7).

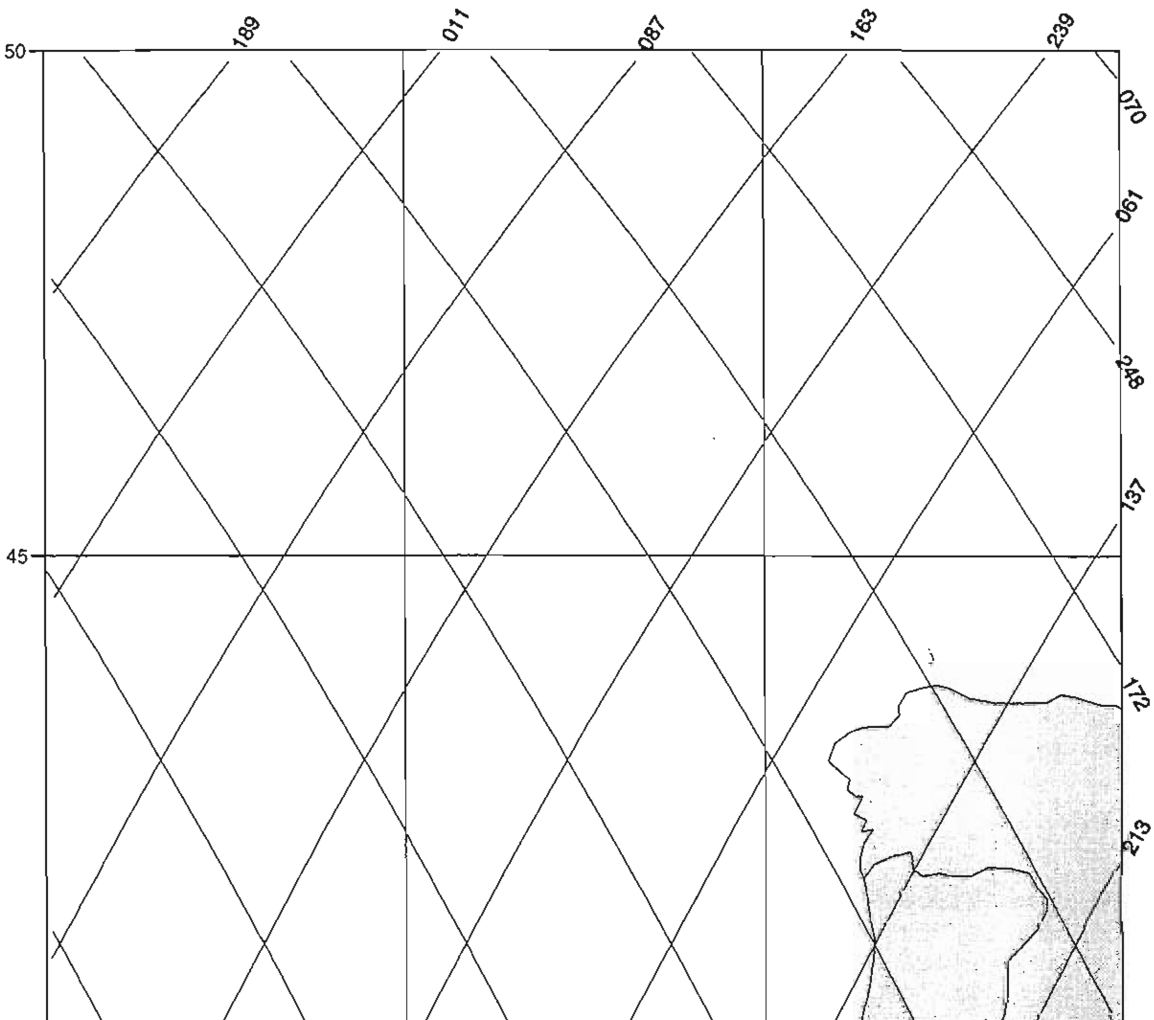


Figure A.2 *Discovery* track during survey A. Crosses on the track show the ship's position every 12 hours, and the day number and time are given alongside. The numbering of the survey lines (A1 to A3) is also indicated. Line A1 lies on Topex/Poseidon track 087, and A3 on track 122 (see Figure A.1).

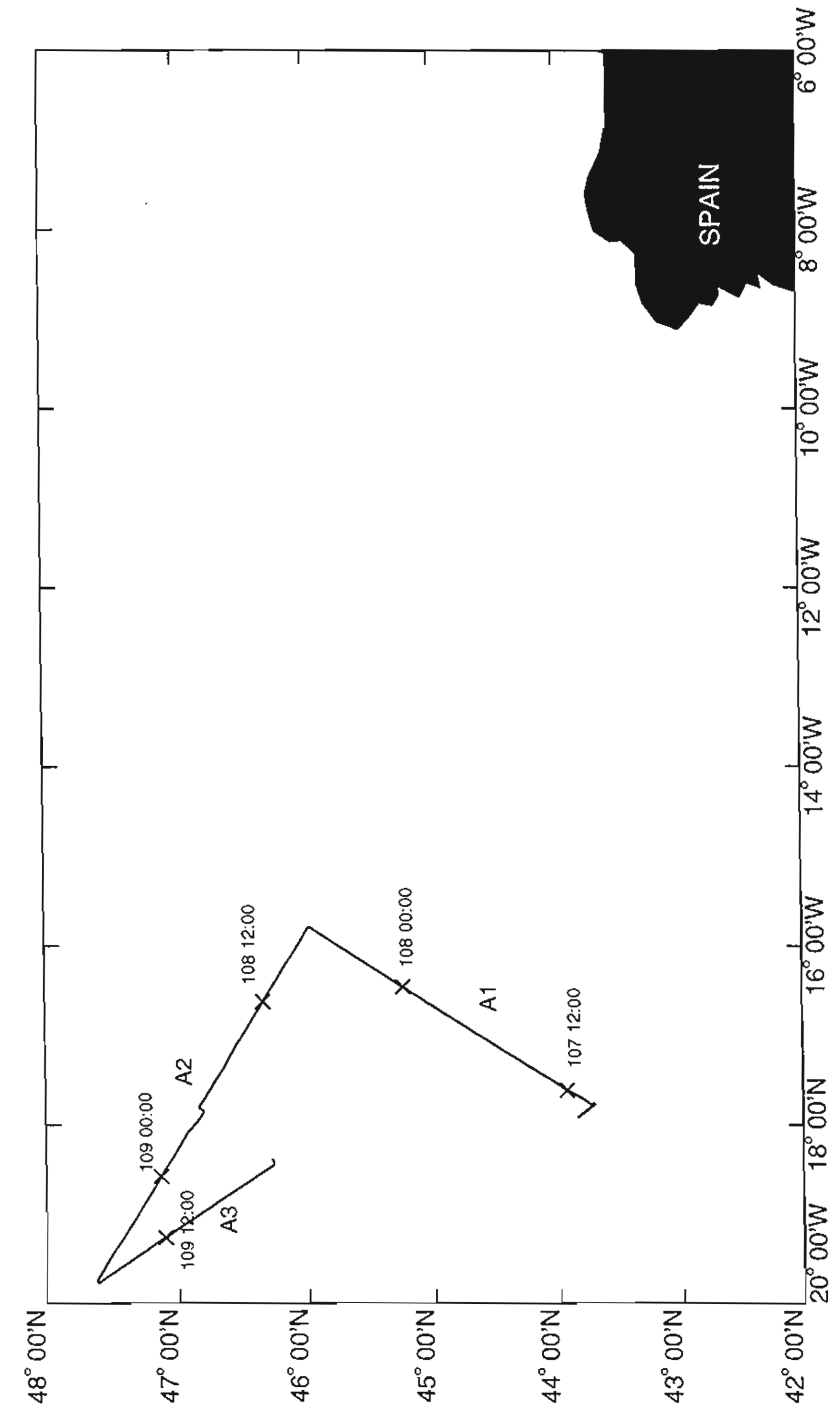


Figure A.3 *Discovery* track during survey B. Crosses on the track show the ship's position every 12 hours, and the day number and time are given alongside. The numbering of the survey lines (B1 to B14) is also indicated. Topex/Poseidon ground tracks are shown dotted (see Figure A.1; B1 lies on track 122, B13 and B14 on track 198).

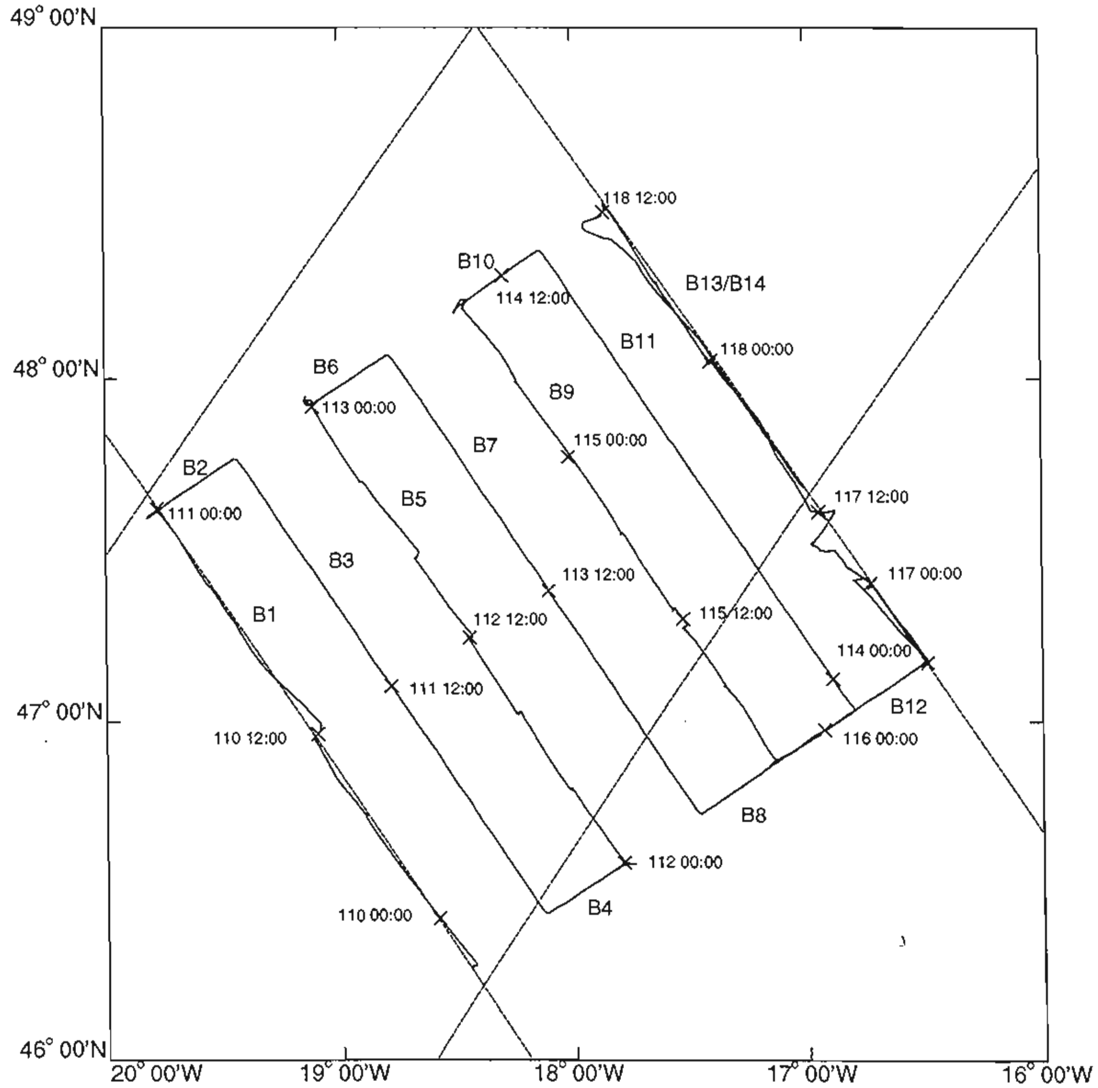


Figure A.4 *Discovery* track during survey C. Crosses on the track show the ship's position every 3 hours, and the day number and time are given every 6 hours. The numbering of the survey lines (C1 to C10) is also indicated.

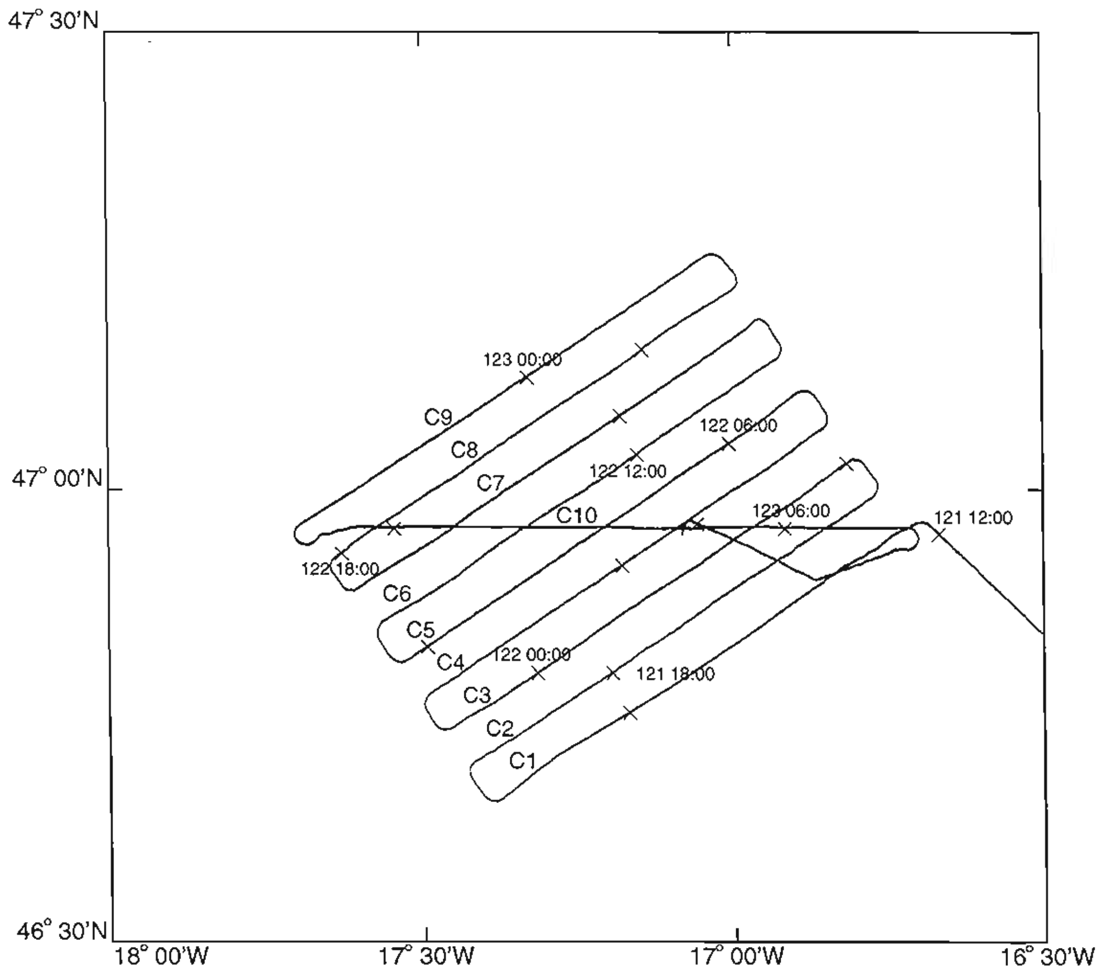


Figure A.5 *Discovery* track during survey D. Crosses on the track show the ship's position every 3 hours, and the day number and time are given every 6 hours. The numbering of the survey lines (D1 to D3) is also indicated. This survey had to be curtailed halfway along line D3, in the early hours of day 125, due to bad weather (see section 2, narrative).

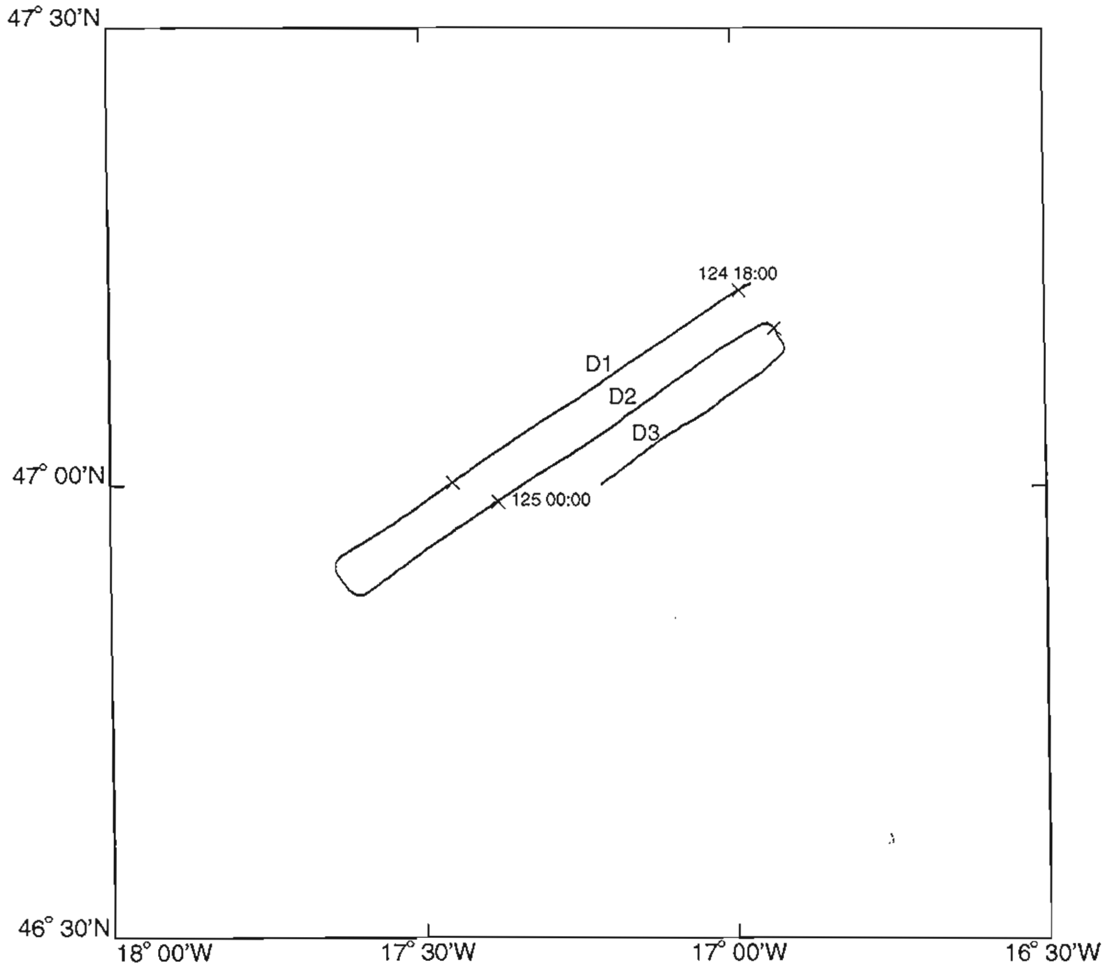


Figure A.6 *Discovery* track during survey E. Crosses on the track show the ship's position every 3 hours, and the day number and time are given every 6 hours. The numbering of the survey lines (E1 to E5) is also indicated.

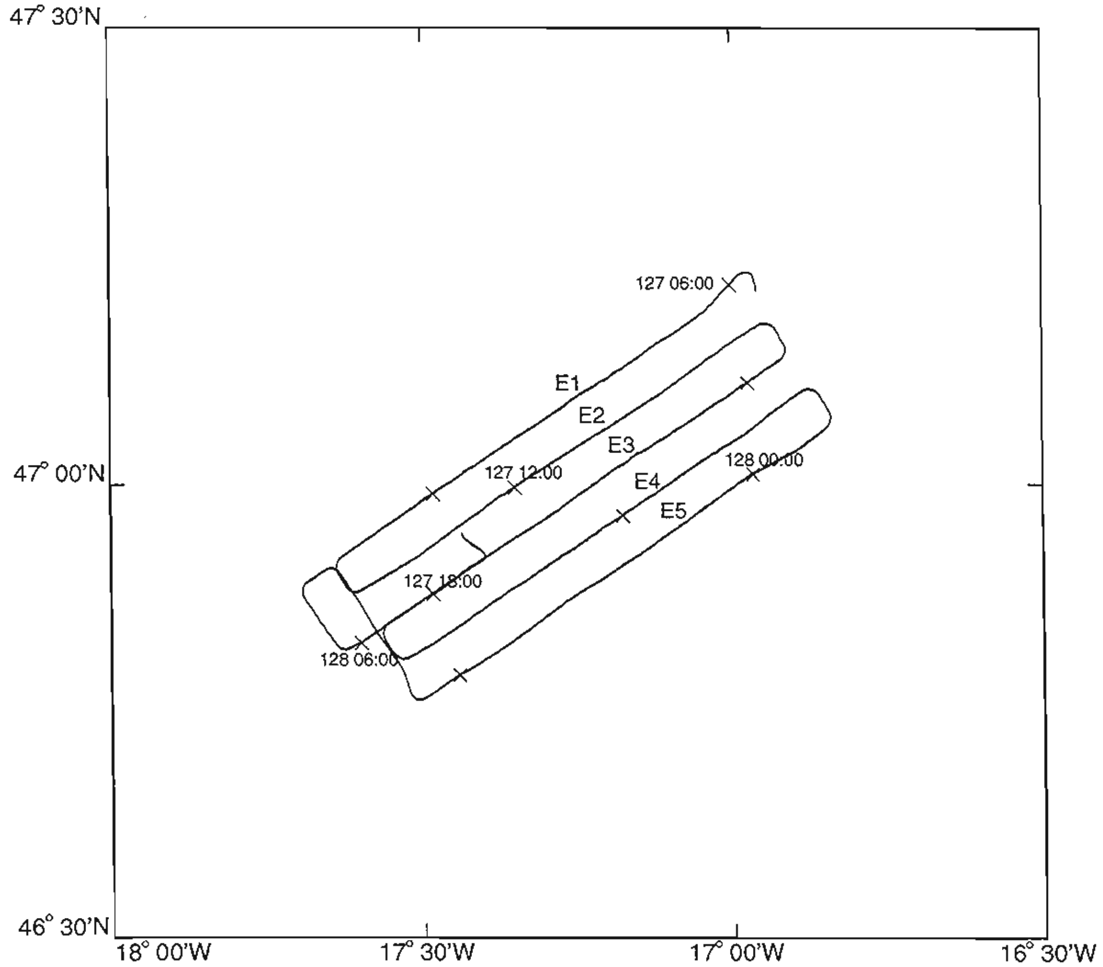


Figure A.7 *Discovery* track during survey F. Crosses on the track show the ship's position every 12 hours, and the day number and time are given alongside. The numbering of the survey lines (Fl to F12) is also indicated. Topex/Poseidon ground tracks are shown dotted (see Figure A.1; F11 lies on track 122, F12 on track 011).

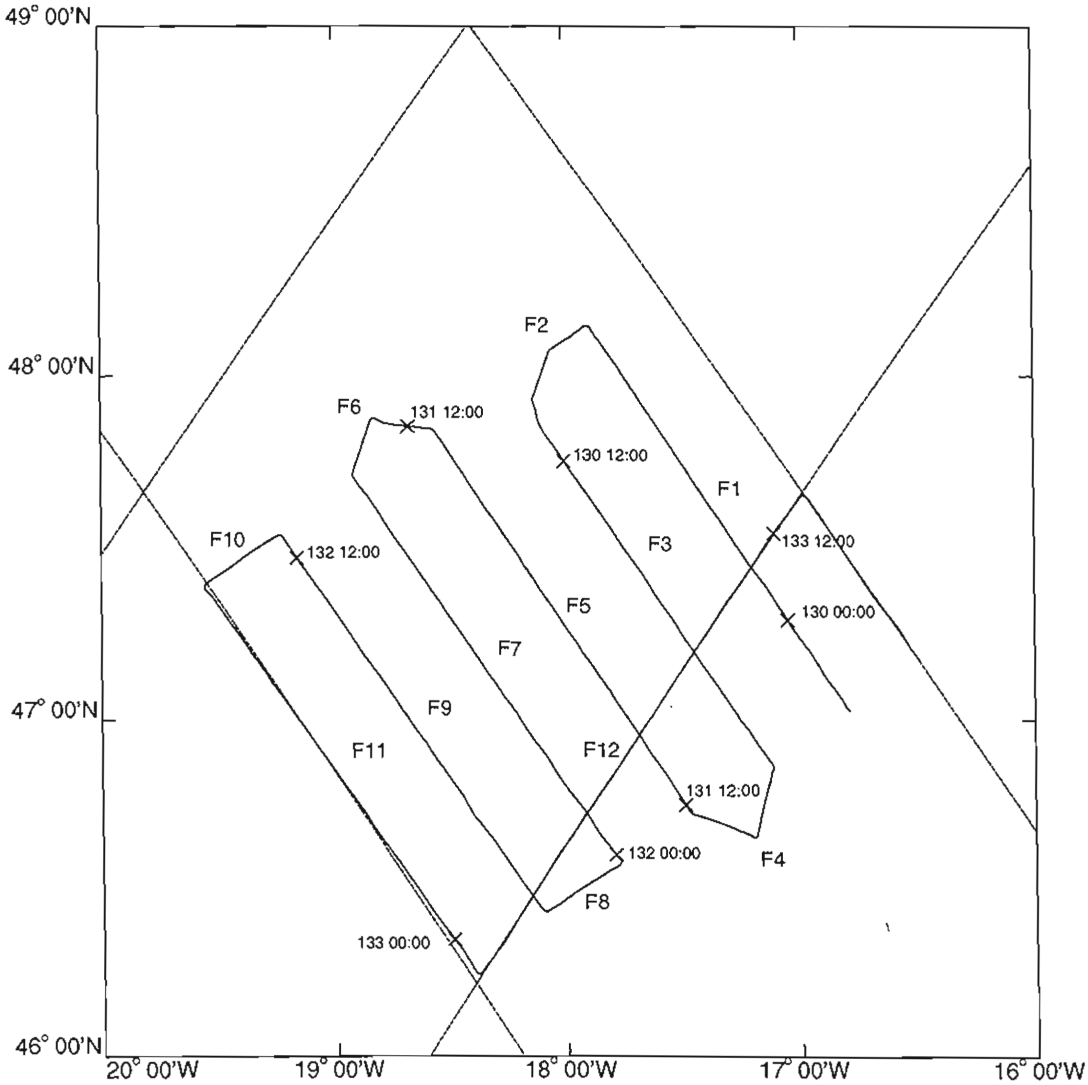
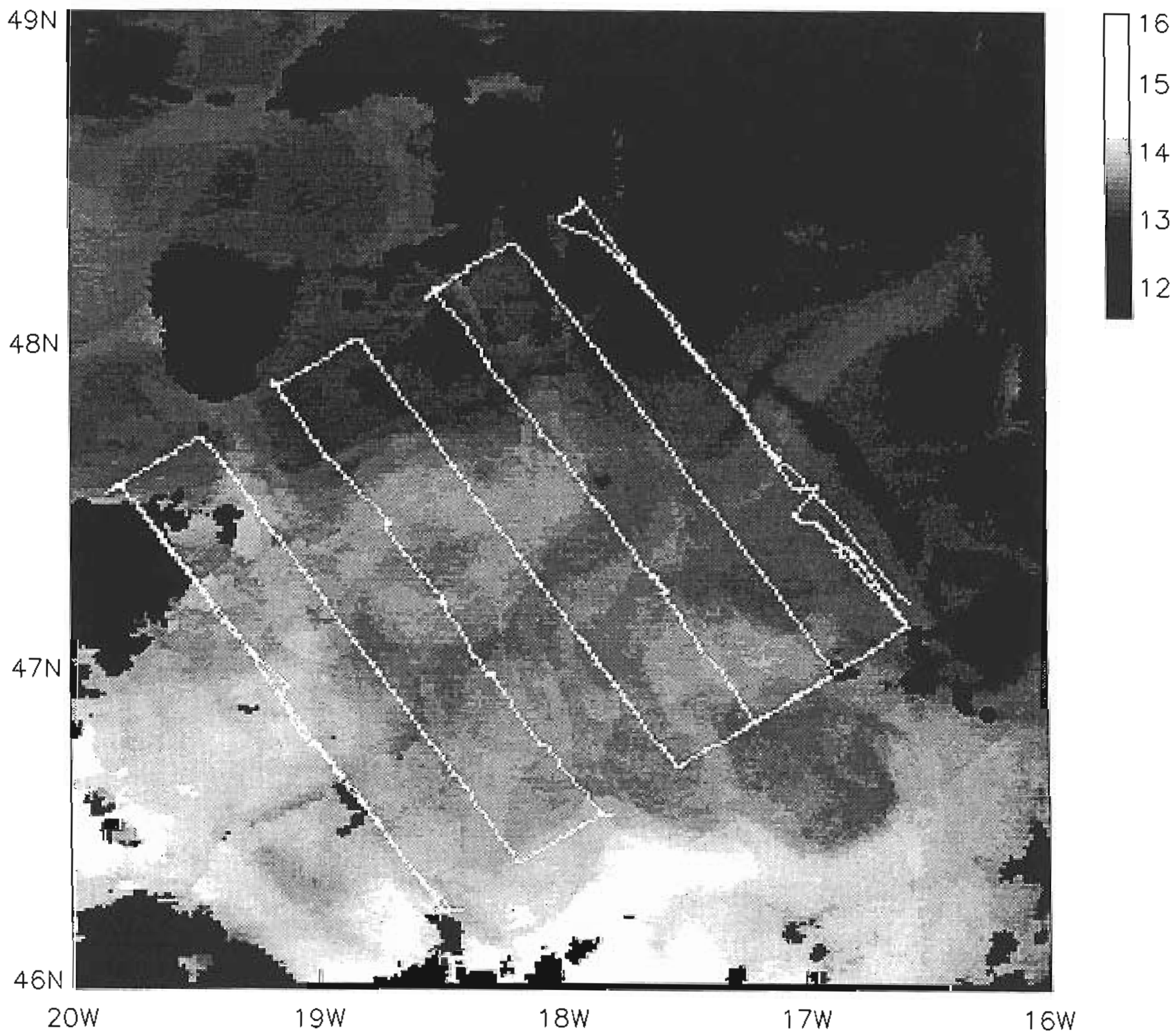


Figure A.8 AVHRR SST image composite, using data acquired on 24 and 27 April 1997 (afternoon passes; days 114 and 117). Clouds are masked in black. Superimposed on the image is the *Discovery's* track during survey B (see Figure A.3).



APPENDIX II - Stations list

Station	Type	Start day	Start time	End day	End time	Start Lat N	Start Long W	End Lat N	End Long W	Depth m	Comments
13079	CTD	106	0944	106	1022	42° 50.43'	14° 42.00'	42° 50.13'	14° 42.09'	120	test deployment
13080	CTD	106	1116	106	1336	42° 49.70'	14° 42.70'	42° 49.30'	14° 43.50'	2000	test deployment
13081	Vertical net	106	1413	106	1457	42° 49.40'	14° 43.60'	42° 48.80'	14° 43.80'	200	test deployment
13082	SeaSoar	106	1728	106	1943	42° 51.23'	15° 15.48'	42° 37.73'	15° 28.39'	~300	test deployment
13083	SeaSoar	107	0947	109	1946	43° 43.10'	17° 47.09'	46° 16.87'	18° 23.33'	~300	survey A (& B0)
13084	Lightfish	107	1431	107	1834	42° 12.80'	17° 22.10'	44° 39.58'	16° 59.27'	~3	test deployment
13085	CTD	109	2035	109	2253	46° 16.45'	18° 27.20'	46° 16.81'	18° 25.72'	2000	first CTD of B1
13086	CTD	110	0048	110	0258	46° 30.10'	18° 40.10'	46° 30.20'	18° 40.60'	2000	
13087	CTD	110	0457	110	0648	46° 43.40'	18° 53.56'	46° 43.31'	18° 53.76'	2000	
13088	Satlantic	110	0742	110	0811	46° 43.38'	18° 53.56'	46° 43.27'	18° 53.54'	60	test deployment
13089	CTD	110	0958	110	1200	46° 57.01'	19° 06.49'	46° 57.79'	19° 05.94'	2000	
13090	Satlantic	110	1215	110	1245	46° 58.00'	19° 05.70'	46° 58.50'	19° 05.40'	60	
13091	Vertical net	110	1312	110	1347	46° 58.90'	19° 05.30'	46° 59.30'	19° 05.10'	200	
13092	Satlantic	110	1530	110	1556	47° 10.30'	19° 20.00'	47° 10.20'	18° 19.90'	60	
13093	CTD	110	1612	110	1800	47° 10.19'	19° 19.88'	47° 10.11'	19° 20.17'	2000	
13094	CTD	110	1958	110	2159	47° 23.75'	19° 33.18'	47° 23.80'	19° 33.53'	2000	
13095	CTD	110	2345	111	0136	47° 51.25'	19° 46.70'	47° 37.50'	19° 46.00'	2000	last CTD of B1
13096	Vertical net	111	0145	111	0222	47° 37.60'	19° 45.90'	47° 37.60'	19° 45.60'	200	
13097	SeaSoar	111	0300	111	2043	47° 35.90'	19° 49.10'	46° 34.89'	17° 44.86'	~300	B2, B3, B4
13098	Lightfish	111	0727	111	1707	47° 34.70'	19° 51.11'	46° 32.64'	18° 14.37'	~3	
13099	CTD	111	2122	111	2319	46° 34.81'	17° 47.39'	46° 34.95'	17° 47.45'	2000	first CTD of B5
13100	Vertical net	111	2337	112	0006	46° 34.99'	17° 47.37'	46° 35.03'	17° 47.42'	200	
13101	CTD	112	0153	112	0342	46° 48.20'	18° 00.90'	46° 48.10'	18° 01.50'	2000	
13102	CTD	112	0534	112	0728	47° 01.65'	18° 13.96'	47° 01.28'	18° 14.50'	2000	
13103	Secchi disk	112	0655	112	0705	47° 01.38'	18° 14.39'	47° 01.35'	18° 14.44'	??	
13104	Satlantic	112	0745	112	0819	47° 01.26'	18° 14.53'	47° 01.40'	18° 14.77'	60	
13105	CTD	112	1019	112	1226	47° 15.00'	18° 27.19'	47° 14.80'	18° 26.60'	2000	
13106	Vertical net	112	1230	112	1311	47° 14.70'	18° 26.50'	47° 14.80'	18° 26.30'	200	
13107	Satlantic	112	1318	112	1336	47° 14.80'	18° 26.30'	47° 15.10'	18° 26.20'	60	
13108	Satlantic	112	1545	112	1606	47° 28.90'	18° 40.20'	47° 29.11'	18° 40.02'	60	
13109	CTD	112	1620	112	1816	47° 29.40'	18° 39.90'	47° 29.87'	18° 39.71'	2000	
13110	CTD	112	2006	112	2208	47° 42.20'	18° 54.09'	47° 42.00'	18° 54.48'	2000	
13111	CTD	113	0017	113	0203	47° 55.60'	19° 07.00'	47° 55.90'	19° 06.70'	2000	last CTD of B5

Station	Type	Start day	Start time	End day	End time	Start Lat N	Start Long W	End Lat N	End Long W	Depth m	Comments
13112	Vertical net	113	0215	113	0246	47° 55.90'	19° 06.70'	47° 56.00'	19° 06.70'	200	
13113	SeaSoar	113	0311	114	1348	47° 54.60'	19° 08.80'	48° 11.40'	18° 30.20'	~300	B6, B7, B8, B11, B10
13114	Lightfish	113	0729	113	1455	47° 52.36'	18° 35.25'	47° 06.10'	17° 49.80'	~3	
13115	Lightfish	114	0731	114	1007	47° 59.97'	17° 45.46'	48° 16.20'	18° 01.85'	~3	
13116	CTD	114	1427	114	1622	48° 13.30'	18° 27.00'	48° 12.53'	18° 28.01'	2000	first CTD of B9
13117	Satlantic	114	1634	114	1654	48° 12.49'	18° 27.98'	48° 12.56'	18° 27.87'	60	
13118	Vertical net	114	1702	114	1728	48° 12.49'	18° 27.81'	48° 12.23'	18° 27.98'	200	
13119	CTD	114	1931	114	2138	47° 59.61'	18° 14.38'	47° 59.35'	18° 14.27'	2000	
13120	CTD	114	2343	115	0151	47° 46.27'	18° 01.27'	47° 46.40'	18° 00.70'	2000	
13121	CTD	115	0413	115	0624	47° 32.84'	17° 47.63'	47° 32.97'	17° 47.26'	2000	
13122	Vertical net	115	0636	115	0658	47° 32.98'	17° 47.21'	47° 33.06'	17° 47.21'	200	
13123	CTD	115	0903	115	1100	47° 19.38'	17° 34.37'	47° 19.75'	17° 34.05'	2000	
13124	Satlantic	115	1113	115	1133	47° 19.80'	17° 34.08'	47° 19.88'	17° 33.81'	60	
13125	CTD	115	1420	115	1626	47° 06.10'	17° 21.20'	47° 06.24'	17° 21.53'	2000	
13126	Satlantic	115	1635	115	1703	47° 06.24'	17° 21.40'	47° 06.05'	17° 20.95'	60	
13127	CTD	115	1907	115	2115	46° 52.76'	17° 07.98'	46° 52.54'	17° 08.81'	2000	last CTD of B9
13128	Vertical net	115	2125	115	2149	46° 52.44'	17° 08.90'	46° 52.38'	17° 09.03'	200	
13129	SeaSoar	115	2220	116	0600	46° 52.38'	17° 09.50'	47° 24.86'	16° 48.00'	~300	B12, problem@0500
13130	CTD	116	0844	116	0854	47° 10.58'	16° 29.40'	47° 10.57'	16° 29.28'	na	abandoned
13131	Vertical net	116	0915	116	0948	47° 10.59'	16° 29.33'	47° 10.46'	16° 29.14'	200	
13132	CTD	116	1512	116	1749	47° 10.40'	16° 30.40'	47° 10.76'	16° 29.45'	2000	first CTD of B14
13133	CTD	116	2016	116	2230	47° 23.82'	16° 43.34'	47° 23.53'	16° 44.17'	2000	
13134	CTD	117	1116	117	1327	47° 36.92'	16° 56.85'	47° 36.50'	16° 56.30'	2000	
13135	Satlantic	117	1346	117	1405	47° 36.60'	16° 56.50'	47° 36.80'	16° 56.90'	60	
13136	Vertical net	117	1651	117	1715	47° 50.26'	17° 10.15'	47° 50.19'	17° 09.59'	200	
13137	Satlantic	117	1732	117	1752	47° 50.25'	17° 09.68'	47° 50.54'	17° 09.46'	60	
13138	CTD	117	1813	117	2054	47° 50.25'	17° 10.00'	47° 50.25'	17° 09.60'	2000	
13139	CTD	117	2302	118	0109	48° 03.26'	17° 24.35'	48° 02.70'	17° 24.40'	2000	
13140	CTD	118	0419	118	0654	48° 16.66'	17° 38.15'	48° 16.60'	17° 38.09'	2000	
13141	Satlantic	118	0720	118	0737	48° 16.62'	17° 38.36'	48° 16.62'	17° 38.42'	60	
13142	CTD	118	0933	118	1140	48° 29.99'	17° 51.75'	48° 28.97'	17° 51.43'	2000	last CTD of B14
13143	Satlantic	118	1145	118	1212	48° 28.82'	17° 51.46'	48° 28.50'	17° 51.90'	60	
13144	Vertical net	118	1220	118	1250	48° 28.10'	17° 52.30'	48° 28.10'	17° 52.30'	200	

Station	Type	Start day	Start time	End day	End time	Start Lat N	Start Long W	End Lat N	End Long W	Depth m	Comments
13145	SeaSoar	118	1343	118	2208	48° 27.50'	17° 53.90'	47° 41.05'	17° 00.10'	~300	B13
13146	Lightfish	118	1452	118	2208	48° 24.20'	17° 51.20'	47° 41.05'	17° 00.10'	~3	ended for medevac
13147	SeaSoar	121	0534	123	0924	46° 24.19'	15° 50.22'	46° 57.00'	17° 04.86'	~300	survey C
13148	Lightfish	121	0543	121	0714	46° 24.56'	15° 50.62'	46° 31.76'	16° 01.75'	~3	problem
13149	Lightfish	121	0737	121	0750	46° 33.28'	16° 04.22'	46° 33.73'	16° 05.02'	~3	continuing problem
13150	Lightfish	122	0727	122	1727	46° 56.52'	17° 14.49'	46° 53.60'	17° 35.70'	~3	
13151	CTD	123	0946	123	1050	46° 57.65'	17° 02.78'	46° 58.06'	17° 02.21'	300	
13152	Satlantic	123	1107	123	1125	46° 58.14'	17° 02.05'	46° 58.41'	17° 02.04'	60	
13153	Vertical net	123	1132	123	1153	46° 58.36'	17° 02.06'	46° 58.44'	17° 01.66'	200	
13154	Satlantic	123	1200	123	1205	46° 58.43'	17° 01.60'	46° 58.43'	17° 01.60'	60	
13155	CTD	124	0659	124	0823	47° 04.49'	17° 03.28'	47° 04.25'	17° 03.34'	300	
13156	Satlantic	124	0834	124	0855	47° 04.21'	17° 03.35'	47° 04.29'	17° 03.67'	60	
13157	Vertical net	124	0902	124	0933	47° 04.34'	17° 03.64'	47° 04.23'	17° 03.46'	200	
13158	Satlantic	124	0940	124	0954	47° 04.23'	17° 03.37'	47° 04.22'	17° 03.47'	60	
13159	CTD	124	1026	124	1133	47° 05.71'	17° 00.50'	47° 05.71'	17° 00.84'	300	
13160	Satlantic	124	1143	124	1200	47° 05.78'	17° 00.87'	47° 05.89'	17° 01.05'	60	
13161	Vertical net	124	1208	124	1248	47° 06.00'	17° 01.10'	47° 06.00'	17° 01.10'	200	
13162	Satlantic	124	1252	124	1305	47° 06.00'	17° 01.20'	47° 06.10'	17° 01.30'	60	
13163	CTD	124	1348	124	1515	47° 08.00'	17° 03.10'	47° 08.20'	17° 04.20'	300	
13164	Vertical net	124	1527	124	1606	47° 08.20'	17° 04.40'	47° 08.25'	17° 04.46'	200	
13165	Satlantic	124	1615	124	1629	47° 08.35'	17° 04.47'	47° 08.59'	17° 04.21'	60	
13166	Satlantic	124	1636	124	1656	47° 08.67'	17° 04.23'	47° 08.98'	17° 04.23'	60	
13167	SeaSoar	124	1745	126	0833	47° 13.21'	16° 58.18'	48° 07.65'	17° 08.65'	~300	survey D - abandoned
13168	SeaSoar	127	0526	128	0750	47° 12.78'	16° 57.53'	46° 56.69'	17° 26.21'	~300	survey E
13169	CTD	128	0911	128	1300	46° 59.25'	17° 15.06'	46° 58.10'	17° 17.20'	2000	wire kinked
13170	Vertical net	128	1620	128	1645	46° 59.10'	17° 15.17'	46° 59.19'	17° 15.36'	200	
13171	CTD	128	1749	128	1856	46° 57.46'	17° 18.76'	46° 57.66'	17° 18.72'	300	
13172	Vertical net	128	1916	128	1939	46° 57.69'	17° 18.76'	46° 57.65'	17° 18.89'	200	
13173	CTD	128	2021	128	2211	46° 55.49'	17° 22.62'	46° 55.62'	17° 22.89'	300	
13174	Vertical net	128	2127	128	2203	46° 55.58'	17° 22.93'	46° 55.28'	17° 23.27'	200	
13175	CTD	128	2243	128	2334	46° 53.89'	17° 26.62'	46° 53.79'	17° 26.74'	300	
13176	Vertical net	128	2344	129	0023	46° 53.76'	17° 26.83'	46° 53.50'	17° 27.10'	200	
13177	CTD	129	0105	129	0225	46° 52.10'	17° 30.40'	46° 51.70'	17° 30.70'	300	

Station	Type	Start day	Start time	End day	End time	Start Lat N	Start Long W	End Lat N	End Long W	Depth m	Comments
13178	Vertical net	129	0240	129	0343	46° 51.70'	17° 30.70'	46° 51.60'	17° 30.90'	200	
13179	CTD	129	0429	129	0811	46° 50.27'	17° 34.30'	46° 50.00'	17° 34.70'	2000	
13180	Satlantic	129	0831	129	0847	46° 50.07'	17° 35.00'	46° 50.09'	17° 35.08'	60	
13181	Satlantic	129	0856	129	0914	46° 49.92'	17° 35.23'	46° 49.78'	17° 35.38'	60	
13182	Vertical net	129	0926	129	0954	46° 49.69'	17° 35.70'	46° 49.27'	17° 35.86'	200	
13183	LHPR	129	1518	129	1712	46° 50.20'	17° 34.30'	46° 53.53'	17° 38.20'	100	winch/LHPR problem
13184	SeaSoar	129	2119	134	1200	47° 01.80'	16° 47.42'	45° 36.10'	14° 10.70'	~300	survey F
13185	Lightfish	130	1257	130	1840	47° 38.90'	17° 53.80'	47° 00.43'	17° 15.68'	~3	
13186	Lightfish	131	0834	131	1122	47° 32.25'	18° 15.71'	47° 49.94'	18° 33.25'	~3	
13187	Lightfish	131	1422	131	1845	47° 40.20'	18° 52.50'	47° 11.34'	18° 23.25'	~3	
13188	Lightfish	132	0718	132	1849	46° 58.30'	18° 39.06'	46° 55.00'	19° 04.35'	~3	
13189	Lightfish	133	0719	133	0915	47° 00.42'	17° 38.41'	47° 12.67'	17° 26.37'	~3	problem
13190	Lightfish	133	1311	133	1847	47° 38.10'	16° 57.10'	47° 04.60'	16° 20.78'	~3	
13191	Lightfish	134	0738	134	1126	45° 58.16'	14° 42.96'	45° 37.10'	14° 12.70'	~3	
13192	CTD	134	1227	134	1536	45° 35.90'	14° 10.40'	45° 35.73'	14° 10.40'	3000	test of nitrate sensor

Discovery stations listing (all times are GMT). For numbering of surveys and survey lines see section 3 and Appendix I of the report.

APPENDIX III - GrhoMet sensors and variables

Variable	Position	Instrument	Note
Wet and Dry Bulb [psy1td psy1tw]	Stbd side of foremast platform (forward sensor)	Psychrometer IO2003 (SOC)	
Wet and Dry Bulb [psy2td psy2tw]	Stbd side of foremast platform (aft sensor)	Psychrometer IO2003 (SOC)	
Humidity & air temp. [hum humt]	Port side of foremast platform	Vaisala HMP 35A (RVS)	(1)
Air temp. [atemp]	Stbd side of foremast platform	Vector Inst. T351 (RVS)	
Longwave [lw1]	Top of foremast (port sensor)	Eppley PIR 31170 (SOC)	
Longwave [lw2]	Top of foremast (starboard sensor)	Eppley PIR 31171 (SOC)	
Shortwave [ptir]	Gimbal mounted on port side of foremast platform	Kipp & Zonen CM6B 962301 (RVS)	
Shortwave [stir]	Gimbal mounted stbd side of foremast platform	Kipp & Zonen CM6B 962276 (RVS)	
Photosynthetically active radiation [ppar]	Gimbal mounted on port side of foremast platform	Didcot DRP-1 1678 (RVS)	(2)
	Port side of foremast platform	IOS/PML type instrument	(2)
Photosynthetically active radiation [spar]	Gimbal mounted stbd side of foremast platform	Didcot DRP-1 1752 (RVS)	(2)
Wind speed & direction [ws1 wd1]	PORT side of foremast platform	RM Young AQ (RVS)	
SST [sst2]	Trailing from 6m scaffold pole, off port bow	Trailing Thermistor pd0006 (electronics 55) (SOC)	
SST [sst1]	Hull mounted, approx. 5 m depth.	PRT (RVS)	
Pressure [baro]	Lab	Vaisala DPA21 (RVS)	
Time	Lab	Ship's clock (RVS)	

Variables and sensors logged by the GrhoMet system. The variable names in the data files are shown [thus]. For each instrument (RVS) indicates that the sensor is part of the standard ship's system; (SOC) that the instrument was added for the cruise.

Notes: (1) the humidity sensor failed throughout the cruise.

(2) The Didcot PAR instruments failed for almost the entire cruise.

APPENDIX IV - Radiosonde ascents list

Flight No.	Day	Launch time and position			Burst time and pressure		Filename		Comment
D227/		time	lat N	long W	time	mb approx	ascent	descent	
1	107	1149	43.91	17.63			1071138		
2	109	1143	47.14	19.29	1250	55	1091135		First sonde failed before launch
3	110	1138	46.96	19.10			1101127		
4	111	1135	47.15	18.83	1254	38	1111123	1111253	
5	112	1136	47.25	18.45	1249	47	1121125	1121248	
6	113	-	-	-	-	-	-	-	Launch during rain squall - string broke.
7	114	1127	48.34	18.20	1241	43	1141115	1141240	Possibly good satellite day
8	115	1129	47.33	17.56	1230	150	1151108	1151229	Launch during squall
9	116	1126	47.18	16.49	1246	34	1161110	1161245	
10	117	1135	47.61	16.95	1259	33	1171123	1171259	
11	118	1124	48.49	17.85	1250	35	1181115	1181250	
12	120	1121	44.26	12.52	1240	45	1201109	1201240	Blue sky - good satellite day
13	121	1133	46.91	12.52	1301	35	1211123	1211302	
14	122	1124	46.99	16.60	1243	37	1221112	1221242	
15	123	1117	46.97	17.05	1220	80	1231107	1231224	
16	124	1129	47.10	17.01	1244	47	1241118	1241243	Ascent before Cb line reached ship
17	125	1132	47.20	17.35	1308	30	1251124	1251308	
18	126	1139	48.18	17.05	1245	100	1261117	1261245	First balloon burst before launch
19	127	1126	46.95	17.44	1228	100	1271116	1271228	
20	128	1125	46.98	17.28	1238	58	1281114	1281238	
21	129	1129	46.83	17.58	1252	58	1291124	1291251	Launched in rain
22	130	1131	47.81	18.06	1244	37	1301118	1301243	
23	131	1124	47.24	18.57	1225	47	1311224	1311224	Rain just before launch
24	132	1126	47.42	19.10	1226	65	1321116	1321226	
25	133	1127	47.48	17.17	1250	40	1331117	1331249	
26	134	1130	45.62	14.21	12.48	35	1341124	1341247	Raining

APPENDIX V - SST radiometer deployments

file / start	end	Top (old)		Bottom (new)		Comment
		T1 aft	T2	T3 aft	T4	
106.1002	1021	180	180	180	180	sky view, T3 and T4 look at deck for short time.
106.1059	1219	0	0	0	0	all sea view.
106.1305	1446	0	0	0	0	mirrors cleaned on old radioms. Rads on deck looking at sky towards end of file.
						All Tascos fitted with new mirrors; new probes fitted to 'old' Tascos.
110.1403	1634	0	0	0	0	
110.1635	1710	0	0	0	0	as at 1403 but probes swapped between T1 & T2.
		180	180	0	0	from 1710 on.
111.0903	1307	180	180	25	25	
111.1321	1430	180	0	0	0	
111.1445	1640	180	30	20	0	30° later measured as 40°.
111.1648	1911	180	40	40	0	
111.1938	0851	180	0	0	0	
114.0831	1307	180	0	0	0	
114.1320	2345	180	40	25	0	
117.1729	2032	180	0	0	0	
118.2059	2210	180	0	0	0	Terminated due to medical evacuation.
120.1310	1352					Terminated due to interface failure.
121 1934	2022	0	0	0	0	
122 0853	1405	180	0	0	30	sea view instruments fitted with sun shades
122 1406	1820	180	0	0	30	
122 1827	1944	180	0	0	0	T4 batteries ran down.
123 1300	1615	180	0	0	0	
124 0853	1317	180	0	0	0	brought in due to rain.
127.1313	1334	180	0	0	0	
127.1343	2049	180	180	0	0	brought in - water on lenses.
128.0836	1405	180	180	0	35	rain on lenses.
129.0835	2037	180	180	0	35	rain on lenses at various times.
130.1335	1927	180	0	0	35	
131.1910	2325	180	0	0	35	
132.0831	2135	180	0	0	35	
133.0829	2311	180	150	0	35	

The view angle is defined by: up = 180°, forward = 90°, down = 0°.