BOFS '*STERNA 92*' CRUISE REPORT

DISCOVERY 198
11/11/92 - 17/12/92

PRINCIPAL SCIENTIST:
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ACKNOWLEDGEMENTS

Many people have assisted in the planning and execution of this cruise, and to all we extend our grateful thanks:

Captain Mike Harding, the Master of *Discovery*, for ensuring a safe and productive maiden scientific cruise, despite the unfavourable weather conditions typical of the Bellingshausen Sea. Thanks are also due to the the engineers, led by Chief Engineer Andy Adams, who kept the engines and other machinery running smoothly when it mattered most; to the deck department, led by Chief Officer Phil Evans, who worked hard to enable us to achieve our scientific objectives; and to the catering department, led by Colin Hubbard, who kept us well fed despite the loss of the Chef early in the cruise.

RVS technicians Bill Miller, Colin Day, Rod Pearce, Phil Taylor, and Tony Poole for an outstanding effort in delivering excellent scientific support on a maiden cruise.

Nick Owens and his colleagues on the *James Clark Ross* for their enthusiastic collaboration, despite spending a week evacuating our chef to the Falklands.

Ian Bellan for abandoning the luxuries of the *James Clark Ross* for several days to carry out a UOR survey with us following the loss of the SeaSoar.

Mike Lucas (Capetown) for arranging the loan of a laboratory container, and also arranging for the disposal of chemical waste in Capetown.

Duncan Purdie (Southampton) for the loan of the Endeco pulsed oxygen system.

Mike Fasham (Rennell Centre) for the loan of the Turner Designs flow-through fluorometer.

Miriam Booth (British Antarctic Survey, Stanley) for her assistance during mobilisation.

Malcolm Woodward for his work as logistics coordinator for the *Sterna 92* expedition.

Europa Scientific for their support of Sean Debney's participation in the cruise.

On a personal note, I wish to thank the whole scientific party for their enthusiasm, professionalism, and support during the cruise, which greatly eased my task as Principal Scientist.

David Turner
Plymouth, January 1993

1. OVERVIEW

1.1 Introduction

This cruise formed part of the *Sterna 92* expedition, carried out in conjunction with RRS *James Clark Ross*. It is noteworthy that this, the final expedition of the BOFS programme, saw new and productive collaboration with other groups of oceanographers. The collaboration with the British Antarctic Survey was most marked on the *James Clark Ross*, although we were pleased to welcome two BAS scientists to BOFS aboard the *Discovery*. The major new collaboration aboard the *Discovery* was with physical oceanographers from the WOCE community, whose enthusiastic participation helped to make this the most thoroughly interdisciplinary cruise of the BOFS programme. Equally welcome and enthusiastic was the contribution of visiting American and South African scientists to the primary production studies. The full scientific party in listed in Appendix A.

1.2 Cruise objectives

The overall objective of the *Sterna 92* expedition, as set out in the cruise proposal, was *"To evaluate the magnitude and variability of biogeochemical fluxes (particularly carbon and nitrogen), during early summer in the South East Pacific Sector of the Southern Ocean, with emphasis on rates and processes in the marginal ice zone"*.

Four specific objectives were identified:

1. To determine ocean-atmosphere exchanges of radiatively active gases, and the factors influencing such fluxes, over a wide latitudinal range.

2. To investigate the interactions between the biological, chemical and physical processes that control carbon fluxes in the euphotic zone.

3. To assess the impact of sea-ice on biogeochemical fluxes, in order to estimate the importance of climatic feedback effects.

4. To determine the export of biogenic material from the upper ocean and its subsequent fate.

The *Discovery* programme, with a strong emphasis on underway survey measurements, concentrated on the first two of these components, while the *James Clark Ross* concentrated on components 3 and 4 with a programme emphasising station work.

1.3 Cruise itinerary

5/11/92	*Discovery* arrives in Stanley
10/11/92	*Discovery* departs Stanley for Berkeley Sound
11/11/92	Bunkering complete: *Discovery* departs Berkeley Sound
17/12/92	*Discovery* arrives in Punta Arenas

1.4 Scientific achievements

The cruise track is shown in Figure 1.1. The first objective listed above was addressed by two transects, one across the Drake Passage and one along longitude 88°W. Measurements of a wide range of gases in surface water (oxygen, carbon dioxide, sulphur gases, halocarbons and hydrocarbons) were complemented by biological, physical, and meteorological measurements. The line of the Drake Passage transect was chosen to coincide with a WOCE repeat section, thus allowing the physical oceanographers to address WOCE objectives simultaneously with the BOFS studies. Similarly, the 88°W transect coincides with a WOCE Hydrographic Programme line to be worked during 1993, with the hope that the BOFS data will complement that of WOCE. Both transects crossed the Subantarctic and Polar Fronts and will, when the data are worked up, provide valuable information on gas concentrations and fluxes in those areas. The 88°W transect is particularly valuable since it is an area where no previous pCO_2 measurements are available.

The second objective was addressed by two intensive grid surveys, together with a CTD section, centred around longitude 85°W (see Figures 1.2 and 1.3 for the survey tracks). The surveys were designed to map an intense phytoplankton bloom which extended southwards for approximately 70 miles from a sharp northern boundary close to 67°S. The first survey covered the northern edge of the bloom, and the second the southern edge. The two surveys overlap, thus providing information on the temporal evolution of the bloom. A wide range of physical, chemical, and biological measurements were carried out during the survey, as can be seen from the detailed scientific reports in section 3.

Many features of this bloom remain unexplained at the present time. We had envisaged in the proposal that blooms close to the ice edge would be formed in shallow mixed layers of lower salinity water, i.e. stabilised by fresher water from melting ice: this expectation was based on (scanty) published data from the Ross and Weddell Seas, there being no previous work from the Bellingshausen Sea to guide us. The bloom we found, in waters which had been largely covered by brash ice only a few weeks before, was actually in water more saline than the surface water immediately to the north (which contained very little chlorophyll; see Figure 1.4). Our colleagues on the *James Clark Ross* reported that even at the ice edge, which was to the south of our working area, there was no sign of a mixed layer stabilised by meltwater. Nutrients were plentiful both within and outside the bloom. It is clear that this bloom is unlike those encountered in the North Atlantic in previous BOFS cruises.

In scientific terms, the cruise can be judged successful. We have successfully mapped a large phytoplankton bloom off the ice edge. In addition, station work by the *James Clark Ross* within our survey area has complemented our underway survey measurements with a wide range of *in situ* rate and particle flux measurements.

1.5 Logistics and equipment

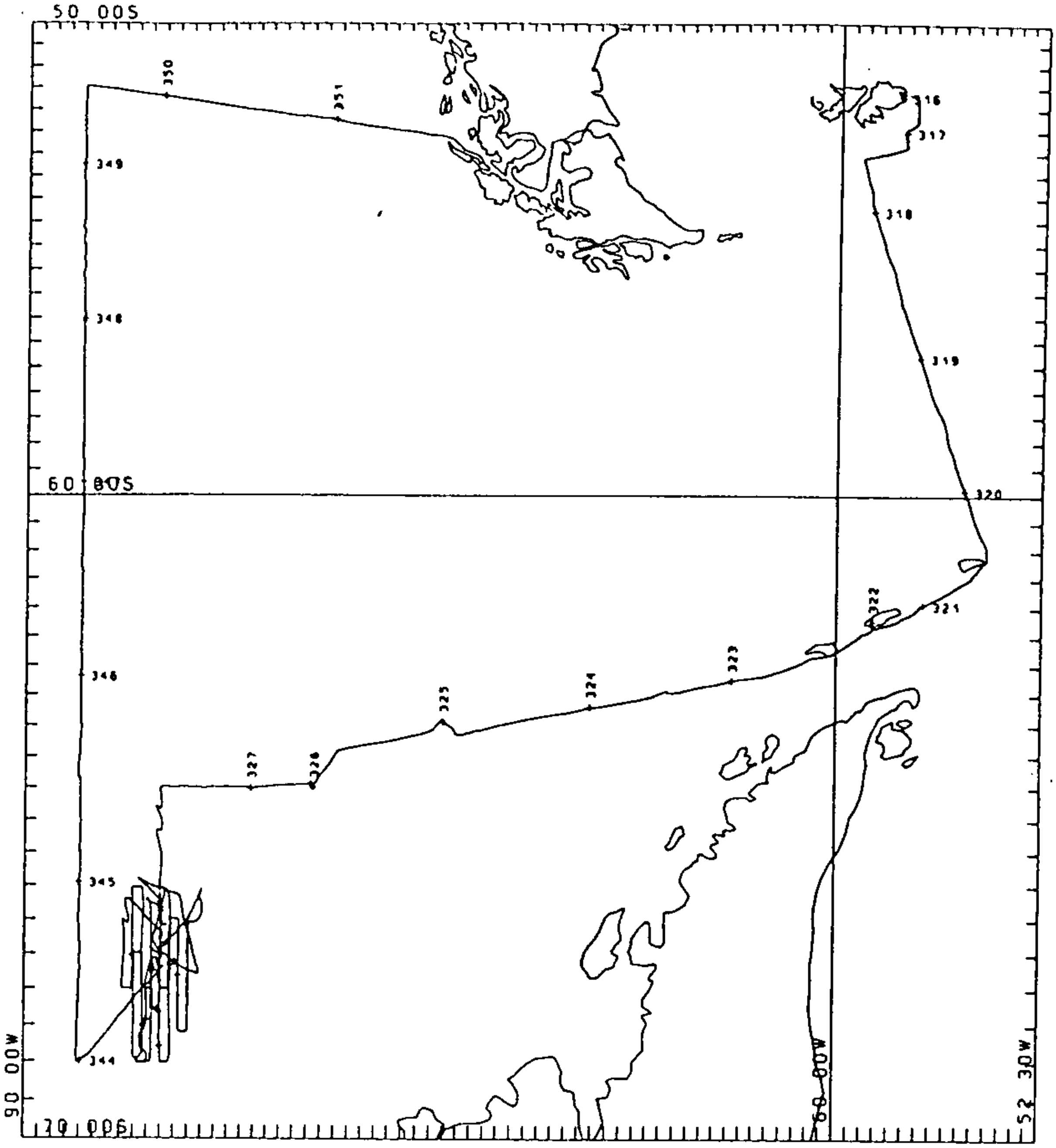
A number of problems in this area added to the difficulties of the cruise, and limited the amount of scientific work which could be carried out, although the major cruise objectives were achieved as reported above. The major problem areas are summarised here; a full report has been submitted separately to RVS.

First, the ship. This was the first scientific cruise on the *Discovery* following a major rebuild which added 11m to the ship's length. Prior to the cruise, a significant time had been spent on winch trials, but very little time had been available for scientific trials. This resulted in some delays and slow progress, particularly in the first few days of the cruise, since many systems were being used or deployed for the first time.

Second, the ship's chef became seriously ill in the early part of the cruise, and had to be evacuated to land by the *James Clark Ross*. This was a major loss of science time to *Sterna 92* as a whole.

Third, the loss of the SeaSoar halfway through the second survey was a major blow to the scientific programme. We were fortunate to be able to borrow a UOR from the *James Clark Ross* to enable us to collect at least some data on mixed layer structure during the final part of that survey.

Figure 1.1 Cruise track



MERCATOR PROJECTION GRID NO. 1

SCALE 1 TO 10000000 (NATURAL SCALE AT LAT -60)

INTERNATIONAL SPHEROID PROJECTED AT LATITUDE 0

STERNA 92 RRS Discovery Cruise 198 Nov/Dec 1992

Figure 1.2 First survey track. Capital letters show the names given to the survey legs (section 3.8; Appendix C).

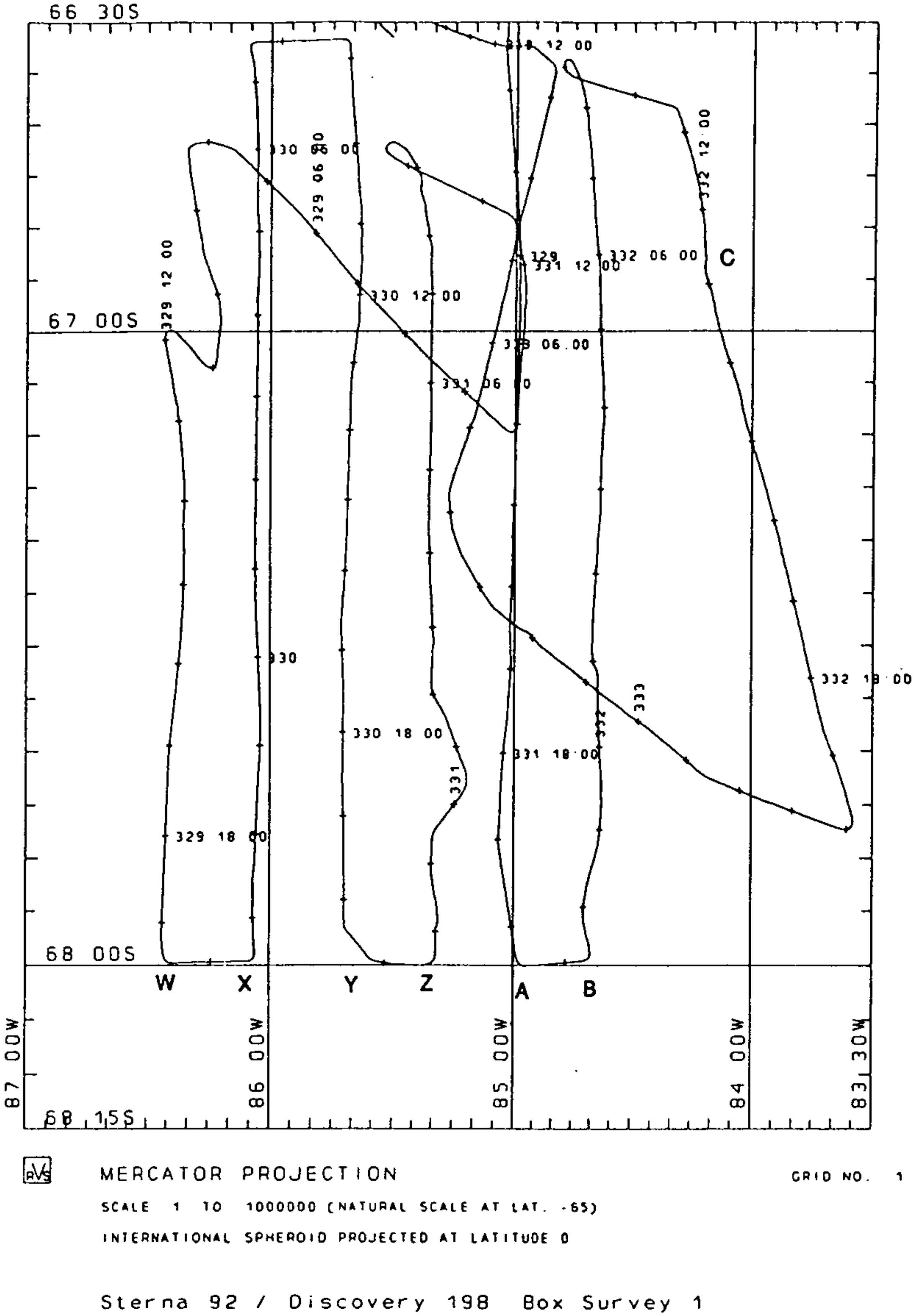


Figure 1.3 Second survey track. Capital letters show the names given to the survey legs (sections 3.8, 3.10; Appendices C, D).

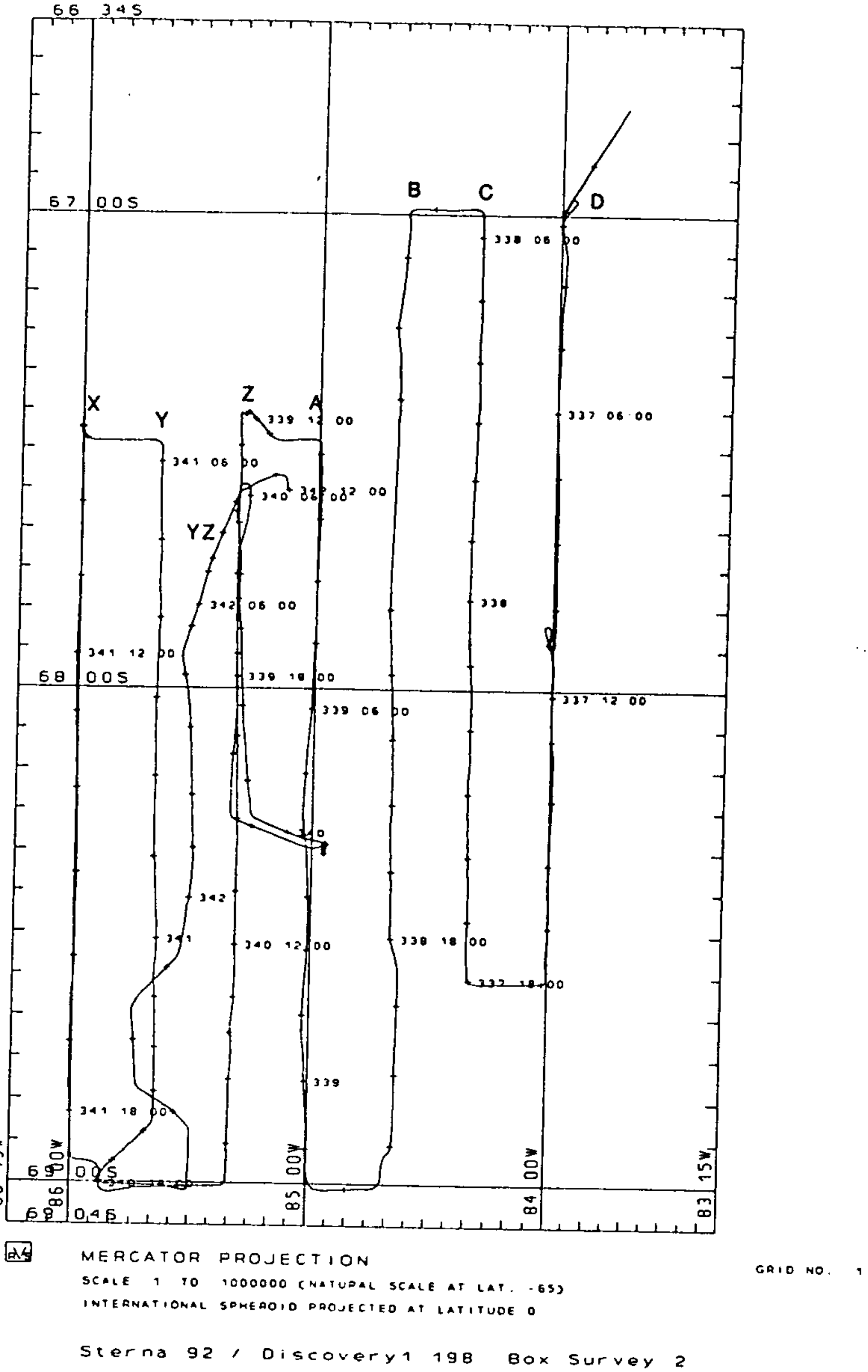
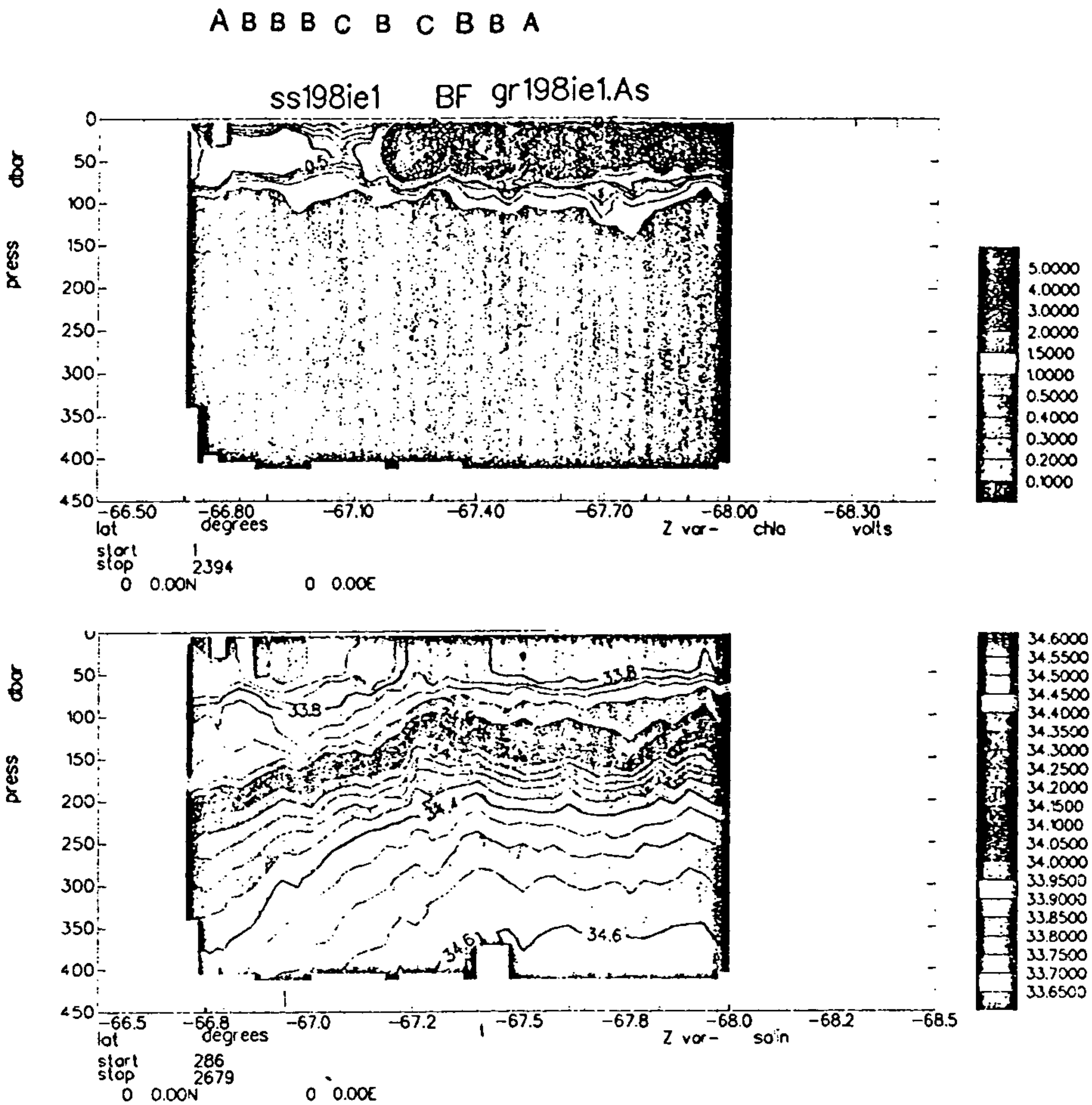


Figure 1.4 Chlorophyll and salinity sections (leg A, first survey). Letters above the upper panel show CTD section locations: A - deep CTD; B - 1000m CTD; C - productivity station.



2. CRUISE NARRATIVE

2.1 Mobilisation

Following cancellation of our original flights (2/11/92) by the RAF, the scientific party flew to Stanley in two groups: an advance party of 6 scientists and 2 RVS technicians (arrived in Stanley 30/10/92), and a main party (arrived in Stanley on 7/11/92 after a 30 hour delay in their RAF flight). *Discovery* arrived in Stanley on 5/11/92, 48 hours later than planned, having been delayed 60 hours in Capetown awaiting the arrival of spares by airfreight. Departure from Stanley on the planned date of 8/11/92 was impossible because (i) the late arrival of *Discovery* and of the main scientific party meant that preparation of scientific equipment for sailing was far from complete, and (ii) it was necessary to await further airfreighted ship's spares, which arrived on the evening of 10/11/92. *Discovery* then left Stanley for Berkeley Sound for bunkering: this was completed on the morning of 11/11/92. The scientific log begins on departure from Berkeley Sound.

With the benefit of hindsight, it is apparent that Stanley is an inconvenient port for RVS ships. Port calls at Stanley leave scientists and RVS staff reliant on the RAF, whose Tristars provide the sole air link between the UK and the Falklands. Seats on the RAF flights are available only when not required by the military, and are not confirmed until a few weeks before departure: we were given 4 weeks notice that our request for seats on 2/11/92 could not be met. It also appears that delays to the flights are not uncommon: our main party were delayed 30 hours at Brize Norton, while the scientific party returning from the *James Clark Ross* BOFS cruise were delayed 24 hours at Ascension Island. It is recommended that future Southern Ocean cruises should use ports served by commercial airlines wherever possible.

2.2 Scientific log

Note: all times are in GMT and all dates as day number: see Appendix I for day number to date conversions.

<u>Drake Passage transect</u>
Discovery got under way at 316/1400 following completion of bunkering. Since there had been no scientific trials prior to this cruise, the first requirement was to test all equipment to be deployed overside. We steamed east in order to reach 300m depth for a shallow CTD cast. On reaching this depth (1615), further work was required before the CTD was deployed, so we steamed south to remain at this water depth, heaving to at 2230 for a shallow CTD cast. This was completed successfully, together with firing of Niskin bottles. This was *Discovery* station 12198, the first scientific station for over two years. On the same station, a 30L GoFlo cast was also successfully completed, using a kevlar line on the starboard gantry. The BAS acoustic fish was given a brief test, revealing some problems in the deck unit. Deck lab watches, including regular water sampling, started at 317/0200. Instruments on line at that stage were pCO_2, oxygen, and the autoanalyser. The RVS surface system had also begun logging. ADCP

calibration was carried out between 317/0030 and 317/0353. The *James Clark Ross* had turned south at that time, having reached 65°S 84°W.

SeaSoar was launched at 317/1355, and was soon undulating well to 380m. It was decided to proceed with the Drake Passage SeaSoar and ADCP transect for UK WOCE. The SeaSoar cable was shortened to 90m for passage over Burdwood Bank (317/1826 to 320/0502). The Turner Designs fluorometer was by this time on-line in the deck lab. Lightfish was deployed at 318/1458 using the starboard stern crane instead of the Schatt Davit, which towed the fish too close to the ship. Even on the crane, the lightfish appeared to tow close to the SeaSoar, which was itself to starboard of the centre line. The potentiometric pH system was on-line at this stage, and tests of the various batches of TCO_2 chemicals continued. Major problems were encountered with the oxygen titrator. The size-fractionated productivity groups began a 3-4 day experimental sequence.

At 319/0940 the SeaSoar cable was shortened to 200m due to fog, increasing again to 600m at 319/1400 in clearer weather. At 319/1652 SeaSoar cable was again shortened (to 300m) and speed reduced to 6 knots in poor visibility. The first icebergs were sighted on the radar south of the Polar Front in very cold surface water(-1°C). The remainder of the SeaSoar transect was completed with 300m cable out at 6 knots: SeaSoar undulating to 200m but not reaching the surface. SeaSoar was recovered at 320/0745. Even in calm water the SeaSoar swung to within 18" of the ship's stern on leaving the water, showing the need for improved control of the fish on recovery. *Discovery* then continued on passage to Potter Cove (King George Island) for calibration of the acoustic fish. At 320/1100 the fog cleared, giving a stunning view of Elephant Island as the ship steamed into the Bransfield Strait. At 320/1330, the wire jumped off the PES winch sheave during recovery of the acoustic fish. Fast reactions by Colin Day, and skilful work by RVS and ship's staff ensured a safe recovery. Deck lab watches stood down at 320/1900 following completion of the transect into the Bransfield Strait.

Potter Cove

Discovery anchored in Potter Cove at 321/1233. Another stunning view! The initial anchorage dragged, with re-anchoring complete by 1420. The acoustic fish calibration began at 1436, and was complete at 2040. Radio contact was made with the Argentine research base *Jubany*, which is situated on the shore of Potter Cove: Jane Robertson communicating very effectively in Spanish. At 1700, when the weather had abated a little, a small party (David Turner, Jane Robertson and Anne Morrison) went ashore to the base, bearing traditional gifts (whisky and wall shield) which were well received. We were given a friendly reception, although there were few English speakers on the base. Plans to entertain some of the base staff to dinner on *Discovery*, and for more scientists to visit the base, were curtailed by worsening weather. Getting the ship's boat off a lee shore for return to the *Discovery* could be described as challenging, but was safely accomplished thanks to the efforts of Andy Adams, Phil Gauld and Ian Slater. All were back on board at 2050.

Bellingshausen Sea transect

With the Drake Passage transect and acoustic calibration completed, *Discovery* headed for the 85°W longitude along which the James Clark Ross had made their transect into the ice. We headed initially for 65°S 85°W, following which the intention was to carry out an exploratory transect southwards. SeaSoar was not be towed on this westward transect - the physicists had discovered that the CTD level A had been incorrectly programmed, and had to reprocess the raw data files from the Drake Passage transect. Changes to the code could not be made on board (development software not licensed for this ship), so revised code was awaited from Barry in time for the next Seasoar deployment. On day 321 one of the thermosalinograph temperature sensors failed, leaving us with no high quality sea surface temperature measurement (although in the event the ADCP sensor gave good data, see section 3.4).

Productivity stations (300m CTD followed by GoFlo casts on kevlar) were carried out at 1100 on days 322 and 323, complete within 2 hours each time. The acoustic fish was recovered at 323/1300 following completion of a shelf break transect to allow the ship to proceed quickly to 85°W (the acoustic fish cannot be towed safely above 10 knots). Most of the rest of day 323 was spent doing 3 knots in thick fog! The fog cleared at 2000.

A third daily productivity station at 324/1100 resulted in the loss of a 30L GoFlo bottle when the kevlar line broke, for reasons which were not clear. The weather then steadily worsened, and by 1540 the lightfish was recovered and the ship battened down in 40-50 knot winds. At 1718 the roller door to the water bottle annex was stove in by a wave, which proceeded to flood the deck lab to a depth of several inches, causing wet feet but no other damage. The ship then hove to for repairs, which were complete at 325/0030. During day 324 the Master became increasingly concerned about the health of Chef Glyn Davies, and spoke at length to the doctor on board the *James Clark Ross*. As a result, it was agreed that the two ships should rendezvous as soon as possible to allow the doctor to examine Glyn. On-line measurements and sampling continued in the deck lab during passage to the rendezvous.

The two ships met at 325/1600: the *James Clark Ross* doctor came over to *Discovery*, examined Glyn Davies, and advised that he required urgent evacuation to shore on medical grounds. The use of *Discovery* for this evacuation was offered, but the doctor was clear that medical considerations, which were paramount in this situation, favoured the use of the *James Clark Ross*. This was a major blow to the scientific programme on the *James Clark Ross*, which had already suffered one medical evacuation during their cruise. Glyn was duly transferred and evacuated to Stanley, receiving a blood transfusion on the ship. He was later reported to be recovering well in the Falklands. During the rendezvous, Nick Owens visited *Discovery* to discuss plans for the two cruises, and intercalibration CTD casts were carried out. The ship remained hove to for the evening. On day 326, following a productivity station at 1100, the ship remained on station until 1500 to allow completion of welding work to make good storm damage. At the same time, the oxygen and alkalinity photometers were moved to the cooler climes of the water bottle annex and the hangar respectively to try to overcome the problems of intense degassing of samples during titration. At 326/1500 the weather was too poor to launch SeaSoar as hoped, so we carried out instead a section of 1000m CTD stations every 20 miles from 82°W to 85°W along 65°S. The surface water was much warmer at 85°W, probably on the edge of the polar front. The westerly section was completed at 328/0030, with weather still too poor for launching SeaSoar, so a southerly CTD section at 20 mile spacings was begun along

85°W. On the southerly course there was a heavy swell on the starboard quarter, but there seemed to be no danger of being pooped at 10 knots, much to the relief of the productivity groups with their incubators on the aft deck.

First survey

The CTD station at 65°40'S, together with productivity casts, was completed by 328/1324, and with an improvement in the weather SeaSoar was launched and a southerly transect begun. We crossed the Antarctic Circle at 2134. By 329/0200 we had reached 67°09'S, and headed northwest away from the ice during the hours of darkness to avoid the need to recover SeaSoar: the ice edge at this time was believed to be between 67°30'S and 68°S. A southerly course was resumed at 329/0800 in improved light and weather: a further northwesterly diversion was caused by a blizzard between 1100 and 1150. When the southerly course was resumed we were at longitude 86°20'W. South of 67° we encountered high chlorophyll (seen briefly also at the southern end of the earlier transect on 85°W). The *James Clark Ross* had earlier encountered high chlorophyll at this latitude when the area was covered with brash ice. It was decided to survey this chlorophyll patch with north-south legs at 8 mile (20' longitude) spacings, with northern and southern limits of 66°30'S and 68°S. In order to minimise speed reductions due to poor visibility, the survey was arranged so that the northern end was carried out at night and the southern end during the day. The current tow along 86°20'W was declared to be the first leg of the survey. The intention was to work to 84°W, and to ask the *James Clark Ross* to work from 68°S into the ice on their return.

The first 6 legs of the survey worked according to plan (see Figure 1.2), although leg Z (85°20'W) was terminated early in order to keep the correct day/night timing. Some deviations were required to avoid icebergs, and occasional slowing was required in fog. On day 331, Nick Owens confirmed that the *James Clark Ross* would work southwards down 85°W on their arrival (expected day 332). The timetable for their ice station work had been reduced from 4 days to 2 days per station in view of the time lost. On day 332, it was impossible to keep to the southerly course planned for leg C (84°20'W) owing to 50 knot winds and heavy seas; the track drifted steadily to the east. At 332/1943 the survey was abandoned, and the ship headed northwest into the weather. A further problem concerned the pendulum arm attached to the stern gantry: it could be seen that the securing bolts had worked loose, rendering the arm liable to come away entirely if the remaining supports (hydraulic ram and weld) gave way. Since the arm was above the SeaSoar recovery position, SeaSoar could not be recovered either.

On day 333 the weather had moderated: at 0940 the lightfish was recovered and the SeaSoar cable shortened. The weather was calm enough to allow access to the top of the stern gantry, and temporary repairs to the pendulum arm were completed by 1727, following which SeaSoar was recovered using a drogue to keep the fish away from the stern: this worked very successfully.

Intensive CTD section

The next scientific activity was a CTD section crossing the northern edge of the chlorophyll patch: the water to the north is less saline, flowing easterly, and has very low chlorophyll concentrations (Figure 2.1). The survey had revealed a large bloom, but nothing like the meltwater-stabilised mixed layer envisaged in the proposal! The plan was to carry out casts every 5 miles from 66°45'S to 67°30'S along 85°W, with 4000m casts at the ends, 1000m elsewhere (Figure 1.4). The stations at 67°05'S and 67°15'S incorporated productivity casts in low and high chlorophyll water respectively. The first deep cast was very slow (333/2227 to 334/0543) due to spooling problems on recovery, although this problem was successfully overcome by Colin Day and Tony Poole, and deep casts ran very smoothly thereafter. When the first deep cast was eventually completed, the multisampler was found to have fired all the bottles at the same depth. A replacement multisampler was installed ready for the next cast at 334/1625. The remainder of the section proceeded without incident, and bottle samples eventually obtained for all stations. The section was completed at 335/2125. Despite the large number of samples, the deck lab crew managed to cope with full sets of oxygen and nutrient samples from this section.

Second survey

The initial plan for the second survey was a repeat of the first, but moving 30' further south to map the southern edge of the chlorophyll bloom, and to study the evolution of the bloom itself. Contacts with the *James Clark Ross* revealed that the chlorophyll decreased to a low level at about 68°15'S, and remained low all the way to the ice edge at 69°S: this indicated that there was no value in the Discovery working all the way to the ice edge. The SeaSoar was launched at 335/2230, and the ship steamed towards the survey start point at 67°S 84°W (the survey worked east to west this time, again synchronising the north/south cycle with night/day in the same way). However, SeaSoar was recovered at 336/0300 before the start of the survey itself, due to incipient bad weather. Recovery, in poor conditions, using the drogue once again, plus lateral lines, kept the fish well under control. When the weather had abated, the SeaSoar was launched once again at the start point (67°S 84°W) at 337/0200 and the survey restarted.

On the first leg, there was a sharp change in chemistry at about 68°25'S, with pCO_2 increasing rapidly to equilibrium with the atmosphere, and nutrients also increasing sharply. The leg was continued to 68°35'S to sample these new conditions fully: however, when the SeaSoar data were processed it was clear that this had not been far enough south to define the physical boundary, so with effect from leg B (84°40'W) the survey was run from 67°30'W to 69°S in order to map the southern boundary fully (see Figure 1.3). The northern boundary of the chlorophyll bloom was abandoned in order to keep the survey legs the correct length for a repeating day/night cycle. All went well until SeaSoar was lost at 338/1037 just after completing leg A. Separate reports have been submitted on this event.

In order to obtain mixed layer information for the western half of this second survey, we requested loan of the UOR, plus driver Ian Bellan, from the *James Clark Ross*. To our pleasure they readily agreed. The *James Clark Ross* was then on station at 68°15'S 85°W, so we steamed along leg Z (85°20'W) to collect surface data before rendezvous at 339/2045. The transfers were completed successfully, and a new UOR cable was wound onto the SeaSoar winch.

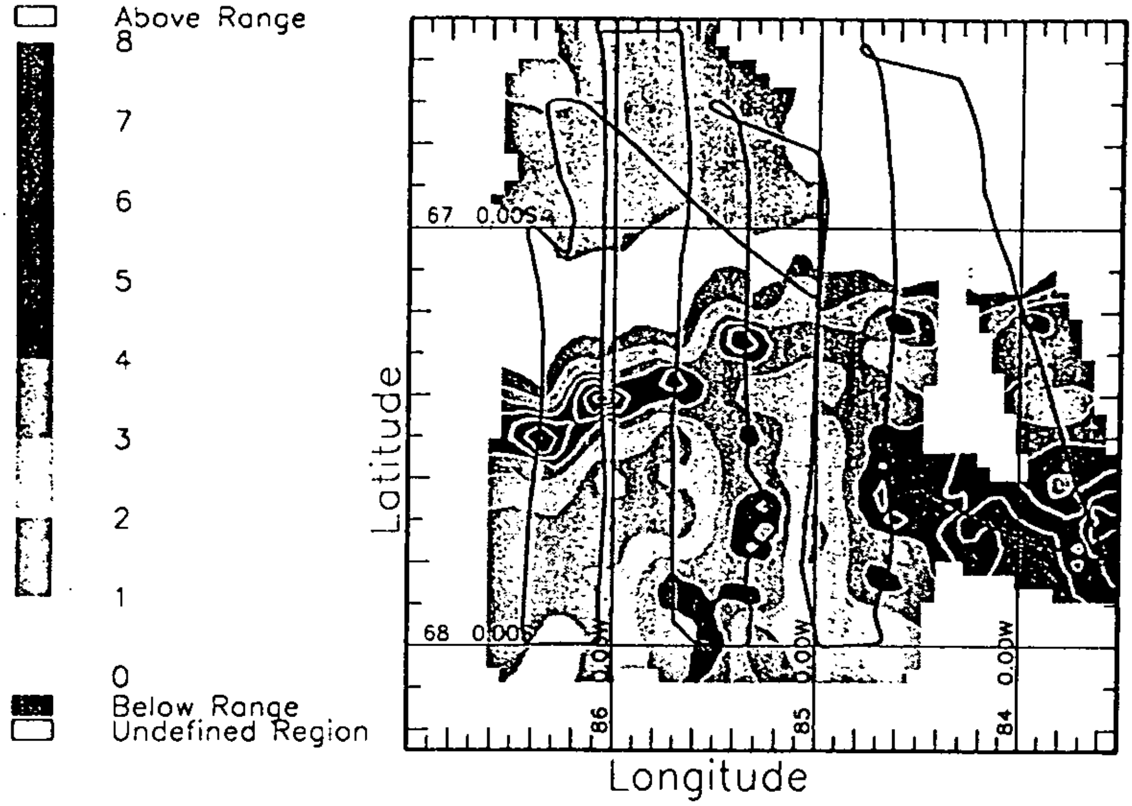
In order to re-establish the day/night cycle correctly, we steamed to 67°40'S 85°20'W, and launched the UOR at 340/0518. Ian Bellan had advised that tows of no more than

8-9 hours should be attempted due to limited battery life in these cold waters. The UOR was recovered at 1327, and launched again at 1700 for leg Y (85°40'S). However, shortly after commencing this leg, examination of the first leg data revealed a problem with the temperature sensor. The UOR was recovered and the sensor replaced, launching again at 2300. This leg was completed successfully, but a fault was found with the UOR conductivity sensor on recovery. Further attention by Ian Bellan solved this problem, and two further tows were carried out along legs X and YZ (86°W and 85°30'W), these being chosen to cover the western half of the survey as effectively as possible. All survey work was completed by 342/0527. *Discovery* hove to close to the *James Clark Ross* at 342/1230, but no transfer was possible due to poor weather. A productivity station was carried out while hove to. The Master of the *James Clark Ross* preferred to wait until day 343 for transfer, and transfers were finally completed by 343/1250, although the weather was by then poorer than on the afternoon of day 342. Figure 2.1 shows surface chlorophyll from this survey.

88°W transect

This transect had originally been envisaged as a combined SeaSoar/surface chemistry/CTD transect. With the loss of the SeaSoar, it was decided to carry out CTD stations at 2.5' (150 mile) intervals, with XBT casts every 20 miles, and full surface chemistry and biology sampling, with the addition of particulate sampling (section 3.28). A limited number of productivity stations were also worked. The transect was started at 69°S (344/0024) in order to assess the extent of the chlorophyll bloom at this longitude. The final station at 51°30'S was completed at 349/1315.

Figure 2.1 Surface chlorophyll, both surveys



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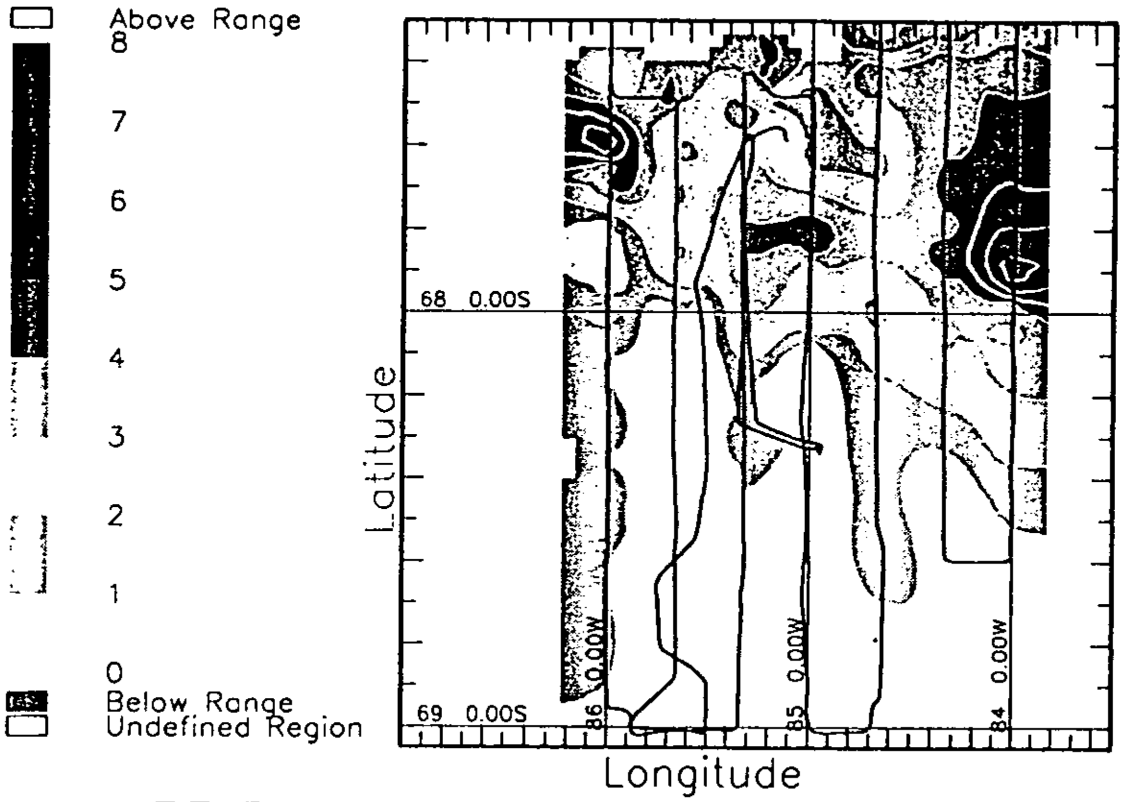
VARIABLE:-chlorophyll



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3. SCIENTIFIC ACTIVITIES

Note: all times are in GMT and all dates as day number: see Appendix I for day number to date conversions.

3.1 Navigation (Gwyn Griffiths)

Discovery is presently fitted with five satellite navigation receivers; four operate with the Global Positioning System (GPS), of which one is the radio-code clock, and the fifth operates on the Transit system. Of the GPS receivers, the bridge tend to prefer the Racal/Decca receiver for navigation, with the older Trimble receiver as a back-up. Scientific navigation information comes from the Trimble. The other GPS receiver is a 24 channel Ashtech instrument, used primarily for attitude measurements - see below on measuring the ship's heading.

Dead reckoning.

Unlike the Trimble receiver on *Charles Darwin*, the one on *Discovery* is not supplemented by a rubidium clock that allows fixes when only two satellites are visible. The periods of two satellites amounted to about 45 minutes a day in the working area. Therefore, the lack of an external clock compromised the navigation for a significant period, for both deck officers and scientists. The traditional method of coping with an absence of navigation fixes is to use dead reckoning, using ship's heading and speed. However, the electromagnetic speed log had been unusable since Cape Town. Phil Taylor and Bill Miller traced the problem to the sensor unit itself, and searched in vain for a spare unit on board. There was no spare - this is unacceptable for such an essential navigation tool. There were occasions on which it was necessary to keep the bridge informed by telephone from the main lab every 2 minutes of the ship's speed through the water from the ADCP.

GPS availability

The availability of GPS coverage, *irrespective of quality*, during the cruise was generally acceptable, indeed had the rubidium clock been available, it would have approached 100%. Typically, there were 30 gaps a day of over 1 minute, with about 6 greater than 10 minutes. However, many fixes were of poor precision due to satellite geometry, the cumulative time of poor fixes (pdop>5) amounting to about three hours a day. The 'mission planning' software supplied with the Ashtech GPS receiver allows graphical and tabular displays of GPS availability and it was invaluable in planning the time of the adcp calibration, when good GPS coverage is essential. As the almanac data are obtained from the satellites each pass, the information is up-to-date and accurate.

GPS accuracy

The quoted accuracy of GPS with Selective Availability (SA) in operation is that a position is within 100m of the true position for 95% of the time (SA is the deliberate degradation of the GPS signal for commercial users). The error can be estimated from a stationary ship, and this was done whilst tied up to the pontoon at Port Stanley. Over an 18 hour period, the standard deviation of the longitude was 25.8m, and that of the latitude was 32.5m from the Trimble receiver. The comparable figures for the Ashtech receiver were 27.4m and 37.9m. This accuracy is acceptable for normal navigation requirements, but when deriving ship's speed over the ground for the calculation of absolute velocities from the ADCP the degradation introduced by SA is very noticeable.

Navigation procedure

The raw one second GPS position data from the Trimble were read from the level C into PStar. Fixes with a pdop of greater then 5 were rejected, and then averaged to provide positions one minute apart. Gaps in the position data were filled by linear interpolation between good fixes as no DR was possible. The speed of the ship over the ground, and the distance run were then calculated from the one minute data. The ship velocity over the ground needed for obtaining absolute currents from the adcp were obtained by taking the one minute velocities, median filtering and then averaging to 15 minutes, to match the adcp averaging interval. Archive copies in PStar format of the raw GPS and Transit navigation data were made at the end of the cruise.

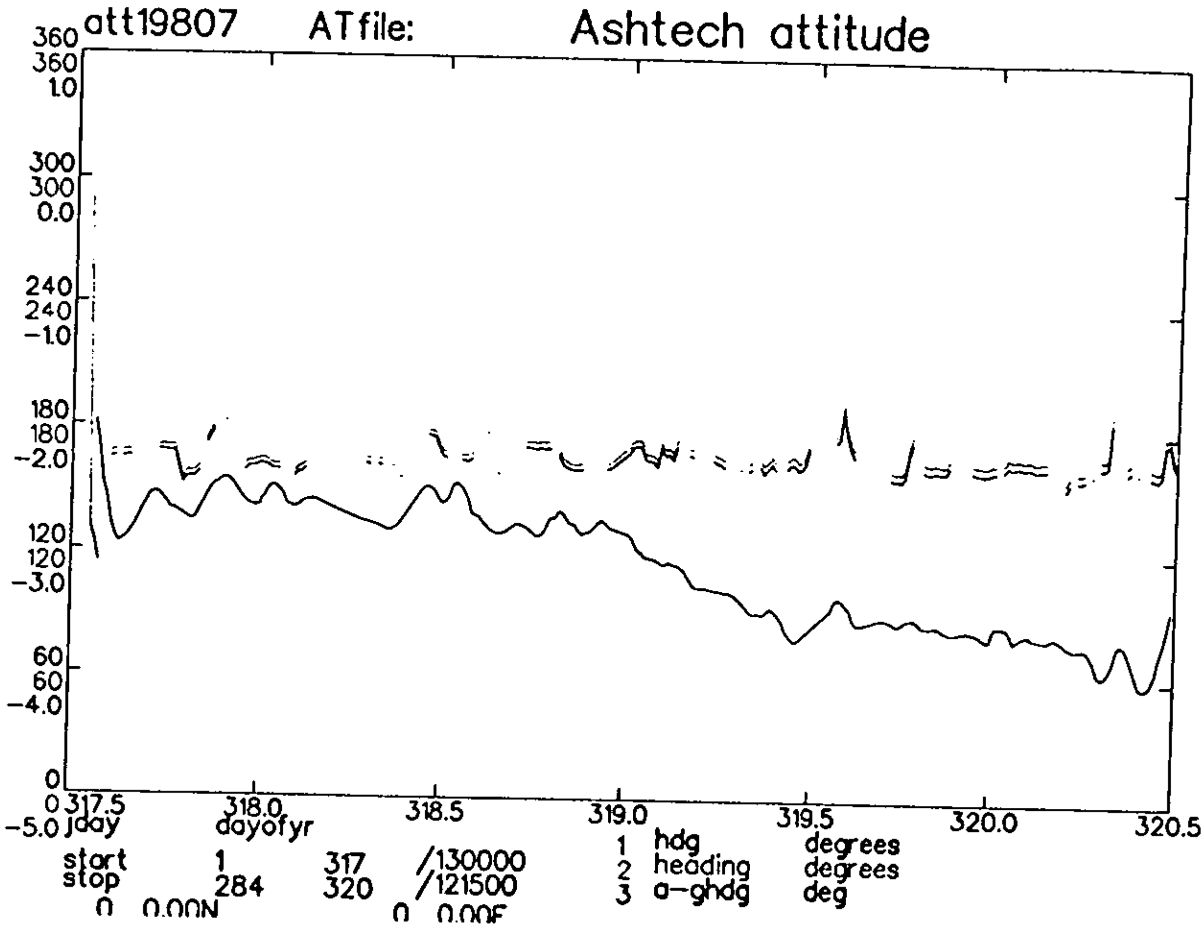
Measuring the ship's heading - gyro and 3D GPS

The ship's heading is traditionally measured using a gyrocompass, the new *Discovery* is fitted with two SG Brown Mk1000 instruments, known as No.1 and No.2. Heading input to the shipboard computer system was from No.1 gyro throughout the cruise. The No.1 gyro was also used as the navigating gyro from leaving Port Stanley until 334/1600, when a power failure caused both gyros to shut down. As No.2 settled quicker, it was switched to act as the navigation gyro.

This cruise saw the first operational use on an NERC research vessel of a new system to determine heading based on differential GPS measurements. By measuring the relative positions of an array of four antennas to a precision of 1-2mm over baselines of 6-10m, it can provide heading measurements to an accuracy of 0.05°. The technique is free from drift and heading dependent errors that can reach 2-3° with marine gyrocompasses. The primary reason for installing the system is to provide accurate heading for underway ADCP current measurements. However, the GPS heading data are not continuously available, as each of four antennas needs to be locked on to four satellites to acquire attitude information. With the present incomplete GPS constellation, this requirement is only met for part of the day, such that only some 40% of 15 minute intervals through a day had attitude data from GPS. The system also suffers from short-term drop-outs, even in the presence of good satellite coverage, and no data are available for tens of seconds whilst the system re-acquires lock. This may well be due to two of the antennas being located next to the lifeboats, and it is suggested that they be raised whilst maintaining their rigidity.

The new heading data were used to correct the gyro headings, the gyro then acting as an interpolation method between 3D GPS data. A series of four C shell scripts running PStar programs (including two new ones) were written to handle the attitude data and to apply the corrections to the adcp velocity data. An example of where the GPS system showed a significant drift in the gyrocompass was along the Drake Passage section. A drift of 2° occurred over the three days of the passage, as shown in Figure 3.1. The effect of correcting the adcp for the heading error was to reduce the mean east component of current from $11 cm.s^{-1}$ to $7.1 cm.s^{-1}$, the difference, $3.9 cm.s^{-1}$, being due to a spurious component to the left of the ship's track caused by gyro error.

Figure 3.1 Ashtech GPS heading (hdg), gyrocompass heading, and difference (a-ghdg) during the 3 day crossing of the Drake Passage. The slow drift amounts to 1.5°



3.2 Acoustic Doppler Current Profiler (Gwyn Griffiths, Bill Miller)

Instrumentation

The RD Instruments 150kHz ADCP was in operation throughout the cruise. Neither the instrument or the IBM data acquisition system (DAS) gave any hardware problems. The firmware version was 17.10, released on 5 March 1992, and the DAS software was version 2.48. The system PC should not be run in 'turbo' mode as this will cause gpib comms errors. VMtest was run whilst at Port Stanley, with satisfactory results. The firmware revision incorporates a new 'fish rejection' algorithm and minor improvements to bottom tracking.

Air was bled from the transducer space several times during the cruise, probably the air was getting trapped during the frequent periods of heavy seas. It is recommended that a more automated method of bleeding the system should be devised.

Whilst alongside the pontoon at Port Stanley, the ADCP heading was checked against gyro compass No.1, and was found to agree to 0.1°. The ADCP temperature sensor was also checked against the hull temperature readout on the bridge - the ADCP showing 0.9° low. The configuration was 64 by 8m cells, the ensemble average period was two minutes, and the auto scaling mode was selected for sound velocity correction using the ADCP sea surface temperature.

Calibration

The zig zag course technique was used to calibrate the ADCP whilst steaming at 8 knots on the continental shelf on passage from the Falklands to the first station, each leg of the zig zag was 20 minutes. The scaling factor (A) and the misalignment angle (ϕ) were calculated following the procedure developed on previous cruises. However, after the Drake Passage section, it became clear that the calibration was incorrect. There was a bias towards the left of the ship's track, and currents approaching and leaving a station were inconsistent with those on station. The source of the problem, and the solution, took a few days to puzzle out. The culprit was found to be the method of calculating the ship's velocity from successive 1 minute GPS fixes averaged over the steady part of the zig-zags. This method had proved itself using GPS without degradation due to Selective Availability (SA). Evidently, with SA in full effect, the method did not work, as it introduced a bias into the ship speed estimate because of the 'bad' fixes that were thrown out before forming the one minute averages. The effect of this editing was to bias the ship velocity. For example, setting an acceptance window of ±500cm.s^{-1} for ship speed rejects spikes above 500cm.s^{-1} but does not reject a spike to -499cm.s^{-1} from a true value of +400cm.s^{-1}. The solution was to calculate the mean ship speed during the zig zag from the positions at the start and end of the steady section only. This revised procedure gave an amplitude scaling factor (A) of 0.997 with a standard deviation of 0.016 The alignment angle error (ϕ) was -1.55° with a standard deviation of 0.65°.

Data processing

The majority of the data processing for the ADCP was done using PStar command scripts as developed on *Vivaldi* and previous cruises. The ADCP data were processed every 24 hours as one set. After all calibration, editing and merging with navigation, it was split into two series: 'on station' covering periods of minimal ship speed whilst on CTD and productivity stations, and 'underway' covering SeaSoar runs and all associated course changes and manoeuvres. Obtainable ranges varied from in excess of 450m down to 100m, primarily related to the amount of scattering organisms present in the water column and the ship's speed. The greatest ranges were achieved in the plankton bloom and when the wind and sea were low - the lowest ranges were on courses steaming into moderate to high winds (>25 knots) and at ship speeds in excess of 10 knots. At such times there were periods of total data loss, where the %good did not exceed 25% at any depth, and there were periods where there was an indication of a spurious current along the ship's track. However, the installation is a great improvement on the original *Discovery* installation with the transducer in the asdic pod, and subjectively, the performance in poor weather was better than, or certainly no worse than on the *Charles Darwin*.

Results

Colour contoured velocities were plotted for each section of the SeaSoar surveys. They showed clear correlation between the ADCP cross track currents and the density structure. In general, the currents showed little shear, the features extending to beyond the depth range of the instrument. Maps of the currents at 101m along the survey tracks were also produced. Whilst on station the ADCP velocity measurements showed much lower scatter than whilst underway.

The ADCP backscatter strength forms a broad-brush estimate of zooplankton abundance. The two minute ensemble averages for all beams clearly showed diurnal migration, and enhanced scattering near fronts and eddies. The contrast in scattering across the polar front in the Drake Passage was particularly remarkable. Single ping data were also collected from the individual beams. At times, these data showed the presence of krill swarms, with spatial dimensions such that only some of the beams were affected, and that the 2 minute average (covering typically 500m) hardly showed a signature. The backscatter intensity of such swarms was at times over 50dB above the background level, and the new RD fish rejection algorithm was turned off to avoid data rejection.

3.3 Meteorology (Polly Machin, Gwyn Griffiths, Bill Miller)

Instrumentation

The meteorological monitoring system used on *Discovery* is a modified version of the metlogger installed on *James Clark Ross* in 1991 and comprises the following instruments :

(i) an R.M.Young Instruments 05103 wind monitor (sn 11277), including wind vane and anemometer - this is situated on the foremast

(ii) two Vector Instruments psychrometers, located port and starboard on the foremast (sn 1072 and 1073 respectively), measuring wet and dry bulb air temperatures

(iii) two Didcot cosine collector PAR sensors (spectral range 400-700nm) located port and starboard on the foremast (sn 27150 and 27151 respectively)

(iv) two Kipp and Zonen total irradiance sensors located port and starboard (sn 92015 and 92016 respectively)

(v) a longwave pyrgeometer, fitted by Keith Birch prior to *Discovery*'s departure from UK waters, also on the foremast;

(vi) a hull-mounted RS Components platinum resistance thermometer, recording sea surface temperatures

(vii) a Vaisala DPA21 aneroid barometer (sn 465569), located in the main lab

(ii) and (v) are IOSDL instruments replacing components of the standard RVS system. The metlogger system was designed as a general purpose meteorological data package for use on cruises not requiring meteorological research standard instrumentation and therefore complements the IOSDL designed Multimet system which is geared towards a higher standard of performance. The *Discovery* metlogger system was developed as part of a joint project between BAS and the Instrument and Sensors Group at RVS and uses modular sensor packages and signal conditioning. For all sensors apart from the barometer, the conversion to digital data takes place at the module (by Rhopoint) and data are transmitted to the logger by an RS485 link (data from the barometer are transmitted by an RS232C link). Pre-cruise maintenance and inspection of the foremast sensors was carried out in Port Stanley, but no maintenance was done at sea.

Data processing

As this cruise was the first time the metlogger system had been used on *Discovery*, considerable thought was given on how best to process the data from the various instruments. Unlike most shipboard instruments that have a dedicated Level A interface, the metlogger PC emulates a standard Level A interface and transmits the data directly to the Level B in Ship Message Protocol (SMP). The data are transferred to the Level C and then reformatted from Level C to PStar format to allow processing under Unix, using a series of pexec scripts based on the set of scripts used for the IOSDL Multimet system. However, given the new instrument configuration on this cruise and a number of errors and inconsistencies in the Multimet scripts, a considerable degree of rewriting was necessary. Additionally, since the emlog was unavailable for the cruise, the speed of the ship over ground was calculated from GPS position fixes, averaged over one minute. Note that all wind velocities in this report are given in meteorological convention, i.e. where the wind is coming from - this differs from the standard oceanographic convention for currents etc which are defined as where they are going to.

The Unix shell script *metexec0* was used to retrieve 24 hour sections of data from the Level C and convert them into PStar format. *Metexec1* was used to calibrate all instruments apart from the aneroid barometer and wind monitor, and histograms of the calibrated output were produced for all sensors as a range check, to allow editing of obvious spikes. Ship's navigation data were merged with the met file by *metexec2*. *Metexec3* would normally be used to merge the emlog file and was therefore not used for this cruise. Ship's heading (gyro) was merged by *metexec4* and a combination of the ship's velocity components and heading was used in *metexec5* for the conversion from relative to absolute wind velocities. *Metexec6*, an appending script was used to generate a full time series from the individual 24 hour files and 10 minute averaged data files (vector averaging for the absolute wind velocities) were created by *metexec7*, both for general use by interested scientists and to allow the production of time series and vector summary plots.

Calibration

With the exception of the aneroid barometer and wind monitor, which were calibrated by the manufacturers prior to installation and were therefore logged through to the Level B as calibrated output, all instruments were calibrated during PStar processing of the met. data. The calibration algorithms applied were derived either from manufacturers calibration certificates or from calibrations undertaken by RVS and IOSDL prior to the cruise. Details are given in Table 3.1.

Table 3.1 Calibration coefficients for the met. sensors

Measurement	Calibration	Source	Comments
wind speed	y = 0.1x	manufacturer	$dm.s^{-1}$ to ms^{-1}
wind dir	none	manufacturer	calibrated on installation
port wet bulb temp	a = -23.71101 b = 6.84806E-3 c = 5.626587E-6 d = 1.077627E-9	IOSDL	equation takes the form : y=a+x(b+x(c+dx))
port dry bulb temp	a = -23.84735 b = 5.788879E-3 c = 5.648462E-6 d = 9.076649E-10	IOSDL	as above
starboard wet bulb temp	a = -21.63646 b = 2.580562E-3 c = 7.893778E-6 d = 6.608683E-10	IOSDL	as above
starboard dry bulb temp	a = -20.18834 b = 9.73387E-4 c = 7.835114E-6 d = 5.250384E-10	IOSDL	as above
sea surface temp	a = 2.9755E-4 b = 0.99189 c = 0.26705	RVS (range +5 to +25°C)	equation takes the form : $y=ax^2+bx+c$
port PAR	y = x/(5*12.86E-6)	manufacturer	5 is the signal amplification factor
starboard PAR	y = x/(5*12.87E-6)	manufacturer	as above
port total irradiance	y = x/(2*48.49E-3)	manufacturer	2 is the signal amplification factor
starboard total irradiance	y = x/(2*43.63E-3)	manufacturer	as above
longwave radiation	y = 0.23364486x	IOSDL	includes a *5 signal amplification factor
barometric pressure	none	manufacturer	calibrated prior to installation

Performance

Generally, the instruments performed very well, particularly for a first cruise. The PC display was very useful and frequently consulted, particularly when crossing fronts, during storms and generally by those who resented being cut off from reality by dogged portholes! There were, inevitably, a couple of problems which have been detailed below, but these are minor details in a system which has generally proven reliable and readily usable.

The port dry bulb sensor was very noisy throughout the majority of the cruise, particularly at near-zero and sub-zero temperatures; the reason for this is not clear. However; the remaining signal is strongly correlated with the port wet bulb temperature and is almost certainly worth keeping - the noise can easily be flagged out at BODC using an interactive graphical editor.

The longwave radiometer channel gave intermittent communication errors, which most likely arise from the Rhopoint module. Both PAR sensors recorded negative irradiances during dark periods. At present it is not clear whether this is a calibration offset, in which case the entire PAR profiles will be consistently underestimated by approximately $5Wm^{-2}$ or whether it is a nonlinearity near zero, as suggested by comparison at low-zero light levels with the output from the PML PAR sensor However, this comparison is of limited use due to the different configurations of the two types of sensor. (The Didcot instruments are cosine collectors; the PML sensor is hemispherical - i.e. 2π). Recalibration of the sensors would be the only unequivocal way to resolve this problem.

The conversion from relative to absolute wind velocities is dependent upon a continuous record of heading from the ship's gyro. The current PStar processing script merges the ship's navigation file to the met file by linear interpolation: this is not suitable for a parameter such as ship's heading which "wraps around" at 360°. The problem was circumvented on this cruise by going back to the original 1 second gyro file, but this is, at best, a temporary solution.

Redrawing of the LabTech display on the PC causes an unacceptable loss of data acquisition. This is exacerbated by users' impatience with the slow screen redraw, sometimes resulting in several redraw commands being issued. Separation of the screen handling and data acquisition functions of the system would be a welcome bonus - the display is an excellent one, but need not compromise data acquisition.

<u>Results</u>

Winds were predominantly northeasterlies and northwesterlies, and were fairly stable in terms of direction (although a reversal did occur during leg C of the second SeaSoar survey). The second survey was generally blessed with lighter winds than the first, whereas the westward transect was more prone to strong winds (and greater swell) than the Drake Passage run, with the final part of the westward transect / start of the first SeaSoar survey being particularly hard hit by winds consistently in the range 10-20 ms^{-1}. The 88°W transect was notable for the consistently westerly winds, mostly in the range 8-15 ms^{-1}.

The solar radiation data, although noisy, are encouraging - where there is a drop in longwave radiation signalling breaks in cloud cover, total irradiance increases relative to PAR (clouds are less "transparent" to PAR). From the longwave radiation plots it is apparent that cloud cover is intermittent, but generally quite high - there are very few cloud-free periods greater than 12 hours.

The wind speed and barometric pressure data show that the operational area was swept by rapidly changing weather systems, where wind speed was not closely related to pressure. Even when the pressure dropped to almost 950mb, the wind speed did not exceed 20ms^{-1}, while the period of 15-20ms^{-1} winds persisted for less than 12 hours. There were very few occasions when the wind speed dropped below 5ms^{-1} and these also tended to be of short duration (6 - 12 hours).

Future work

Several of the data channels as they stand are fairly noisy and need to be rigorously screened on a datacycle-by-datacycle basis; this can probably be best achieved at BODC by making use of the available interactive graphical editing facilities. The port dry bulb temperature in particular needs careful attention. The calibration uncertainties of the port and starboard PAR would ideally be resolved by a recalibration of the instruments. Failing that, detailed comparisons of all the available, fully screened PAR and total irradiance channels will be necessary to determine and correct the calibration offsets. Given a relatively cloud-free day, it should be possible to predict the ratio of PAR to total irradiance, given the solar constant and knowledge of the appropriate geometries of the hemispherical and cosine collector instruments.

3.4 Surface temperature and salinity (Anne Morrison, Bill Miller)

Instrumentation

The thermosalinograph (TSG) system consists of a Falmouth Scientific (FSI) Ocean Temperature Module (OTM) mounted in the hull, at the non-toxic water supply intake, and an Ocean Conductivity Module (OCM) mounted, along with a second TM, within a polythene tube, through which the non-toxic supply passes. The OTM contains an FSI reference grade PRT. The hull-mounted OTM (sn 1339) is located in the forward hold at a depth of approximately 4-4.5m below the water surface, 2.2m to the starboard of the centreline: the datastream from this module is known as the "remote temperature". The OCM (sn 1331) and second OTM (sn 1340) are located on the starboard side of the hangar; they are mounted in a polythene tube through which the non-toxic water supply is pumped: this OTM measures the "housing temperature". A header tank is located approximately 2.5m above (by the winch control room) to supply enough water pressure for adequate rate of flow, free of bubbles; the volume flow rate through the tube is approximately 20L.min^{-1}, well within the manufacturer's recommendations. The flow through the tube is upwards, passing the OTM before the OCM. The measurements of temperature and conductivity from all the modules are logged through a PC, emulating a level A interface, and on to the level B at 15s intervals. The sampling frequency is adjustable, through the computer. The temperature resolution of the FSI OTM is 0.0001°C with manufacturer's quoted accuracy being 0.003°C in the range -2 to 32°C. Its specifications state that is should be stable to 0.0005°C per month.

During the first few days of the cruise it was apparent that the remote temperature module had noise spikes in the data (0.01 to 0.015°C)). On day 321 whilst investigating this problem by swopping with the housing temperature module, the latter module stopped functioning properly. For the rest of the cruise the original remote temperature module was used in the housing in order to get salinity data, relying on the met. and ADCP sensors for sea surface temperature. The problems with the FSI temp modules have been reported separately to RVS and to the manufacturers, who are in the process of providing modifications.

Sea surface temperature
Near-surface temperature measurements were obtained from four different sensors: (i) SeaSoar; (ii) met. package sensor; (iii) ADCP sensor; (iv) thermosalinograph (FSI) sensor.

SeaSoar temperature sensor. This is believed to be the most accurately calibrated and most stable of the temperature sensors; its resolution is 0.0005°C and is accurate to 0.001°C. In the following sections, the results from the other sensors are compared with those from SeaSoar to assess their stability and accuracy. The SeaSoar was deployed in the Drake Passage and in the two ice edge surveys. Data from all of these surveys are used in this assessment of the quality and calibration of temperature measurements from each instrument.

Met. package sensor. This is a hull-mounted sea temperature module consisting of an RS components platinum resistance thermometer (PRT) mounted on the port side (around 4m from the centreline) of the hull in the forward hold at approximately 3m below the sea surface. 30s averages of 1s data are transferred to the level B system. After extraction to the level C computer, the sensor output is corrected according to Table 3.1; it should be noted that the calibration was valid only down to 5°C, while the temperatures in our survey regions were within the range -2 to 8°C.

SeaSoar temperatures at 3m depth were extracted and combined with the meteorological measurement of sea temperature.The correlation between the two temperatures is quite good at low temperatures, but poorer at the higher temperatures in our range of measurements. The met-measured sea temperature is steadily higher than the SeaSoar temperatures by about 0.15°C, with standard deviation of 0.175°C, which can be applied as a shift to correct the met. measurement. The Rhopoint module for this sensor limits its resolution to 0.1°C, which makes it of very limited value for sea surface temperature measurements; 0.05°C or better would be more useful. However, it is worth noting that this instrument gives stable results.

ADCP temperature sensor. This is a PRT mounted in the transducer unit at the forward end of the winch room, about 1.2m to port of the ship's centreline, at approximately 5m below the sea surface. Temperature is sampled every ping, approximately once per second, then averaged over each 2 minute ensemble and logged through a PC which emulates a level A interface unit. The 2 minute measurement is then transferred to the level B system. No laboratory calculated calibration coefficients are available for this device. The temperature resolution of the PRT is 0.012°C, and the manufacturer's specification accuracy is 0.2°C within the range -5 to 45°C.

SeaSoar data between 4.5 and 5.5m below the sea surface were extracted from the survey datasets, and merged with the ADCP temperature. Over the Burdwood Bank region, massive spikes occur, as great as 0.7°C in magnitude; these are believed to occur because there is much structure in the near-surface temperature, and if the SeaSoar depth and ADCP measurement depth are different by even a small amount, a large temperature difference will be recorded. During the first of the two ice edge surveys, a shift in differences from day 330 to day 332 cannot be explained. Excluding the large differences at the higher temperatures, a temperature dependent relationship is evident between the SeaSoar/ADCP temperature difference and ADCP temperature. A linear regression gives

$$\Delta T = (-0.014 * T_{ADCP}) + 0.011$$

After applying the correction ΔT to ADCP temperature, the ADCP temperature to SeaSoar temperature difference has a standard deviation of 0.031°C.

Thermosalinograph. During the transect of the Drake Passage, both temperature sensors were available on the TSG. Comparisons of its temperature measurements with those of SeaSoar were made with extracts from SeaSoar data at depths between 3.5 and 4.5m, because the TSG is taking the temperature of water at around 4m. In regions where the SeaSoar was towed at shallow depths (less than 200m of cable), for example, over Burdwood Bank, the agreement is poor because there was a great deal of structure in the near-surface temperature, which means that even a small error in matching SeaSoar depth to thermosalinograph intake depth, leads to large differences in temperature. In the region from 55 to 58°S, the agreement between the remote temperature and SeaSoar temperature is excellent. Within this region, the offset has a mean value of -0.008°C and standard deviation of 0.008°C, which can be applied as a correction to the remote temperature. At 58°S the SeaSoar was again towed at shallow depth (fog and the risk of icebergs slowed the ship down) causing large differences between the remote and SeaSoar temperatures. On returning to deeper towing (59°S). the same offset as before is seen in remote temperature, but the data is much spikier, having a standard deviation of 0.035°C, which was why the remote module was removed for investigation. During the two ice edge surveys, only housing temperature was available. This does not show a steady difference from SeaSoar temperatures, not surprisingly, because heating of the non-toxic supply on its way to the hangar unit may vary. Variations in the mean of the difference between the housing temperature and SeaSoar temperature are of the order of 0.1°C.

Salinity

The output from the conductivity and housing temperature sensors of the TSG were processed using PStar program sal83 to give salinity measurements, taking the pressure to be 0db at all times. Water bottle samples were taken from the non-toxic system at hourly intervals throughout the duration of the cruise, and their salinities determined using a salinometer (section 3.11). These were combined and compared with the TSG salinity data. This showed that the TSG salinities differed from the bottle salinities by a varying amount up to 0.1psu It was decided that the best way to calibrate the TSG was to first of all ignore any bottle salinities which differed greatly from the TSG (probably due to errors in recording the time of drawing the sample). Then, the bottle samples being sparser in time than the TSG data, the differences were interpolated in time to assign a correction factor to each TSG value. This correction was then added to the TSG data. The mean difference was -0.091psu, with standard deviation of 0.019. Therefore, corrected salinities should be correct to within about 0.02psu.

3.5 Starboard winch (Colin Day, Tony Poole)

A total of 39 CTD operations were required during this cruise. The depths of deployment ranged between 150m and 5200m. Considering that this was the first fully operational scientific cruise since the Discovery conversion, the operation of both the winch and starboard gantry systems proved to be reliable and effective. Several problems were encountered on the first deep cast (station 12212), as was only to be expected on the first operational use of the new Discovery winch to full depth. A slack turn on the cable drum at the start of the haul caused cable lay problems which were not spotted until 2500m of wire had been hauled in. Several hours were lost while the cable was paid out and the drum relaid. This teething problem was resolved thereafter by careful setting of the back-tension on the inboard accumulator, and all subsequent CTD operations were successfully completed. The winch/gantry system demonstrated the potential to significantly reduce the deployment and recovery time, the limiting factors in this case being the operational speed of the CTD package through the water. The operation of the starboard gantry provided the additional benefit of allowing CTD operations to proceed safely and unhindered in sea conditions which would have made deployment hazardous on other NERC ships.

3.6 CTD operations (Bill Miller, Phil Taylor, Raymond Pollard)

Instrumentation

The main sensor package included an EG&G Neil Brown MK IIIb CTD (sn 01-1195) fitted with a new oxygen sensor (sn 2-6-20). Also fitted were a Chelsea Instruments Aquatracka MK II fluorometer (sn SA226), a Sea Tech 25D transmissometer (sn 79D), and two PAR sensors measuring upwelling light (sn 8) and downwelling light (sn 10). In addition a General Oceanics 1015 rosette sampler (sn RVS-02) was used for bottle sampling; this comprised 12 x 10L Niskin bottles fitted with stainless springs. Finally 2 x SIS 4002 (sn 220 and 238) deep sea reversing thermometers were fitted to one of the bottles.

Some initial problems were encountered with connectors: the sea cable tail and its Y-cable mating connector gave intermittent operation as did the rosette bulkhead connector and its mating connector. The sea cable connection was bypassed (spliced) and the rosette bulkhead connector replaced. The transmissometer mating connector had to be 'adjusted' after one noisy cast.

During the first deep cast (station 12212) the rosette failed (a manufacturing fault on the pylon top plate assembly), this was replaced by the spare rosette unit (sn RVS-04) which, apart from not confirming, worked fine. Bottle depths were confirmed from salinity measurements. The original unit functioned properly in the lab after the damaged top plate had been replaced with a new assembly and the unit refilled with oil.

CTD casts

CTD casts (see Appendix B for details) can be divided into three kinds:

(i) shallow (150-300m) casts to determine near-surface productivity and light levels for productivity casts using 30L GoFlos that immediately followed

(ii) intermediate depth casts to 1000m to determine the upper ocean water masses, often used also for light and productivity information

(iii) full depth casts to determine water masses and geostrophic transport through the whole water column

After an initial trial cast (station 12198) shortly after sailing from Port Stanley, the next five casts (12200-04) were shallow productivity casts usually in the morning. One of these (12203) was occupied during a rendezvous with the *James Clark Ross*, who made a CTD cast simultaneously. Duplicate salinity samples were drawn and exchanged between ships for calibration and intercalibration (see section 3.7 for results). Five casts to 1000m (12205-09) were then made along 65°S at 20 mile intervals.

On reaching the working longitude of 85°W, the weather was too poor to launch SeaSoar, so the CTD section was continued down 85°W for two more casts (12210-11) at 20 mile intervals. The SeaSoar was then deployed for a 4-day survey, following which 12 more CTD stations (12212-23) were occupied along 85°W. These casts were designed to span the west to east front which had been repeatedly crossed during the SeaSoar survey. The casts were to 1000m at 5 mile intervals, to resolve deeper structure than the 400m SeaSoar could observe. The northern- and southern-most casts (12212 and 12223) were to full-depth to allow the geostrophic transport to be calculated. As noted above, the multisampler failed on the first deep station (12212): on analysis of the bottle samples it was realised that all had been tripped at the same depth. Indeed, the multisampler could not be cocked at the start of 12213, so the cast was done without bottle samples to obtain light levels so that productivity work could proceed, and the station was reworked with multisampler later as 12214. Similarly, the top 1000m of the first deep cast (12212) were reworked as station 12218 once the multisampler had been replaced. At the beginning of 12213 it was also found that the conductivity cell had frozen, and the cast was restarted once it had defrosted.

After 12223, the SeaSoar was deployed for the second ice-edge survey, which terminated prematurely with the loss of the SeaSoar. Stations 12224-6 were occupied for productivity during the subsequent UOR survey. Finally, stations 12227-37 were worked along 88°W from 69°S to 51°30'S. Deep stations were occupied every 2.5° of latitude, occasionally preceded by a shallow cast for productivity work.

3.7 CTD data processing and calibration (Raymond Pollard, John Allen, Anne Morrison, Jane Read)

Processing

CTD data were logged in the usual way through the RVS Level A/B/C computer system, then transferred into the IOSDL PStar system on another workstation. Each cast was split into down and up casts, the former being fully processed, the latter used only to obtain calibration values. In processing the SeaSoar data (section 3.9), it was realised that the Level A software, which had been rewritten, no longer obeyed the correct algorithm for matching the time constant of the temperature sensor to that of the conductivity sensor in order to calculate salinity without bias and with minimal spiking. This problem was present in the CTD Level A also, but to a lesser extent because of its slower profiling rate, particularly during the first 6 casts, all of which were shallow. Revised Level A software was received and tested in time for use in all the 1000m casts, starting with station 12205. Final calibrations were derived and applied as described below.

Calibration

Initial calibration was done by PStar program 'ctdcal'. Further calibrations were applied later, as described below.

Pressure. The calibration used was:

$$P = -7.1 + 0.1 * 0.9987653 * P_{raw}$$

The constant offset supplied by RVS was -5.13287, but this was changed to -7.1 after noting the value of pressure when the CTD entered the water.

Temperature. The calibration supplied by RVS was used throughout:

$$T = 0.0044057 + T_{raw} * 0.0005 * 0.9999902$$

The reversing thermometers (section 3.6) were used to record temperature on 27 casts. After correction, T220 read higher than T238 by between 0 and 2mK, giving a difference of (0.85 $\pm$ 0.82mK) (mean $\pm$ standard deviation). Thus the thermometers agreed to better than 0.001°C in the mean. The comparable CTD temperature was between 0 and 8mK higher than the mean of the two thermometers, giving a correction to the CTD temperatures (if the SIS thermometers are absolutely correct) of (-4.48 $\pm$ 1.74mK). However, experience has shown that the SIS reversing thermometer calibrations are no more reliable than the CTD calibration, so the CTD temperatures have not been adjusted. We conclude that the CTD calibration was stable throughout the cruise, and that temperatures are absolutely correct to within 0.004 - 0.005°C, and are possibly high by that amount.

Salinity. CTD salinity was first calculated using the default conductivity ratio

conductivity = 0.001 * raw conductivity.

To match the differing time constant of the temperature and conductivity cells, the temperature response was speeded up by 0.5s. During the first part of the cruise salinity samples were drawn from all 12 Niskin bottles, fired at various depths. The samples were analysed by three analysts (section 3.11). Once it was established that the conductivity cell was stable, the number of samples drawn was reduced, first to 6 and later to 4 samples per cast. The exceptions were the two full depth casts (12212 and 12223) made on either side of a front in the Bellingshausen Sea. The first of these had problems and the bottles were all tripped together at an unknown depth. Samples from the second cast gave greater confidence to the calibration. The difference between discrete bottle samples and CTD values was found to vary with salinity so a linear correction was calculated. Where the difference between bottle and CTD values was less than 0.025 and greater than 0.045 the values were ignored. The calibration coefficients calculated were:

$$S_{true} = S_{CTD} * 0.99347 + 0.257$$

with a standard deviation of $\pm$ 0.002

Oxygen Oxygen is calculated for the Beckmann oxygen sensor attached to the CTD by

$$[O_2]/mL.L^{-1} = \rho * C_{oxy} * \exp(-\alpha * T + \beta * P)$$

where

$$T = a * T_{CTD} + b * T_{oxy} \quad (\text{with} \quad a + b = 1)$$

and C_{oxy} and T_{oxy} are the oxygen sensor current and temperature readings respectively and P is the CTD pressure. The CTD oxygen sensor was calibrated from 126 discrete bottle samples drawn from various depths over 13 different casts up to 12223. The data were combined to produce the coefficients ρ=1.276292, α=-0.02666 and β=0.0001494 with a standard deviation of 0.12 $mL.L^{-1}$. The residuals from this least squares regression varied from cast to cast, averaging from -0.14 to +0.15, and over depth, with the greatest residuals in the thermocline. Oxygen temperature was weighted to CTD temperature in the ratio b:a=0.25:0.75 for the calculations.

Considerable problems were experienced with the oxygen titration unit (section 3.21), so the bottle values may require further reworking and culling to improve the calibration. However, it was noted that the surface values of percent oxygen saturation for stations 12209-23 using the above calibrations were well correlated with the patchy blooms that were present, ranging from 104% in the strong bloom to 98% where the bloom was virtually absent. This suggests that the oxygens are correct within about 2%.

Chlorophyll. This calibration is reported separately (section 3.24)

Transmissometer. The A/D converter in the transmissometer scales 4096 counts to 0 to 10V. The instrument converts 100% transmittance to 5V. The basic conversion equation is thus

$$\%T = 0.002442 * 20.0 * \text{count}.$$

Ageing of the light source may change this calibration, so the highest deck reading after thorough cleaning of the glass (4.763) was used to correct transmittance by comparison with the manufacturer's value (4.744) to give

$$\text{corrected } \%T = (4.744 / 4.763) * \text{raw } \%T$$

Potential transmittance (potran) is then calculated by correcting for the index of refraction and compressibility of seawater using *in situ* values of pressure, temperature and salinity. The RVS transmissometer has a 0.25m path length. Thus, the beam attenuance per metre, independent of instrument, is given by the attenuance divided by path length:

beam attenuance (m^{-1}) = - ln (potran/100) / 0.25

Light. The CTD was fitted with upward and downward looking PAR irradiance sensors, with calibrations supplied as follows:

dwirr (downward) = 6.6470 - 0.001 * 12.353 * count
uwirr (upward) = 6.5746 - 0.001 * 12.427 * count.

CTD Intercalibration between *Discovery* and *James Clark Ross*

During the first rendezvous between the *Discovery* and the *James Clark Ross* an intercalibration of CTD and discrete samples was undertaken. This was *Discovery* station 12203 (Appendix B) and *James Clark Ross* station 27. Two sets of samples were drawn on board each ship and duplicates exchanged almost immediately. The results are shown in Tables 3.2 and 3.3. The duplicate samples from each cast are within 0.004 of each other with a mean difference of better than 0.002 (0.0017) and standard deviation of ±0.0008. The results from the *Discovery* analysis are all consistently higher than those from the *James Clark Ross*, which should be born in mind if making comparisons between the data from each cruise. Comparison between the samples from the different casts reflects the variability in the upper ocean structure, and the only real comparison that can be made is within the surface layer. This was well mixed down to 50m and it can be seen that the samples from the two casts were generally within 0.001psu. CTD data in the tables is uncalibrated and so cannot usefully be compared.

Table 3.2 Salinity intercalibration on *Discovery* samples (Station 12203)

	CTD readings		Analysis (Disco)		Analysis (JCR)		
Wire out/m	Temp/°C	Salinity /psu	Bottle no	Salinity /psu	Bottle no	Salinity /psu	Difference /psu
250	1.492	34.415	B31	34.446	S1	34.445	0.001
200	0.860	34.280	B32	34.314	S3	34.313	0.001
150	0.710	34.177	B35	34.187	S5	34.186	0.001
100	-1.382	33.941	B37	33.976	S6	33.976	0.000
80	-1.372	33.782	B39	33.819	S8	33.818	0.001
60	-1.173	33.765	B41	33.801	S10	33.800	0.001
40	-1.099	33.763	B43	33.800	S15	33.799	0.001
30	-1.084	33.763	B45	33.799	S13	33.798	0.001
20	-1.064	33.761	B47	33.800	S17	33.799	0.001
10	-1.045	33.761	B49	33.800	S18	33.798	0.002
2	-1.038	33.761	B51	33.799	S19	33.797	0.002
			B52	33.799	S22	33.797	0.002
2	-1.038	33.761	B53	33.799	S23	33.797	0.002

Table 3.3 Salinity intercalibration on *James Clark Ross* samples (Station 27)

Wire out/m	CTD readings		Analysis (JCR)		Analysis (Disco)		Difference /psu
	Temp/°C	Salinity /psu	Bottle no	Salinity /psu	Bottle no	Salinity /psu	
250	1.391	34.345	14	34.430	3	34.432	0.002
200	0.903	34.240	15	34.328	4	34.324	0.004
150	0.294	34.095	16	34.171	5	34.173	0.002
100	-1.360	33.873	17	33.966	6	33.967	0.001
80	-1.384	33.729	18	33.818	7	33.820	0.002
60	-1.102	33.710	19	33.798	8	33.801	0.003
40	-1.108	33.711	20	33.798	9	33.800	0.002
30	-1.052	33.710	21	33.798	10	33.800	0.002
20	-1.052	33.710	22	33.798	11	33.800	0.002
10	-1.042	33.709	23	33.798	12	33.799	0.002
2	-1.032	33.708	24	33.797	13	33.799	0.002

3.8 SeaSoar operations (Bill Miller, Phil Taylor, Raymond Pollard)

Instrumentation

The RVS SeaSoar (manufactured by Chelsea Instruments) was fitted with a Chelsea Instruments Aquatracka MK II fluorometer (sn SA 240) together with an EG&G Neil Brown MK IIIb CTD (sn 01-1181) fitted in a lightweight pressure case. The CTD was also fitted with oxygen and light sensors. The oxygen sensor (sn 1-8-27) was a new unit fitted prior to deployment. An independent pressure sensor, used for control purposes only was also included.

The performance of SeaSoar was good maintaining a yoyo from surface to 400m plus at ship speeds between 7.5 and 9 knots, sometimes in heavy swells. In periods of bad weather the ship's speed reduced to 5-6 knots and SeaSoar would not reach the surface. Data quality was good with only the occasional fouling of the conductivity cell.

At 339/1034 the towing cable parted some 20m from the SeaSoar, with the ensuing loss of all instrumentation. No warning of impending failure was given, good data being collected until 2s before. The details of the loss have been reported separately.

SeaSoar surveys

The SeaSoar tows undertaken are summarised in Appendix C. One day after sailing from Port Stanley, Falkland Islands, the SeaSoar was deployed on day 317 for a trial run in the passage south of the Falklands and north of Burdwood Bank. However, as it functioned perfectly, the first survey line, across Drake Passage (Figure 1.1), was run without a break. The cable length outboard was shortened from 600m to 200m during the transit across Burdwood Bank from 317/1830 to 318/0440, and was again shortened to increase the ship's manoeuvrability in poor visibility and in the vicinity of ice from 319/0940 to 319/1040 and from 319/1630 to 320/0707.

The second deployment began as an exploratory run from 65°40'S at 85°W south towards the ice edge. It was soon decided to convert the run without a break into the first ice edge survey (Figure 1.2). After a dogleg to move the southward track westward to 86°20'W, a survey of 8 legs at 8 mile spacing (20' longitude) from 66°30'S to 68°S was planned. The central leg down 85°W is labelled A. The first six legs (W, X, Y, Z, A and B) were completed without major incident, although there were detours to avoid icebergs and it was occasionally necessary to drop the speed below the optimum 8 knots in poor visibility.

Weather conditions were poor throughout the first ice edge survey, and on the 7th leg (C), running south along 84°20'W it was impossible to keep to the track (Figure 1.2). It was also found that a boom attached to the stern gantry had sheared several bolts and was in danger of falling onto the SeaSoar cable. Because the SeaSoar could not safely be recovered until the boom was secured, and the boom could not be secured until the weather abated, the ship steamed slowly into the wind on a northwestward track from 332/2000 and later east of north until repairs could begin at 333/1100. Although the survey was officially abandoned at the end of leg C, the last run across the middle of the survey area has been processed as 'stormleg'.

The first attempt at a second survey (335/2230 to 336/0300) was aborted because of forecast severe weather, and the ship remained hove to for 24 hours until 337/0200, when SeaSoar was again successfully deployed. Thus the second survey (Figure 1.3) began nearly 4 days after the first had ended. The intention was to run north-south at the same longitudes as in the first ice edge survey, but from 67°S to 68°30'S, later extended to 69°S. Also, the lines were worked upstream from east to west, as the first ice edge survey had repeatedly crossed a strong front with an eastward flowing frontal jet. The first four legs (D, B, C and A, using the same labels as for the first survey) were completed without incident. Shortly after the end of leg A along 85°W, the SeaSoar was lost.

3.9 SeaSoar data processing and calibration (Raymond Pollard, John Allen, Polly Machin, Anne Morrison, Jane Read)

Processing

SeaSoar data were logged in the usual way through the RVS Level ABC computer system, then transferred into the IOSDL PStar system on another workstation. Data were split into 4-hourly sections, for the convenience of watchkeepers, who processed, applied initial calibrations, plotted and edited the data. The major task, as always, was to examine the data for offsets caused by biological fouling, usually requiring an offset in salinity to recover to a good calibration relative to data before and after the fouling event. While this procedure is time-consuming, the great merit of the Neil Brown conductivity cell is that, once the fouling clears, it recovers its calibration reliably, and calibration drift is rare.

Towards the end of the Drake Passage survey, it was realised that the Level A software, which had been rewritten, no longer obeyed the correct algorithm for matching the time constant of the temperature sensor to that of the conductivity sensor in order to calculate salinity without bias and with minimal spiking. The value allowed for pressure spiking had also been set too small, resulting in good data being discarded whenever the climb or dive rate exceeded $2ms^{-1}$, which commonly occurs shortly after each turn. The software could only be corrected by RVS at Barry. While this was being done, the entire Drake Passage survey was replayed from the backups of raw 8Hz data maintained by the RVS electronics division. A PStar program to reduce the data from 8Hz to approximately one sample per second using the correct algorithm was revived, and very clean data with the 16 light channels correctly demultiplexed were retrieved. The time base was retrieved by setting the start time, which was logged on the backup tape, and calculating the time between samples so that the resultant plots matched those originally processed through the Level A. This revealed that the CTD sampling rate was 8 samples in 1.02413s. Revised Level A software was received and tested in time for use in the ice edge surveys. It was not perfect, particularly in regard to demultiplexing of the light channels, but the time constants of temperature and conductivity could be correctly matched, so the normal Level A route was used for the remainder of the cruise. The 4-hourly sections were appended and contoured either every 12 hours (Drake Passage) or for each leg (ice edge surveys). Final calibrations were derived and applied as described below.

Calibration
Initial calibration was done by PStar program 'ctdcal', and further calibrations were applied later, as described below.

Temperature. The calibration supplied by RVS was used throughout:

$$T = 0.00274 + T_{raw} * 0.0005 * 0.9996194$$

Experience has shown that the temperature calibration is precise and very stable, and cannot be easily checked, as it is more accurate than any other sensor onboard ship. Any shift would probably manifest itself as a severe offset in salinity, which was not observed. No bias could be detected when our T/S plots were compared with those of other investigators who had recently worked in similar areas (R Peterson, Burdwood Bank, September 1992, personal communication; J Swift, Bellingshausen Sea along 67°S, February 1992, personal communication). We therefore take the SeaSoar temperatures to be absolutely correct to within perhaps 0.003°C, with relative drift during the survey no more than that.

Salinity
The SeaSoar salinity was first given an approximate calibration by use of a conductivity ratio that gave reasonable answers for the area being surveyed. Bias between down and up profiles caused by the different time constants of the temperature and conductivity cells was minimised by choosing a time constant by which the temperature was speeded up (for the calculation of salinity only) to minimise the hysteresis between down and up T/S profiles. The value chosen was 0.35s, on the large side for the Neil Brown platinum resistance thermometer.

Relative calibration was maintained by comparing T/S profiles four at a time with a master T/S plot which was gradually developed for each survey area. Fouling of up to

0.2 or larger in salinity could occur, with frequent offsets of order 0.010 to 0.050. These were not always easy to spot, but the contour plots proved to be sensitive indicators of offsets (maintained for a profile or more) of as little as 0.010. Despite the care that was taken, there were occasions, in particular when the T/S relation changed rapidly across the front that lay across the ice edge survey area, when determination of the timing and magnitude of an offset proved almost impossible to correct with 100% confidence. Thus there may be occasions when the salinity is in error by as much as 0.030, but we expect the calibration to be within 0.010 more than 99% of the time.

Absolute calibration was subsequently achieved by comparison with hourly samples drawn from the sea-water supply to the thermosalinograph. The taking of the samples was timed to coincide with the SeaSoar surface turn, however, later comparisons between the time the bottle sample was drawn and the corrected SeaSoar time showed that the two rarely coincided. However, the seasonal mixed layer was sufficiently horizontally homogeneous that interpolating between SeaSoar profiles gave a good comparison with the bottle samples, except across fronts where the surface gradients were higher. These latter data were ignored in assessing the salinity correction.

The SeaSoar conductivity cell proved very stable for most of the cruise and straight offsets were applied for the first two deployments to bring the surface data within ±0.010 of the salinity samples. Across the Drake Passage salinity was corrected by +0.015 and for the first ice edge survey the correction increased to +0.024. On the second ice edge survey the conductivity cell displayed a previously unobserved, aberrant behaviour, oscillating wildly over a 0.04 salinity range. The cause of this is unknown but it was most likely some kind of fouling, possibly by krill, as it recovered eventually. The oscillation in salinity made it very difficult to identify offsets due to fouling, or to ascertain the relative calibration. Comparison with discrete salinity samples showed that the deployment began with a +0.024 offset, but after the conductivity cell started oscillating this was masked by a larger and more variable offset which appeared to jump randomly between two values about 0.030 apart. Together with the 0.024 offset, we estimate the correction to be 0.044±0.015. About half way through the deployment the conductivity cell appeared to recover and relative calibration of the potential temperature/salinity plots left a correction of only +0.010 to be made.

Oxygen. Oxygen is calculated for the Beckmann oxygen sensor attached to the CTD by

$$[O_2]/\mathrm{mL.L^{-1}} = \rho * C_{oxy} * \exp(-\alpha * T + \beta * P)$$

where

$$T = a * T_{CTD} + b * T_{oxy} \quad (\text{with } a + b = 1)$$

where C_{oxy} and T_{oxy} are the oxygen current and temperature values, and P is the CTD pressure. For deep CTDs, normal practice has been to choose 'a', the ratio between the CTD temperature (which has a short time constant) and the internal Beckmann unit temperature (T_{oxy}) to reduce hysteresis between down and up casts. The constants ρ, α and β are then chosen by a least squares fit to all available oxygen data from one or many CTD casts. This procedure did not significantly reduce the hysteresis when tried on the sensor in the SeaSoar, because (a) there was very little temperature variation

with depth south of the Polar Front and (b) the SeaSoar cycles through the oxygen gradient much more rapidly than a CTD.
A new procedure was therefore adopted on this cruise. The oxygen current was speeded up by the formula

$$C_{oxy}(t_0) = rawC_{oxy}(t_0) + \tau\,[rawC_{oxy}(t_1) - rawC_{oxy}(t_{-1})]/(t_1 - t_{-1})$$

where t_{-1}, t_0 and t_1 were successive 1-second values, and the oxygen temperature was ignored (b = 0). Several values of τ were tried until hysteresis was minimised. It was found that the value of τ depended on the depth of profiling, and two values which improved the fit were chosen as 15s for the Drake Passage section, and 10s for the ice edge surveys. The least squares fit to determine the remaining constants also could not be applied because (a) oxygen samples obviously cannot be drawn at the SeaSoar position, (b) the least squares fit equations tend to be ill-conditioned. This is so because both pressure and temperature tend to vary monotonically with depth, so the fit is sensitive to errors in bottle values caused by sampling problems or samples not carefully matched to the SeaSoar values in space and time.

Oxygen samples available consisted of (a) those drawn from CTD casts along 85°W between the first and second ice edge surveys and (b) two-hourly surface samples during SeaSoar runs. The latter were used to choose ρ with a typical value of α (-0.036), but exhibited rather wide scatter with some obviously bad sample values possibly caused by difficulties in sampling off the non-toxic supply. However, it had been noted that the percent saturation of the calibrated CTD oxygens correlated well with patches of high and low productivity, ranging from 1.04 (104%) in the major bloom, through 1.00 in smaller blooms to 0.98 where the bloom was absent. By choosing $\rho = 1.472$, $\alpha = -0.036$, these percent saturations were closely matched by the SeaSoar oxygens in and out of the bloom areas. The pressure coefficient β does not affect the fit at zero pressure.

To approximate the vertical profiles of oxygen, we made use of the samples drawn on CTD casts at 300m. T/S profiles from the CTD casts along 85°W were compared with SeaSoar T/S profiles from the 4-km gridded file (averaged over down and up casts) for the 85°W run during the first ice edge survey. As this survey crossed and recrossed the front, where the T/S relation changed rapidly, profiles could be matched within a few km of similar features. Applying ρ and α given above, with a nominal value of β = 0.00014, it was found that the SeaSoar values were too low. By adjusting the value of β to 0.0003965, the 300m values were brought in line with the sample values to within 0.02 ± 0.10 mL.L^{-1}, where 0.10 is the standard deviation over 10 samples. This is equivalent to a near-linear stretching of the oxygen values with pressure, because

$$\exp(\beta * P) = 1 + \beta * P$$

for $\beta * P << 1$.
In the thermocline, accurate calibration is impossible because of the oxygen sensor hysteresis. In summary, we expect that our calibrated oxygen values will be correct within about 2%, and are more likely to be low than high (if the 98% surface saturation values should be increased to 100%, say).
Chlorophyll. See section 3.24

Light. See section 3.12

3.10 Undulating Oceanographic Recorder (David Turner, Ian Bellan)

After the loss of the SeaSoar, the second ice edge survey was completed using the UOR loaned by the *James Clark Ross*. Five runs were completed, four of them of about 8 hours duration, which was the maximum battery life at this water temperature; the UOR tows are summarised in Appendix D. The second tow, along leg Y, was terminated after less than an hour, since examination of the data from the first tow revealed a problem with the temperature sensor. The UOR was recovered, the sensor replaced, and the tow restarted. On completion, a fault was found with the UOR conductivity sensor, although this did not affect the other sensors on this tow. Further attention by Ian Bellan solved this problem, and two further tows were carried out along legs X and YZ (86°W and 85°30'W), these being chosen to cover the western half of the survey as effectively as possible. After transfer to PStar, the UOR data was processed in a similar way to that from SeaSoar.

3.11 Discrete salinity measurements (Anne Morrison, Jane Read, John Allen)

The RVS Autosal salinometer (Model 8400A, sn 52395) was used routinely throughout the cruise to measure the salinity of samples drawn hourly from the thermosalinograph and from most CTD casts. The salinometer was operated at 24°C in a controlled environment of 22°C, and proved to be fairly stable. However, on day 345 it was extremely unstable, apparently a result of power surges in the 'clean' electricity supply, which cut out completely at 0840. Subsequently an uninterruptable power supply unit was used to ensure steady power to the Autosal, and very stable results were obtained. We suspect that some air was being drawn into the cell, leading to slow filling and the odd bubble, but because the coils were completely covered, the results were not adversely affected. Standard sea water ampoules (batch P120) were used to standardise at the beginning and end of each session, which generally consisted of 24 samples: this standardising was less frequent than is usually recommended, because we had a limited supply of standard sea water. We used the "Salinity Master" Excel spreadsheet to generate salinities from hand-recorded conductivity ratios.

We also experimented with the SIS Softsal (Version 1) data management package. This system acquires the conductivity ratio data directly from the salinometer to a personal computer, where they are converted to salinities by an undocumented method. The user can select the allowed standard deviation and standardise using standard sea water and substandards. The results are stored to datafiles with headers containing information on the status of the Autosal. In automatic mode the system requires that three consecutive measurements are within the selected standard deviation, with each single measurement being the average of ten consecutive readings which must be within another selected standard deviation. We found that this can sometimes mean that many flushings are required if the standard deviation allowed is small, and the occasional rogue value is occurring. This can be overcome by operating in manual mode, where the user selects which measurements to accept. The package also includes a post-processing facility which uses the control data (standard sea water, substandards) to remove zero order drift from the results. We found a few bugs in operating the package, but nothing insurmountable. The salinities achieved from

Softsal were compared with the results from "Salinity Master" for the same dataset, and found to be very close, within 0.0005psu.

3.12 Optics (Alison Weeks, Gerald Moore)

Seasoar

Optical sensors were installed on Seasoar to provide data for the interpretation of images from SeaWiFS (Sea viewing Wide Field of view Sensor), due to be launched in mid to late 1993; the spectral reflectance from surface Seasoar data will be used for early development of Southern Ocean bio-optical algorithms. In addition, the relationship between the optical properties of the ocean and the mixed layer depth (from spectral diffuse attenuation coefficients, K_d, K_u, derived from Seasoar data) will be investigated.

The data from the upwelling and downwelling irradiance sensors on Seasoar have been processed for the first time on this cruise. The sensors measured upwelling and downwelling radiance at seven wavelengths centred on the SeaWiFS bands (410, 443, 490, 520, 550, 635 and 665nm); additionally downwelling PAR and upwelling chlorophyll natural fluorescence (683nm) were recorded. The data from the seven SeaWiFs bands were used to derive reflectance, K_d & K_u, and the data from PAR to derive K_d. The data was processed separately from the other Seasoar sensors because it was necessary to pair adjacent up and down casts to eliminate the attitude change between up and down casts.

The data obtained from Seasoar were processed to obtain optical profiles from the upper 180m of the water column, the exact extent of the profile depending on light levels and water constituents. The Drake passage transect produced 287 profiles, and the first and second surveys produced 441 and 255 respectively. Of the sensors, good data were obtained from all but the 665nm sensors and the 683nm upwelling sensor; these sensors proved insufficiently sensitive. A number of problems were encountered in processing the data: first, that the sign bit was not passed to the Level-A, causing light levels at the surface to be apparently lower than those at depth; and second, the optical data were multiplexed whereas the CTD data were not. The CTD data comes from Seasoar in 1 second averages, but the light data comes in discrete samples within that second. Furthermore, the upwelling and downwelling lights are sampled out of phase. The maximum rate of climb or descent from Seasoar can be up to $4ms^{-1}$. The result of this is that reflectance is changed by ±10% in waters with high K_d when Seasoar has a high vertical velocity, and that K_d/K_u is changed when SeaSoar decelerates or accelerates. With some software effort these problems were resolved, and the entire SeaSoar data set was processed to produce reflectance, K_d and K_u.

Preliminary analysis has begun on the first SeaSoar survey. Near surface reflectance has been related to chlorophyll fluorescence, which had a simple linear quench function applied (section 3.24), removing some of the variance due to quenching, but not all. The relationship between reflectance and chlorophyll fluorescence (Table 3.4) shows the best agreement at 443nm, or the peak chlorophyll a *in vivo* absorbance, indicating a species assemblage with low accessory pigment levels for the levels of chlorophyll encountered.

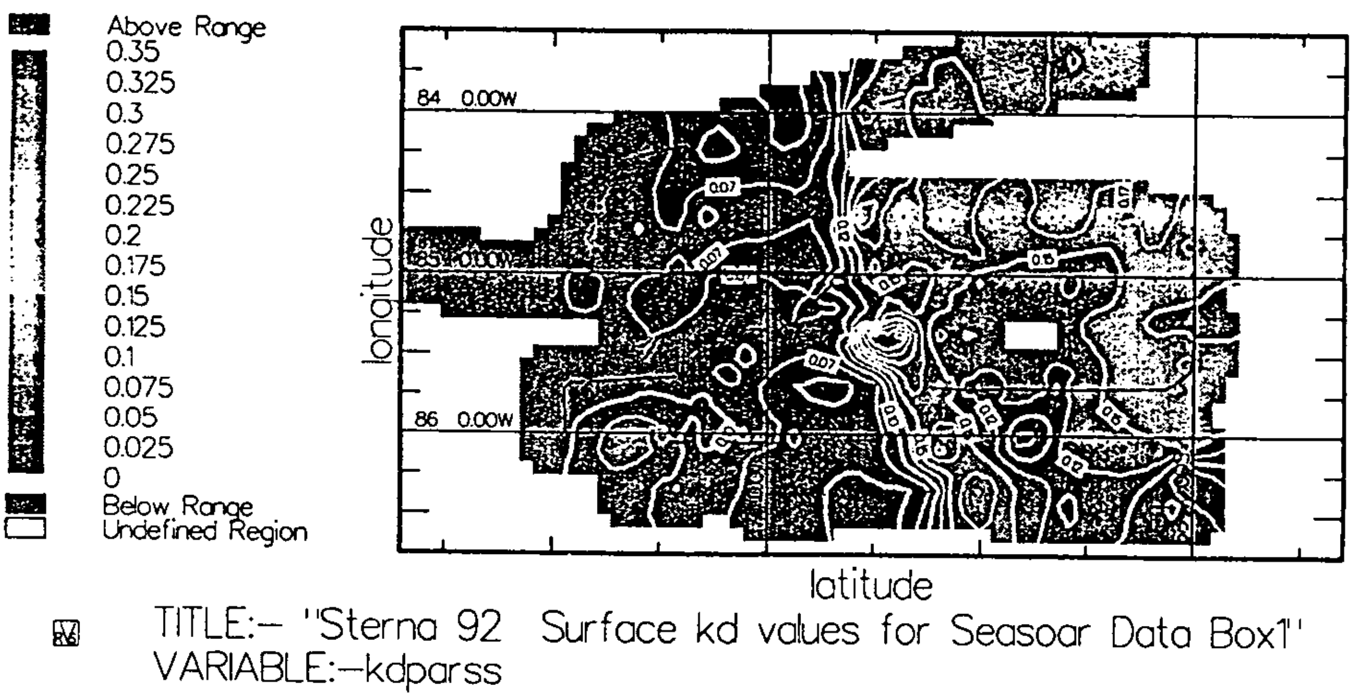
Table 3.4 Chlorophyll-reflectance relationships from SeaSoar data[a]

Wavelength/nm	r^2	α	β
410	0.48	1.31	-28.64
443	0.66	1.42	-19.16
490	0.53	1.31	-31.83
520	0.40	1.51	-34.41
550	0.01	-	-
632	0.04	-	-
665	-	-	-

a parameters quoted for the regression $\ln[chl] = \alpha + \beta * R$

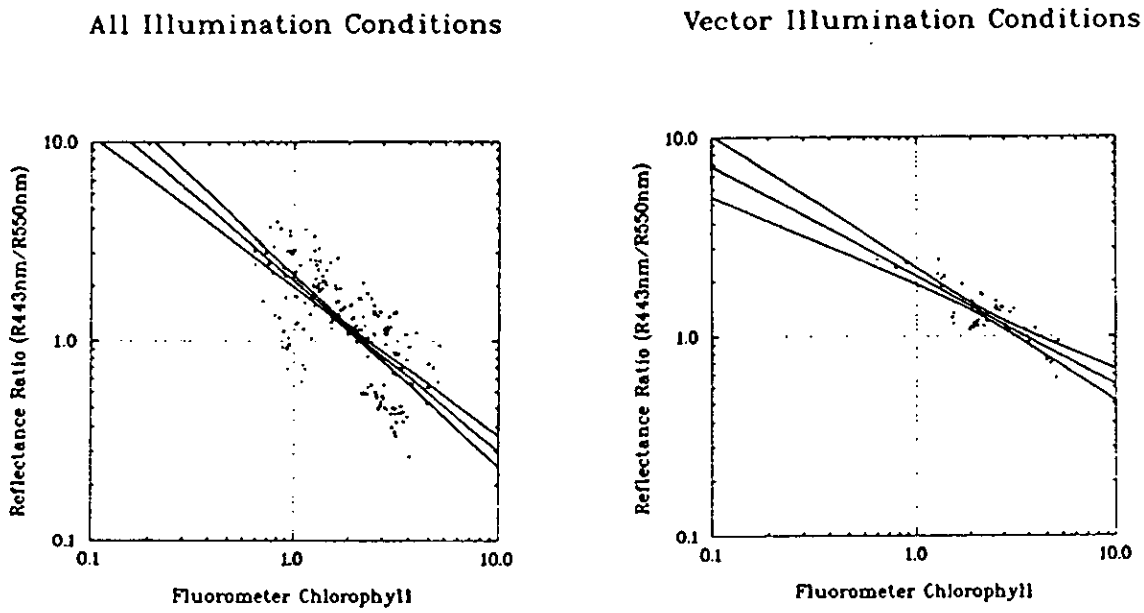
A comparison of surface K_d from the SeaSoar (Figure 3.2) with chlorophyll from the calibrated underway fluorometer (Turner Designs) from the first survey (Figure 2.1) shows that the parameters are highly correlated. The average optical depth north of the front is 14m, whereas to the south it is only 6m.

Figure 3.2 Diffuse attenuation, first survey



Chlorophyll and reflectance data were compared using the NASA CZCS (Coastal Zone Color Scanner) algorithm i.e. chl = $A.(R_i/R_j)^B$, where the wavelengths i,j are usually 443nm and 550nm for oceanic waters. The initial fit for the data with A = 2.63 and B = -0.88 ($r^2 = 0.42$) was promising; however the exponent B was higher than that expected value of -1.27 (Figure 3.3). A comparison against solar altitude showed little improvement. When the data was restricted to those occasions where there was vector illumination (i.e. clear skies), as determined from long wave radiation, and the solar altitude was greater than 70° the resulting exponent was -1.18 (A = 3.11, $r^2 = 0.79$) within error limits of the standard result (Figure 3.3). The scale factor is much higher than the expected 0.51, indicating a possible underestimate of chlorophyll, and differences in phytoplankton biology. The use of the standard NASA retrieval algorithm would result in an underestimate of chlorophyll in remote sensed images.

Figure 3.3 Chlorophyll-reflectance ratio relationships



Work is in progress relating the above water light field to the data, by comparing data from the hemispherical and cosine par detectors. Fully calibrated chlorophyll which will be needed to complete the algorithms is in preparation (section 3.24). The results to date indicate that the SeaSoar light sensors have provided a valuable data set to aid interpretation of Antarctic remote sensing.

Lightfish.

Lightfish was deployed to provide sub-surface irradiance measurements at 6 wavelengths for the development of multi-spectral reflectance algorithms for phytoplankton biomass for SeaWiFS. It was also used to compare the horizontal scales of variation of ocean colour, phytoplankton biomass and physical structure. By conducting a spatial survey in an area of 200km^2 where the phytoplankton biomass is heterogeneous, it will be possible to calculate the loss of accuracy of SeaWiFS by the averaging effect of the pixel dimensions (1.1km local coverage or 4km global coverage).

The data from the upwelling and downwelling irradiance sensors have been logged for the first time via a Level A, along with the other underway parameters. The parameters derived from these sensors are reflectance at 6 wavelengths (410, 443, 490, 520, 550, and 670 nm). Lightfish was deployed for 21 days during the cruise (Appendix E).

The NASA CZCS algorithm for phytoplankton retrieval was applied to uncalibrated fluorescence (Turner) data during the cruise, and showed encouraging results, with typical r^2 values from .5 to.75. Surface plots of reflectance ratios $\log_{10}(R_{443}/R_{550})$ are shown in Figure 3.4, and clearly correlate with the areas of high and low chlorophyll (high chl = low $\log_{10}(R_{443}/R_{550})$). We anticipate some exciting work comparing the reflectance ratio values from Lightfish with other underway parameters sampled on the cruise, such as pCO_2, TCO_2, and HPLC pigment measurements.

A number of problems were encountered with deployment and data acquisition of Lightfish. Firstly, as the portable winch which was situated on the starboard side of the aft deck had no slip rings (despite timely requests to RVS) it was necessary to disconnect Lightfish on every deployment, and every time the depth was adjusted. When Lightfish was disconnected, the Level A had to be reset, sometimes repeatedly. A slip ring winch would have resulted in an uninterrupted data flow between deployments. A second problem was that the ships wiring in the four junction boxes used needed checking and tightening. Other problems with Lightfish concerned the design of the casing around the optical filters, and with the sensitivity of the sensors: these will be addressed at Southampton.

It would be useful to be able to check the linearity and calibration of both the SeaSoar and the Lightfish sensors on board, by using a calibrated light source and a series of ND filters that could be mounted in a Gershun tube.

Diffuse Attenuation (K_d) from CTD casts.

K_d(PAR) was calculated on CTD profiles to enable optical depths of 100, 50, 25,10,1 and 0.1% to be determined for obtaining water for primary production experiments.

The resulting values are shown in Table 3.5 (for full details of CTD stations see Appendix B).

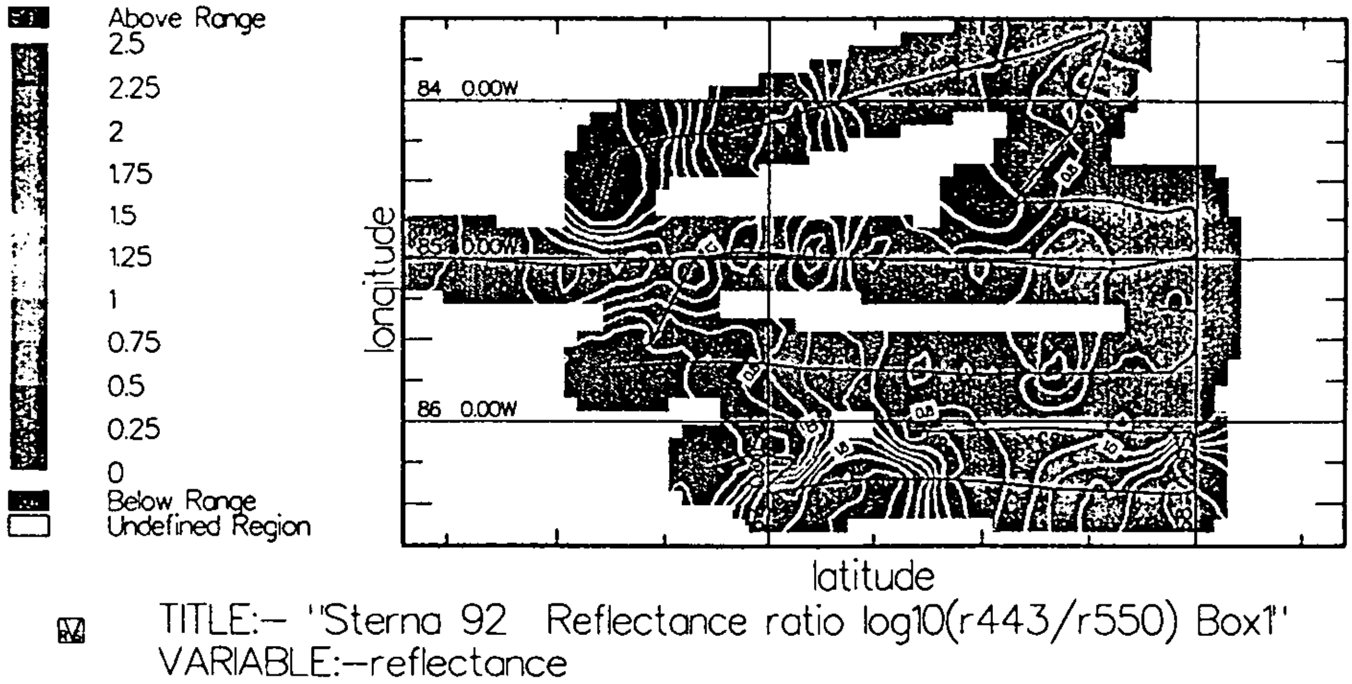
Table 3.5 Diffuse attenuation values from CTD casts

Station[a]	K_d	$r(K_d)$	K_u	$r(K_u)$
12198p	-0.08857	-0.636	b	b
12200p	-0.07393	-0.975	-0.08039	-0.885
12201p	-0.04908	-0.995	-0.05612	-0.987
12202p	-0.04646	-0.992	-0.04835	-0.977
12203p	-0.12164	-0.995	-0.13197	-0.993
12204p	-0.07612	-0.993	-0.08583	-0.994
12205	-0.06934	-0.984	-0.06648	-0.845
12206	-0.09345	-0.424	b	b
12207p	-0.06709	-0.990	-0.07531	-0.982
12208	-0.07451	-0.980	-0.09006	-0.983
12209	-0.04122	-0.994	-0.04175	-0.971
12210	-0.08549	-0.751	b	b
12211p	-0.09685	-0.993	-0.10855	-0.995
12213p	-0.05118	-0.983	-0.05422	-0.917
12214	-0.04607	-0.975	-0.05802	-0.961
12215	-0.04016	-0.993	-0.05438	-0.991
12216	-0.03985	-0.991	-0.06344	-0.828
12217	-0.05448	-0.993	-0.06336	-0.955
12218	-0.06541	-0.951	-0.06022	-0.612
12219	-0.06105	-0.923	-0.07438	-0.978
12220p	-0.11298	-0.968	-0.09884	-0.997
12221	-0.15623	-0.988	-0.19077	-0.978
12222	-0.15401	-0.966	-0.16003	-0.984
12224p	-0.15625	-0.99	-0.17855	-0.990
12225p	-0.12049	-0.995	-0.16295	-0.897
12226p	-0.1192	-0.998	-0.12471	-0.997
12227p	-0.04602	-0.998	-0.05386	-0.997
12230p	-0.04779	-0.999	-0.05045	-0.999
12234p	-0.06275	-0.999	-0.07290	-0.994

a productivity stations are indicated by the suffix p

b insufficient upwelling light for determination of K_u

Figure 3.4 Reflectance ratio, first survey



3.13 Expendable bathythermographs (John Allen, Bill Miller)

The Bathy Systems Inc. XBT program version 1.1 was used on a S.E.S.U. (Hydrographic Department) supplied deck unit to record XBT launches. The XBT probes were launched from a Sippican Corporation hand launcher belonging to RVS. The preferred launch position was the stern quarter more in the lee of the wind. The connection point located in the Bosun's store was used since it provided the best shelter whilst preparing the launcher. The XBT program on the deck unit converted the voltage drop across the probe into resistance and thence to temperature using the manufacturers algorithms. In addition the XBT program identified critical turning points on the temperature v depth trace and transmitted the information in batches to the GOES satellite (part of the GTS network). The XBT data was transferred to the RVS level A by a 'walknet' 3.5" disk as no hard wiring existed between the XBT deck unit and the RVS firmware. The transferred data took the form of a string of ASCII temperature values recorded at 10Hz. This system is both cumbersome and time consuming, and it is suggested that a level A be programmed to receive ASCII coded hex data direct from the XBT controller in real time.

The probe depth (D) was calculated from a 2nd order time of flight (t) polynomial supplied by the manufacturers of the probes, Sippican Corporation.

For T7 (760m) probes $D = 6.472t - 0.00216t^2$
For T5 (1800m) probes $D = 6.828t - 0.00182t^2$

Several authors have suggested that these polynomials are poor and have put forward alternatives. Seven XBT's on the northward transect along 88°W were coincident with CTD stations, and further work will include the assessment of alternative fall rate equations. However, initial comparison of CTD and XBT temperature traces did not suggest any problem existed with the manufacturer's equation.

During the bulk of the cruise five T7 and three of the deeper T5 XBT probes were launched at various points of interest. These were:

xp198012 in 415m of water off the Falkland Islands shelf, partly as an equipment test and partly to obtain a temperature profile during the ADCP calibration tracks.

xp198016, 017, 019 deep XBT T5 drops during the SeaSoar transect across Drake Passage to examine the deeper temperature structure. Copper wire found around the SeaSoar cable discouraged further XBT launching during SeaSoar tows.

xp198020, 021, 022, 023 XBT's dropped alternately with CTD casts on the east - west transect along 65° S.

The other 59 XBT probes, all T7s, were launched on the transect up 88° W at the end of the cruise. Details of all successful XBT launches are given in Appendix H. Gaps in the sequential numbering indicate probe failures for one or more of the following reasons:

(i) Insulation leakage During periods of poor weather, when launching from the rear of the afterdeck was felt to be unsafe, the probes were launched from just outside the Bosun's workshop. Under such circumstances the ship was generally turned into the wind when launching, however the shape of the superstructure was such that a considerable quantity of the copper wire was blown over the afterdeck as it spooled from the launcher resulting in short circuiting of the copper wire.

(ii) Premature and delayed launching of the probe This generally resulted from poor use of radios when communicating between the main lab and the afterdeck.

(iii) Thermal shock The first box of T7 XBTs were brought out of the hold and stored at too high a temperature before being launched into sub-zero water temperatures. Two probes are believed to have failed for this reason.

A fourth, and more serious problem encountered with the XBT probes was that of wire stretch. The thin, two core, copper can become stretched during the descent of a probe due to snagging at either the spool in the launching canister or that in the probe itself. This has the effect of increasing the resistance measured at the deck unit and hence recording erroneously high temperatures. Once the wire has stretched it can of course never recover and if detected on a temperature trace, any record below that point of detection should be disregarded. Occasionally wire stretch was obvious, however, more often the wire stretch would be very gradual and a temperature would look good: in such cases detailed comparison with known T/S curves for the area was required in order to identify erroneous temperature profiles.

3.14 MacSat satellite receiver (John Allen)

This cruise saw the first use of this latest version of Newcastle Computer Services satellite image grabbing software and hardware on an RVS ship. As with the previous version, it can only be used on board ship with an omni-directional aerial which can receive infrared (IR) and visible spectrum images from polar orbiting satellites. The major change with the new version concerned hardware as virtually all the receiver switching was software driven via a Dartcom micro-controlled interface box and an Apple Macintosh standard SCSI connection. The requirement for a special interface board to be inserted into the Macintosh has disappeared and an LC or more powerful Macintosh could be used as a platform for the software. In addition, the new software contained several useful new image processing tools; of particular merit were the image resampling and the auto contrast options. The most welcome change was the auto-save option, not for the reason that its name suggests, but that with this option switched on both the IR and the visible images were recorded simultaneously. A major disappointment, however, was the new geographical overlay tool, which, despite great care being taken to input our position correctly, failed to be of much assistance at these high latitudes. The suggested overlay was simply not believable and our doubts were generally confirmed when on odd occasions land was identified on an image.

Unfortunately cloud cover, as expected at these latitudes, prevented any useful thermal images of fronts being made during the cruise. However, ice extent could be identified at times and the tracks of particular storms were followed. Only the long near overhead passes were worth receiving as others were not geographically relevant and gave poor reception.

Little attempt was made to pick up other than NOAA satellites as it was not clear how old our prediction data was for other polar orbiting platforms. NOAA's 10, 11 and 12 were successfully received during the cruise. Table 3.6 lists all images that have been archived on 3.5" disk. The image format still takes up considerable space and compression routines do not help very much. A shortage of disks forced the making of only one copy of each image and only images that could be located geographically and showed significant cloud free areas were archived.

Table 3.6 Archived MacSat images

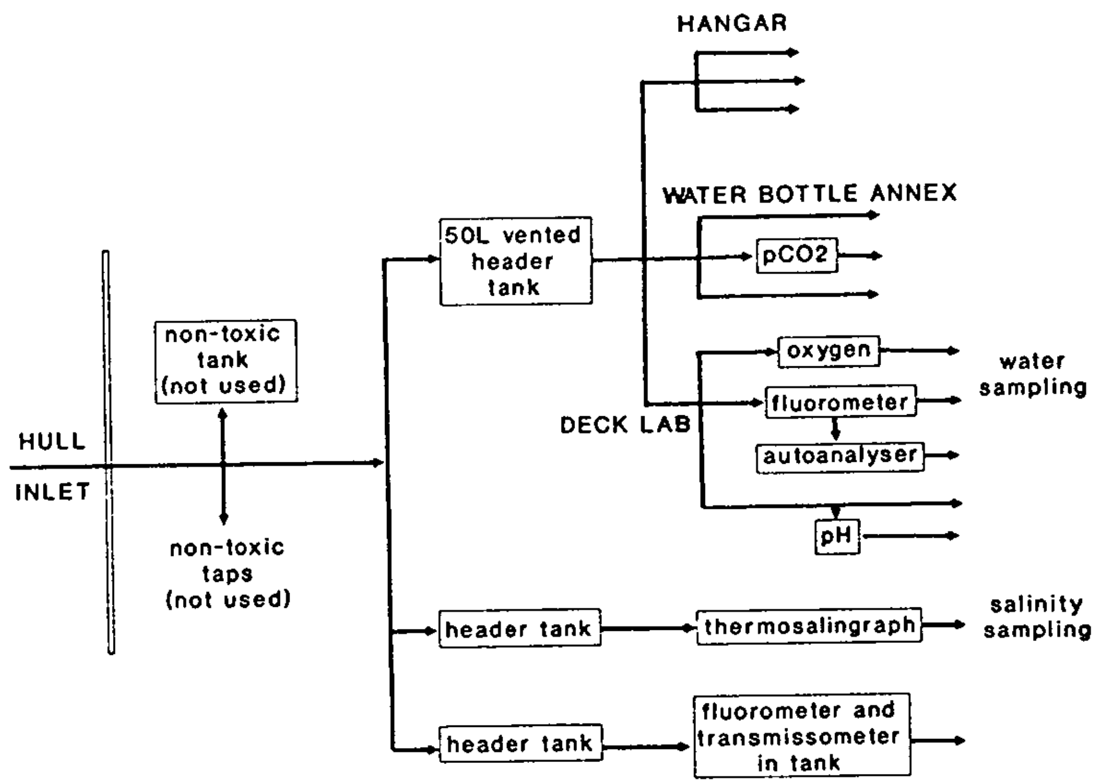
Date	Time	IR	Visible	Disk no.
11/11/92	23:26z	yes	yes	198001
14/11/92	20:33z	yes	yes	198002
15/11/92	11:31z	yes	yes	198003
17/11/92	04:28z	yes	yes	198004
17/11/92	06:08z	yes	yes	198006
18/11/92	03:52z	yes	yes	198005
18/11/92	05:56z	yes	yes	198007
19/11/92	10:05z	yes	yes	198008
23/11/92	06:36z	yes	no	198009
26/11/92	12:38z	yes	no	198009
1/12/92	12:00z	yes	no	198010
1/12/92	12:34z	yes	no	198010
2/12/92	01:37z	yes	yes	198011
2/12/92	08:13z	yes	yes	198012
2/12/92	03:58z	yes	no	198013
3/12/92	16:58z	yes	yes	198014
5/12/92	09:27z	yes	yes	198015
5/12/92	12:04z	yes	yes	198016
6/12/92	22:53z	yes	yes	198017
7/12/92	23:15z	yes	yes	198018
8/12/92	11:42z	yes	yes	198019
8/12/92	13:25z	yes	yes	198020
9/12/92	11:20z	yes	yes	198021
9/12/92	20:34z	yes	yes	198022
10/12/92	10:57z	yes	yes	198023
10/12/92	11:40z	yes	yes	198024
10/12/92	12:39z	yes	yes	198025
11/12/92	10:37z	yes	yes	198026
11/12/92	12:17z	yes	yes	198027
12/12/92	07:52z	yes	yes	198028
12/12/92	11:54z	yes	yes	198029

3.15 Non-toxic supply (David Turner)

The non-toxic intake is drawn from approximately 4m below the waterline, using a pump with a nominal throughput of 200L.min^{-1}. This supply is fed to a header tank on the hangar top through 2" stainless steel piping, and thence to the non-toxic taps in the laboratories. Since a debubbled non-toxic supply was required for this cruise, the normal non-toxic taps were not used: instead the non-toxic supply on the hangar top was fed directly into a black plastic header tank (nominal volume 50L) with a headspace connected to the atmosphere. The (debubbled) outlet from this tank was then piped directly to the laboratories: hangar (3 taps); water bottle annex (3 taps);

deck laboratory (3 taps). We are grateful to Tony Poole for installing the necessary pipework in time for the cruise. The RVS surface system in the hangar (thermosalinograph, transmissometer, fluorometer) was fed by two further debubbling header tanks connected in parallel. The arrangement of the supply to the various on-line instruments is shown in Figure 3.5.

Figure 3.5 Non-toxic water system



During most of the cruise, a regular sampling schedule from the debubbled supply was maintained. The sampling periods are detailed in Appendix G, where it can be seen that sampling was suspended on days 320-321 (Potter Cove), days 326-327 (first *James Clark Ross* rendezvous), and days 342-343 (final *James Clark Ross* rendezvous). Samples were taken for chlorophyll (section 3.23), phytoplankton species (section 3.23), oxygen (section 3.21), alkalinity (section 3.19), and ammonium (section 3.22). Salinity samples (section 3.11) were drawn from close to the thermosalinograph. From flow rate measurements, the water was estimated to take 2 minutes on average to travel from the hull inlet point to the deck lab sampling position: this delay was taken into account in synchronising water sampling with SeaSoar surfacing. Salinity samples (section 3.11) were drawn from close to the thermosalinograph.

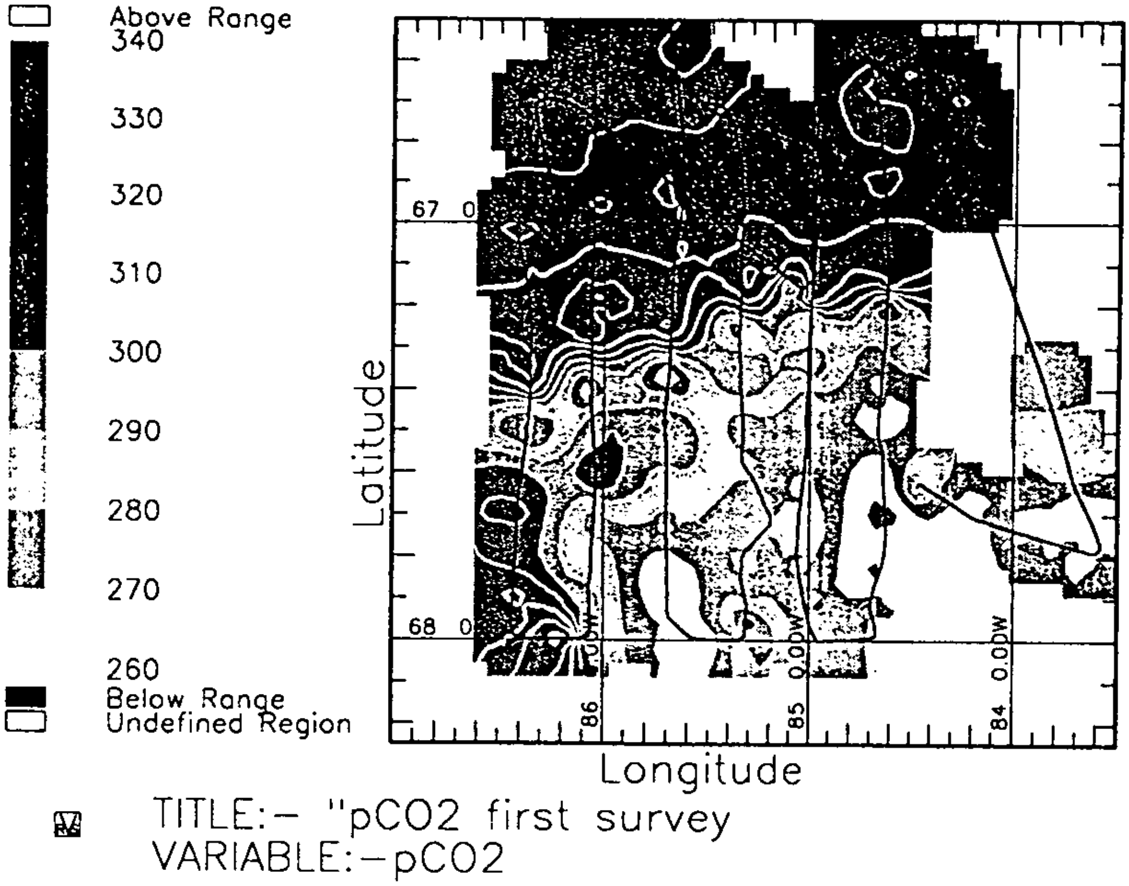
3.16 pCO_2 (Jane Robertson)

pCO_2 was measured using a gas chromatograph and showerhead equilibrator. Air for the GC system was supplied using a compressor in the lab and hydrogen through the piped gas supply into the deck lab. The hydrogen line was pressure tested before leaving Stanley and was found to be leak free, but subsequently several leaks were found on the valve and tap fittings in the gas bottle store. It is not apparent whether this was the result of vibration from the ship or the change in temperature experienced as the ship went south. The leaks did not set off the gas alarm in the gas bottle store, which could have been due to the considerable draught in the store as both doors were commonly kept open and/or due to a fault in the alarm itself. Subsequent to this event both doors were kept closed and a faulty electrical connection on the alarm repaired. It is recommended that checks are made periodically on both the gas supply lines and the respective alarms.

The equilibrator was placed in the water bottle annex as this kept it close to both the de-aerated non-toxic supply and the GC in the deck lab. The water bottle annex was kept cold, with auxiliary heating switched off enabling us to keep the temperature in the equilibrator as close as possible to the *in situ* temperature. The pCO_2 system required a few modifications as originally it was designed to operate on one continuous run of lab bench. After some soldering by the PSO the equipment was joined up around a corner. The programme for the system was written on board with an original cycle time of 17 mins which was reduced to 13 mins following the first survey. During each cycle two measurements of the pCO_2 in the water were made bracketed by standard and marine air measurements. Marine air was approx. 355 ppm ± 2 ppm as measured throughout the cruise with no discernible change with latitude, which is as expected in the Southern Ocean. The equilibrator caused some problems by filling up with water, which was not draining away fast enough to cope with the flow. This was partially solved by re-machining parts of it, although it still required occasional attention. There was an average increase in temperature of 1.5° in the equilibrator from *in situ* temperature, which is four times that experienced on previous (temperate water) BOFS cruises. After about one week of constant use the two motors on the system sheared and had to be replaced with spares. The spares worked successfully with no further problems. The system was working almost continuously on surveys and the final transect, giving a pCO_2 value approximately every 6 minutes.

Preliminary calibration with a single standard value was done on board to provide data for the first survey to be contoured. The contour map (Figure 3.6) shows considerable structure similar to chlorophyll and pH distributions, and related to the front that was part of the survey area. This data is only preliminary and further calibration using a running standard and temperature corrections will be necessary before the data is ready to go onto the Bidston database. These corrections and changes should be made in the next few months and the data will be sent to Bidston by the end of April along with data from a further cruise in the Southern Ocean in Feb/March 1993 (Discovery 200).

Figure 3.6 pCO_2, first survey



3.17 Total CO_2 (Sean Debney, Jane Robertson)

Total CO_2 is a measurement of dissolved inorganic carbon (DIC) and represents carbonate, bicarbonate and un-ionised species of CO_2. A thermodynamic relationship exists between TCO_2, pCO_2, pH and alkalinity and it was an aim of this cruise to determine all four parameters sequentially at sea for the first time.

The analytical system consists of two main components, the extractor unit and coulometric detector. A sea water sample is filled from the non toxic supply and is fed under gravity to a calibrated pipette. This is discharged into a stripping chamber where orthophosphoric acid quantitatively converts the DIC to CO_2. The CO_2 is purged by a nitrogen carrier gas flow into the reaction cell where it is coulometrically titrated to an end point.

It was originally intended to measure TCO_2 in continuous underway mode to parallel pCO_2 and pH but several major problems made this impossible. The coulometer chemicals and the WOCE TCO_2 standards of known carbon content were stored in the deck lab chill store during transit from the UK. At some time during this period the temperature fell from the nominal 10°C to below 0°C as was evident from the shattered remains of the standard storage bottles. The standards were stored in 500mL Pyrex bottles and well insulated with polystyrene suggesting that the temperature remained below 0°C for a significant period. Apart from the financial loss, which was in excess of £500, the loss of standards meant that the quantity and quality of the science originally proposed for this cruise was completely disrupted. The coulometer chemicals would also have been subjected to freezing temperatures and it is not certain what effect this had on the solutions. The chemical suppliers were contacted once freezing was suspected, and they explained that the chemistry of the solutions may be sensitive to such a temperature change. These factors forced a change to discrete sampling from the non toxic supply, and the analysis of up to 5 replicates of each sample to give a measure of confidence in analytical precision of the technique. There were additional periods of system downtime due to various hardware problems in the extractor unit. These included the failure of two valves, contaminated sample lines, defective glassware and degassing of the water in the sample bottle, the latter being solved by the employment of an insulation jacket.

A continual problem throughout the duration of the cruise was the intermittent electrical spikes and surges from the 'clean' supply. This was also experienced by other operators in the deck lab, main lab and winch control. It is difficult to determine the absolute effect of this variability in supply on the performance of the coulometer, though there were definite periods when large surges adversely affected several other pieces of instrumentation simultaneously. The synergistic effect of substandard chemical performance and variability in power supply undoubtedly reduced the sensitivity and stability of the coulometer. This was manifested in poor intra sample reproducibility, high unstable blank values and premature demise of the reaction cell.

In discrete mode the system allowed, at best, a sample throughput of twenty samples a day, which seriously reduced the spatial resolution of surface mapping compared with that achievable in underway mode. Despite this, the initial intercalibration of raw TCO_2, pCO_2 and pH data from survey one shows no major offset, giving some confidence in the accuracy of all three measurements made on this cruise. The forced employment of a discrete sampling regime, although vital for quality control under the imposed conditions, did not provide a large number of data points for accurate contouring. The plot included, however does indicate the delineation of TCO_2 across the front which compares favourably with contouring plots of pCO_2 and pH. (TCO_2 data points used in contouring are marked on the plot). All TCO_2 analyses have been entered on the 'underway' spreadsheet, however the data have to be recalculated to take into account calibration of the pipette volume and corrected thermosalinograph data. These data will therefore not be ready for inclusion on the BOFS database at BODC until the summer of 1993.

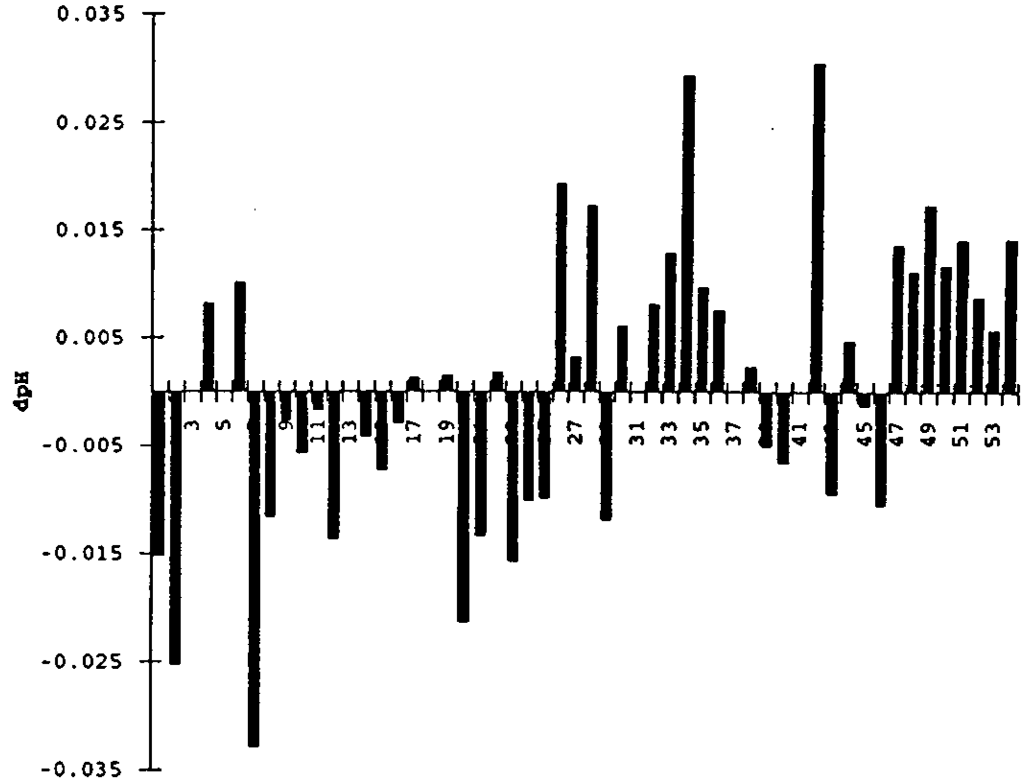
3.18 pH (Richard Bellerby)

As a master variable, pH exerts an important control on geochemical and biological processes in aquatic systems. Seawater pH reflects the status of the carbonate system which provides the major short term CO_2 buffer. The carbonate system can be quantified by measuring any two of the parameters pH, pCO_2, TCO_2 and alkalinity. It was the aim of this work to accurately measure pH and in so doing validate a novel spectrophotometric method for the on-line, real-time measurement of seawater pH. Seawater pH, on the total hydrogen scale, was measured using a continuous, on-line multi-wavelength spectrophotometric method which utilises the acid-base absorption properties of the sulfonaphthalein indicator phenol red. Simultaneously, an on-line potentiometric system was available to compare methods on the same seawater.

pH was measured at temperatures some 20-25°C above *in situ*, and require correction for *in situ* salinity. Preliminary calculations have been performed at selected times in the first survey: coincident pCO_2 and TCO_2 measurements were used to calculate pH, and the result compared with the measured spectrophotometric pH. The results should be treated with some caution, since all three parameters require further salinity and/or temperature corrections. The residual pH, the difference between measured and calculated pH, is presented in Figure 3.7. The mean residual for all analyses was 0.01pH units with a standard deviation of 0.007pH (n=48). This reduces to 0.007 ± 0.005pH when only those values with absorption standard deviation less than 0.001 are used (n=24). Continual analysis of discrete samples have shown a precision of about 0.005 pH units throughout the cruise. Contour plots of raw pH data for surveys 1 and 2 show distinct areas of high and low pH which correlate well with features on the survey plots of pCO_2 and temperature.

Data from the traditional potentiometric method experienced large jumps in electrode potential observed on other cruises. This has previously been attributed to electrical noise from the ship's motion through the water, passing through the on-line system, and the ship's electrical supply. Maintaining a constant temperature between the pH buffers and the seawater also proved difficult. Spectrophotometric measurements in areas with high chlorophyll levels were affected by the particulate load of the seawater. High standard deviations were observed in these regions possibly due to settling of detritus whilst the sample is held in the flowcell for analysis. Increasingly throughout the northward transect, small bubbles were seen to become entrapped in the flowcell where previously they had passed through. This was thought to be due to organics coating the inner walls. The system was flushed with Decon to no avail, and then with nitric acid, which worked only in the short term. It is suggested that the on-line seawater should be filtered prior to analysis to reduce the particulate load of the supply and that regular flushing with hydrogen peroxide may alleviate the problem of bubble trapping.

Figure 3.7 pH offsets



3.19 Alkalinity (Susan Knox)

Alkalinity was measured by photometric titration of seawater with hydrochloric acid in a procedure developed at Plymouth Marine Laboratory. The indicator was bromophenol blue, chosen because its pK value lies beyond the bicarbonate equivalence point, the area of the titration curve of interest. The absorbance was measured at 582±2nm in a 100mL sample bottle: the hardware is based on a standard oxygen endpoint detector, modified for measurement at the appropriate wavelength.

The alkalinity procedure was fully automated until the Metrohm burette irretrievably broke down. The only other burette on board was attached to the oxygen titration system and so had to be shared between the two analyses. Unfortunately the replacement burette had different external control connections, with the result that alkalinity titrations had to be run by a semi-manual procedure. As with the oxygen titration method, a rapid and precise photometric measurement was necessary, this time at each addition of acid, in order to obtain a good titration curve. Initially all the problems that beset the oxygen analysis (section 3.21) applied to the alkalinity titration, especially degassing which was exacerbated by the release of carbon dioxide as the sample became more acidic. By moving the equipment to a cold area (the hangar) the degassing was effectively subdued, as was the analyst in these spartan conditions. Thereafter it became apparent that the movement of the ship, either itself or in its effect on the water in the water jacket was causing the light signal to vary significantly so that no reliable alkalinity data was forthcoming. Several series of samples were analysed when the ship was hove to and at quiet intervals but the amount of successful data was very scanty.

The alkalinity procedure itself has been shown to work but more modification is necessary before it can be used at sea.

3.20 On-line oxygen (Susan Knox)

On-line oxygen was measured using an Endeco type 1125 pulsed dissolved oxygen system loaned by Southampton University Department of Oceanography. The oxygen sensor comprises a Clarke type polarographic cell containing a silver anode and a gold cathode surrounded by electrolyte and covered by a Teflon membrane. Two such sensors were mounted in a perspex container through which the bubble free non-toxic supply flowed at a rate of 2 litres per minute. The sampling rate was micro-processor controlled and was set to once every 5 minutes. Four sensors were provided and each had been pre-calibrated in low temperature seawater at Southampton University. To provide extra calibration points, samples were taken from the sensor container outlet every 2 hours and analysed by Winkler titration. A more detailed analysis of the calibration data is necessary before absolute oxygen values can be extracted from the Endeco output.

At the start of the cruise the pair of sensors did not track one another, with one sensor steadily drifting downwards and the other appearing to respond as expected. A replacement electrode with fresh electrolyte and a new membrane also showed the same downward drift . At first this was thought to be due to the low temperature of the seawater, about 1°C, but the same drift was also seen in distilled water held at ambient laboratory temperature. A closer inspection of the sensors revealed the gold cathode to be heavily tarnished. A light application of crocus paper removed the film and thereafter the electrodes performed satisfactorily. As a result of the delay in getting the sensors to work continuous oxygen data is available from one electrode for the second box survey and from two sensors for the 88°W transect north.

3.21 Oxygen titrations (Susan Knox)

Discrete oxygen samples were taken from the non-toxic supply at 2 hourly intervals throughout the cruise, and from Niskin bottles on selected CTD casts. These samples were analysed by Winkler titration with a photometric endpoint detection using equipment loaned from Queens University, Belfast.

At first the system was unworkable because of air leaks in the Metrohm burette. These were traced to the washers which proved to be incompatible with the tube terminations. Once the washers were removed the system became airtight and usable. The next area of concern was the endpoint detection. It was often very difficult and at times impossible to get an endpoint due to the degassing of the sample as it warmed up from its sampling temperature of 1°C or less to the laboratory temperature of 23°C. Minute gas bubbles coated the sides of the sample bottle and floated free in the solution causing interference with the light path. Neither allowing the sample to warm to ambient temperature before analysis, nor filling the water jacket with ice cold water helped in any way. The eventual solution was to move the equipment to a cold environment (the water bottle annex) with an ambient temperature near that of the sample. This solved the gas bubble problem, and in doing this the water jacketed measuring cell was sited fore and aft rather than athwartships as it had been in the laboratory. This reduced the slopping of the water across the light path whenever *Discovery* rolled, which the new ship has a marked tendency to do, and reduced the noise on the photometer output.

The oxygen titration data available at the end of the cruise require further correction for (i) the standardised thiosulphate concentration, and (ii) the correct calibrated bottle volumes, which were not available from Belfast during the cruise. The Antarctic surface waters were generally saturated with respect to dissolved oxygen and the CTD casts in this area showed the presence of a very well marked oxygen depletion layer below about 200m. Along the 88°W transect going north the oxygen minimum layer occurred at 1500m.

3.22 Nutrients (Bob Head)

A Chemlab based autoanalyser system (ex North Sea Community project and Charles Darwin cruises 46/90 and 47/90 of the BOFS programme) was used to measure concentrations of nitrite, nitrate, phosphate, silicate and ammonium. The methods used were the standard wet chemical methods developed at PML. The colorimeter outputs were logged to a Siemens chart recorder and a level A interface. The autoanalyser system was used in an online mode with the seawater input being taken from the Turner designs fluorometer outflow (section 3.23): the fluorometer output was logged to the same chart recorder to enable visual comparison and fluorescence and nutrient changes). Change-over to discrete sampling mode was effected by a three way valve in the autoanalyser sample input line to enable the input of both calibration standards and discrete samples from CTD casts or productivity experiments (sections 3.31 and 3.32). Nutrient calibration was effected by daily running of standards dissolved in low nutrient seawater (collected at Berkeley Sound, Falkland Islands) until a constant plateau was attained. Milli-Q water was used as a reagent blank.

Discrete sample analysis required human autosamplers, running each sample for 4 minutes interspersed with a 1 minute wash in low nutrient seawater. Calibration was effected by running standards in the same way. Ammonium samples were run manually using 10mL seawater samples in test tubes, addition of reagents and colour development in the dark for 3 hours. The sample was then introduced into the flowcell (minus the debubbler) with a 20mL syringe. Optical densities were recorded as chart units. The main bulk of samples was composed of the CTD section across the working area on 85°W and samples from productivity experiments (sections 3.31 and 3.32). Workup of the discrete data should be completed in approximately 6 months. Work up of the on-line measurements will be undertaken by BODC.

In the working area typical maximum nutrient values were 35μm nitrate, >50μm silicate and 2μm phosphate. Ammonium values were low with maximum values being of the order of 0.6-0.7μm. In the high bloom areas during the two surveys nutrient reduction could be observed corresponding to changes in chlorophyll fluorescence. Some small surface ammonium increases could be detected in areas of intense krill swarms. The high values of nitrate and silicate were an analytical problem which needed to be resolved as the system was set up initially for nutrient levels encountered in the North Atlantic. Nitrate and silicate concentrations were physically reduced by incorporating a Milli-Q diluent line in a ratio of 1:4. Due to the set up of the analyser with 50mm flowcells it was observed that for both these analytes that there was a non-linear relationship between concentration and output. Concentrations of nitrate and silicate will therefore have to be calculated using a nonlinear curve fit. The main reason for non linearity at high concentrations was assumed to be the provision of a 50mm flowcell, use of a 15mm cell would have improved the precision of calibration values. During the cruise the ammonium channel gave trouble due to precipitation of reagents in the analytical line. The reason for this was unclear, but it was certainly due in part to the low water temperature. There was also contamination of the reagents in the deck lab which manifested itself as a steady upward drift. Due to all these factors, ammonium was measured manually as described above, with samples taken hourly from the non-toxic supply.

The Chemlab system has now been around for a number of years and is really overdue for refurbishment and updating. As the autoanalyser is a multi-user piece of equipment, there is a need for a manual together with parts lists and suppliers to be written and supplied with the equipment as not all users are expert in automated analysis. Hopefully in the near future some funding can be made available to update a number of the components to enable continued use and better reproducibility.

3.23 On-line fluorescence, chlorophyll, and phytoplankton sampling (Bob Head, Bill Miller)

On-line chlorophyll fluorescence was measured with a Turner Designs model 10-005 rack mounted fluorometer (kindly loaned by M J Fasham of the Rennell Centre) fitted with a 10-020 high volume flowcell with a debubbled seawater input at a flowrate of 3 litres per minute. The fluorometer output was recorded on a Siemens chart recorder and also logged to a level A interface. In addition, a fluorometer (sn 229) and transmissometer (sn 99D) were incorporated in the RVS 'surface' system in the hangar (see sections 3.4, 3.15) These were logged by the same system as the thermosalinograph (section 3.4), and ran virtually continuously through the cruise, outputting their data in SMP format to the level B system. There appeared to be no problems communicating directly with level B. During mobilisation a communication error with the transmissometer and fluorometer Rhopoint modules was indicated. This was found to be a software error and was soon rectified. At present, the FSI and Rhopoint modules communicate through separate ports on the PC. Future modifications to the FSI modules should allow the system to be configured using a single port as was originally planned.

More than 800 discrete samples were taken for chlorophyll 'a' and phaeophytin determinations. Samples were taken both from the fluorometer output at hourly or 2 hourly intervals, and from CTD and GoFlo casts. At the same time 100mL preserved samples for phytoplankton species identification were taken into both Lugols iodine and borax-buffered formaldehyde. Analysis of these samples will be used not only to identify the distribution of the different species of phytoplankton in the cruise area, but also to estimate levels of phytoplankton carbon.

Analysis of chlorophyll 'a' and phaeopigments was carried out by filtering 100mL aliquots of seawater onto 25mm GFF micropore filters and extraction by 10mL 90% acetone for a minimum of 15 hours. Prior to analysis a further addition of 10mL acetone was made. Analysis was carried out on a Turner Designs 10AU fluorometer (QUB Belfast) fitted with a 25mm cuvette system: the chlorophyll fluorescence was measured before and after the addition of 10% hydrochloric acid. Fluorometer calibration was carried out with pure chlorophyll 'a' standard (Sigma C5753 from spinach). Calibration checks were made at regular intervals during the cruise. The results are reported as $mg.m^{-3}$ chlorophyll 'a' and phaeopigments. The underway discrete chlorophyll 'a' analyses have been used to calibrate the Turner Designs on-line fluorometer, the Chelsea Instruments Aquatracka fluorometer mounted in the tank in the hanger area, and the SeaSoar fluorometer. Similarly, the chlorophyll 'a' data from CTD bottle casts have been used to calibrate the CTD sensors (see section 3.24 for details of these calibrations).

All chlorophyll analyses were completed during the cruise. The time scale for work up of the Lugols and formaldehyde preserved samples is uncertain but it is hoped that a proportion of the samples may be completed before the end of 1993. In the survey area, chlorophyll 'a' values were low both to the north and south of the bloom ($<1mg.m^{-3}$) whilst in the main bloom values greater than $7mg.m^{-3}$ were observed. Phaeopigment values were generally low, both in the bloom and non-bloom areas.

3.24 Chlorophyll calibrations (Gerald Moore, Alison Weeks)

<u>CTD</u>

The fluorescence from the CTD sensor was quenched at the surface. Data for an initial calibration was selected where PAR was below $2Wm^{-2}$. On this basis two distinct calibrations were determined, for stations 12198 and 12200 combined, and for stations 12201 and beyond:

$\ln[chl] = -8.0345 + 6.313V - 1.2020V^2$ (stations 12198, 12200; $r^2=0.95$)
$\ln[chl] = -7.5940 + 4.603V - 0.5721V^2$ (stations 12201 *et seq*; $r^2=0.88$)
where V (volts) = fluorescence raw counts * 0.002441

The difference in calibration is due to a change in species assemblage. Both calibrations were found to be non-linear at low chlorophylls or depths greater than 50m. The calibrations are given below. There were insufficient data to determine a reliable quench correction factor. When the individual calibration curves are combined the overall variance explained was 95%, which gives an upper bound on the variability of the chlorophyll analysis.

On-line

The initial intention was to use the suite of programs developed during the Vivaldi cruise by John Hemmings (Rennell Centre). However, there were problems in using these programs due to instrument errors, the light regime, and the species assemblages encountered during the cruise. John Hemmings' methodology was used whenever possible, as discussed below.

The initial problem was caused by the Turner Designs fluorometer. The first stage was to establish an instrument offset, which proved to be difficult due to range switching of the fluorometer. The new level A software automatically adjusts the recorded data for the instrument range setting. This assumes that the gain for each range is calibrated exactly, and that no offsets occur between ranges. Without processing a set of standards it was not possible to determine if the gains were correctly calibrated, however a simple manual range check showed that there was a change in offset between ranges. The range is not recorded by the level A, so the range change was determined by examination of a probability plot of the output from the fluorometer. This showed a range change at 6.5 and 12.7V rather than the expected 5 and 15.8V. For a preliminary calibration, the ranges identified were adjusted by inter-calibration with the Chelsea Instruments fluorometer, a second underway sensor. A full check will involve a test of the instrument base and manual extraction of the range changes from the chart recorder output.

With the Turner and Chelsea datastreams adjusted it was possible to determine an offset and an initial calibration. From this the chlorophyll yield was determined at the light minimum (PAR less than $5Wm^{-2}$ as logged by the met. system, section 3.3). This "night" yield was adjusted for changes in region, by using cluster analysis. Three regions were determined: the Drake Passage transect; Potter Cove to the survey grid; and the survey grid. These areas provided a base to adjust the "dark" chlorophyll for quenching. When John Hemmings' model was used it was not possible to get a reliable fit between fluorescence yield and PAR. Six other theoretical and empirical models were tested on the data. None of these proved able to remove the effect of light in a reliable manner. The cause of this problem is twofold: first the particular characteristics of the area; and second the statistical bias produced by the operational need to survey the high chlorophyll area in the daytime (see section 2). There are two possible methods to correct the data: first is to use an empirical fit of the daily yield to a smooth function and correct the chlorophyll on a sample to sample basis; the second is to develop a better model of the quenching, to account for latitude and variation in photoadaptation. For preliminary data analysis, the calibrations developed for the Chelsea and Turner fluorometers for night time are detailed below.

Turner Designs: (output is V volts)

Instrument offset 5.9240; calibration after offset correction is:

$[chl] = 0.009853V + 0.004236V^2$ (r^2=0.86)

Region adjustments (scale factor)	6.0849 (Drake Passage)
	4.2519 (from Potter Cove)
	0.9622 (survey area)

Aquatracka (output X is exp(volts))

Instrument offset 2.8368; calibration after offset correction is:

$[chl] = 0.02772X + 0.001753X^2$ (r^2=0.91)

Region adjustments (scale factor) 3.4571 (Drake Passage)
1.4859 (from Potter Cove)
0.9416 (survey area)

Seasoar

The Chelsea Instruments fluorometer on the Seasoar showed a good relationship with the underway samples when data were selected for PAR less than $2Wm^{-2}$. Two linear calibrations were obtained, one for the Drake Passage transect and one for the survey area. One of the main problems with the calibration was the poor time recording for the samples, which resulted in about 5% of the values being unusable because it was ambiguous as to which undulation they corresponded to. The SeaSoar chlorophyll was subject to the same problems in determining a quench function as discussed above. The calibrations are given below.

Drake Passage transect: $\ln[chl] = -2.5067 + 1.1071V$ ($r^2 = 0.81$)

Survey area: $\ln[chl] = -4.8823 + 1.8957V$ (r^2 =0. 92)

where V (volts) = fluorescence raw counts * 0.002441

Discussion

The major problem was caused by the range changes in the Turner Designs fluorometer. This could have been solved if the ranges were available on the level A datastream, for incorporation into a calibration model, and this is strongly advised. Another option is to keep the instrument on a single range; this would give a resolution of 0.2% for the selected range, which is sufficient on a 0-10 $mg.m^{-3}$ nominal range given the accuracy of the instrument. Although the nature of the present survey caused special problems, it is doubtful that full calibration of chlorophyll fluorescence data can be achieved in near real time except on cruises which return to a previously studied area.

3.25 Biogenic sulphur compounds (Phil Nightingale, Wendy Broadgate)

The main aim of this work was to determine the surface water concentration field for dimethyl sulphide (DMS) in order to estimate sea to air fluxes. Of particular interest was the opportunity to investigate the influence of the large seasonal algal blooms in the Antarctic ocean on the global flux of marine biogenic sulphur. A secondary aim was to determine the inter-relationships between DMS, its precursor dimethyl sulphoniopropionate (DMSP) in both the particulate and dissolved phases and chlorophyll, temperature, salinity, phytoplankton species and other parameters such as primary productivity.

Methodology

Samples were predominantly collected from the ship's non-toxic seawater supply, sampling being coordinated with discrete measurements of oxygen, alkalinity, chlorophyll and preserved phytoplankton. In addition, comparative samples of surface seawater were collected from CTD casts. All samples were processed within 10 minutes of collection (except for deep water casts where samples were stored underwater at *in situ* temperatures for a maximum of 6 hours). Volumes of seawater used for DMS analyses were typically between 100 and 200mL reflecting the low levels observed in the study area. All samples were filtered using AP25 depth filters, the filter then being used for DMSP particulate analysis. These were stored in the dark in a NaOH solution (~ 0.3M) for a minimum of six hours. Dissolved levels of DMSP were determined by addition of 35mL of seawater to 1mL of 10M NaOH and samples stored as for DMSP particulate. DMS was extracted from samples and pre-concentrated using purge and cryo-trap techniques and subsequently analysed *in situ* by dual channel flame photometric gas chromatographic techniques.

Results

Over 150 samples were successfully analysed for DMS and DMSP in both the particulate and dissolved phases. These were collected with a 4 hourly frequency on the transects south from the Falklands and west from Elephant Island to the Bellingshausen Sea. Extremely low levels of these compounds were encountered, concentrations were typically between 5 and 25ngSl^{-1} and 150 to 1000ngSl^{-1} for DMS and DMSP (particulate) respectively. Levels of DMSP (dissolved) were regularly below the detection limit, estimated to be 300ngSl^{-1}. The sampling frequency was doubled during the first bloom survey and considerably elevated levels of DMS and DMSP were observed in this region. Preliminary data analysis suggests the maximum DMS concentration to be 300ngSl^{-1}, over an order of magnitude lower than levels typically encountered in algal blooms in the North Sea and North Atlantic.

Unfortunately, equipment problems encountered close to the end of the first survey lead to the cessation of both DMS and DMSP determinations, permanently in the latter case. The fault appears to be electronic and the GC will require specialised attention back in the UK. Total loss of detector sensitivity coincided with other equipment failures and the problem may well be related to surges and/or spikes in the ship's electrical supply. Damage to one channel of the FPD GC initially appeared to be of a temporary nature only and DMS analyses were resumed after a loss of nearly four days. However, detector sensitivity was unusually unstable and data collected during the second bloom survey will require careful screening in the UK to assess it's validity. This second channel ceased to work permanently during the 88°W transect, and DMS determinations were reluctantly abandoned.

3.26 Low molecular weight halocarbons (Phil Nightingale)

A combination of electron capture detection and megabore capillary analytical techniques enables the concentrations of a wide range of halogenated compounds in seawater to be determined. The sources of these compounds can be predominantly natural (eg methyl iodide), purely anthropogenic (eg carbon tetrachloride) or may be a combination of both (eg bromoform). One of the main aims of this cruise was to obtain data on the spatial variation in levels of halocarbons in areas where no data have been reported. Data obtained will be used to obtain estimates for sea to air fluxes. In addition, this cruise offered a unique opportunity to investigate the marine source of biogenic halocarbons in particular, methyl iodide, chloroiodomethane, dibromomethane, bromoform, dibromochloromethane, dichlorobromomethane and chloroform. Previously the only field data to provide firm evidence for natural production of these compounds has come from coastal areas (such as the North Sea) where macroalgae known to release halocarbons are present. Data from a bloom area where both anthropogenic and macroalgal sources are absent will be invaluable in determining the role of phytoplankton in the global cycling of bromine and iodine. Deep water casts are also useful in this respect as the presence of these compounds in waters where carbon tetrachloride and freon-11 are absent indicates that they must have substantial natural sources.

Methodology

Underway samples were collected from the non-toxic supply and coincided with sampling for DMS, chlorophyll, oxygen and other parameters also measured discretely. Samples were collected from CTD rosette casts, using steel-sprung Niskins, varying in depth from 2 to 4500m. Initial comparison of surface waters collected from the non-toxic supply and from the CTD indicate that although the former is heavily contaminated with F11 it is suitable for determination of most low molecular weight halocarbons. Samples were analysed within 10 minutes with the exception of deep water casts where samples were stored under water at ambient seawater temperatures for up to a maximum of ten hours. Halocarbons were extracted from seawater by purging with nitrogen doped with hydrogen (1%) that had been precleaned by passage over a palladium catalyst. Samples were preconcentrated by trapping above liquid nitrogen and separation achieved using a DB 624 megabore column. Detection was by electron capture and chromatograms were collected and archived using a specialised data software package.

Results

No results are available for the transects south from the Falklands to Elephant Island and west from there to the Bellingshausen Sea. The extraction system was badly contaminated and a new line consisting of entirely new valves, tubing and fittings had to be constructed. In addition, peak separation by the DB624 column originally used was found to be unacceptably poor and a new column plumbed in. Problems were also encountered with one of the PCB's in the GC and with spiking affecting the data capture unit. However, all of the aims of the cruise were achieved. Samples were collected at frequencies of 1hr and 2hr during both bloom surveys, from deep CTD casts and on the 88°W transect. During the latter period, samples were taken to coincide with Si, TCO_2, POC, C/N ratio determinations in an effort to gain more insight into possible production of methyl iodide by diatoms and other species of phytoplankton. Transects into and out of the bloom area should also give unique information on production of halocarbons by phytoplankton. Samples of marine air have also been collected for analysis using a GCMS that should enable some of the unknown peaks routinely seen on chromatograms to be identified. Data will, however, require considerable and careful analysis before any conclusions can be reached.

3.27 Hydrocarbons (Wendy Broadgate)

Due to their high reactivity, particularly with the OH radical, light non-methane hydrocarbons play an important role in tropospheric chemistry, especially in the global budget of carbon monoxide and ozone. Anthropogenic emissions (fossil fuel burning, natural oil and gas excavation, and biomass burning) are the major source of these compounds. However, little data has been published on the marine production of non-methane hydrocarbons, although it's importance has been recognised. Measurements in both air and surface seawater in unpolluted regions, especially during periods of high biological activity, are necessary to determine the fluxes of hydrocarbons between the sea and air and therefore the global marine source. Samples were analyzed for the following non-methane hydrocarbons using gas chromatography and flame ionisation detection (GC-FID): ethane, ethene, propane, propene, acetylene, n- and i-butane, butene, pentane, pentene, hexane, hexene, heptane, heptene, benzene, 2-methyl butane, 2,2-dimethyl propane, 2-methyl pentane, 3-methyl pentane and 2,2-dimethyl butane.

Methods

Samples of air and seawater were preconcentrated and analyzed in situ by GC-FID employing a 50m 0.53mm i.d. Al_2O_3 capillary column. Air samples (2L) were cryoconcentrated on a 1/8" o.d stainless steel trap packed with 60 mesh glass beads. Seawater samples (1.4L) were purged with nitrogen gas (CP grade) at 60 mL/min for 30 minutes to remove the volatile gases which were carried in the gas stream through several water traps and condensers and concentrated in the same way as the air samples. Calibration of the system was carried out by the injection of gaseous standards into a nitrogen gas stream and concentration as above. The sample bottles were flushed six times to 60 p.s.i. with nitrogen gas between each analysis and a blank was run. After each seawater analysis the sample was drained from the purge tube under nitrogen gas and a blank was obtained by purging the empty vessel. Because the temperature programme of the GC took one hour the rate of analysis was reduced to approx. one sample every 3 hours. As the analysis required constant attention it was not run 24 hours a day.

None of this work could have been carried out without a reliable supply of liquid nitrogen. In general this is a problem at sea because loss rates from storage dewars are such that 100% loss is observed within 30 days. However, the use of an "Iwatani" liquid nitrogen plant on this cruise has proved to be very successful. It consists of a nitrogen gas generator, a cooling unit and a compressor. The 40L dewar which the unit uses was maintained at a level greater than 30L despite the removal of around 10L per day for use in experiments.

Sampling and storage

Air samples were obtained by pumping air into stainless steel electropolished canisters using a battery operated metal bellows pump. Due to potential problems with navigation and communication it was not permitted to run a stainless steel tube from the mast on the monkey island to the lab. Two tubes (one nylon and one teflon, 1/4" o.d.) were installed along this route and tested for contamination by comparison with samples taken on the monkey island using a 3m stainless steel tube (1/4" o.d.) but both were found to be unsatisfactory. All air samples were therefore taken through a 3m stainless steel tube either on the monkey island or through a window on the bridge with the tube protruding over a metre from the bridge to windward (14m above sea level). To eliminate the possibility of contamination from the ship's funnel no samples were taken when the wind direction was astern. Samples obtained in this way were analyzed within 2 hours of collection.

High pressure air samples were taken at five sites. These samples are stable for several years and can be taken back to the laboratory for reanalysis by gas chromatography-mass spectrometry. Bottles were flushed with the sample as above, then partially immersed in liquid nitrogen for 5 minutes. This liquefies air and a pressure of 200 p.s.i. can be obtained once the bottle warms to room temperature.

Water samples (1.6L) were taken from the non-toxic supply. The bottles were stored in the dark under flowing seawater for up to 4 hours but generally analyzed immediately. Samples at depth were taken from CTD and GoFlo deployments. Underway samples were routinely collected over the whole cruise track, although analytical problems resulted in few successful measurements early in the cruise. Seven CTD casts were analyzed each at two depths (combinations of 2m, 25m, 40m, 150m and 4000m). Surface CTD samples were compared with non-toxic seawater samples at the same site.

Problems encountered

Initial problems with the air sampling lines were time consuming. Once these had been overcome, severe problems with the seawater blanks were observed. Eventually it was found that the prep. line was contaminated, and it was rebuilt with new valves and tubing. Further contamination resulted from two O-rings which were replaced with teflon fittings. There were also ongoing problems with the sensitivity of the detector. These were thought to be due to changing flow rates of the air and hydrogen gas supply lines which were shared with two other GC's. However it may also be due to changing voltages and spikes produced by the "clean" electricity supply which was found to be "dirty". Confusing behaviour from the data acquisition system attached to the computer was also due to spikes in the electricity supply. The removal of a high current-drawing air compressor from the circuit corrected this malfunction.

Results

Despite the problems encountered during the first half of the cruise, a varied raw data set has been acquired from regions of diverse biological productivity. However, the data requires processing before the results are available.

3.28 Particulate sampling (Jane Robertson)

Along the 88°W transect, samples were taken and filtered on an hourly basis for approximately 20 hours per day. The samples were frozen and will be taken back to the UK at the end of Discovery 200 (March 1993). They will be analysed by Dr. H. Kennedy (UCNW) for particulate and dissolved ^{13}C, and for particulate C, N, and Si.The resulting data will be analysed in conjunction with concomitant measurements of pCO_2 , TCO_2 and pH. The analyses will probably be complete by the end of 1993.

3.29 ^{13}C sampling (Colin Attwood)

Stable carbon isotope ratios are useful indicators of fluxes of carbon around the globe and through trophic webs. The primary variation of the ratio of inorganic ^{13}C:^{12}C occurs latitudinally on a macro-scale in the atmosphere and in the ocean, and between water masses of different origin. Both air and sea-water samples were taken for later mass-spectral analysis in Cape Town to measure the carbon isotope ratios in the Bellingshausen Sea and Antarctic Peninsula regions.

Air sampling

A polycarbonate hose of 8mm internal diameter was secured to an upright structure on the ship's monkey island, 16m above the water line and well forward of the ship's exhaust outlets. The hose was run down to the water bottle annex and connected to the sampling apparatus. This consisted of a water trap and a glass sampling bottle (500mL) with a silicon sealed plastic screw-cap through which an inlet and an outlet 6mm tube were inserted. Air was sucked from the supply hose through the water trap and through the sample bottle with a suction pump. After twenty minutes of suction, the pump and water trap were disconnected and the air sample was sealed in the bottle. Initially a tubular drying chamber was attached at the terminal end of the supply hose on the monkey island. This chamber was later inserted adjacent to the water trap inside the deck laboratory as sub-zero temperatures had blocked the chamber with ice. In total, forty air samples were taken, seventeen of which were spaced one degree of latitude apart along the northward transect of 88°W.

Seawater sampling

While underway, seawater samples were taken from the ship's non-toxic sea-water supply. When the CTD was deployed, water was taken from selected depths. The sampling procedure was the same in both cases. 350mL plastic sampling bottles with a press on cap were used to store the samples. The bottles were filled to overflowing from a Teflon tube. 0.15mL of 50% saturated $HgCl_2$ solution was pipetted into the sample to poison metabolic activity. The bottles were slightly squeezed when sealed, which allowed for the expansion of sea-water as it warmed without the necessity of leaving an air space. Thirty-three underway samples were collected covering a range of latitudes between 53 and 69°S. 141 samples were taken from Niskin bottles deployed with the CTD. From shallow casts samples were taken from the following depths: 2, 40, 100, 200, 300, and 500m; from the deeper casts samples were taken from 2, 500, 1500, 2500, 3500m and the bottom.

Sample processing

The samples will be processed at the University of Cape Town upon the ship's arrival (February 1993). From air and water samples, CO_2 gas will be extracted and then injected into a mass-spectrometer for ^{13}C analysis. Details of procedures to be carried out in Cape Town will be made available together with the results.

3.30 Krill acoustics (Alistair Murray and Doug Bone)

Objectives

The study aims to provide an acoustic data set at two frequencies (38 and 120kHz) in the marginal ice edge zone (MIZ) in the Bellingshausen Sea, an area not previously surveyed by BAS. We hope this will lead to an increased understanding of the physical and biological factors controlling the distribution and aggregation of krill.

Equipment and deployment

The equipment used was a Simrad EK400 scientific sounder operating in multiplex mode at 38 and 120kHz. The data were logged to a PC using a custom data acquisition card and software - the Biosonics Echo Signal Processor (ESP). The PC and sounder were set up in the main lab. Some problems were experienced with the EK400 and PC in the early stages of the cruise. It proved impossible to achieve multiplex operation although everything appeared satisfactory when logging either frequency on its own. After a visit from the BAS technician from James Clark Ross the problem was resolved by reverting to the earlier version of the Biosonics software running under Windows 3.00.

The towfish was installed whilst the ship was alongside at Port Stanley. A test deployment of the fish was made not long after departing Berkeley sound. Unfortunately, whilst lowering the fish to the water, it swung as the ship rolled and the tail fins struck the side of the ship distorting them sufficiently to cause problems later in the cruise when attempting to tow at more than about 9 knots. This problem was cured temporarily by fitting thin wire stays to realign the fins, unfortunately these soon broke and thicker replacements had sufficient drag to cause the fish to veer under the ship. This problem prevented us using the system on the final transect up 88°W where it was necessary to maintain 10 knots steaming speed.

Calibration

This was carried out on day 321 with the ship anchored in Potter Cove, King George Island in a depth of about 30m. The calibration rig was assembled on the starboard deck and craned over the side with the standard target (a 38.1mm tungsten carbide sphere) suspended about 5m below it. The calibration of the 38kHz sounder was straightforward and the results appear satisfactory. However, the 120kHz calibration was very difficult and the results are suspect.

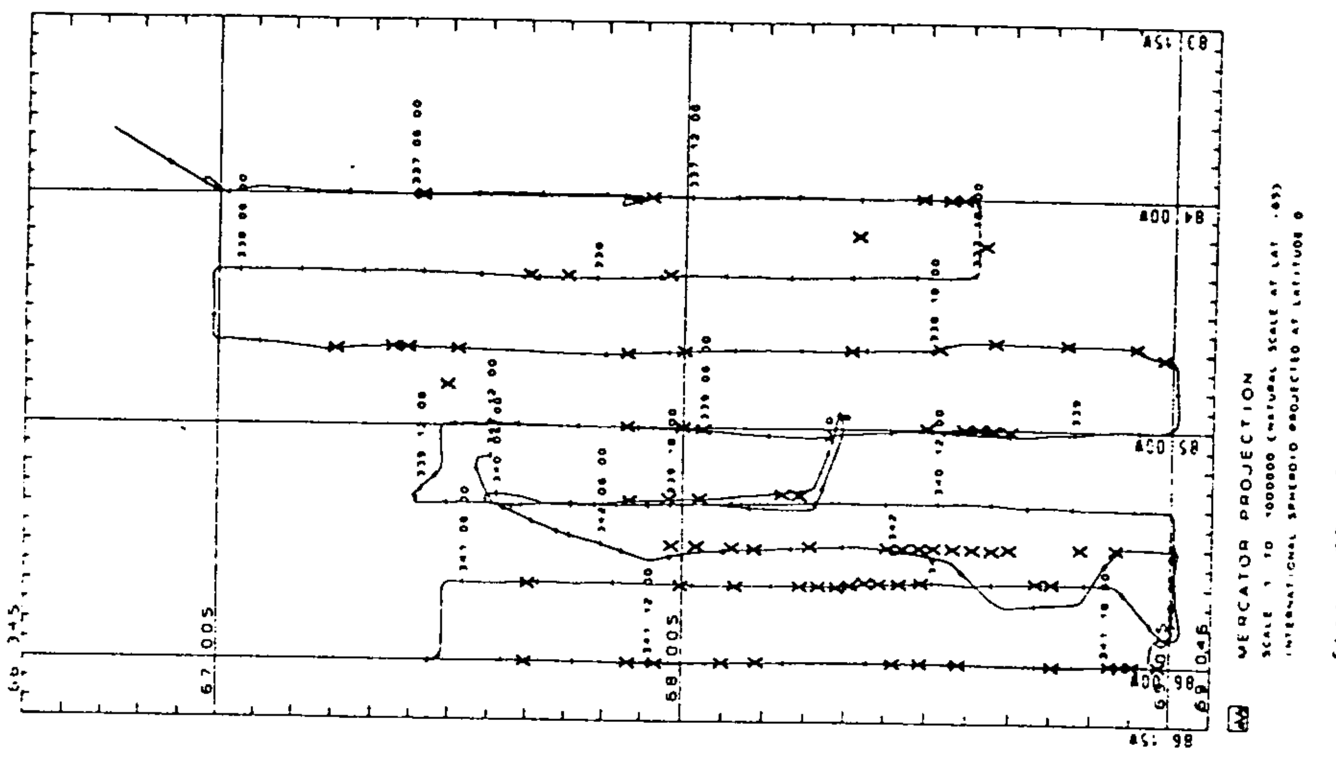
Operation

Details of all acoustic tows are given in Appendix F. On the transect from the Falklands to Elephant Island, several acoustic runs were made at both 38 and 120kHz. After the calibration at Potter Cove, the passage down the Bransfield Straight was run at 38kHz. The fish was recovered during the passage to the marginal ice edge zone study area as the ship's speed was at times too fast for the towfish. The towfish was deployed during the first and second grid surveys and much useful data collected.

Results

Some targets were detected on the runs just to the south of the Antarctic polar front. A few scattered marks were seen on the 38kHz run from Potter Cove down the Bransfield Strait. On arrival at the MIZ study area, no significant targets were detected for some two days, until the ship steamed south of about 67°30'S. The general pattern of target distribution is shown in Figure 3.8. Most echo traces were characteristic of krill swarms in appearance. No large layers or concentrations were found, and only a few large swarms. Most swarms were small and many were fairly shallow (in the top 80m or so of the water column). There was a total absence of the diffuse layer type targets that are common around South Georgia (for instance) and which usually turn out to be copepods or small species of euphausid. When observed on the scope display most swarms gave a very similar response on both 38 and 120kHz. Some swarms were clearly associated with chlorophyll patches and some were being preyed on by Minke whales. The area where krill swarms were found was south of a front found during the first grid survey. Thus there was a clear association of krill with watermass. Some swarms at the southern end of the second survey were in an area of low chlorophyll and high nutrients where the CO_2 was in equilibrium with the atmosphere - suggesting that there had not been any bloom in this area. When the physics and biology of the survey area are further analyzed and interpreted it may be possible to make some inferences about the processes controlling the distribution of krill swarms.

Figure 3.8 Observed krill distributions, plotted on second survey track



3.31 Size-fractionated primary production (Graham Savidge)

This work was designed to address two linked objectives based on separate but complementary experimental approaches. The foremost aim of the programme was to employ the ^{14}C uptake technique to establish the spatial variability of size-fractionated (SF) primary production within the survey zone and to relate this to the prevailing conditions. The secondary objective was to obtain estimates of the growth potential of SF phytoplankton populations maintained under a range of ambient irradiances using batch cultures of natural populations obtained from the survey area.

With the cruise programme being based on survey mode, it was not possible to obtain estimates of primary production from *in situ* incubations. The considerable variability expected in the ambient environmental conditions for the area suggested that the optimal approach to determining primary production should be based on estimates derived from α and P_{max} values obtained from P:I curves generated under defined artificial irradiance conditions. During the cruise, the P:I characteristics of 40 samples were determined with 11 samples being assayed during the transect to the main survey area, 21 assayed during the study in the main survey area and the remaining 8 samples being collected from the final northwards transect. Comparisons between productivity determined from *in situ* observations and derived values of α and P_{max} have been made during the concurrent James Clark Ross cruise.

Samples were collected once or twice per day either from the surface using a bucket or from selected depths using clean GoFlo bottles mounted on Kevlar line and incubated for 4h at 24 constant irradiances in a light gradient incubator. The samples were cooled by running seawater from the non-toxic supply, with temperatures generally being held within 0.5°C of ambient. Following incubation, samples were filtered under controlled vacuum through a cascade of defined pore size filters allowing separation of the phytoplankton population into fractions >18µm (microphytoplankton), 2-18µm (nanophytoplankton) and 0.2-2µm (picophytoplankton). ^{14}C uptake by the SF populations was assayed using standard liquid scintillation techniques with the counts being corrected for dark uptake based on samples to which 100µL of saturated DCMU had been added. No problems were encountered with the ^{14}C uptake technique. α and P_{max} values were estimated from the uptake data using a curve fitting routine based on a standard P:I curve. For each ^{14}C uptake determination, complementary samples were also taken for the determination of SF chlorophyll concentrations in the initial sample and also for taxonomic assay. Primary processing of the ^{14}C and associated data has been virtually completed.

Seven growth experiments were carried out during the cruise with the initial three sample populations being taken during the transit passage to the main survey area and the remaining four samples being taken from a range of sites in the survey area itself. The experiments were set up using surface samples which were incubated for 4 days in 1l polycarbonate bottles under 100, 70, 53, 34, 14 and 3% ambient irradiance in an incubator mounted on the aft deck and cooled from the non-toxic seawater supply. Sub-samples were taken at approximately 24h intervals for the determination of SF chlorophyll concentrations, using size divisions as previously, and also for the assay of nutrient concentrations in the culture bottles. These data were available from all experiments at the end of the cruise.

Preliminary assessment of the SF chlorophyll data has confirmed the generally low chlorophyll concentrations throughout much of the cruise area indicated from other approaches employed with the exception of the well-defined band of high chlorophyll located well offshore of the ice edge in the main survey zone. In the extensive low chlorophyll areas, the nano- and picophytoplankton constituted the greater proportion of the total phytoplankton population but with the microphytoplankton fraction responsible for the major increases in the zone of higher chlorophyll. Large diatom cells were clearly visible in several samples from this area.

The ^{14}C productivity data indicated particularly low values of α and P_{max} expressed on a per unit chlorophyll to be predominant throughout the cruise area with values for α generally ranging from $0.001\text{-}0.002 \mu gC[\mu Em^{-2}s^{-1}]^{-1}[\mu gchl]^{-1}h^{-1}$ and P_{max} values ranging from <0.5 to 1 $\mu gC[\mu gchl]^{-1}h^{-1}$. Higher values of both parameters were typically associated with the two smaller size fractions. On a per unit volume basis, values of P_{max} tended to reflect the local chlorophyll concentration. Within the detailed survey area variations in the values of α and P_{max} on a per unit chlorophyll basis were, however, observed and these data will be analysed in relation to the local phytoplankton population characteristics and hydrographic structure.

A significant and unexpected observation from the cruise was the relative constancy of the mixed layer depth (MLD), as indicated by the distribution of chlorophyll fluorescence, at approximately 70m across much of the cruise area, including the detailed survey zone. The transcending of this common depth across hydrographic structures characterised by contrasting phytoplankton biomass levels suggests that the MLD may not be significant in controlling the growth of phytoplankton in this region. A very marked feature of the region was the extremely short time scale variability in the meteorological conditions and a major objective in data work-up will be to model the phytoplankton response to this variability using observed α and P_{max} values together with representative data on ambient irradiance input, MLDs, PAR vertical attenuation coefficients and vertical distributions of chlorophyll as obtained during the cruise. The basic format for an appropriate model is in place. The model will also provide predictions of integrated column productivity.

Phytoplankton population increases were recorded in all growth experiments with greatest increases generally being observed for the microphytoplankton fraction. In cultures with relatively large inocula nutrient limitation was recorded after 2-3 days. A clear pattern to emerge was for maximum growth to be associated with the two lowest irradiances employed and for growth to commence after a 24h lag period. Data on the growth;irradiance characteristics will be referred to ambient irradiance levels recorded over the period of the experiment and analysed in conjunction with both the depth distribution of total irradiance and the MLD.

This report would be incomplete without an especial thanks to Mike Behrenfeld and Mike Hilles for their help in sample collection, to Bob Head for carrying out the

nutrient analyses and to Alastair Murray for his willingness to assist with the chlorophyll analyses.

3.32 Size-fractionated new and regenerated production (Howard Waldron, Colin Attwood)

The primary objective of this study was to investigate the nitrogen dynamics of the phytoplankton community in an open ocean area of the Bellingshausen Sea, close to the retreating ice-edge during the austral Spring, and along a S-N transect from the main study area to around 50°S. Additional work of a similar nature was also undertaken opportunistically across the Drake Passage and in the north eastern sector of the Bellingshausen Sea whilst en route from the Falkland Islands. The sampling programme consisted mainly of two types of experiment:

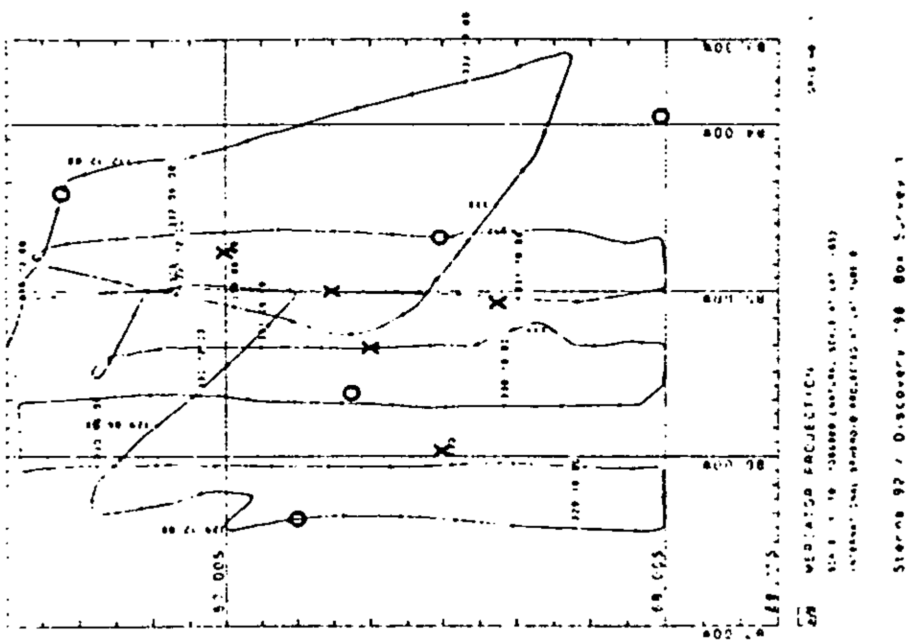
1. Size-fractionation. This work was carried out while underway using bucket samples of surface water. Grazers were excluded by pre-screening (<200μm) and two 5L sub-samples (for NO_3 and urea uptake) and one 6L (for NH_4 uptake and regeneration) were supplemented with the appropriate concentration of ^{15}N salt solution. 1L of the NH_4 sub-sample was drawn off and treated for later particulate N and isotope dilution analyses at time zero (R_0). The three 5L bottles were then incubated at ambient sea surface temperature for 24h on deck at the 100% light level. The samples were size-fractionated, post-incubation (<200μm, 2L; <20μm, 2L; <2μm, 1L) and the experiment terminated by filtration onto pre-ashed 47mm GFF filters. 900mL of the NH_4 filtrate was retained as previously for isotope dilution measurements at time R_t.

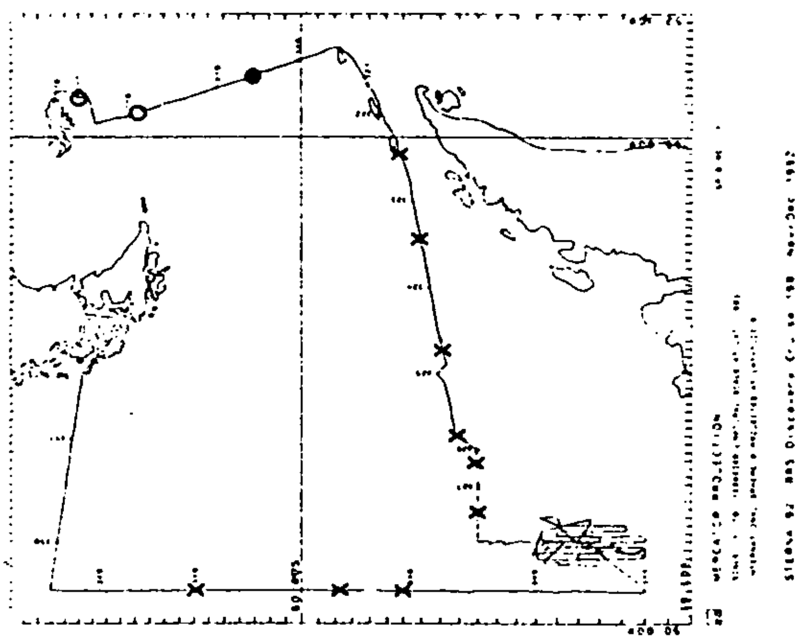
2. Productivity Stations. A light profile was obtained from the CTD deployment and bulk GoFlo water samples were subsequently obtained from the 100, 50, 25, 10, 1 and usually 0.1% light levels. For each of these depths two 2L subsamples of water were supplemented with the appropriate concentration of $Na^{15}NO_3$ and $CO(^{15}NH_2)_2$ respectively. For NH_4-N uptake, a 3L sample was spiked with $^{15}NH_4Cl$. 2L of this were drawn off and incubated with the NO_3 and urea samples for 24h on deck at the appropriate light level (cooled/warmed by surface water supply). Note that all samples were pre-screened. As in the case of size-fractionated work, 1L of the NH_4 subsample was used at time R_0 and time R_t for a combination of particulate N and isotope dilution analyses. Experiments were terminated by filtration.

In addition to the above, a time-series experiment was conducted over 3 days during the early part of the cruise and one of the productivity stations consisted of an inter-calibration exercise with the *James Clark Ross*. Figure 3.9 shows the generalized location of stations and detail with respect to the study area. In summary, 14 productivity stations were completed (including one inter-calibration) and 8 underway experiments (one of which was a time-series). The identification of a density (haline-dominated) and fluorescence front during the SeaSoar survey made for a particularly rewarding choice of station positions.

Results from this work will not be available until some time after *Discovery* returns to Cape Town in early February 1993. It is anticipated, however, that when post-cruise analyses have been completed, figures will be published of new and regenerated production (and ammonium regeneration) over the depth range of the euphotic zone and between different size classes of the phytoplankton community. This has important implications for the biological viability of the early spring bloom and the extent to which these waters act as a sink for carbon.

Figure 3.9 New and regenerated productivity stations. Legend: O size fractionation experiment, surface water; ● time series experiment, surface water; X water column production station





3.33 UV-B radiation and primary production (Mike Behrenfeld, Mike Hilles)

Man-made chemicals released at the earth's surface are resulting in global decreases in stratospheric ozone concentrations. The direct effect of stratospheric ozone depletion is an increase in surface intensities of ultraviolet-B radiation (UVBR: 290-320nm). The short wavelengths of UVBR are biologically damaging and, therefore, increases in UVBR represent a significant threat to both terrestrial and marine organisms. Currently, the largest decreases in stratospheric ozone have occurred over Antarctica each austral spring since 1978. This cruise provided a unique opportunity to measure UVBR effects on marine organisms in this region of large stratospheric ozone depletions.

Measurements were made on the photoinhibitory potential of UVBR on Antarctic marine phytoplankton productivity, as measured by radiolabelled carbon uptake ($NaH^{14}CO_3$). UVBR effects on phytoplankton photosynthesis were determined for both ambient and artificially enhanced UVBR doses. Enhanced UVBR doses were both quantitatively and spectrally realistic. Phytoplankton samples were collected from 100%, 10%, and 1% light levels during cruise stations using GoFlo bottles and incubated at surface intensities. Three sample depths were used to allow determination of UVBR photoadaptation as a function of light history. In addition to productivity experiments, measurements were also made of ambient solar radiation. These measurements included broadband photosynthetically active radiation (PAR) doses, narrow band UVBR doses (at 290, 300, 310, 320nm), and per-nm spectral measurements for 280-330nm. Light data were collected as mean intensity over 1-2 minute intervals.

Carbon fixation rate, as measured during the UVBR studies, ranged from 0.02 to 3.05 $mgCm^{-3}hr^{-1}$ in phytoplankton samples exposed to surface intensities of PAR and shielded from all UVBR. Carbon fixation in the ambient UVBR treatment samples were generally not significantly different than those in the UVBR excluded treatment. The lack of an ambient UVBR effect was not surprising, however, since weather conditions during almost the entire cruise were such that solar UVBR intensities were negligible. Carbon fixation rates in the enhanced UVBR treatment were significantly depressed compared to the UVBR excluded treatment. Decreases in carbon uptake from UVBR enhancement ranged from <10% to 50%, with an average decrease of ≈15%. All productivity values stated above are preliminary and will require additional analysis before being publishable.

Solar broadband PAR measurements were collected for each day from 316 to 347 (excluding 320), have been condensed onto Lotus spreadsheets, and copies rendered for the BOFS database. Spectral and narrow band measurements of UVBR were also completed each day during the cruise (excluding days 334 and 335), but will require substantial time for analysis since these data have to be carefully checked for wavelength offset and calibrated for intensity. At best, this data may be available for the BOFS database at BODC by June/July, 1993.

3.34 Instrumentation notes (Bill Miller, Phil Taylor)

Wave Recorder

The system was run only during deep CTD cast when the ship was hove to. No problems were observed; the data will be analysed at the Rennell Centre to assess system performance.

Millipore Water Purification System

The system provided good quality water throughout the cruise; many thanks to Tony Poole for connecting it the ship supply prior to arrival at Port Stanley.

Test equipment

It is strongly recommended that a few thousand pounds be invested in new equipment for use by RVS personnel on the ship. There is not a decent oscilloscope on board, the equipment looks like that which came off the old *Discovery* over two years ago.

Clean AC Supply

This has already been reported to RVS and actions proposed. The salinometer had periods of instability until it was supplied through an UPS (borrowed from BAS). The clean supply is going to cause problems until an adequate dirty distribution is put in so as to keep the clean supply clean. This is particularly so in the deck lab.

30L GoFlo bottles

All bottles were serviced on board before deployment and worked well. One bottle was lost when the kevlar line parted as the bottle was being hauled to the surface. It is suspected that a slack turn may have fouled a roller on the rex roth winch and jammed; as a precaution the roller was removed.

EM log

No EM log data was provided during the cruise owing to a faulty sensor and a lack of spares on board. It was confirmed soon after leaving Port Stanley that the fore/aft sensor on the EM log was u/s, one of the electrodes showing a 32Ω resistance path to ground. The log was subsequently removed and a blanking plug inserted in its place.

SIMRAD EA 500 echo sounder

The EA 500 echo sounder had to be run on the hull transducer for the duration of the cruise because the PES winch was being used for the deployment of the BAS acoustic fish (section 3.30). Performance was adversely affected (no bottom trace!) when the ship was pitching even in moderate weather, however no such deterioration in performance was present when the ship was rolling. Although much improved, the same characteristics were displayed when the ship was on station.

3.35 Computing (Rod Pearce, Raymond Pollard)

ABC system

Discovery was equipped with an RVS ABC data logging and processing system. Scientific, navigational and operation data were logged in 'real-time' by 13 level A units and a further 3 level A emulating PC's. Details of the instruments and equipment logged by level A are given below:

Navigational	Trimble GPS receiver, Ashtech GPS receiver, Transit satellite receiver, Chernikeef log, gyrocompass.
Underway sampling	RVS surface sampling system, nutrient analyzer, Turner Designs fluorometer, pCO2 analyzer, pH analyzer.
Deployed packages	CTD, SeaSoar, Lightfish.
Other instruments -	RVS metlogger, PML PAR light meter, wave recorder, echo sounder, RVS winch monitoring system.

The CTD and SeaSoar instrument packages were logged using an VME architecture, OS-9 based Mk 2 level A. After completing the first SeaSoar transect it was identified by Raymond Pollard that the Mk 2 level A software derived the ΔT variable incorrectly. Gerald Moore also identified that the level A was misinterpreting some of the sign information in the raw data frames. It was not possible to rectify these faults on board as no code development facilities for the Mk 2 level A's had been provided. Details of the problems and the associated solutions had to be sent to RVS Barry for compilation, copies of the corrected Level A executables were then returned five days later via the ship-shore communications link. The raw data from the first SeaSoar transect was retrieved from the PC archive files and converted into level C format for reprocessing by the PStar team.

Both the Trimble and the Ashtech GPS receivers were logged by Syntel/OS-9 based Mk 2 level A units. There were problems associated with the logging of data from both receivers; the Trimble level A frequently failed to log all the data contained in the fix messages output by the receiver; the Ashtech level A regularly stopped logging data and had to be restarted manually. Both of these problems have been reported to RVS Barry for further investigation.

The level B unit received over 1.2 Gigabytes of serial data and system messages from the various level A sources during the cruise. The messages were logged to tape and forwarded via an ethernet link to the level C system.

The level C system was based around a single SUN IPC workstation with 400 Mbytes of hard disk capacity for holding raw and processed data files. In addition to the data received from the level B the level C system also logged data directly from the PC controlling the ADCP (section 3.2). Data from other off-line sources (including the towed UOR package, the acoustic fish, the XBT system and some surface sample analyzers) were also incorporated into level C system as individual data files.

Level C data processing was limited to navigation, depth and the contouring of some surface sample files. As the ship's log was inoperative, the processed navigation data was derived purely from averaged GPS fixes. The SeaSoar/CTD processing and the surface sample calibration work was carried out by the PStar team. A further three SUN workstations were provided for use by the PStar team. All four workstations were connected to the ship LAN (Local Area Network) allowing PStar users direct access to the raw data files held on the level C workstation.

PStar

Three SUN workstations were used for PStar processing throughout the cruise, with several Macs used as extra terminals. All saw heavy use. Most of the system and data were held on a 1.4Gbyte drive attached to Discovery2, but three 0.3Gbyte drives attached to Discovery3 and 4 were also filled. One of the disks associated with PStar workstations developed a fault early in the cruise, it is unclear whether this fault was in any way linked with the electrical supply problems experienced by other scientific equipment during the cruise. The large space allocation proved most valuable in allowing data to be reworked and scientifically analysed during the cruise. Archiving utilised 150mbyte cartridges, and an optical drive was a new innovation. Files were backed up on both media before being deleted from the system. Heavy use was made of an HP Laserjet colour printer and the Nicolet drum plotter. While there were a few system or computer crashes, most often through lack of swop space, the system proved reliable, allowing all data from the CTD, SeaSoar, ADCP and navigational instruments to be processed to near-final state during the cruise.

APPENDIX A. SCIENTIFIC PARTY

David Turner (Principal Scientist)	Plymouth Marine Laboratory
John Allen	James Rennell Centre
Colin Attwood	University of Capetown
Mike Behrenfeld	Oregon State University
Richard Bellerby	Plymouth Marine Laboratory/University of Plymouth
Doug Bone	British Antarctic Survey
Wendy Broadgate	University of East Anglia
Sean Debney	University College of North Wales/Europa Scientific
Gwyn Griffiths	James Rennell Centre
Bob Head	Plymouth Marine Laboratory
Mike Hilles	Western Washington University
Susan Knox	Plymouth Marine Laboratory
Polly Machin	British Oceanographic Data Centre
Gerald Moore	Southampton University/Plymouth Marine Laboratory
Anne Morrison	NERC Remote Sensing Applications Development Unit
Alistair Murray	British Antarctic Survey
Phil Nightingale	University of East Anglia/Plymouth Marine Laboratory
Raymond Pollard	James Rennell Centre
Jane Read	Institute of Oceanographic Sciences Deacon Laboratory
Jane Robertson	Plymouth Marine Laboratory/University College of North Wales
Graham Savidge	Queen's University, Belfast
Howard Waldron	University of Capetown
Alison Weeks	Southampton University
Bill Miller (Senior Technical Officer)	NERC Research Vessel Services
Colin Day	NERC Research Vessel Services
Rod Pearce	NERC Research Vessel Services
Tony Poole	NERC Research Vessel Services
Phil Taylor	NERC Research Vessel Services

APPENDIX B. STATIONS WORKED

Day	Time	Station	Lat. S	Long. W	Cast depth/m	Water depth/m	Gear
316	2255	12198#1	52°29.2'	57°38.7'	349	361	CTD
317	0009	12198#2	52°30.7'	57°37.7'			30L GoFlo
320	0805	12199#1	60°49.5'	54°45.6'	70		30L GoFlo
320	0824	12199#2	60°49.5'	54°45.5'	30		30L GoFlo
320	0830	12199#3	60°49.5'	54°45.5'	5		30L GoFlo
322	1138	12200#1	62°49.9'	60°34.8'	248	293	CTD
322	1215	12200#2	62°50.1'	60°34.9'	124		30L GoFlo
322	1224	12200#3	62°50.2'	60°35.0'	62		30L GoFlo
322	1230	12200#4	62°50.2'	60°35.0'	37		30L GoFlo
322	1236	12200#5	62°50.2'	60°35.0'	23		30L GoFlo
322	1242	12200#6	62°50.2'	60°35.0'	2		30L GoFlo
323	1126	12201#1	63°27.5'	66°17.5'	299	3246	CTD
323	1210	12201#2	63°26.7'	66°17.5'	182		30L GoFlo
323	1226	12201#3	63°26.8'	66°17.5'	97		30L GoFlo
323	1235	12201#4	63°26.6'	66°17.5'	54		30L GoFlo
323	1244	12201#5	63°26.4'	66°17.4'	28		30L GoFlo
324	1130	12202#1	64°05.8'	73°28.9'	298	3748	CTD
324	1207	12202#2	64°06.1'	73°30.0'	60		30L GoFlo
324	1215	12202#3	64°06.3'	73°30.3'	100		30L GoFlo
324	1225	12202#4	64°06.5'	73°30.6'	80		30L GoFlo
324	1233	12202#5	64°06.6'	73°30.9'	40		30L GoFlo
324	1336	12202#6	64°06.6'	73°31.9'	12		30L GoFlo
325	1835	12203#1	65°01.1'	79°22.6'	246	4109	CTD
325	1930	12203#2	65°00.6'	79°20.3'	27		30L GoFlo
325	1940	12203#3	65°00.6'	79°20.3'	2		30L GoFlo
326	1120	12204#1	64°54.4'	79°28.5'	297	4175	CTD
326	1204	12204#2	64°55.6'	79°25.7'	2		30L Go Flo
326	1211	12204#3	64°55.6'	79°25.7'	100		30L Go Flo
326	1221	12204#4	64°55.7'	79°25.7'	76		30L Go Flo
326	1228	12204#5	64°55.9'	79°25.7'	46		30L Go Flo
326	1235	12204#6	64°56.0'	79°25.6'	23		30L Go Flo
326	2342	12205	65°00.7'	81°39.3'	993	4299	CTD
327	0601	12206	64°59.7'	82°30.8'	994	4478	CTD

Day	Time	Station	Lat. S	Long. W	Cast depth/m	Water depth/m	Gear
327	1100	12207#1	65°00.4'	83°22.1'	1000	4540	CTD
327	1254	12207#2	65°00.7'	83°22.7'	2		30L GoFlo
327	1302	12207#3	65°00.7'	83°22.8'	99		30L GoFlo
327	1312	12207#4	65°00.8'	83°22.8'	66		30L GoFlo
327	1320	12207#5	65°00.9'	83°22.8'	33		30L GoFlo
327	1324	12207#6	65°00.9'	83°22.9'	20		30L GoFlo
327	1327	12207#7	65°01.0'	83°22.9'	10		30L GoFlo
327	1736	12208	65°00.2'	84°09.8'	996	4547	CTD
327	2358	12209	64°59.2'	85°00.3'	993	4591	CTD
328	0421	12210	65°20.0'	84'59.9'	995	4537	CTD
328	1220	12211#1	65°40.4'	84°59.9'	993	4533	CTD
328	1309	12211#2	65°40.6'	84°59.6'	60		30L GoFlo
328	1317	12211#3	65°40.7'	85°00.1'	30		30L GoFlo
328	1323	12211#4	65°40.7'	85°00.0'	2		30L GoFlo
334	0012	12212	66°44.7'	85°00.5'	4349	4389	CTD
334	0953	12213#1	67°04.3'	84'55.8'	999	4310	CTD
334	1210	12213#2	67°05.9'	84°51.1'	5		30L GoFlo
334	1220	12213#3	67°06.0'	84°50.9'	38		30L GoFlo
334	1226	12213#4	67°06.0'	84°50.9'	19		30L GoFlo
334	1237	12213#5	67°05.9'	84°50.4'	6		30L GoFlo
334	1707	12214	67°05.3'	84°57.2'	1000	4310	CTD
334	1946	12215	66°59.4'	84'59.7'	1001	4329	CTD
334	2145	12216	66°54.9'	84°59.0'	999	4346	CTD
334	2334	12217	66°49.9'	84°59.6'	998	4356	CTD
335	0143	12218	66°45.0'	84°59.9'	998	4386	CTD
335	0714	12219	67°09.8'	84°59.1'	998	4291	CTD
335	1123	12220#1	67°16.1'	85°00.8'	998	4281	CTD
335	1229	12220#2	67°15.6'	84°59.6'	60		30L GoFlo
335	1238	12220#3	67°15.5'	84°59.3'	40		30L GoFlo
335	1244	12220#4	67°15.5'	84°59.1'	20		30L GoFlo
335	1249	12220#5	67°15.5'	84°59.1'	12		30L GoFlo
335	1254	12220#6	67°15.4'	84°59.0'	2		30L GoFlo
335	1431	12221	67°20.2'	84°59.4'	999	4295	CTD
335	1642	12222	67°25.4'	84°59.6'	1001	4243	CTD
335	1957	12223	67°29.8'	84°59.2'	4185	4207	CTD

Day	Time	Station	Lat. S	Long. W	Cast depth/m	Water depth/m	Gear
339	1322	12224#1	67°25.6'	85°18.3'	301	4220	CTD
339	1351	12224#2	67°25.7'	85°18.6'	43		30L GoFlo
339	1357	12224#3	67°25.7'	85°18.7'	28		30L GoFlo
339	1403	12224#4	67°25.8'	85°18.8'	14		30L GoFlo
339	1408	12224#5	67°25.8'	85°18.8'	9		30L GoFlo
339	1412	12224#6	67°25.8'	85°18.8'	4		30L GoFlo
341	0748	12225#1	67°27.6'	86°00.1'	301	4159	CTD
341	0808	12225#2	67°27.5'	85°59.9'	46		30L GoFlo
341	0820	12225#3	67°27.5'	85°59.9'	30		30L GoFlo
341	0830	12225#4	67°27.5'	85°59.9'	15		30L GoFlo
341	0840	12225#5	67°27.5'	85°59.9'	9		30L GoFlo
341	0845	12225#6	67°27.5'	85°59.9'	5		30L GoFlo
342	1310	12226#1	67°36.0'	85°03.7'	300	4146	CTD
342	1336	12226#2	67°35.9'	85°03.9'	57		30L GoFlo
342	1343	12226#3	67°35.8'	85°04.0'	38		30L GoFlo
342	1352	12226#4	67°35.8'	85°04.1'	19		30L GoFlo
342	1356	12226#5	67°35.7'	85°04.2'	12		30L GoFlo
342	1401	12226#6	67°35.7'	85°04.2'	6		30L GoFlo
344	0039	12227	69°00.0'	88°00.3'	154	3440	CTD
344	0235	12228	69°00.5'	88°02.1'	3423	3445	CTD
344	2129	12229	66°30.6'	88°00.1'	4459	4470	CTD
345	1411	12230	63°59.9'	87°59.4'	295	4761	CTD
345	1745	12231	63°58.6'	87°59.8'	4710	4763	CTD
346	1110	12232	61°29.9'	87°59.8'	4781	4868	CTD
347	0550	12233	59°00.4'	88°00.2'	5012	5023	CTD
347	2143	12234	56°30.7'	87°59.4'	204	5476	CTD
347	2359	12235	56°31.8'	87°58.0'	5071	5482	CTD
348	1827	12236	53°59.9'	88°01.0'	5025	5060	CTD
349	1137	12237	51°29.4'	87°59.2'	4700	4759	CTD

APPENDIX C. SEASOAR TOWS

1. Drake Passage transect (66 hours)

	Day	Time	Lat. S	Long. W
Launch	317	1330	53°08.0'	59°11.0'
Recovery	320	0745	60°44.5'	54°46.6'

2. First survey (125 hours)

	Day	Time	Lat. S	Long. W
Launch, northern end of leg A	328	1355	65°40.7'	85°01.2'
Alter course to NW in heavy weather	329	0200	67°09.2'	84°59.4'
Begin leg W	329	0820	66°43.1'	86°20.4'
Alter course to NW again	329	1059	67°03.6'	86°14.1'
Resume leg W	329	1148	66°59.9'	86°23.8'
Turn to leg X	329	1924	67°58.7'	86°26.0'
Begin leg X	329	2024	67°59.7'	86°04.8'
Turn to leg Y	330	0730	66°32.5'	86°05.3'
Begin leg Y	330	0843	66°31.7'	85°42.6'
Turn to leg Z	330	2018	67°56.4'	85°41.7'
Begin leg Z	330	2142	67°59.0'	85°19.0'
Turn to leg A	331	0930	66°41.9'	85°29.4'
Begin leg A	331	1130	66°50.3'	84°59.6'
Turn to leg B	331	2020	67°59.5'	84°59.0'
Begin leg B	331	2122	67°58.9'	84°40.0'
Turn to leg C	332	0845	66°36.4'	84°46.0'
Leg C, forced off course by weather	332	1045	66°39.2'	84°18.7'
'Stormleg'	332	2007	67°47.1'	83°39.4'
Recovery	333	1906	66°23.7'	85°51.2'

3. Passage tow (5 hours)

	Day	Time	Lat. S	Long. W
Launch	335	2232	67°29.4'	84°58.2'
Recovery	336	0356	67°04.4'	84°05.5'

4. Second survey (56 hours)

	Day	Time	Lat. S	Long. W
Launch, northern end of leg D	337	0245	66°59.7'	83°58.5'
Turn to leg C	337	1651	68°35.2'	84°00.2'
Begin leg C	337	1751	68°35.9'	84°17.2'
Turn to leg B	338	0620	67°00.0'	84°20.0'
Begin leg B	338	0730	67°01.4'	84°38.4'
Turn to leg A	338	2132	68°59.6'	84°41.0'
Begin leg A	338	2245	68°58.2'	85°00.1'
Turn to leg Z	339	1010	67°29.3'	84°59.6'
SeaSoar lost	339	1037	67°29.0'	85°07.9'

APPENDIX D. UOR TOWS

	Day	Time	Lat. S	Long. W
Launch, leg Z	340	0518	67°37.2'	85°20.4'
Recover, leg Z	340	1327	68°22.6'	85°19.7'
Launch, leg Y	340	1700	69°00.4'	85°32.9'
Recover to fix temp. sensor	340	1754	69°00.5'	85°52.7'
Relaunch, leg Y	340	2312	68°37.3'	85°39.6'
Recover, leg Y	341	0700	67°28.7'	85°59.2'
Launch, leg X	341	0906	67°27.9'	86°00.0'
Recover, leg X	341	1733	68°48.8'	86°00.3'
Launch, leg YZ	341	2012	68°59.0'	85°59.9'
Recover, leg YZ	342	0503	67°52.2'	85°35.5'

APPENDIX E. LIGHTFISH TOWS

File	Start				End			
	Day	Time	Lat.S	Long.W	Day	Time	Lat.S	Long.W
lf318	318	1233	55°51.5'	57°52.6'	319	0000	57°18.8'	57°01.3'
lf319	319	0000	57°18.8'	57°01.3'	320	0000	59°54.0'	55°22.0'
lf320	320	0000	59°54.0'	55°22.0'	320	1300	61°13.0'	54°41.8'
lf322	322	1503	62°55.1'	61°10.0'	323	0000	63°15.4'	63°54.0'
lf323	323	0000	63°15.4'	63°54.0'	323	2331	63°42.7'	69°06.3'
lf324	324	1105	64°05.6'	73°28.2'	324	1457	64°09.2'	73°56.1'
lf328	328	1711	65°58.2'	85°00.9'	329	0000	66°52.7'	85°02.8'
lf329	329	0000	66°52.7'	85°02.8'	330	0000	67°30.8'	86°03.4'
lf330	330	0000	67°30.8'	86°03.4'	331	0000	67°44.4'	85°19.0'
lf331	331	0000	67°44.4'	85°19.0'	332	0000	67°39.6'	84°37.8'
lf332	332	0000	67°39.6'	84°37.8'	333	0000	67°37.1'	84°28.4'
lf333	333	0000	67°37.1'	84°28.4'	333	0926	66°33.1'	84°54.0'
lf335	335	2159	67°25.5'	84°56.5'	336	0000	67°20.9'	84°47.3'
lf336	336	0000	67°20.9'	84°47.3'	336	0300	67°05.1'	84°10.8'
lf337	337	0257	67°00.9'	84°00.0'	338	0000	67°48.7'	84°21.3'
lf338	338	0000	67°48.7'	84°21.3'	339	0000	68°47.5'	85°00.1'
lf339	339	0000	68°47.5'	85°00.1'	339	2142	68°19.2'	84°56.4'
lf340	340	0000	68°17.3'	85°08.7'	340	2351	68°30.9'	85°39.3'
lf341	341	0000	68°30.9'	85°39.2'	341	1258	68°03.1'	86°00.3'
lf343	343	1859	68°21.4'	86°28.5'	344	0000	68°59.4'	87°57.4'
lf344	344	0000	68°59.4'	87°57.4'	344	1530	67°11.2'	88°05.7'

APPENDIX F. ACOUSTIC FISH TOWS

Run	Start				End			
	Day	Time	Lat.S	Long.W	Day	Time	Lat.S	Long.W
1	319	1143	58°34.2'	56°10.0'	319	1300	58°42.4'	56°05.6'
2	319	1301	58°42.4'	56°05.6'	319	1400	58°48.0'	56°03.8'
3	319	1400	58°48.0'	56°03.8'	320	0700	60°41.6'	54°48.3'
4	320	1110	60°54.0'	54°35.0'	320	1253	61°13.0'	54°41.8'
5	322	0200	62°22.5'	58°42.3'	322	1055	62°50.1'	60°34.5'
6	322	1340	62°51.3'	60°49.2'	323	1040	63°27.8'	66°15.6'
7	327	0734	64°54.7'	82°55,0'	327	1100	65°00.0'	83°20.6'
8	327	1100	65°00.0'	83°20.6'	327	1202	65°00.4'	83°22.1'
9	327	1400	65°00.9'	83°28.2'	328	0100	65°00.3'	85°00.6'
10	328	0130	65°00.3'	85°00.6'	328	0324	65°20.2'	84°59.8'
11	328	0909	65°17.7'	85°10.8'	328	1125	65°40.2'	84°59.5'
12	328	1400	65°40.7'	85°01.2'	330	0608	66°42.2'	86°03.5'
13	330	0844	66°31.7'	85°42.6'	331	0930	66°41.9'	85°29.4'
14	331	1130	66°50.3'	84°59.6'	332	0845	66°34.0'	84°46.0'
15	332	1043	66°39.2'	84°18.7'	333	0922	66°35.1'	84°52.6'
16	333	1920	66°24.9'	85°48.0'	333	2215	66°44.7'	85°01.0'
17	334	0645	66°44.1'	84°58.7'	334	0852	67°05.1'	84°57.8'
18	334	1757	67°05.3'	84°55.4'	334	1857	66°59.7'	85°00.1'
19	334	2026	66°59.5'	84°59.4'	334	2057	66°55.0'	84°59.8'
20	334	2228	66°54.9'	84°58.4'	334	2304	66°49.9'	84°59.8'
21	335	0224	66°44.8'	85°00.3'	335	0618	67°10.0'	85°00.1'
22	335	1318	67°15.3'	84°58.5'	335	1821	67°30.2'	84°59.8'
23	335	2320	67°24.0'	84°53.4'	336	0245	67°05.1'	84°10.8'
24	336	2315	66°38.0'	83°34.9'	337	0130	66°57.4'	83°57.0'
25	337	0300	67°00.9'	84°00.0'	337	1700	68°35.8'	84°01.7'
26	337	1700	68°35.8'	84°01.7'	338	0620	67°00.0'	84°20.0'
27	338	0632	66°59.2'	84°22.6'	338	2230	68°59.5'	84°58.0'
28	338	2230	68°59.5'	84°58.0'	339	1010	67°29.3'	84°59.6'
29	339	1430	67°25.9'	85°19.0'	339	2051	68°19.2'	84°57.1'
30	339	2345	68°18.2'	85°02.5'	340	0500	67°37.8'	85°20.5'
31	340	1400	68°42.2'	85°20.2'	340	1820	68°59.0'	85°52.1'
32	340	2315	68°37.3'	85°39.6'	341	0615	67°29.5'	85°41.4'
33	341	0916	67°27.9'	86°00.0'	341	2000	69°00.4'	85°30.0'
34	341	2015	68°59.0'	85°29.9'	342	0500	67°52.3'	85°31.6'
35	343	1525	67°57.0'	85°29.2'	343	2354	68°59.4'	87°57.4'
36	344	0406	68°59.4'	88°04.9'	344	1212	67°39.9'	87°59.8'
37	344	1445	67°19.0'	88°00.9'	344	1620	62°02.0'	88°03.1'
38	344	2335	66°29.8'	88°02.1'	345	0245	65°59.8'	88°00.7'

APPENDIX G. NON-TOXIC SAMPLING PERIODS

Start				End			
Day	Time	Lat.S	Long.W	Day	Time	Lat.S	Long.W
317	0200	52°41.8'	57°39.4'	320	1900	61°40.3'	55°46.8'
322	0400	62°26.0'	59°01.7'	325	1400	64°44.1'	78°56.9'
328	0000	64°59.2'	85°00.3'	342	0300	68°04.7'	85°31.3'
344	0000	68°59.4'	87°57.4'	349	0900	51°35.0'	87°58.5'

APPENDIX H. XBT CASTS

XBT no.	Day	Time	Lat.S	Long. W	Depth/m	Probe type
xp198012	317	0007	52°30.7	57°37.7'	415	T7
xp198016	318	1512	56°13.2'	57°43.9'	3761	T5
xp198017	319	0203	57°34.0'	56°53.2'	3620	T5
xp198019	320	0815	60°44.5'	54°45.5'	3167	T5
xp198020	327	0011	65°00.8'	81°40.1'	4333	T7
xp198021	327	0252	64°59.9'	82°07.1'	4313	T7
xp198022	327	0910	65°00.0'	82°56.8'	3866	T7
xp198023	327	1520	65°00.0'	83°45.7'	3887	T7
xp198026	344	0053	69°00.2'	88°00.6'	3482	T7
xp198028	344	0354	69°00.1'	88°03.4'	3488	T7
xp198029	344	0607	68°40.0'	88°05.0'	3880	T7
xp198030	344	0759	68°19.8'	88°03.6'	4450	T7
xp198031	344	1002	67°58.9'	88°00.8'	4024	T7
xp198032	344	1212	67°39.9'	87°59.8'	4060	T7
xp198033	344	1418	67°20.1'	87°59.5'	4390	T7
xp198034	344	1654	66°59.6'	88°04.0'	4446	T7
xp198035	344	1848	66°40.0'	88°00.0'	4324	T7
xp198036	344	1959	66°30.1'	87°59.7'	4500	T7
xp198037	345	0040	66°20.0'	88°00.6'	4534	T7
xp198038	345	0240	66°00.0'	88°00.4'	4061	T7
xp198039	345	0436	65°39.9'	87°59.8'	4616	T7
xp198040	345	0618	65°20.0'	88°00.0'	4643	T7
xp198041	345	0759	64°59.8'	88°00.3'	4676	T7
xp198043	345	1039	64°39.4'	88°04.3'	4700	T7
xp198044	345	1238	64°20.0'	88°01.4'	4813	T7
xp198045	345	1533	63°59.8'	87°59.3'	4779	T7
xp198046	345	2138	63°38.5'	88°00.9'	4800	T7
xp198047	345	2315	63°19.7'	88°01.0'	4810	T7
xp198048	346	0055	63°00.0'	88°00.1'	4820	T7
xp198049	346	0248	62°39.7'	88°01.4'	4829	T7
xp198050	346	0434	62°19.9'	88°00.5'	4842	T7
xp198051	346	0620	62°00.0'	87°59.9'	4850	T7
xp198053	346	0818	61°39.0'	88°00.6'	4600	T7
xp198054	346	1247	61°30.0'	87°59.7'	4880	T7
xp198055	346	1440	61°19.3'	88°01.6'	4880	T7
xp198056	346	1642	61°00.0'	88°00.6'	3920	T7
xp198057	346	1845	60°39.1'	88°00.1'	4371	T7
xp198058	346	2038	60°19.8'	88°00.0'	4446	T7
xp198059	346	2232	59°59.8'	87°58.2'	4900	T7
xp198060	347	0029	59°39.5'	87°59.4'	5056	T7
xp198061	347	0215	59°19.9'	87°59.1'	4607	T7
xp198062	347	0717	59°00.5'	88°00.4'	5041	T7

XBT no.	Day	Time	Lat.S	Long. W	Depth/m	Probe type
xp198063	347	0922	58°29.2'	87°59.1'	5232	T7
xp198064	347	1101	58°20.3'	88°00.0'	5107	T7
xp198066	347	1300	57°59.3'	88°00.4'	5175	T7
xp198068	347	1458	57°37.8'	88°00.6'	5240	T7
xp198069	347	1636	57°19.9'	88°00.0'	4984	T7
xp198070	347	1824	56°59.8'	87°59.3'	4081	T7
xp198071	347	2013	56°39.9'	88°00.8'	4000	T7
xp198072	348	0156	56°32.6'	87°56.9'	5440	T7
xp198074	348	0335	56°19.9'	88°00.2'	5000	T7
xp198075	348	0528	56°00.0'	88°00.0'	4743	T7
xp198076	348	0720	55°40.1'	88°02.4'	4000	T7
xp198077	348	0911	55°20.0'	87°59.9'	4613	T7
xp198078	348	1104	54°59.5'	87°59.3'	4000	T7
xp198079	348	1305	54°40.0'	88°00.4'	4000	T7
xp198080	348	1459	54°19.7'	87°59.9'	4601	T7
xp198081	348	2002	54°00.1'	88°01.4'	5150	T7
xp198082	348	2156	53°39.8'	88°01.5'	5016	T7
xp198083	348	2335	53°20.1'	88°01.7'	4996	T7
xp198084	349	0118	53°00.0'	88°00.2'	4944	T7
xp198085	349	0302	52°40.0'	88°00.5'	4850	T7
xp198086	349	0449	52°19.3'	88°00.8'	4680	T7
xp198087	349	0638	51°59.9'	88°00.5'	5000	T7
xp198088	349	0830	51°40.0'	87°59.0'	4697	T7
xp198089	349	0945	51°29.6'	87°59.9'	4500	T7

APPENDIX I. DAY NUMBER/DATE INTERCONVERSION

Day	Date
11/11/92	316
12/11/92	317
13/11/92	318
14/11/92	319
15/11/92	320
16/11/92	321
17/11/92	322
18/11/92	323
19/11/92	324
20/11/92	325
21/11/92	326
22/11/92	327
23/11/92	328
24/11/92	329
25/11/92	330
26/11/92	331
27/11/92	332
28/11/92	333
29/11/92	334
30/11/92	335

Day	Date
1/12/92	336
2/12/92	337
3/12/92	338
4/12/92	339
5/12/92	340
6/12/92	341
7/12/92	341
8/12/92	342
9/12/92	343
10/12/92	344
11/12/92	345
12/12/92	346
13/12/92	347
14/12/92	348

FILE END

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