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12 FEB - 19 MAR 1997

Scheherezade: an interdisciplinary study of the
Gulf of Oman, Strait of Hormuz and the
southern Arabian Gulf

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1997

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ABSTRACT

Scheherezade is a multidisciplinary survey of the Gulf of Oman, Strait of Hormuz and the southern Arabian Gulf. Leg 1 took place between 12 February to 19 March 1997, from Muscat to Abu Dhabi. It comprised a mix of hydrography, biology and remote sensing. CTD, meteorology, biology, multifrequency bioacoustics, hull mounted ADCP, surface thermosalinograph and multispectral irradiance surveys were carried out in all three areas. SeaSoar - fitted with an Optical Plankton Counter - was used in the Strait of Hormuz and Arabian Gulf.

KEYWORDS

ACRONYM, ADCP, ALGAL BLOOMS, ARABIAN GULF, BIOACOUSTICS, BIOLOGY, *CHARLES DARWIN*/RRS, CONCHODERMA, CRUISE 104 LEG 1 1997, CTD OBSERVATIONS, GULF OF OMAN, HYDROGRAPHY, IRRADIANCE, LIGHTFISH, METEOROLOGY, PLANKTON COUNTER, PROJECT, REMOTE SENSING, SCHEHEREZADE, SEASOAR, STRAIT OF HORMUZ, TOWED UNDULATING BIOACOUSTIC SENSOR, TUBA

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INTRODUCTION

Scheherezade is a multidisciplinary environmental survey in the Gulf of Oman, Strait of Hormuz and the southern Arabian Gulf. The survey was carried out in two legs; leg 1 between 12 February 1997 to 19 March 1997 and leg 2 between 21 March 1997 to 19 April 1997. Leg 1 undertook an interdisciplinary programme of hydrography, pelagic biology and meteorology and is the subject of this report (Fig. 1). Leg 2 focused on surface geology, geoacoustics and geotechnics and is the subject of a separate report (Kenyon et al, 1997).

CRUISE OBJECTIVES

1. Carry out high resolution integrated hydrographic, biological and meteorological surveys of the region to:

   a: provide fine scale (horizontal scales 100sm - 10sKm, vertical scales ms: time scales hours to weeks) interdisciplinary data sets;

   b: evaluate short term, small scale, variability;

   c. examine the relationships between hydrography, topography, meteorology and pelagic biology in the region.

2. Use satellite remote sensing to:

   a. provide greater spatial and temporal context to the *in situ* observational programme;

   b. validate new satellite sensors;

   c. study the relationships between remotely-sensed parameters and subsurface structure and dynamics.

NARRATIVE

Charles Darwin sailed from Muscat at 0900h local time on 12 February. Formal confirmation of permission to launch radiosondes was received shortly after sailing. The hull-mounted ADCP was calibrated, and the EK500 and PES fish were deployed en route to the first CTD station. During this first afternoon it became apparent that the SeaSoar winch drum would not turn - and this was worked on by members of the scientific party, the RVS technicians and the ship's officers for the next 48 hours.

The first full depth (2480m) CTD station was worked the following morning with the standard set of oxygen, salinity and chlorophyll samples and with the lowered ADCP. The first radiosonde was launched at 1103h, a second full depth CTD station worked during the afternoon, followed by the second radiosonde. We remained hove to from the late afternoon until the following morning because of the unavailability of technical staff to operate winches whilst efforts to free the SeaSoar winch continued.

On Friday 14.2 it became apparent that the SeaSoar winch bearing cage had collapsed and that repairs could not be carried out on board. The agent in Muscat was contacted about possible repair and a fine scale CTD grid planned to replace the intended SeaSoar survey in the Gulf of Oman. This CTD grid continued for the next 9 days - until 23 February - during which we carried out 107 CTD stations at ca 10 mile spacing in a series of lines running from the continental shelf to the deep water in the Gulf of Oman (Fig. 2). Standard chlorophyll, oxygen and salinity samples were taken at each station. The depth range varied from ca 270 to 3200m with full depth stations worked at the most northerly sites and where the bottom depth over the continental slope was less than 500m. The majority of the casts were made to 500m. The lowered ADCP was deployed beneath the CTD at the deep stations.

During this CTD grid radiosondes were launched routinely at ca 12 hourly intervals and these continued throughout the cruise (Fig. 3). Lightfish was also deployed on the 14 February, and again remained deployed for much of the cruise.

On the evening of 18 February we received quotations from the agent for repairing the SeaSoar winch. Since successful repair was uncertain; the alternative CTD grid was proving very successful; and there would be significant loss of time to re-enter Muscat for repairs; it was decided to proceed without the SeaSoar winch and to transfer sufficient cable from this to a small slip ring winch so that Aquashuttle could be used in the Strait of Hormuz and Arabian Gulf. This cable transfer continued until the 21 February.

On 22 February the first red tide was encountered, spectacular streaks of tomato-soup-like sea composed of the dinoflagellate *Noctiluca*. Red tides were thereafter seen regularly in the Gulf of Oman and on the eastern side of the Masandam Peninsula (Fig. 4).

The initial CTD survey was completed on 23 February, Lightfish recovered and the EK500 calibrated. The day/night vertical series with the RMT 1+8M nets in the deep water of the Gulf of Oman commenced in the early afternoon and continued without a gear failure until 26 February. The series sampled the biota to depths of 2000m, confirming our previous observations on the effects of the oxygen minimum layer on animal distributions and tying in very well with the bioacoustic data from both the ADCP and EK500. The first Longhurst Hardy tow - to provide fine spatial resolution of the biota - was on the 25 February.

On completion of the biological series in the Gulf of Oman, course was made to the southeasterly end of the Strait of Hormuz for trials of Aquashuttle. These were totally unsuccessful, the Aquashuttle vehicle would not undulate routinely - but it erratically and infrequently moved up or down some 10m. It was decided to abandon Aquashuttle as an option and to attempt to use SeaSoar on the small OSSEL slip rig winch using the 250m of unfaired cable recovered earlier. Whilst SeaSoar was being prepared, and whilst concerns over its proposed use on the OSSEL winch resolved, further series of biological trawls and LHPR tows were made in this slope region aimed at scattering layers shown up on the EK500. The fauna was strikingly different to that in the Gulf of Oman, being dominated by decapod crustacea. Trials of the new near bottom echo sounder on the net monitor were successfully carried out.

The following day, 28 February, we experienced our first Shamal. An abrupt 40 knot wind and marked drop in temperature delayed the planned SeaSoar trials. Lines of CTDs were done at the southern end of the Strait whilst waiting for the wind to abate for the trials (Fig. 5). These were eventually carried out on 1 March and were totally successful, SeaSoar reaching a depth of ca 100m with 200m of unfaired cable and undulating well at speeds of between 6-8 knots. We observed our first sea snakes that evening - these were a regular feature throughout the rest of the cruise.

On 2 March the EK500 was serviced, cable damage repaired and the transducers cleaned of hydroids and *Conchoderma*. The first SeaSoar survey through the Strait of Hormuz began in the morning. This continued until the evening of 7 March by which time we had successfully carried out 6 transects through the Strait (Fig. 6). The area is heavily populated by longlines and fish traps. HMS *Roebuck* was surveying in the same area and reported loss of towed gear. We fouled 2 sets of fishing gear with SeaSoar during the survey, on each occasion we were able to recover our equipment without loss - but with damage to the EK500 cable which necessitated replacement. To minimise risk of loss/damage we stopped doing surveys at night on the eastern side of the Strait, but this only caused the loss of one night's work (5 March).The surveys were extremely successful; the Optical Plankton Counter was fitted to SeaSoar and the entire package showed the marked differences in hydrography and biology which occur in the Strait, and the variability in this due to currents, topography and wind. On the 6 March we rounded the tip of the Masandam Peninsula going westwards into a Shamal - this was accompanied by internal waves seen clearly on both SeaSoar data and the EK500.

The SeaSoar survey was completed on the eastern side of the Masandam Peninsula on the evening of 7 March. Further CTD lines and net samples were made at the SE end of the Strait until leaving the area at 0706h on the 9 March to sail to Abu Dhabi for water. Most of 10 March was spent in Abu Dhabi, we sailed at 1612h and made for the University of Miami's CTD line at the western tip of the Masandam Peninsula. This CTD line was sampled on the morning of 11 March, followed by an LHPR tow to validate the SeaSoar OPC data, and a final CTD line at the western end of the Strait (Fig. 7).

The Arabian Gulf survey began with CTD lines in the morning of 12 March, there was some evidence of internal waves on the EK500 data in an area marked "large overfalls" on the chart. CTD lines continued until the evening of 13 March when we began a SeaSoar survey repeating the most northerly (deeper) CTD lines (Figs 8 & 9). The SeaSoar survey was successfully completed at 1009h the following morning, and LHPR tow for OPC validation carried out, and the final CTD survey into the very shallow southwestern area of the Gulf carried out until 1200h on the 15 March. The final CTD (CTD Stn 187) was done in a depth of 12m, such shallow depths were necessary to identify the source of high salinity water originating from the Gulf and subsequently spreading into the Indian Ocean.

Final biological trawls were made on the 15 and 16 March. These were followed by a trial of SeaSoar fitted with the new bioacoustic sensor TUBA. This was the first sea trial of this multifrequency sensor; acoustic data were obtained concurrently with SeaSoar data and areas requiring further work were identified. The final radiosonde launch (no. 89) was made at 2018h on the 16 March, after which the vessel left the work area to wait off Abu Dhabi until docking in the morning of 19 March.

The cruise was very successful despite, or in part because of, the problems we had with the main SeaSoar winch. We achieved very extensive multidisciplinary data sets, and the revised programmes of CTD grids and very high resolution SeaSoar surveys in the shallow waters of the Strait of Hormuz and Arabian Gulf using the small OSSEL winch were all extremely successful. The success of the shallow SeaSoar surveys is a tribute to the flexibility and imagination of all concerned, and the overall success of the cruise depended entirely on the expert way in which the officers, crew and scientists worked together. It is my pleasure to record my thanks to everyone involved with the cruise.

GEAR AND TOPIC REPORTS

CTD and SeaSoar Operation

Preparation:

All equipment used during the cruise was loaded during the Charles Darwin port call at SOC in January, or transferred from RRS Discovery at the end of the OMEGA cruise(D 224) in Cartagena during February. The equipment was installed and tested in Cartagena. The SeaSoar winch was connected and run in port, and the CTD frame and SeaSoar vehicle were stowed on deck for the transit to Muscat. Laboratory computers were set up and signal cables were run and tested.

Equipment and sensors provided for the cruise are listed below.

Vertical Profiling CTD Equipment :

General Oceanics MkIIIb CTD Deep 01 (Pressure, Temperature, Conductivity and Oxygen Current plus an 8 channel multiplexed 12 bit analogue to digital converter.)

Chelsea Instruments 25 cm. pathlength Alphatracka Transmissometer (161/2642/003)

Chelsea Instruments Mk.III Aquatracka Fluorometer (88/2050/95)

FSI `Sure-fire` 24 position multisampler pylon.

Simrad Mesotech Systems Model 807 Acoustic Altimeter (Ser. No. 92010101)

The sensors and bottles were mounted on a large stainless steel profiler frame with 24 bottle mounting plates. Twelve 10 litre Ocean Test Equipment Niskin bottles were fitted to alternate mounting points on the plates.

An RD Instruments Acoustic Doppler Current Profiler, frequency 150kHz (Ser. No. CSN 1503), with separate battery pressure case, was mounted centrally within the profiler frame as an independent instrument.

SeaSoar Equipment :

Horizontal drum winch with 600 metres faired cable.

SOC SeaSoar undulating vehicle (hydraulic unit 002)

Neil Brown / G.O Mk.IIIc CTD Shallow 04 (Pressure, Temperature, Conductivity and Oxygen Current plus 8 channel multiplexed 12 bit analogue to digital converter)

Chelsea Instruments MkIII Aquatracka Fluorometer (88/2960/163)

Chelsea Instruments PAR Lightmeter 46-2835/012.

Focal Technologies Inc. Optical Plankton Sampler (OPC)

At the end of the cruise a prototype multi-frequency bio-acoustical sensor (TUBA)was mounted in place of the OPC on SeaSoar for a trial tow.

Cruise Operations :

The CTD profiler and SeaSoar vehicle were assembled in Muscat, with sensors and cabling, and checks for correct operation. The main horizontal drum winch holding the faired cable for towing SeaSoar was found to be jammed and the drum could not be turned. Despite great efforts by Robin Bonner, Jason Scott, Ben Boorman, Andy Adams and John Clarke over several days, the drum could not be freed. For a cruise so dependent upon SeaSoar operation this was a serious problem.

Profiling CTDs

The proposed first SeaSoar survey, in the Gulf of Oman, was replaced by a grid survey using the CTD system. 108 CTD casts were made in this initial survey (Fig. 2). At the start of CTD operations a badly corroded coaxial cable between a deck junction box and the slip-rings of the midship CTD winch, caused signal noise from the CTD; after replacement no further problems occurred.

CTD casts 109 to 133 were made in four lines running from near coast to deep water between the first survey area and the Strait of Hormuz (Fig. 5). Two further lines of CTD profiles were completed in the Strait of Hormuz (Fig. 7). The first of these was a repeat of an earlier line carried out by Miami University (casts 134 -139). A final CTD survey (casts 145 to 187) was done in shallow water (less than 50 metres) of the Southern Arabian Gulf (Fig. 8).

Throughout the cruise all of the CTD profiling equipment performed perfectly. Calm weather and short casts resulted in little strain on the CTD cable, allowing 187 casts on the original electro-mechanical termination. Particularly pleasing was the performance of the FSI rosette pylon, which successfully fired all bottles on the cruise. Such was the reliability of this unit, on its third cruise, that secondary readings from reversing thermometers and pressure sensors were not needed to check bottle depths. Further investment should be made in these units to replace our much older and less reliable General Oceanics rosette pylons. One 10 litre Niskin bottle was believed to have developed a leaking glued joint between the tube and lower neck. This bottle was marked and not used for the remainder of the cruise.

CTD data was logged by a dedicated laboratory personal computer and the RVS Level `A` system, which averaged the 15 Hz. data frames to one second averaged values. These readings were then passed to the Level `B` and `C` systems for calibration and analysis during the cruise. Bottle firings were recorded on a dedicated Level `A` unit without problem.

SeaSoar Surveys.

To enable underway surveys it was decided to attempt to use a small winch with unfaired cable. This required the removal of approximately 250 metres of the faired SeaSoar tow cable from the seized winch by manually unwinding it from the winch drum. Once on deck, copper ferrules between each three metre long section of fairing were removed and the sections slid by hand off the cable.

The resulting unfaired cable was wound onto the RVS `Ossel 1 ` winch and terminated to the sliprings , which were then cabled through to the laboratory. Although the load rating of this winch was only 450 kg. it proved capable of safely deploying and recovering SeaSoar at 6 knots. A `Chinese finger` cable gripping device was used to take the load of the cable to a deck fixing point and the drum of the winch was secured against rotation by a chain and shackle to the deck.

The original intention was to use a Chelsea Instruments `Aquashuttle` vehicle with an `Aquapack` sensor package for the shallow underway survey work. This vehicle is designed for such work and was purchased for such use on this cruise. Its performance was very disappointing; the vehicle behaved erratically and resisted our efforts to command a regular undulation pattern. After some three hours of trials it was decided that we could not operate the system reliably and decided that all future surveys would be carried out using SeaSoar. The Aquashuttle system will be investigated on its return to SOC and advice sought from the manufacturers.

Two surveys were carried out using SeaSoar (Figs 6 & 9). The first consisted of a series of six parallel tracks from the Gulf of Oman, through the Strait of Hormuz and into the Southern Arabian gulf. This was carried out over a period of five days and covered a distance of approximately 1,600 kilometres. Depth of water during this survey varied from 125 metres to 25 metres. As the winch we were using had slip-rings for the electrical connections we were able to adjust the tow cable length whilst under way.

At the start of the first survey the pressure transducer temperature sensor (CTD Shallow 04), was found to be faulty. As this reading is not used in the final computation of pressure values, the term was removed from the calibration file so that it could not affect any other readings. This problem will be investigated when the equipment is returned to SOC

On one occasion (7 March) the SeaSoar would not dive to depth under command. Upon recovery of the vehicle a fishing long-line was found to be caught around it complete with baited hooks and anchor. The only damage to the SeaSoar vehicle was to the flexible strain relief tail where the tow cable is attached to the towing bridle. This strain relief was not replaced because the low tow loading on the cable, in ideal weather conditions, did not put the tow cable at risk of major damage.

A second survey was carried out in the Southern Arabian Gulf in shallow water of 25 to 50 metres depth. For this survey a shorter tow cable length of approximately 70 metres was deployed. This required careful monitoring of the SeaSoar controller program by the operators to get good depth coverage without undue risk to the equipment. This survey was completed in approximately 20 hours and covered a distance of 340 km.

A third and final SeaSoar tow session was carried out near the end of the cruise with a prototype multi-frequency, bio-acoustical sensor (TUBA) in place of the OPC. Some noise pick-up was seen in the signal returns and time was spent trying to isolate the source. The SeaSoar was recovered and the fluorometer was disconnected to try and eliminate the noise source. Eventually cross talk between the CTD signal lines and the TUBA signal line was suspected; this will be investigated at SOC.

During these shallow SeaSoar surveys an inline load cell in the cable gripper showed maximum loading on 250 metres of tow-cable to be 800 kg. with SeaSoar at 90 metres depth and only 100 kg. with the vehicle at the surface. Shorter tow lengths, 70 -100 metres, were used in shallow waters and the control program designed by John Smithers enabled us to `fly` SeaSoar in water depths of 25-30 metres.

SeaSoar CTD data was recorded on laboratory computers and a high performance VME-bus RVS Level `A` system. The high data rate from the CTD used in the SeaSoar (25Hz.) caused some logging problems on the level `A` and occasional 'crashes'. This resulted in temporary loss of data whilst the unit was manually reset. The cause of these `crashes` and a solution will be investigated at SOC.

The fluorometer and PAR light sensor carried on SeaSoar worked well throughout each tow survey. An optical plankton counter (OPC), was deployed on SeaSoar as an independent instrument sending its own data back aboard ship. Initial indications are that it performed well during the tows.

For CTD and SeaSoar operations it is necessary to have navigational data, echo sounder and clock readouts within easy reach of the operators. Whilst echo sounder and clock data was available there is no dedicated readout for GPS position in the main laboratory of Darwin. We hope that these readouts can be provided in the future.

R E KIRK , S F WATTS, R N BONNER

CTD data processing

187 lowered CTD profiles were made. Twelve bottles, a fluorometer, a transmissometer, an altimeter and an ADCP were also mounted on the CTD frame. This report describes the onboard processing of the CTD data..

Data acquisition

Data were collected in three areas. The Gulf of Oman, the Strait of Hormuz and the Arabian Gulf. A summary of the 187 CTD profiles is given in Table 1.

Gulf of Oman

A grid of 108 stations was surveyed (Fig. 2). Most casts were to a depth of 500m or to the bottom if it was less than 500m. At nine stations full depth profiles, ranging from 650m to 3250, were made. Four samples were taken at each of the 500m stations: at 5m, 50m, 250m or 300m, and at the bottom. Up to 12 samples were taken at the full depth stations. Samples were analysed for salinity, oxygen and chlorophyll.

The dominant feature in this area was the current formed by the Arabian Gulf water flowing along the shelf break at depths between 200 and 350m This current was both warmer and saltier than the water above and below it, thus enabling diffusive convection above and salt fingering below. Many layers were seen to interleave with the surrounding water and step like temperature salinity profiles were observed below the current The current extended 10 to 20km from the shelf break but meanders were observed much further off shore.

Strait of Hormuz

A total of 37 stations were made on seven sections across the strait. Most were full depth. At least two samples, one at 5m and one at the bottom were taken at each station.

Within the strait the bottom depth is mostly less than 100m, but increases rapidly in the Gulf of Oman. Outflow from the Arabian Gulf descends along the slopping bottom as it leaves the strait until it reaches a depth at which its density is equal to that of its surroundings. Initial examination of the CTD sections in this area indicate a rapid mixing of the outflow as it descends and thus a significant reduction in the salinity maximum.

Arabian Gulf

An array of 42 stations was completed in the Arabian Gulf. All were full depth profiles ranging from 12m to 54m. Two samples, one at 5m and one at the bottom were taken at each station. The area surveyed was transitional between shallow well mixed high salinity water to the south and west, and stratified water in the deeper area to the north and east. There were thus large gradients in the surface properties.

Initial calibration

Data from the CTD deck unit was passed to the level A acquisition system in which the data were averaged to one second values and a time stamp was added to each record. The number of frames in the average and the rate of change of temperature were also evaluated. Data are subsequently passed to level B (logging) and level C (processing). There were two occasions when data was lost - a section of the downcast at station 8 and the upcast of station 12.

Data were then copied from the RVS level C to enable further processing using PEXEC software.

Extreme values of pressure, temperature and salinity were deleted as were records for which the number of frames was less than 12 or greater than 20. Initial calibrations described in Appendix A below were then applied.

Pressure

The following calibration was applied to the raw values:

$$press(\text{dbar}) = -9.3832 + 0.996263 \times praw + 5.743323 \times 10^{-7} \times (praw)^2$$

Temperature

Temperature in degrees Celsius was calculated from the raw values as

$$temp(°C) = -.0165549 + 4.99282 \times 10^{-4} \times traw + 7.97259 \times 10^{-13} \times traw^2$$

The platinum thermometer has a slower response than the conductivity cell. Thus the temperature values need to be advanced. This was done by calculating a corrected value,

$$T_c = T + \tau \times deltat \ ,$$

where deltat is the change in temperature during the one second average as evaluated by the RVS level C software. The time lag, τ, was chosen to be 0.2 seconds.

Conductivity

The initial calibration applied was

$$cond(\text{mmho}/cm) = 0.988156 \times 10^{-3} \times craw$$

Values were then corrected for the call material deformation using the default values in the program *ctdcal.*

Salinity

Salinity was evaluated from the calibrated values of conductivity, temperature and pressure.

A future calibration was carried out by comparison with salinity measured from the bottle samples. The very large vertical gradients in salinity meant that many of the bottle samples could not be used for calibration. Samples in the mixed layer and other low gradient areas were most useful. Based on these samples the accuracy of the calibrated salinity is 0.005psu.

In the Gulf of Oman sharp interfaces and layers a few metres thick were often observed. At these locations the use of a lagged temperature does not adequately correct for the different time response of the temperature and conductivity sensors and larger errors in salinity may occur.

Transmittance

The following calibration was applied to the raw data to obtain the instrument output in volts

$$trans(\text{volts}) = 0.00181789 + 1.21934 \times 10^{-3} \times traw + 6.05678 \times 10^{-10} \times traw^2$$

No further calibration has been made at this time

Fluorescence

The following calibration was applied to the raw data to obtain the instrument output in volts..

$$fvolts(\text{volts}) = -.00172 + 1.219711 \times 10^{-3} \times fraw + 3.4386 \times 10^{-13} \times fraw^2$$

Fluorescence was then evaluated as

$$flour = \exp(fvolts) - 1.0$$

An improved calibration will be made using the bottle data.. An initial comparison with the samples shows good correlation with the measured chlorophyll at low concentrations. It will probably be necessary to take account of quenching for the high near surface measurements.

Oxygen

Output from the oxygen cell was calibrated by *ctdcal* using the following equation to obtain the oxygen current.

$$oxyc = 5 \times 10^{-4} \times craw$$

Oxygen concentration is calculated from the oxygen current, temperature, pressure and salinity,

$$oxygen(um/l) = R \times osat(P,T,S) \times oxyc \times \exp(-aT + bP)$$

The coefficients a and b were determined by comparison with oxygen samples from the deep stations. The parameter R was determined using all the samples.

Extremely low values, less than 1um/l, were observed in the oxygen minimum layer in the Gulf of Oman. To obtain an accurate calibration at these low values it was found to be necessary to vary the offset in the calibration for the oxygen current.

The calibrated oxygen were very well correlated with the sample data. It will be necessary to make further corrections to some of the profiles in the upper 50m.

Bottle samples

The times at which the bottles were fired was recorded by the RVS level A software. This data was read from the level C files into pstar data files. The results of the analysis of the bottle samples for salinity, oxygen and chlorophyll were read into a sample file for each station. Also included in the sample file were corresponding data from the CTD upcast and downcast. Data from the upcast (averaged over 10 seconds) was extracted at the time the bottle was fired. Data from the downcast was selected at the depth where the density was equal to that on the upcast at the time the bottle was fired..

D A SMEED

SeaSoar data processing

During RRS Charles Darwin cruise 104 a SeaSoar fitted with a CTD, a fluorometer, a light sensor and optical plankton counter was deployed. This report describes the onboard processing of the data.

Data acquisition

The times when SeaSoar was deployed are listed in Table 2. Two areas were surveyed

Survey 1 - The Strait of Hormuz

SeaSoar was towed through the strait along 6 tracks each approximately 280km long. The vehicle oscillated between the surface and a maximum depth that varied from 30m to 90m. This was within 10m of the bottom over most of the strait. The time for one complete cycle was 90 seconds or less. This enabled a horizontal resolution of the order of 1km. The structure on the flow varied rapidly along the strait. In the Arabian Gulf the interface above the high salinity outflow was within 30m of the surface. The interface descended rapidly at the narrowest section of the strait and then rose again as the bottom depth decreased before again descending as the depth increased again at the entrance to the Gulf of Oman.. The interface was also observed to slope down in the across strait direction, indicating that the earth's rotation affects the flow. Large amplitude (>30m) internal waves were also observed within the strait.

Survey 2 - The Arabian Gulf

Three parallel lines each approximately 200km long were surveyed in the Arabian Gulf. SeaSoar profiled to within 5 or 10m of the bottom which varied between 25m and 65m.

Data calibration

Data from the CTD deck unit was passed to the level A acquisition system in which the data were averaged to one second values and a time stamp was added to each record. The number of frames in the average and the rate of change of temperature were also evaluated. Data are subsequently passed to level B (logging) and level C (processing). There were a number of occasions when small amounts of data (of the order of 30s on each occasion) were lost due to problems with the level A system. The cause of the problem is not yet known. However, the problem did not occur when using the lowered CTD, and it is probable that the problem is related to the higher frame rate of the SeaSoar CTD.

Data were then copied from the RVS level C to enable further processing using PEXEC software.

Extreme values of pressure, temperature and salinity were deleted from the raw data before applying the initial calibration described below. During the cruise it was noted that there were a significant number of records with low (<16) numbers of frames. Therefore an additional step in processing was introduced to filter out records for which the number of frames was less than 16 or greater than 40. Typically one in two hundred records were affected.

The calibrations applied to the data were as follows (see also Appendix B).

Pressure

The following calibration was applied to the raw values:

$$press(\text{dbar}) = -43.6421057 + 3.2280473 \times (0.01 \times praw)$$

no other corrections have been made.

Temperature

Temperature in degrees Celsius was calculated from the raw values as $temp(°C) = -2.70934 + 4.93708996 \times (0.0001 \times traw) + 0.000239076 \times (0.0001 \times traw)^2$. The platinum thermometer has a slower response than the conductivity cell. Thus the temperature values need to be advanced this was done by calculating a corrected value,

$$T_c = T + \tau \times deltat \ ,$$

where deltat is the change in temperature during the one second average as evaluated by the RVS level C software. The time lag, τ, was initially set to be 0.15 seconds, the value usually used for this CTD unit. However, inspection of the data indicated the temperature and salinity values on the up casts were significantly different from those on the down casts. This indicated that the time constant was incorrect. The optimum value was found to vary between 0.15 and 0.3 seconds. The time constant is not usually varied. The cause of the variation is not clear, but could be fouling of the temperature sensor. The very rapid changes in temperature and salinity made the results very sensitive to the value of τ.

Conductivity

The calibration applied was:

$$cond(\text{mmho}/cm) = -0.012146727 + 0.960765192 \times (0.001 \times craw) + 0.0000461212 \times (0.001 \times craw)^2$$

Salinity

Salinity was evaluated from the calibrated values of conductivity, temperature and pressure.

Frequently there are low spikes in salinity where the SeaSoar reaches the surface. After examination of a histogram of salinity values a cut off was selected (for each 4 hour file) below which all salinity data were set to absent.. Further despising of individual data was done after inspecting the profiles.

Material can get caught in the aperture of the conductivity cell resulting in sudden drops in the value of salinity. Sometimes this appears as a constant offset with salinity stepping up to the correct value when the cell clears or the value drifts back over a period of time. To overcome this problem all of the profiles were examined both on temperature-salinity plots and salinity-pressure plots. When a fouling event was found either a constant correction was applied if there was a constant offset, or the affected cycles were set to absent if there was a drifting offset. The large range of salinity and the rapid change of the temperature salinity characteristics along the straits made this task particularly difficult during the first survey.

The salinity calibration is verified by comparison with data from the thermosalinograph and surface samples taken at hourly intervals during the surveys. So far only the first survey has been calibrated. The results indicate that the salinity values are accurate to 0.02, but at depths where there are large vertical gradients accuracies may be lower. These errors are larger than that usually found for SeaSoar measurements, however, the range of salinities, from 36.4 to 40.5 is also very large.

Light

The instrument output in volts is given by:

$$light(\text{volts}) = -4.960675 + 1.51391 \times (0.0001 \times lraw) - 0.000002982 \times (0.0001 \times lraw)^2$$

Values of light in physical units given by the following calibration:

$$\ln\left(light(Wm^{-2})\right) = -11.65617 + 4.854 \times lvolts$$

The two steps above were combined to obtain the logarithm of light directly from the raw values..

Fluorescence

The calibration in Appendix B was applied to the output from RVS files to obtain the instrument output in volts.. No further calibration has been made at this stage.

Oxygen

Output from the oxygen cell was calibrated using the coefficients in Appendix B. However, measurements of oxygen on SeaSoar are known to be poor and no attempt to check the calibration was made. The data will not be presented in this report.

Navigation

The SeaSoar data were merged with navigation data so that position and distance run could be added to each record. The navigation data used was given at one minute intervals. Merging was done using the common time variable.

Gridded data

To produce plots of the results data were averaged in bins 4db deep and 1.5km long. Each 1.5km box contains 4 to 6 profiles.

D A SMEED, J T ALLEN

Salinity sampling

During CTD surveys salinity samples were taken from each CTD Niskin using 200ml glass sample bottles, closed with disposable plastic inserts and screw-on caps. Each bottle and cap was rinsed three times with sample water to remove any old sample and any salt crystals from the neck of the bottle, and then filled to the base of the neck and sealed. During SeaSoar deployments, hourly samples were taken from the outflow of the thermosalinograph. Samples were left in the constant temperature laboratory for at least 24 hours before being analysed in order for the temperature to equilibrate.

All analyses were carried out using a Guildline Autosal model 8400A fitted with an Ocean Scientific International peristaltic sample intake pump. The salinometer was situated in the constant temperature laboratory. The laboratory temperature was set at 20°C initially and the salinometer water-bath temperature was set at 21°C. The controller for the Air Conditioning heat exchanger failed on Jday 054. This meant that the CT laboratory could then only be held grossly stable to between 20°C and 24°C with a slow drifting between these extremes. The salinometer water bath temperature was reset and re-standardised to 24°C to cope with this change in environment. Despite these problems the readings on the salinometer generally remained very stable. The salinometer cell had been replaced just before the last cruise to use this salinometer (Di224, 27/11/96-29/12/96). However it was noticed that some discoloration on the inside of the glass of the cell was already starting to appear. Flushing with diluted Deacon solution did not have any affect on the discoloration; but the discoloration did not seem to have any effect on the stability of the measured conductivity ratios.

Standardisation was achieved by use of IAPSO standard seawater ampoules. Only a single standard batch P130 (79 ampoules) was used during the cruise. Standards were run at the beginning and end of each crate of bottle samples irrespective of the number of bottles in a crate, which never exceeded 24. Thus analysis sessions never lasted more than 1.5 hours and with only one exception the drift in measured conductivity ratio of IAPSO standard seawater did not exceed 0.00010 and was generally better than 0.00005. The one exception occurred as a result of a sharp change in laboratory temperature and a drifting correction was applied to the bottle sample conductivity ratios.

During the cruise, duplicate samples were frequently drawn from one Niskin bottle on a CTD cast and occasionally second bottles were fired at particular depths. Duplicate samples from the same Niskin bottle were generally within 0.00003 in conductivity ratio. Replicate samples from two bottles fired at the same point differed more, generally within 0.00010 in conductivity ratio, which may probably be accounted for by the very large horizontal and vertical salinity gradients and the finite time delay in sequential firing of the bottles. However these tests did indicate that Niskin bottle no. 1 may have developed a leak during the cruise. Further suspicion of this bottle arose following the discovery of salt crystals around the bottom seam of this bottle after it had stood on deck for some time full of sea water. As a result, Niskin bottle no. 1 was not used after Jday 060.

J T ALLEN

Oxygen Sampling

Oxygen samples were drawn first from the Niskin bottles at each CTD station. For the first five deep CTD stations the samples and duplicates were taken from every bottle. However, the intense nature and the shallow depths of the rest of the Gulf of Oman survey meant that samples were only taken at three depths and duplicates only in the oxygen minimum. In the Arabian Gulf the samples were only taken at two depths, as this was more suited to the profiles. This sampling protocol still produced over 60 samples every day, with processing time the main constraint on the number taken. The samples were drawn into clear, wide necked calibrated glass bottles and fixed on deck with reagents added using Anachem bottletop autodispensers. The samples were shaken for at least two minutes on deck and again in the constant temperature laboratory 1/2 an hour after collection. The samples were then stored underwater until analysis.

The temperatures of the water when sampling was taken using a hand held electronic thermometer probe. These temperatures were used to calculate any temperature dependant changes in the sample bottle volumes. These were measured straight away after sampling because the water in the Niskins heated up very quickly once the warm air was let in.

Samples were analysed in the constant temperature laboratory, between two and ten hours after sample collection, following the Winkler whole bottle titration with an amperometric method of endpoint detection, as described by Cutherson and Huang (1987). The equipment used was supplied by Metrohm and included the Titrino unit and control pad, exchange unit with 5ml burette (unit 3) to dispense the thiosulphate in increments of 1ul, with an electrode for amperometric end point detection.

The thiosulphate normality was checked with each batch of samples against the potassium iodate. The exact weight of this standard, the calibration of the 10ml exchange unit in the Metrohm Dosimat and the 1l glass volumetric flask used to dispense and prepare the standard were accounted for in the Excel worksheet used the oxygen values.

The introduction of oxygen with the reagents and impurities in the manganese chloride were corrected were corrected for by blank measurements made on sample batch, as described in the WOCE manual of Operations and Methods (Culberson, 1991).

There was a pronounced oxygen minimum especially in the first study area where deeper waters were surveyed. Minimum concentrations of oxygen were 0.4 umol/l and the maximum concentrations which were at the surface reached to 235 umol umol/l. The mean difference for the duplicate pairs sampled on each station was 0.6 umol/l. The data quality may have been affected by the Niskin bottles warming up on deck prior to sampling. But this value is lower than on the last cruise to use this equipment, the WOCE cruise D223, with many duplicates being taken on both cruises.

A MUSTARD

Chlorophyll Analysis

Chlorophyll samples were taken to calibrate the fluorometers on the CTD, the SeaSoar and the underway TSG. The sampling for the CTD concentrated on the surface and 50 metre bottle (where the water was deep enough). Chlorophyll samples were the last samples to be drawn from the rosette, and were stored in the dark until they were filtered. Underway samples were taken every two hours while the SeaSoar was deployed and samples were taken from the non toxic hose either in the wet lab sink or on the starboard deck just outside. Sampling was changed to the latter because it was a more direct supply and therefore provided a less mixed sample. Both surface CTD bottle and underway samples were used to calibrate the TSG fluorometer.

Samples were collected in 2 litre plastic flasks which were rinsed out with the sample prior to being filled. These were stored in the dark until they were filtered. Two aliquots of 100ml were measured out with a cut off plastic volumetric flask and filtered through separate Whatman GF/F 25mm filters at low pressure (<6mm Hg). The filter set up was shaded with a black plastic curtain and the wet lab blinds were closed to further reduce the light. Once the 100ml had passed through the filter paper they were removed with forceps and placed in the glass vials which were labelled with the date and time or the station and Niskin number. The vials were stored in the dark at -20°C until extraction.

To extract the chlorophyll pigment 20ml of 90% acetone was added to batches of samples from a Anachem 25ml adjustable autodispenser. The vials were then placed back in the freezer for 20 to 22 hours.

After this time samples were removed and warmed to lab temperature in a water bath before the fluorescence was measured in a Turner Designs Fluorometer (model 10-000R, serial no. 00859). Then 2 drops of 10% hydrochloric acid were added to the sample and the fluorescence was remeasured.

Eight chlorophyll solutions were made up covering the expected range of the samples at 0.56, 1.13, 2.26, 3.39, 4.52, 6.78, 9.04 and 11.3 mg m^{-3} which were used to calibrate the fluorometer. This was done twice during the cruise, and the standards remained very constant for the two calibrations. These calibration standards were dilutions of a primary standard which was made up from a Sigma chlorophyll pellet dissolved in 90% acetone. The chlorophyll concentration of the primary standard was determined from the absorbence measured before and after acid at 665 and 750nm in Pye Unicam SP6-500 spectrophotometer.

Chlorophyll and phaeopigment concentrations were calculated using the equations from the JGOFS protocols (1994) in a Microsoft excel spreadsheet. The resulting values transferred to PSTAR as a text file.

Equations

1° standard concentration:

$$\text{Chlorophyll a (mg m}^{-3}) = \frac{26.7(665b-665a)v}{l}$$

$$\text{Phaeopigments (mg m}^{-3}) = \frac{26.7((1.7*665a)-665b)v}{l}$$

where: 665b = Absorbance at 665nm before acidification.

665a = Absorbance at 665nm after acidification.

v = Volume of extract (ml)

l = path length of cuvette (cm)

Sample concentrations:

Chlorophyll a (mg m^{-3}) = FD*(Fm/(Fm-1))*(Fb-Fa)*(v/V)

Phaeopigments (mg m^{-3}) = FD*(Fm/(Fm-1))*((Fm*Fb)-Fa)*(v/V)

where: FD = Chlorophyll Standard concentration / Chlorophyll standard Fluorescence before acidification.

Fb, Fa = Fluorescence value before and after acidification of sample.

Fm = Fb/Fa of chl a standard solution.

v = volume of 90% acetone used in extraction(ml).

V = Volume of seawater filtered (ml).

Chlorophyll samples varied between 0 to and 4.5 mg m^{-3} but were usually between 0.5 and 2 mg m^{-3} from the 5 metre Niskin and the underway samples. This wide spread is not unexpected with the wide range of conditions surveyed and the high variability encountered during the cruise. The duplicates were generally good reproductions of the samples and both provided reliable values for the calibration.

A MUSTARD

Thermosalinograph

Underway surface conductivity and temperature measurements from the thermosalinograph (TSG), and fluorescence and light transmission measurements from a tank mounted fluorometer and transmissometer were continuously logged using the RVS surflog system. The equipment consisted of :

a) Falmouth Scientific Inc (FSI) Remote temperature sensor mounted near the non-toxic intake, at a depth of ~3 m.

b) FSI conductivity and temperature sensors mounted in a polysufanone housing wet lab. A header tank was used to provide a constant flow of de-bubbled non-toxic water to the thermosalinograph. The header tank was checked periodically throughout the cruise.

c) Chelsea Instruments MKII fluorometer and Seatech transmissometer mounted in a tank on the aft deck fed from the non-toxic sea water supply.

The data were sampled at 1Hz and averaged over 30 second periods by the surflog system.

When the system was first switched on it was found to be noisy (although enough good data was being gathered). This problem has been known about since the system was first installed but has become worse since the last refit. To help the data processing the data gathering software was modified by adding an extra filter to the data input stream. This discards any data that equals exactly zero, (this is because any corrupt ASCII characters found on the serial line are interpreted as being zero in the ìstring to realî conversion subroutine in labview). Following this modification the data was found to be almost entirely clean. The only other problem with the system occurred when the glass flow rate indicator shattered. This resulted in six hours loss of data.

The temperature and conductivity modules were initially calibrated using laboratory standards and calibration data. The 30 second averaged conductivity measurements were used to determine salinity, given a pressure of 0 bar and the housing temperature (peos83). These salinity values were then despiked (pmdian), records being rejected if salinity differed by more than 0.05 from a 5 point median. The data were than averaged over one minute periods (pavrge) and merged on time with the bestnav navigation data (pmerge) to include latitude and longitude. No account has been made for the time bias in the TSG salinity values to allow for the time taken for the non toxic supply to travel from the intake to the TSG. By looking for sharp temperature gradients in the remote and housing temperatures from the TSG, and measuring the time offset between them this has been estimated as being of the order of 150 seconds.

During underway SeaSoar surveys salinity bottle samples were taken from the non-toxic supply at one hour intervals. These plus salinity values averaged over the depth range 3-7 dbar from the calibrated CTD data were used as true salinity from which to calculate an offset to be applied to the TSG salinities. The CTD data were appended to the underway samples files and the resulting file was sorted on ascending time (psort).

The TSG data and the CTD/bottle sample values were merged on time and a linear regression used to derive A1 and B1 coefficients (TSG salinity against bottle salinity). After calibration new residuals were calculated (parith) and the mean and standard deviation of the differences found with phisto. A second calibration was made having removed sample data where the differences (bottles - TSG) were outside 2 standard deviations of the mean.

calibration 1:

calib' TSG salinity = TSG - 0.136 + 1.8E-8*time

and after calibration mean offset = 0.0002 and

standard deviation = 0.0325

calibration 2:

calib' TSG salinity = TSG - 0.0490 + 8E-10*time

and after calibration mean offset = 0.0001 and

standard deviation = 0.0208

The calibration may still not be entirely satisfactory. Although the outliers in the bottles-TSG differences (i.e. those greater than 2 standard deviations from the mean) are generally associated with regions of large horizontal salinity gradients, they are all high, indicating that there may be a source of systematic error. Further inspection of the data set as a whole suggests that the calibration offset increases with salinity and therefore indicates that the laboratory conductivity ratio calibration may be in error. This will require further examination after the cruise.

J T ALLEN

Lightfish

The University of Southampton's Lightfish is based on an Undulating Oceanographic Recorder (UOR) vehicle. The undulating capability of the vehicle has been disabled and a long probe containing 12 irradiance sensors bolted to the top of the vehicle so that 6 sensors pointed upwards and the other six sensors pointed downwards. Lightfish measures upwelling and downwelling irradiance at six different wavelengths, 410 nm, 443 nm, 490 nm, 520 nm, 550 nm and 632 nm. During the cruise the vehicle was deployed three times as shown below and towed, whilst steaming at up to 8 knots, at a depth of around 3 metres from the aft port side davit. It measured upwelling.

CTD survey (Gulf of Oman)

Jday 045, 05:18:30 - Jday 054, 04:01:30

SeaSoar survey (Straits of Hormuz)

Jday 061, 00:00:00 - Jday 066, 14:41:00

SeaSoar/CTD (Arabian Gulf)

Jday 071, 02:05:30 - Jday 075, 10:52:30

Initially the system worked well, however during the second deployment the data became noisy and eventually unusable. It was found that the electrical termination had failed. The in-line termination style was not repairable, and it was decided to replace the bridle with the one from the Chelsea Instruments Aquashuttle. This uses a more straight forward thimble (SeaSoar) style termination. Once the fish was redeployed it worked well for the rest of the cruise.

The data stream from the Lightfish went through the RVS level ABC system before being read into PSTAR using datapup. An initial calibration was applied to the data by an RVS program to create a second level C Lightfish data stream called prolitef. This calibration was as follows:

$$\text{Irradiance(E)} = \ln(A + B(\text{counts}) + \exp(C.(\text{counts}/1000) + D))$$

where

	A	B	C	D
ed410	-12.211	0.3987	3.3364	-1.3131
eu410	0.7905	0.0500	3.0422	-2.3630
ed443	3.1779	0.2449	3.2435	-1.2772
eu443	-0.00172	0.04899	3.18252	-2.8348
ed490	-2.9895	0.4832	3.4329	-1.1660
eu490	1.9869	0.13521	3.1770	-1.8074
ed520	-4.5540	0.4507	3.4374	-1.5478
eu520	-2.9213	0.1285	3.4808	-2.9404
ed550	-17.259	0.3263	3.6189	-2.4563
eu550	-1.8405	0.0763	3.1832	-2.4928
ed632	-14.487	0.3858	3.6437	-2.3253
eu632	-2.2111	0.0753	3.0565	-2.1304

Both the uncalibrated and the calibrated data streams were read into PSTAR using datapup in the UNIX c shell script lfget. This script also removed gross spikes in the calibrated data using pedita although in practise such spikes only occurred during the second deployment when the termination was beginning to fail.

During the cruise a second UNIX c shell script was written to calculate reflectance. This script was called lfishexec and used a combination of the programs parith and psoup to derive

$$R(nnn) = \ln(Eu(nnn)-Ed(nnn))$$

where nnn is the wavelength, R is reflectance and Ed and Eu are the downwelling and upwelling irradiance values respectively. In addition parith was run a second time to calculate the ratios, R443/R550 and R490/R550. These ratios are expected to show an inverse relationship to chlorophyll fluorescence.

J T ALLEN

Optical Plankton Counter

The optical plankton counter (OPC) was deployed with the SeaSoar on both the survey around the Strait of Hormuz and within the Arabian Sea. The OPC was fitted with it's acrylic flow insert, which reduces the tunnel cross sectional area to $0.001 m^2$ to make it suitable for the towed sampling. It was fitted to the underside of the SeaSoar in place of the weight. The data was logged via the OPC deck unit attached to a PC. The PC was networked using PC-NFS, allowing the raw data files to be written directly to a UNIX file system as a network drive. This enabled completed raw data files to be accessed without the need to stop logging on the PC. The manufacturers software was set up on the PC to allow the data to be viewed as it came in. This software was also set up on another PC to allow the files to be replayed so that the exact start time of each could be checked.

In order to keep the file sizes manageable the data files were changed every 4 hours at the end of the first hour of the watch by moving the logging switch off and on menu-driven display on the PC. This automatically updated the raw data file name, by increasing the suffix number by one. The time to the second of this operation was noted down by the watchkeepers. A couple of problems occurred firstly with files opc104.d01 and opc104.d26 being over written during the switching process. This was suspected to be caused by toggling the logging on/off switch too quickly and causing a new file to be written before the file name had updated. The other problem was that there was no data file opc104.d28 written in the hard disk of the UNIX file system. There does not appear to be an explanation to this as it should be impossible for the software to miss out a file. Otherwise the system worked well and produced 39 raw data files at 4 million data cycles every day.

The raw data files were read into PSTAR using the D223 version of OPCEXEC0. This produced PSTAR output files containing the two variables time and count, and also attenuance files with this recorded twice per second against time. These files were the master data files for the OPC. A count data cycle is produced each time a particle breaks the OPC's light beam, and is recorded as a digital size which is the maximum attenuance drop produced by the particle.

In order to see the data against pressure and position the data was merged with a SeaSoar sawtooth file in OPCEXEC1. This file was made using PMERGE with a raw

SeaSoar file providing pressure and the processed navigation file the distance run. Since this was done using a raw SeaSoar file 50 seconds was subtracted from the time variable to represent the time lag of the fish behind the ship. OPCEXEC1 was modified in several ways to produce output files in the correct format for the current processing. The time taken off the raw Counts and Attenuance files was only 50 seconds, because of the short cable length. Also the counts file was not gridded, but the attenuance file was. Therefore the files are not joined together by PJOIN. PAPEND was used to create 12 hour files for the rest of the processing. After this stage the files were looked at with POPCAV to check that the up and down profiles were producing consistent numbers. No differences were found, despite this cruise using the same OPC and SeaSoar that caused problems on D224.

The counts files were then gridded using GROPC2. This program creates a 3 dimensional file by binning the data into size classes of 0.2mm (between 0.2 and 3mm) and gridding with pressure intervals of 4m and distances of 2km (the same as SeaSoar). The counts are now displayed per m^3 of water calculated from distance run for each size class.

The position data from the navigation file was now brought in with PMERGE.

The next stage was to convert the digital size to mm and therefore produce a volume in mm^3 of zooplankton per m^3 for each size class. The manufacturer's lookup table relating digital size to equivalent spherical diameter was used for this. The volume was also converted to carbon using Wiebe's (1988) equation. These calculations were performed by POPCAL1. The data was also integrated over depth, summed over the size classes and integrated and summed together to produce three separate files with POPCVERT. The outputs of OPCEXEC0, OPCEXEC1, POPCAL1 and POPCVERT were compressed and archived.

The survey of the Strait produced the highest biomass (mm^3m^{-3}) in the size classes between 0.4 and 0.8mm. This was usually concentrated in the top 20 metres, although in frontal regions deeper maxima of these size classes were measured (e.g. at 3480km distance run). High values in the <1mm size classes were between 800 and 1000 mm^3m^{-3}, with values above 500 mm^3m^{-3} recorded over about 50% of the survey. But in a few areas the values fell to close to zero, even at the surface. Larger size classes (1 to 3mm) were much more patchy, and although they reached similar maximums of biomass these were very concentrated in both space and size distribution (e.g. at 3720 km). The short survey in the Arabian Sea recorded lower biomass than in the Strait, with maxima in the <1mm sizes only reaching 700 mm^3m^{-3}.

The patterns of biomass observed by the OPC correlate well with the hydrographic measurements of the SeaSoar, however the uncalibrated fluorescence shows very little because quenching was so widespread in these shallow waters. The measurements of the EK500 often picked out the same features, however the two instruments were sampling different size ranges and exact matches were not expected. LHPR samples were taken after the survey to help to produce a more accurate calibration than the manufacturer's conversion tables.

A MUSTARD

Acoustic Doppler Current Profiler

The RD Instruments 150 kHz narrow band acoustic Doppler current profiler (ADCP) was used throughout the cruise to provide current profiles and profiles of acoustic backscatter. The instrument operated primarily in water-track mode, set to record 100 by 4 m depth cells with ensemble averages over 2 minutes. Bottom track was enabled during transits of the Straits of Hormuz, primarily as a source of bottom depth readings for the Bridge and for the SeaSoar operators. However, patches of intense backscatter found in the Gulf of Oman confused the ADCP bottom tracking algorithm, causing it to sense the scattering layer as the bottom , and therefore ignoring real current and backscatter data beyond. For this reason, the instrument was mainly operated in water track mode.

A calibration run using the zig zag method (Pollard & Read, 1989) was undertaken on day 43, from 0645 to 1115 GMT, following the narrow Omani shelf with three pairs to the south east followed by three pairs to the north west. The mean for the scaling factor A was 1.0338 with a standard error of the mean of 0.0041 and the misalignment angle ϕ was 6.24_ with a standard error of the mean of 0.11_ from 8 sets of observations. The large apparent misalignment angle was due to an offset between the gyrocompass and the Level A gyrocompass reading, see the **Navigation** section.

Data Processing

The first stages of ADCP processing followed standard procedures, Griffiths (1992), and later amendments documented in the series of Unix cshell scripts *adpexec0* to *adpexec5*. No heading correction was available, and so a modified version of *adpexec2* was used as a dummy to maintain compatibility with later scripts. Averaging to 10 minutes was done within a new script *adpexec5*,; 10 minutes providing an accuracy of better than 5 cm/s using the GLONASS position data (see **Navigation** section), but only during periods of steady speed and course due to the lack of a 3DF GPS receiver. *Adpexec5* also incorporated two new features:

- automatic spike removal using *pmdian* along columns, and after *pinvrt*, along rows, with the maximum spike set at 30 cm/s; automatic editing is not feasible with GPS alone, but this technique has proven useful with DGPS and now GLONASS/GPS derived ship velocities;
- merging with Simrad EA500 bottom depth, with automatic editing of ADCP velocity and backscatter data for bins closer to the bottom than 20% of the water depth. This automatic

procedure to suppress interference from sidelobes was essential during this cruise in such shallow waters.

Daily current vector profiles were plotted as were horizontal maps of currents for each of the surveys.

The raw AGC data were calibrated using default manufacturer's data and an approximate value for the sound absorption coefficient α. At the end of each survey, ADCP data was merged with CTD/SeaSoar data and corrected values for α computed.

G GRIFFITHS, N A CRISP

Navigation

Information on the ship's position and velocity over the ground was obtained from two satellite navigation receivers. The Trimble GPS-4000 receiver, usually the primary source on *Charles Darwin,* took a secondary role on this cruise to a new Ashtech GG24 combined GLONASS/GPS receiver. GLONASS is the satellite navigation system, akin to GPS, installed and operated by Russia. Unlike GPS, GLONASS does not deliberately degrade its position fixes with Selective Availability, and position uncertainties of less than 10 m are possible without differential corrections.

We were able to assess the position uncertainty over a 22 hour period whilst moored at Muscat. Root mean square values for latitude and longitude were slightly different, and the distributions were not truly normal (Gaussian), in that the tails of the distributions were extended (Table 3). These extended tails were most likely to be due to short periods when insufficient GLONASS satellites were visible to provide a 3-D fix based purely on GLONASS and the consequent use of GPS satellites with SA degraded the overall position accuracy.

Accurate positions are especially required for computing ship motion over the ground for use with the ADCP; Table 3 shows the root mean square ship velocity errors in the east and north components from 2 minute averaged position ensembles. At ~ 5 cm/s rms the 2 minute ensemble error is acceptable, being further reduced by a factor of 3 when 10 minute ADCP current averages were computed.

GLONASS does **not** offer the 1 m precision of DGPS (when using high quality corrections within 500 km of a reference station), but it does provide an acceptable reference for position fixing and ship velocity calculation for most oceanographic purposes. Offsets for the positions of the echosounder transducers from the GLONASS/GPS antenna are given in Table 4, obtained from ship plans, to an accuracy of 1.5 m.

As an Ashtech 3DF system was not available on Charles Darwin, gyrocompass errors could not be determined or corrected. Operating in low latitudes, the error is less than that at mid-latitudes (varying with secant of latitude), but, given the amount of station work during the cruise, with attendant course and speed changes, dynamic errors (Schüler oscillations) noticeably reduced the ADCP data quality.

Consideration should be given again to fitting a 3DF GPS system to Charles Darwin. The gyrocompass (digital) data available on the Level ABC computer system had a large offset from the true gyrocompass readings. The offset was responsible for most of the 6.24_ heading error correction used for the ADCP. This magnitude of offset is unacceptable, the source of the offset needs to be determined and the problem corrected as a matter of urgency.

Navigation Processing

Bestnav was read in to the pstar file abnv1041 each day, forming the master navigation file for all other pstar data streams. Raw one second GLONASS data were read in to files gps10401 and gps10402 before filtering to 2 minutes in files gps10401.av and gps10402.av for merging with the ADCP.

G GRIFFITHS

SIMRAD EK500 Echosounder

The EK500 is a scientific echo-sounder, comprising 3 frequencies at 38, 120 and 200kHz, and has an extremely wide (>150 dB) dynamic range which enables it to measure target strengths reliably down to -120dB. As well as measuring individual targets (which it has algorithms for resolving), it is ideal for measuring Mean Volume Backscatter Strengths (MVBS, or Sv). The 2 lower frequency transducers are split-beam transducers made up of 4 quadrants (4 separate transducers). These transmit as one, but receive individually so that differences in the phase and amplitude of the returned signal can be used to give position information of targets relative to the orientation of the beam. The 200kHz transducer is a standard single beam unit.

The EK500 system is self-contained, comprising a portable winch with fixings for a 1m deck matrix which includes a cradle for the tow-fish when in-board, and a davit arm which enables the fish to be deployed over the bulwark without the need for a cut-away or gate. The winch drum includes 50m of cable, 25m of which is faired, and there is a junction box on the side of the drum for inter-connection cables to the lab-electronics. Slip-rings are not used because of the sensitivity of the equipment to external noise. The tow-fish houses the 3 transducers, and comprises a stainless-steel framework with fibreglass nose and tail, and clear polycarbonate covers in the central section where the transducers are mounted. The winch was installed on the starboard after-deck of RRS Charles Darwin about 5m aft of its position on a trials cruise in February 1996. No problems with operation were encountered with the system in this position.

Following an earlier report of the trials cruise CD98a (Griffiths, Crisp and Bishop 1996), the system electronics and cabling are well known to be sensitive to proximity with computer equipment despite being properly earthed to the ship. Consequently, the deck unit was installed in the gunshop which contains no such equipment. The ethernet link to the electronics was found to be a significant noise source and this was reduced by grounding the ethernet outer shield both in the main lab and in the gunshop. The resulting background noise values, using long pulse lengths and narrow bandwidths for the 200kHz and 120kHz, were measured as being between -133 and -139dB. These noise values were worse than those encountered previously on the RRS Charles Darwin by about 5dB, but we could not improve on the above values. Such variations are likely to exist in any such portable system, and we should consider semi-permanent installations for ships on which the system is frequently installed. Such installations would conceivably include running the cables to the winch in steel pipes (as recommended by SIMRAD), and rack mounting the electronics and VDU in a steel, well earthed cabinet.

The use of long pulse lengths and narrow bandwidths are suggested by SIMRAD when the background noise is high. The narrow bandwidth (1.2kHz & 2.0kHz for 120 and 200kHz) filters out a lot of unwanted acoustical noise, but with a loss in vertical resolution with the longer pulse lengths (approx. 3 times longer at 1.0ms and 0.6ms respectively). However, the subsequent resolution of about 0.5m was of little consequence to our measurements using 1m bins for these frequencies.

On several occasions during the cruise, the system was brought inboard at night coincident with the SeaSoar, due to the large number of long-lines present on the eastern side of the Strait of Hormuz. In general the EK500 was brought inboard for visual inspections on a weekly basis, as the polyurethane outer of the kevlar tow-cable can be easily torn by such fishing lines. Such inspections proved worthwhile - several superficial repairs to the tow-cable were made throughout the cruise. Suspect data from the 38kHz transducer was noted on the morning of 7 March, the fish was brought in, and the tow-cable found to be defective. The problem was due to a combination of recent damage, and an excess of seawater in the cable - two of the 38kHz quadrants were effectively shorted to ground, and other quadrants in both the 38kHz and 120kHz were severely impaired by low-resistances to ground. The unit was out of action for approximately 24 hours while a replacement cable was installed on the winch.

EK500 Calibration

The calibration procedure for the EK500 was carried out late in the evening of the 5th of March. Three SIMRAD standard calibration spheres, separated by distances of approximately 4m on a 0.5mm mono-filament line, were hung below the transducers in the fish, by suspending the top one (the 200kHz sphere) from 3 mono-filament lines positioned to give as much control over the position of the spheres as possible. A 3m long piece of wood with a clean hole in one end, through which one of the 3 lines was passed, was clamped to the bulwark so that it lay perpendicular to the ship and enabled some, albeit limited, port-starboard control. The other 2 lines were attached at suitable points fore and aft of the fish position giving control in the other plane. Once the spheres were in place over the side and the spheres at depths of 8.3, 12.5, and 16 metres, the fish was lowered into the water to a depth of about 2 metres. This set-up ensured that the lines did not tangle with the fish.

For the split beam transducers, calibration was carried out using the 'LOBE' program supplied by SIMRAD. This software runs on a PC which is connected to the echosounder via an RS232 lead, so that it can control the unit and receive target strength data.

The LOBE program displays the four quadrants of the beam (i.e. a circle divided into four quadrants). The depth of the relevant target sphere, and it's nominal TS value are entered into the program, and target strength data are collected. The software displays the positions of the detected targets that fall within a given range window, and a window around the nominal target strength of the sphere being used. Ideally the program should run until at least 100 samples have been collected, with roughly an equal number of samples taken in each quadrant. When ready, the program can be interrupted by the user and a polynomial fit applied to the data. Subsequently, plots of Target Strength versus position in the beam can be displayed, and the transducer gain parameters including beam alignment offsets can be sent directly to the echosounder, or they are stored to an ASCII file for later perusal (or editing of suspect data - e.g. where data are contaminated by real fish echoes).

Following less successful calibration attempts on this and previous cruises where the spheres were suspended directly from the fish on a single line, we found that even a limited amount of control over the position of the spheres was helpful in ensuring that the targets were viewed reasonably equally in each quadrant of the beams.

Calibration of the single-beam 200kHz transducer is less straight-forward, as the LOBE program cannot be used. However, the position of the target in either the 38kHz, or 120kHz beam can be viewed on the standard EK500 Target Strength display with the assumption that when in view, the 200kHz beam will also see the target. TS data were collected via the ASCII link using a Microsoft Windows Terminal program, and a histogram of the TS values plotted to show, as well as the highest values (which must occur when the sphere is closest to the centre of the beam), the frequency distribution of the data collected, which can give confidence in the calibration if the higher frequencies coincide with the higher TS values (as in our observations).

The calibration results are given below :

Frequency	Default TS gain	New TS gain	operational settings	Ref. Target TS
38kHz	24.5 dB	24.58 dB	Medium and Wide	-33.65 dB
120kHz	24.2 dB	24.00 dB	Long and Narrow	-40.4 dB
200kHz	26.3 dB	23.85 dB	Long and Narrow	-45.0 dB

Although this calibration was concluded to be generally successful, further analysis of the data revealed that the -3dB beamwidths of the 120kHz and 200kHz transducers could be as much as 2 degrees wider then the documented values of given on the data-sheets for our specific transducers - perhaps an effect of our curved polycarbonate cover below the transducers on the fish acting as an acoustic lens. Rather than incorporating the revised TS Transducer gains into the system, therefore, it was decided that the EK500 data would be re-worked back at the laboratory, after consulting with the manufacturers.

Data acquisition and processing

Data from the EK500 are broadcast over the ethernet in UDP packets, and received using a SIMRAD program 'record'. Each telegram type from the EK500 can be set up to use a different UDP port number, so that each invocation of the 'record' program can deal with a specific data type.

We run a modified version of SIMRAD's 'show' program, which in our case translates the binary data collected by 'record' directly into PSTAR format data files instead of into ASCII files. Due to the large size of the subsequent data files, we start a new file every 2 hours, and create daily files by appending these.

Two different data types were collected during the cruise - Mean Volume Backscatter (MVBS) Echograms, and Target Strength data. Once in daily files, the MVBS data were edited for data below the bottom depth from the EA500 Hydrographic Echosounder, and then data below the noise floor removed using the equations for sound absorption and spherical spreading (20log(R) + 2αR, where R is range and α, frequency dependant absorption coefficient) and estimated values of the noise floors at each frequency.

The EK500 MVBS data showed spectacular diel variability throughout the cruise with complex patterns varying with location. In the deep water of the Gulf of Oman biological distributions are dominated by the oxygen minimum layer which occurred at a depth of ca 100m. MVBS showed high backscatter during the day above the oxygen minimum and also in a broad "layer" at ca. 300-400m. This latter "layer" migrated to the top 100m at sunset, returning again at sunrise and formed a dense scattering region above the oxygen minimum depth at night. The migration scattering "layer" was composed of many discrete layers, some of which remained at depth for all or part of the night. Horizontal/temporal variability was also a feature of this multilayered system.

Moving to the slope regions and the Strait of Hormuz the dense scattering layer(s) occurred close to, or on, the bottom, migrating upwards at night to either completely fill the water column with high backscatter, or to form a dense surface layer depending on the water depth. Similarly in the Arabian Gulf there was relatively low scattering in the water column by day, but high scattering throughout the depth range by night.

Penetration varied with the 3 frequencies as expected. The 38kHz penetrated to ca 500m, the 120kHz to ca 250m but the 200kHz to only ca 70m. Highest backscatter was seen in the 38kHz because of the dense populations of myctophid fish with resonant swimbladders which occur in this part of the world. It was possible to estimate the numbers and sizes of the likely targets from the 38 and 120kHz data, these agreed broadly with previous commercial fish surveys in the area but were far in excess of the numbers of myctophids caught by our rectangular midwater trawls. Avoidance of slow, relatively small mouthed nets is clearly a major biological sampling problem here.

N A CRISP, G GRIFFITHS, H S J ROE

TUBA (Towed Undulating Bio-Acoustic Sensor)

TUBA is a novel multifrequency bioacoustic sensor developed as part of the NERC Sidal Special Topic. This cruise was the first opportunity to test the sensor *in situ.*

Frequencies.	250kHz, 353kHz, 500kHz, 707kHz, 1MHz, 1.4MHz and 2MHz
Pulse Widths.	20μs, 50μs, 100μs. 200μs, 500μs and 1ms
Repetition Rates.	0.05s 0.1s, 0.2s, 0.5s 1s and 2s
Range.	Software 'windowed' to a maximum of 12m

The first opportunity to test this multi-frequency bio-acoustic sonar was during the first week of the cruise in the Gulf of Oman . It was deployed whilst hove to from a small davit to a depth of 10m. After a few adjustments to the deck unit receiver gains a return echo could be observed at each of the five frequencies implemented in the prototype (250, 353, 500 707 kHz and 1MHz). The spectral display on the data processing PC indicated interference from system clocks and some receiver oscillation. This interference was substantially reduced by introducing band pass filters to the mixer IC's local oscillator inputs.

Improvements having been made, a second deployment was made at dusk to cover the upward vertical migration of animals. This showed a variety of moving targets giving differing return amplitudes. The EK500 200kHz -45 dB calibration sphere was then suspended 3m below the instrument and it was re-deployed. Although the target drifted laterally it could be observed at all five frequencies. A beam pattern was plotted to show the range at which coherence could be expected. The energy returned at each frequency was logged. Comparing data for each frequency whilst the sphere was in view indicated the relative gain adjustments required to bring each channel to a similar level. However, as the TS of the standard target may well have peaks and nulls over the frequency band this could only provide a rough calibration.

Another opportunity arose to deploy the instrument with both the 200kHz and the 38kHz EK500 calibration spheres. These were suspended at 2.4m and 8.5m respectively. At 353, 500 and 707 kHz the corrected TS differences were within the range of -0.4 to +1.9 dB of the expected TS difference of 11.4 dB (-36.6 - -45.0 dB). However at 250 kHz and 1MHz the differences were larger being -10.9 and +5.8 dB respectively. These discrepancies may be due to oscillations in the TS-frequency relationship of the copper spheres as oscillations of up to -10 and +5 dB have been reported. Acoustic tank calibrations will need to be made using spheres of other diameters (and possibly other materials) upon return.

Towards the end of the cruise the 1.4 and 2MHz channels were built into the instrument and it was deployed over the side with all three EK500 calibration spheres suspended below the instrument. The -45 dB target at 2.5m the -40.4 dB at 4m and the -36.6 dB target at 5.5m. All three targets could be seen at the seven different frequencies. The top target return echo was 6 to 10 dB down on the lower two at 1.4 and 2MHz.. Over an hour's raw data and some screen images were recorded during this experiment.

The following day TUBA was mounted in place of the Optical Plankton Counter under the SeaSoar vehicle. SeaSoar towed extremely well maintaining stability on 50m of cable going to a depths of 18-34m. On deployment it quickly became obvious that the SeaSoar CTD signal or switching power supply was introducing interference in TUBA's receiver band (30 to 250kHz). The SeaSoar vehicle was recovered to investigate this noise problem. We found that by using a different CTD supply, linking the -ve to the cable outer and terminating the TUBA data line, brought the interference down to -40 dB (near the noise floor of the instrument). The termination used was a 68Ω resistor in parallel with a 0.1μF capacitor, much the same values as that of a full length SeaSoar tow cable. Further improvements may be made by synchronising the TUBA receive cycle to the SeaSoar CTD data frame. On re-deployment we could observe many targets and raw spectral distribution data were recorded.

The real time data processing, acquisition and display software is written in C using National Instruments' 'LabWindows/CVI' which is a powerful software development package allowing rapid user-interface design and implementation. It also provides comprehensive graphing routines which enable the data to be displayed in real-time (currently at 10Hz). If the display was updated only once-per second, showing for example, 1 second averaged data, then the ping-rate could potentially be much faster (> 20Hz) if necessary. The filtered data from the deck unit are digitised by a 16-bit A/D and Digital Signal Processing (DSP) card (Microstar Laboratories' DAP3200a), which samples at 769kHz, and performs a Fast Fourier Transform (FFT) on the data in the selected range window. The results of this, and the raw data are then passed to the PC for display and further processing.

Prior to the cruise, the software was still in it's very early stages, and simply displayed the real-time amplitude and spectral data, with a minimal capability for logging the raw amplitude data. Changes and improvements, made throughout the cruise to carry out and analyse the data sets from the various trials are described below:

In addition to the spectral display, the logarithms of the relative energies returned within each frequency band (bandwidth appropriate to the pulse length in use) were calculated and displayed as a bar-graphs (concurrently with both the FFT and raw data), providing a relative measure in decibels. Also, a binary data format was designed, which enabled enhancements to the data logging capabilities - allowing the user to log one or more of the 3 data types (raw, FFT, distribution) on a ping-by-ping basis. Subsequently, a program 'tubalist' was also written to decode the binary files into ASCII formats suitable for reading into PSTAR using 'pascin'.

There seemed to be a few problems running LabWindows (a Windows 3.1 application) under Windows95, causing system hang-ups and crashes, but in general the application was invaluable for this development work. A copy of LabWindows for Windows95 will be purchased after the cruise.

Further improvements to the software include compensation for spherical spreading and sound absorption, and for change in scattering volume with range. Some work has started towards this aim, additionally, data averaging options will be implemented.

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Nets

The Rectangular Midwater Trawl Multiple net (RMT1+8M) and the Longhurst-Hardy Plankton Recorder (LHPR) were both fished successfully on this cruise (Appendix C).

The RMT1+8M was fished with the new monitor and deck unit on seventeen occasions without problems. The altimeter had some problems locking on to the bottom early in the cruise but by altering its angle of attack a good bottom signal was obtained without fail. At the end of the cruise, in very shallow water (c.50m), three reduced versions of the RMT were fished without electronics and with only one pair of nets tied open to minimise losses if the net fouled the bottom. At least one of the deployments hit the sea-bed but fortunately no damage was caused to the nets.

The LHPR was fished five times with one failure. The first deployment was in internal logging mode, due to the conducting cable termination not being ready, and worked perfectly. Once the termination had set, the LHPR was transferred to conducting cable operation giving real time data viewed on a PC in the lab. Three good tows followed. The last tow failed due to a misunderstanding with the control software.

B BOORMAN

RMT1 + 8 Trawl Data

A total of 51 net hauls (17 RMTI+8M deployments) were carried out in the Gulf of Oman and 4 hauls (4 deployments of the RMT I + 8 system without the monitor) in the Arabian Gulf. The objectives of the trawling programme were twofold: 1) a series of vertical hauls to at least 1600m to compare with the 1994 D209 data set off the eastern coast of Oman and to relate the distribution of macroplankton and micronekton to the oxygen minimum layer of the region, and 2) to ground-truth the EK500, in particular to identify the main components of the strong scattering layers.

The vertical hauls were achieved without incident at the eastern end of the Gulf of Oman, with stratified horizontal hauls to a depth of 1800m. The catch volumes were higher than anticipated, both by day and by night, but very low (particularly by day) between 400m and 100m. This was reflected in both the RMT8 and RMT I volumes, but below 1100m (marking the approximate boundary of the oxygen minimum layer) there was a marked rise in the volumes of both size fractions. The species composition was limited: mesopelagic myctophids were represented by one species each of *Benthosema, Diaphus and Lampanyctus,* and the other fish present at similar depths were largely *Valenciennellus* and the codlet *Bregmaceros.* At night there was an increase in the volumes of the catches in the upper 200m and a reduction in those below 300m, signifying vertical migration out of the oxygen minimum layer into the near-surface waters by many of the mesopelagic species. This migration was very clear on both the ADCP and EK500 data sets. The RMT1 volumes were remarkably high, consisting largely of small copepods and chaetognaths, and in several tows were larger than those of the RMT8. Small siphonophores were occasionally abundant in the shallowest hauls of both nets.

Below 1100m there was a substantial increase in the volume of the catches of both macroplankton and micronekton, reflecting the increase in the oxygen content of the waters. The fauna was more diverse, contained a typical deep-sea range of species including the fishes *Cyema, Platytroctes, Rondeletiola and Cyclothone acclinidens,* and adults of the squids *Liocranchia and Chiroteuthis.* Pasiphaeids and the opophorids *Hymenodora, Ephyrina, Acanthephyra* sp. and *Systellaspis braueri* were among the decapod fauna at depth, combined with the mysid *Gnathophausia.* Other important contributors to the catch volumes were a large isopod, the holothurian *Psychropotes* (1000m off the bottom) a macrurid and a very large and diffuse fragment of a purple medusa.

A second day/night series was taken further west in the Gulf of Oman, on the slope to a depth of 650m, and yielded similar substantial day/night differences in catch volume. The main difference at this position was that the fish catch was greatly reduced and a significant component of most of the catches was the pandalid shrimp *Plesionika persica,* together with specimens of *Pasiphaea* sp. and *Sergestes* sp. Very few specimens of fish were caught, merely a few *Benthosema* by day.

Three further hauls were made further to the northwest in the Gulf of Oman, largely to target specific scattering layers. Very large numbers of *Plesionika persica* were caught in most hauls, and very few fish, despite (stn 54005) fishing for almost 90 minutes in a very tight scattering layer at about 175m. The conclusion must be that the RMT system is not an effective sampler of myctophids, even those as small as *Benthosema.* The high day catches of fish in the east of the Gulf of Oman, in the deoxygenated water, did not occur in the northwest, where the oxygen levels increased considerably. It is possible that the deoxygenated water renders the animals more lethargic and therefore more vulnerable to capture by the trawl.

The very shallow (ca 50m) two day and two night hauls in the Arabian Gulf were dominated by jelly but the night hauls also contained a number of fish. *Bregmaceros* was the most abundant of the fish but a few coastal species were also present. Several specimens of the shrimp *Thalassocaris were* taken at the same time. *Bregmaceros and Thalassocaris* were absent from the day hauls. Both day hauls and one of the night hauls touched the bottom.

The RMT system and "new" monitor performed well throughout, with no serious problems. This is probably the longest consecutive series of tows achieved without any monitor problems for some years, No range limitations were encountered, down to the operational depths of 2000m. The weather conditions were ideal, however, and no assessment could be made of potential range limitations resulting from worsening sea conditions.

P J HERRING, B BOORMAN, H S J ROE

Red Tides

Red tides were significant features of the surface, along all the length of the Gulf of Oman (Fig. 4). At night they resulted in an intense bluish bioluminescence at the leading margin of the bow wave, and at the breaking edge of all lateral ripples, to a distance of several hundred metres from the vessel. Samples of the red tide were taken by bucket from the ship and proved to be dense concentrations of the dinoflagellate *Noctiluca.* Surface scums of this species (visible as surface “red tides”) were apparent during the wind-free periods when the surface slicks re-established themselves. These phenomena were sighted 18 times, from the eastern Gulf of Oman to the northwest region of the Arabian Gulf, just within the Straits of Hormuz, but not further to the west in the Arabian Gulf. They were always associated with surface slicks, and often with accumulations of gelatinous animals such as medusae, ctenophores, salps and siphonophores.

These large heterotrophic dinoflagellates were not visible at the surface after any significant increase in wind speed and are clearly mixed down very rapidly. Their positive buoyancy ensures that they rapidly return to the surface as soon as wind mixing ceases. In the Arabian Gulf dinoflagellate blooms were not observed much beyond the Masandam peninsula.

A reddish-brown scum of rather similar appearance was present at CTD station 166; this turned out to be a bloom of the cyanobacterium *Trichodesmium*.

P J HERRING

Meteorology

During Charles Darwin cruise CD104 several meteorological systems were deployed on the ship; these included the GRHOMET system acquiring surface meteorological parameters, Sonic fast sampling system, SST Radiometer and Radiosonde balloons. In addition, routine WMO observations were made (Fig. 10).

1. Surface meteorological instrumentation

The GRHOMET meteorological instrumentation system was in operation throughout the cruise, with logging starting on day 43 15:23hrs. Data files were generated in raw and calibrated format, and written to the PC's hard disk. The GRHOMET system also outputs raw data via an RS232 link to the level 'B' in SMP format, where the data was logged by the RVS computer system. A total of 11 sensors were mounted on the main and foremasts, measuring air temperature, air pressure, wind speed, wind direction, downward long and shortwave radiation (Fig. 10, Table 5). Installation of meteorological sensors was started in Cartagena, Spain, and completed in Muscat prior to sailing on day 043.

Sensor Performance

A difference in slopes was noticeable in the relative measurements made by the two longwave sensors during the cruise. This agrees with previous data from these two particular sensors where they have reasonable agreement for down welling fluxes of order 350 W/m2, but at lower values LW1 (31171) reads consistently lower than LW2 (31170). In addition further analysis shows that there is shortwave contamination, but our investigation could not define this effect completely. Generally speaking LW2 had a tendency to read higher by approximately 5 Watts for values of shortwave around 900 watts, but this was not always the case and the effect does not necessary last for the complete solar cycle. This indicates that it is not just shortwave leakage through the sensor dome, but has other components which have not yet been determined.

A large difference in calibration between the two shortwave sensors became apparent with the Starboard sensor (840607) consistently reading lower by 40 watts for shortwave fluxes of order 900 watts. The Starboard sensor was replaced on Day 62 by sensor 903290, resulting in better agreement between the two sensors.

The trailing thermistor (Soap) SST sensor performed well throughout the entire cruise and when compared to the TSG had a general offset of approximately +0.05 deg. It should be noted that while steaming the Soap trails in the top 0.5 m, but while on station the Soap has a tendency to sink to about 5 m. The effect of this can clearly seen on the Soap data during calm days, where there is intense surface heating during the day in the top few meters, but then when the ship is stationary during CTD stations the Soap drops into the cooler bulk temperature water. This can results in two differences between the Soap and TSG which has its water intake at about 5m. Generally the Soap is hotter than the TSG which has a delay in seeing the warm surface water, but can be cooler than the TSG when the Soap has dropped down into the cold bulk temperature water (Table 6).

Two SOC developed psychrometers (Psy1 & Psy2) were deployed, along with a commercially manufactured version of these instruments (Psy3), which on a previous cruise had been shown to be affected by direct sun light. The conditions during the cruise enabled various tests to be done on Psy3 and compared to the less affected SOC sensors. The major step was to wrap baking foil around the outside of both the outer and inner tubes, which cover the PRT's, to make them impenetrable to sun light. This was done on Day 47 to good effect. Further tests done such as putting a bottom plate on Psy3 on day 54, but to no noticeable effect, silver tape was also applied to the psychrometer body and fan again to little effect. The final change was to extend the radiation shield with white cardboard to cover the psychrometer body, which produced a small improvement. Generally all three psychrometers performed reliably during the cruise, except for odd periods where the wet bulb of one or other psychrometer dried out. Dropouts on the dry bulb of all three psychrometers were evident , but particularly Psy3. A similar problem has been reported before, and is believed to be the result of the wet bulb dripping with the occasional drip affecting the dry bulb.

Data Processing

A series of UNIX scripts were revised during Discovery cruise D224 in an attempt to improve daily processing and quality control of the GRHOMET data. Reading and calibrating the data from RVS format to pstar format, merging of navigational and EM log data, calculation of the true wind speed and direction, and plotting of the data were all performed efficiently on a daily basis using these scripts.

2. Sonic Fast sampling System

The Sonic fast sampling system comprises of a Solent Sonic research anemometer, Sonic interface, laptop PC 486dx and a Sony Magneto-Optical drive RMO-S550. This system acquires 3 component wind speed data at 21Hz from the sonic anemometer, spectrally processes the data and stores spectral parameter files at quarter-hourly intervals. Each acquisition/processing cycle starts on the quarter hour i.e. at 00, 15, 30 and 45 minutes past the hour as given by the processor system clock. The system writes data to three media as follows:

1) Raw data are written to magneto-optical (Drive D:) as a binary *.RAW files after the 10 minute acquisition period (length 98,348 kbytes).

2) Processed spectral data and parameterised data are written to hard disc (c:\data\ ) as ASCII.PRN files after the processing phase is completed (24hrs data = 358,464 bytes)

3) Parameterised data are written to floppy disc (Drive A:) as ASCII *.MWS files after the processing phase is completed (24 hrs data = 11,424 bytes)

Measurements of the wind stress (using the "inertial dissipation" method) were determined from a Research sonic anemometer (asymmetric version), mounted on the port side of the foremast platform. The Research sonic was mounted as close as possible to the location of the Solent Sonic anemometer on Charles Darwin cruise CD43. Giving the opportunity for direct comparisons of the data sets. The system worked continuously throughout the cruise producing spectral estimates every 15 minutes and logging them to disk. Periodically data were transferred to UNIX where further processing was performed using PSTAR. Plots of the power spectral density (PSD) as a function of true wind speed were produced and compared with previous results from CD43 to confirm that the system was operating satisfactorily.

3. SST Radiometers

Sea surface temperature was measured by a Satellites International Ltd STR 100-1 infra red radiometer located at the bow, and by two Tasco radiometers mounted on the outside of the SIL radiometer case. One Tasco viewed the sea surface (parallel to the SIL at about 25 degrees to the vertical) and the other viewing the section of the sky which would be reflected into the sea view of the SIL radiometer.

The SIL radiometer was setup with calibration intervals set to 10 min, and a constant sky correction of 240K, while the Tasco values assume an emissivity of 1 and have no sky correction applied. In addition the Tasco's were set to produce 10 second averaged data, which approximates the sampling time of the SIL radiometer. Calibrations were performed on both sensor types by siting them over a stirred bucket of known temperature; the towed thermistor probe was placed in the same bucket for comparison (Tables 7, 8).

Generally both types of radiometers worked reliably for the entire cruise, although the SIL radiometer started producing bad data on day 046 in high air temperatures with little wind. The fault was located in the power supply unit, also mounted in the bows, which was over heating. Covering the unit in black mesh bag, to provide shade but with some ventilation, cured the problem. On day 53 the SST Tasco started giving high values, but a check on its internal batteries showed them to be almost fully discharged. Batteries in both Tasco units were replaced, resulting in good data from both sensors. Occasional periods of data were lost through premature termination of the logging software, the cause being faulty software code which was corrected on day 059.

Data were logged and displayed on a PC, with data being periodically transferred to UNIX where further processing was performed using PSTAR.

4. Radiosondes

Radiosondes were launched throughout the cruise, between two and four times daily, providing vertical profiles of the temperature, humidity, wind speed and direction in the troposphere. The aim of which is to provide a description of the atmospheric conditions for the cruise period and area, as well as to derive the water vapour content at various levels for validation of ERS-2 altimeter and ATSR atmospheric corrections. Ascents were generally timed for 1100 and 2300 GMT, with additional launches made to coincide with times when the ship was in the swath of the ATSR on ERS-2 (Fig. 3).

The new Viasala DigiCORA II MW15 GPS Wind Finding Receiver was used with Viasala RS80-15 GPS sondes, which were launched using 200g TOTEX balloons. Measurements are based on the use of a free flying balloon-carried radiosonde, transmitting data to the receiving station at a frequency of 400 - 406 MHz. Pressure, temperature and humidity (PTU) are measured by sensors in the radiosonde, wind speed and direction is determined by relaying GPS wind finding data to the MW15 receiver. The aerials were mounted on opposite sides of the mainmast platform, boomed out approximately two meters from the outboard edges. Balloons were inflated in the balloon launcher situated on the aft portion of the boat deck. Provided the relative wind was at least 20 degrees on the starboard bow balloons could be released clear of obstructions for all wind strengths. In light winds a wide range of relative wind directions could be tolerated. Successful launches were made in winds up to 17 m/s, with only one launch failure out of 90 launches. A summary of the flight details for each launch is given in Table 9.

Generally the radiosonde transmit frequency was detuned from 403 MHz to 401 MHz as the MW15 receiver was picking up noise in the region of 404 MHz. This was particularly noticeable at the start of the cruise while at the first survey area, but this practise was continued throughout the cruise to minimise the chance of interference from other sondes in the area. About 14% of the sondes had either poor or no GPS wind data, caused by either defective sondes which were unable to see any GPS satellites, or by poor GPS satellite coverage. A minimum of four satellites are needed for wind finding, and using only the minimum number may form a poor geometry, so more than four visible satellites is often required.

Data Processing

Data from each ascent was logged via the DigiCORA receiver to a PC and then transferred on a floppy to the UNIX system. Scripts all_scrp.ptu and all_scrp.raw were used to process the ptu and wind data respectively, converting the ASCII output to PSTAR calculating several thermodynamic variables and the components of the wind speed and producing postscript plots of the profiles. Post-processing was carried out to remove spikes from the data using a five-point median filter with tolerance limits of $1^{o}C$ for the temperature variables, 5mb for the pressure, 5% for relative humidity, 0.4 g/kg for specific humidity and 0.02 g/kg for air density. The despiked fields were then averaged onto 10 mb levels from 1040 mb to 10mb and appended into a single file from which time-height plots were produced using the PSTAR program ucontr.

R W PASCAL, B I MOAT

Table 1. Charles Darwin Cruise 104 CTD casts

No	J day	Bottom time Z	Position	
001	97 044	07:28:00	24 21.67N	59 19.80E
002	97 044	13:19:00	24 28.07N	58 45.32E
003	97 045	04:33:00	24 33.87N	58 13.85E
004	97 045	09:38:00	24 40.38N	57 44.11E
005	97 045	14:29:00	24 44.62N	57 17.54E
006	97 045	14:11:00	24 44.82N	57 17.65E
007	97 046	15:45:00	24 21.16N	57 13.47E
008	97 046	17:28:00	24 28.62N	57 15.13E
009	97 046	20:20:00	24 37.81N	57 16.85E
010	97 046	22:11:00	24 44.05N	57 23.98E
011	97 047	00:01:00	24 36.78N	57 22.86E
012	97 047	01:55:00	24 27.67N	57 21.23E
013	97 047	03:34:00	24 19.87N	57 19.92E
014	97 047	05:58:00	24 9.72N	57 17.99E
015	97 047	07:24:00	24 7.46N	57 23.89E
016	97 047	09:25:00	24 18.43N	57 26.03E
017	97 047	11:02:00	24 26.39N	57 27.42E
018	97 047	12:46:00	24 35.58N	57 29.26E
019	97 047	14:18:00	24 42.97N	57 30.50E
020	97 047	16:29:00	24 41.69N	57 37.05E
021	97 047	18:19:00	24 34.55N	57 35.61E
022	97 047	20:15:00	24 25.38N	57 34.12E
023	97 047	21:59:00	24 17.32N	57 32.41E
024	97 047	23:30:00	24 10.21N	57 30.91E
025	97 048	00:45:00	24 5.06N	57 29.80E
026	97 048	02:06:00	24 3.08N	57 36.02E
027	97 048	03:25:00	24 8.90N	57 37.28E
028	97 048	05:05:00	24 16.03N	57 38.72E
029	97 048	07:03:00	24 23.99N	57 40.44E
030	97 048	09:23:00	24 33.00N	57 42.37E
031	97 048	11:12:00	24 39.95N	57 50.02E
032	97 048	12:56:00	24 32.09N	57 47.56E
033	97 048	15:28:00	24 23.15N	57 45.18E
034	97 048	17:10:00	24 14.93N	57 43.33E
035	97 048	18:46:00	24 8.04N	57 41.57E
036	97 048	20:19:00	24 1.52N	57 39.38E
037	97 048	21:46:00	23 58.76N	57 45.73E
038	97 048	23:19:00	24 6.48N	57 47.81E
039	97 049	00:54:00	24 13.71N	57 49.74E
040	97 049	02:35:00	24 21.64N	57 51.67E
041	97 049	04:19:00	24 30.71N	57 54.11E
042	97 049	06:01:00	24 38.14N	57 55.96E
043	97 049	07:23:00	24 37.09N	58 2.25E
044	97 049	08:57:00	24 29.50N	58 0.60E
045	97 049	10:42:00	24 20.41N	57 58.00E
046	97 049	12:52:00	24 12.51N	57 55.89E
047	97 049	14:26:00	24 5.42N	57 54.10E
048	97 049	16:09:00	23 56.85N	57 51.88E
049	97 049	17:49:00	23 56.88N	57 58.52E
050	97 049	19:22:00	23 59.96N	57 59.76E
051	97 049	20:42:00	24 4.12N	58 0.93E

Table 1. **contd.**

No	J day	Bottom time Z	Position	
052	97 049	22:15:00	24 11.03N	58 2.93E
053	97 050	00:29:00	24 19.01N	58 5.30E
054	97 050	02:19:00	24 28.06N	58 7.80E
055	97 050	03:51:00	24 35.44N	58 9.59E
056	97 050	05:51:00	24 26.85N	58 13.76E
057	97 050	09:06:00	24 17.55N	58 11.54E
058	97 050	11:29:00	24 9.70N	58 8.84E
059	97 050	13:06:00	24 2.87N	58 7.22E
060	97 050	15:15:00	23 57.09N	58 5.19E
061	97 050	16:41:00	23 57.04N	58 11.93E
062	97 050	17:48:00	24 1.39N	58 13.41E
063	97 050	19:44:00	24 8.51N	58 15.44E
064	97 050	21:30:00	24 16.81N	58 17.46E
065	97 050	23:19:00	24 25.44N	58 19.97E
066	97 051	00:53:00	24 33.28N	58 21.91E
067	97 051	02:19:00	24 32.22N	58 29.03E
068	97 051	05:39:00	24 23.99N	58 27.20E
069	97 051	07:35:00	24 15.10N	58 24.22E
070	97 051	09:13:00	24 7.11N	58 22.13E
071	97 051	11:24:00	24 0.46N	58 20.46E
072	97 051	12:50:00	23 56.06N	58 19.17E
073	97 051	14:12:00	23 55.04N	58 25.54E
074	97 051	15:20:00	23 59.14N	58 26.50E
075	97 051	16:44:00	24 5.77N	58 28.26E
076	97 051	18:27:00	24 13.86N	58 30.18E
077	97 051	20:07:00	24 22.59N	58 32.96E
078	97 051	21:54:00	24 30.66N	58 35.10E
079	97 051	23:18:00	24 29.15N	58 41.95E
080	97 052	00:51:00	24 22.20N	58 39.78E
081	97 052	02:55:00	24 12.10N	58 37.07E
082	97 052	04:33:00	24 5.03N	58 35.20E
083	97 052	06:36:00	23 57.73N	58 33.12E
084	97 052	07:55:00	23 53.26N	58 31.95E
085	97 052	09:29:00	23 46.98N	58 30.21E
086	97 052	10:57:00	23 42.13N	58 35.71E
087	97 052	13:01:00	23 47.10N	58 36.99E
088	97 052	14:37:00	23 51.72N	58 38.44E
089	97 052	15:49:00	23 56.03N	58 39.52E
090	97 052	17:23:00	24 3.63N	58 41.61E
091	97 052	19:48:00	24 10.23N	58 43.32E
092	97 052	22:47:00	24 20.57N	58 46.02E
093	97 053	00:39:00	24 26.48N	58 53.99E
094	97 053	02:19:00	24 19.06N	58 52.10E
095	97 053	04:32:00	24 9.12N	58 49.77E
096	97 053	06:03:00	24 2.67N	58 48.02E
097	97 053	08:17:00	23 54.56N	58 45.94E
098	97 053	09:36:00	23 48.77N	58 44.40E
099	97 053	11:22:00	23 43.24N	58 43.06E
100	97 053	12:39:00	23 38.10N	58 41.71E
101	97 053	14:07:00	23 35.99N	58 47.81E
102	97 053	15:26:00	23 41.08N	58 49.17E

Table 1. contd.

No	J day	Bottom time Z	Position	
103	97 053	16:45:00	23 47.07N	58 50.93E
104	97 053	18:17:00	23 53.21N	58 52.50E
105	97 053	19:49:00	24 1.30N	58 54.33E
106	97 053	21:21:00	24 7.73N	58 55.88E
107	97 053	23:14:00	24 17.97N	58 58.58E
108	97 054	00:41:00	24 25.27N	59 0.48E
109	97 059	05:57:00	24 38.01N	56 42.14E
110	97 059	07:53:00	24 42.45N	56 50.34E
111	97 059	09:41:00	24 47.38N	56 57.85E
112	97 059	11:36:00	24 51.64N	57 4.88E
113	97 059	13:40:00	24 56.45N	57 12.10E
114	97 059	16:19:00	25 5.77N	57 3.49E
115	97 059	18:42:00	25 0.15N	56 53.06E
116	97 060	09:51:00	24 55.29N	56 43.48E
117	97 060	11:30:00	24 50.17N	56 34.60E
118	97 060	13:22:00	25 2.14N	56 28.86E
119	97 060	17:00:00	25 7.38N	56 36.65E
120	97 060	19:07:00	25 11.87N	56 48.71E
121	97 061	04:43:00	25 16.88N	56 57.14E
122	97 066	20:33:00	25 6.84N	56 36.99E
123	97 066	21:50:00	25 9.33N	56 42.52E
124	97 066	22:56:00	25 11.76N	56 48.22E
125	97 067	00:04:00	25 14.33N	56 53.07E
126	97 067	01:04:00	25 16.88N	56 57.14E
127	97 067	20:10:00	25 38.01N	56 50.14E
128	97 067	22:27:00	25 36.51N	56 46.46E
129	97 067	23:19:00	25 35.14N	56 42.92E
130	97 068	00:21:00	25 33.64N	56 38.62E
131	97 068	01:16:00	25 32.17N	56 34.53E
132	97 068	02:14:00	25 30.85N	56 30.34E
133	97 068	02:58:00	25 29.58N	56 26.60E
134	97 070	04:11:00	26 11.92N	56 8.45E
135	97 070	04:50:00	26 14.06N	56 7.97E
136	97 070	05:30:00	26 16.61N	56 6.37E
137	97 070	06:10:00	26 18.73N	56 4.01E
138	97 070	06:50:00	26 21.37N	56 1.99E
139	97 070	07:27:00	26 23.75N	56 0.30E
140	97 070	14:23:00	25 42.04N	55 37.94E
141	97 070	15:05:00	25 44.71N	55 35.36E
142	97 070	16:05:00	25 49.77N	55 30.99E
143	97 070	17:07:00	25 54.08N	55 26.59E
144	97 070	18:16:00	25 59.56N	55 22.42E
145	97 071	01:45:00	25 18.12N	54 26.41E
146	97 071	02:48:00	25 23.23N	54 20.97E
147	97 071	03:46:00	25 27.63N	54 16.05E
148	97 071	04:40:00	25 31.78N	54 12.10E
149	97 071	05:52:00	25 36.09N	54 6.91E
150	97 071	07:18:00	25 40.75N	54 1.48E
151	97 071	08:47:00	25 40.80N	53 52.99E
152	97 071	10:10:00	25 40.87N	53 43.92E
153	97 071	11:23:00	25 41.01N	53 35.08E

Table 1. **contd.**

No	J day	Bottom time Z	Position	
154	97 071	12:32:00	25 41.05N	53 26.37E
155	97 071	13:54:00	25 41.08N	53 15.87E
156	97 071	15:24:00	25 31.61N	53 15.82E
157	97 071	17:24:00	25 31.65N	53 27.02E
158	97 071	18:45:00	25 31.51N	53 36.02E
159	97 071	20:06:00	25 31.44N	53 44.69E
160	97 071	21:27:00	25 31.47N	53 53.74E
161	97 071	22:43:00	25 31.44N	54 2.44E
162	97 072	00:37:00	25 23.06N	54 12.23E
163	97 072	01:47:00	25 23.16N	54 3.08E
164	97 072	02:55:00	25 23.19N	53 54.31E
165	97 072	04:07:00	25 23.11N	53 45.47E
166	97 072	05:25:00	25 23.18N	53 36.55E
167	97 072	06:43:00	25 23.20N	53 27.94E
168	97 072	08:27:00	25 22.91N	53 20.33E
169	97 073	10:50:00	25 11.53N	54 22.44E
170	97 073	12:00:00	25 4.99N	54 18.05E
171	97 073	13:12:00	25 4.52N	54 11.02E
172	97 073	14:08:00	25 5.03N	54 4.85E
173	97 073	15:21:00	25 5.03N	53 55.98E
174	97 073	16:53:00	25 7.21N	53 46.83E
175	97 073	18:21:00	25 5.02N	53 38.33E
176	97 073	19:49:00	25 4.73N	53 29.29E
177	97 073	21:23:00	24 56.97N	53 24.38E
178	97 073	22:26:00	24 57.69N	53 30.14E
179	97 073	23:28:00	24 58.39N	53 38.92E
180	97 074	00:39:00	24 58.21N	53 47.48E
181	97 074	01:48:00	24 56.08N	53 56.60E
182	97 074	02:48:00	24 56.18N	54 4.68E
183	97 074	04:03:00	24 56.08N	54 11.80E
184	97 074	05:07:00	24 52.31N	54 15.69E
185	97 074	06:05:00	24 48.29N	54 18.83E
186	97 074	07:05:00	24 43.68N	54 21.73E
187	97 074	07:57:00	24 40.52N	54 24.28E

Table 2. SeaSoar deployment times

Deployed Day of year	Deployed Time GMT	Recovered Day of year	Recovered Time GMT
61	0650	62	2330
63	0245	64	1445
65	0220	66	0145
66	0330	66	1430
72	0920	73	0615
75	0840	75	1310

Table 3 Estimates of GLONASS/GPS position and velocity errors whilst alongside at Mina al Qaboos, Muscat (23° 37' 37.6" N 58° 33' 56.2" E)

Parameter	Mean Error	rms	% observations > 3 rms	% > 3 rms for Gaussian error	No. of Observations
Relative Latitude (metres)	-3.70	7.88	0.97	0.27	77965 one second
Relative Longitude (metres)	3.17	8.58	1.38	0.27	77964 one second
Velocity east 2 min. (cm/s)	-0.24	5.31	5.3	0.27	678 2 minute
Velocity north 2 min. (cm/s)	-0.28	5.25	4.1	0.27	678 2 minute

Table 4 Location offsets of echo sounder transducers from the GLONASS/GPS antenna.

Sounder/Transducer	Alongship offset (m)	Athwart offset (m)
EA500 Hull	9m aft	8 m stbd
EA500 Towfish	5 m aft	4 m port
EK500 Towfish	35 m aft	14 m stbd

Table 5 Sensors logged by the GHROMET system.

Variable	Position	Instrument	Period
Wet and Dry Bulb [Psy1]	PORT side of foremast platform (STBD sensor)	Psychrometer TDIO2002 (SOC)	043-077
Wet and Dry Bulb [Psy2]	PORT side of foremast platform (PORT sensor)	Psychrometer TDIO2003 (SOC)	043-077
Wet and Dry Bulb [Psy3]	PORT side of foremast platform (Forward sensor)	Psychrometer TDHS1032 (HYDROSPHERE)	044-077
Longwave [lw1]	Top of foremast (Aft sensor)	Eppley PIR 31171	043-077
Longwave [lw2]	Top of foremast (Forward sensor)	Eppley PIR 31172	043-077
ShortWave [ptir]	Gimbal mounted on port side of foremast platform	Kipp & Zonen CM11 902837	043-077
ShortWave [stir]	Gimbal mounted stbd side of foremast platform	Kipp & Zonen CM11 840607	043-062 10:30 hrs
		Kipp & Zonen CM11 903290	10:30 hrs 062 - 077
Wind Speed & Direction [ws1 wd1]	PORT side of foremast platform	RM Young AQ 7768	043-077
Wind Speed & Direction [ws2 wd2]	PORT side of main mast	RM Young AQ 1552	043-077
Wind Speed & Direction [ws3 wd3}	PORT side of main mast	Gill Windmaster Sonic	043-077
SST [sst1]	Trailing from 6 M scaffold pole off port Bow	Trailing Thermistor pd004 (electronics 51) (SOC)	043-077
Pressure [baro]	PORT side of foremast platform	IO002 (SOC)	043-077

Table 6. Mean differences between Sea surface temperature and Radiometers.

Comparison	Mean	s.d.	No.	No. Out
Soap-TASCO	0.6111	2.9965	35469	0
Soap-TSG	0.0411	0.9472	35945	0
SIL-TASCO	-0.7241	2.9377	35519	0
SIL-TSG	-1.2940	3.1114	35514	0
TASCO-TSG	-0.5699	2.9559	35514	0

Table 7. SIL Radiometer Calibration.

JDAY	Thermometer	SST 'Soap'	SIL
60.5003	5.8	6.0603	-0.5445
60.5024	6.5	6.6431e	0.2544
60.5045	7.2	7.2573	1.3609
60.5066	8	7.9038	2.1748
60.508	8.5	8.3519	2.6852
60.5094	14.5	14.5881	10.8104
60.5115	14.7	14.7916	10.8792
60.5135	14.9	15.0034	11.0818
60.5156e	15.1	15.2117	11.299
60.5372	18.4	18.621	15.7779
60.5392	18.5	18.5804	15.8607
60.5413	18.5	18.6538	15.9652
60.5434	18.6	18.7251	15.9546
60.5455	18.7	18.7956	16.099

Table 8. Tasco Radiometer Calibration. Missing data points correspond to the Sky Tasco not viewing bucket correctly.

JDAY	Thermometer	SST Soap	SST Tasco	SKY Tasco
63.417	7.8	7.62	10.1503	
63.4191	8.3	8.2376	10.5273	
63.4205	8.9	8.6491	10.7508	
63.423	9.5	9.3701	11.3993	
63.4247	10.1	9.7576	11.5457	
63.4288	16.6	16.5256	17.7	17.54
63.4309	16.8	16.7823	17.79	17.7688
63.433	17.0	17.0088	18.0	17.9245
63.4691	20.6	20.6151	20.9382	21.0782
63.4712	20.7	20.7221	20.98	21.1279
63.4733	20.8	20.8291	21.09	21.2256
63.4753	20.9	20.9269	21.19	21.3895
63.483	23.9	23.8787	23.8858	24.02
63.4851	23.9	23.9185	23.99	24.0126
63.4872	23.9	23.9629	23.99	24.1262

Table 9. Radiosonde Flight Summary

Flight No.	Jday	Launch time (Z)	File	Latitude (N)	Longitude (E)	Notes
MB1	044	08:04	0440659	024:21.64	059:19.83	(1)
MB2	044	11:08	0441104	024:25.55	058:57.38	
MB3	044	23:09	0442302	024:33.80	058:15.50	
MB4	045	10:55	0451052	024:41.01	057:42.46	
MB5	045	14:22	0451418	024:44.70	057:17.58	
MB6	045	22:58	0452354	024:48.20	056:53.70	
MB7	046	02:57	0460245	024:49.25	056:55.14	
MB8	046	11:09	0461105	024:29.90	056:53.50	
MB9	046	23:09	0462306	024:40.60	057:24.20	
MB10	047	11:02	0471059	024:26.40	057:27.40	
MB11	047	23:07	0472303	024:10.90	057:31.10	
MB12	048	11:03	0481057	024:40.05	057:50.00	
MB13	048	14:35	0481431	024:26.95	057:46.24	
MB14	048	23:04	0482300	023:04.00	057:47.80	
MB15	049	03:24	0490319	024:25.80	057:52.80	
MB16	049	11:20	0491116	024:20.20	057:57.80	
MB17	049	23:15	0492315	024:16.20	058:04.50	
MB18	050	11:00	0501057	024:10.60	058:09.10	
MB19	050	23:01	0502302	024:25.20	058:20.00	(2)
MB20	051	11:22	0511119	024:00.40	058:20.50	
MB21	051	14:42	0511438	023:56.50	058:26.10	
MB22	051	23:00	0512255	024:29.00	058:41.70	
MB23	052	10:52	0521048	023:42.10	058:25.70	
MB24	052	23:25	0522319	024:21.70	058:47.50	
MB25	053	10:54	0531045	023:43.70	058:43.00	
MB26	053	14:30	0531415	023:36.00	058:47.77	
MB27	053	23:15	0532309	024:18.00	058:58.60	
MB28	054	10:58	0541053	024:13.00	058:37.20	
MB29	054	22:53	0542247	024:14.00	058:37.20	
MB30	055	02:55	0550249	024:11.46	058:47.60	
MB31	055	11:12	0551106	024:14.50	058:37.80	
MB32	055	14:58	0551447	024:11.80	058:42.60	
MB33	055	23:03	0552254	024:13.00	058:37.70	
MB34	056	11:03	0561102	024:12.40	058:33.40	(3)
MB35	056	23:01	0562251	024:16.40	058:23.70	

Table 9. **Contd.**

Flight No.	Jday	Launch time (Z)	File	Latitude (N)	Longitude (E)	Notes
MB36	057	11:19	0571115	024:23.40	057:14.80	
MB37	057	22:52	0572249	024:33.10	057:10.60	
MB38	058	02:45	0580243	024:29.40	057:15.50	
MB39	058	11:10	0581107	024:37.90	057:04.30	
MB40	058	14:33	0581428	024:51.70	056:47.80	
MB41	058	22:54	0582249	024:4640	057:07.20	
MB42	059	06:01	0590559	024:37.90	056:42.10	(4)
MB43	059	11:22	0591117	024:51.70	057:05.00	(3)
MB44	059	22:52	0592247	024:51.80	056:58.20	
MB45	060	11:03	0601101	024:51.30	056:36.40	
MB46	060	23:30	0602326	025:10.90	056:49.60	
MB47	061	11:05	0611426	025:41.80	056:42.00	
MB48	061	14:26	0611426	026:07.40	056:43.40	
MB49	061	23:10	0612306	026:16.80	056:59.80	
MB50	062	02:55	0620252	026:01.67	055:29.21	
MB51	062	11:10	0621106	026:24.90	056:13.60	
MB52	062	23:39	0622336	025:24.80	056:43.00	
MB53	063	11:02	0631059	026:24.40	056:40.70	
MB54	063	23:03	0632300	025:52.00	055:29.10	
MB55	064	11:24	0641120	026:10.40	056:39.40	(3)
MB56	064	14:20	0641415	025:48.09	056:33.71	(4)
MB57	064	23:04	0642301	025:47.00	056:39.10	(3)
MB58	065	02:50	0650248	025:43.80	056:34.51	
MB59	065	11:03	0651100	026:10.30	056:37.20	
MB60	065	22:53	0652250	025:45.27	055:32.66	
MB61	066	11:02	0661059	026:25.60	056:27.10	(4)
MB62	066	23:28	0662325	025:12.70	056:50.20	
MB63	067	11:05	0671100	025:17.70	056:41.50	(3)
MB64	067	14:33	0671431	025:15.90	056:51.10	
MB65	067	23:06	0672303	025:35.40	056:43.40	(3)
MB66	068	03:00	0680257	025:29.62	056:26.60	
MB67	068	11:05	0681101	026:14.60	056:08.00	
MB68	068	22:51	0682251	024:56.10	054:25.00	
MB69	069	12:47	0691243	024:36.04	054:18.56	
MB70	069	-	-	-	-	(*)

Table 9. Contd.

Flight No.	Jday	Launch time (Z)	File	Latitude (N)	Longitude (E)	Notes
MB71	069	23:42	0692336	025:52.00	055:35.50	(4)
MB72	070	11:07	0701104	026:08.70	056:46.50	
MB73	070	15:28	0701524	025:46.60	055:35.50	
MB74	070	11:02	0702257	025:29.10	054:50.00	(4)
MB75	071	02:48	0710243	025:23.23	054:20.92	
MB76	071	11:06	0711102	025:41.10	053:36.50	
MB77	071	23:17	0712315	025:29.10	054:05.00	
MB78	072	11:13	0721109	025:23.00	053:38.60	
MB79	072	16:06	0721600	025:24.66	054:19.87	
MB80	072	23:13	0722309	025:31.40	053:18.90	
MB81	073	11:17	0731113	25:09.10	54:21.10	
MB82	073	15:48	0731545	25:05.11	53:52.64	
MB83	073	23:07	0732304	24:58.30	53:36.80	
MB84	074	06:17	0740617	24:47.95	54:19.23	
MB85	074	11:17	0741101	25:00.30	54:09.30	(3)
MB86	074	18:38	0741828	25:35.60	53:45.70	
MB87	074	23:05	0742301	25:35.60	53:40.25	(3)
MB88	075	11:02	0751059	25:31.40	53:25.10	
MB89	075	16:18	0751615	25:20.98	53:31.12	

(1) Very noisy signal, tightened antenna connections.
(2) Logging started at 960 mbar.
(3) No GPS data.ata
(4) poor GPS d
(*) Launch failure

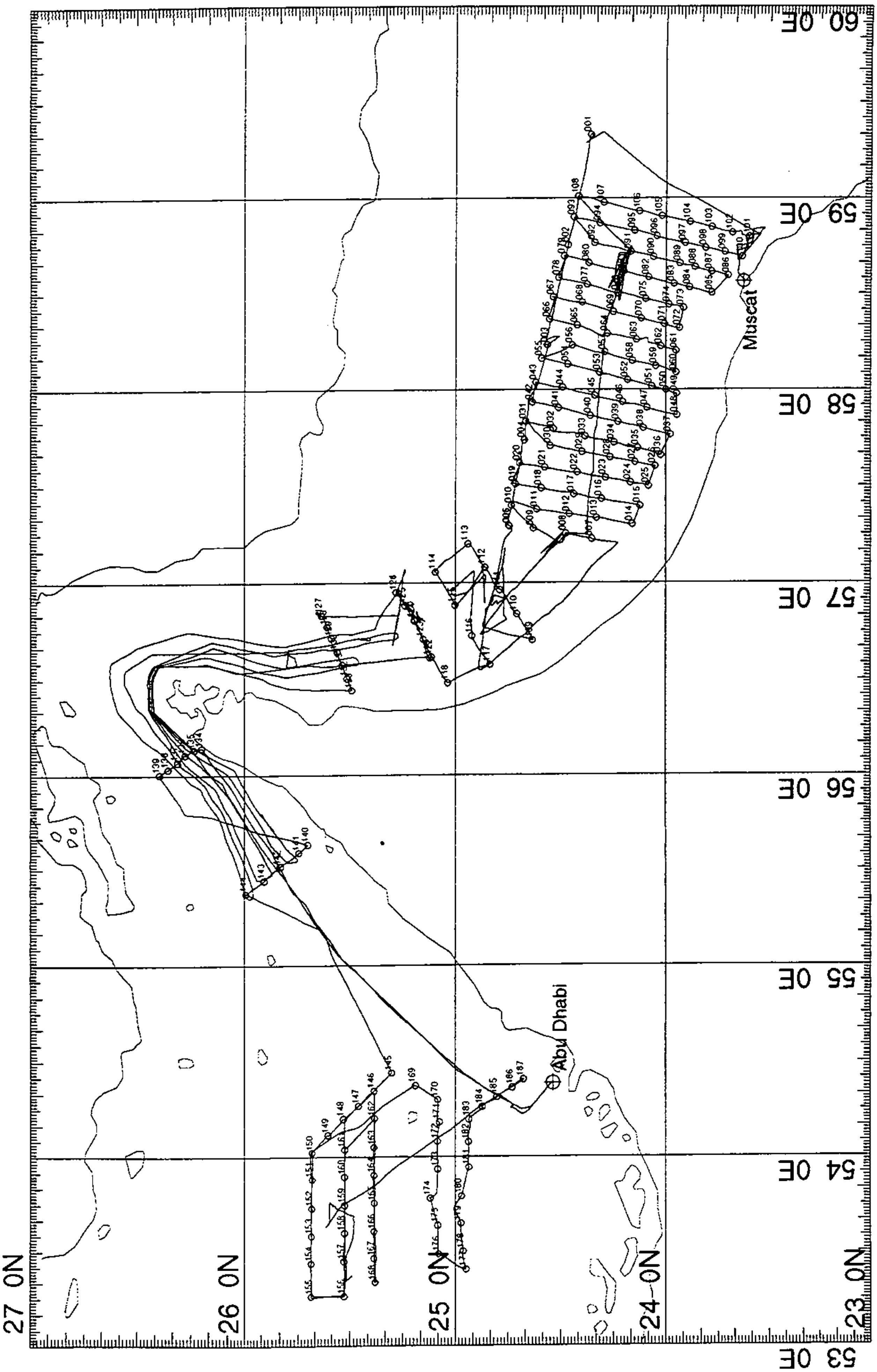

Figure 1. CD 104 Leg 1. Overall track and station positions

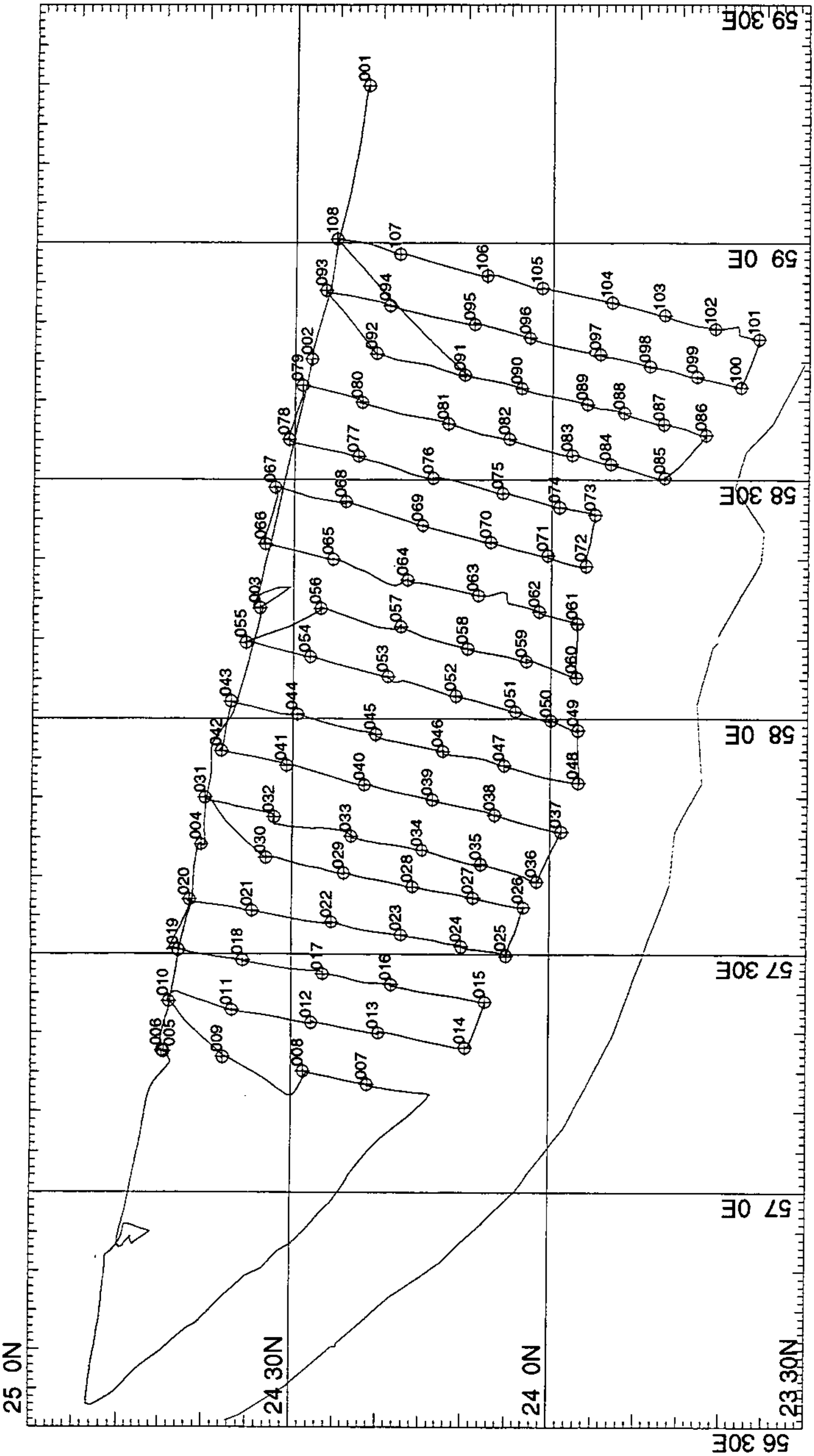

Figure 2. Gulf of Oman CTD survey

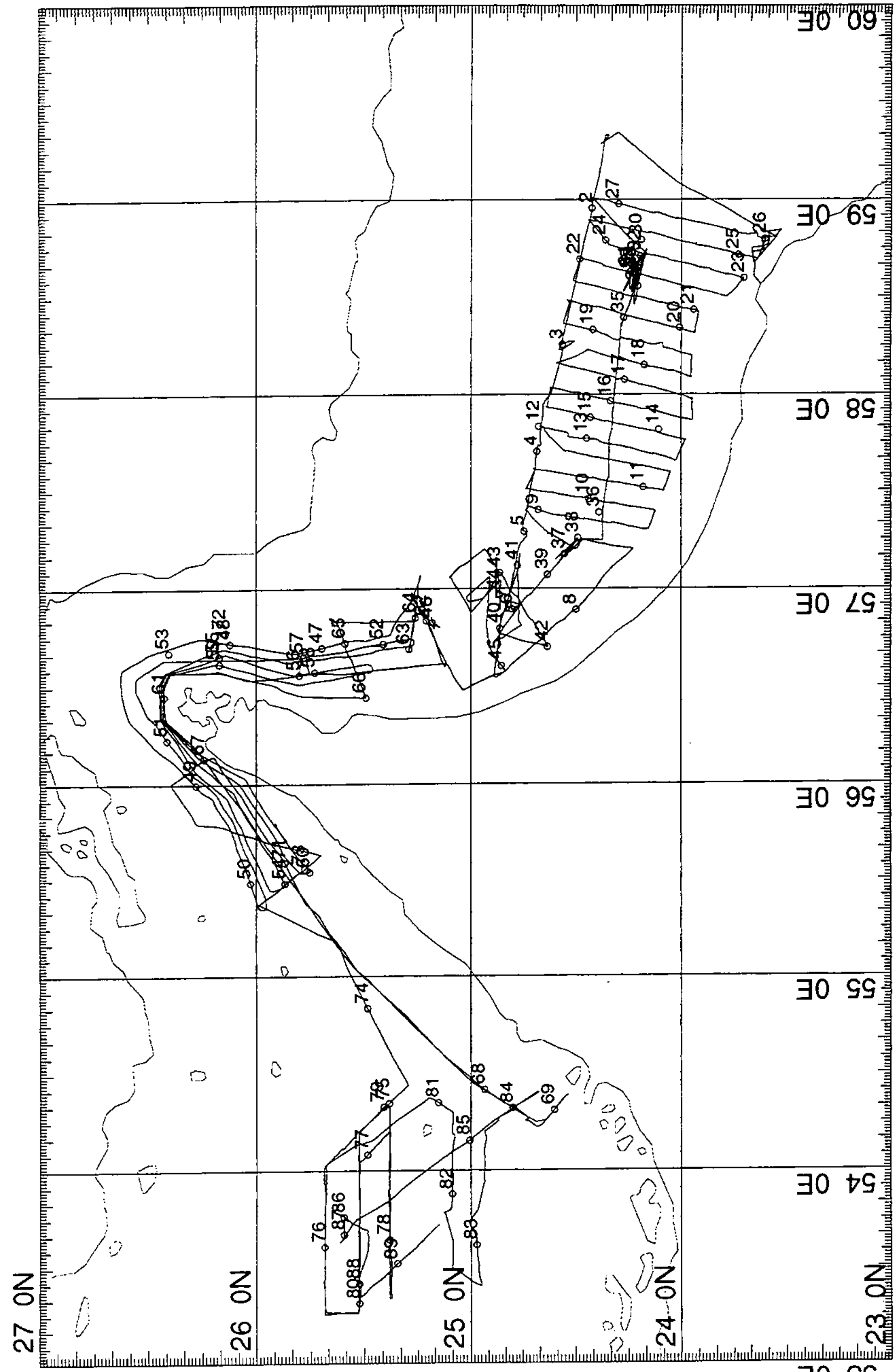

Figure 3. Radiosonde launch stations

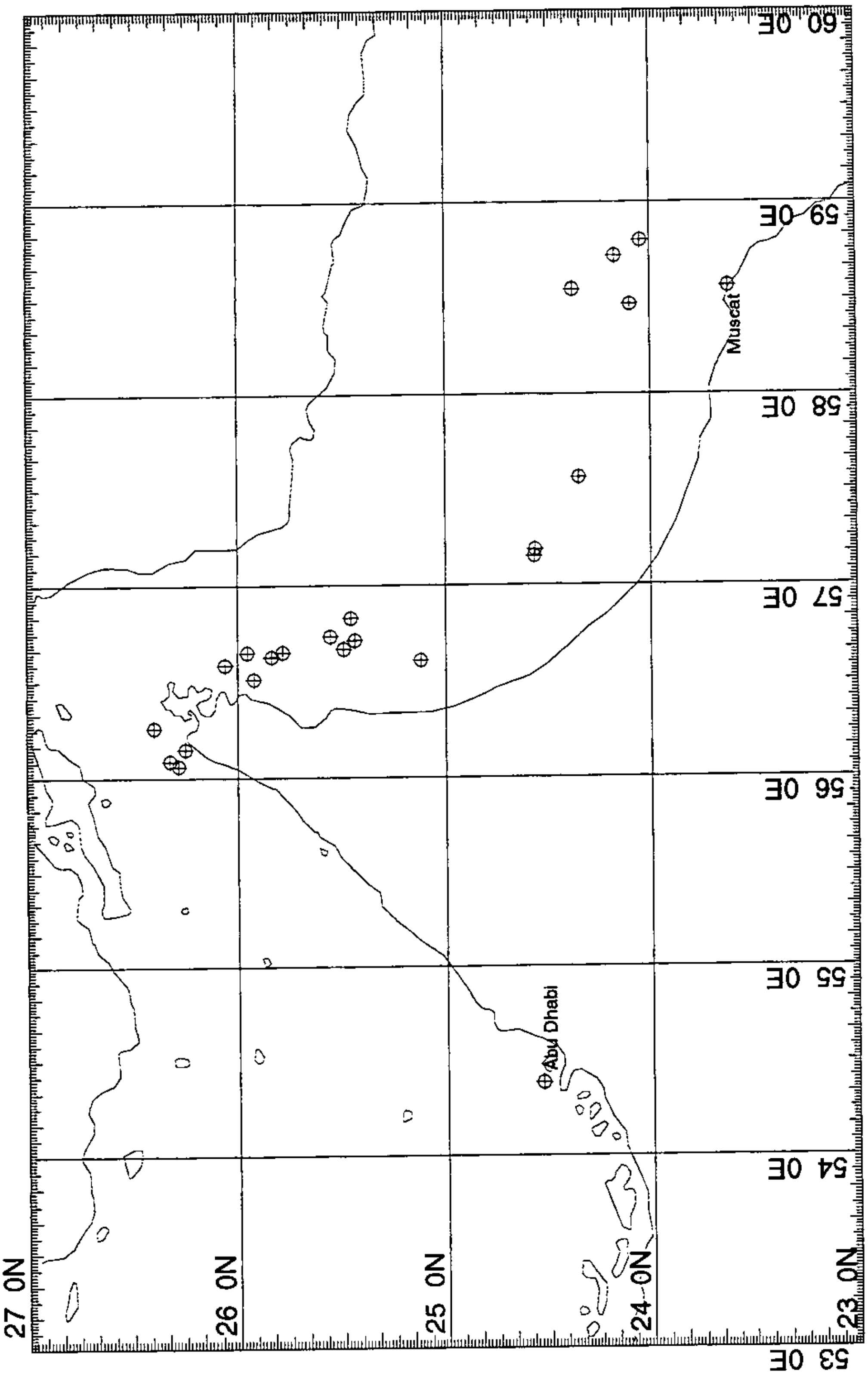

Figure 4. Red tide observations

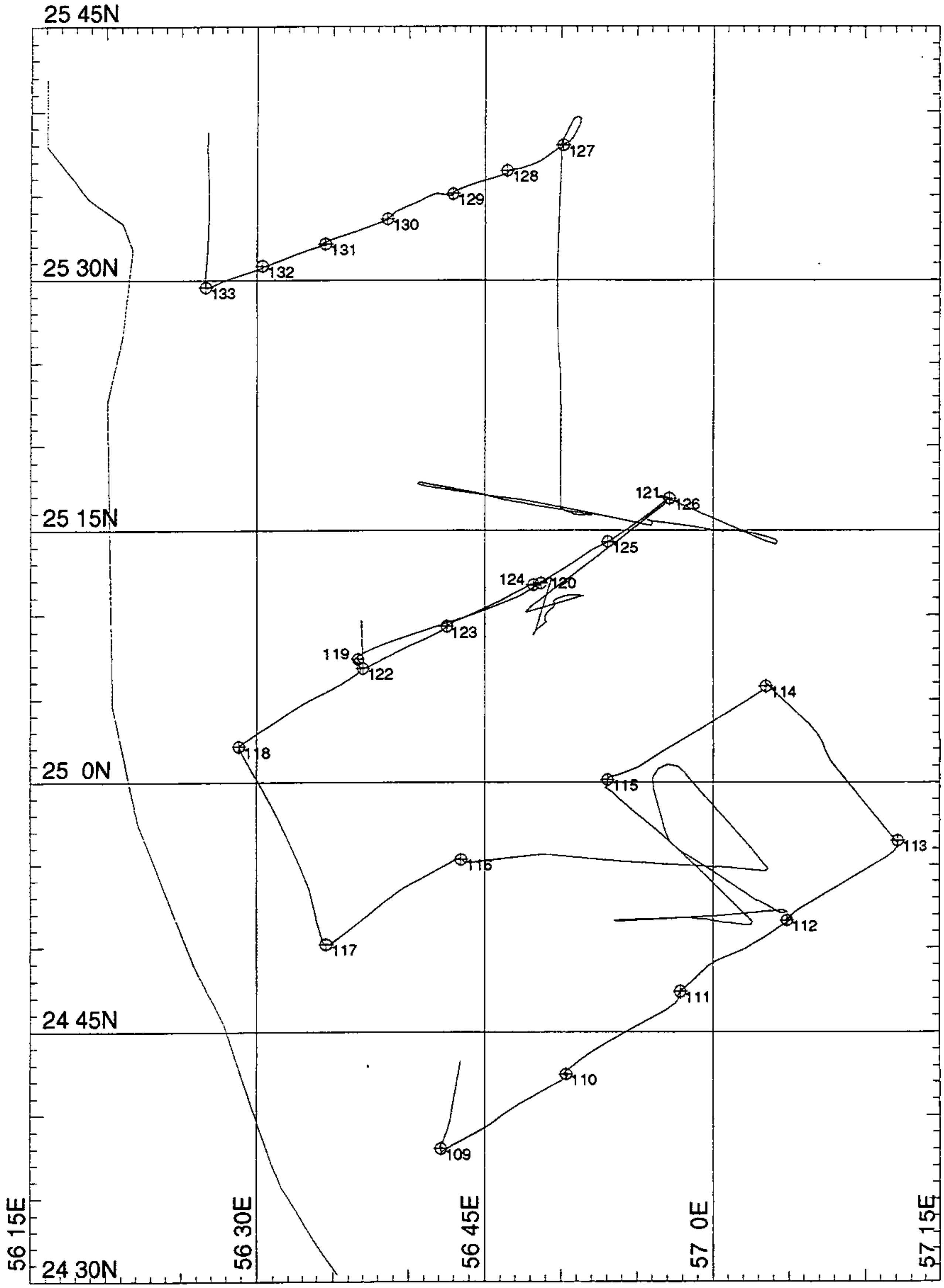

Figure 5. Track and CTD positions S E of the Strait of Hormuz

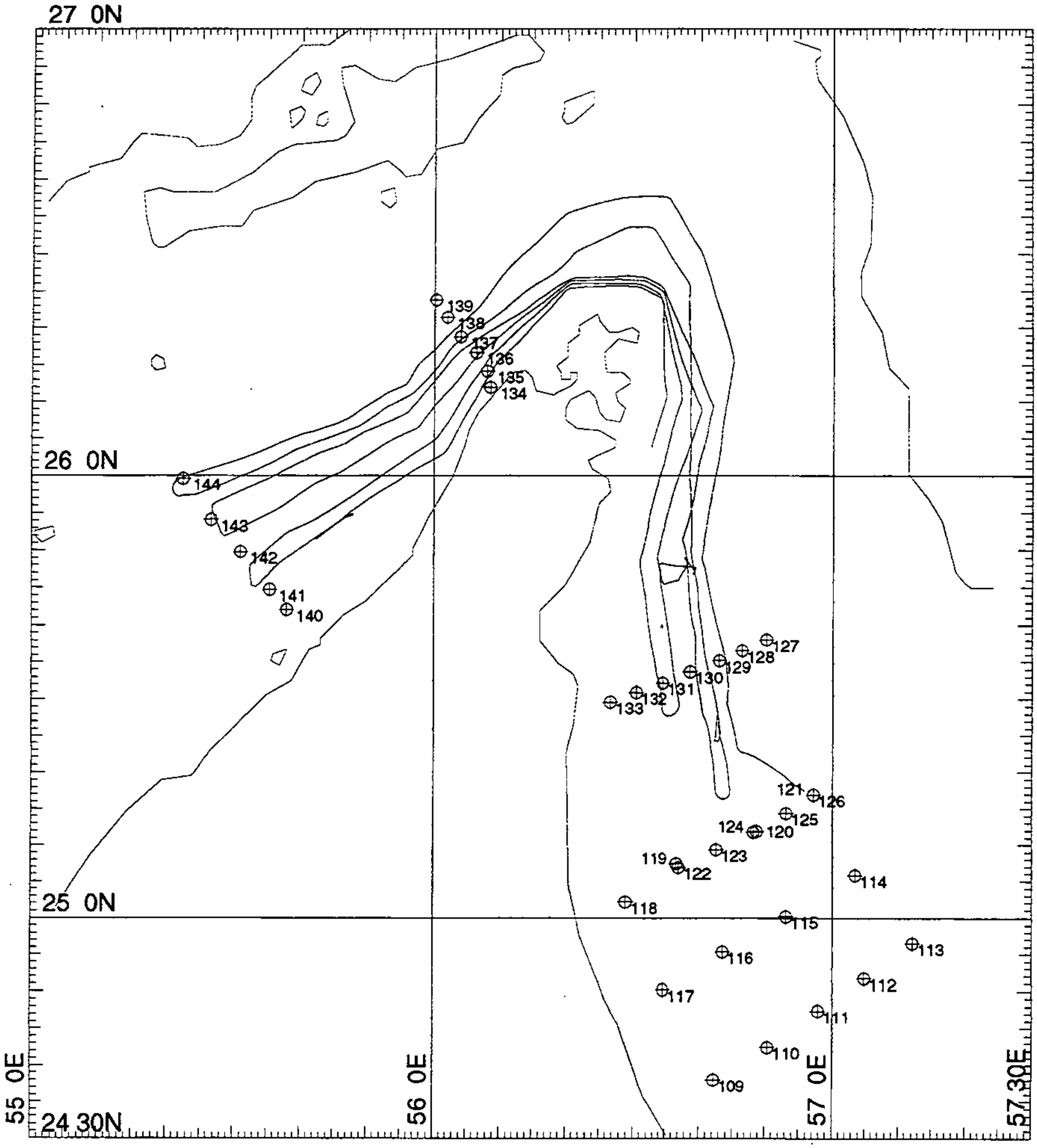

Figure 6. Strait of Hormuz SeaSoar tracks and CTD positions.

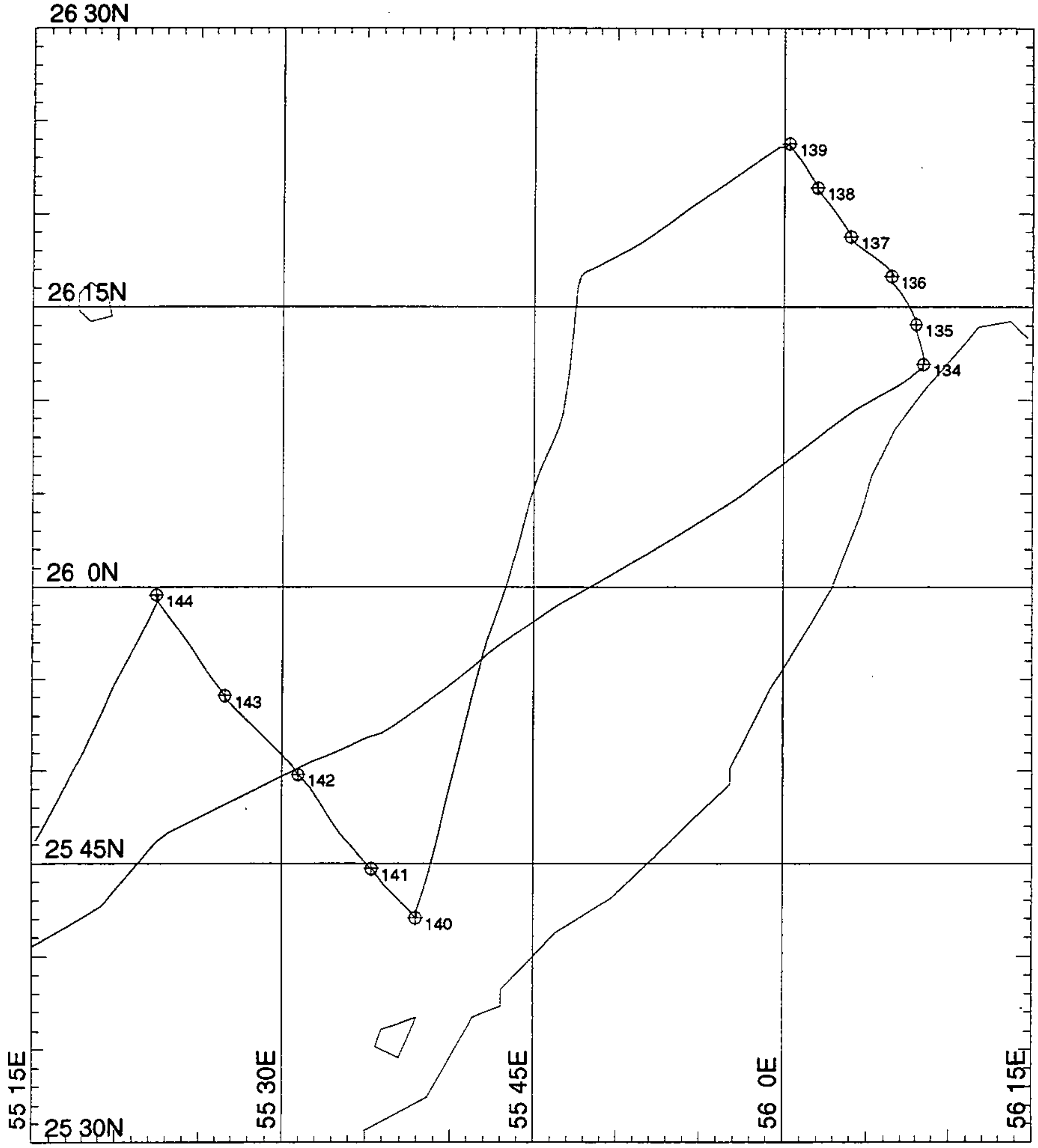

Figure. 7. Track and CTD positions SW of the Strait of Hormuz

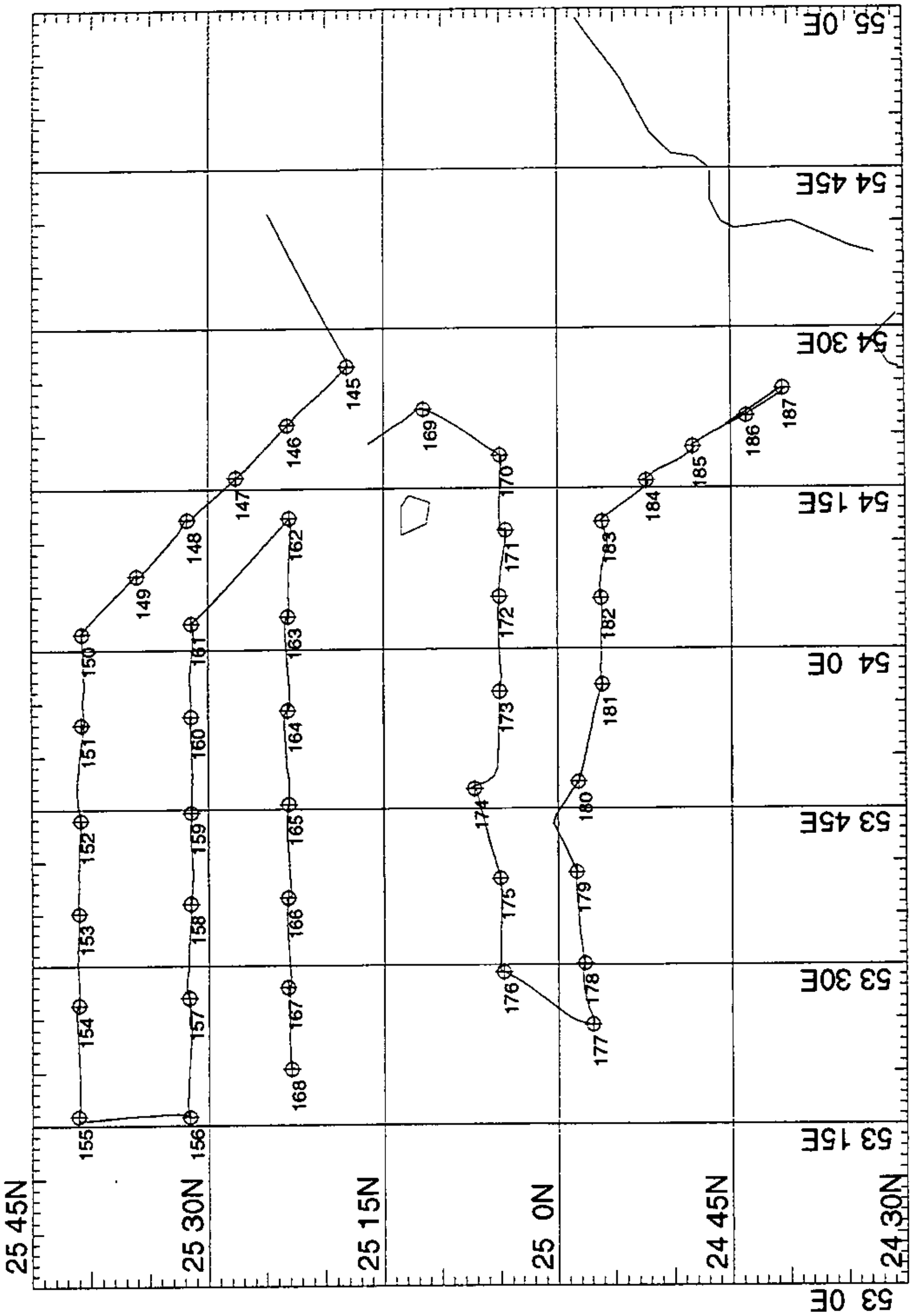

Figure 8.   Arabian Gulf. Track and CTD positions

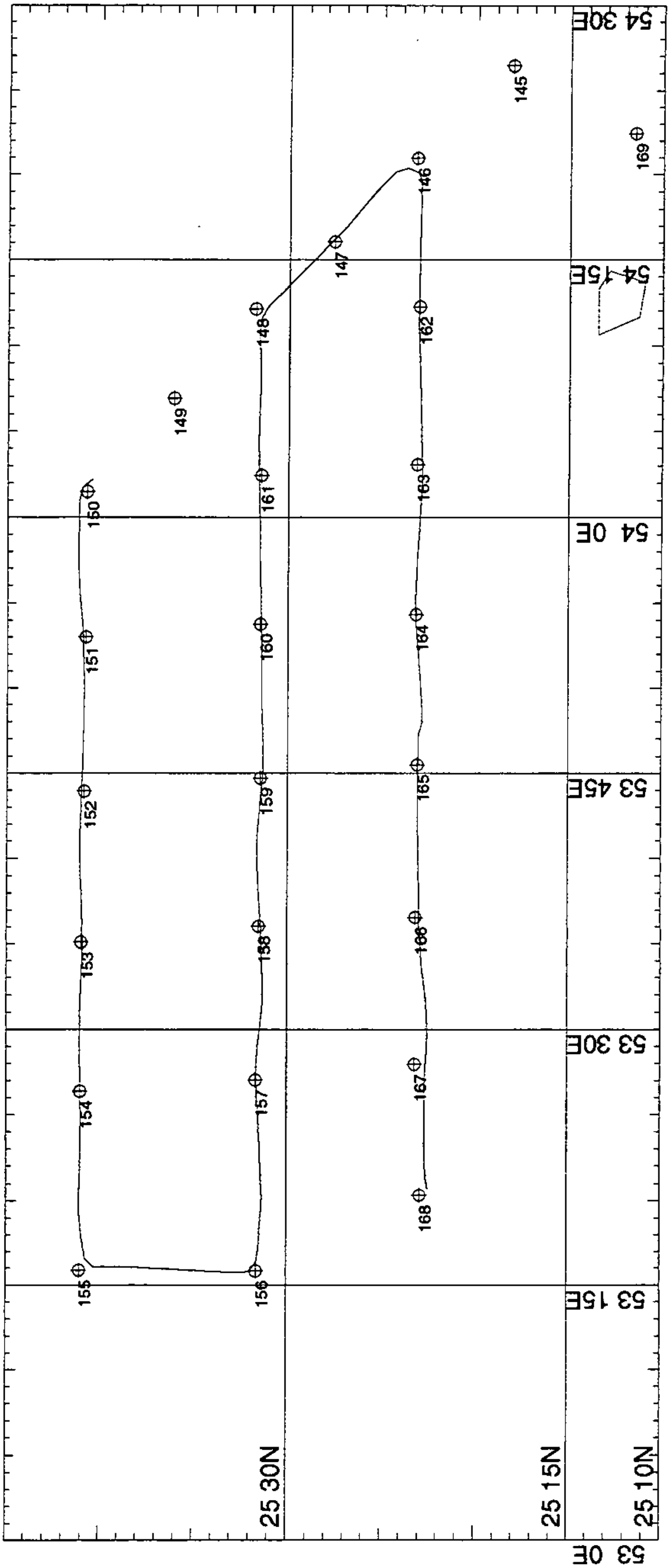

Figure 9. Arabian Gulf. SeaSoar track and CTD positions

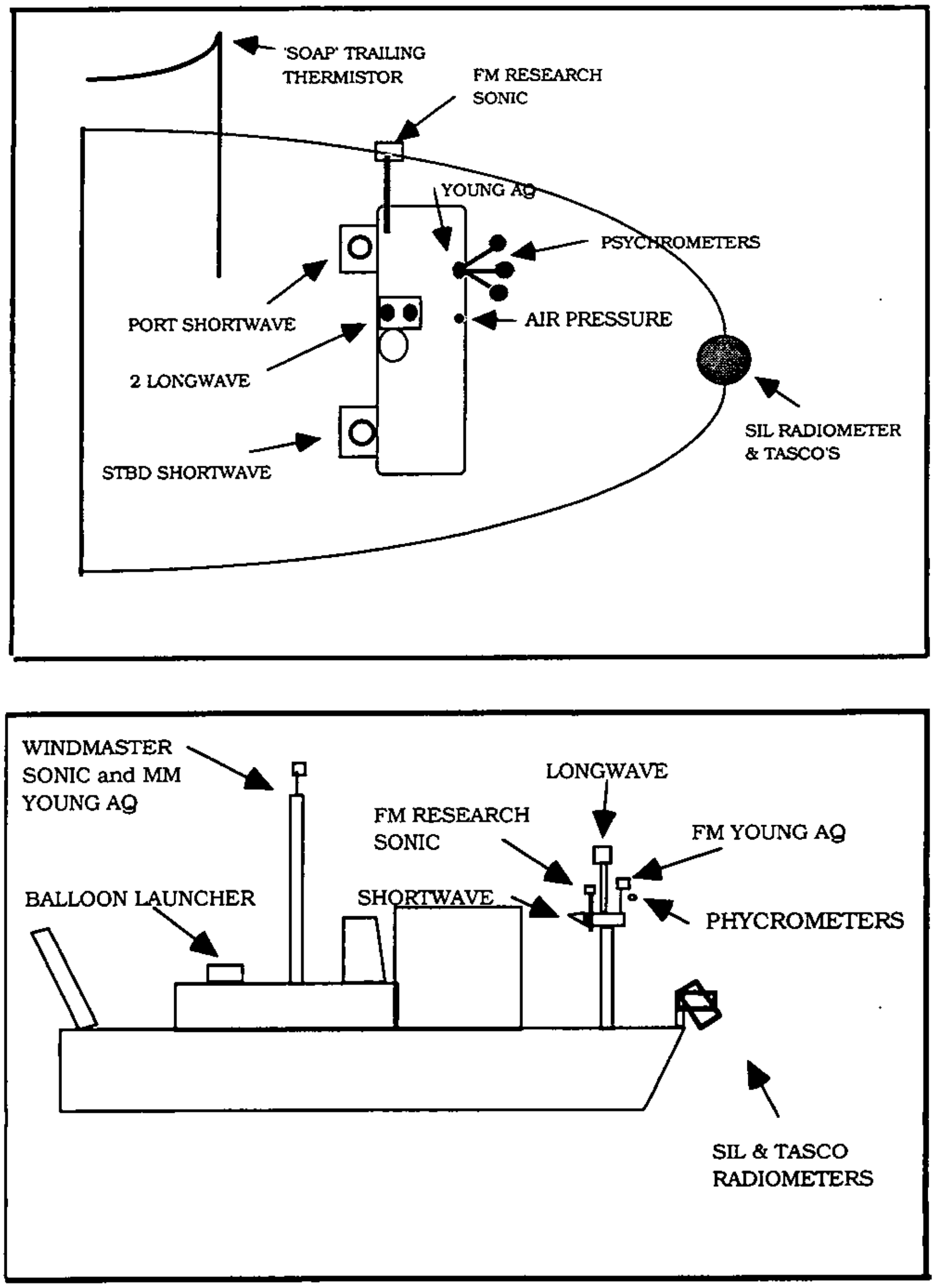

Figure 10. Meteorological sensor positions

Appendix A: CTD calibration file

Below is a list of the calibration file (deepctd.cal):

```
temp     1.      -0.0165549  0.000499282   7.97259e-13   0.  0.
deltat   .20     0.          0.            0.  0.  0.
press    .1      -9.3832     0.996263      5.743323e-7 0. 0.
cond     .001    0.          0.988156  0.  0   0.
oxyc     .001    0.          0.5       0.  0.  0.
oxyt     .128    0.          1.        0.  0.  0.
oxyfrac  -.030   0.000150    1.0       0.  0.  0.
fvolts   1.      -1.719631e-3  1.219711e-3   3.438596e-10   0.  0.
fluor    1.000   0.0         1         -1.0  0.0 0.0
nframes  1.      0.          1.        0.  0.  0.
alt      1.0     0.20299     5.1479e-2   -5.861688e-8   0. 0.
:trans is new Chelsea Instr transmissometer
trans    1.0     1.81789e-3  1.21934e-3   6.05678e-10 0. 0.
:Deck air value on 5/12/96
potran   4.692   4.2         1.0       0.        0. 0.
atten    0.      20.0        0.        0.25  0.  0.
utility  1.0     0.     0.     0.     0.  0.
```

Appendix B: SeaSoar calibration file

Below is a list of the calibration file (shalctd.cal)

press .01 -43.6421057 3.2280473 0.0 0.0 0.0

temp .0001 -2.70934753 4.93708996 0.000239076 0.0 0.0

cond .001 -0.012146727 0.960765192 -0.0000461212 0.000000619047 0.0

fvolts .0001 -4.96067468 1.51390595 -0.000002982 0.0 0.0

fluor 1.000 0.0 1. -1.0 0.0 0.0

: New backscatter probe

bscat .0001 -4.96067468 1.51390595 -0.000002982 0.0 0.0

light (In W/m^2) .0001 -35.73526 7.348500 -0.0000144746

deltat 0.15 0.0 0.0 0.0 0.0 0.0

nframes 1. 0. 1. 0. 0. 0.

zvolts .0001 -4.96067468 1.51390595 -0.000002982 0.0 0.0

Appendix C. Biological station list

Gear abbreviations used in station list

LHPR	Longhurst-Hardy Plankton Sampler
RMT1+8M	Rectangular Midwater Trawl, having 3 pairs of nets with nominal; mouth openings of $1m^2$ (RMT1, mesh size 0.33 mm) and $8m^2$ (RMT8, mesh size 4.5 mm).
RMT1	RMT1 net (as above) but not fished in multinet mode.
RMT8	RMT8 net (as above) but not fished in multinet mode.

STN.	DATE 1997	POSITION LAT.	LONG.	GEAR	DEPTH (M)	TIMES GMT	COMMENT	MEAN SOUND. (M)
54001	23/ 2	24 12.3N	58 40.8E	RMT1M/1	300- 403	0922-1022		
# 1		24 12.8N	58 38.6E	RMT8M/1		Day	Flow Dist. 2.920 km.	
54001	23/ 2	24 12.8N	58 38.6E	RMT1M/2	200- 300	1022-1122		
# 2		24 13.2N	58 36.3E	RMT8M/2		Day	Flow Dist. 3.010 km.	
54001	23/ 2	24 13.2N	58 36.3E	RMT1M/3	150- 200	1122-1222		
# 3		24 13.8N	58 34.2E	RMT8M/3		Day	Flow Dist. 3.190 km.	
54001	23/ 2	24 12.0N	58 41.4E	RMT1M/1	305- 400	1530-1631		
# 4		24 12.7N	58 38.8E	RMT8M/1		Night	Flow Dist. 3.410 km.	
54001	23/ 2	24 12.7N	58 38.8E	RMT1M/2	201- 305	1631-1730		
# 5		24 13.2N	58 36.3E	RMT8M/2		Night	Flow Dist. 3.685 km.	
54001	23/ 2	24 13.2N	58 36.3E	RMT1M/3	152- 201	1730-1831		
# 6		24 13.9N	58 33.9E	RMT8M/3		Night	Flow Dist. 3.684 km.	
54001	23/ 2	24 12.8N	58 40.0E	RMT1M/1	894-1016	2131-2231		
# 7		24 13.7N	58 38.0E	RMT8M/1		Night	Flow Dist. 2.965 km.	
54001	23/ 2	24 13.7N	58 38.0E	RMT1M/2	800- 894	2231-2331		
# 8		24 14.5N	58 35.9E	RMT8M/2		Night	Flow Dist. 3.190 km.	
54001	23/ 2	24 14.5N	58 35.9E	RMT1M/3	699- 800	2331-0031		
# 9	24/ 2	24 15.4N	58 33.7E	RMT8M/3		Night	Flow Dist. 3.415 km.	
54001	24/ 2	24 12.1N	58 40.7E	RMT1M/1	896-1000	0503-0603		
#10		24 12.7N	58 38.4E	RMT8M/1		Day	Flow Dist. 2.785 km.	
54001	24/ 2	24 12.7N	58 38.4E	RMT1M/2	800- 896	0603-0703		
#11		24 13.3N	58 36.3E	RMT8M/2		Day	Flow Dist. 3.055 km.	

STN.	DATE 1997	POSITION LAT.	LONG.	GEAR	DEPTH (M)	TIMES GMT	COMMENT	MEAN SOUND. (M)
54001	24/ 2	24 13.3N	58 36.3E	RMT1M/3	695- 800	0703-0803		
#12		24 13.9N	58 34.0E	RMT8M/3		Day	Flow Dist. 3.190 km.	
54001	24/ 2	24 14.7N	58 34.1E	RMT1M/1	600- 700	0942-1042		
#13		24 14.7N	58 36.4E	RMT8M/1		Day	Flow Dist. 3.010 km.	
54001	24/ 2	24 14.7N	58 36.4E	RMT1M/2	504- 605	1042-1142		
#14		24 14.3N	58 39.0E	RMT8M/2		Day	Flow Dist. 3.729 km.	
54001	24/ 2	24 14.3N	58 39.0E	RMT1M/3	394- 504	1142-1242		
#15		24 13.9N	58 41.3E	RMT8M/3		Day	Flow Dist. 3.460 km.	
54001	24/ 2	24 12.0N	58 40.8E	RMT1M/1	598- 694	1545-1645		
#16		24 12.4N	58 38.2E	RMT8M/1		Night	Flow Dist. 3.505 km.	
54001	24/ 2	24 12.4N	58 38.2E	RMT1M/2	497- 598	1645-1745		
#17		24 12.9N	58 35.6E	RMT8M/2		Night	Flow Dist. 3.640 km.	
54001	24/ 2	24 12.9N	58 35.6E	RMT1M/3	403- 497	1745-1845		
#18		24 13.6N	58 33.1E	RMT8M/3		Night	Flow Dist. 3.640 km.	
54001	24/ 2	24 11.7N	58 41.7E	RMT1M/1	100- 157	2116-2217		
#19		24 12.4N	58 39.4E	RMT8M/1		Night	Flow Dist. 3.189 km.	
54001	24/ 2	24 12.4N	58 39.4E	RMT1M/2	50- 100	2217-2316		
#20		24 13.2N	58 37.3E	RMT8M/2		Night	Flow Dist. 3.055 km.	
54001	24/ 2	24 13.2N	58 37.3E	RMT1M/3	0- 50	2316-0016		
#21	25/ 2	24 14.0N	58 35.3E	RMT8M/3		Night	Flow Dist. 3.145 km.	
54001	25/ 2	24 11.6N	58 40.2E	RMT1M/1	1195-1415	0250-0450		
#22		24 12.6N	58 35.4E	RMT8M/1		Day	Flow Dist. 5.659 km.	

STN.	DATE 1997	POSITION LAT.	 LONG.	GEAR	DEPTH (M)	TIMES GMT	COMMENT	MEAN SOUND. (M)
54001 #23	25/ 2	24 12.6N 24 13.0N	58 35.4E 58 33.1E	RMT1M/2 RMT8M/2	1100-1190	0450-0550 Day	Flow Dist. 3.100 km.	
54001 #24	25/ 2	24 13.0N 24 13.4N	58 33.1E 58 30.9E	RMT1M/3 RMT8M/3	1007-1100	0550-0651 Day	Flow Dist. 3.190 km.	
54001 #25	25/ 2	24 13.3N 24 13.0N	58 28.4E 58 29.6E	RMT1M/1 RMT8M/1	100- 150	0849-0919 Day	Flow Dist. 1.595 km.	
54001 #26	25/ 2	24 13.0N 24 12.8N	58 29.6E 58 30.7E	RMT1M/2 RMT8M/2	50- 100	0919-0949 Day	Flow Dist. 1.550 km.	
54001 #27	25/ 2	24 12.8N 24 12.6N	58 30.7E 58 31.9E	RMT1M/3 RMT8M/3	0- 50	0949-1019 Day	Flow Dist. 1.550 km.	
54001 #28	25/ 2	24 12.3N 24 10.9N	58 34.4E 58 42.7E	LHPR	0- 450	1130-1435 Dusk		
54001 #29	25/ 2	24 11.9N 24 13.5N	58 36.9E 58 31.9E	RMT1M/1 RMT8M/1	1821-2009	1709-1909 Night	Flow Dist. 6.875 km.	
54001 #30	25/ 2	24 13.5N 24 15.0N	58 31.9E 58 27.3E	RMT1M/2 RMT8M/2	1600-1833	1909-2109 Night	Flow Dist. 7.010 km.	
54001 #31	25/ 2	24 15.0N 24 16.5N	58 27.3E 58 23.5E	RMT1M/3 RMT8M/3	1387-1600	2109-2309 Night	Flow Dist. 6.200 km.	
54002 # 1	26/ 2	24 29.1N 24 30.9N	57 14.3E 57 12.2E	RMT1M/1 RMT8M/1	201- 250	1230-1329 Day	Flow Dist. 4.405 km.	
54002 # 2	26/ 2	24 30.9N 24 31.8N	57 12.2E 57 11.1E	RMT1M/2 RMT8M/2	100- 204	1329-1400 Day	Flow Dist. 2.719 km.	

STN.	DATE 1997	POSITION LAT.	LONG.	GEAR	DEPTH (M)	TIMES GMT	COMMENT	MEAN SOUND. (M)
54002	26/ 2	24 31.8N	57 11.1E	RMT1M/3	0- 100	1400-1426		
# 3		24 32.7N	57 10.3E	RMT8M/3		Day	Flow Dist. 2.048 km.	
54002	26/ 2	24 30.6N	57 14.2E	RMT1M/1	199- 251	1551-1624		
# 4		24 31.4N	57 13.2E	RMT8M/1		Night	Flow Dist. 1.862 km.	
54002	26/ 2	24 31.4N	57 13.2E	RMT1M/2	100- 201	1624-1724		
# 5		24 33.1N	57 11.4E	RMT8M/2		Night	Flow Dist. 4.000 km.	
54002	26/ 2	24 33.1N	57 11.4E	RMT1M/3	0- 100	1724-1824		
# 6		24 35.0N	57 9.5E	RMT8M/3		Night	Flow Dist. 4.180 km.	
54002	26/ 2	24 30.9N	57 13.7E	RMT1M/1	448- 645	2100-2200		680
# 7		24 32.1N	57 12.2E	RMT8M/1		Night	Flow Dist. 2.740 km.	
54002	26/ 2	24 32.1N	57 12.2E	RMT1M/2	352- 450	2200-2300		
# 8		24 33.3N	57 10.3E	RMT8M/2		Night	Flow Dist. 3.550 km.	
54002	26/ 2	24 33.3N	57 10.3E	RMT1M/3	251- 354	2300-0000		
# 9	27/ 2	24 34.3N	57 8.4E	RMT8M/3		Night	Flow Dist. 3.730 km.	
54002	27/ 2	24 30.1N	57 14.5E	RMT1M/1	450- 654	0341-0440		
#10		24 31.2N	57 13.0E	RMT8M/1		Day	Flow Dist. 2.380 km.	
54002	27/ 2	24 31.2N	57 13.0E	RMT1M/2	349- 455	0440-0541		
#11		24 32.2N	57 11.5E	RMT8M/2		Day	Flow Dist. 2.829 km.	
54002	27/ 2	24 32.2N	57 11.5E	RMT1M/3	250- 347	0541-0640		
#12		24 33.5N	57 10.0E	RMT8M/3		Day	Flow Dist. 3.370 km.	
54002	27/ 2	24 29.6N	57 14.8E	LHPR	0- 398	0824-1135		
#13		24 38.9N	57 3.2E			Day		

STN.	DATE 1997	POSITION LAT.	LONG.	GEAR	DEPTH (M)	TIMES GMT	COMMENT	MEAN SOUND. (M)
54003	27/ 2	24 52.3N	56 44.2E	RMT1M/1	100- 150	1546-1648		237
# 1		24 50.0N	56 45.5E	RMT8M/1		Night	Flow Dist. 3.863 km.	
54003	27/ 2	24 50.0N	56 45.5E	RMT1M/2	51- 100	1648-1748		
# 2		24 48.2N	56 46.8E	RMT8M/2		Night	Flow Dist. 3.415 km.	
54003	27/ 2	24 48.2N	56 46.8E	RMT1M/3	0- 51	1748-1848		
# 3		24 46.2N	56 48.1E	RMT8M/3		Night	Flow Dist. 3.280 km.	
54004	27/ 2	24 46.5N	57 4.6E	RMT1M/1	201- 302	2134-2234		1072
# 1		24 46.5N	57 6.5E	RMT8M/1		Night	Flow Dist. 2.875 km.	
54004	27/ 2	24 46.5N	57 6.5E	RMT1M/2	103- 207	2234-2334		
# 2		24 46.2N	57 8.3E	RMT8M/2		Night	Flow Dist. 2.740 km.	
54004	27/ 2	24 46.2N	57 8.3E	RMT1M/3	0- 103	2334-0034		
# 3	28/ 2	24 45.9N	57 10.3E	RMT8M/3		Night	Flow Dist. 3.550 km.	
54005	8/ 3	25 14.8N	57 3.0E	RMT1M/1	197- 307	0520-0620		
# 1		25 15.0N	57 0.8E	RMT8M/1		Day	Flow Dist. 3.190 km.	
54005	8/ 3	25 15.0N	57 0.8E	RMT1M/2	98- 201	0620-0750		
# 2		25 15.4N	56 57.4E	RMT8M/2		Day	Flow Dist. 5.145 km.	
54005	8/ 3	25 15.4N	56 57.4E	RMT1M/3	42- 105	0750-0820		
# 3		25 15.5N	56 56.2E	RMT8M/3		Day	Flow Dist. 1.910 km.	
54006	8/ 3	25 17.9N	56 40.7E	LHPR	0- 101	1055-1305		
# 0		25 15.9N	56 52.0E			Day		
54007	11/ 3	26 23.5N	55 59.6E	LHPR	0- 68	0806-1002		77
# 0		26 17.1N	55 48.6E			Day		

STN.	DATE 1997	POSITION LAT.	LONG.	GEAR	DEPTH (M)	TIMES GMT	COMMENT	MEAN SOUND. (M)
54008	14/ 3	25 33.4N	54 7.3E	LHPR	0- 34	0706-0812		42
# 0		25 28.5N	54 9.1E			Day		
54009	15/ 3	25 33.6N	53 43.9E	RMT1	0- 50	1620-1650		54
# 1		25 34.3N	53 44.7E	RMT8		Night	Flow Dist. 1.872 km.	
54009	15/ 3	25 34.7N	53 44.6E	RMT1	0- 48	1742-1810		48
# 2		25 35.2N	53 45.4E	RMT8		Night	Flow Dist. 1.595 km.	
54010	16/ 3	25 32.9N	53 43.3E	RMT1	0- 53	0422-0505		53
# 1		25 31.7N	53 42.8E	RMT8		Day	Flow Dist. 2.447 km.	
54010	16/ 3	25 30.5N	53 42.0E	RMT1	0- 50	0635-0708		50
# 2		25 29.4N	53 41.6E	RMT8		Day	Flow Dist. 2.065 km.	