Institute of
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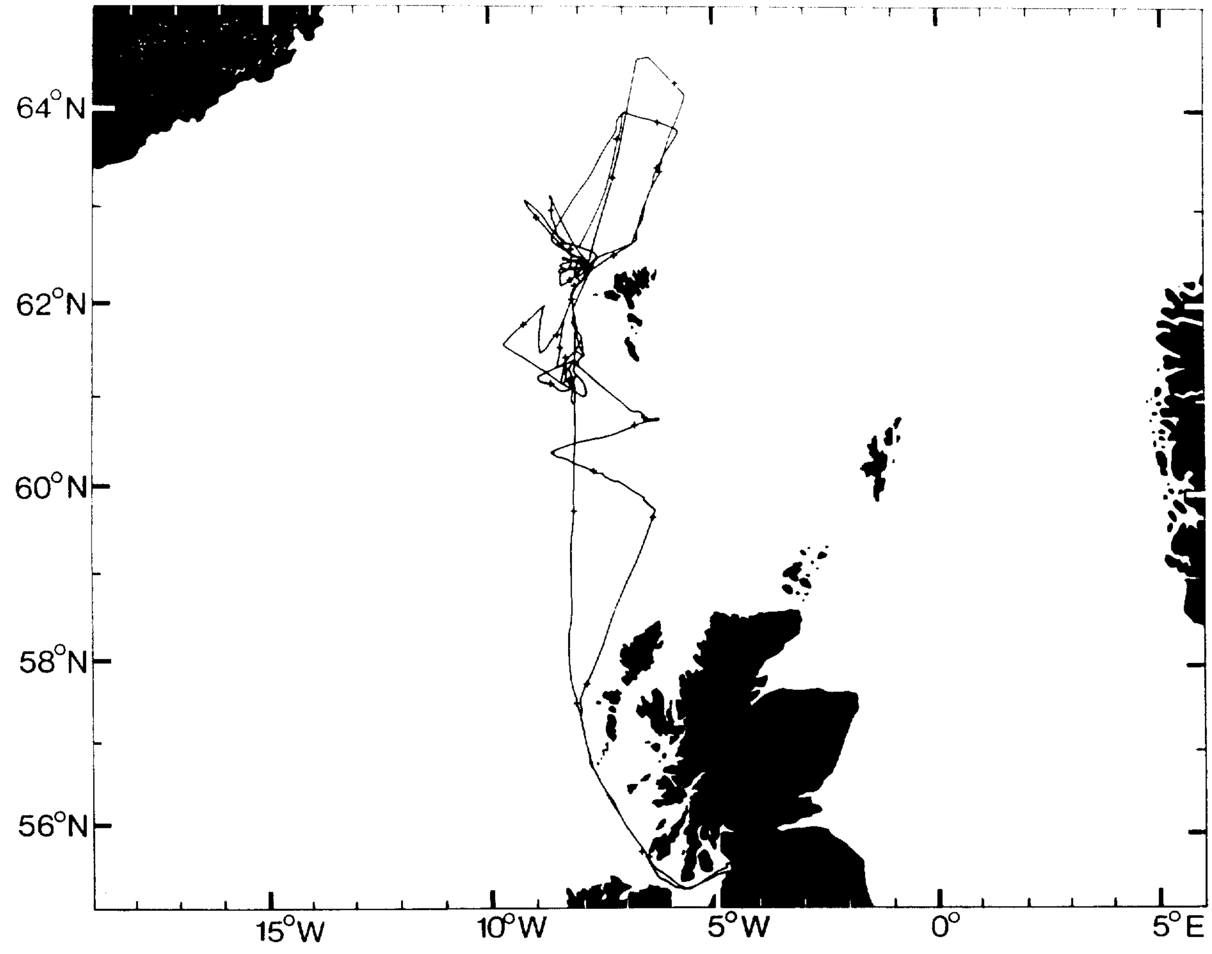
RRS Charles Darwin Cruise 43

20 Oct - 22 Nov 1989

Air sea interaction and oceanography off the Faeroes

Cruise Report No 227 1991



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CRUISE REPORT NO. 227

UMIST CRUISE REPORT 89/1

RRS CHARLES DARWIN CRUISE 43
20 OCT-22 NOV 1989

Air sea interaction and oceanography off the Faeroes

Principal Scientists
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1991

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ABSTRACT

RRS *Charles Darwin* Cruise 43 in October to November 1989 was a joint UMIST/IOSDL cruise to the Faeroes region. The aims were to investigate the transfer of momentum, heat, water, and aerosols between the atmosphere and ocean, particularly under conditions of high winds or of changing sea state, and to continue investigations of the hydrographic structure of the Iceland-Faeroes front region, and of the overflow of dense cold water from the Norwegian Sea, through the Faeroe Bank Channel.

KEYWORDS

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ISSUING ORGANISATION

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STAFF STATIONED ON FAEROES

CLAYSON, Charles	IOSDL	Ocean Instrumentation

ITINERARY

RRS Charles Darwin sailed from Troon, Scotland, on October 20th, 1989 and steamed directly to the working areas, the Faeroe Bank Channel, and a region to the northwest of the Faeroes (Figure 1). At the end of the cruise the ship returned to Troon, docking on 22nd November 1989.

OBJECTIVES

Overall objectives

The scientific work on *RRS Charles Darwin* Cruise 43 was undertaken jointly by the Institute of Oceanographic Sciences Deacon Laboratory (IOSDL), and the Atmospheric Physics Research Group of the University of Manchester Institute of Science and Technology (UMIST). The overall aims were:

(i) to investigate the transfer of momentum, heat, water, and aerosols between the atmosphere and ocean, particularly under conditions of high winds or of changing sea state (UMIST,IOSDL);

(ii) to continue investigations of the hydrographic structure of the Iceland-Faeroes front region, and of the overflow of dense cold water from the Norwegian Sea, through the Faeroe Bank Channel (IOSDL).

By scheduling a 35 day cruise to the Faeroes area in October to November, it was hoped to provide the mix of weather conditions required for the meteorological work (aim (i)), while allowing enough good weather for the oceanographic operations (aim (ii)). In the event, the weather experienced (see Weather Summary below) included winds of up to 25 m/s, with rapid changes of sea state, and large variations in atmospheric conditions. More periods of higher wind speed would have been desirable for the aerosol measurements, however the periods of calmer weather allowed the oceanographic work to be successfully completed.

Method of Operation

A particular feature of the cruise was that combining meteorological and oceanographic research resulted in the ship being worked very efficiently. Lower wind periods were generally of lesser meteorological interest and, during such episodes, oceanographic work could proceed whilst aerosol probes could be serviced and meteorological data processed. In rougher conditions, the ship hove to for meteorological observations. At this time, the salinity samples could be processed, and the hydrographic data analysed.

Whilst, in principle, the meteorological observations could be continued during ship transit, most of these measurements were obtained with the ship hove to in order to reduce shipinduced flow distortions. Also, to ensure satisfactory aerosol sampling, without risk of contamination from various ship emanations, the optical particle counters had to remain oriented to within about 45° of the prevailing wind. When appropriate, meteorological and aerosol samples could be obtained at CTD stations by remaining hove to for periods of an hour or so before proceeding with the CTD run.

Objectives - IOSDL Meteorology

The specific aim of IOSDL meteorological research was to relate the wind stress to the wind speed, atmospheric stability, and sea state, and also to wind-induced changes in the near surface currents. The wind spectra, needed to estimate the stress using the inertial dissipation technique, were obtained using a propeller-vane sensor and a new type of sonic anemometer loaned for evaluation by Gill Instruments Limited.

Wave measurements were obtained using a Shipboard Wave Recorder (SBWR), and from a moored Wavec buoy. Because the ship would not always be within radio range, the buoy was moored within range of a receiving station which was placed on the Faeroes. The mean meteorological variables were measured near the Wavec on a meteorological buoy, and on the ship using an IOSDL MultiMet system. The near surface currents were measured by the ship's Acoustic Doppler Current Profiler (ADCP), and by a Vector Averaging Electromagnetic Current Meter (VAECM) buoy moored near the Wavec. Deployment and recovery of the three surface buoys was successfully accomplished and good data obtained.

The sea surface temperature, needed to calculate atmospheric stability, was measured on the ship using a trailing thermistor, a Thermosalinograph, and an infrared radiometer. Since the latter instrument was under evaluation, the area of sea surface viewed by the radiometer was recorded on video to allow later analysis for foam cover, sun reflection, and surface roughness.

Recording and initial processing of most of these data was performed on the ship's Sun based computer system, the sensors being either connected directly through "level A" interfaces, or indirectly by logging the data on PC systems and transferring the data by disc. These arrangements generally worked very well, allowing the data to be evaluated in near real time. However the large quantity of data sometimes caused problems; desirable improvements to the Sun systems are discussed below (section 11 of the Project Reports).

Objectives - UMIST Meteorology

The major objectives being addressed by the UMIST Group consist of determining the factors which influence the concentration of sea-surface generated aerosol particles in the marine atmospheric boundary layer and to study their potential contribution to the vapour flux. Additionally, the fluxes of momentum, moisture and heat, under various meteorological conditions, are being investigated by means of the dissipation technique. A further objective is to attempt the direct measurement of these fluxes and of the aerosol particulates by eddy correlation methods. Finally, studies are being undertaken of the composition of the smaller aerosol components in relation to their air mass origins.

In order to achieve these objectives, instrumentation capable of providing meteorological information with a high degree of temporal resolution were required. A high level of redundancy in the measuring devices was sought to minimise the impact of instrument malfunctions upon the research project. To this end, three separate instruments were available for measuring three-dimensional wind field, two for water vapour density observations (including a new device developed at UMIST) and two for recording high frequency air temperature observations, as well as slower devices for measuring baseline wet and dry bulb temperatures. Similarly, for the aerosol observations, a total of eight optical particle counters were available, with four probes operational at any given time, plus a further aerosol counter, on loan from University College, Galway (UCG), for estimating aerosol composition from its volatility. Air mass characteristics were determined by means of instruments for measuring radon daughter product concentrations and an aethalometer, again on loan from UCG, for recording the elemental carbon content of air. Each of the instruments is described in more detail in the relevant sections below.

Most of the instrumentation was mounted on the forward mast with the wind field instruments being fixed to the mast platform. A group of aerosol samplers, together with the hygrometers and the sonic temperature device, were fixed to a pallet which could be raised to a position just below this platform. The UCG aerosol probe and equipment for measuring air mass characteristics were located on the wheelhouse port deck.

A base sampling frequency of 40Hz was adopted to maximise the information available from most of the instrumentation, especially the wind field measurements. More slowly varying analogue parameters, together with aerosol particle spectra, were sampled every second. A slower data rate of one-tenth the above was available for less interesting baseline periods but was rarely used.

Such fast data sampling over extended periods places considerable demands upon the data logging and recording system. After careful consideration of the various options, optical WORM disk drives were chosen as the primary data storage medium and have dealt successfully with the data (in excess of 2000 Mb) recorded during this project. The details of the UMIST-developed data handling system are described below (Project Report 11.4).

Objectives - IOSDL Oceanography

The oceanographic component of the cruise was aimed at pursuing improvements in estimates of the fluxes of water between the N Atlantic Ocean and the Norwegian Sea as a contribution both to the ICES NANSEN project and to the World Ocean Circulation Experiment. The studies carried out on this cruise extend those made by IOSDL on *RRS Challenger* cruise 15/87, *RRS Discovery* cruise 174 and *RRS Charles Darwin* cruise 42.

The geographical foci of the work were to the north of the Faeroes where CTD sections were worked across the eastward-flowing modified N Atlantic water and in the Faeroe Bank Channel. The combination of CTD sections for the derivation of geostrophic shear profiles with currents determined from the ship-mounted ADCP will be used to make transport estimates in these two locations.

The CTD/ADCP combination was supplemented with XBT observations to increase the spatial resolution of the sections. Cruises 42 and 43 also presented an opportunity to carry out a further evaluation of the ATTOM (Acoustic Travel Time Ocean Monitor) devices which effectively act as a very long baseline (12 nm) acoustic current meter.

General Comments

This was a long cruise, lasting 34 days without a port call. Meteorological observations over a period of several weeks were necessary to ensure an acceptable probability of a wide range of meteorological conditions. While the combined use of the ship for oceanography and meteorology worked very well, it was only possible because the weather varied between calm to moderately rough conditions. These variations in working regimes provided some relief for the scientific personnel, despite many being fully involved in both types of work. The ship's officers and crew performed their duties consistently and professionally while experiencing no such relief. Had the weather been continually rough during the cruise, which is possible given the region and season, both scientists and crew would have become exhausted and performance would have suffered. Where it is geographically possible, as it was in this case, it is recommended that future cruises of this length should be scheduled with a mid-cruise port call.

On such a long cruise food plays an important role, affecting the morale of all the ship's personnel. It seemed therefore particularly insensitive to run down stocks to the point at which the catering staff had difficulty in providing adequate and varied menus. Much of the food consumed on this cruise was obviously very old, having been purchased during the vessel's world cruise from Chile or even from Australia and New Zealand. Some may even have sailed with the vessel from the UK almost 3 years ago. Many of these items were well beyond their "sell by" date, some by a year or more.

The failure to have an adequately victualled vessel is hard on all staff, but particularly on the catering personnel who have to face the inevitable complaints. Had the vessel been one on charter to NERC it seems certain that the owners would have been taken to task over this matter.

NARRATIVE

The *RRS Charles Darwin* left Troon at 293/1630 (day number/time GMT) and proceeded to the Faeroe Bank Channel region (61°15N to 61°30N, 8°W to 8°20W) where several moorings had been deployed on *RRS Charles Darwin* cruise 42. These included five subsurface current meter moorings and one of a pair of Acoustic Time Travel Monitor (ATTOM) moorings. Following an XBT drop to confirm the thermocline depth the second ATTOM mooring was deployed at 295/0954, the moorings were checked acoustically, and the ship proceeded to the surface mooring site northwest of the Faeroes arriving at about 295/1630.

Having determined a position, near the Faeroese 12 mile limit, at which the Wavec signals could be reliably obtained by the receiver positioned on Kollur headland, an ADCP calibration was commenced at 295/1700 and continued until 295/2000. An XBT line was run 60 nm northwest along the Iceland - Faeroes shelf, finishing at 296/0140 before returning to survey the Wavec site, the mooring being deployed at 296/1120 at 62°23N 7°44W. The meteorological buoy and VAESAT buoy were deployed at 296/1347 and 296/1506 respectively 1 nm northeast and 1.25 nm east of the Wavec. The ship then hove to near the moorings for meteorological sampling which continued overnight and throughout day 297 in 11 m/s winds, initially blowing off the Faeroes but then from the southeast following a 100 degree wind shift at about 297/1430.

With the prospect of a decreasing wind, the moorings were inspected at 298/0740 to 298/0900 before heading toward the Faeroe Bank Channel for a CTD survey. The winds remained above 10 m/s however, and the vessel hove to between 298/1330 and 298/1655 for meteorological sampling before proceeding to complete an XBT section (from 61°41'N 7°56'W at 298/1815 to 61°21'N 8°31W at 298/2207). The ship then returned north to the surface mooring site, checked the moorings (at about 299/0930), and continued northward to begin an XBT and CTD section across the Iceland-Faeroes front from 62°38'N 6°47'W (at 299/1253) to 64°09'N 5°34'W (at 300/1105).

By the end of this section the observed sea surface temperatures had not fallen below about 6.5°C. In order to seek lower sea temperatures the ship proceeded about 30 nm northwest to 64°31N 6°23W, but the lowest temperature found was about 6.25°C. Meteorological sampling was performed from 300/1400 to 300/1700 under light winds (less than 5 m/s) and opposing swells. The ship then returned south to arrive at the surface moorings at 301/0515, the moorings being visually checked at first light.

From 301/1036 to 303/0933 the ship remained hove to for meteorological sampling in the vicinity of the surface moorings. The winds varied between about 10 to 13 m/s with a rapid fall in wind speed and veer in direction at a frontal passage on about 303/0500. The relatively large concentration of aged small aerosol fell substantially as the front passed. With the prospect of weaker winds a second CTD line was commenced extending north across the Iceland-Faeroes front, from 62°30N 7°59W at 303/1050 to 63°58N 6°59W at 304/0750. A moderate swell had commenced from evening of day 303, and the ship was rolling in 8 m/s winds during meteorological sampling which continued until 304/1012, when course was set to return to the surface moorings, arriving in their vicinity at 304/2130.

Meteorological sampling was conducted overnight in 8 m/s winds, the surface moorings were checked visually at 305/0800, and the ship proceeded to the Faeroe Bank Channel for a CTD line commencing at 61°30'N 7°55'W (305/1650) and ending at 61°14'N 8°14'W (306/0200) where the vessel remained hove to for meteorological sampling. Winds had now freshened to about 10 m/s from the southeast. Sampling was completed by 306/1300 and following a 6 hour passage, a repeat of CTD line "Q" (*RRS Charles Darwin* Cruise 42) was commenced from 61°35N 9°45W (306/1912) to 62°01'N 8°46'W (307/0350). An XBT section was then run southwards to the southern end of cruise 42 line "P" which was repeated with CTD stations from 61°28'N 8°56'W (307/0700) to 61°44'N 8°26'W (307/1330). Meteorological sampling then continued until 307/1530 in 12 m/s northwesterly winds and a sea-air temperature difference of 2°C, before returning to the surface moorings. Further meteorological sampling was performed overnight from 307/1934 to 308/0734, providing a dataset in decreasing wind conditions (from 12 m/s to 5 m/s). The air was 4°C colder than the sea at this time.

Having visually checked the surface moorings by 308/1135 the ship moved to the area of one of the deepest points in the Iceland Faeroes ridge to commence, from 308/1416, an intended 24 hour XBT and ADCP survey within one nautical mile of 62°30N 8°26W. However the wind freshened from about 308/2000 and by 309/0530 the 15 m/s winds and rough seas made keeping station, and XBT launching, impracticable. Commencing with the period of rising winds, meteorological samples were continued with 10 to 15 m/s winds and sea-air temperature differences of up to 7°C. The aerosol samples during this period showed very low levels of land contamination. Sawtooth variations occurred in the high frequency relative humidity measurements. By 310/0842 the wind had decreased to about 7 m/s, and the ship returned to the surface moorings.

A close visual inspection of each mooring, during which the ship was swept alongside the Wavec by the current, was completed by 310/1400. An ADCP calibration continued to 310/1920, and the vessel then hove to for meteorological sampling overnight. Winds freshened to 15 m/s by 311/0400 when a front brought a wind veer and decrease to 7 m/s. Following a frontal cloud clearance at 311/0730 the wind continued to decrease, and at 311/1120, course was set northeast, to begin a CTD section from 62°40'N 6°48'W on 311/1453.

The CTD section ended at 63°48'N 5°44'W on 312/0705. Winds were now under 5 m/s, an anemometer intercomparison was conducted by steaming the ship around a rotating box pattern, and the airflow over the ship was investigated by releasing smoke flares on the forward deck. An XBT and CTD section was then run back to the surface moorings on a line northwest of the outward section. This took from 312/1114 (63°51N 5°55W) to 313/1148 (62°31N 8°06W). The surface moorings were visually checked by 313/1340 and at 313/1450 the ship hove to for meteorological sampling until 314/0750 in winds of 8 to 10 m/s. During this period the high frequency relative humidity data exhibited smooth undulations.

Between 314/0830 and 314/1215 the meteorological buoy was recovered by using the inflatable boat to fit a recovery line, which was then grappled from the ship. Problems with the outboard motor prevented lifting strops being fitted to the other moorings, as planned, and meteorological sampling was continued overnight from 314/1600 to 315/0815 in 10 m/s winds. Using the inflatable boat, recovery strops were fitted to the Wavec buoy and VAESAT buoys before heaving to at 315/1130 to continue meteorological sampling.

During the following night the winds increased to 12 m/s and the air temperature decreased to 4.5°C. With the wind then decreasing after 316/0600, sampling was ended at 316/0725 and the Wavec was recovered by 316/1050. During the start of the recovery the upper bungee parted and, toward the end, the mooring line became caught on the ship and parted. Although this only resulted in the loss of the anchor, there was concern that the loose end of the line might remain on the surface as a hazard to other ships. A box search was conducted but the line appeared to be clear of the surface.

The VAESAT buoy was successfully recovered by 316/1335 and course was set for the Faeroe Bank Channel where a CTD section was worked from 61°30'N 7°55'W (316/2000) to 61°14'N 8°14'W (317/0235) along the line of the sub-surface moorings. The ship then stayed hove to for meteorological sampling while the winds freshened reaching 23 m/s from the west during afternoon and evening (317). Although this was cold sector air, temperatures remained high at about 10°C. The winds began to decrease after 318/0300, to 10 m/s at 318/0700.

The daylight hours of day 318 were spent recovering the subsurface moorings, which had been laid in the Faeroe Bank Channel by cruise 42. The order of recovery was "E" (318/1033), "C" (318/1253), "B" (318/1410), and "A" (318/1528). The ship then proceeded to the site of ATTOM 2 but did not achieve acoustic contact with the mooring. A CTD line was worked between the ATTOM sites, from 61°16N 8°04W (318/1728) to 61°28N 8°17W (318/2306).

For the following 3 days the ship was now in a southerly wind flow between high pressure to the east and frontal systems to the west. Meteorological sampling was continued overnight until 319/0900. The ship then proceeded to the site of mooring "D" which had not responded acoustically since being laid on cruise 42. Attempts to release the mooring failed and the only acoustic contact during a box search was the release pinger, lost during recovery of mooring "C". The ship then hove to on the site of ATTOM 1 for meteorological sampling from 319/1700 to 320/0630, the winds continuing southerly, about 12 m/s.

The ATTOM 1 mooring was successfully recovered by 320/0940, but attempts to contact the ATTOM 2 mooring failed. Meteorological sampling commenced at the ATTOM 2 site on 320/1330 and continued overnight until 321/0400. A further attempt to acoustically contact ATTOM 2 was abandoned at 321/0930 and the ship then began dragging for the first attempt to lay current meter string "D" which had parted during laying on cruise 42. This exercise was not successful however and the ship hove to for meteorological sampling from 321/2032 to 322/0730. This was a period of light winds with a cold front passage at 0600.

A second attempt to drag for the lost "D" moorings was made between 322/0900 to 322/1745 again with no success, although the remains of the first mooring may have been snagged. The ship then moved to a position (60°45'N 6°30'W) chosen to be clear of the effect of the Faeroes for the expected northeast or easterly wind. Meteorological sampling continued from 323/0025 to 323/1018 in winds of 10 to 15 m/s. A frontal passage at about 323/0500 caused a marked change in the smaller aerosol particles.

Course was then set for the west end of the Wyville-Thompson ridge to begin a CTD section from 60°25'N 8°40'W (323/1714) to 59°47'N 6°18'W (323/1118). The PES fish was brought inboard and the passage to Troon commenced. The ship docked on day 326 at 0750.

Track charts for the whole cruise, and the Iceland-Faeroes ridge and Faeroe Bank Channel working areas are shown in Figures 1 to 3. A summary of the various work performed in the cruise is shown in bar-chart form in Figure 4.

WEATHER SUMMARY

Means and Extremes

For the majority of the cruise, the paths of most of the North Atlantic depressions were from mid-Atlantic to the North Sea over mainland UK, before turning north to the Norwegian Sea. However, a sequence of depressions tracked to the vicinity of Iceland throughout the cruise period. This complex system gave rise to extended periods of calm weather, relatively clear skies (displays of Aurora Borealis were observed frequently during the first week of the cruise) and variable wind directions, interspersed with episodes of higher surface wind speeds and frontal activity. The lowest wind speeds measured were virtually calm (day 296, sea state 1), the highest was a gust of about 25 m/s (day 317, sea state 9) and the average for the cruise was in the region of 10 m/s (sea state 5). Air temperature and air-sea temperature difference also varied widely throughout the cruise: The maximum air temperature was 11°C (day 302); minimum air temperature was greater than 1.2°C (days 309, 310); the most stable air-sea temperature difference of 2°C ($T_{air} > T_{sea}$) occurred on day 302; and the most unstable air-sea temperature difference of 7°C ($T_{sea} > T_{air}$) occurred on both days 309 and 310.

Synoptic Summary

From day 293 to day 296, a deep depression, initially over Iceland, tracked northeast and filled from 954 to 986 mb leaving the Faeroes region in a southwesterly flow. A new low (990 mb) moved from mid-Atlantic to S.E. Iceland and an associated trough approached the Faeroes from the southwest. The trough passed over the ship as a cold front at 296/1300.

During the next 24 hours, a ridge of high pressure passed to the east as another depression (970 mb) moved to S.W. Iceland. The associated warm and cold fronts passed over the ship at about 297/1430 and 297/2330 respectively. During day 298, the surface winds remained at about 10 m/s and began to decrease and veer northeast at 2 m/s by midday 299.

Over the next couple of days, the Faeroes were in a region of slack air as a vigorous depression (971 mb) passed to the south over mainland UK. The warm front associated with this depression passed over the ship from the east at about 302/1000. After the warm front, the air temperature exceeded the sea surface temperature by 1.2°C. A new low (932 mb and filling) then tracked towards Iceland from the southwest and the associated fronts passed over the ship at 303/0500 and 303/1600 respectively. This depression continued to fill and track northeastwards, leaving westerly winds and troughs in the Faeroes vicinity. During day 305, cumulonimbus, of moderate height, resulted in marked variations in both surface winds and air temperatures.

This situation continued until a new mid-Atlantic depression moved quickly east, pushing the winds to a more southerly point, and passed to the south of the Faeroes on day 306. The depression then began to fill and move north to become centred over the Faeroes by midnight day 307. The low then became slow, north-eastward moving and complex, with cyclonic, variable and light winds until midnight day 310. During this period, a succession of fronts passed over the ship: at 308/0200, a cold front when the wind backed from northeast to northwest and slowly freshened to 10 m/s; and at 308/2200 a warm front passed, after which the winds continued to increase to about 17 m/s.

During the next week of the cruise, an almost identical pattern emerged, with a new depression moving towards Iceland, pushing the winds back to the south and west by 310/1800. Wind speeds at the ship declined to almost 0 m/s, from the north by 310/1200 before returning to 15 m/s southwesterlies by 311/0400. The occluded front associated with the new depression passed to the east over the area soon after this causing the winds to decline to about 7 m/s and veer to the south west. For the remainder of day 311 winds remained light south-westerlies. A depression then formed off southern Ireland and tracked across the mainland UK, up the North Sea during day 313 forcing a more northerly wind. A new depression then approached the Faeroes from the south-west during day 314 and the three low centres became a complex area moving slowly north-east by midnight day 315. During this time the winds remained around 10 m/s with variable direction tending to a northerly, leading to low air temperatures on the morning of day 316.

An anticyclone then built over the North Sea during day 316 and up to 317/0000 as a new low headed towards S.W. Iceland. Winds became light southerlies. The depression over Iceland then deepened and the high pressure retreated south. Winds became gale force westerlies (maximum gust about 25 m/s at 1300) during almost all of day 317 as first a warm front passed to the east at about 317/1000 followed at 317/1330 by the cold front. Air temperatures remained reasonably high (9.5°C) since this cold sector air had a southerly origin. The winds began to decline rapidly after midnight 318. By 318/0800, the air temperatures had fallen as the winds veered to the north and continued to decline. At midday, surface winds were merely 2 m/s. For the remainder of day 318, the winds continued to veer, but began to freshen, reaching a southerly 10 m/s by midnight. During almost the whole of 319, the winds remained constant at 12 m/s southwesterly and the air temperature slowly climbed from 8 to 9°C.

The high pressure zone over Denmark continued to dominate the weather pattern throughout day 320, winds remained southerly at about 12 m/s. A depression (997 mb) over Iceland spawned fronts, to the west of the ship, which extended from almost the North Pole to the Tropics. By day 321 at noon, a further depression had moved north, along the cold front, to be centred near the west coast of Ireland. During day 322, the high pressure zone slipped east, allowing the cold front to pass over the ship, from the south west, at 0600. A vigorous depression (966 mb) was moving from mid-Atlantic towards Biscay.

By midnight day 323, a new anti-cyclone (1037 mb) became established over Iceland and winds at the site backed to the northeast. At 323/0500 a front, trapped between the high over Iceland and the depression near Biscay, passed over the ship in 10 to 15 m/s northeasterly winds. This general situation continued throughout day 324, as the cruise came to its conclusion.

PROJECT AND EQUIPMENT REPORTS

1 Mean Meteorological variables

1.1 Introduction

In order to relate the sea surface stress to variations in wind speed and atmospheric stability, accurate measurements are required of the mean meteorological variables (wind speed and direction, air temperature, etc.). The primary source for these data were instruments situated on the foremast platform (Figure 5) where good exposure was obtained for a broad range of relative wind directions.

To obtain data values when the wind was from other directions, instruments were also situated on the main mast and on the wheelhouse top. Data from these instruments will also allow the relative merits of the different sites to be investigated, both to determine the accuracy of the ship's meteorological reports, and to assist in selecting instrumentation sites for forthcoming WOCE and BOFS cruises.

Because the ship was not always working in the vicinity of the Wavec and VAESAT moorings, a meteorological buoy was moored nearby to provide a continuous records of the mean meteorology.

(PKT)

1.2 MultiMet/Metman System

The IOSDL MultiMet meteorological logging system was installed in four days prior to sailing from Troon with the aid of a shore side crane for mast top sensors. On the forward mast (Figure 5) a Young propeller-vane wind sensor and two accelerometers were mounted for wind stress measurements, together with an aspirated psychrometer. On both sides of the mast, gimbal mounted short wave radiation sensors were deployed, with a gimbal mounted longwave sensor on the mast top. Above each of the ships met screens on the wheelhouse top a cup anemometer, wind vane, and an aspirated psychrometers were sited. Adjacent to the ship's anemometer, on the main mast, a cup anemometer and wind vane were also mounted. When in the working area the trailing thermistor SST sensor ("Soap-on-a-Rope") was deployed from a towing point on the port side foredeck. One minute means of ship's head were also recorded from the output of a Level A interface.

Data output from MultiMet was recorded by the internal Eprom logger and via RS232 connections to the MetMan System on a Master 128K microcomputer. The raw data was also logged through a Level A interface to the SUN computer system and daily plots of calibrated data were produced.

During the cruise only three of the sensors suffered any malfunctions: SST, longwave radiation, and the main mast wind direction sensor The SST sensor had to be replaced twice; on the first sensor the moulding leaked after day 301, with the second being damaged by long-line fishing tackle on day 313. The main mast wind direction sensor was unreliable from day 317 but the fault could not be identified. Signal levels from the Long wave sensor showed variations after day 316 but due to inaccessibility the nature of the fault was not determined.

Throughout the cruise MetMan was used to display calibrated MultiMet data and to record raw data to allow realtime access to the previously logged data set.

Intercomparisons were made between sensors at different locations, based on data collected between days 295-305, in an attempt to assess their performance. Comparisons were made between the wind speed, wind direction and psychrometers with the key features as follows :

i The wheelhouse psychrometers, when compared with the foremast psychrometers, showed positive variations of up to 0.5°C due to their location in relation to the ships structure - the increase in readings being accounted for by heat from the ship.

ii Comparisons between the Young and the Gill sonic anemometer showed differences of approximately 1m/s in certain wind directions. Their positions relative to the foremast suggested that the differences in readings were due to one or the other sensor lying in the wake of the foremast.

iii The main mast anemometer readings taken with a mean relative wind direction of 225 degrees differed by as much as 10m/s when compared with those from the foremast. This was believed to be due to the Inmarsat satellite communication dome shielding the sensor.

iv The offsets caused by mounting misalignments were quantified.

(KGB,RWP,ALIW,SGA)

1.3 Meteorological Buoy (Mooring 499, Figure 6)

The buoy consisted of a 2.45 m diameter toroid hull supporting a 2.5 m high aluminium alloy tower and 1 m deep steel keel. The buoy was tested in the North Sea in December 1988 and handling methods and mooring details determined. The meteorological recording package (assembled and tested on cruise 42) consisted of an Aanderaa sensor scanning unit type 511 with a 2990E (expanded) data storage unit. The sensors were all Aanderaa supplied and consisted of:

Sensor	Type No.
Anemometer	2593
Solar Radiation	2770
Wind direction	2053
Air temperature	1289A
Sea temperature	2812
Buoy orientation	2084

The anemometer was used to obtain mean and gust values. The logging package, enclosed in a modified IOSDL wave buoy canister which also contained the ARGOS satellite location transmitter and battery pack and the Novatech VHF RDF beacon, was mounted on the buoy and the all sensors connected on day 293.

Deployment was on day 296, using the technique described for the Wavec (section 5.2 below). Unfortunately during buoy release from the crane the Wind Direction vane fouled the release hook breaking off the lower vane fin. ARGOS beacon transmissions were monitored using the Handar test set, and the VHF beacon by the RDF receiver situated in the Plot (Ch.68, 156.425 Mhz). The light beacon was observed overnight (296/297) and gave good visual fixes to 5 miles. Radar detection was achieved to 3.5 miles using the ships ARPA set.

For recovery (day 314) the Sea Rider boat was used to board the buoy and remove the sensors from the tower. The temperature sensors were left connected and recording whilst other sensors were removed completely. A 10 m length recovery line was attached to the lifting point on top of the buoy tower, towed clear, and buoyed with 11" DWC floats. The recovery line was grappled from the ship at 314/1058 and recovery carried out from aft. The anchor was lifted aboard at 314/1215.

Approximately 11 days of data were downloaded to diskette using the P3059 current meter program which indicated correct sensor operation. No errors were detected in the data and a very clean record has been produced.

(IW,KMG)

2 Momentum Flux (IOSDL)

2.1 Introduction

The main aim of the IOSDL meteorological research on the cruise was to relate the wind stress at the ocean surface to the wind speed, atmospheric stability and sea state. Estimates of the wind stress were obtained by the inertial dissipation technique. In this method the turbulent fluctuations of wind velocity in the inertial sub-range of the spectrum, are used to estimate the dissipation of turbulent kinetic energy (TKE). If it is assumed that, under most conditions, the dissipation equals the production, then it is possible to calculate the sea surface stress. The method has the advantage that the measurements are taken above the frequency of the ship's motion; however the wind sensor used must be capable of being sampling at at least 1 Hz, and preferably higher.

A propeller-vane anemometer, manufactured by R.M.Young, was used on the port side of the forward mast platform. The fast-response (about 1 m distance constant) polystyrene propeller was used. This instrument was logged by two systems; an IOSDL MultiMet system connected to a BBC microcomputer, and a NEC portable PC system.

2.2 MultiMet Fast Sampling

This was the identical system which was in use on the Ocean Weather Ship *Cumulus* during winter 1988/89. An IOSDL MultiMet meteorological instrumentation system was used to sample the output from the Young propeller-vane, and fore-aft and port-starboard accelerometers at 8 Hz. The data were then processed by a BBC Master computer with ARM based second processor. Five 512 sample FFT's were averaged for each sample period of about 5 minutes. The spectra were averaged in log frequency bands and stored on hard disk. This system is designed to restart automatically if an error occurs and it functioned reliably through-out the cruise.

During the cruise the data were down-loaded from the hard disk and, after initial processing on an Acorn Archimedes to correct for sensor response, transferred into the PEXEC system on the SUN's.

(PKT)

2.3 NEC Fast Sampling

This is a new system under development and was run in parallel with the present system based on MultiMet and the ARM processor with which it will be compared.

The analog signal output of the Young propeller-vane was acquired using an NEC PC with a 12 bit ADC interface. A BASIC program was used to control three stages of data acquisition and data processing using Labtech Notebook software. The signals were sampled and stored at 8Hz, subsequently replayed at four times sampling rate and operated on in five blocks of 1024 by FFT. The resultant spectra were averaged and frequency binned before being plotted on a logarithmic timebase. The average spectra were also recorded in files with ten spectra per file.

During the cruise, modifications to the processing techniques were made by separately calculating the mean wind speeds and improving the resolution of the screen display.

For part of the cruise, the NEC based data acqusition system was reconfigured to sample the Gill sonic anemometer analog output. This was to allow comparative measurements between analog and the digital outputs of the Gill sensor. Initally the sampling rate was 40 Hz but it was subsequently reduced to 20 Hz. The analog data were then processed using the same suite of programs as used with the digital data on the SUN.

(KGB,RWP)

2.4 Gill Sonic Anemometer

Shortly before leaving Troon, a fast response Gill sonic anemometer was delivered on loan from Gill Instruments Ltd., and was installed on the port side of the foremast near the Young propeller-vane anemometer (Figure 5). One of the aims of using the Gill on this cruise was to compare its performance with that of the Young anemometer and other wind sensors.

The Gill provided both digital and analogue signal outputs. The mean wind measurement from the Gill was produced, using the MultiMet system, by sampling the analogue output at 1 Hz and averaging the values for 50 seconds out of each minute.. The mean wind measurements for the Gill and Young anemometers were in good agreement when the wind was blowing on to the port bow, so that the flow over both instruments was unobstructed, except for a small offset. After comparing the results with those of the anemometer on the mainmast, this offset was attributed to the Gill, and was corrected for by subtracting 0.5 m/s from the measured y direction value before calculating wind speed and direction. The need for this correction will need to be confirmed by wind tunnel tests after the cruise. It was also necessary to correct the direction by -30 degrees due to the Gill being aligned so as to minimise the disturbance of flow past the support arms.

The digital output of the Gill was in the form of records of x, y, z orthogonal components of wind speed together with transmission time. The sample interval between records was 0.0462 seconds, and one block of 20 such records was output per second. Data acquisition was performed by an NEC PC, which ran a GWbasic program. This used a modified version of the supplied TurboC Fastcom program to produce files holding 20 minutes worth of data (about 700 Kbytes) on the hard disk of the NEC. These were then down-loaded onto floppy disks and loaded onto the Sun, via an IBM PS2, where the data was converted into PSTAR format and the power spectral densities (PSD) produced by FFT. Approximately 600 such files were produced during the cruise.

Typically the spectra produced showed the $f^{-5/3}$ slope of the inertial subrange between 0.8 Hz to 2 Hz. This was found by plotting log plots of PSD*$f^{5/3}$ against frequency for each file, in order to show the range over which the PSD could be averaged. However, the plots also showed an unexpected increase in PSD at high frequencies, which may have been due to high frequency contamination of the signal, or to aliasing. To test this, the analogue output from the Gill was passed through a 100 Hz RC low-pass filter and sampled at 20 and 40 Hz using a 12 bit analogue to digital converter installed in an NEC PC compatible, which ran Labtech Notebook software. The spectra so produced appeared flat at moderate wind speeds, but showed high frequency noise at low wind speeds. Further investigation in this area is needed.

Preliminary estimates of the PSD values obtained for the Gill were approximately 20 percent higher than those of the fast sampled Young anemometer; as yet, the reason for this is uncertain.

(MJY,ALIW,SGA)

3 Momentum and Humidity Fluxes (UMIST)

3.1 Aims

The exchanges of momentum, moisture and heat between ocean and atmosphere are not well quantified or understood, especially under moderate and high wind conditions. Such information is vital to the improvement and application of global circulation models currently being developed for synoptic and climatic forecasting. In order to measure these exchanges, a collection of instruments, described in more detail below, have been installed to provide observations of the three-dimensional wind field, water vapour density and air temperature with a very high degree of temporal resolution. As a check upon the mean values of vapour density and air temperature, conventional wet and dry bulb temperature sensors were also installed.

3.2 Wind Velocity

Three separate instruments for measuring this parameter were employed as it was the most fundamental of our measurement programme, being vital for the aerosol observations as well as the flux studies. These comprised a Kaijo Denki ultrasonic anemometer, a Gill three-axis propeller system and a propeller bivane device, mounted on the forward mast platform, as indicated in Figure 5, in order to minimise flow distortions caused by the ship. As this location was likely to be inaccessible for the majority of the cruise, it was essential that a high degree of equipment redundancy existed. Residual flow distortions will be dealt with by rotation of the frame of reference such that long-term integration of the vertical air flow is reduced to zero.

The Kaijo Denki ultrasonic anemometer, provided on loan from British Antarctic Survey, was installed on an arm reaching forward from the forward mast platform and has worked faultlessly throughout the project. This device has a sampling rate of 20 Hz and provides good power spectral information in the inertial sub-range.

The three-axis Gill propeller anemometer, mounted on the starboard side of the forward mast, has a lower frequency response than the ultrasonic device, with a claimed distance constant of about 1 m, and has worked well as a back-up system. With suitable speed response corrections, alternative estimates of power spectral densities should be obtained from this instrument for comparison with the other wind velocity measuring devices.

The bivane anemometer consists of a lightweight propeller generator, giving true wind speed, mounted on a neutrally-balanced, two-axis bivane system providing simultaneous azimuth and elevation information. This instrument suffered slight damage to its polystyrene propeller in a hail storm during passage from Troon, and further damage to its elevation measuring system due to incorrect installation (the relevant information being hidden inside the instrument casing). Despite its delicate construction, this instrument functioned well following its repair and proper installation.

3.3 Water Vapour Density

Two separate fast-response instruments were deployed for the measurement of water vapour densities, an infra-red device manufactured by Ophir Corp, Boulder, Colorado, and a UMIST-developed capacitative instrument.

The Ophir infra-red hygrometer is a newly developed instrument which compares the short-path transmission at wavelengths of 2.5 and 2.6 μm in order to directly infer the water vapour density, and has the advantage of using sapphire windows, which are much more stable in harsh, moist marine conditions than those required by Lyman-α devices. It incorporates a chopper wheel and provides a basic response at 20 Hz, with internal software being capable of presenting averaged absolute water vapour densities, or other engineering units, at a 2 Hz repetition rate. Communication with this hygrometer is via a serial link and the instrument response mode is determined by the code sent to it. Whilst the basic instrument stood up well to the rigours of the marine salt-spray environment, a number of problems, generally associated with its internal software, were encountered and are described below.

Firstly, the device demonstrated a tendency to enter a continuous output mode where it returned output signals without being requested to do so, leading to rapid loss of synchronisation with the receiving system. Secondly, the instrument exhibited oscillations about its median absolute humidity value, limiting its effective frequency response to 5 Hz. Finally, the internal algorithms were not sufficiently accurate for the high humidity periods encountered on this cruise, as the instrument frequently flagged errors when its derived dew point temperatures and relative humidities exceeded ambient air temperature and 100%, respectively. This problem was of little consequence to the cruise objectives as the directly calculated vapour densities continued to be reasonable. In summary, this instrument should prove to be very useful, given appropriate revisions of its internal software, by the manufacturer, to overcome these deficiencies.

The UMIST-developed hygrometer (CHUM) is relatively simple in concept, being based upon the direct measurement of the dielectric constant of moist air. A prototype version of this instrument was flight tested on the UMIST aircraft, where it gave high frequency measurements (up to 1 kHz or so), but with some tendency for electrical drift. A revised version was constructed for operation on the ship which includes a dry air reference cell and a small fan to transport air through the sample volume.

CHUM worked flawlessly throughout the project, apart from occasional radio frequency interference during transmissions from VHF radios on the ship and slight frequency distortions resulting from vibrations of the pallet on which it was mounted. Calibration of the device was achieved simply by venting argon or carbon dioxide through it from small disposable welding gas cylinders, as these gases have dielectric constants appropriate for this purpose.

3.4 Air Temperature

In addition to providing three-axis wind field measurements, the Kaijo Denki ultrasonic anemometer produces a 20 Hz signal proportional to air temperature. However, this signal proved sensitive to vertical ship accelerations and to water vapour density, thus, to obtain dissipation estimates of sensible heat flux, substantial post-cruise data processing will be required to remove these influences.

During the later part of the cruise, a prototype of a very low cost ultrasonic thermometer was installed and initial results from this instrument show considerable promise.

3.5 Ship Motion

In order to derive the true three-dimensional wind field over the ocean, accurate information on ship orientation and acceleration is required. Accordingly, sensitive accelerometers and tilt sensors were installed on the forward mast platform, close to the axis origin of the three wind sensor instruments. These devices were recorded at 40 Hz so that the influences of ship motion could be removed from the high speed analogue information. Also, the ship's gyroscopic compass was recorded at 40 Hz whilst the E-M log and wave recorder were logged on the lower frequency analogue inputs.

(MHS, IEC, MKH)

4 Aerosol Measurements

4.1 Aims

A major objective of the UMIST aerosol observations was to provide measurements of particle concentrations over the size range from 0.1 to 300 μm, for a wide range of environmental conditions, using a number of optical aerosol counters. The aerosol loadings may be used, in combination with the wind field information, to determine aerosol fluxes at the observation height. The consistency of these fluxes with values derived from whitecap observations, coupled with laboratory estimates of the aerosol productivity of artificial whitecaps may then be examined. The role of these spray droplets in the exchange of moisture between ocean and atmosphere will also be investigated.

Previous experiences of operating these optical counters in the harsh marine environments of the HEXOS cruise and on the Outer Hebrides have emphasised the necessity of frequent cleaning and maintenance of these devices. Accordingly, a means of mounting these instruments was sought from which they could be readily removed for maintenance purposes, but which kept them close to the wind field observations for the purposes of eddy correlation analysis. After discussions with RVS at Barry, a sliding pallet system was devised which is described in section 4.3

In addition to the aerosol equipment described above, further apparatus for estimating the composition of the smaller aerosol fractions was installed on the wheelhouse deck. This equipment comprised an ASAS-X optical particle counter, modified to examine aerosol particle volatility as described in section 4.4, and an aethalometer for measuring elemental carbon concentrations in the aerosol described in section 4.5. The measurement of airborne radon levels as an indicator of air mass origins and history is discussed in section 4.6 and, finally, Nuclepore filter samples were taken for subsequent analysis, as mentioned in section 4.7.

The various studies of aerosol characteristics complemented each other in that comparisons between the various optical particle counters gave good confirmation that each instrument was functioning satisfactorily. Whilst the loss processes for small aerosol particles, elemental carbon and radon daughter products are not necessarily identical, preliminary results from each study were mutually consistent, thus improving confidence in the individual elements of the investigation. For example, increased small aerosol concentrations were generally associated with elevated carbon and radon levels, indicating land-based aerosol sources and confirming air mass origins estimated from daily weather charts. From differences in the results from the various methods, it should prove possible to distinguish between air trajectories passing over rural and industrial areas of land.

4.2 Particle Concentrations

The primary instruments for studying aerosol properties comprised a number of Particle Measuring Systems optical particle counters, namely Active Scattering Aerosol Probes (ASASP-300), Forward Scattering Spectrometer Probes (FSSP-100), Classical Scattering Aerosol Probes (CSASP-100HV) and an Optical Array Probe (OAP-230X).

The ASASP and FSSP are each four-range devices covering particle sizes from 0.15 to 3.0 μm and 0.5 to 47 μm, respectively. The CSASP is similar in concept to the FSSP, though it possesses only two ranges and measures particles over a reduced range from 0.5 to 32 μm. These instruments function by measuring forward scattered light resulting from the passage of individual particles through a collimated laser beam and, since they contain optical elements and sensitive photodetectors, are prone to external contamination. The FSSP was originally designed for aircraft use and, therefore, is better able to withstand the rigours of the marine environment than the other devices, especially when compared with the ASASP which utilises an open laser cavity to extend its sensitivity. The CSASP has a similar layout and casing design to the ASASP, though without the open cavity laser. Therefore, its susceptibility to environmental contamination is between that of the ASASP and the FSSP.

The OAP device, covering the size range from 10 to 300 μm, employs a different principle which involves the shadowing of a linear array of photocells by particles passing through a laser beam. Again, this instrument was developed for aircraft use and required little maintenance during the project. When operated at ground level, it is usual to draw particles into the sample volume by means of a very large intake horn to which two high-speed fans are fitted. However, this approach is not feasible on board ship and, thus, the OAP was operated without its horn, relying upon the prevailing wind to transport particles though the sampling volume with an appropriate velocity. Consequently, valid data is only obtained from this device for wind speeds in excess of about 5 m/s. Since very few of the largest sea spray particles are encountered at low wind velocities, negligible information is lost by adopting this method.

The aerosol probes worked well throughout the project, with little data lost due to equipment failures. The earth leakage trips for the CSASP and ASASP actuated on three occasions due to the ingress of water during heavy sea conditions. Although not exposed to conditions as severe as those encountered during the HEXOS project, the positioning of these instruments kept them clear of the majority of the bow spray, thus contributing to their longer periods of useful service. Obtaining substantial quantities of valid and useful data from the OAP was especially pleasing in view of the difficulties experienced with this instrument during the HEXOS project. The pallet, together with improved probe mounting arrangements, made removal of the probes for servicing much simpler and less hazardous than previously.

4.3 Instrument Pallet

The UMIST pallet was constructed from 1" stainless steel angle sections welded together to form a box-shaped space frame, as shown in figure 5, approximately 2 m wide and 1.7 m high. Plates fitted with quick release fastenings were welded to this frame so that the aerosol probes could be readily installed and removed without tools being required. The frame had tube sections bolted on the outside of each corner enabling it to slide up and down 3.5" o.d. aluminium poles. These poles were fixed between the deck and the under-side of the forward mast platform, to which a pulley was also attached so that the pallet could be raised and lowered by means of a deck-mounted hand-driven winch. Grease nipples fitted to the sliding tube sections were required to ensure that the package would slide smoothly along the tubes.

Equipment housed on the pallet comprised four PMS optical particle counters, two of which were aircraft mounting types and were hung from the top of the frame, whilst the other two were box-shaped and sat upon shelves. Also, the Ophir and CHUM hygrometers were installed on the pallet, together with the sonic temperature instrument, as their maintenance requirements were uncertain prior to the start of the cruise. Simple instruments for determining wind speed and direction were mounted forward of the pallet as correct operation of the aerosol probes requires that they point within about 45° of the prevailing wind direction, and that local wind speed is known for volume sampling rate corrections to be applied. Finally, two boxes housing power supplies, signal conditioning electronics and the pallet computer were incorporated in the lower corners.

As mentioned in a previous section, this system worked well by greatly simplifying the installation and removal for maintenance of the aerosol equipment and the cleaning and calibration of the hygrometers. Vibrations are apparent in the recorded data at about 2Hz, especially affecting the hygrometer data, which will require the application of digital filtering techniques. These oscillations may have been due resonance in the long poles, but are more likely to arise from movements of the entire forward mast. Greater rigidity of the support poles could probably be achieved by the substitution of I-section girders for the aluminium poles and the use of spring-loaded wheels for the attachment of the pallet.

4.4 Volatility and Characteristics of North East Atlantic Aerosols

This experiment aims to characterise the NE Atlantic aerosol by examining the percentage concentration of various components for a range of meteorological conditions. As most aerosol constituents are volatile at some temperature, substantial information about aerosol composition may be obtained by investigating changes in particle concentration produced by varying the temperature between ambient and about 900°C.

For this project, an ASAS-X optical particle counter, fitted with a heated intake tube, was mounted on the port side bridge walkway. The logging and control equipment were located in Plotting Lab, with the inter-connecting cables entering via a roof-top vent. However, aerosol sampled from this location was found, on occasions, to be subject to contamination from the ship when hove to. To overcome this problem, a 1.5 m extension intake was constructed to draw air, at a relatively high flow rate, into a buffer cavity mounted on top of the heated intake with the minimum of particle loss.

The aerosol was drawn through a quartz tube, heated to 900°C and allowed to cool down at a controlled rate for an hour. The sampled aerosol then passed through the optical particle counter, which covers the size range from 0.09 to 3.0 μm. The probe was controlled by a data acquisition system (PMS DAS-32), connected to a PC which provided temperature control of the heated tube and data storage.

This system functioned satisfactorily on board ship, once the problems associated with local contamination of the sampled aerosol were overcome. However, the low aerosol loadings found over the ocean required that sampling continued for extended periods of about 8 hours, so that statistically meaningful concentrations could be gathered over the range of temperatures investigated. Improved siting of this apparatus on future cruises would be of benefit in extending the periods over which good aerosol samples could be obtained, and would reduce the impact of this work upon other ship operations.

4.5 Elemental Carbon Mass Measurements

Elemental carbon is a major constituent of continental aerosols, occurring mainly in the fine particle mode. Since its primary source is from combustion processes, it generally indicates anthropogenic influences and the age of the aerosol. The mass concentration of elemental carbon is measured with an aethalometer, which operates on the principle that the carbon particles absorb light in proportion to their combined mass. Air is drawn through a quartz fired filter and the attenuation of a light beam across it is measured.

This instrument was mounted in Plotting Lab, with an intake tube drawing air from the wheelhouse top. Air from this location was usually uncontaminated by ship emissions apart from during periods of steaming downwind when engine exhaust gases could enter the sampling system.

4.6 Radon Concentrations and Air Mass Origins

Radon and its daughter products are injected into the air during its passage over land, with negligible contributions from oceanic sources. Since radon concentration is reduced by radioactive decay (half-life 3.8 days), it serves as a useful indicator of the degree of land influence upon maritime air masses. Radon concentrations over land, at a height of 10 m, are typically 100 pCi/m^3, whilst aged maritime air may possess values of 2 to 4 pCi/m^3.

For the purposes of this project, radon was measured by episodic collection of the daughter products using a high volume filter sampler for 20 minute periods. The beta decay activity of these filter samples was observed subsequently by means of thin plastic scintillators mounted on photomultiplier tubes. The radon levels inferred from these samples was qualitatively consistent with limited air trajectory analysis based upon daily weather charts.

4.7 Nuclepore Filter Samples

Air samples were collected on Nuclepore filters for subsequent examination by x-ray dispersive single particle analysis on a scanning electron microscope. This study should provide details of the fractional elemental distribution of the particles present for comparison with the results of the volatility analysis. These air samples were drawn into Plotting Lab from an intake fixed to the wheelhouse-top port rail.

(MHS, IEC, MKH, C.O'D)

5 Wave Measurements

5.1 Introduction

Wave measurements were required to define the sea state under which the atmospheric momentum transfer data were collected. Two systems were used, a moored Wavec buoy and a Shipborne Wave Recorder (SBWR). The Wavec provided directional wave spectra, but data retrieval required a receiving station within radio range. For this purpose a receiving station was established in the Faeroes on Kollur headland. The SBWR provided data on the sea state at the ship's location, however no direction information can be extracted.

5.2 Wavec (Mooring 498, Figure 7)

The Wavec buoy required positioning with respect to the shore station on the Faeroes. Data reception range was checked on day 295. A bathymetric survey (day 296) on a two mile square of the good reception area showed a mean water depth of 100 m with rock outcrops 5 to 15 m high across the area. Since this was considerably shallower than the mooring design planned, a rework of the design was carried out following Datawell guidelines. The addition of a 20 m riser of 15 mm alloy chain from the anchor clump was made to prevent mooring line damage from the rock outcrops observed.

The buoy was deployed on day 296 (at position 62°23'N 7°44'W) from the after deck using the port Atlas crane. The mooring line was deployed by hand to the anchor chain which was held on deck whilst the ship towed the buoy on to position. The anchor was then cut away to freefall to the sea bed. The buoy was observed to settle on position with a considerable length of bungee being buoyed up by the 11" DWC floats. This could have caused the bungee to foul the mooring cross beneath the buoy and so all the floats were removed. An 8 kg weight was inserted at the top of the polypropylene mooring line to ensure the bungee would remain beneath the surface.

In addition to the Faeroes shore station, the raw data transmitted from the Wavec was also received by a Direc receiver on the ship, using a quarter wave whip aerial with three ground plane elements. The Direc checked the quality of the data received and carried out simple error correction. The acquisition of data starting on the hour for a duration of twenty minutes. The directional spectral output from the Direc was recorded via an HP 85 Microcomputer onto tape cartridge.

Initial reception on the shipboard receiver was poor but improved when the aerial input was changed on the Direc receiver. Problems caused by the Direc clock, which initiates automatic time sequenced data collection, resulted in low data returns, despite constant resetting of the clock manually via the HP microcomputer. An alternative recording system was developed using a Master 128K microcomputer with software to reset the clock automatically, produce screen plots of the spectral data, and record data to disc.

As shown in Figure 4 improvement in the collection of spectral data occurred from day 302 with the implementation of the revised logging system. However this may have been influenced by changes in RF propagation over this period. In Figure 8 the distribution of spectra received is shown as a polar plot of range and bearing of the Wavec from the ship. The problems with data reception highlighted the lack of a signal strength meter to evaluate RF properties at the Wavec transmission frequencies. This should be remedied if this technology is to continue in operational use, or alternative techniques with higher data transfer reliability and range should be investigated.

Before recovery, the ship's Sea Rider boat was used (day 315) to attach a 10 m lifting line with stiffened loop to the buoy deck. For recovery (day 316) the ship manouvering alongside the buoy. The stiffened loop was picked off the buoy by pole and the recovery line broken from the buoy deck. The buoy was then lifted into the aft A frame by winch. At this point the bungee was stretched almost to its elastic limit whilst the nylon bypass line was in slack coils. As line tension increased the bungee broke causing the buoy to surge in towards the A frame. The nylon bypass then took the strain allowing the buoy to be removed from the line. All proceeded well until the polypropylene section was reached and the 8 kg weight removed. At this point the line was fouled beneath the ship, and despite attempts to free it, the line parted at the counter. A search pattern was run to establish if the line was at the surface but no contact was made.

(Moorings - IW, KMG; Data - KGB,RWP,PKT; Faeroes - C.Clayson)

5.3 SBWR

The shipborne wave recorder (SBWR) was installed on *RRS Charles Darwin* for cruise 43. The outputs of wave height and time were logged by the ship's computer system at a rate of 1 Hz, via a level A. Data acquisition was also carried out on a NEC portable computer, running under Labtech Notebook software, sampling at 2 Hz. Every 20 minutes, the NEC produced a spectrum of the wave heights, which was then saved to disc.

SBWR sampling on the NEC started at 294/2200. Some initial problems occurred when logging was stopped, causing loss of the current data file. Since a days data was held on one file, this resulted in the loss of data for day 295, 299 and half of 300. Thereafter the number of spectra per file was reduced to 10 (3 hours) and the controlling software was modified so that logging could be exited without any data loss. No further problems were incurred enabling the NEC to be interrupted at regular intervals to down-load the spectral data. Both normalised spectra and log spectra were plotted by a PC using Dadisp software.

The data files were converted into PSTAR format using the SUN workstation. Time series of averaged log spectra were produced by the SUN, as colour-filled contour plots, clearly showing the build-up of swells and wind driven seas.

(RWP,KGB,SGA)

6 SST Radiometer and video

6.1 Introduction

The turbulent transfer of sensible and latent heat from ocean to atmosphere, and radiative cooling from the sea surface, results in the ocean surface having a comparatively cool surface skin. This is particularly important when interpreting sea surface temperature measurements from satellites, since the values obtained will be lower than temperatures measured in situ.

The ERS-1 satellite, due to be launched in 1990, will carry an Along-Track Scanning Radiometer (ATSR) to measure SST. The RAL SST radiometer has been designed for use in validation of the ATSR. It is a self calibrating radiometer in which a detector views the sea surface and a reference blackbody through a chopper mirror. A hot blackbody, and a further blackbody at ambient temperature, can be moved into the viewing path for calibration. For this cruise a RAL SST radiometer, on loan from the Admiralty Research Establishment, Portland, was mounted on the port bridge wing.

The radiometer viewed the sea at about 38 degrees from the vertical. This angle was chosen to attempt to view sea water undisturbed by the ship, while remaining close enough to the vertical to keep the sea surface emissivity acceptably high. However it was unavoidable that the radiometer would view sea disturbed by the ship, probably most of the time when the ship was steaming. In order to keep a record of what the radiometer was viewing a video camera was mounted next to the radiometer.

The radiometer functioned reliably during the cruise. On future cruises it is suggested that the radiometer be placed on the foremast platform looking out abeam, to ensure undisturbed water is viewed.

6.2 Radiometer data

The radiometer was controlled by a BBC Basic program running on a Master Turbo computer. This program recorded the data to disk and also switched on and off the video recording. Following tests at IOSDL prior to the cruise the program options were set up as follows:

Quantity	Value
No. of sea signal values averaged	80
No. of black body temperatures averaged	50
No. of black body signal values averaged	200
Period between calibrations	3 mins
No of cals between instrument temperatures	5

Given this setup, a calibration sequence took 2 minutes, 9 seconds. However on most occasions the instrument performed an auto-alignment before and after the calibration, extending the total time to 4 minutes, 29 seconds. Thus the radiometer was viewing the sea surface for only 44% of the time.

Preliminary examination of the data was performed on an Archimedes computer and the calibration data files were transferred to the PEXEC system on the SUN. One problem discovered was that, due to heating within the radiometer case, the "cold" black body was in general a few degrees above the SST value. Thus extrapolation was needed to infer the SST.

The in situ SST data available for comparison were:

i the Trailing Thermistor ("Soap-on-a-rope") logged by the MultiMet system;
ii a thermosalinograph (TSG) drawing water from the non-toxic sea-water supply;
iii an on-deck CTD system also supplied from the non-toxic supply;
iv the near surface values from the CTD dips.

The trailing thermistor and thermosalinograph traces tracked together well with both the thermistor and CTD dip values indicating an offset of about 0.3 degrees (TSG cold). The on-deck CTD system did not perform well. The data were noisy and it is recommended that the thermosalinograph values be used in preference.

Preliminary comparisons showed that the radiometer SST tracked the in situ measurements qualitatively. However careful analysis will be necessary to obtain an acceptably noise-free radiative SST value.

(PKT)

6.3 Sea state videos

In order to establish the sea state in the SST radiometer's viewing field, a standard 8 mm video camera was mounted inside a protective casing on the port side of the bridge, facing the sea at approximately 38 degrees to the vertical. Pictures were relayed to a VHS recorder and monitor situated in the scientific plot. The video recorder was controlled by the SST radiometer control program so that recordings were made when the SST radiometer was looking at the sea. This resulted in a 180 minute tape covering a 7 hour recording period. Also connected to the system was a video timer which meant that the date and time of day were recorded on the video cassettes.

At the end of each day, the video cassettes were transferred to the main lab for processing using a frame grabber set up on a Tandon PC. Two viewing windows were set up using the frame grabber, one window covering a large area of the frame, and the other window only covering a small area - which was to correspond with the radiometer's viewing field. Two histograms were then derived of the grey level in each window.

For each histogram, the values of every four bins were averaged and the results stored in separate data files. The two files created were both approximately 2 Mbytes in size and had the same format. Each one started with an identification header followed by the data sets, each data set comprising of the time of day and the averaged histogram values. These files were then passed to the PSTAR system on the SUN for further analysis.

Problems however did arise at the beginning. Raindrops were found to be accumulating on the camera casing's viewing window, so a temporary rain hood had to be fitted. This also proved useful in reducing some of the sun glare that often distorted some of the pictures.

Another problem was encountered when trying to use the frame grabber to "read" the date and time off each different frame. The program which was written to perform this function was primarily tested in the laboratory using live pictures. Because the video recordings had considerably less quality and clarity than those of the live pictures, some amendments had to be made to the program. In addition to this, a small area of the camera's viewing field was blackened out, so that the background colour behind the date and time was constant. These changes proved satisfactory in that a good percentage of time and dates were recognised accurately off the frames, hence resulting in more efficient processing on the PSTAR system.

In total, 31 tapes were recorded (see Figure. 4) of which 4 were examined on the ship. Examination of more tapes was prohibited by file space shortage on the SUN system.

(A.Ll.W)

7 Hydrography

7.1 CTD stations.

A total of 81 CTD stations were worked using the IOSDL new deep NBIS Mk III CTD (with oxygen sensor) and Sea Tech 1 m path length transmissometer. The CTD was mounted in a protective frame alongside the General Oceanics 1.7 litre, 12 bottle multisampler with the transmissometer mounted across the top of the package. Data were logged by the ship's level A computer and later transferred to the level C for subsequent processing using the PSTAR programme suite. PSTAR processing was identical with that used on the previous cruise (*RRS Charles Darwin* 42). A data back-up was provided by a Digidata tape deck.

No oxygen calibration samples were taken. Salinity calibration information was collected by bottle samples (between 2 and 4 levels per station) near surface, near bottom and, where appropriate, at intermediate depths. Duplicate salinity samples were drawn from each bottle and salinities determined using a Guildline Autosal Salinometer. SIS digital reversing thermometers were used as a check on in situ temperatures.

The CTD package carried a 1 sec 10 kHz pinger to monitor the height of the package above the sea bed. Most profiles were made from the surface to within 10 m of the sea bed. In the subsequent processing the down cast was used as the main data set but the calibration data were obtained from listings of the up cast.

The CTD behaved well throughout the cruise with the only delays or gaps in data caused by having to re-terminate the CTD wire because of catspaws (two 10 m lengths were cropped), and on station 61 the data stream was lost after firing a bottle at 400 m. This problem was thought to be due to a loose connector.

The salinity calibration values showed a mean offset of 0.003 (CTD high compared to bottles) compared with the nominal calibration used on *RRS Charles Darwin* cruise 42 (conductivity ratio 0.99049). The offset varied between stations and between batches of salinity sample determinations. The salinometer worked well throughout the cruise but exhibited occasional instabilities which lasted for 1 or 2 sample determinations. A more worrying feature is that standardisations during runs jumped by the equivalent of 0.003 thus leaving open to question the relative stabilities of the CTD and of the Autosal salinometer. Repeat stations in the deep stable theta-S regime of the Norwegian Sea (1500 m and below) suggest that there are indeed variations in CTD salinities of order 0.003.

The performance of the SIS thermometers was disappointing in that differences between pairs could at times be of order 0.1°C. Interchange of pairings has identified the badly calibrated thermometer. A pressure "thermometer" was also used.

CTD Station position data are given in Table 2.

7.2 XBT data

T7 (nominal 750 m) and T4 (nominal 450 m) probes were dropped using a hand held launcher and Bathysystems SA810 deck unit. The data were recorded on the SA810 HP 85 cassettes and the data later transferred via level ABC to PSTAR format. The PSTAR files have the depth variable as pressure in order to facilitate the integration of CTD and XBT data.

XBT's were used primarily to infill between CTD stations to give enhanced spatial coverage and were also employed when weather conditions precluded the use of the CTD. A time series of hourly XBT drops in a saddle in the Iceland Faeroes Ridge was used to examine intermittency in the overflow of cold water over a tidal cycle. This series of measurements had to be curtailed when the ship could no longer keep position in worsening weather and it also became too hazardous to work on deck.

A list of XBT drops is given in Table 3.

(WJG, GG)

8 Current Measurement

8.1 Faeroes Bank Channel Moored Array. (figure 10)

An array of five current and temperature measuring moorings spanning the channel was deployed for Dr.P.M.Saunders (IOSDL) on cruise 42 by Waddington and Goy. Recovery of all these moorings was scheduled for cruise 43. Opportunities were taken to check on the positions of these moorings during the cruise. These confirmed that all moorings known to be in place at the end of cruise 42 were still in place during cruise 43.

Recovery operations commenced on day 318, moorings 488, 489, 490, 492 being successfully relocated and recovered. Mooring deck operations were conducted from aft using the DBC and stern A frame. The recoveries were uneventful with the exception of rather mediocre acoustic performance thought to be due to a poor acoustic release deck unit. During the recovery of mooring 492 ("C") the release became detached from the mooring. This occurrence could be due either to a shackle having become unscrewed or corroded or to the hard eye having jumped out of the Boss Hook. The adjacent current meter showed evidence of severe vibration in that the spindle bearing was worn and the fin balance weight loose.

The following day attempts were made to recover mooring "D". On cruise 42 contact could not be made with the release on this mooring. The mooring was at that time thought to have pre released or to have an inoperative pinger. A wideranging visual search on cruise 42 did not find the mooring and it was assumed therefore to be in place, upright but with an inoperative release pinger. Extensive transmissions of the release frequency on cruise 43 failed to bring the mooring to the surface. This was followed by an attempt to drag for the mooring. Despite good weather and excellent GPS navigation the mooring was not found and must now be assumed to have pre released and drifted away.

On cruise 42 during the first attempt to deploy mooring 493 ("D") the wire broke and the three RCMs and one C/R attached to a 750 kg anchor fell to the sea bed. On day 322 a dragline was rigged and deployed navigating on GPS with the C/R being monitored on the PES. Several passes were made over the site at 2 knots with the dragline pulled astern. One contact was made which caused the C/R unit signal to become erratic, however on recovery of the dragline there was no evidence of the mooring. The C/R was switched off and the site abandonned.

The data from the recording instruments was all read onto 5.25" diskette using the P3059 program on the PC1512. Raw data dumps were made to printer to check data quality which is summarized in the following table..

Mooring	Instrument	Comments
499	Met logger	8 channel. 12668 data words.
488	RCM 7643	Read as 3 files.Poor quality.
489	RCM 421	2526 records. Short record.
490	RCM 9590	36702 data words. Good data.
	RCM 7401	4153 records. Good data.
	RCM 6867	4043 records. Good data.
	RCM 4738	4043 records. Good data.
492	RCM 9648	36702 words. Good data.
	RCM 7517	No data. Tape transfer failure.
	TL 806	Read as two files. Poor quality.
	RCM 7945	4045 records. Good data.
	TL.879	4050 records. Good data.
	RCM 2109	4049 records. Good data.
	RCM 3624	4049 records. Good data
495	RCM 9657	34686 words. Good data

(IW, KMG)

8.2 ATTOM

The Acoustic Travel Time Ocean Monitor (ATTOM) consists of two units which were in this case deployed on a diagonal path across the Faeroe Bank Channel. The units transmit, receive and retransmit signals at 5.6 KHz (with a frequency sweep of 1 KHz). Their measurements of round trip and each way travel times transmitted via the sound channel which exists at the top of the homogeneous Norwegian Sea water in the Faeroe Bank channel allow estimates to be made of the mean temperature along the path between the units and also the integrated water velocity along the channel.

Both ATTOM units were deployed on cruise 42 but unit 2 failed to work properly and was redeployed on cruise 43. Unit 1 was recovered uneventfully but unit 2 could not be located acoustically despite its having three independent acoustic transmission sources (10 KHz release, 10 KHz transponder and the 5.6 KHz ATTOM transmissions). Since none of these could be heard at ATTOM 2 and a search down current around the edge of Faeroe Bank failed to locate then mooring it must be assumed to be adrift. NATO Fleet HQ at Northwood were notified of the fact.

The loss of the ATTOM unit is particularly unfortunate since this experiment provided the best opportunity to intercompare data from the ATTOM prototypes with in situ measurements from an array of moored current and temperature recorders

(WJG, IW, KMG)

8.3 RDI Shipboard ADCP

The Acoustic Doppler Current Profiler (ADCP) was in use throughout the cruise to provide measurements of the current profiles beneath the ship. Transfer of ensemble processed data to the 'edison' SUN workstation was via an RS232 link. This was the first cruise to make exclusive use of this direct data transfer path to the SUN. Data errors were very rare, although the system would occasionally miss entire ensembles (section 11.1).

No hardware or software problems were encountered with either the RDI deck unit or the IBM PC-AT data acquisition system. However, the transducer unit (belonging to ARE) had not been regularly upgraded. This meant that the temperature measurement was not working, and, more importantly, the recent firmware changes available from RDI were not installed. Changes to the direct commands, approved by RDI, were therefore used namely : A06, B000000.

In general the setup of the instrument was as on Cruise 42, with two and a half minute ensembles of 64 by 4 m cells. During high wind events in shallow water the configuration was changed to 32 by 2 m cells averaged over one minute. The PSTAR processing route followed that of Cruise 42. However, as we were within bottom tracking range for most of the cruise, absolute velocities were calculated using the ADCP bottom track velocity. Navigation information was merged with the ADCP data and will be used to obtain absolute velocities during periods when bottom track was not possible. Several PSTAR programs were modified to deal with gridded ADCP files (section 11.2). One of these was TIDAL which was used to examine the tidal current profile obtained from the instrument.

Data quality.

The data quality under calm conditions and moderate ship speed was as expected. Bottom tracking to 750 m and a profiling range of up to 400 m were possible, generally with over 90% good data to 300 m. However, even in no more than moderate sea states the data quality deteriorated markedly. A high sea state and speeds in excess of 5 kts would usually result in very poor data at all depths. We believe that this is due to aeration in the vicinity of the transducer. Air trapped within the transducer space was regularly bled off. This was a useful procedure after active aeration had ceased, but could not be considered a cure. As a matter of urgency, the causes of the poor data should be further investigated and advice sought on methods of improving the performance of the instrument in rough weather.

Calibration.

Two calibration runs were carried out using the 90 degree zig-zag method described by Pollard and Read (1989). These were especially valuable as they added to the calibrations carried out on Cruise 42. Using GPS navigation and bottom tracking tentative values for A, the linear correction factor, and PHI the clockwise angular correction were:

A	= 1.0153	rms = 0.0054
PHI	= 2.02°	rms = 0.29

(GG)

8.4 VAESAT - Near Surface Current Measurement (Mooring 500, Figure 9)

The VAESAT comprises an electromagnetic current meter at 1 m below the sea surface and a 1 MHz acoustic Doppler current profiler mounted on a wave-slope following buoy. A summary of the electromagnetic current meter data and the buoy position were available using the ARGOS satellite system. The purpose of the near surface current measurements was to provide information on the tidal, residual and wind-driven shear currents and also, through the acoustic scattering strength measurements and the scatter in the velocity measurements, estimates related to the near surface stress.

Onboard, prior to sailing, all of the electronic sub-systems were checked and powered up before being installed in the buoy. The buoy was then sealed and made ready for deployment. An ARGOS test set was set up in the plot with a ground plane antenna on the wheelhouse top.

The buoy was deployed on day 296 using the technique described for the Wavec (section 5.2). The mooring subsurface buoy was slipped over the stern using the line tension as the ship steamed ahead at 2 knots. Mooring line was then hand deployed with the Command/Release (C/R) being carefully lifted outboard. With the mooring streamed well astern the anchor was cut away at 296/1506. The sub-surface buoy was seen to approach the ship and submerge with the surface buoy settling correctly on position.

The initial data received on board showed that the electromagnetic current meter was working correctly. Whenever the ship was within about 2 miles of the VAESAT data reception was possible and a vector plot of the current was kept. This showed a tidal ellipse similar to that of the nearby 'tidal diamond C' on Admiralty Chart 117. A mean flow to the north east, part of the clockwise circulation around the Faroes, was also observed.

A 10 m recovery line was attached to the buoy deck with a stiffened loop attached to antenna cone using the Sea Rider on day 315. Recovery of the buoy system commenced at 316/1248. The subsurface buoy was sighted on the surface at 1257 simultaneously with the command release indicating anchor release. The buoy was grappled mid-ships and hauled to the stern where the winch lifted the system aboard. Unfortunately the flashing light and the upper part of the ARGOS antenna cone were damaged through collision with the side of the ship. Otherwise, the recovery went well and was completed by 316/1335. The data tapes were extracted from the SeaData loggers and the data from the ADCP EPROM logger transferred via a PC to the PSTAR system on the SUN workstation. The ancillary engineering data showed that the ADCP had been working correctly. The velocity and scattering strength measurements were encouraging in their mean properties and in their scatter, the latter correlating well with wind speed. This deployment has confirmed the feasibility of making ADCP measurements from a moored wave-slope following buoy.

(GG; mooring: IW, KMG)

9 Computer Systems

9.1 Ship system

The shipborne computer facilities were based on the three tier (ABC) system. Levels A and B were used for the acquisition and logging of navigation, surface and vertical data from the appropriate ship mounted devices. These were:

Navigation:
- EM Log
- Gyro
- Transit Fixes
- GPS Fixes

Sea Surface:
- Temperature (x2)
- Salinity (x2)
- Conductivity

Wave height (SBWR)

IOSDL MultiMet

Vertical:
- CTD + Oxygen
- Transmittance
- XBT

The Level C system based on three networked SUN 3/60 Workstations was used to process, display and archive data.

Workstation "edison" was used to receive and demultiplex data transmitted by the Level B and the ADCP into the appropriate raw data files.

Workstation "darwin" the network fileserver was used for RVS data processing and system management. The RVS processing suite was used to provide navigation and real time calibrated CTD data. Vertical section contour plots were produced for a number of variables along XBT and CTD transects.

Workstation "newton" was used extensively for PEXEC processing (11.2).

This was the second cruise to utilise the SUN Workstation based Level C processing system on *RRS Charles Darwin* and the first to attempt the direct collection of ADCP data.

The ADCP data acquisition method worked for the duration of the cruise with minimal operator intervention, however occasionally a data ensemble was not captured by the SUN. This failing could be eliminated by the use of a small data buffer or by establishing a reliable means of handshaking between the ADCP IBM and the SUN.

During the cruise it has been demonstrated that the demands on the Level C system made by PEXEC (with no Seasoar processing) have reached a level beyond the capacity of the currently available hardware. There are three areas which need to be given consideration:

a) Disk usage and space:- available disk space for PEXEC and data have been fully used. The PEXEC system expanded from 40 Mbytes to 50 Mbytes between cruise 42 and cruise 43, because of this expansion it was necessary to remove some other utilities to provide the additional space. A lack of data space was apparent within the first 10 days of the cruise, this was partially due to a backlog in PSTAR processing but was mainly due to the volume of data generated during PSTAR processing. With the current system configuration all data access for PEXEC processing is across the ethernet network, as is any swapping required by the workstation "newton", this contributes to a slow running system.

b) Terminal Access: Additional graphics and ANSI terminals were required by the users. It was possible to satisfy the need for ANSI terminals by the connection of three user supplied PCs running terminal emulators.

c) Spares and inbuilt redundancy: the shipborne computing capability would be significantly reduced by a malfunction of any of the SUN hardware during a cruise using PEXEC. All available hardware was used during this cruise, leaving no inbuilt redundancy or space for future expansion of either the RVS or PEXEC systems.

There are a number of options which might be considered to allay the aforementioned system limitations.

i. The inclusion of a Fileserver with an 892 Mbyte SMD Disk.

ii. The addition of a 327 Mbyte disk for use with Workstation "newton".

iii. The addition of further Workstations including disks for swap.

The limitations on the above system enhancements are financial rather than technical. These improvements should be given proper consideration within the context of shipborne computing and the science programme that is being supported. In the year 1990 - 91 there are four cruises that will utilise PEXEC more extensively than this cruise, with more demands imminent from the WOCE community programme.

(EBC, ANC)

9.2 PEXEC

The PEXEC suite of programs consists of nearly 200 routines to input data from diverse sources, edit, calibrate and process it, and then display it in different graphical forms. Where many instruments are being logged, as on this cruise, the ability to bring different observations together for comparison and interpretation greatly enhances the scientific decision making. This was illustrated by the heavy use that was placed on the system during the cruise.

The programs were loaded from tape at the start of the cruise and executeable files created with the UNIX makefile system. Because of the addition of programs between cruises 42 and 43 the space allowed for the system proved to be too small. Extra space was created by removal of rarely used PEXEC executeables and a word processing package loaded by RVS.

Initially one SUN workstation (newton) and one terminal were provided for use by the scientists. This proved inadequate for computing needs when up to five personnel required access to PEXEC. This was resolved later in the cruise by linking three PC's via terminal server 2 to the SUN network. These PC's were subject to intermittent hanging without apparent cause which required RVS intervention to clear. Eventually free lines on terminal server 1 were created and used without further problem.

It was apparent that as PEXEC usage increased, access to the SUN server (darwin) via Ethernet became steadily slower. This was particularly severe when programs were running which were inefficient in their use of input/output. A number of programs were altered to improve the way they handled disk accesses.

Data input into PEXEC format was achieved through the RVS routine 'datapup', which proved to be a reliable and fast data route. This converted data stored on the raw data SUN (edison) into PEXEC format. Data input from sources other than RVS files proved labour intensive and slow. Output from the many PC based logging systems was transferred either by 'kermit' (via the PC's connected to the SUN through the terminal server) or by floppy disk using the RVS PS/2 to copy direct to the SUN disk space. Programs had then to be written for each ASCII data format used in these files.

Processing with PEXEC programs was speeded up by creating execs containing the relevant commands which could be run routinely. There is however a danger in their use since it can become indiscriminate and may leave files whose exact history cannot be determined.

Hardcopy plot output was produced by creating a plot file in HPGL code which was then directed to a specific device through a driver (e.g. 'nic', 'adv'). As on Cruise 42, problems were encountered plotting to the zeta plotter. The plot buffer was not cleared at the end of each plot which caused a return to the previous origin at the start of the next. This shift had to be allowed for each time to prevent overplotting. Due to the limitations of the software drivers no plot bigger than A3 could be produced.

Tape archiving was performed using the UNIX "tar" command writing to 60 Mbyte cartridge tapes on a drive connected to workstation "darwin" via a SCSI link. A drawback of the tar command is that it makes no attempt to test for existing tape files, so that it is easy to overwrite data already archived. It must therefore be used with care. The alternative is a user-program driven archiving system (e.g. GF3) which checks for overwriting. The difficulty here is that of space (e.g. tests with GF3 produce files up to one and a half times the size of their PEXEC equivalent). Initially relatively small numbers of PEXEC files were bundled together into one tar tape file. However on two occasions the SUN crashed when writing further tar files to a partially filled tape. No apparent cause could be found for these failures. Tar files which are not completed (either through a crash or because of end of tape) leave a partially filled tape which cause tape errors if attempts are again made to append files. In these cases the whole tape must be read back and be rewritten. To try to avoid these crashes a buffer storage area was set up in the RVS processed data directory, where 60 Mbytes could be assembled and then written on to tape as one tar file. The size of these tar files would obviously be a problem where space was not available on a land based system to receive the data. It is important that this problem be investigated and resolved before future cruises using this system.

(SGA)

9.3 UMIST Data Acquisition & Processing System

Introduction

To meet the data requirements of the Flux Estimation, Eddy Correlation and Aerosol Sampling objectives of the UMIST group, a new integrated data recording and processing system was developed for the cruise. Four forms of data had to be accommodated: Fast (40 Hz) Analogue, Slow (1 Hz) Analog, Serial ASCII from the Ophir Humidity device, and Fast Digital, originating from the Aerosol Samplers. The system used a PC Clone to co-ordinate collection of data from four peripheral processors, each dealing with one data type. The accumulated data were stored on optical disk, and passed as a high speed data stream to 4 additional PC-type computers for on-line analysis and diagnostic display. The system functioned well throughout the cruise, with the exception of occasional failures caused by power transients during winch-operations, all but three of which occurred when the recorder was in standby mode.

Peripheral Processors

The peripheral processors were configured from a series of low-cost modules on a common bus structure, the primary components being a central processor card, based on standard Z80 technology, and a data buffer/PC interface. Communication between the data buffer and the PC was via a high speed bi-directional parallel link. The processor card was equipped with a simple EPROM boot-strap loader, which also included drivers for reading data from other cards in the system. The program to be executed by the processor was first down-loaded, in Intel-Hex format, from the PC, then automatically decoded and finally, commenced execution on command from the PC. Other cards for the system included an analog-to-digital converter, serial link handler, 4 x 32-bit counters and a syncro-resolver interface designed to directly read the ship's gyrocompass.

Analog Signal Acquisition

As previous experience had shown there to be the potential for serious radio transmission interference on analog signals, the low level analog data were converted to frequency modulated digital streams as near to the sensors as possible. Each signal passed through a voltage-to-frequency converter, located in one of the instrument cases mounted on the pallet. The frequency range gave a nominal resolution equivalent to 14.5 bits when sampled at 40 Hz, with the linearity of the converters being of the same order. The digital data was transmitted to the peripheral data processors using a differential protocol (RS485) which is highly noise immune, and insensitive to cable length (up to 1 km).

At the peripheral processor, each signal was routed to its own 32-bit counter which was read at intervals for 25 ms for the fast analog data, or 1 second, for the slow analog. In both cases, a 16 bit (2 byte) value was read. The two data rates were dealt with by separate processors, the buffered fast analog data being read every 2 seconds, the slow every ten. The integrating nature of the signal conversion process precluded any aliasing problems associated with those devices whose frequency response extended beyond the sampling rate.

ASCII Data Handling

The construction of the interface electronics of the Ophir humidity device necessitated the use of a peripheral processor solely for this data source. Communication between the processor and the device was via a full-duplex RS485 serial link. To reduce data storage demands, the ASCII information was converted to 16-bit binary by the processor. The resulting data was buffered and read every 10 seconds by the PC.

Aerosol Data Handling

To reduce the cabling requirements of the installation, the processing of the digital streams from the aerosol samplers was performed by a processor installed on the forward mast pallet. Communication between the data recorder and the pallet computer was via a high speed (150 KBaud) bi-directional serial link, the software being downloaded to the processor from the recorder, allowing the algorithm to be changed when required even if access to the pallet was impossible. The standard software accumulated histograms of particle size data from four probes until requested to transmit by the recorder.

Data Storage

The interleaved data from the four streams was stored, along with housekeeping information, on 'Write Once/Read Many ' (WORM) optical disk, at a rate of 21280 bytes per ten seconds. Each disk was capable of holding 800 MBytes, or approximately 4 days continuous data. Although this medium is a relatively recent development, and has had few ship-borne trials, it operated exceptionally well, with a zero error rate.

On-line Diagnostics & Processing

A series of programs were developed to view the data stream as it became available (approximately 15 seconds retrospective). Oscilloscope-type displays were available for all major flux parameters, with accumulated spectra from the aerosol samplers displayed in digital form.

Whilst some data reduction for the purposes of dissipation estimates were performed on-line (using both Fast Fourier Transform and Maximum Entropy Methods), the need to remove the influences of ship motions and flow distortion from the data for eddy correlation studies placed the task beyond any realistic ship-borne computer system. Even for the dissipation estimates, meaningful reductions in the quantity of data recorded could have been achieved only by adopting compromises which which would have seriously impaired the possibilities for subsequent analysis.

For these reasons, it has been UMIST policy to record raw data during these and other field projects and to utilise on-line systems to monitor the validity of the recorded data.

(MKH)

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That the scientific work was able to continue without interruption throughout this five week cruise was only possible because of the highly professional way in which the ship's officers and crew performed their duties; for which our thanks. The support of the RVS staff for their work in preparation, mobilisation, and during and after the cruise, is also gratefully acknowledged.

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The IOSDL group wish to thank their shore-side support; the Admiralty Research Establishment for the loan of the SST radiometer; Gill Instruments Ltd and Biral for the loan of the Sonic anemometer.

TABLES

Table 1 MultiMet sensor list

Position	Sensor	Serial Number
Forward Mast	Young Propeller Vane	YG0005
Forward Mast	Accelerometer	ACIO0001
Forward Mast	Psychrometer	VI1058 (Day 294-310) VI1059 (Day 310-323)
Forward Mast (port)	Kipp & Zonnen Short Wave Radiometer	RSKZ1958
Forward Mast (Stbd)	Kipp & Zonnen Short Wave Radiometer	RSKZ0606
Forward Mast (top)	Eppley Long wave radiometer	RLEP6207
Main Mast Top	Anemometer	VI1991
Main Mast top	Wind Vane	VI2117
Wheelhouse Top (Stbd)	Psychrometer	VI1059 (Day 294-310) VI1058 (Day 310-323)
Wheelhouse Top (Stdb)	Anemometer	VI2238
Wheelhouse Top (Stbd)	Wind Vane	VI2103
Wheelhouse Top (Port)	Psychrometer	VI1055
Wheelhouse Top (Port)	Anemometer	VI1895
Wheelhouse Top (Port)	Wind Vane	VI2102
Forward side (Port)	SST	SPIO0006(Day 296-301) SPIO0004(Day 301-310) SPIO0005(Day 310-323)
Plot	Ships Head	RVS Level A
Plot	Air Pressure	IO0001

Table 2 CTD station list

(NOTE 1) TIME IS TIME AT WHICH BOTTOM OF CAST REACHED
2) POSITION IS BESTNAV AT THAT TIME
3) WATER DEPTH IS IN UNCORRECTED m WHEN AT BOTTOM OF CAST
4) DEPTH REACHED IS MAXIMUM WIRE OUT READING
5) HT IS MINIMUM BOTTOM SEPARATION m

No.	DAY	TIME	LAT	LONG	Water Depth	Depth reached	HT
1	299	1337	62 38.5	06 47.9	180	165	10
2	299	1532	62 50.9	06 39.5	510	500	15
3	299	1733	63 00.9	06 30.8	1255	1217	10
4	299	2012	63 14.4	06 20.8	1672	1630	10
5	299	2303	63 24.8	06 13.1	1636	1585	10
6	300	0153	63 35.7	06 02.4	2068	2000	-
7	300	0447	63 48.1	05 53.7	2870	2000	-
8	300	0730	63 59.1	05 42.7	3520	2000	-
9	300	1015	63 09.7	05 33.8	3546	2000	-
10	303	1100	62 29.7	07 58.7	190	180	15
11	303	1258	62 37.4	08 25.0	498	485	10
12	303	1411	62 42.9	08 36.3	500	485	10
13	303	1607	62 53.8	08 22.4	479	465	11
14	303	1842	63 04.9	08 07.6	614	605	8
15	303	2036	63 15.9	07 52.7	762	735	7
16	303	2244	63 26.4	07 39.6	945	925	15
17	304	0138	63 37.7	07 24.8	1300	1263	18
18	304	0425	63 48.8	07 11.3	1950	1500	-
19	304	0714	63 59.8	07 00.5	2412	1500	-
20	305	1717	61 30.2	07 54.7	198	180	12
21	305	1828	61 26.9	08 00.8	330	309	18
22	305	1922	61 26.0	08 02.2	505	485	10
23	305	2024	61 24.8	08 03.2	580	670	10
24	305	2145	61 21.5	08 05.0	836	860	15
25	305	2310	61 18.2	08 08.2	727	720	12
26	306	0025	61 16.6	08 09.8	527	520	20
27	306	0134	61 14.1	08 14.0	320	302	15
28	306	1940	61 34.7	09 45.8	1108	1106	4
29	306	2130	61 39.8	09 34.3	974	970	15
30	306	2303	61 45.1	09 24.4	832	815	10
31	307	0033	61 49.7	09 12.8	690	675	10
32	307	0153	61 56.0	09 00.1	525	520	15
33	307	0339	62 01.5	08 46.1	320	310	12
34	307	0710	61 28.8	08 55.1	450	440	12
35	307	0820	61 31.3	08 48.7	630	620	10
36	307	0942	61 35.1	08 41.3	878	865	12
37	307	1056	61 38.6	08 37.6	814	805	12
38	307	1216	61 41.3	08 29.6	652	637	10
39	307	1324	61 43.8	08 25.5	270	255	14
40	311	1501	62 39.8	06 47.6	193	175	10

No.	DAY	TIME	LAT	LONG	Water Depth	Depth reached	HT
41	311	1630	62 48.9	06 40.9	447	425	10
42	311	1816	62 57.8	06 33.6	933	920	15
43	311	2027	63 06.7	06 26.6	1580	1570	16
44	311	2233	63 15.5	06 29.8	1682	1630	10
45	312	0049	63 24.9	06 09.3	1670	1620	10
46	312	0325	63 35.9	06 00.8	2019	2025	12
47	312	0620	63 48.1	05 43.6	2840	2000	–
48	312	1450	64 00.0	07 00.2	2430	2000	–
49	312	1810	63 49.2	07 09.6	2018	1960	17
50	312	2053	63 38.2	07 24.6	1325	1280	10
51	312	2317	63 26.1	07 39.8	945	907	10
52	313	0128	63 16.0	07 52.4	765	735	10
53	313	0341	63 05.2	08 07.3	625	605	13
54	313	0606	62 54.4	08 21.5	497	475	12
55	313	0827	62 42.9	08 35.7	505	478	10
56	313	0948	62 36.8	08 24.8	511	490	15
57	313	1110	62 31.3	08 06.0	195	175	14
58	316	2009	61 30.3	07 53.8	175	160	10
59	316	2115	61 26.9	08 00.1	350	330	11
60	316	2211	61 24.4	08 01.4	670	660	25
61	316	2322	61 21.6	08 04.3	828	820	20
62	317	0042	61 17.9	08 07.7	708	680	18
63	317	0136	61 15.9	08 10.0	491	470	10
64	317	0226	61 13.9	08 14.1	310	282	15
65	318	1742	61 16.0	08 04.2	686	668	10
66	318	1852	61 18.5	08 07.2	835	810	16
67	318	1954	61 21.3	08 10.2	851	825	12
68	318	2051	61 23.7	08 12.0	803	780	18
69	318	2152	61 25.7	08 15.0	777	765	15
70	318	2252	61 28.0	08 17.6	714	710	23
71	323	1731	60 24.8	08 40.1	455	432	15
72	323	1920	60 21.3	08 22.2	518	497	12
73	323	2106	60 16.5	08 05.1	531	513	10
74	323	2228	60 14.5	07 54.9	540	510	16
75	323	2343	60 12.6	07 45.2	659	632	18
76	324	0219	60 11.6	07 32.8	610	580	20
77	324	0340	60 08.7	07 27.3	532	510	12
78	324	0531	60 04.9	07 08.1	560	530	20
79	324	0714	60 00.3	06 50.0	445	430	18
80	324	0857	59 55.0	06 31.3	360	335	17
81	324	1050	59 46.6	06 17.3	390	365	18

Table 3 XBT station list

NOTE 1) DATE/TIME IS THAT OF XBT DROP
2) POSITION IS FROM BESTNAV FILE
3) DEPTH IS INDICATED DEPTH IN UNCORRECTED METRES

No.	DATE	TIME	LATITUDE	LONGITUDE	DEPTH	TAPE/FILE
1	295	0837	61 16.3	08 04.4	—	1/71A
2	295	1920	62 31.1	08 02.0	—	1/42A
I-F RIDGE RUN						
3	295	1959	62 31.7	08 10.2	400	1/73A
4	295	2029	62 37.5	08 20.7	493	1/44A
5	295	2058	62 37.3	08 20.4	504	1/45A
6	295	2130	62 40.6	08 26.3	510	1/46A
7	295	2200	MISFIRE			
8	295	2207	62 44.3	08 33.7	497	1/48A
9	295	2230	62 46.3	08 38.1	500	1/49A
10	295	2300	62 49.2	08 44.1	495	1/410A
11	295	2330	62 52.1	08 50.0	442	1/411A
12	295	2357	62 54.9	08 55.7	431	1/412A
13	296	0030	MISFIRE			
14	296	0034	62 58.6	09 02.6	449	1/414A
15	296	0058	63 01.2	09 07.1	490	1/415A
16	296	0127	63 04.7	09 12.1	518	1/416A
END I-F RIDGE RUN						
FAROE BANK CHANNEL RUN						
17	298	1814	61 41.0	07 56.2	227	1/417A
18	298	1953	61 31.4	08 06.3	255	1/418A
19	298	2019	61 29.3	08 10.5	326	1/419A
20	298	2027	MISFIRE			
21	298	2031	61 28.4	08 12.4	480	1/721A
22	298	2040	61 27.7	08 13.8	650	2/722A
23	298	2051	61 26.7	08 15.9	745	2/723A
24	298	2104	61 25.6	08 18.1	820	2/724A
25	298	2122	61 24.1	08 21.3	750	2/725A
26	298	2130	61 23.4	08 22.8	630	2/726A
27	298	2143	61 22.3	08 25.8	485	2/427A
28	298	2204	61 20.9	08 30.2	358	2/428A
END F BANK CHANNEL RUN						
START N FAROE LINE 1						
29	299	1441	62 46.4	06 42.2	346	2/429A
30	299	1628	62 56.0	06 33.1	816	2/730A
31	299	1850	63 07.5	06 26.5	1600	2/731A
32	299	2140	63 21.3	06 17.9	1633	2/732A
33	300	0038	63 32.0	06 06.6	1885	2/733A
34	300	0319	63 41.8	05 58.7	2358	2/734A
35	300	0608	63 53.1	05 48.2	3280	2/735A
36	300	0901	64 05.6	05 37.2	3580	2/736A
37	300	1423	64 31.1	06 25.0	—	2/737A
END N FAROE LINE 1						

NO	DATE	TIME	LATITUDE	LONGITUDE	DEPTH	TAPE/FILE
START N FAROE LINE 2						
38	303	1000	MISFIRE			
39	303	1016	62 27.9	08 11.1	206	3/439A
40	303	1152	BAD DATA		470	3/440A
41	303	1159	62 34.3	08 13.7	493	3/441A
42	303	1333	62 39.7	08 31.8	507	3/742A
43	303	1506	62 48.4	08 30.7	502	3/743A
44	303	1747	63 00.3	08 16.7	517	3/744A
45	303	1952	63 12.3	07 57.6	705	3/745A
46	303	2139	63 20.8	07 45.6	860	3/746A
47	304	0004	63 31.5	07 31.6	1080	3/747A
48	304	0257	63 43.3	07 19.8	1565	3/748A
49	304	0551	63 54.4	07 05.6	2262	3/749A
END N FAROE LINE 2						
FAROE BANK EXIT CTD SECTION						
50	306	2223	61 42.6	09 28.6	910	3/750B
51	306	2351	61 47.7	09 18.2	770	4/751A
52	307	0118	61 52.2	09 07.0	619	4/752A
53	307	0246	61 58.0	08 54.3	455	4/753A
END F B EXIT SECTION						
DIAGONAL RUN IN EXIT						
54	307	0428	61 55.1	08 48.8	446	4/754A
55	307	0458	61 49.5	08 50.7	575	4/755A
56	307	0528	61 44.0	08 52.7	826	4/756A
57	307	0558	61 38.7	08 54.2	865	4/757A
58	307	0635	61 31.8	08 54.9	604	4/758A
END DIAGONAL RUN						
START I-F RIDGE TIME SERIES						
59	308	1428	62 39.5	08 26.1	510	5/459A
60			MISFIRE			
61	308	1535	62 39.6	08 26.3		5/461A
62	308	1627	62 39.6	08 27.1		5/462A
63	308	1726	62 39.3	08 28.0		5/463A
64	308	1831	62 39.8	08 26.2		5/463B
65	308	1941	62 40.4	08 27.9		5/465B
66	308	2037	62 41.5	08 23.5		5/466B
67	308	2130	62 42.1	08 23.0		5/467A
68	308	2230	62 40.1	08 20.7		5/468A
69	308	2331	62 39.1	08 24.1		5/469A
70	309	0030	62 39.7	08 25.0		5/470A
71	309	0130	62 40.0	08 24.7		5/471A
72	309	0240	62 39.9	08 24.0		5/472B
73	309	0332	62 40.1	08 23.5		5/473A
74	309	0436	62 40.0	08 23.7		5/474B
75	309	0528	62 40.4	08 23.7		5/475B
END I-F RIDGE TIME SERIES (WEATHER)						

NO	DATE	TIME	LATITUDE	LONGITUDE	DEPTH	TAPE/FILE
START REPEAT OF N FAROES LINE 1						
76			MISFIRE			
77	311	1552	62 45.0	06 40.6	290	6/477B
78	311	1723	62 54.4	06 35.4	670	6/778A
79	311	1919	63 02.5	06 29.9	1360	6/779B
80	311	2128	63 10.9	06 23.5	1755	6/780A
81	311	2337	63 20.1	06 15.3	1680	6/781A
82	312	0202	63 30.2	06 06.2	1845	6/782A
83	312	0453	63 42.1	05 52.3	2690	6/783A
END REPEAT OF N FAROES LINE1						
84	312	1113	63 50.5	05 53.9	3065	6/784A
85	312	1210	63 53.6	05 53.9	3250	6/785A
86	312	1306	63 56.7	06 37.2	2717	6/786A
START REPEAT N FAROES LINE 2						
87	312	1611	63 55.4	07 04.4	—	6/787A
88	312	1940	63 43.0	07 16.1	1615	6/788A
89	312	2210	63 32.0	07 31.7	1100	7/789A
90	313	0018	63 21.0	07 46.1	870	7/790A
91	313	0235	63 10.4	08 00.2	690	7/491A
92	313	0447	62 59.3	08 14.2	550	7/492A
93	313	0730	62 47.7	08 29.5	500	7/493A
94	313	0907	62 39.4	08 29.5	505	7/494A
95	313	1040	62 33.5	08 13.0	495	7/795A

Table 4 Mooring List

Mooring	Position		Deployed	Recovered
488	61 26.8N	08 06.1W	05-10-89*	14-11-89
489	61 19.1N	08 14.9W	07-10-89*	14-11-89
490	61.20.5N	08 13.7W	07-10-89*	14-11-89
492	61 21.1N	08 09.8W	08-10-89*	14-11-89
495	61 27.1N	08 17.4W	09-10-89*	16-11-89
496	61 24.2N	08 10.2W	09-10-89*	Not recovered
497	61 16.8N	08 04.0W	22-10-89	Not recovered
498	62 23.8N	07 43.0W	23-10-89	9-11-89
499	62 24.4N	07 42.8W	23-10-89	12-11-89
500	62 23.5N	07 40.3W	23-10-89	12-11-89

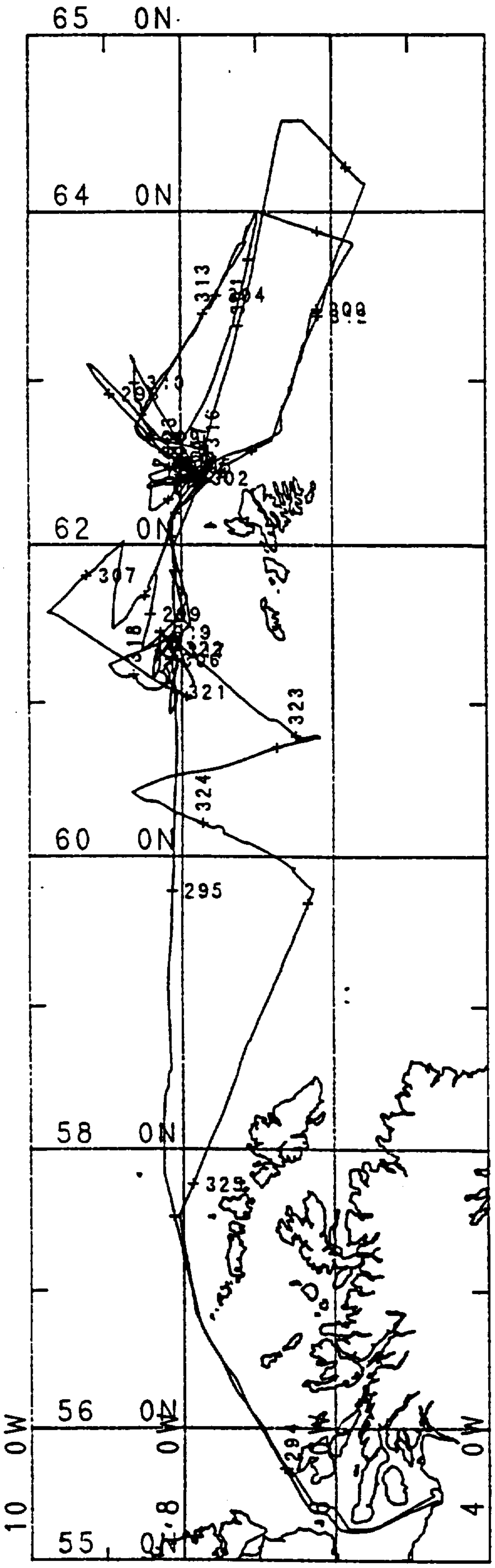


Figure 1. RRS *Charles Darwin* Cruise 43, 20 Oct-22 Nov 1989. Track plot - Troon - Faroes (Mercator Projection; natural scale at Lat 64 is 1 to 5000000)

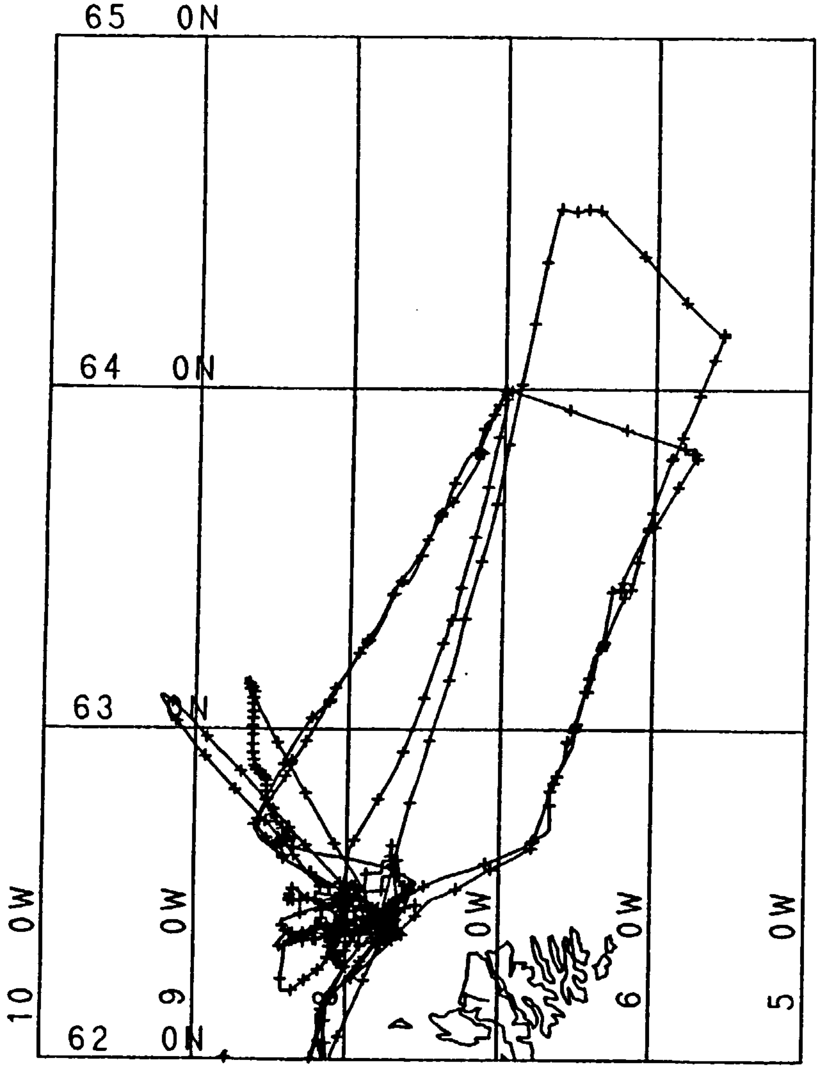


Figure 2. *RRS Charles Darwin* Cruise 43: Track plot - Iceland Faeroes Ridge region. (Mercator Projection; natural scale at Lat 60 is 1 to 2500000)

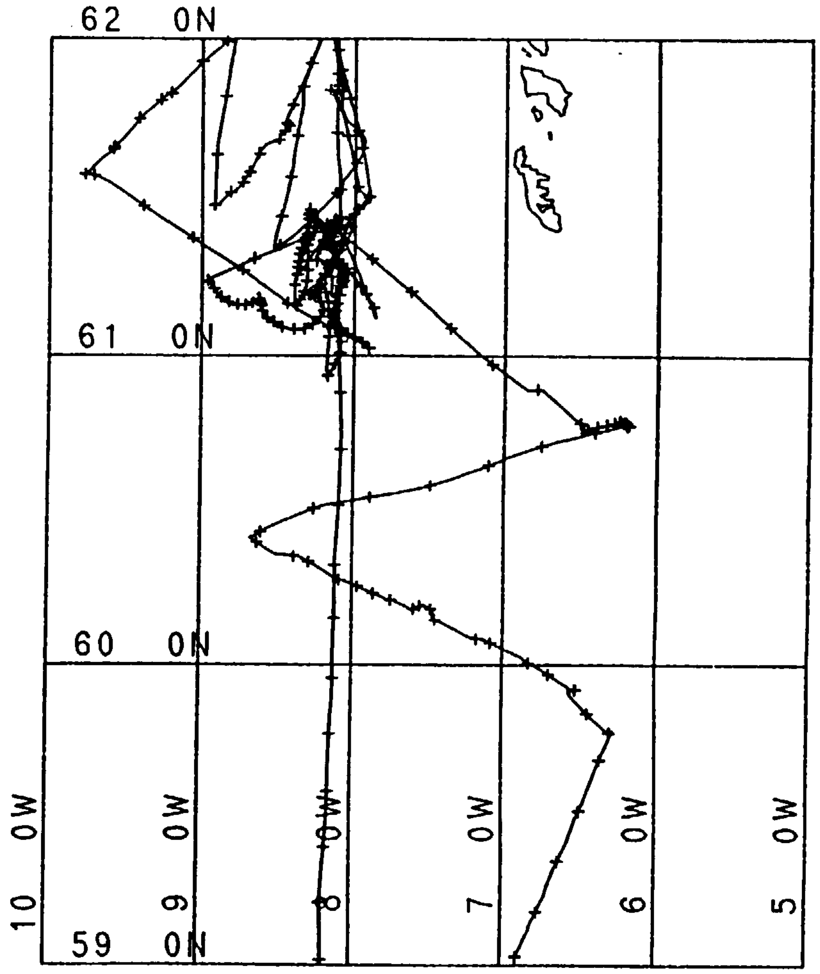


Figure 3. *RRS Charles Darwin* Cruise 43: Track plot - Faeroe Bank Channel region (Mercator Projection; natural scale at Lat 64 is 1 to 2500000)

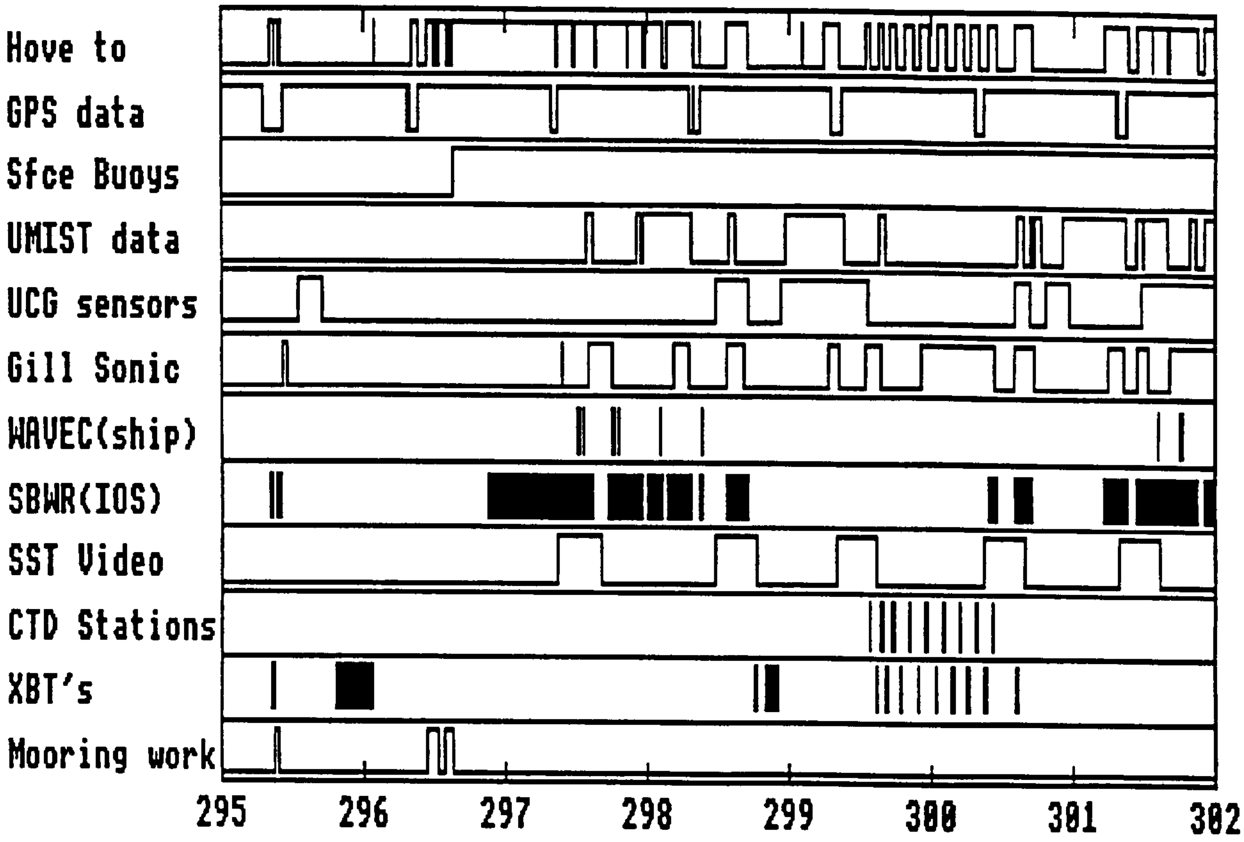


Figure 4a. Time line plot - summary of scientific activity from start of period in working area to day 302. Periods during which an activity took place are shown as a peak. or a vertical line. Key:

Activity	Explanation.
Hove to	Ship hove to for measurements.
GPS data	GPS data available for navigation.
Sfce Buoys	Period during which the surface buoys were deployed.
UMIST data	Meteorological and aerosol data being collected by the UMIST data logging system.
UCG Sensors	Air sampling by the UCG sensor package.
Gill Sonic	Periods for which the Gill sonic anemometer data were logged.
WAVEC (ship)	WAVEC spectra received by the ship-board receiver.
SBWR (IOS)	Shipborne Wave Recorder data logged by the IOS system.
SST video	Video tape of the SST radiometer field of view.
CTD ststions	Times of CTD dips.
XBTs	Times when XBT's were launched.
Mooring Work	Periods of mooring deployment or recovery.

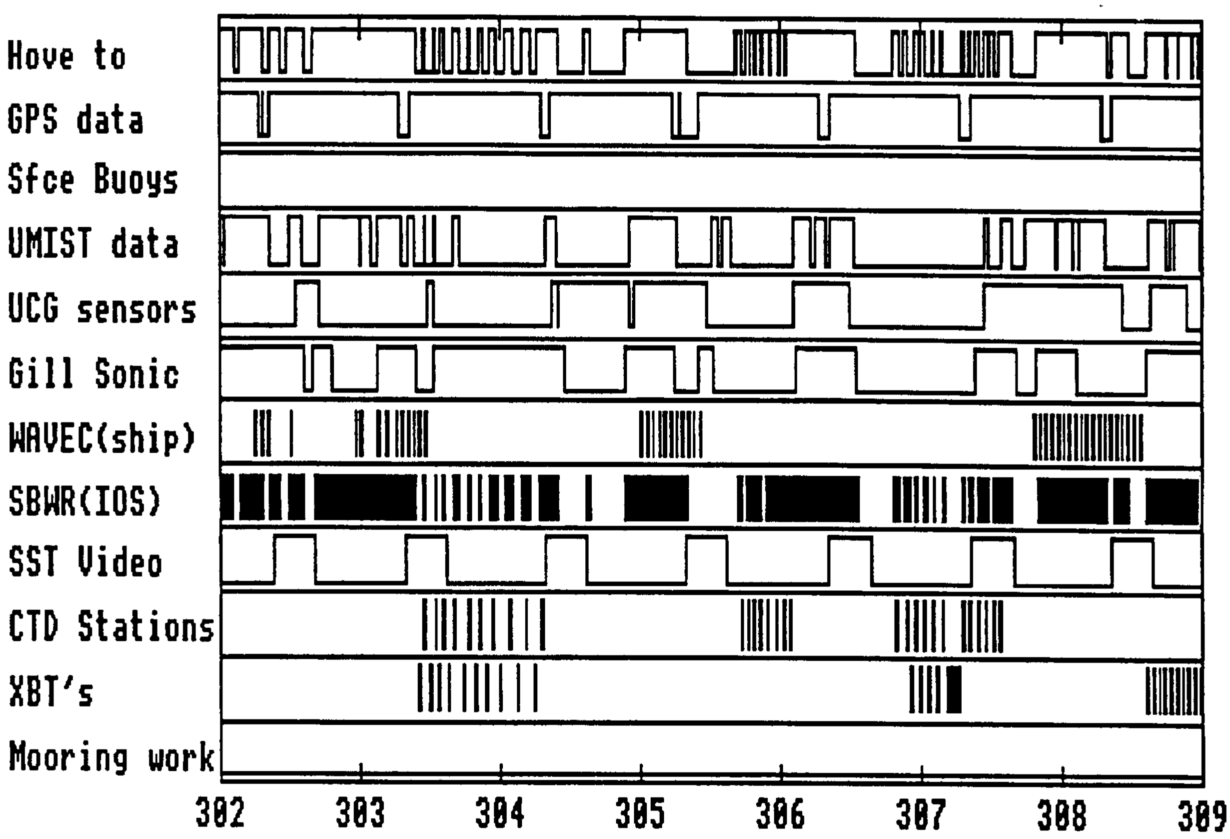


Figure 4b. As figure 4a but for the period day 302 to day 309.

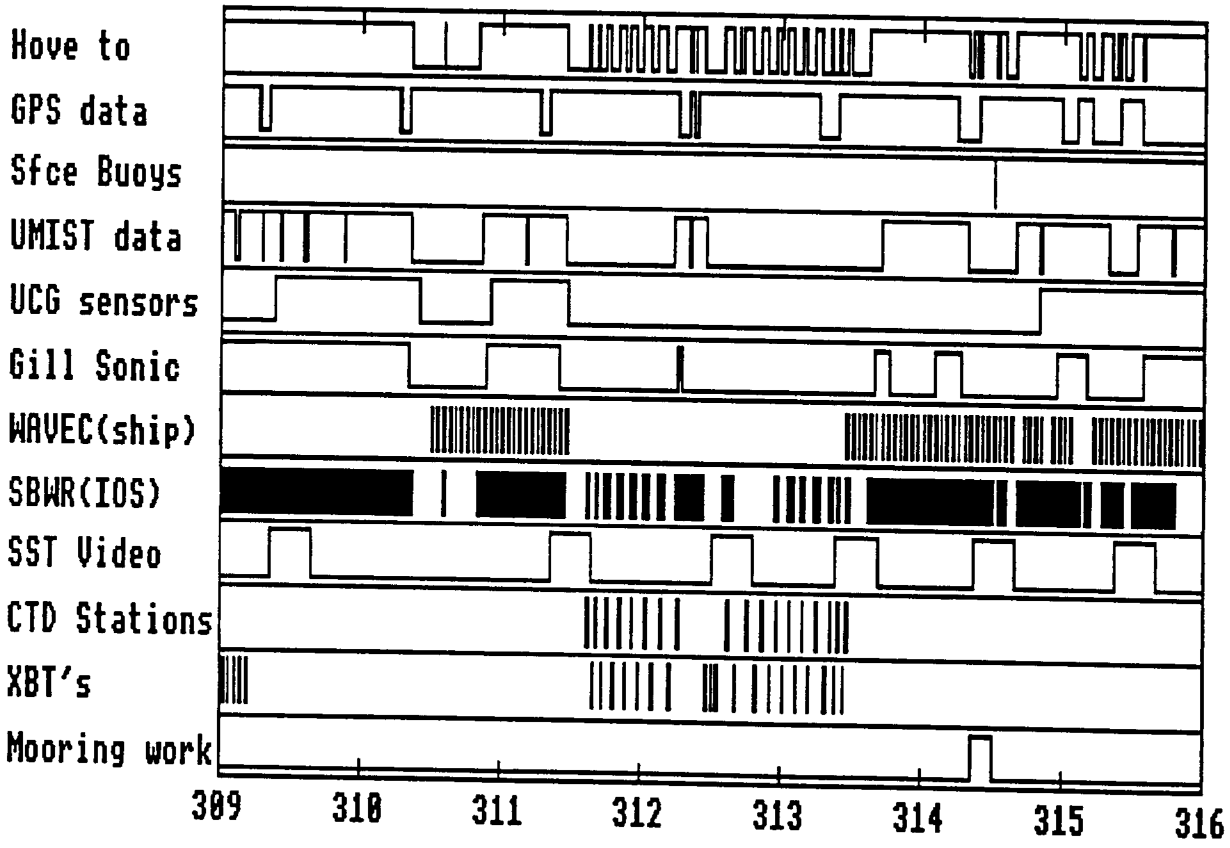


Figure 4c. As figure 4a but for the period day 309 to day 316.

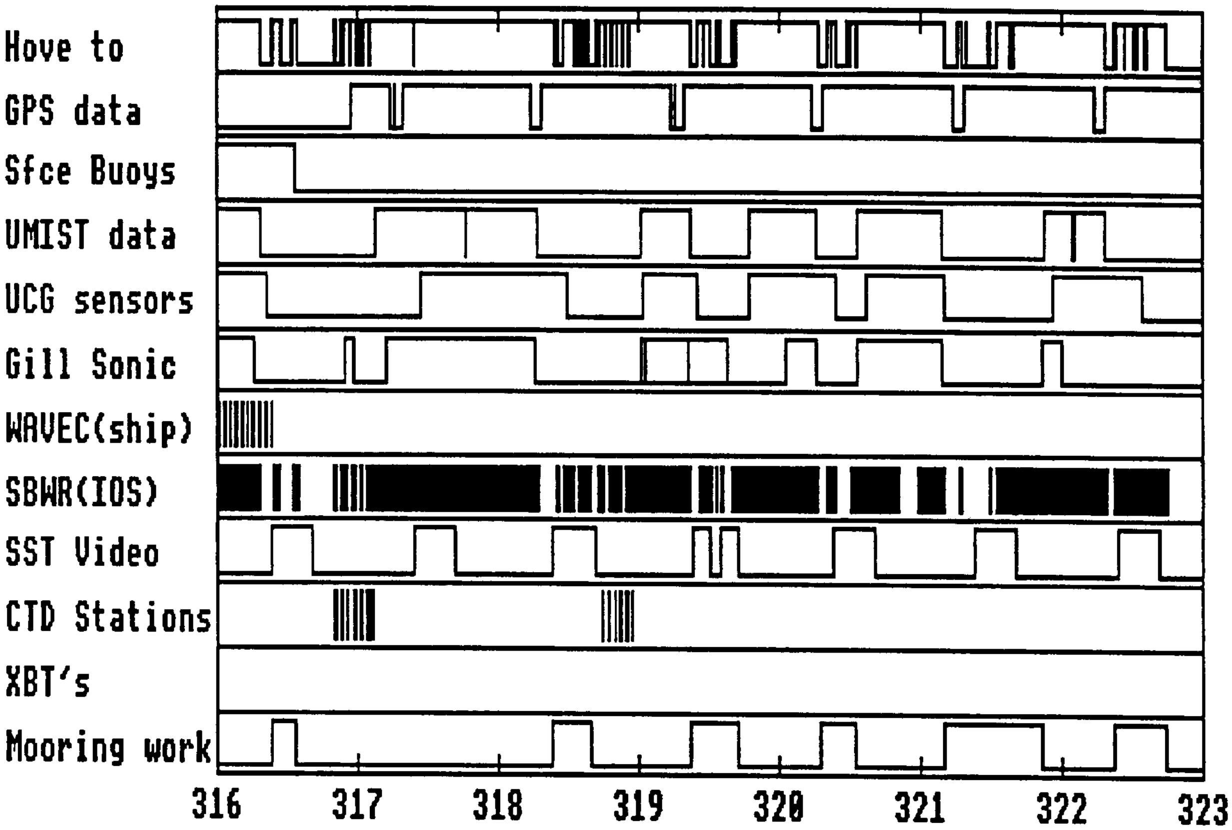


Figure 4d. As figure 4a but for day 316 to the end of the period in the working area (day 323).

CD 43 FORWARD MAST

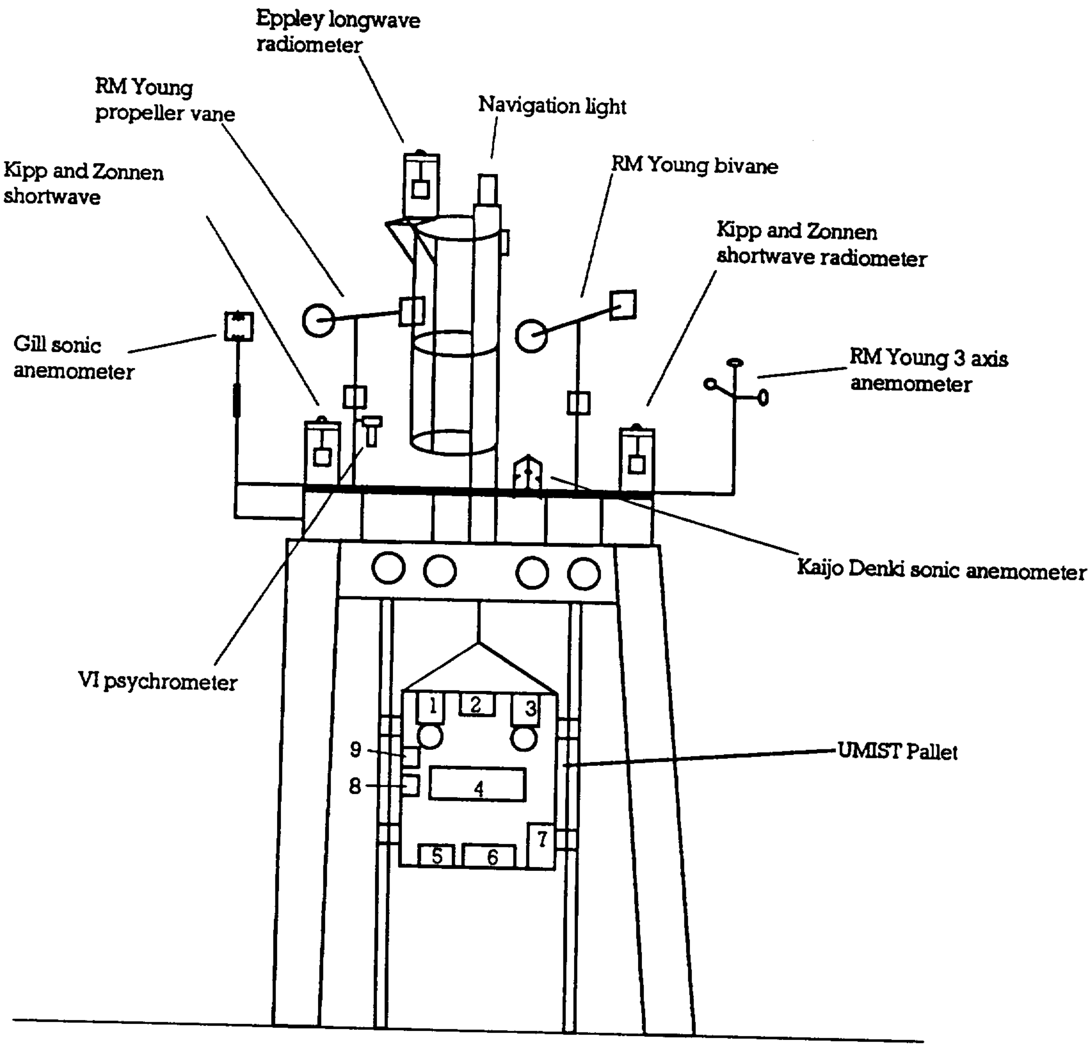
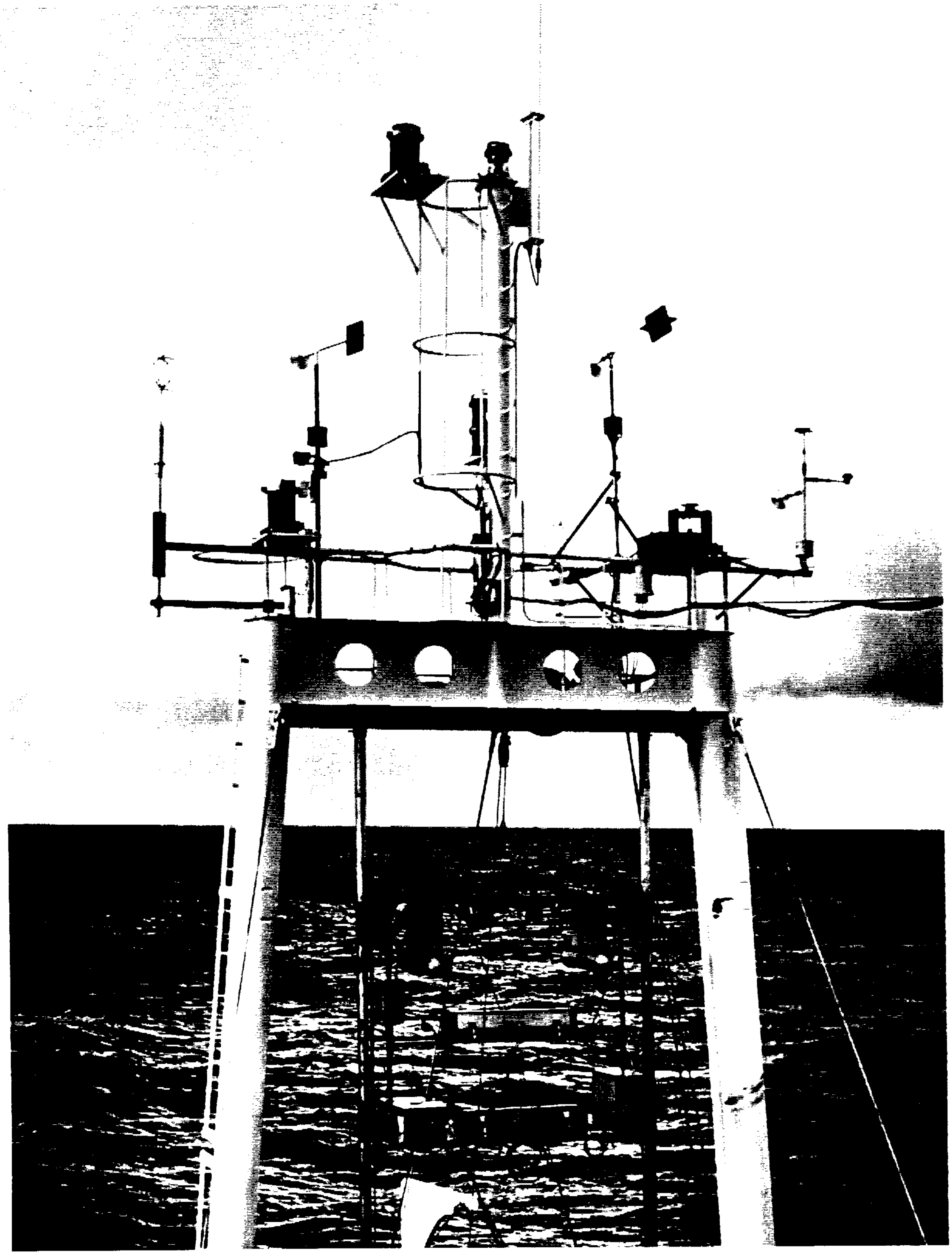


Figure 5. Layout of instrumentation on Forward mast. The instrumentation on the UMIST Pallet was: (1) FSSP, (2) OPHIR, (3) OAP, (4) ASASP, (5) Pallet CPU, (6) CSASP, (7) Pallet Power, (8) CHUM, (9) SONIC Temperature Sensor.



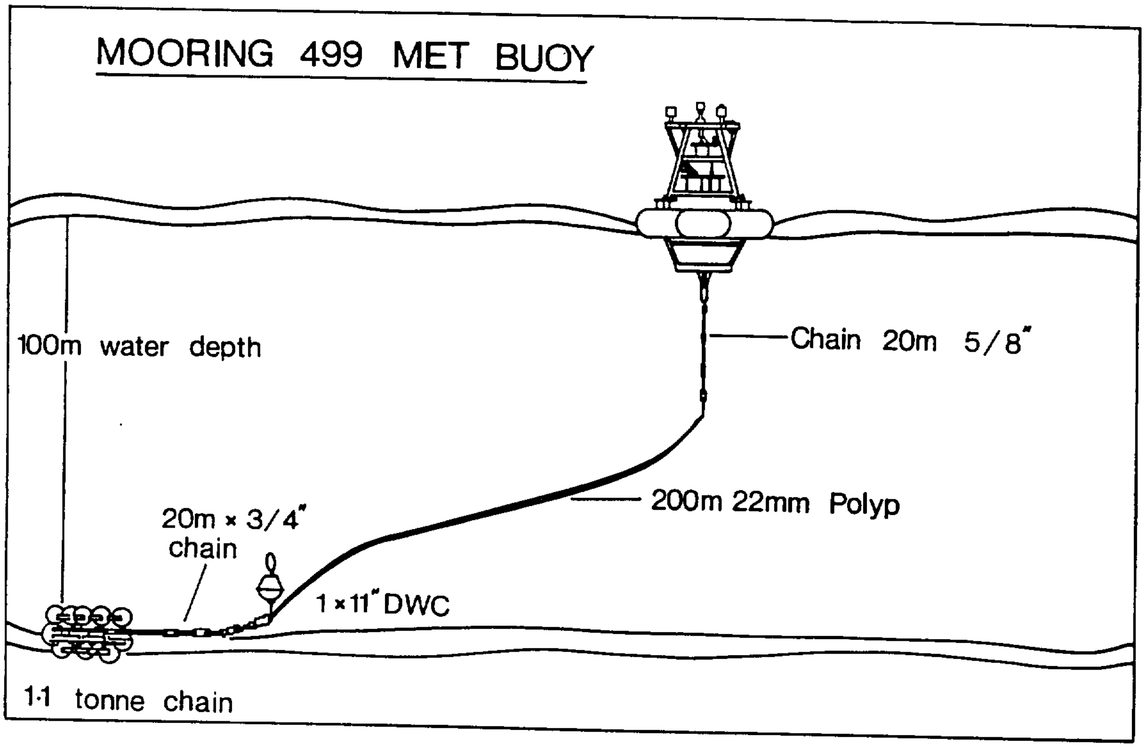


Figure 6. Meteorological mooring.

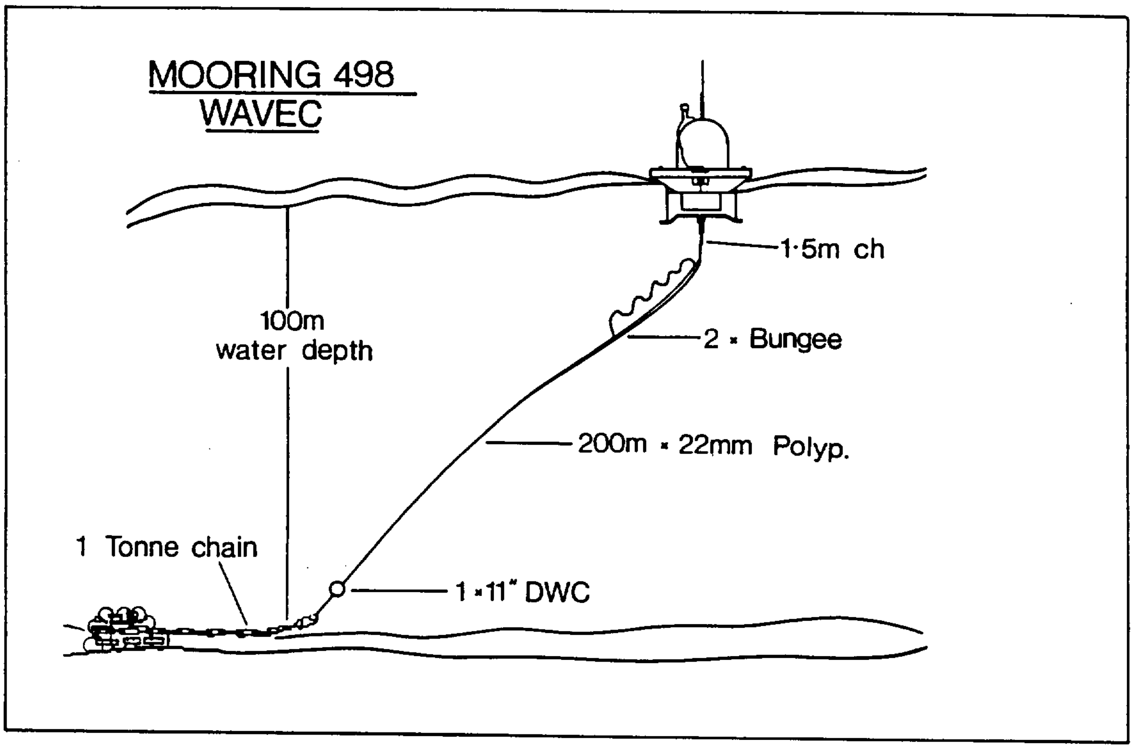


Figure 7. Wavec mooring.

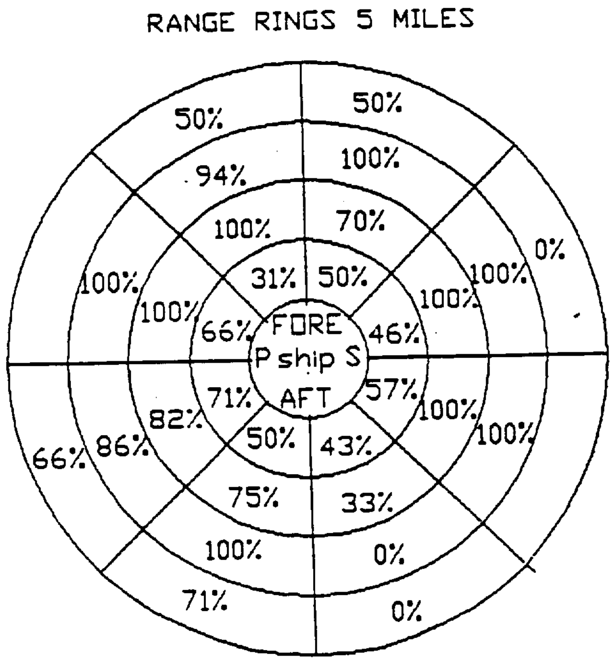


Figure 8. Range and relative bearing at which the Wavec was received.

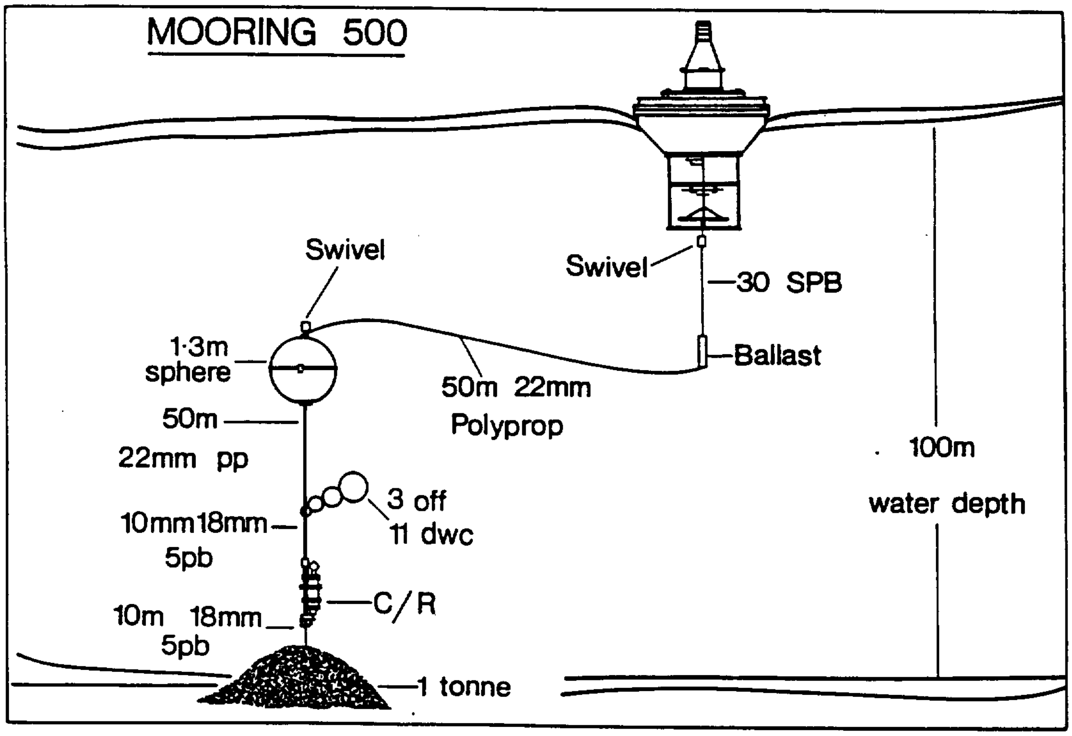


Figure 9. VAESAT mooring.

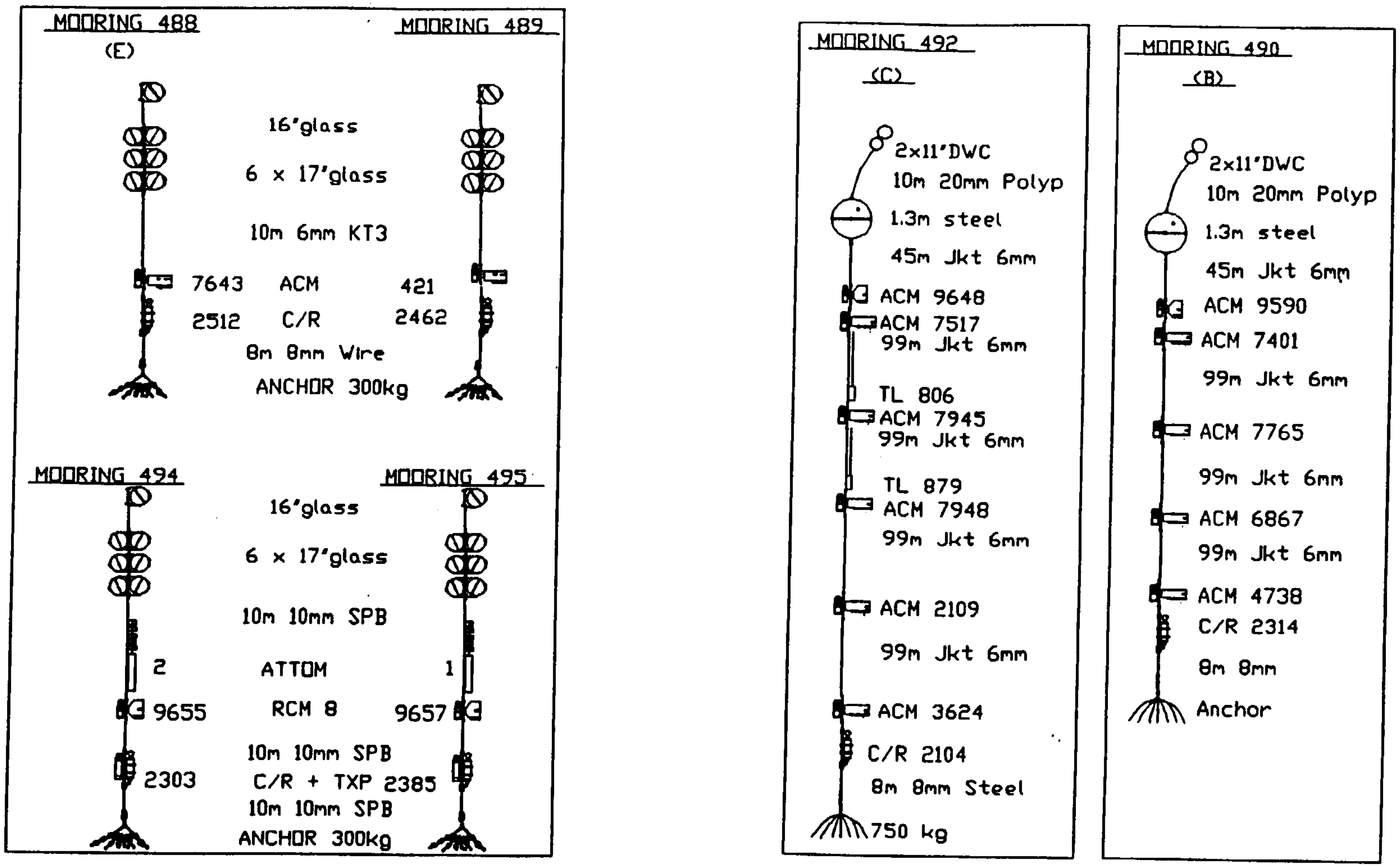


Figure 10. Subsurface moorings.