ATLANTIC MERIDIONAL TRANSECT (AMT)

AMT-3 CRUISE REPORT
Atlantic Meridional Transect

AMT-3
CRUISE REPORT

cruise period
16 September - 25 October 1996

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Finally, though already alluded to, the AMT project and the scientific party on AMT3 would like to extend their gratitude to Captain Jerry Burgan, his officers and men, for their professional, positive support throughout the voyage.
1. Rationale and Objectives

Background

The Atlantic Meridional Transects (AMTs) were conceived as a means of acquiring a time series of oceanographic, biological, chemical and optical data over large latitudinal ranges (50° N to 50° S) and through a number of contrasting oceanographic provinces. The core scientific objectives are to refine our understanding of the role of the ocean biota in the biogeochemical processes, carbon fluxes and ultimately global climate and to develop remotely-sensed measurements of global primary production.

The AMTs take advantage of the twice yearly passage of the NERC vessel, RRS James Clark Ross, operated by the British Antarctic Survey, during its passage to and from Antarctica each year. Since the only ship costs involved are to cover the additional time required for course deviations and station work, the AMT is a highly cost-effective project for fundamental marine science. AMT-3 is the third Atlantic transect in the current series.

Objectives

The AMT forms a significant component of two NERC PRIME Special Topic projects; P19: ‘The optical characterisation of zooplankton in relation to ocean physics; discrimination of seasonal, regional and latitudinal variations’ (Robins, Harris & Pilgrim) and P20: ‘Holistic biological oceanography: mesoscale to basin-scale and seasonal studies of phytoplankton processes linked to functional interpretation of bio-optical signatures and biogeochemistry’ (Aiken and Holligan). In addition, through international collaboration, the AMT also forms a component of the calibration and validation of the NASA SeaWiFS and NASA ADEOS/OCTS programmes as well as providing input to SIMBIOS, a programme to develop the methodology and operational capability to combine data products from various ocean colour missions. In the longer term, the AMT project aims to contribute to the refinement of global (basin scale) primary production and ecosystem models which will be important for our ability to predict climate change. The specific objectives of AMT-3 remained similar to previous transects:

• To improve our understanding of the relationship between physical processes and biological production.

• Identify, define and quantify latitudinal changes in biogeochemical provinces.

• Determine phytoplankton characteristics and photosynthetic parameters.

• Identify nutrient regimes and their role in biogeochemical cycles.

• Characterise plankton community structure, including the accurate determination of carbon values (to JGOFS protocols).

• Relate the partial pressure of CO₂ (pCO₂) in surface waters with the biological production.

• Acquire data for the calibration of remotely sensed observations (primary validation).
• Secondary validation of remotely sensed products (e.g. chlorophyll concentration).
• Interpret basin-scale remote sensing observations.
• Develop models that enable the interpretation of satellite imagery in terms of total water column properties.

2. Cruise Personnel

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JIM AIKEN
RAY BARLOW
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CLIFF LAW

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YOSHIHISA MINO

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CRAIG DONLON (ROSSA EXPERIMENT)

Rutherford Appleton laboratory, UK;
TIM NIGHTINGALE (ROSSA EXPERIMENT)

NASDA, Saga University, Japan:
YASUNORI TERAYAMA (ROSSA EXPERIMENT)

British Antarctic Survey:
GRAHAM BUTCHER

NB Full postal addresses, phone and e.mail numbers are given in Appendix A
3. Cruise itinerary, track and sampling strategy

Itinerary

<table>
<thead>
<tr>
<th>Date</th>
<th>Activity</th>
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<tr>
<td>16 September</td>
<td>-joined ship in Grimsby</td>
</tr>
<tr>
<td>17</td>
<td>-commenced installation of scientific equipment</td>
</tr>
<tr>
<td>20</td>
<td>-depart Humber Estuary</td>
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<tr>
<td>21</td>
<td>-called Portsmouth for fuel; sailed 18:00</td>
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<tr>
<td>22</td>
<td>-Station 1 (practice) SDY 266</td>
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<td>24</td>
<td>-nearest approach to 47N x 20W; Station 3, SDY 268</td>
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<tr>
<td>30</td>
<td>-end science (EEZ); Station 9, SDY 274</td>
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<td>02 October</td>
<td>-start science; Station 10, SDY 276</td>
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<tr>
<td>16</td>
<td>-end science off R. Plate; Station 27, SDY 290</td>
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<tr>
<td>21</td>
<td>-depart R. Plate (Montevideo)</td>
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<tr>
<td>23</td>
<td>-resume science; station 297</td>
</tr>
<tr>
<td>25</td>
<td>-(am) final Station 30, SDY 299; move to Mare Harbour</td>
</tr>
<tr>
<td>25</td>
<td>-(pm) arrive Stanley</td>
</tr>
<tr>
<td>30</td>
<td>-flight to UK via Ascension Is.</td>
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</table>

NB A full list of stations, times and corresponding sequential day of the year (SDY) are given in Appendix B

Cruise track and sampling strategy

The *RRS James Clark Ross* left Grimsby on the Humber Estuary on September 20 and sailed for Portsmouth to load aviation fuel. Thereafter a course via the Western Approaches was taken towards the first major waypoint (see Figure 1) at 47°N 20°W. At this station the course was then altered to due south, with only minor deviations, as required, to stay outside of territorial waters off Madeira, Africa and the Cape Verdes. At the latitude of 10°N the ship altered to a south-westerly course for the R. Plate entrance in Uruguay arriving in Montevideo on October 17 to load stores and make repairs. On leaving Montevideo, the course was generally southerly to the Falklands arriving in Port Stanley on October 25.

The scientific work fell into two main components: 1) a conventional station, generally once a day to make CTD profiles, take bottle samples and make optical measurements; 2) continuous or intermittent underway measurements on samples drawn for a number of determinants from the pumped surface water supply while on passage between stations.

Operations on stations

At about 10:00hrs each day the vessel stopped for typically 90 minutes and two CTD/rosette casts were made to a maximum depth of 200m. The timing of the station was a compromise between the requirements of the primary production specialists who would ideally sample at dawn and the optical scientists who would prefer to work closer to local noon. Water sample bottles were fired at typically 10 depths on each cast and the sampling depths were chosen primarily by reference to the CTD fluorometer which was installed for this work. The positions of the stations are given in Appendix B and the water bottle sampling depths for each station are given in Appendix C. The samples taken were used for a number of determinations which are described in the individual reports.
Figure 1. Mercator projection of the Atlantic showing the cruise track for AMT3 and the location of the principal, mid-morning stations.
Simultaneously with the CTD casts, vertical hauls were made to 200m for zooplankton from the forward crane and an optical cast was carried out from the aft telescopic crane. For these the ship was oriented, when possible, with the sun on the starboard side to minimise the effect of ship shade on the optical results. In addition to the wire-deployed light meters, a free-fall light meter and tethered surface reference meter (NASA) were deployed on most stations and a tethered surface up- and down-welling light meter (NASDA) were allowed to drift away from the starboard quarter on each station. Various ancillary samples and observations (e.g. sea and sky photographs) were also taken on each station. The scientific log recording the timing and order of all scientific operations is given as Appendix D. From October 12 - 16, extra optical casts were made during the afternoon to increase data frequency co-incident with the trials of the OCTS/ADEOS satellite trials.

**Underway measurements**

The underway measurements included salinity, temperature and fluorescence which were measured using flow-through sensors connected to the uncontaminated sea water supply drawn from a nominal depth of 7m below the hull. These data were logged continuously to the Level C logging system. The inherent optical properties of the water were monitored using an AC-9 system fed from the seawater supply and logged to PC. In addition, meteorological, environmental and navigational data were also logged continuously to the main computer (Table 1). Dissolved gases (CO₂, CH₄ & N₂O) were extracted from seawater samples taken from the pumped seawater supply and analysed semi-automatically.

At intervals, generally following the daily station through until nightfall, an Undulating Oceanographic Recorder (UOR) instrumented with CTD, F, transmissometer and up- and down-welling light meters, was towed at passage speed.

A number of radiometer systems were deployed, mainly from the foredeck and foremast, to measure sea surface skin temperatures underway for comparison with satellite-derived data and to enable relationships between skin temperatures and bulk surface temperature to be derived (ROSSA).

In support of the radiometric work, a meteorological, radio-sonde balloon was launched daily and a detailed (hourly) log of meteorological and sea state conditions were recorded by the bridge officers and tabulated by Jenny Rust of BAS. A sub-set of this data at four hourly frequency is given in Appendix E.

In addition to the continuous measurements, a number of discrete samples were taken from the pumped supply at various time intervals (see Appendix F). These were analysed for major nutrients, and chlorophyll and samples were taken for iodine/iodate determination and for Bacterial enumeration (see below). Samples were taken from the sea water supply and from CTD bottles for accurate measurement of salinity using the Guildline Autosal precision salinometer on board. These data were used to check the calibration of the Neil Brown conductivity sensors on the CTD and SeaBird sensors on the flow through system. Precision thermometers were deployed with the CTD and used to check the temperature of the effluent from the SeaBird thermosalinometer in order to check the temperature responses.
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<td>2 of these files per day - numbered by Julian days - some readings not calibrated.</td>
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Table 1. List of variables logged on the Level ABC on-board computer.
4. Specific reports and preliminary results

4.1 Water chemistry and bio gases

4.1.1 Total Iron Analyses
Andrew Bowie, University of Plymouth

Introduction
The marine biogeochemistry of iron is complicated by its redox speciation, low solubility
and involvement in biological cycles. Fe(III) is the thermodynamically favoured redox state
dissolved iron in seawater, but undergoes rapid hydrolysis to form insoluble mixed oxy-
hydroxides. Fe(III) is collooidally stabilised by organic ligands which also photoreduce
Fe(III) to Fe(II). This results in a redox loop which is thought to retain dissolved iron at
nanomolar levels in seawater. Furthermore, iron is an important trace nutrient for
phytoplankton growth and actually limits primary production in certain nutrient-sufficient
oceanic waters.

Objectives
To determine the total reducible iron levels in various depths obtained from daily CTD casts
and underway samples. The analyses will focus on evidence of Fe delivered from Saharan
dust fallout off NW Africa, increased Fe through upwelling regions, and the extent of
possible Fe limitation in the Southern Ocean sectors of the transect.

Analytical methodology
Shipboard determinations were performed using an automated flow injection
chemiluminescence (FI-CL) analyser. The system is based around the oxidation of luminol,
which is catalysed by Fe(II) ions, emitting light. After in-line Fe(III) reduction, iron is
preconcentrated and separated from the seawater matrix using a 8-hydroxyquinoline cation-
exchange resin column. This allows the eluant Fe to be determined in the sub-nanomolar
range in open ocean waters.

Unfiltered seawater samples were acidified to pH 2 with Ultrapur® HCl prior to analysis,
and the Fe content determined by standard additions. Identical CTD samples were collected,
acidified and stored for subsequent laboratory analysis of total dissolvable (including labile
particulate) Fe, together with analysis of other micro-nutrients (e.g. Co, Zn) and aerosol
delivered metals (e.g. Al, Pb).

Early Results
No significant problems were encountered and the system performed well in what was its
first open-ocean sea trials. Initial difficulties with the injection valve and sample pump were
resolved, and the system was stable and reliable from day to day. The detection limit of the
analyser was 0.1nmol l⁻¹ when 1.1ml of sample was passed through the column. Total Fe
levels ranged from the limit of detection, measured in the waters of the southern oligotrophic
gyre, up to 5nmol l⁻¹ which was observed on the European shelf. A surface water profile of
the transect, using samples collected from the CTD 7m depth, is contained in Figure 2. A
typical CTD depth profile (2-200m) collected at station #9 (N 20° 05.14', W 20° 37.74') is
shown in Figure 3.
Although the profiles fluctuate somewhat, early indications indicate that elevated iron concentrations in surface seawater are possible due to high atmospheric input and upwelling. Increased Fe levels, due to sedimentary regeneration, are found on both the continental shelves of the Western Approaches and off East Falkland. A clear increase is noted at 20°N off West Africa, a dual Fe input of aerosol dusts and the Mauritanian upwelling system. Further enrichments are observed at the Equatorial upwelling zone, and at 35°S in the frontal system where the cold Falklands' current mixes with the warm Brazilian current.

The Fe laden atmospheric input will be verified through measurements of Al and Mn on replicate samples collected for laboratory analysis. Other macro-nutrients levels (shipboard auto-analyser data) and micro-nutrients (Co, Zn) will be determined by cathodic stripping voltammetry analyses to correlate with Fe enrichment through upwelling systems. In order to estimate particulate iron levels through the transect, laboratory samples will be subjected to a strong acid leach, determining total dissolvable Fe, and comparisons made with the Coulter multisizer particle data. Finally, any organically bound Fe will be recovered after on-line UV photo-oxidation.

Future improvements to the FI-CL analyser, which will be investigated after the cruise, include adaptations to allow continuous Fe determinations via the JCR's pumped surface seawater supply. The acquisition of an autoanalyser to couple with the Fe monitor will improve sample throughput, and any modification which would allow the Fe(II) and Fe(III) content to be evaluated individually would help clarify iron redox speciation and undoubtedly lead to a greater understanding of iron's role as a micronutrient for primary production.

![Surface Water Profile: CTD 7m Depth](image)

Figure 2: Surface Water Profile, Portsmouth (UK) to Stanley (FL)
4.1.2 Iodine/Iodate

Tony Bale for Victor Truesdale, Oxford Brooks University

Samples for iodine-iodate/iodide analyses were collected for Dr Victor Truesdale of Oxford Brooks University. A 15ml tube was flushed and filled from each of the sample bottles on the 'productivity' CTD cast (see appendix C). Generally, ten depths were sampled between 7m and 200m with extra samples concentrated around the chlorophyll maximum. From about 100N to 400S, underway samples were taken from the ships pumped supply at about 4 hourly frequency, the sampling times for these are given in Appendix F which lists all the underway sample events. The samples were stored at 40C and were transported to Oxford for subsequent analysis.

Generally, iodine is present in the oceans at about 0.5 µmol, as iodide and iodate; in deeper waters there is little iodide. It has been suggested that the ratio of iodide to iodate might indicate something about the redox condition of seawater, but more recent ideas focus upon the iodine cycle resembling that of the nutrients, with uptake and regeneration akin to the N system. The pioneering work of Sugawara and Terada showed that there is a general depletion of total iodine as the tropics are approached from either the N or S in the Pacific. At the same time, iodate is reduced to iodide in the surface waters. There is no other published meridional transect. This study was therefore undertaken to "confirm" this trend, and to check that the Atlantic behaves as the Pacific. The methods used are different to those of Sugawara and Terada, and that is an interesting dimension in itself. Here, total iodine is determined by the catalytic action of iodine on the reaction between Ce(IV) and As(III), and iodate by converting it to I2 by acid and KI. (The others used precipitation by silver.)
The results shown in Figure 4 illustrate the expected trend clearly. However, the loss of total iodine is less than expected. Indeed, it suggests that the system could be modelled entirely without assimilation as the dominant process. That is, iodate reduction could be non-assimilatory. If this is so the quasi-nutrient status of iodine can be dropped. It is believed that iodate can be reduced in oxic bacterial cultures, so maybe the iodate reduction really reflects bacterial action in the general regeneration of detritus. It will be interesting to examine how well iodine correlates with nutrients, chlorophyll, etc.

Figure 4. Total iodine and iodate/iodine results for AMT3

4.1.3 Inorganic nutrient analyses
Colin Griffiths, Tony Bale, Plymouth Marine laboratory

Objective: To determine the concentration of dissolved nitrate, nitrite, silicate and phosphorus in CTD and underway samples in order to contribute to the definition of biological 'provinces' and to support the primary production measurements.

Methods: The concentrations of nutrients were measured colourimetrically using a 4-channel, Technicon auto-analyser with standard methodologies. All depths from the CTD (typically 10) were measured on each cast, generally within 2 hours of collection. Surface samples taken at approximately 4 hourly intervals were stored at 4°C and analysed with the samples from the following CTD cast. A list of CTD stations and the underway samples are given in Appendices B and F, respectively.

Results: All samples were analysed except for one batch where the phosphate channel was lost temporarily. There were a number of technical problems throughout; these consisted of: 1) noisy colourimeter responses initially, particularly for the silicate channel which was also prone to drift non-linearly. However, this improved with time and became less problematic as the voyage progressed. 2) All the colourimeters blew bulbs, sometimes frequently. There are only a few spare bulbs left. 3) The orange-green pump tubes in the present batch only lasted a few days despite being run for only 4-5 hours a day. All the analytical results are presently stored as colourimeter responses on paper traces and await digitisation before the responses can be converted to quantitative results. At the time of writing, the nitrate and
silicate data has been digitised and it is anticipated that the phosphate and nitrite will be completed by the AMT3 workshop. Qualitatively, the surface water nutrient samples and surface mixed-layer samples from the CTD were always below detection except in the shelf waters of the Western Approaches and in the Falklands Current waters. Nutrient values increased with depth and were markedly elevated in the Mauritanian and Equatorial upwelling regions.

4.1.4 Ocean-atmosphere bio gas fluxes
Cliff Law, Plymouth Marine Laboratory

A. Nitrous oxide and Methane

Introduction

The ocean is a source of the biogenic gases nitrous oxide (N\textsubscript{2}O) and methane (CH\textsubscript{4}) to the atmosphere, accounting for ~ 1-10% of total global emissions. These species are both radiative gases which contribute to the greenhouse effect and influence tropospheric and stratospheric chemistry. Variability in the oceanic source strength results from lateral gradients at the mesoscale and also variability on seasonal timescales. This variability, combined with the relative paucity of actual observational data, significantly reduces the precision of present global ocean-atmosphere flux estimates and hence the quantification of the impact of the ocean upon climate change. Continuous onboard measurement of these gases in air and surface waters during AMT3 will contribute significantly to the oceanic flux database. In addition, the potential for correlation of optical parameters and ocean surface gas concentrations, with the development of algorithms across a range of water mass types, will improve remote predictive capabilities. Prediction of surface concentrations and hence flux fields from satellite imagery will also circumvent the problems and costs associated with obtaining shipboard observational data, and hence contribute significantly to the interpretation and prediction of climate change.

Instrumentation

The analytical system employed during AMT3 was a composite of two systems used previously for the analysis of other trace gas species. It consisted of an equilibrator unit for surface water measurements, and a pumped supply from the ships bridge for air measurement, with chromatographic separation and detection of N\textsubscript{2}O by ECD (Electron Capture Detector) and CH\textsubscript{4} by FID (Flame Ionisation Detector). Two gas standards, previously cross-calibrated with NOAA certified standards, were used to cover the sample range for both detectors. The system ran in continuous mode throughout and was supplied with surface water from a depth of 7m via the ships non-toxic system. An analytical routine consisted of one surface water sample, one atmospheric sample, and two standards every 25 minutes.

The system performed well, particularly considering the limited pre-cruise time spent configuring it. Data collection north of 40° N was adversely affected by equilibrator flow problems and contamination and so the data is not presented. Approximately 1000 measurements of both air and surface concentration were obtained between 40° N and Montevideo (35° S) following a change of equilibrator unit, with a break between 130° N and 6° N for further equilibrator tests. Measurements were made between Montevideo and Port
Stanley, although data collection was initially restricted by the increased permeability of the equilibrator. Daily downtime resulting from desiccant changes and data downloading was minimal.

Results

Atmospheric N₂O in the northern hemisphere exhibited a mean concentration of 312.7 +/- 0.8 ppbv (1 S.D.), declining to 312.1 +/- 1.2 ppbv (1 S.D.) south of the intertropical convergence zone (ITCZ) as shown in Figure 5. The position of the ITCZ was not identified as continuous sampling was suspended between 13°N and 6°N, but it has previously been observed between these two latitudes. CH₄ also fell sharply at the ITCZ, from 1791.7 +/- 9 ppbv (1 S.D.) in the NH to 1753 +/- 3.9 ppbv (1 S.D.) in the southern hemisphere.

![Atmospheric Nitrous Oxide](image)

**Figure 5a. Atmospheric nitrous oxide concentration**

![Atmospheric Methane](image)

**Figure 5b. Atmospheric methane concentration**

Figure 6 shows the percentage saturation of surface water relative to atmospheric concentration for each gas. CH₄ was always supersaturated relative to the atmosphere, whereas N₂O showed areas of undersaturation in the North Atlantic Gyre between 30°N and 23°N (A). Strong localised sources were identified for N₂O and CH₄ including the Mauritanian upwelling system (B), Equatorial Upwelling/Front (C), the frontal system between 32°S and 36°S (D) and the River Plate plume (E). The high supersaturations observed in these areas concurs with previous observations from other productive regions. Both gases exhibited strong relationships with fluorescence, chlorophyll and biovolume in
some regions, but there was no significant trend throughout. CH$_4$ often exhibited a sharp increase coincident with elevated fluorescence maxima, but also increased in the relatively oligotrophic waters of the North Atlantic Gyre. The overall mean percentage saturation for N$_2$O was 103.5%, excluding the Mauritanian upwelling region, which compares favourably with previous global estimates of 102.5%. CH$_4$ exhibited a mean saturation of 106.2%, excluding the Mauritanian upwelling. It should be noted that these are preliminary data in that they are uncorrected for temperature changes between in situ and the equilibrator, and are also relative to the uncorrected atmospheric data.

Figure 6a. Surface water saturation values for nitrous oxide

Figure 6b. Surface water saturation values for methane
Carbon dioxide

Introduction

To assess the impact of climate change and global warming, it is vital that the behaviour and cycling of carbon dioxide (CO₂) is understood. Although it is presently unclear whether a terrestrial or oceanic sink for CO₂ is more significant to the global carbon budget, previous studies have shown that the Atlantic, and particularly the North Atlantic, are important buffers to the build-up of pCO₂ in the atmosphere. The AMT cruises provide a perfect opportunity to obtain a large number of measurements with extensive spatial coverage of atmospheric and surface CO₂. This data will expand upon the ΔpCO₂ database for the Atlantic ocean already obtained during other programmes, such as JGOFS and the PML Ship of Opportunities project, and will contribute to global carbon cycle models, thereby tightening estimates of the carbon budget and feeding directly into global environmental policy decisions.

Instrumentation

Continuous measurements of atmospheric and surface water CO₂ were made using an autonomous analytical instrument designed at PML, and used previously on AMT1 and AMT2. The computer controlled system consists basically of a series of solenoids which direct gas samples from a percolating packed bed equilibrator, a pumped air supply from the ships bridge and two WMO traceable standards, to an infra-red transmissometer (LiCOR). The system is also equipped with a GPS receiver so that measurements are logged relative to time and position.

Initial problems were experienced due the lack of maintenance and attention given to the system following its use on the previous summer cruise to the Arctic. Initial blockage of the marine air line was cleared and a PTFE trap installed to try to prevent this in future. Water had penetrated in both marine air and equilibrator gas lines, and consequently the system was badly corroded internally. As a result the apparatus required a complete mechanical overhaul during the first few days of the cruise, after which the system ran continuously from 49°N to 35°S. After shutdown for four days in Montevideo the system required further maintenance with replacement of an air pump and a solenoid valve, but data collection continued between 33°S and Port Stanley. Some software problems were experienced during the cruise but these had minor impact on data collection.

Results

Generally the pCO₂ data shows similar trends to AMT1, with variability over shelf and upwelling regions and fronts associated with elevated productivity, increased nutrient availability and enhanced mixing. Undersaturation was observed in the higher latitudes around 45°N, resulting from the relatively more rapid cooling of these waters compared to the rate of re-equilibrium with the atmosphere. Of particular note is the region of undersaturation centred on 5 N (see Figure 7), which was also observed on AMT1. This feature exhibited similar levels of undersaturation on both cruises, of approximately 20-30 μatm, but was more spatially restricted than on AMT1 to 3°N to 7.5°N. Once again this feature was associated with a salinity minimum of < 35 psu. Also apparent in Figure 7 is an area of undersaturation around 10°S, which exhibited a maximum drawdown of 20 μatm. This feature was also observed during AMT1, but was not associated with a salinity minimum; it corresponds to the boundary of the SEC and the S. Atlantic gyre. It should be
noted that these are preliminary data and have not been filtered for atmospheric contamination from ships emissions whilst on station.

Figure 7a. Delta pCO$_2$ for the region 12.5° N to 12.5° S

Figure 7b. Surface salinity for the region 12.5° N to 12.5° S
4.2 Bacteria and phytoplankton distributions

4.2.1 Microbial web studies: bacterial dynamics,
Mike Zubkov, Southampton University

Introduction and objectives
The studies of the microbial web included quantification of the activity of two general
groups: bacteria and nanoplanktonic flagellates in terms of vertical distribution, size
structure, bacterivory and control of bacterial numbers by protozoa.

Bacterioplankton size structure, abundance and production
The samples from ten depths were collected daily from the ‘productivity’ CTD casts to
provide vertical distribution of bacterioplankton using flow cytometry (carried out in the
laboratory on return from sea). Also the samples collected from these depths were pooled
into three integrated samples (on the basis of vertical profiles of temperature, salinity and
fluorescence) representative for surface mixed layer, deep chlorophyll maximum layer or
layer of hydrophysical gradients and a layer below seasonal thermocline down to 200m. Size
fractionation of bacteria was used to estimate the median cell diameter of bacterial
populations that inhabited these layers. Samples were filtered through Nuclepore filters with
pore size 0.2, 0.4, 0.6, 0.8 and 1μm and filtrate fixed for subsequent analysis by flow
cytometry. Bacterioplankton production was estimated using simultaneous uptake of 3H-
thymidine and 14C-leucine by bacteria. The integrated samples were inoculated with
radioactive precursors and incubated in the dark at in situ temperature.

Abundance of nanoplanckton and bacterivory
The samples were collected from the same CTD casts and integrated into three pooled
samples to estimate abundance of nanoplanckton and common microplankton using
epifluorescence technique. Assay of enzymes that cut off glucosamine at acid pH (disrupting
bacterial cell wall in protozoan food vacuoles) was employed to estimate the activity of
bacterivorous protozoa. These analyses were conducted in conjunction with the
measurements of bacterial production. The experiments to study bacterivory were carried out
using dilution technique and dual radioactive labelled natural bacterioplankton.
Supplementary bacterial numbers, bacterial production and protozoan enzyme activity were
monitored in dilution series.

The analysis of all collected material and samples was carried out in the laboratory and the
results are summarised in Figure 8.
Concentration of Bacteria total (stars), Prochlorophytes (triangles), Cyanobacteria (circles) and picocukaryotes (squares) in underway surface samples along the AMT-3 track from 20 N to 52 S.

**Fig. 8.** Underway surface samples to measure the concentration of picoplankton by flow cytometry were collected at 2 h intervals from 20 to 5 N and at 4 h intervals from there down to the Falkland Islands. There were considerable changes in picoplankton structure and abundance along the track. In general, heterotrophic bacteria and prochlorophytes dominated numerically in tropical waters. The concentration of cyanobacteria gradually decreased to the southern oligotrophic gyre and increased again towards the frontal system between warm Brazil and cold Falklands Currents. The picocukaryotes showed a roughly similar trend. These data will be compared later with the results of analysis of profile samples.
4.2.2 Pigments and underwater optics, $\delta^{13}$C in particulate organic material and effect of UV-B radiation on primary productivity.

Koji Suzuki and Yoshihisa Mino, Nagoya University
(supported by NASA and RESTEC, Japan)

1. Intercalibration exercise on the measurement of phytoplankton pigments and underwater light field by Japanese and British scientists

A new Japanese satellite, ADEOS/OCTS, launched on 17 August 1996, is expected to monitor changes of global biogeochemical cycles. To accomplish this objective, the calibration and validation of remotely sensed data obtained from the satellite is needed at the first priority. However, intercalibration exercises between laboratories on routine shipboard measurements such as algal pigment analysis have seldom been conducted for the accurate "ground truth" of ocean colour satellite data. Therefore, we tried an intercalibration exercise on the measurements of phytoplankton pigments using HPLC as well as measurements of underwater light field with Drs. R. G. Barlow (pigments) and J. Aiken (optics) from Plymouth Marine Laboratory, UK.

Seawater samples were collected from surface to deeper layers (<200 m) using CTD-RMS for algal pigment analysis. The water samples (1.5-4 l) were filtered through Whatman GF/F filters (see Appendix C for details of the CTD bottle depths). The filters obtained were stored in liquid nitrogen until analysis on land.

A spectroradiometer PRR-600 (Biospherical Insts. Co.) and a tethered optical buoy TSRB (Satlantic) transported from Nagoya, was deployed to measure surface irradiance and underwater light field in the almost same time of pigment sampling. The radiometers are calibrated before and after the cruise against a standard lamp which is traceable to NIST standard lamp.

2. Latitudinal variations of $\delta^{13}$C in particulate organic matter

Many investigations of photosynthetic $\delta^{13}$C fractionation by marine phytoplankton have been attempted over several decades, because stable isotopic characterisation of marine organic matter can provide useful information on variabilities of biogeochemical processes in surface waters. Recently, interest has focused on the relationship between $\delta^{13}$C of POM and some factors such as sea surface temperature, concentration of aqueous carbon dioxide [CO$_2$(aq)] and growth rates of phytoplankton ($\mu$). Therefore, we would like to examine the effect of both CO$_2$(aq) and $\mu$ on the $\delta^{13}$C of POM in the Atlantic ocean, taking advantage of the wide range of environmental variability during the AMT cruise.

Sample collection and storage was conducted as following. All surface water samples were collected from underway sampling system at each stations (see our table).

Suspended POM samples in surface water (15 l) were filtered through Whatman GF/F filters, and the filters were stored frozen until isotope analysis.

DIC samples (125 ml) were poisoned with 0.1 ml of saturated HgCl$_2$ solution, stored in a dark serum bottle at room temperature. The total amount of DIC and its $\delta^{13}$C will be determined on land.
We determined the growth rate of phytoplankton using dilution technique under simulated in situ incubation, on deck, in running surface seawater. This incubation was conducted in polycarbonate bottles for 24 hrs. After the incubation, samples were filtered onto GF/F filter for Chl a. The pigment was extracted in DMF at -20°C in the dark, and was measured by a Turner Designs fluorometer with non-acidification method (Welshmeyer’s method). Net growth rate of phytoplankton was estimated from the changes in amounts of Chl a.

3. Effect of UV-B radiation on primary productivity with special reference to the production patterns and composition of photosynthetic products in marine phytoplankton

Although the level of biologically harmful UV-B radiation (280-320 nm) arriving at low latitudes is generally higher than that at high latitudes, the UV-B radiation at high latitudes has enhanced because of the depletion of the protective stratospheric ozone. Hence, much attention has recently focused on the biological effect of UV-B radiation. Most studies on the impact of UV-B radiation on phytoplankton have dealt with its effect on photosynthetic rates and on total primary production, but the biochemical implications of such effects have not been well investigated. In addition, its latitudinal variation has never been examined in the open ocean yet.

Therefore, we incubated surface phytoplankton, which were collected from underway sampling system, both in UV-B radiation transparent quartz bottles and in non-transparent polycarbonate bottles on deck during daytime after adding NaH\(^{13}\)CO\(_3\) as a tracer. The seawater samples were filtered through Whatman GF/F filters, and the filters were stored in liquid nitrogen. The amount of UV-B radiation was continuously measured using a UV-B meter during this cruise. We will estimate the effect of UV-B radiation on the production patterns and composition of photosynthetic products in marine phytoplankton in relation to primary productivity, and its latitudinal variation in the Atlantic Ocean after the cruise.
4.2.3 Phytoplankton abundance, composition and production
Emilio Marañón¹ and Beatriz Mouriño²

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Objectives

1.- To describe the latitudinal distribution of size-fractionated phytoplankton abundance and taxonomic composition.

2.- To describe the latitudinal distribution of carbon and nitrogen standing stocks of the microplankton.

3.- To determine the patterns of carbon fixation by phytoplankton in different size fractions (pico-, nano- and net-plankton).

4.- To determine the latitudinal and vertical variability of the photosynthetic parameters of phytoplankton and their relationship with the physical and chemical environmental factors and the taxonomic composition of the microalgal assemblages.

Methods

All sampling and experimental techniques were the same as previously used during AMT-2, and therefore only a brief description will be included here. Phytoplankton stock and rate measurements were conducted on water samples collected from the rosette at 7 depths on each station. Size-fractionated chlorophyll a concentration was determined fluorometrically on 90 % acetone extracts on a 10 AU Turner Designs Fluorometer. The fluorometer had been set up to use the non-acidification technique of Welchmayer (1994) and was calibrated on two occasions during the cruise. In order to compare the results obtained using this technique with the chlorophyll data from AMT-1 and AMT-2, a number of samples were counted every day on both the 10 AU Turner Designs fluorometer and the PML fluorometer used during previous cruises. Correlation between both measurements was high (r²=0.87) and the slope of the regression line was not significantly different from 1. The results of this inter-calibration exercise indicate that chlorophyll data from AMT-1 and 2 and AMT-3 are perfectly comparable.

Both formaline and Lugol's iodine samples for microplankton species identification and counting were taken from each station at 3 depths: surface (7 m), deep chlorophyll maximum (DCM) and an intermediate depth. These depths were the same as those where photosynthesis-irradiance experiments (see below) were conducted. 1.5 litre samples from 5 depths at each station were filtered in duplicate onto pre-ashed Whatman GF/F filters for particulate organic carbon and nitrogen (POC/N) analyses. Filters were frozen, then dried at 60 °C for 24 hours and finally kept in plastic containers with silica gel at room temperature.

Vertical profiles of size-fractionated primary production were obtained from ¹⁴C incubations conducted in an on-deck incubator provided with a range of 10 irradiances from 97 % to 1 % of I₀. Triplicate 70 ml samples were spiked with 10 μCi NaH¹⁴CO₃ and incubated for 7-8 hours at an irradiance close to that of their original depth, as determined by the optical cast. At the end of the incubations, samples were sequentially filtered through 20 μm, 2 μm and 0.2 μm polycarbonate filters and the radioactivity of each fraction determined on a Beckman liquid scintillation counter after decontamination of the filters in acid fumes.
Photosynthesis-irradiance (P-I) experiments were carried out on a bench incubator equipped with an 100 W halogen lamp which provided a range of light intensities from 5 to 2500 µE m⁻² s⁻¹. P-I experiments were conducted with water from 3 depths at each station (surface, deep chlorophyll maximum and an intermediate depth) and lasted for 2.5 hours. At the end of the experiments, the samples were filtered through 0.2 µm polycarbonate filters, decontaminated and counted as described above. All the samples and experiments are listed in Appendix J.

Preliminary Results

Total chlorophyll concentration ranged from less than 0.15 mg m⁻³ in the upper mixed layer of the subtropical north Atlantic and the tropical south Atlantic to more than 0.6-0.8 mg m⁻³ in subsurface waters of the temperate regions (Figure 9). The vertical distribution of chlorophyll a was characterised by the presence of a deep maximum (>0.3-0.4 mg m⁻³) during most of the transect. The DCM was deeper in the tropical South Atlantic and shallower in the Mauritania upwelling region.

![Image of Chlorophyll a concentration map]

Figure 9.- Latitudinal distribution of chlorophyll a concentration (mg m⁻³) from 47° N to 52° S. Shaded areas indicate chlorophyll a concentration >0.3 mg m⁻³.

The latitudinal distribution of primary production mirrored that of chlorophyll a concentration (Figure 10). Highest rates of carbon fixation (>1.5 mgC m⁻³ h⁻¹) were measured in surface waters of the African upwelling region and the temperate South Atlantic. Primary production took low values (<0.40 mgC m⁻³ h⁻¹) throughout the water column in the subtropical North Atlantic and the tropical South
Atlantic. Enhanced photosynthesis was detected in the region from 5° N to 5° S, which was presumably due to an increase in the upward diffusion of nutrients as a result of the equatorial upwelling.

Figure 10.- Latitudinal distribution of total primary production (mgC m⁻³ h⁻¹) from 47° N to 48° S. Shaded areas indicate primary production >0.4 mgC m⁻³ h⁻¹.

Picoplankton was the dominant size fraction in terms of productivity during most of the cruise, usually accounting for 40-70 % of total production (Figure 11). Maximum contribution (>70 %) of picoplankton to total production took place in the equatorial and South tropical regions. Lower relative picoplankton productivity was not always associated with increased total carbon fixation rates. Reduced picoplankton productivity rates were found in the upper mixed layer of the subtropical North Atlantic and the region between 10° and 20° S.

Photosynthesis in the intermediate size fraction (2-20 μm) was generally lower than 0.2 mgC m⁻³ h⁻¹, representing 20-40 % of total primary production (Figure 12). A higher contribution (>50 %) of nanoplanktom to total productivity in subsurface waters at subequatorial and equatorial stations was actually due to a reduction in picoplankton productivity.

Net-plankton (>20 μm) production was very low throughout the cruise, generally accounting for less than 10-20 % of total primary production (Figure 13). The highest contribution (>50 %) of netplankton to total production occurred in subsurface waters at the southernmost station, coinciding with moderate levels of total phytoplankton biomass and production.
Figure 11.- Latitudinal distribution of picoplankton production (mgC m\(^{-3}\) h\(^{-1}\)) from 47° N to 48° S. Shaded areas indicate production >0.4 mgC m\(^{-3}\) h\(^{-1}\).

Figure 14 illustrates the way in which the vertical physical structure of the water column affects the photoadaptation parameters of the phytoplankton assemblages. At an equatorial station, microalgae from the upper mixed layer (samples from 7 and 40 m) showed the same light-saturated photosynthesis rate (PB\(_{\text{max}}\)), whereas microalgae from below the thermocline (sample from 80 m) exhibited a much lower PB\(_{\text{max}}\) and strong photoinhibition (Figure 14A). It is interesting to note that samples from 7 and 40 m depicted a different light response in terms of initial slope and photoinhibition, even though both belonged to the upper mixed layer. This suggests that vertical mixing within the upper mixed layer in equatorial regions may not be so quick as to hamper the development of photoacclimation responses by phytoplankton.

A different pattern was found at a temperate station where all the phytoplankton biomass was concentrated in the upper mixed layer (Figure 14B). No photoinhibition was evident at any depth and differences in PB\(_{\text{max}}\) between assemblages were comparatively small, reflecting the effects of rapid vertical mixing.
Figure 12. Latitudinal distribution of nanoplankton production (mgC m\(^{-3}\) h\(^{-1}\)) from 47° N to 48° S. Shaded areas indicate production >0.2 mgC m\(^{-3}\) h\(^{-1}\).

Figure 13. Latitudinal distribution of net-plankton production (mgC m\(^{-3}\) h\(^{-1}\)) from 47° N to 48° S. Shaded areas indicate production >0.1 mgC m\(^{-3}\) h\(^{-1}\).
Figure 14. - Photosynthesis vs irradiance curves from 3 different depths at A) an equatorial and B) a temperate station during AMT-3. Note differences in the scale of the Y-axis between A and B.
4.2.4 Phytoplankton pigment distributions
Ray Barlow, Plymouth Marine Laboratory

OBJECTIVES

1) To investigate the distribution of chlorophyll and carotenoid biomarker pigments along the AMT in order to determine the basin scale variations in phytoplankton biomass and community structure.

2) To provide an accurate pigment data base for the calibration of fluorescence and optical sensors, and the development of ocean colour remote sensing algorithms for phytoplankton biomass and primary production estimates.

METHODS

Underway surface sampling for pigments was conducted every 2 hours by drawing water from the non-toxic sea water supply and filtering 0.5-2.1 for HPLC analysis, and duplicate 0.25 l for on board chlorophyll measurements. For vertical profiles, a 2.1 l sample was drawn from each of the 9 depths down to 200m for HPLC analysis, and 0.25 l from 5 depths for on board chlorophyll analysis. All HPLC samples were filtered through GF/F filters and stored frozen in liquid nitrogen for analysis of water column samples at PML and surface samples in San Diego (Chuck Trees). Duplicate samples were collected from the surface 7m depth and the chlorophyll maximum depth for HPLC analysis in San Diego. Chlorophyll samples were filtered through GF/F filters, immediately extracted for 12-18 hours in 90% acetone, and the chlorophyll fluorescence measured with a Turner Designs 10-AU fluorometer using the method of Welschmeyer (Limnol. Oceanogr., 39, 1985-1992, 1994). The fluorometer was calibrated with Sigma chlorophyll a standard. Detailed pigment analysis will be conducted using reverse phase HPLC to determine the concentrations of a range of light-harvesting and light-protecting chlorophylls, carotenoids and phaeopigments.

PRELIMINARY RESULTS

Details of the underway surface pigment sampling, temperature, fluorescence, salinity and corrected chlorophyll concentrations are presented in Appendix F and the daily station pigment log and corrected chlorophyll concentrations are summarized in Appendix G

There were considerable variations in surface chlorophyll along the AMT track (Figure 15), ranging from 7 mg m⁻³ at 49-50°N and at 50°S to levels of <0.1 mg m⁻³ in the oligotrophic gyres in both the northern and southern hemispheres. Chlorophyll concentrations increased substantially in the frontal systems associated with the West African upwelling influence (22°N-14°N) and smaller increases were observed at 4°N and at the equator. Further increases in chlorophyll levels were again observed between 30°S and 40°S in the frontal systems between the southern extremity of the warm Brazil Current and the northern limit of the cold Falklands Current. South of 40°S, there was considerable fluctuation in the chlorophyll a, indicating the patchiness of the phytoplankton distribution during the spring in these southerly water masses.

The vertical distribution of chlorophyll along the transect is illustrated in Figure 16, and it may be noted that the bulk of the chlorophyll was located in the upper 30m at 50-40°N. The chlorophyll maximum was then observed to occur at progressively deeper depths to reach 140m at 15°S in the southern oligotrophic gyre. The chlorophyll maximum shallowed
progressively through the more southerly latitudes and at 40-50°S most of the chlorophyll was again located in the upper 30m (Figure 16).

Figure 15. Underway surface chlorophyll $a$ concentration along the AMT transect.

Figure 16. Vertical distribution of chlorophyll $a$ (mg m$^{-3}$) along the AMT transect.
4.3 Zooplankton

4.3.1 Particulates and zooplankton carbon
Ignacio Huskin, Universidad de Oviedo

Particulates
Samples for CNH analyses were obtained from two different depths: surface (7m) and chlorophyll maximum, as determined by in situ fluorescence. Water from the two depths was filtered through membrane filters of 2, 5 and 10µm and a 200µm gauze. Filtrate from each size fraction was filtered in triplicate onto pre-ashed Whatman GF/F filters to produce a series of replicate samples of the four size fractions (<2,<5,<10,<200µm). Filters were maintained for 48 hours in the oven (60°C) and then compacted in pre-ashed aluminium foil for CNH analysis.

Zooplankton
At each station, a WP2 plankton net (200µm) was deployed to 200m. The sample was split into two halves, one half was used for OPC analysis and the other half for size fractionated carbon. The different size fractions were obtained by screening the sample through 2000,1000,500 and 500µm sieves to create fractions of 200-500,500-1000,1000-2000 and >2000µm. Subsamples of each size fraction were filtered onto pre-ashed Whatman GF/C filters (in triplicate). Filters were maintained for 48 hours at 60°C and then compacted in aluminium foil. The remainder of the sample was preserved with borax buffered formaldehyde (4%) for later taxonomic identification.

Ingestion rates
Ingestion rates were obtained using the gut fluorescence method. At each station, one WP2 plankton net (200µm) was deployed to 200 m. The sample was immediately screened to obtain three different size fractions (200-500, 500-1000, 1000µm). Subsamples of each fraction were filtered onto paper filters and frozen for further determination of initial gut contents in each fraction. The remainder of one of the three fractions (one different fraction each day) were used for gut evacuation experiments. Copepods were introduced in a cold box filled with filtered sea water from the station (7m) and subsamples were taken every 5 minutes during the first half an hour. Two extra subsamples were taken at 45 and 60 minutes. Subsamples were filtered onto paper filters and frozen for further gut content analysis.

A fixed number of copepods were taken from the frozen filters to extract gut contents. The copepod number used was: 15 for the large fraction, 25 for the medium fraction and 50 for the small fraction. Three replicates were taken at each time. Chlorophyll was extracted from the copepods guts using 5ml acetone (90%) in 20ml vials during 24 hours at -20°C. Copepod gut fluorescence was determined using a Turner Fluorometer. Plots of each gut evacuation experiments were obtained (copepod gut contents against time). Data were fitted to an exponential curve and the inverse of the slope was assumed to be the gut passage time. Finally, ingestion rates were obtained dividing the initial gut content by the gut passage time.
Figure 17. Example of gut evacuation experiment: date 7-10, fraction 500-1000μm

4.3.2 Optical Plankton Counter and Video Zooplankton Analyser

Chris Gallienne, Plymouth Marine Laboratory

Equipment:

The optical plankton counter (OPC) can produce reliable, real time abundance and size distributions of mesozooplankton (250μm - 16mm equivalent spherical diameter - ESD). The device uses a collimated beam of light received by a sensor. When this beam is occluded by a particle, the sensor response is a pulse whose size is proportional to the cross-sectional diameter of the particle. This pulse is digitised, and the digital size mathematically converted to equivalent spherical diameter using a semi-empirical formula.

The OPC was deployed as for AMTs 1 & 2, both for continuous underway sampling from the ship’s uncontaminated supply, and for processing samples from the 200m integrated vertical net samples from daily stations. The seawater intakes were fitted with steel, 6mm mesh filters, as on AMTs 1 & 2.

The video zooplankton analyser (ViZA) is a video based system for acquiring images of the water volume passing through the OPC, and using computer automated pattern recognition techniques to attempt to classify organisms to major taxonomic groupings. The OPC is able to give reliable abundance and size distribution data, but is unable to tell us anything about shape, and therefore the species community structure. The ViZA device is being developed under PRIME project P19 in order to add this dimension to the survey.

Methods

At each daily station, three WP-2 (200μm mesh) net casts were made. The first, using a double net to 200m, the second using a single net to 200m and the third using a single net to 20m. The sample from the double net was used for gut evacuation experiments. The single
200m net was split and processed as for AMT 1 & 2, using a Folsom splitter. Half of the sample was passed through the OPC, and collected and preserved for subsequent microscopic taxonomy analysis.

The OPC was used in continuous flow-through mode during the whole cruise, using the uncontaminated seawater supply. This was interrupted only briefly at local dusk and dawn to change data files, and for about two hours each day on station to process the net samples. For about an hour on each of seven days a 200μm mesh filter was connected to the flow outlet to collect the sample passed through the OPC. This was preserved for subsequent analysis to validate the OPC data.

The ViZA system was also used continuously in underway mode, and also for the processing of each of the vertical net samples, the sample water passing through the OPC and ViZA flow cells in series. A burst of water connection flooded the video camera, causing some damage on day 275. The initial damage was successfully repaired by day 278, when ViZA sampling continued, but image quality gradually deteriorated until day 282 when the camera failed completely. Fourteen days of ViZA data are available for analysis, however.

Results

OPC

Figure 18 shows the biovolume in parts per billion in each of the four JGOFS size classes for each daily 200m net cast throughout the cruise. Figure 19 shows total biovolume plotted in parts per billion, with the same data for AMT1 plotted for comparison.

Biovolume was generally distributed similarly to AMT1, with the exception of a peak of about 40 ppb at 43°N, which did not appear on AMT1. The double peak around the West African upwelling system was of similar magnitude to AMT1, but centred further south at 9°N rather than 19°N on AMT1. As with AMT1 the plot shows a ridge of enhanced biovolume stretching from the African system across the equator to about 7°S, at about 30 ppb in both cases. Biovolume minima in the Brazil basin were about 10 ppb in both cases. A peak at about 33-36°S of about 70 ppb also appears in both data sets. Size distributions are generally similar in both data sets, although the 1000-2000μm size class in the African system was less dominant than on AMT1.

Figures 18. Bio-volume size along transect

Figure 19. Total volume for AMTs 1 and 3
Figures 20a to h show zooplankton abundance in raw particle counts per cubic metre in underway mode for the whole cruise.

High zooplankton counts during days 266-269 (20a) show the influence of the coastal environment, declining to much lower counts in the 'blue' waters of the Canary Basin on days 270-272 (20b). Counts are higher again across the West African upwelling area and the equator, marked by the vertical line on day 279 (20e). Counts are very low on days 280 to 287 (20f) across the Brazil Basin, and increase again in the more coastal environment approaching the River Plate estuary on days 288 - 290 (20h).

As on previous AMT cruises, there is evidence of increases in counts at dusk and dawn, particularly between 5°N and 20°S (days 278 - 284), which may offer some support to the theory of 'midnight sinking'.

Midnight sinking is a phenomenon associated with diel vertical migration is the appearance of peak abundances at the surface at dusk and dawn, with lower surface counts between these
peaks. It has been suggested (Raymont, 1963) that this may be due to species seeking ‘optimum’ light levels. As light levels fall below this optimum, these species rise to the surface. Further reduction in light level to a point at which vertical position makes no difference results in the cessation of active swimming in response to light levels, and the natural tendency of zooplankton to sink passively takes over. As dawn approaches, and light levels again increase above this threshold, these species again rise in an attempt to reach this optimum light level. Shortly after dawn the surface light level exceeds this optimum, and the zooplankton again actively descend to deeper waters.

ViZA

The data from the ViZA system for the fourteen days before the failure of the video camera are available and are currently being processed. The ViZA system is still under development, and these data will be used to assess the current performance of the system. It is intended that this assessment and analysis should be completed during the two months subsequent to the end of the cruise, and these data will then be available.
4.4 Physical Oceanography

4.4.1 Salinity and temperature calibrations
Colin Griffiths and Tony Bale, Plymouth Marine laboratory

The precision of the Neil Brown CTD unit was checked by reference to salinity bottle values collected on each CTD cast (typically at three depths) and with certified, ISO reversing digital thermometers. Likewise the SeaBird, flow-through thermostalinograph interfaced to the Ocean Logger was checked with salinity bottles taken from the salinometer outlet and by measuring the temperature of the effluent water, also with an ISO precision digital thermometer.

The salinity bottles were analysed for conductivity using a Guildline, AUTOSAL, precision salinometer standardised against IAPSO (Ocean Scientific Ltd.) standard seawater according to the operating instructions. Salinity was calculated from the conductivity ratio at the temperature of the measurements using the algorithm developed by A. Bennett (B.I. O.) which is consistent with the UNESCO salinity tables.

CTD thermostalinograph

A total of 98 thermometer readings and 54 salinity bottle analyses were used to check values produced by the Neil Brown CTD unit. The errors are plotted against time for the duration of the cruise in Figure 21a-b. Although calibration work for oceanographic purposes would not normally be carried out on surface samples where large variations in temperature over small vertical distances can give rise to imprecise readings, the average temperature error was only -11.9 mdeg C (standard deviation 29.4 mdeg C) and showed no significant trend with either time over 33 days or with the temperature of the measurement. Likewise, the salinity measurements undertaken on-board indicated that the salinity values generated by the CTD instrument were reading very slightly high with an average error of +0.0033 ppt (standard deviation = 0.0082 ppt) and that there was also no trend with either time or salinity.

SeaBird (Ocean Logger) thermostalinograph

Eighteen values of temperature by thermometer and salinity by Autosal were compared with the SeaBird values of temperature and salinity (derived from conductivity and temperature), respectively. The errors are plotted against time for the leg UK to Montevideo in Figure 21c-d. The average temperature error was -0.4 mdeg C (standard deviation 29.7 mdeg C) and the average salinity error was -0.008 ppt (standard deviation 0.011 ppt) with no significant drift over time or trends with temperature or salinity.
Figure 21a-d. Salinity and temp errors with time (AMT3 all data)
4.4.2 CTD operations
Colin Griffiths, Plymouth Marine Laboratory

Measurements of conductivity and temperature with depth were made by profiling a Neil Brown Mk IIIB CTD (Instrument Systems, Inc.) when the ship was stationary. Also fitted to the CTD was a PML (Aiken, 1981) fluorometer. The CTD package contained a rosette sampling system fitted with 12 x 10l General Oceanics water bottles. There was one station each day mid morning. At each station the CTD profiled to 200m on the first cast for ‘Productivity etc.’ and typically to 200m on the second cast for ‘Pigments’, (see Appendix C). Data was logged on a PC and onto the Level ABC system which reduced the 8Hz sampling to 1 Hz averages. Processing and presentation was performed on the level C system using RVS software. Use was made of the downcast fluorescence profile to determine the bottle firing strategy on the upcast for each profile.

Calibrations were obtained from bottles 1, 5 and 11, (typically 200m, mid depth and 7m) on the first cast using digital reversing thermometers manufactured by Sensoren-Instrumente Systeme and by taking salinity samples which were analysed onboard with a Guildline, Autolab salinometer.

4.4.3 Expendable Bathythermographs (XBT) profiles
Colin Griffiths, Plymouth Marine Laboratory

During the cruise a total of 36 Sippican T5 XBT’s and 108 Sparton T7 XBT’s were deployed. Temperature profiles were obtained down to a depth of 1830m for the T5’s and 760m for the T7’s. XBT’s were deployed at regular intervals during the cruise, typically 0000, 0600, 1200 and 1800 local time. T5’s were deployed at noon as we were leaving station, T7’s were deployed the rest of the time. Problems were encountered with the launching system on 10th October. The problem was traced to a damaged cable within the hand launcher. At certain times the sampling rate was increased; this was aided by the AVHRR composite images transmitted to the ship. A contour plot of the temperature structure (surface to 750m) on the UK to Montevideo leg is given in Figure 22.

4.4.4 Acoustic Doppler Current Profiler (ADCP)
Colin Griffiths, Plymouth Marine Laboratory

Acoustic doppler current profiling (ADCP) uses the doppler shift of the signals reflected from four, pulsed acoustic beams radiating out and downwards at angles of 45° to each other to derive sub-surface currents. The method relies on particulate material in the water to reflect the acoustic signals and the acoustic frequency employed on AMT3 (250 kHz) is optimal for scattering from particles of the dimensions of zooplankton. Contained within the backscattered signal data, therefore, is information on the number density (signal strength) of zooplankton in the surface waters. The ADCP data obtained during AMT3 was logged and archived for subsequent processing. Distinct migration patterns on diel timescales were observed as the zooplankton migrated to great depths during the day and returned to surface waters (within the depth range of the ACDP) by night. The combination of ship speed and very low particle numbers during the day time meant that signal returns were unuseable for large parts of the transect within the oligotrophic gyres.
4.5 Optical Oceanography

4.5.1 Ocean Colour Optics
Stanford Hooker, NASA Goddard Space Flight Centre

Introduction
As with many of the other types of measurements collected during AMT-3, optical data was collected underway and on station. The UOR, which was fitted with Atlanticafootnote1 radiometers, and a Wetlabs nine-channel absorption and attenuation meter (AC-9) provided the former; whereas, the latter were provided by three different multispectral profilers: the SeaWiFS Optical Profiling System (SeaOPS) and the SeaWiFS Free-Falling Advanced Light Level Sensors (SeaFALLS), which are both based on Atlantica radiance and irradiance sensors, as well as the Profiling Reflectance Radiometer-600 (PRR-600) made by Biospherical Instruments, Inc. (BSI). Underway and station surface irradiance was provided by SeaOPS and a photosynthetically available radiation (PAR) sensor; the latter was JCR equipment. Monitoring of the calibration of the UOR, SeaOPS, and SeaFALLS radiometers was provided by the SeaWiFS Quality Monitor (SQM).

A summary of the bio-optical sampling used to interpret the biogeochemical fields was as follows:

a) Discrete vertical profiles of the in situ light field using the SeaOPS, SeaFALLS, and PRR-600 multispectral instruments;
b) Synoptic measurements of near-surface optical properties using the UOR light sensors and beam transmissimeter; and
c) Underway measurements of the underlying inherent optical properties of absorption and attenuation using the AC-9 instrument.

The UOR, SeaOPS, SeaFALLS, and PRR-600 light sensors all measured optical properties at SeaWiFS wavelengths. The AC-9 was coupled to the uncontaminated seawater supply and its data can be used to interpret and model the optical measurements made by the light sensors. Additionally, the AC-9 provided the interpretation of the other underway measures when in situ optical observations were unavailable. For the light measurements, the diffuse attenuation coefficient Kd of the water was used as a quick-look product to determine the efficacy of the sensors.

Profiling Rig
A custom-built profiling rig was used to carry SeaOPS, the PRR-600, a CTD package with fluorometer and tilt and roll sensors (CTDFTR), a transmissimeter, and an underwater PAR sensor. This rig was the same one used during AMT-1 and AMT-2. The positioning of the equipment on the rig was developed with a geometry that ensured all radiance sensors did not view any part of the support. The narrow geometry of the rig was designed to provide the minimum optical cross section. The field of view of the irradiance sensors was only influenced by the 7mm wire and careful attention was paid to the balance of the rig, even though SeaOPS and the CTDFTR have tilt and roll sensors. The rig was trimmed with lead weights in air, accounting for the in-water weights of the sensors; after final assembly of the rig, visual checks for correct trim were carried out in situ.

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1 Identification of commercial equipment does not imply recommendation or endorsement, nor does it imply the equipment identified is necessarily the best available.
The profiling rig was deployed from a stern crane with a reach of about 8–9 m over the side of the ship. The typical lowering and raising speed of the winch used was approximately 1 m in 5 s or 20 cm per s. Since the crane was on the starboard side of the ship, the sun was kept on the starboard side during all stations except during adverse weather conditions. In addition, sea- and sky-state digital photographs were taken at the bottom of the down cast whenever the optical instruments were deployed.

Data was logged on a Macintosh Quadra 700 using software developed at the University of Miami Rosenstiel School for Marine and Atmospheric Science (RSMAS) and GSFC. The software, called Combined Operations (C-OPS), is written in LabVIEW and is used to control both the in-air and in-water SeaOPS data streams. The primary task of C-OPS is to integrate the RS-232 outputs from the DECK-100 and to control the logging and display of these data streams as a function of the data collection activity being undertaken: dark data (caps on the radiometers), upcast, downcast, bottom soak, surface soak, along track, etc. All of the telemetry channels are displayed in real time and the operator can select from a variety of plotting options to visualize the data being collected.

C-OPS file naming is handled automatically, so all an operator has to do is to select what data streams are to be recorded and then set the execution mode of the data collection activity. Each tab-delimited file has a single header, identifying what is recorded in each column, and all data records are time stamped. The files are written in ASCII and are easily viewed with a simple text editor or ingested into a commercial off-the-shelf (COTS) spreadsheet software package.

SeaOPS

SeaOPS is composed of an above-water and in-water set of sensors comprising five subsystems. The in-water sensors are a downward-looking radiance sensor which measures upwelling radiance, L, and an upward-looking irradiance sensor which measures downwelling irradiance, E. The former is a Satlantic ocean color radiance (OCR-200) sensor (S/N 021), and the latter a Satlantic ocean color irradiance (OCI-200) sensor (S/N 029). The two units send their analog signals to an underwater data unit, a Satlantic DATA-100 (S/N 004), that converts the analog signals to RS-485 serial communications. The above water unit, a Satlantic Multichannel Visible Detector System (MVDS), measures the incident solar irradiance, E. The MVDS unit (S/N 009), is composed of an OCI-200 irradiance sensor (S/N 030) packaged with an analog-to-digital (A/D) module that converts the analog output of the OCI-200 unit to RS-485 serial communications.

All of the SeaOPS radiometers take measurements in the same six spectral bands (approximately 412, 443, 490, 509, 555, 665, and 683 nm) which have been selected to support SeaWiFS calibration and validation activities (McClain et al. 1992). During AMT-1, the underwater SeaOPS sensors were deployed on a T-shaped frame with the OCI-200 and OCR-200 sensors on one side of the frame and a PRR-600 on the other side (Robins et al. 1996); this strategy was repeated for AMT-3.

The RS-485 signals from the MVDS and the DATA-100 are combined in a Satlantic deck box, the DECK-100 (S/N 008), and converted to RS-232 communications for computer logging. The DECK-100 also provides the (computer controlled) direct current (DC) power for all the sensors and is designed to avoid instrument damage due to improper power-up sequences over varying cable lengths. For AMT-3, the MVDS cable length was approximately 200 m whereas the DATA-100 cable length was about 260 m (250 m on the winch and 10 m from the winch to the DECK-100). The unit also acts as a useful diagnostic
should telemetry problems be encountered. Details of the station operations are contained in Appendix I.

**SQM**

The validation of ocean color satellite sensors requires a quantification of the uncertainties associated with *in situ* radiometric measurements. Presently, there is no convenient way to check or monitor the calibration of a field radiometer while it is being deployed. Consequently, individual investigators have relied either on the manufacturer's calibration data or on pre- and post-cruise calibrations of their instruments. The severe environmental changes encountered by a radiometer during shipment or a long cruise, however, calls in to question whether either one of these practices is satisfactory which in turn raises the concern of the data quality achieved during field deployments.

In response to a demand for an onboard calibration capability the NASA Goddard Space Flight Center (GSFC) and the National Institute of Standards and Technology (NIST) jointly designed and constructed a prototype of a portable light source to illuminate various radiometers during oceanographic cruises. This device, called the SQM, produces a diffuse and uniform light field and is designed to be flush-mounted to radiance or irradiance sensors with a spectral range from 380-900 nm. The uniformity of this source is less that 2% over an area of 6 inches in diameter. To account for changes in the illuminance of the SQM, three temperature-controlled photodiodes measure the exit aperture light level: one has a responsivity in the blue part of the spectrum, another in the red part of the spectrum, and the third has a broad-band response.

The SQM has two banks of halogen lamps with eight lamps in each bank. The first bank is populated with Gilmour model 187 (4.2 V and 1.05 A) lamps and the second with Welch Allyn model 01160 (5.0 V and 3.45 A) lamps. The power supply for the lamps is via two highly regulated Hewlett Packard (HP) model 6030A power supplies. Both power supplies are controlled with voltage sources provided by a computer-controlled 16 bit digital-to-analog (D/A) board. The output current values from the power supplies are monitored by measuring the voltages across two precision 0.5 ohm shunt resistors with a HP 3457 digital voltmeter (DVM). The DVM voltages are acquired over an HP interface bus (HPIB), and the program controlling the D/A boards and acquiring the signals converts the resistance values to current and adjusts the output of the power supplies to ensure a constant current supply to the lamps.

Data logging for the SQM involves two computer systems: one for the device under test (DUT) and one for the SQM. Three of the DUTs were fiducials, that is, dummy radiometers with different reflective surfaces: a white one, a black one, and a black one with a glass face (made of the same glass used in the Satlantic radiometers). The purpose of the fiducials is to be able to collect data with them before and after actual radiometers as another way of tracking the short- and long-term characteristics of the SQM light chamber as determined by the internal photodiodes.

Whenever the DUT was a field radiometer, a computer system was needed to acquire and log the data from the radiometer. For AMT-3, the UOR and SeaOPS radiometers were logged using the C-OPS software running on a Macintosh 180c PowerBook computer, and the SeaFALLS radiometers were logged using ProVIEW and the Compaq computer normally used for that purpose.

The SQM software is written in Visual Basic and is hosted on a Toshiba PC laptop. The SQM computer controls the HP 6030A power supplies and acquires seven other signals from
the HP 3457 DVM: three photodiode voltages from inside the SQM, two thermistor (temperature) voltages from the two shunts, and two voltages across the two shunts. The latter are converted into currents, since the resistance of the shunts is known. All of this information is time stamped and logged into a tab-delimited ASCII file. The file has descriptive headers which record the DUT being used and what the configuration of the SQM was during the experiment.

**SeaFALLS**

SeaFALLS is composed of two subsystems both manufactured by Satlantic: a SeaWiFS Profiling Multichannel Radiometer (SPMR) and a SeaWiFS Multichannel Surface Reference (SMSR). The latter measures downwelling irradiance and upwelling radiance as it falls through the water column, while the latter measures downwelling irradiance just below the sea surface. The profiler receives its power and sends its data via an umbilical cable; it is sufficiently buoyant in water that one person can deploy and recover the profiler. The reference floats just below the surface suspended from a square floating frame; it can also be deployed and recovered by one person. Because both the profiler and the reference can be deployed far away from the ship, any ship-induced disturbances to the *in situ* light field are minimized.

The SPMR and SMSR units utilize 13-channel radiometers with the same wavelengths (approximately 406, 412, 443, 470, 490, 509, 532, 555, 590, 665, 670, 683, and 700 nm) and bandwidths (10 nm). The SeaOPS band set is a subset of this: approximately 412, 443, 490, 509, 555, 665, and 683 nm. SeaFALLS is equipped with OCI-1000 and OCR-1000 radiometers which employ 24-bit A/D converters and are capable of detecting light over a seven decade range (SeaOPS uses OCI-200 and OCR-200 radiometers which use 16-bit A/D converters).

Data telemetry for SeaFALLS is very similar to SeaOPS. A deck unit, a PRO-DCU (S/N 008), supplies the power for both the profiler and reference independently. The output voltage is automatically adjusted for the cable length being used. An internal computer shuts the system down under fault conditions while indicating the type of fault. RS-485 telemetry at 19.2 Kbaud is converted in the deck box to RS-232 for input into a microcomputer, in this case a Compaq laptop personal computer (PC).

The logging and display software used with SeaFALLS was provided by Satlantic and is called ProVIEW. There are several display windows associated with this software which can show all the channels in raw counts or calibrated units. Data is logged in a packed binary format, although ASCII data can be produced using an included utility. Details of the station operations are given in Appendix I.

### 4.5.2 AC-9 Measurements

**Tony Bale, Plymouth Marine laboratory**

**Objective:** 1) To investigate particle-size/light scattering relationships in marine waters for the improvement of models which describe the fundamental behaviour of light in sea waters.

2) To obtain data on the inherent optical properties (IOPs) of water along the Atlantic Meridional Transect to support the development of remote sensing algorithms capable of predicting constituents which influence ocean colour.

**Methods**
The attenuation of light due to absorption and scattering by species within seawater was measured at 9 wavelengths in the visible spectrum (412, 440, 488, 510, 555, 630, 650, 676 & 715nm) using a Wetlabs AC-9, double beam (a and c) transmissometer. These measurements provide a fundamental link between the optical characteristics of the water and the constituents which influence light behaviour.

The instrument was connected to the ships pumped water supply and was operated continuously between Portsmouth and Stanley apart from the leg into and out of the R. Plate where the supply was switched off. The instrument was operated in a light-tight water jacket maintained at ambient seawater temperature and inclined at an angle of 45° to allow efficient flushing of small bubbles.

Data was logged at a frequency 30 seconds and files were closed twice a day; once on each daily station while the vessel was stopped and again at night when the pure water and air calibration values were checked. Thus, two data files were generated each day; these were named: AC followed by the SDY (Serial Day of Year) number plus A or B to denote the first or second file for each day.

The instrument performance was tracked every night using 0.2mm filtered, deionised water from the Elgastat HPC pure water system which was pumped through the sample line in place of the sea water supply; these files are named WAT SDY.dat. Every 4-6 days the instrument and optical windows were also thoroughly cleaned and air calibration values were obtained (AIR SDY.dat). Pure water calibration values were obtained immediately before and after the air calibration (WAT SDY PR.dat & WAT SDY PO.dat).

This combination of water and air performance checks provided a rigorous control of both the instrument stability and the optical cleanliness of the windows which tend to become slowly contaminated with adsorbed, presumably organic, material.

A complete set of data was obtained for the 9 absorption channels but no attenuation data (c) was taken after day 276 when the source lamp failed on that channel.

4.5.3 Particle Size and Numbers

Tony Bale & David Robins, Plymouth Marine laboratory

Objective To determine particle numbers in the 2-60μm size range to relate to the IOPs measured by AC-9.

Methods
A standard Coulter multisizer fitted with a 100μm orifice was used to count the particle numbers in the size range 1.9-60.0μm in the surface waters at every station. The sample was taken from the pumped supply while the ship was on station. Calibration of the instrument was checked using 14.02mm latex calibration spheres and the manometer flow time was calibrated relative to the siphon volume so that particle numbers could be calculated from the sampling time interval (generally 30 seconds). System blanks obtained by passing seawater through a 0.2mm pore-sized filtration cartridge were typically less than 60 particles per ml.

Results
The results obtained are shown in Figure 23 and reveal a latitudinal pattern which is closely related to the distribution of surface chlorophyll determined from acetone extracts.
Figure 23 shows particle numbers per ml at each station plotted against latitude.

Figure 24 shows the relationship between chlorophyll (R. Barlow) and particle numbers.

4.5.4 UOR report
Jim Aiken, Plymouth Marine Laboratory

The UOR was towed 25 times, for a total time of 123 h, covering a total distance of 2760 km. Details of the individual tows are given in Appendix H and the positions of the tows are given in Figure 25. Typically, the UOR was towed from the mid-morning station, for 4 to 7 h, through the sunlit period of the day, at a speed of 11-12 knots (20 km/h), with 370 m cable deployed, giving an undulation depth amplitude of 5 to 66 m and an undulation pitch of 3 km. There were 2 long over-night tows; tow A313 (18h 44) across the equatorial upwelling and tow A323 (14h 41) into the station off Montevideo. There were 3 undulation failures
due to tailplane jams; the port tailplane bolt was dislodged on 2 occasions and servo S/N 05 was replaced after an unexplained failure on tow A312. The instrumentation package comprised a D, T, C, F1 sensor package (JAS, JA3), Satlantic downwelling irradiance (OCI-200, S/N 001) and upwelling radiance (OCR-200, S/N 001) sensors and PML solid state logger (JA8, JA10); a CI Alphatecra Mk II, 660 nm, 0.25 m transmissometer (S/N 006) was included for tows A308-A312 and A321-end. All sensors worked reliably with minor exceptions: JA5 seawater switch was intermittent causing the chlorophyll sensor signal to float high and was replaced after tow A312; logger JA10 had a damaged plug and was replaced; there was some data loss due to premature battery failure (variable 15 - 18 h) of both AA (sensor electronics) and C cells (chlorophyll flash) due to old batteries from 1995.

Observations were typical for sites and season and comparable to measurements acquired on AMT-1. Temperature stratification persisted throughout the whole of the N. Atlantic from the western approaches to the Equator, with mixed layer depths ranging from 20 to 50 m. There was strong salinity stratification in the equatorial zones (fresher on the surface). In the south equatorial gyre, temperature and salinity stratification disappeared until ca 15° S when weak temperature stratification re-appeared (ca 1 °C). Generally there was greater stratification (1-2 °C) in the Brazilian current than had been observed on AMT-1. On the final section 30° to 37° S, extremely heterogeneous mixing of temperature and salinity was observed on the periphery of the confluence of the Brazilian and Falklands current systems.

Chlorophyll concentrations were high in the surface waters in the stratified European shelf seas (1-2 mg m⁻³) declining in the North Atlantic gyre (0.1 surface, 0.5 sub-surface, thermocline max.); there were regions of high concentrations around the N.W. African upwelling (values up to 1 mg m⁻³); there were elevated values at the equatorial upwelling, rising to 0.25 mg m⁻³ on the surface; south of the equator surface values were less than 0.1 mg/m3 and only 0.2-0.3 mg m⁻³ at 60-70 m; concentrations of 1-1.5 mg m⁻³ were observed in the heterogeneous waters at 30 to 35° S with surface and sub-surface maximum at diverse frontal and eddy structures. Water transmission measurements were generally consistent with the fluorometer measurements of chlorophyll concentration though free from the surface quenching artefact and hence more representative of the biomass distribution, surface and sub-surface.

It was not possible to assess the quality and accuracy of the Satlantic light sensor measurements whilst at sea, but on a cursory glance the data looked qualitatively good; notably the upwelling radiance measurements seemed free from any general artefacts arising from towing; the profiles were generally "clean" and "noise-free" even at the top of the undulation where sun-glitter and UOR pitch and roll were potential sources of noise. The downwelling irradiance measurements showed contrasting characteristics between over-cast, diffuse conditions, when the profiles were clean and noise-free, and under direct sunlight conditions where sun-speckle, sea roughness and UOR pitch and roll all contributed to noisy measurements; the simultaneous measurement of pitch and roll by the UOR logger will allow these data to be screened later, to exclude data with excessive angles (> +/- 10 deg) which render the data quality unacceptable at the standards of SeaWiFS protocols.

Figure 26 shows the contoured vertical sections of a) Temperature (°C; 0.1°), b) Chlorophyll fluorescence (mg.m⁻3; 0.1), c) Salinity (PSU; 0.05) for UOR tow A313 across the equator from 1° 18.2° N, 25° 46.6°W to 1° 45° S, 27° 08.9°W, showing the effect of the equatorial upwelling, bringing cooler (26.3° C) water to the surface, leading to enhanced chlorophyll concentrations (> 0.4 mg.m⁻3); note the increase of salinity from 35.85 to 36.2 across the front.
Fig 25. Ship's track showing UOR deployment during AMT3
Figure 26 Contoured vertical sections of a) Temperature (°C; 0.1°) b) Chlorophyll fluorescence (mg m⁻³; 0.1), c) Salinity (PSU; 0.05) for UOR tow A313 across the equator.
4.6 Sea Surface Temperature

4.6.1 Radiometric Observations of the Sea Surface and Atmosphere (ROSSA) 1996
C J Donlon, University of Colorado/Southampton Oceanography Centre/BAS
T J Nightingale, Rutherford Appleton Laboratory, UK

Experiment Summary
The ROSSA experiment has operated within the framework of AMT-3 and the measurements made complement the biochemical measurements made by the AMT team. ROSSA is concerned with both the accurate validation of precision satellite sea surface temperature observations (such as those made by the ERS-2 Along Track Scanning Radiometer, the NOAA Advanced Very High Resolution Radiometer and the ADEOS Ocean Colour Temperature Scanner), and also the investigation of the small scale processes which in combination, are thought to govern the magnitude and variability of the SSST when referenced to a sub-surface bulk sea surface temperature (BSST). Such processes include the momentum flux (wind stress), the longwave, sensible, solar and latent heat fluxes which in combination define the thermal state of the air sea interface.

<table>
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<th>Instrument</th>
<th>Parameter</th>
<th>Location</th>
<th>Accuracy</th>
</tr>
</thead>
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<td>Skin SST</td>
<td>Forward mast</td>
<td>0.15 +/- 0.1K</td>
</tr>
<tr>
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<td>0.21 +/- 0.1K</td>
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<td>SISTeR</td>
<td>Skin SST</td>
<td>Forward mast</td>
<td>0.1 +/- 0.05K</td>
</tr>
<tr>
<td>TH ?</td>
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<td>Monkey Island</td>
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</tr>
<tr>
<td>Thermal Camera</td>
<td>Skin SST (2D)</td>
<td>Monkey Island</td>
<td>0.1 +/- 0.1K</td>
</tr>
<tr>
<td>OPHIR MISTRC</td>
<td>Skin SST</td>
<td>Bow</td>
<td>Faulty for whole trip</td>
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<td>Port flank</td>
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<td>Roughness</td>
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</table>

Table 1. Summary of instruments installed on the RRS James Clark Ross for ROSSA 1996.

Instrumentation
Table 1 summarises the measurements made during ROSSA 1996. Two, solid state, single channel TASCO-THI-500 radiometers were attached to the forward mast of the JCR where one instrument views the sky and a second the sea surface. These data were logged to a Campbell Scientific CR-10 data logger at the base of the JCR mast. Storage capacity was 12 hours and the system required 2 daily backups. Figure 27 shows the coverage of THI-500 data obtained during ROSSA 1996. A sky and sea view is necessary to return a true SSST as the emissivity of water is less than unity. Consequently a small portion of the measured sea signal is in fact sky signal (at typically much lower temperatures than those returned from the sea surface) is reflected at the sea surface into the sea view radiometer. By measuring the downwelling sky term using an identical radiometer to the sea measurement, the sea measurements can be corrected for the effect of changing sky temperatures due to the passage of clouds. Figure 28 shows typical traces from the sky and sea viewing instruments. This figure shows in the sky radiometer trace a relatively clear sky (low temperatures) which
is perturbed by the passage of 2 cloud banks (higher temperatures). Calibrations for this instrument were performed at the CASOTS workshop/meeting held in Southampton in June 1996 using precision black body units operated inside temperature controlled rooms. These experiments showed that the TASCO instrument remains very linear over the typical temperature range expected during the AMT cruises. There was no appreciable shift in offset or gain as the temperature of the instrument/logger was modified. Calibrations were again performed in Montevideo, and prior to arrival in Stanley.

The Scanning Infrared Sea surface Temperature Radiometer (SISTeR) designed and built by Tim Nightingale (RAL) was deployed during ROSSA 1996 using a specially designed mount plate attached to the JCR front mast. This instrument uses a scanning mirror arrangement to view the sea surface, the sky, a hot calibration source and finally, a cool calibration source. This is the first deployment of the instrument under oceanic conditions. After some initial problems, the SISTeR radiometer began to deliver what appear to be the best radiometric SSST measurements on September 25th. The instrument was monitored carefully throughout the experiment as the current design required protection from rain and sea water spray in poor weather conditions. This was achieved by constructing a door arrangement that could effectively protect the instrument aperture from serious water ingress. On extremely poor days, the entire instrument was wrapped in a plastic bag. These data from the core SSST observations for the ROSSA 1996 experiment and as a calibration source for the TASCO radiometers which will be used (if possible) to ‘patch up’ the SISTeR data record during spells of potentially poor weather when the SISTeR instrument was non operational. Figure 29 shows the SISTeR data transects collected during ROSSA 1996. The break after the 18th October is due to a mid experiment calibration using a precision black body radiance source. This was required as the scan mirror of the instrument was contaminated and required replacement. Contamination was originally thought to be salt build up on the mirror but careful inspection soon demonstrated that this was not the case. It would appear that the aluminium substrate used to take a rhodium mirror coating had corroded and ‘burst’ through the mirror. A second mirror was fitted and a calibration performed. This was checked again on October 13th. Calibrations were performed in Montevideo and the mirror inspected which showed less contamination than the predecessor. In future a new mirror design will be implemented on this instrument.

**OPHIR MISTRAC**

This multichannel infrared radiometer was installed successfully on the bow of the JCR using a mount plate engineered at the University of Colorado, USA. Unfortunately, serious problems with the connecting cables that run from the radiometer to the main electronics unit meant that the OPHIR radiometer was unusable for the majority of the experiment. The error reported from the instrument concerned the chopper motor speeds for the optical heads. The instrument carries two independent optical trains one for shortwave and a second for longwave SSST observations. Both chopper drives seemed to be inactive and after several days, the cable in question was finally traced to a +5v return for the optical head chopper motor drives. This was eventually reconnected with great difficulty and the instrument powered up once again. The chopper motors screamed a hellish noise and failed to turn. Consequently, the OPHIR radiometer has been repackaged for shipping back to the USA where a full investigation will be conducted. The advantage of the MISTRAC radiometer over the other instruments used during ROSSA 1996 is that it had several short and longwave channels utilising both polarised and unpolarised radiation in an attempt to minimise sky radiance contamination.
Trailing thermistor
Following the recommendations of the CASOTS meeting on sea surface skin temperature (SOC, June 1996), a bulk SST was required at a depth of 0.1 m or less. This was achieved using a specially designed thermistor arrangement which was trailed from the port side of the ship. Initially the thermistor cable alone was used to trail the instrument which was only marginally successful. A heavy weight was attached to the cable which worked well for 2 days at which point the instrument cable parted. A second arrangement was made using a steel cable to carry the weights to which the thermistor cable was attached. This worked well for all of the cruise although several re-termination’s at the sensor head were required due to steel wire ends rubbing on the thermistor cable. This instrument was brought inboard during poor weather. The sensor output was taken to the BAS Ocean Logger RhoPoint connection box and logged continuously via the Ocean Logger system.

Eppley Pyranometer and Pyrgeometer radiation sensors
These instruments were mounted on the radiation sensor table of the JCR on the forward mast using specially designed gimbal mounts. Data was logged via a MAC 17 serial data logger to a Toshiba portable laptop PC. This system has functioned reliably for the entire experiment and a typical data trace from the Solarimeter (0.3 -3μm) and the Pyrgeometer (5 - 50μm) is shown in Figure 30. These data will be used to compute the fluxes of long and shortwave radiation at the air-sea interface.

IOS Psychrometer
An IOS WOCE standard psychrometer was installed to the JCR mast hand rail using a stub scaffold pole to ensure that contamination of the PRT sensors by convection from the ships decks was minimised. The instruments output was logged to the BAS Oceanlogger system using standard RhoPoint interfaces. These were configured by Paul Woodroffe prior to sailing from Grimsby.

Radiosonde system
In conjunction with the UK meteorological office and BAS, a radiosonde release was made each day at approximately 10:30 local time. The system comprised of a VHF aerial, receiver unit and Vaisala PP11 data processor unit. Figure 31 shows the positions of all radiosonde releases made during ROSSA 1996. 5 sondes were unusable due to incorrect pressure sensor readings, no carrier frequency or no data frequency. Figure 32 plots a typical radiosonde ascent showing the temperature and humidity profile of the atmosphere up to the 30 hPa pressure level (~9 - 10km). These data will be used together with the SSST and satellite SST observations to derive atmospheric correction algorithms for use with satellite SSST observations. All data were reported to the UKMO in near real time via the ships radio officer. Thanks go to Jenny Rust for organisation and operation of the radiosonde system.

Marine Radar system
This was deployed from the JCR mast island to view the sea surface at an angle of 45 degrees. The radar was an X band (10 cm) unit sampled at 512 Hz to standard PC via a 16 bit A/D data acquisition board. Unfortunately for the majority of the experiment, this system was unavailable due to the lack of a configuration file. This was forwarded 2 days before the Montevideo port call and the system brought on line. Although only a short data set was collected, remembering sea conditions for the majority of the experiment had been very light indeed, the wind steadily increased from 1 -2 Kt to 35 Kt overnight. SISTeR radiometer data and radar data were simultaneously collected during this period (15th - 17th October 1996). Several data sets were also obtained while alongside in Montevideo. This system was deployed to measure sea surface roughness and to specifically correlate temperature
changes with roughness characteristics. This system will undergo full calibration on return to the USA at the University of Michigan.

4.6.2, Sea Surface Radiometry
Yasunori Terayama, Saga University and NASA

Purpose of the work
By using the satellite image data, we can know the sea surface temperature on wide area. But the image data include the influence of atmosphere, aerosol, antenna pattern of the satellite and problem of sensor resolution etc. When the method which remove these influence is used, we need the truth data at a point of the satellite observation. So, we can compare with the superiority of some methods, and can estimate more truthfully sea surface temperature. The purpose of this work on the AMT3 cruise is to collect these truth SST data.

Methods
I obtain the truth SST data with two equipments, and get the measurement on atmosphere with a sunphotometer. These three equipments is the following.

Thermal Infrared Camera (TH3100)
This Camera (TIC) can obtain the sea surface temperature image on the looking area. The TIC is composed of camera part and control part made by NEC SANEI controled by GP-IB interface. On GP-IB interface, SUN workstaion send the control command, and the interface is used also to get the SST data and condition data with GMT. TIC is put on the top floor of ship, shot the sea surface of the ship's left side. This TIC has about 50sec interval time, keep on running during clear day and night.

Handy type thermotracer (KEYENCE IT2-60)
This thermotracer (TH) can obtain value of SST. It is connected to a data logger, the SST data is send with GMT time data. This TH has 3sec interval time, and keep on running all day and night.

Sunphotometer (EKO MS-120)
This sunphotometer can obtain the data of wavelength from 368nm to 862nm. It is run by my hand operate, measure at clear day without cloud.

Data type (TOTAL: about 1GByte)
TIC: text and 8bit image raw data saved DDS Tape for Windows 95
text part: Condition data with GMT and TIC's sensitivity, etc
image part: 256*207, 8-bit image data (truth SST is calculated by using before condition data)
TH: text data with GMT
Sun: text data with GMT
Fig 28.
Fig 30
Fig 31

Appendix A: Addresses and contact numbers for cruise participants

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phone: 301-286-9503
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Net: stan@ardbeg.gsfc.nasa.gov
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<th>Phone</th>
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<td>Ignacio Huskin</td>
<td>Zooplankton, Universidad de Oviedo</td>
<td>phone</td>
<td>0034 85 104790</td>
<td></td>
<td>fax</td>
<td>e.mail <a href="mailto:ihuskin@sci.cpd.uniovi.es">ihuskin@sci.cpd.uniovi.es</a></td>
</tr>
<tr>
<td>Cliff Law</td>
<td>Bio gases, Plymouth Marine Laboratory</td>
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<td>direct line</td>
<td>(01752) 633425</td>
<td>switchboard</td>
<td>(01752) 633100</td>
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<tr>
<td>Emilio Maranon</td>
<td>Productivity, Southampton Oceanography Centre</td>
<td>phone</td>
<td></td>
<td></td>
<td>fax</td>
<td>(01703) 596110</td>
</tr>
<tr>
<td>Yoshihisa Mino</td>
<td>NASA Optics/pigments, Institute for Hydropheric-Atmospheric Sciences, Nagoya University</td>
<td>e.mail</td>
<td></td>
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<tr>
<td>Tim Nightingale</td>
<td>ROSSA, Space Science Dept, Rutherford Appleton Laboratory</td>
<td>phone</td>
<td>+44 1235 445688</td>
<td></td>
<td>fax</td>
<td>+44 1235 445848</td>
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<tr>
<td>Koji Suzuki</td>
<td>NASA Optics/pigments, Institute for Hydropheric-Atmospheric Sciences, Nagoya University</td>
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<tr>
<td>Yasunori Terrayama</td>
<td>NASA/ROSSA, Saga University</td>
<td>e.mail</td>
<td></td>
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<td><a href="mailto:terra@is.saga-u.ac.jp">terra@is.saga-u.ac.jp</a></td>
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<tr>
<td>Mike Zubkov</td>
<td>Nanoplankton/production, University of Southampton</td>
<td>phone</td>
<td>(01703) 594387</td>
<td></td>
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<td>Biomedical Sciences Building</td>
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<td><a href="mailto:m.v.zubkov@soton.ac.uk">m.v.zubkov@soton.ac.uk</a></td>
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58
### Appendix B. Station times and positions

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291-296 Montevideo

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**Notes:**

1. No CTDs - gantry failure
2. Limited cast due to bottle misfires
3. Gantry failure: extra 4hrs on station
4. No hydrographic station due to EEZ restrictions
5. CTD wire stranded & fouled on washer
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<td>Plankton net redeployed (200m, 3rd cast); CTD recovered</td>
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<td>1125</td>
<td>Plankton net recovered</td>
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<td>1128</td>
<td>Plankton net redeployed (20m, 2nd cast); CTD recovered</td>
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<td>1131</td>
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<td>1150</td>
<td>Drift net deployed</td>
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<td>CTD deployed; light meter recovered, buoy deployed</td>
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<tr>
<td>1210</td>
<td>CTD recovered; Plankton net recovered</td>
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<tr>
<td>1215</td>
<td>Drifting buoy recovered</td>
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<td>1216</td>
<td>Freefall buoys deployed</td>
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<tr>
<td>1225</td>
<td>Freefall buoys recovered</td>
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</table>
1230  Station complete; UOR deployed to 360m
1455  UOR recovered
2215  XBT launched

05/10/96  279

0515  XBT launched
0925  XBT launched
1055  Stopped on station #13
1058  Optical rig deployed
1105  Plankton net (1st cast) deployed; CTD deployed
1114  Plankton net recovered
1116  Plankton net redeployed (20m, 2nd cast)
1118  Plankton net recovered
1122  Plankton net redeployed (200m, 3rd cast)
1125  CTD recovered
1130  Optical rig recovered
1132  Optical rig deployed
1134  Optical rig recovered
1136  Drifting buoy deployed; plankton net recovered
1140  Drift net deployed
1148  CTD deployed
1155  Drifting buoy recovered
1210  Drift net recovered; CTD recovered
1215  Station complete
1223  UOR deployed
1225  XBT launched
2013  XBT launched

0° 00.0  W 26° 21.3
2016  Vessel crosses equator
2230  XBT launched

06/10/96  280

0040  XBT launched
0320  XBT launched
0525  XBT launched
0707  UOR recovered
0726  XBT launched

S 2° 23.4  W 27° 27.2
1055  Stopped on station #14
1100  Plankton net deployed (1st cast); optical rig deployed
1103  CTD deployed
1113  Plankton net recovered
1116  Plankton net redeployed (20m, 2nd cast)
1120  Plankton net recovered
1122  Plankton net redeployed (200m, 3rd cast); optical rig recovered; CTD recovered
1128  Drifting buoy deployed
1136  Plankton net recovered
1140  Drift net deployed
1145  Drifting buoy recovered
1150  Freefall buoys deployed; CTD deployed
1210  Freefall buoys recovered; CTD recovered
1212  Drift net recovered
1220  Station complete
1223  UOR deployed to 360m
1225  XBT launched
1625  XBT launched
1758  UOR recovered
2130  XBT launched
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15/10/96 289  
S 35°42.7' W 49°24.2'  
0305 XBT launched  
1230 Stopped on station #25  
1234 Plankton net (1st cast), optical rig deployed  
1242 Drifting buoy deployed  
1245 CTD deployed  
1250 Plankton net recovered  
1251 Plankton net redeployed (2nd cast)  
1254 Plankton net recovered  
1255 Plankton net redeployed (3rd cast)  
1310 Drifting buoy, CTD, optical rig, plankton net recovered  
1315 Drift net deployed  
1326 Freefall buoys deployed  
1338 CTD redeployed  
1345 Drift net recovered  
1350 Freefall buoys recovered  
1400 CTD recovered  
1405 Station complete  
1410 XBT launched; UOR deployed  
1705 UOR recovered  
S 36°05.4' W 50°03.4'  
1710 Stopped on station #26 (optics only)  
1712 Reference and rocket deployed  
1732 Reference and rocket recovered  
1743 Optical rig redeployed  
1812 Optical rig recovered  
1815 UOR deployed to 360m  
2010 UOR recovered  
2011 XBT launched  
2105 UOR redeployed  

16/10/96 290  
S 37°48.0' W 52°11.6'  
0300 XBT launched  
1145 UOR recovered  
1150 Stopped on station #27  
1155 Plankton net deployed (1st cast)  
1157 CTD deployed to 200m  
1200 Optical rig deployed  
1205 Drifting buoy deployed  
1208 Plankton net recovered  
1211 Plankton net redeployed (2nd cast)  
1213 Plankton net recovered  
1215 Plankton net deployed  
1225 CTD recovered  
1227 Optical rig recovered
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## Appendix E. Meteorological record for AMT3

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296

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| 1600  | Good | ESE | 2   | 1027.7 | 7.8  | 8.6 Smooth Mod | SKC  |       |           |                      |
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| We23  | 0400 | Good | NxE | 3   | 1025.4 | 8.9  | 9.2 Slight Low | SKC  |       |           |                      |
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| 1200  | Good | NW  | 6   | 1023.8 | 10.4 | 9.9 Mod Low     | 7/8 Cs, Ac |       |           |                      |
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| 296   | 0000 | Good | NW  | 4   | 1021.4 | 10.0 | 9.7 Slight Low | 7/8 St |       |           |                      |
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Notes:
- HPLC: High Performance Liquid Chromatography
- CHLA: Chlorophyll a Content
- FLUOR: Fluorescence
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Appendix I. Optical data logs:  a) 'Seafalls'

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<td>1252</td>
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<td>Better sky conditions than for SeaOPS cast.</td>
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<td>1249 1257 X X</td>
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<td>Almost completely clear sky.</td>
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<td>106      Good data to compare with last UOR undulation.</td>
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### Appendix I. b): 'Sea

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