SOUTHAMPTON OCEANOGRAPHY CENTRE

CRUISE REPORT No. 26

RRS *DISCOVERY* CRUISE 232
04 APR - 21 APR 1998

Gibraltar exchange processes

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1999

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DOCUMENT DATA SHEET

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PUBLICATION DATE

1999

TITLE

RRS *Discovery* Cruise 232, 04 Apr-21 Apr 1998. Gibraltar exchange processes.

REFERENCE

Southampton Oceanography Centre Cruise Report, No. 26, 86pp.

ABSTRACT

The three principal objectives for RRS *Discovery* Cruise 232 were to carry out mooring operations associated with long-term monitoring of the exchange between the Atlantic and the Mediterranean through the Strait of Gibraltar, to study nonlinear processes resulting from the strong currents in the Strait with new instrumentation uniquely available on RRS *Discovery*, and to measure biogeochemical fluxes associated with the upper layer inflow of Atlantic water and the lower layer outflow of Mediterranean water through the Strait.

Eleven moorings deployed by scientists from Southampton Oceanography Centre (SOC), University of Malaga (UM), and Institut fur Meereskunde (IFM) in Kiel, who are cooperating in a two-year monitoring of the exchange through the Strait of Gibraltar using moored current meters under a multi-disciplinary CEC targeted programme called CANIGO, were scheduled for recovery during the cruise. Eight moorings were successfully recovered: two moorings were pre-released due to an error by an American collaborator and one mooring remains entangled with its anchor at the sill.

The principal nonlinear process studied was the development of a bore on the outgoing tide near the sill, its release as the tide turns, and its conversion into a nonlinear wave train as it propagates eastward into the Mediterranean. Dramatic signatures of 100m amplitude internal waves were measured by acoustic backscatter using EK500 underway profiling. Robust evidence for the waves was simultaneously derived from current profiles measured by the shipboard acoustic Doppler current profiler (ADCP), not only from the horizontal velocity but also from the directly measured vertical velocity, and from tow-yo CTD profiles up and down through the interfacial region between Atlantic and Mediterranean waters.

From hydrographic sections across the eastern and western entrances to the Strait of Gibraltar, we aimed to measure the biogeochemical fluxes through the Strait. Water samples analysed for oxygen, nutrients, chlorofluorocarbons, trace metals and dissolved organic carbon are to be combined with CTD and lowered ADCP velocity profiles to determine the fluxes directly. Such flux calculations represent a challenging sampling and analysis problem due to the tidal variations in the inflow and outflow currents as well as in the depth of the interface between the Mediterranean and Atlantic waters.

KEYWORDS

ACCP, ADCP, BIOACOUSTICS, BIOGEOCHEMICAL FLUXES, CANIGO, CFC, CRUISE 232 1998, CTD OBSERVATIONS, CURRENT METER MEASUREMENTS, *DISCOVERY*, EK500, GIBRALTAR STRAIT, HYDRAULICS, INFLOW, INTERNAL WAVES, MEDITERRANEAN OUTFLOW, MIXING, NONLINEAR PROCESSES, NORTH ATLANTIC, NUTRIENTS, ORGANIC CARBON, SILL CONTROL, STRAIT DYNAMICS, TRACE METALS, TURBULENCE, WATER EXCHANGE

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CONTENTS **Page**

LIST OF TABLES

LIST OF FIGURES

SCIENTIFIC PERSONNEL

Name:		**Role:**	**From:**
Southampton to Tenerife	*4 to 21 April*		
BRYDEN	Harry	Principal Scientist	JRD-SOC
TSIMPLIS	Michael	Watch Leader	JRD-SOC
KING	Brian	Watch Leader	JRD-SOC
BACON	Sheldon	Watch Leader	JRD-SOC
GRIFFITHS	Gwyn	ACCP	OTD-SOC
WADDINGTON	Ian	Moorings	GDD-SOC
CRISP	Nick	EK500	GDD-SOC
BENEY	Martin	Computing	RVS-SOC
LANE-SERFF	Gregory	Physics	SUDO-SOC
BENABDELJELIL	Abdelkader	Physics	EMI-Rabat
BOSCOLO	Roberta	Oxygen	JRD-SOC
MORLEY	Nick	Trace Metals	SUDO-SOC
DAFNER	Evgeny	Organic Carbon	CNRS-Marseille
HARRIS	Andrew	Tuba	OTD-SOC
DAVIDSON	Russell	CFC	GDD-SOC
SOLER	Iris	CFC	GDD-SOC
WHITE	Katherine	Tow-Yo	UEA-Norwich
SMITH	Kevin	Mechanical	RVS-SOC
TILLING	Jason	Instrumentation	RVS-SOC
TURNER	David	Mechanical	RVS-SOC
Southampton to Algeciras	*4-10 April*		
BRADLEY	Steve	ACCP	RDI-San Diego
MURDOCK	Gary	ACCP	RDI-San Diego
BABB	Richard	ACCP	OTD-SOC
Algeciras to Tenerife	*10-21 April*		
GOY	Keith	Moorings	GDD-SOC
WATTS	Simon	CTD	OSI-Petersfield
REDBOURN	Lisa	ADCP	JRD-SOC
HILMI	Karim	Official Observer	INRH-Casablanca
HART	Virginie	Nutrients	SUDO-SOC
BOORMAN	Ben	LHPR	GDD-SOC
OIKONOMOU	Emmanouil	Oxygen	SUDO-SOC

SHIP'S PERSONNEL

Name:	**Initials:**	**Rank/Rating:**
AVERY	K O	Master
GAULD	P D	Chief Officer
MACKAY	A V	Second Officer
PARROTTE	M G	Third Officer
SUGDEN	D M	ETO
McGILL	I G	Chief Engineer
JETHWA	K G	Second Engineer
CROSBIE	J R	Third Engineer
PARKER	P G	Electrician
DRAYTON	M J	CPO(D)
LEWIS	T G	PO(D)
ALLISON	P	S 1A
CRABB	G	S 1A
KESBY	S	S 1A
THOMSON	I N M	S 1A
MACLEAN	A	S 1A
PRINGLE	K	MM 1A
DANE	J P	SCM
HAUGHTON	J	Chef
BRYSON	K N	Messman
ORSBORN	J A	Steward
MINGAY	G M	Steward

ACKNOWLEDGMENTS

We thank the Spanish and Moroccan governments for permission to carry out these scientific studies in the Strait of Gibraltar. The exchange between the Mediterranean and Atlantic through the Strait of Gibraltar is a key issue both for the Mediterranean environment and for global ocean circulation and climate variability. On board *Discovery*, we appreciated the interest and help of Karim Hilmi in his role as official Moroccan observer in these studies.

We thank the officers and crew of RRS *Discovery* for their expert help in carrying out these complex scientific operations in the face of strong currents and heavy ship traffic. The watchful eyes of Alistair Mackay and Phil Gauld enhanced our opportunities to observe the large amplitude internal waves; and Pav Parrotte's maneuvering of *Discovery* among anchored ships in the Bay of Algeciras as we attempted to calibrate the EK500 with brass balls dangling 10 m below the surface was fascinating. K. Jethwa's help in repairing a column in the gas chromatograph used in CFC analysis was much appreciated. Captain Avery's calm efficiency ensured regular progress of the scientific programme.

Michael Tsimplis handled the pre-cruise logistics for the scientific party. Sheldon Bacon organised a disparate band of chemists into a sensible water sampling strategy during CTD stations. Gregory Lane-Serff's enthusiasm for the large amplitude internal waves was contagious. Ian Waddington and Keith Goy remained steadfast during all the difficulties of trying to make high quality time series measurements on moorings in the challenging Strait of Gibraltar environment. Virginie Hart stepped forward only two days before sailing to take charge of the nutrient measurements and enrolled Manolis Oikonomou to help with the oxygen programme. Water sampling was a truly international experience with Spanish, Moroccan, Greek, Italian, French, Russian, American, and British scientists taking turns around the Rosette. After a decade, it was especially enjoyable to work again in the Strait of Gibraltar with Abdu Benabdeljelil.

The ability of Brian King and Gwyn Griffiths to process and analyse underway profiling measurements is world class. The care with which they examined the new measurements (ADCP, ACCP, EK500, and tow-yo) and the thoughtfulness with which they improved our underway sampling and analysis techniques during four nights of "chasing the bore" substantially improved our measurements of the large amplitude internal waves and their propagation characteristics. Martin Beney worked very hard to set up the new Ultra Workstation within the shipboard computer network which proved so useful for almost real-time processing of the underway profiling measurements. Nick Crisp's expertise with EK500 hardware and software resulted in continuous backscatter images of nonlinear phenomena in the Strait which amazed us all.

The scientific objectives of this cruise are supported by the Natural Environment Research Council (NERC) and by the European Commission (EC). Shiptime was provided by NERC through a superstructure grant to the Southampton Oceanography Centre. Study of nonlinear exchange processes was carried out under the NERC Core Strategic Research Programme in Ocean Circulation within the James Rennell Division of the Southampton Oceanography Centre. Long term monitoring of the exchange and measurements of the biogeochemical fluxes were undertaken under the auspices of the CANIGO Project which is equally supported in the United Kingdom by the EC under contract MAS3-CT96-0060 and by NERC.

THE CRUISE

Background

The exchange through the Strait of Gibraltar has been a central problem in scientific research for centuries (Deacon, 1971). The two-layer exchange in which a surface layer of low salinity Atlantic water flows into the Mediterranean over a deeper layer of high salinity Mediterranean water which flows out over the sill and cascades down into the Atlantic has fascinated and stimulated generations of oceanographers. Marsigli's (1681) remarkable model study of the two-layer flow through a strait was only verified two centuries later during a precursor cruise to the Challenger Expedition (Carpenter and Jeffreys, 1870) after which the first estimates of the size of the exchange were made using the Knudsen relations (Buchanan, 1877). It was 30 years ago when the first actual measurements of the exchange were made from anchored ship during Projet Gibraltar, which must be considered to be the first large-scale European cooperative oceanographic experiment in the Strait (Lacombe and Richez, 1982). Ten years ago during the Gibraltar Experiment, the first time series measurements of the exchange made over a period of months reduced the traditional estimates of the exchange by 50% and showed the importance of time dependent processes in effecting the exchange (Bryden, Candela and Kinder, 1994). Also during the Gibraltar Experiment, early versions of underway acoustic backscatter and acoustic Doppler current profiling measurements provided provocative pictures of the complex exchange processes active in the Strait (Armi and Farmer, 1988).

Because the exchange through the Strait of Gibraltar represents the primary source and sink for the Mediterranean Sea, it is important to have a realistic model of the exchange as well as actual measurements of the exchange. Over the last decade, there has been much progress in developing and testing steady, two-layer hydraulic control models for the Gibraltar exchange (Bryden and Stommel, 1984; Armi, 1986; Farmer and Armi, 1986; Bryden and Kinder, 1991). The models appear to give quite realistic predictions for the measured exchange. However, there are two substantial problems. First, it is uncertain whether or not the exchange is constantly in a hydraulically critical state as assumed by the models for making maximal exchange predictions. Indeed, there are some indications that the exchange may vary on a seasonal time scale and hence not be hydraulically critical throughout the annual cycle (Garrett, Bormans and Thompson, 1990). To address this problem it is necessary to monitor the exchange over several annual cycles to determine the nature of any monthly to annual variability in the exchange. The second problem is that present nonlinear models for the exchange do not include time-dependent processes or mixing. The time series measurements have demonstrated the importance of tidal fluxes (not included in the steady models) which contribute about half of the water mass exchange across the sill and the hydrographic surveys have shown that there is substantial mixing which creates an interfacial water mass in the Strait (not present in the two-layer models) which may affect the exchange and its estimation (Bray, Ochoa and Kinder, 1995). To address questions of time dependence and mixing and how to include them in models of the exchange, it is necessary to use new techniques to make quantitative measurements of the exchange processes which can stimulate improvements in understanding these processes.

Measurements of the exchange through the Strait of Gibraltar are fundamental to understanding the overall climate and environment of the Mediterranean Sea since the Strait is the only marine connection between the Mediterranean basin and the global ocean. Measurements of the heat and salinity transports through the Strait determine the overall heat loss and freshwater loss over the entire Mediterranean basin (Bryden, Candela and Kinder, 1994; Macdonald, Candela and Bryden, 1994) and can be used to test or to constrain climatological estimates of the air-sea heat fluxes, and evaporation, precipitation and runoff (Garrett, Outerbridge and Thompson, 1993). Similarly, estimates of biogeochemical fluxes through the Strait can constrain the basin-scale biogeochemical budgets for the Mediterranean. For particular elements such as some trace metals, there may be a net flux through the Strait entering the Mediterranean as pollutants. Measuring the flux of such trace metals entering the Mediterranean can then provide a method for evaluation of potential future problems. Since there are not yet instruments that can routinely make *in situ* time series measurements of most biogeochemical elements, it remains necessary to estimate these fluxes using the traditional method of collecting and analysing discrete profiles of biogeochemical properties which when combined with velocity measurements provide estimates of the biogeochemical fluxes through the Strait. Such flux estimates at the single entrance to the Mediterranean are fundamental to biogeochemical models of the Mediterranean circulation.

Objectives

The three principal objectives for RRS *Discovery* Cruise 232 (D232) were to carry out mooring operations associated with long-term monitoring of the exchange, to study the nonlinear exchange processes with new instrumentation uniquely available on RRS *Discovery*, and to measure biogeochemical fluxes associated with the upper layer inflow of Atlantic water and the lower layer outflow of Mediterranean water.

Monitoring Operations

To determine whether or not the Gibraltar exchange is in a perpetual state of maximal exchange, scientists from Southampton Oceanography Centre (SOC), University of Malaga (UM), and Institut fuer Meereskunde (IFM) in Kiel are cooperating in a two-year monitoring of the exchange through the Strait of Gibraltar using moored current meters and acoustic transmissions under the multi-disciplinary CEC targeted programme called CANIGO (which stands for Canary Islands Azores Gibraltar Observation). This programme involves deploying and recovering instruments in the Strait at approximately six-monthly intervals. The SOC contribution primarily involves monitoring the exchange with bottom-mounted ADCP's and pressure gauges and with standard current meters mounted on 4 moorings across the sill section. The University of Malaga contribution is a similar monitoring of the exchange with 2 to 3 moorings across the eastern entrance to the Mediterranean north of Ceuta and also involves tide gauge measurements at several strategic points around the Strait. The IFM contribution combines an acoustic experiment attempting to estimate the horizontal flow through the Strait by measuring the phase shift in acoustic transmissions across the Strait with standard current meter moorings and inverted echo sounders across the eastern entrance to supplement the Malaga mooring work during October 1997 to April 1998. One objective of D232 was to recover 11 moorings deployed in October 1997.

Exchange Processes

The second objective of D232 was to study the exchange processes operating in the Strait of Gibraltar using the new advanced technology available on *Discovery*. The fascinating phenomena associated with two-layer hydraulics in the Strait of Gibraltar include hydraulic jumps, supercritical flow and solitary waves. Based on previous surveys notably by Armi and Farmer (1988), we have a good idea of when and where in relation to the lunar semi-diurnal tide these phenomena will occur. *Discovery*'s advanced technology includes precision three-dimensional GPS navigation which is regularly used in conjunction with acoustic profiling. The acoustic profiling includes reliable, underway ADCP measurements of the water velocity in the upper 300 to 400m of the water column, a developmental Acoustic Correlation Current Profiling (ACCP) system for underway measurement of the currents down to as much as 1200m depth, and underway bioacoustic profiling using the multi-frequency EK500 backscatter unit. Armi and Farmer (1988) made much progress 10 years ago with a primitive ADCP system providing shear profiles and with uncalibrated backscatter profiles providing qualitative pictures of the exchange processes which they interpreted to be hydraulic jumps, mixing by overturning, supercritical flow, etc. With the advanced systems now on board *Discovery*, we had an opportunity to make similar measurements of these nonlinear phenomena but to make them quantitative with absolute velocity profiles and with calibrated backscatter profiles throughout the entire Strait so that we can make quantitative estimates of important dynamical processes affecting the exchange through the Strait.

The principal phenomena we aimed to study was the development of a bore on the outgoing tide near the sill, its release as the tide turns, and its conversion into a nonlinear wave train as it propagates eastward into the Mediterranean. We were particularly interested in investigating the mixing associated with these nonlinear waves. Is the mixing primarily in regions of critical and supercritical flow? Or mainly in the crests or troughs of the waves? In the hydraulic jump from supercritical to subcritical flow? Or is there more uniform mixing due to shear instability throughout the Strait? Overall, we aimed to define the primary mixing mechanisms in the Strait and to identify how spatially and temporally concentrated the mixing is. To make these studies of exchange processes, we planned a series of transects along the Strait and selected time series stations at critical locations during the night-time hours of each day.

Biogeochemical Fluxes

The third objective of D232 was to make estimates of the biogeochemical fluxes through the Strait of Gibraltar. Unfortunately we cannot yet make moored time series measurements of most biogeochemical constituents so we must rely on synoptic estimates of the biogeochemical fluxes by combining CTD stations with water sample analyses for various trace metal components and on-station ADCP and backscatter profiles of the vertical structure of the currents and possibly biology. The trace metals included antimony, arsenic, copper, iron, lead, manganese, nickel, and zinc. These trace metals can also be sensitive indicators for the origins of various water masses in the Strait (Morley and Burton, 1993). Hydrographic sections each with about a dozen individual stations were taken across the eastern and western entrances of the Strait (Figure 2). Because of filtering and processing time constraints on trace metal determinations from the water samples, these stations were spread over the cruise. With such sampling, tidal aliasing of individual station profiles is inevitable and correction for such aliasing will be addressed by using mass, heat and salt conservation constraints together with tracer/salinity correlations to define the biogeochemical tracer concentration in each water mass. Then the average velocity for each water mass must be estimated in order to determine the biogeochemical fluxes. Determining the overall biogeochemical fluxes thus poses a challenging sampling and analysis problem due to the tidal variations in the inflow and outflow and in the interface between them.

Narrative

We departed Southampton a 1300(local=GMT+1), 4 April 1998, delayed by 4 hours to allow completion of securing all equipment.

Mobilisation on 2-3 April had been hindered by 2 power outages, each for approximately 3 hours: the first on Thursday due to the "breakers" failing when a new air conditioning unit was installed, the second on Friday when the breakers were repaired. Scientists and ship's personnel worked until 1930 on Friday evening to finish loading and begin securing of equipment for scheduled departure at 9am on Saturday. High winds on Saturday morning, however, meant that it was necessary to have everything secured before leaving the pier.

Weather was difficult for mobilisation and departure, with winds of 30 to 35 knots, a series of fronts including a hailstorm on 2 April. Westerly winds as we steamed down the Solent were strong but not troublesome until we turned the corner southeast of the Isle of Wight, at which time we began heading directly into 35 knot winds.

Trials of the ACCP commenced in the Channel in depths less than 50m almost immediately. Trials in depths of about 50 m were again carried out on 5 April. Choppy seas made evaluation of the problems difficult. Fire and boat drill occurred at 1030.

We then headed across the Bay of Biscay toward Cap Finisterre. Winds continued high, nearly 40 knots for much of Sunday, but calmed somewhat on Monday, below 25 knots by 1500.

Monday 6 April

France had not given permission for work in territorial waters so the first test station was planned for Spanish waters. Definition of the boundary between France and Spain is ambiguous so the Captain settled on a station position "well below the median line" which was already closer to Spain than France where we crossed it.

We deployed the CTD/LADCP package at about 2130(l) for a 4800m station. There was also a fluorometer, a mooring release being tested but also acting as a pinger, and an altimeter. CTD profile seemed fine, but the bottles did not fire: only 1 of 18 Niskins closed, while 4 of 6 spring-action bottles closed. The LADCP also seemed to behave badly with no upcast data, just like on last summer's cruise, RRS Discovery 230 (Bacon, 1998). Station finished at 0030. We were able to fire each of the open bottles successfully on deck.

Tuesday, 7 April

The day started badly. After examining the LADCP, with Gary Murdock's help, Brian King and Nick Crisp concluded that we needed to change the LADCP. Taking it out of the CTD frame, water was observed to spill from the unit. So it was carried into the Deck Lab and taken apart. Anything wet was washed twice in de-ionised water by Gary Murdock and ultimately dried with a heat gun.

We took another test CTD station to 300m depth where all bottles were fired. This time, 16 of our 18 Niskins closed but the same 2 spring action bottles did not close. The problems with closing individual bottles continued throughout the cruise. The CTD profile was quite dull but looked fine; the LADCP profile showed good agreement between up and down profiles.

Next we tried the tow-yo system about 1600. There were masses of help on deck for deployment: 3 RVS plus the Deck Crew plus Ian Waddington. First we deployed the EK500 (which actually remained in the water until about 2000 while Nick Crisp and Andy Harris sorted out electrical and recording problems) then the tow-yo CTD plus OPC went over. We put 250m wire out for the first cast and reached 251m depth, then we came up to 50m, down to 300m wire out which appeared to just leave enough wire on the drum for safety, up to 50 down to 250, up to 50 down to 250, and then a series of short downs and ups to fill up an hour's deployment. It seemed to go well except recovery was a bit jerky. We think we should ask the ship to slow before taking it out of the water so there will not be a "snap".

Wednesday, 8 April

It was a day for making plans. We started working out the rules for measuring the bores generated at the sill. Captain wants to stay to the south when heading eastward, to the north when heading westward, and out of the Traffic Exclusion Zone. This put some constraints on how we can sample and on our movement between sites. With Greg Lane-Serff and Kate White, we worked out positions and discussed strategy and timing throughout the day. Station positions were chosen and their locations are listed in Table 1

The Principal Scientist gave a 20-minute talk to the ship's company in the plot at 1300. And we had a meeting on water sampling at 1630 in the plot: lots of exotic ideas. The Principal Scientist would prefer straight sampling but Mikis Tsimplis is keen to work out a complex, time-effective sampling scheme.

Thursday, 9 April

Nick Crisp and Andy Harris finally got the EK500 in the water about 1400. The strumming was terrible as the hairy faring seemed ineffective. We tried speeds of 2,4,6,8,10 knots and the strumming got worse and worse at higher speeds so it was pulled back in at 1545. Then Nick and Andy decided it couldn't be redeployed if we were going to go more than 7 knots. Various ideas about stripping off the faring and putting on the aerofoil pieces from the previous cable or changing back to the other wire were being considered. In the end, the hairy faring was used throughout the cruise and speed during EK500 deployments was restricted to less than 7 knots through the water.

We arrived at L1 west of Spartel sill at 2150(l) and began a straight line steam toward and over the sill. ADCP currents were immediately bottom-intensified. We tried recording the EK500 but the intermediate scattering layer was intermittent.

Friday 10 April, YearDay 100

At 8am we were anchored in Algeciras Bay. By 0830 the six joining scientists including Karim Hilmi (Moroccan observer) were on board. The Chief Engineer left with the 3 departing ACCP folk for a doctor's appointment. While anchored, the block on the stern Aframe was repositioned so that the block and Aframe could be set and not moved during Tow-Yo operations; the winch then had to be moved slightly to be in line. Once the winch was set (the Chief had returned about 1045) at 1115, we set off for a CTD station over the IES mooring at the north end of the East line. While making the CTD cast, Ian Waddington and Keith Goy checked moorings I1 and IES75. IES75 was heard in sampling mode and I1 was on position and talking. On recovery of the CTD, the winch could not lift the package out of the water, so it was a bit of a panic to adjust the winch hydraulics. The package was recovered after a short delay though there was a surprise jerk on the wire when some slack was being taken off. On the way across toward Ceuta, Ian Waddington and Keith Goy also communicated with the two IFM moorings and then with I2 and heard IES77 in sampling mode. Then on the south side we had a Fire and Boat exercise at 1615 while a decision was being made if the winch was up to another CTD station. It was, so we did the CTD profile over IES77 as requested by Uwe Send at IFM in Kiel.

In the evening, Gwyn Griffiths liked the EK500 trace at L7N so the ship hovered there for an extra time as that was where the LHPR tows would be carried out later in the cruise. Moorings M1A, M1B, P1 and M2B were interrogated successfully late in the evening.

Saturday 11 April, Yearday 101

Just before midnight, a buoy had appeared while Ian Waddington and Keith Goy were communicating with M1. Fearful we had released a mooring, we circled for a look and a large orange buoy appeared to be anchored virtually on the spot of M1. Captain contacted Tarifa radio who confirmed buoy was a cable marking buoy and noted that there was a second one on the surface of the Strait as well. We were later confused whether Tarifa was talking about our moorings, M1 and M2 or about cable marking moorings. We never saw a second cable marking buoy.

With the delay, we did not Tow-Yo across the sill. Instead we made underway measurements across the sill from L3 to L4. Then we added the TowYo at L4. The CTD was incredibly noisy however. Once the bore went by we made underway EK500 and ADCP profiles from L4 to L5 and changed the CTD for the next TowYo at L5. We again made underway EK500 and ADCP profiles from L5 to L6E and added a TowYo at L6E, an extra easterly jump to try to catch up with the bore. The backscatter signal disappeared as we steamed off L5. Was it a temporal or spatial disappearance?

Following this sequence, we concluded that it was difficult to take adequate time series and also to keep up with the Bore at multiple locations. We needed about an hour time series at any location. Then we needed about a 10 mile run over a little less than one hour to overtake the Bore. At that speed, we could not keep the EK500 in the water, so it would be necessary to recover the EK500 during the jump ahead.

We then made a slow, 12-hour alongstrait profile from L10 in the Alboran Sea to the Sill with the ADCP and EK500. The only striking feature in the backscatter record was a duplicate (to that on 10 April) descent of the backscatter signal around 1900 near L6N. The backscatter signal disappeared then reappeared as the sill was approached about 2300.

Easter Sunday 12 April, YearDay 102

We were on station L4E just after midnight to get a background time series before the Bore arrived. At 0200 we deployed the ToYo for the remaining 2 hours of the time series. The backscatter signal was spectacular, the Bore followed by 5 waves: big, bigger, biggest, bigger, big. We even took photographs of the display.

Moving eastward for another time series, we found the backscatter signal had effectively disappeared and then the diurnal descent from the surface occurred, superimposed on which we could see a set of waves. There was no evidence of the initial Bore, however. Had we not gone far enough eastward and hence missed it? Or was there just no backscatter signal from which to see the Bore?

We then proceeded to take the northern 3 CTD stations on the eastern section before it was time to set off for the LHPR tow in late afternoon near Tarifa. During the LHPR tow, there was very little backscatter signal initially.

Following the LHPR tow, we proceeded to take a 12-hour time series with EK500, tow-yo, ADCP at L4E on the south side of the Strait south of Tarifa to examine the background for backscatter, density and current structure on which the Bore appears.

Monday, 13 April YearDay 103

The time series profiling was finished about 1000. We had to fit in a pickup of Keith Goy's missing suitcase in Algeciras Bay at 1130 so we did a set of alongstrait and cross-strait profiling with ADCP on the south side and north sides of the Strait before arriving at L5N where the second LHPR tow was planned. Because we were early (before the expected Bore arrival), we did a CTD station before the LHPR tow. Following the tow, we kept the EK500 in the water and profiled westward across the sill, then in the region west of the sill and then back across the sill to L4E where we waited for the Bore.

Tuesday, 14 April

The Bore arrived at L4E right on time and we were ready with tow-yo, EK500 and ADCP profiles. It was another spectacular EK500 trace and we had changed ADCP ensemble averaging to 1-minute (from 2-minute) averages for better resolution. Once the Bore passed, we jumped ahead to L6 on the south side of the narrowest section to make another time series as the Bore passed. The Principal Scientist thought we had caught it, though there were questions as to whether we had gone far enough because once again the backscatter had disappeared.

This was intended to be our final look at the Bore. So we set off to start the CTD stations as the chemists were desperate for water. We completed the eastern section E8 to E1 by midnight.

Wednesday, 15 April

With a little time before daylight when mooring recoveries would start, we steamed across the Strait to a point just southeast of Point Europa to profile across the "slick" seen in Shuttle photographs and noted by Armi and Farmer. We made a tow-yo with EK500 and ADCP profiles across a very thin layer of Atlantic water until it disappeared and then worked our way back south across the surfacing region. Then we headed for I1 to begin mooring recovery operations.

In quick succession, we recovered I1, U1, U2, I2 by 1600. We could not hear IES75 in sampling mode on the north side , nor IES77 on the south side just off Ceuta. As we judged the light might be our best option for recovery and we had an hour of daylight as well, we sent the beacon and release commands (several times) but did not hear any response. Nothing appeared on the surface; we heard nothing on the radio (unfortunately the radio channel is used by Tarifa Control so it is extremely busy); we searched eastward for about 5 hours without seeing any light; and there was never any acoustic signal from the instrument. About 2300 we broke off the search made an alongstrait profile westward on the way to the sill moorings. We stopped just before midnight to make a CTD station in the Narrows, then continued the alongstrait profiling

Thursday, 16 April

During the early morning hours, we made a few cross-sill ADCP profiles, but there were restrictions (we could not go into the Inshore Zones and we could not head eatward in the westward lane) so that we could not repeat the German-American sill section exactly.

At 0800, we were at the site of M2 whose release was fired quickly so that it was all onboard by 0900. Next mooring M1A, P1 and P2 were quickly recovered. Mooring 1B, whose bottom had been lying on the sill since November refused to come up. The release was fired, the release acknowledged that it had released, it was vertical, but it remained at its height (15m) above the bottom. We think that the phone cable is possibly laid over the mooring line lying on the bottom because there is cable buoy only a few hundred metres away from the site of M1A.

8 moorings recovered intact!

We then did a bit of underway profiling with EK500 and ADCP west of the sill around 1730 when the outflowing tide is strongest. Next we set off to take the CTD section across the western entrance to the Strait. We did northern stations W11 through W7, purposely splitting the section over 2 days so as to give the chemists enough sampling-filtering-analysis time.

Friday, 17 April

Just after midnight, we set off back to the eastern end of the Strait to have another go at recovering the IES moorings. We made another alongstrait ADCP section back to the mooring off Ceuta and then a cross-strait section along the eastern mooring line and then an alongstrait ADCP section back to the sill. Our interrogation of both IES moorings was unsuccessful, with no response from either instrument. Following such failure, the Principal Scientist emailed and faxed Randy Watts in Rhode Island and Uwe Send in Kiel on what to do. We took the opportunity being close to Algeciras Bay to go in and try to calibrate the EK500 using copper balls dangling beneath the transducer. The calibration appeared to have worked for the 2 aft quadrants for the 38kHz signal but better conditions (quieter, smaller currents) are needed to get samples in the forward quadrants and to do the same for the higher frequencies.

We checked M1A again and it was still there. Then we went to do the remaining CTD stations on the western section. We took stations W1 and W2 but then there were fishing boats at W3, W4 and W5 so we had to skip them. We proceeded to take W6 and W7 (a repeat) and, because the fishing boats were still in the way, we then went back to ADCP profiling north-south across the sill. Because of fishing activities in the region of the south sill, even this profiling was not successful.

We received return faxes from Watts and Send: the IES moorings had mistakenly been set to timed release after 180 days which occurred on Tuesday evening for IES75 and Wednesday morning for IES77. It was most unfortunate as we were in the area, just off Gibraltar probably when IES75 drifted by, and only 8 hours behind the release of IES77 when we arrived off Ceuta to recover it. Watts and Send naturally asked that we go chase the drifting moorings. But we were already at the western end of the Strait with only 15 hours to finish our work; and we expected the moorings to drift at 1 knot or more so they would be order 50 miles out into the Alboran Sea; finally, the Principal Scientist expects that fishermen would have already picked them up. We sent a Fax to Tarifa radio with information on the drifting buoys and offering "a small reward". That's the best we could do. When the email came in later, there were various instructions and advice on what we were doing wrong in communicating with the IES's. A bit galling, but the instructions were sent with the best intentions. In fact, we had done everything perfectly and it is always the anguish at not recovering moorings that leads to self-doubt and uncertainty. It was nice to learn the cause of the problems and that it was nothing we could have done anything about.

Saturday 18 April

The Principal Scientist decided we would have one more tow-yo in the descending outflow west of the sill in the early hours of Saturday when the outflowing tide was strongest (admittedly it was now Neaps). So we profiled for about 2.5 hours, though the Mediterranean water was really too deep for the Tow-yo which could only get to 250m or so.

We went back to complete the western CTD section with stations W5, W4 and W3, the final station being in the channel near Spartel sill with a nice layer of outflowing Mediterranean water.

After finishing with W3 at about 1330, we steamed along the outflowing channel as far as 7W in order to get an ADCP profile along the outflow path.

Sunday, 19 April

We steamed all day toward Tenerife, making good speed except for some engine trouble in the afternoon.

Monday, 20 April

We made an ADCP calibration run from 0920 to 1250, zigzagging between 180°T and 270°T at full speed. Then we put on the rebuilt ADCP, rebuilt Pylon, and Deep04 CTD for a deep station to 3000m in the late afternoon as a test of all instruments for the following cruise. The Pylon now refused to fire 7 bottles (rather than the 4 before it was rebuilt); the LADCP switched itself off on the way down and recovered on the way up, just like last year; the CTD seemed to work fine.

There was a nice Barbecue on the fantail, much improved by the fact that we were on station for most of it so the wind was down. Then the Principal Scientist hosted an RPC party in the bar from 1930 to 2300.

Tuesday, 21 April

We arrived outside Tenerife at 0700, picked up the Pilot at and were docked close to the centre of Santa Cruz by 0900.

Summary

A timetable of events in the Strait of Gibraltar is included as Table 2. Locations of all station and mooring positions are shown on Figure 1 as well as listed in Table 1. Thus Table 2 and Figure 1 allow easy reference to sampling strategy used during RRS *Discovery* Cruise 232.

Table 1. Location of Stations during RRS *Discovery* Cruise 232, April 1998,

	Latitude (°N)	Longitude (°W)	Depth (m)
Time Series Stations			
L1	35° 48.00	06° 12.67	
L3	35° 54.33	05° 47.25	
L4	35° 55.42	05° 42.50	
L4E	35° 55.50	05° 39.67	
L5	35° 55.67	05° 36.83	
L5N	35° 57.00	05° 36.17	
L5E	35° 56.50	05° 33.50	
L6	35° 57.25	05° 30.33	
L6N	35° 58.25	05° 30.67	
L6E	35° 57.50	05° 27.42	
L7	35° 59.33	05° 22.00	
L10N	36° 06.63	04° 57.20	
N3	35° 57.90	05° 32.09	
X1	36° 02.00	05° 22.45	
Way Points for Cross-Sill Profiling from Baschek			
S1	35° 52.50	05° 43.92	
S2	35° 56.40	05° 45.60	
S3	35° 59.70	05° 43.92	
modified by Bacon and the Bridge to meet Traffic Restrictions			
X2	35° 58.75	05° 45.00	
X3	35° 52.25	05° 45.00	
New X3	35° 54.50	05° 45.00	
CTD Stations			
Western Section			
W1	35° 48.20	5° 56.71	100
W2	35° 49.62	5° 57.48	200
W3	35° 51.25	5° 58.37	340
W4	35° 52.77	5° 59.17	420
W5	35° 54.18	5° 59.90	140
W6	35° 55.13	6° 00.47	200
W7	35° 56.30	6° 01.13	260
W8	35° 57.55	6° 01.76	200
W9	36° 00.00	5° 59.00	160
W10	36° 02.88	5° 55.74	120
W11	36° 05.11	5° 53.26	80
Tarifa Narrows Station			
N2	35° 59.20	5° 32.90	
EasternSection			
E1	35° 50.51	5° 16.50	90
E2	35° 51.58	5° 13.00	400
E3	35° 52.56	5° 09.67	470
E4	35° 53.88	5° 05.63	440
E5	35° 58.48	5° 07.86	500
E6	36° 01.45	5° 09.39	540
E7	36° 04.21	5° 10.80	800
E8	36° 05.93	5° 11.67	760
E9	36° 07.96	5° 13.83	650
E10	36° 10.00	5° 16.14	360
E11	36° 10.37	5° 18.73	90
Two additional CTD stations at 200m depth near the location of the IES moorings prior to the mooring recovery. These positions are:			
E12	36° 02.96	5° 24.48	258
E13	35° 55.93	5° 20.80	192

Table 1b. Locations moorings during RRS *Discovery* Cruise 232, April 1998.

Mooring Positions	Latitude (°N)	Longitude (°W)	Depth (m)
M1B	35° 56.68	05° 45.70	287
P1	35° 58.72	05° 44.23	194
P2	35° 53.28	05° 44.77	196
M2	35° 54.56	05° 44.43	277
M1A	35° 56.90	05° 45.92	280
I1	36° 03.02	05° 24.27	205
I2	35° 55.91	05° 21.03	205
U1	36° 01.02	05° 23.64	614
U2	35° 58.40	05° 22.44	844
IES75	36° 02.96	05° 24.48	258
IES77	35° 55.93	05° 20.80	192

Table 2: Timetable of Events in Strait of Gibraltar during RRS *Discovery* Cruise 232. All times are UTC and locations for positions are in Table 1.

Thursday 09 April High Tide Tarifa at 0021 and 1226

2050-2351	Underway Profile across Sill	L1 to L4,	EK500 and ADCP

Friday 10 April High Tide Tarifa at 0054 and 1309

2351-0130	On Station Time Series	L4	EK500 and ADCP
0130-0218	Underway Profile	L4 to L5	EK500 and ADCP
0218-0405	On Station Time Series	L5	EK500 and ADCP
0800-1130	Anchored in Algeciras Bay to disembark and embark scientists		
1222-1317	CTD Station 13374	E12	over IES75
1552-1642	CTD Station 375	E13	over IES77
1834-2045	On Station Time Series	L6N	EK500 and ADCP

Saturday 11 April High Tide Tarifa at 0125 and 1340

0006-0108	Underway Profile across Sill	L3 to L4	EK500 and ADCP
0108-0257	On Station Time Series	L4 ToYo376	EK500, ADCP and TowYo
0257-0343	Underway Profile	L4 to L5	EK500 and ADCP
0347-0509	On Station Time Series	L5 ToYo377	EK500, ADCP and TowYo
0509-0620	Underway Profile	L5 to L6E	EK500 and ADCP
0620-0840	On Station Time Series	L6E ToYo378	EK500, ADCP and TowYo
1055-2245	Alongstrait Profile	L10N to near L4	EK500 and ADCP

Sunday 12 April High Tide Tarifa at 0154 and 1411 Full Moon

0003-0409	On Station Time Series	L4E ToYo379	EK500, ADCP and TowYo
0455-0655	On Station Time Series	L6 ToYo380	EK500, ADCP and TowYo
0850-0930	CTD Station 381	E11	
0955-1100	CTD Station 382	E10	
1240-1406	CTD Station 383	E9	
1615-1900	LHPR Tow 384	L6N	EK500
2155-1015	On Station Time Series	L4E ToYo 385	EK500, ADCP and TowYo (12 Hours)

Monday, 13 April High Tide Tarifa at 0223 and 1443

1015-1128	Alongstrait Profiling	L4E to L7	ADCP only
1128-1200	Cross-Strait profiling	L7 to Algeciras Bay	ADCP only
1210	Goy's luggage delivered by boat in Algeciras Bay		
1212-1245	Cross-Strait profiling	Algeciras Bay to U1	ADCP only
1245-1350	Alongstrait Profiling	U1 to LHPR site at N3	ADCP only
1350-1453	CTD Station 386	N3	with EK500 deployed
1630-1800	LHPR Tow 387	N3 toward L5N finish at 35°56.88 05°39.92	with EK500
1800-2120	Alongstrait Profiling over Sill	35·56.9 05°39.9 to L5N	EK500 and ADCP
2120-2200	Underway Profiling Sill Region	35°57.0 5°50.85 to L3	EK500 and ADCP
2200-0220	Alongstrait Profiling over the Sill	L3 to L4E	EK500 and ADCP

Tuesday 14 April High Tide Tarifa 0254 and 1516

0230-0536	On Station Time Series	L4E ToYo 388	ADCP, EK500 and TowYo
0536-0626	Alongstrait Profiling	L4E to L6	ADCP and EK500
0626-0840	On Station Time Series	L6 ToYo 389	ADCP, EK500 and TowYo
1015-1124	CTD Station 390	E8	
1201-1316	CTD Station 391	E7	
1422-1508	CTD Station 392	E6	
1606-1645	CTD Station 393	E5	

1741-1820	CTD Station 394	E4	
1913-1950	CTD Station 395	E3	
2040-2118	CTD Station 396	E2	
2208-2228	CTD Station 397	E1	
2228-0250	Across Strait Profiling	E1 to the Rock ADCP only	

Wednesday 15 April High Tide Tarifa 0326 and 1551

0312-0603	Cross-Slick ToYo 398	east of Point Europa	ADCP, EK500 and ToYo
0730-0805	Mooring Recovery	I1	
0942-1112	Mooring Recovery	U1	
1203-1315	Mooring Recovery	U2	
1300-1305	Remembrance Service for Chris Elliott		
1410-1519	Mooring Recovery	I2	
1539-2100	Interrogation and Search for IES77 off Ceuta		
2100-2200	Cross-strait Profiling	IES77 to X1	ADCP only
2200-2339	Alongstrait Profiling	X1 to N2	ADCP only
2345-0036	CTD Station 398	N2	

Thursday 16 April High Tide Tarifa 0400 and 1629

0036-0200	Alongstrait Profiling	N2 to X2	ADCP only
0209-0632	Cross-Sill Profiling	X2 to X3 to X2 to X3	EK500 and ADCP
0640-0750	Mooring Recovery	M2	
0850-0950	Mooring Recovery	M1A	
1020-1100	Unsuccessful Attempt to Recover bottom of M1B		
1222-1233	Mooring Recovery	P1	
1332-1346	Mooring Recovery	P2	
1625-1720	Underway Profiling	west of the Sill	EK500 and ADCP
		35°55.81 05°47.14 to 35°55.9 5°49.8	
1845-1920	CTD Station 400	W11	
1958-2027	CTD Station 401	W10	
2105-2136	CTD Station 402	W9	
2230-2305	CTD Station 403	W8	

Friday 17 April High Tide Tarifa 0439 and 1712

0005-0036	CTD Station 404	W7	
0143-0322	Alongstrait Profiling	L3 to L7	ADCP only
0400-0624	Unsuccessful Interrogation of IES77, Unsuccessful Calibration of EK500		
0624-0730	Cross-strait Profiling	IES77 to IES75	ADCP only
0730-0825	Unsuccessful Interrogation of IES75		
0910-1131	Calibration of EK500 in Algeciras Bay		
1217-1424	Alongstrait Profiling	U1 to M1B	Straight LineCourse for ADCP Calibration
1600-1628	CTD Station 405	W1	
1653-1739	CTD Station 406	W2	
1800-1900	Fishing Boats at W3, W4, W5		
1910-1931	CTD Station 407	W6	
2015-2041	CTD Station 408	W7 Repeat	
2200-0253	Cross-Sill Profiling NewX3 to X2 to NewX3 to X2		ADCP only
	Bridge changed to New X3 due to fishing so this section does not cross the "sill"		

Saturday 18 April High Tide Tarifa 0525 and 1804

0330-0615	Underway Profiling west of the Sill ToYo 409 (35°53.69 05°49.09 to 35°54.67 05°44.49)		ToYo, EK500 and ADCP
0845-0930	CTD Station 410	W5	
0945-1030	CTD Station 411	W4	
1145-1230	CTD Station 412	W3	
1230-1700	Alongstrait Profiling	W3 to L1 to 7°W	ADCP only

MOORING OPERATIONS

Introduction

To monitor the exchange through the Strait of Gibraltar, the Southampton Oceanography Centre's mooring team had deployed five moorings across the sill section from January to April 1997, from May to October 1997, and from October 1997 to April 1998. The monitoring array consisted of bottom pressure gauges, P1 and P2, at 180 m depth on the northern and southern sides of the sill section, an upward-looking broadband acoustic Doppler current profiler (BBADCP) at the sill (M2), and two conventional current meter moorings (M1A and M1B) at the north sill. *Discovery* Cruise D232 represented the final recovery cruise for this monitoring array.

As part of the CANIGO Project, the period from October 1997 to April 1998 was designated an intensive period for measurements in the Strait. As part of this intensive period, the SOC mooring team deployed two additional moorings (I1 and I2) on the northern and southern sides of the eastern entrance to the Strait between Algeciras and Ceuta. Also, for this intensive period, the Kiel mooring team deployed two conventional current meter moorings (U1 and U2) and two inverted echo sounder moorings (IES75 and IES77) across this eastern section to supplement the monitoring array of three conventional current meter moorings maintained by the mooring team from the University of Malaga.

The objective for this element of D232 was to recover 11 moorings (Figure 1a): 5 at the Camarinal Sill section (P1, P2, M1A, M1B, and M2) and 6 at the Algeciras-Ceuta section (I1, I2, IES75, IES77, U1 and U2). All mooring had been deployed in October 1997 by the R/V *Poseidon*. Moorings U1 and U2 belong to the University of Kiel; the two IES's belong to the University of Rhode Island; and the remaining 7 moorings belong to SOC. The location of the moorings is given in Table 3. Table 4 summarises the recovered moorings, while Table 5 has information on the partially recovered and unrecovered moorings.

Relocation of the Moorings

On the 10th of April *Discovery* passed over the position of all the moorings and relocated them acoustically. While interrogating I1 and I2, the two nearby IES's (75 and 77 respectively) were heard to transmit.

Recovery of Moorings at the Algeciras - Ceuta Section

Recovery of the moorings started on the 15th of April from the north with mooring I1 on the Algeciras-Ceuta section. After the successful recovery of I1 an attempt to relocate and release IES75 failed. This was attributed at first instance to the high level of environmental noise and it was decided best to proceed with the recovery of the other moorings and return to IES75 at a later time. U1 was quickly relocated and released, but, because the ship was north of the mooring site at the time of release while the mooring drifted eastwards, it took approximately 45 minutes to relocate the drifting mooring on the sea surface. Subsequently, the ship was always positioned east of the moorings and at a distance of 200-400 m before a mooring was released. Moorings U2 and I2 were recovered next. Fishing lines entangling I1 and I2, both the wire and instruments, delayed operations as they had to be removed before recovery could be completed.

The IES77 mooring could not be found although it had been relocated 5 days earlier in the cruise. Hoping that it was still on position and that it could receive messages but could not respond, we repeatedly sent the release code as the ship was allowed to drift in a west-east direction over the mooring position. Subsequently an extensive search was undertaken which lasted 4 hours. The radio relocation frequency at which the IES transmits when on the surface coincides with that used by the traffic control of the Strait (Tarifa Control) and so it was of little use due to constant interruptions for radio traffic. Search during the night hours in hope of locating the IES's flashing light also failed.

At the end of the recovery of the Algeciras - Ceuta section, the mooring team was puzzled by the simultaneous failure to locate both IES's only 4 days after they had been clearly heard to transmit.

Recovery of Moorings at the Camarinal Sill Section.

Recovery of the moorings started on the 16th of April with the mooring at the south sill (M2) which was equipped with a BBADCP. Simultaneously there was an attempt to relocate an older mooring at the same position which had disappeared without trace. Moorings M2 and M1A were recovered successfully. Unfortunately two out of the three current meters on M1A were recovered without a rotor. An attempt was then made to recover the bottom part of mooring M1B. The upper part (upper buoy and two current meters) of this mooring had broken free and had been recovered at late November 1997, a month after its deployment. The remaining lower part consisted of a third current meter connected to another buoy by 120 m of cable. Below the buoy, there was the acoustic release connected to the anchor chain. The release was interrogated, switched on and off, and it indicated that it was still vertical. When released it seemed to move about a metre towards the bottom and then stay there about 22 m above the bottom. Subsequent attempts (on the same day and following days) to re-release it were all successful, that is the acoustic signal was transmitted, received and executed by the release but the mooring remained stuck in position. It is therefore believed that the release is entangled in the anchor chain, either by its own wire or by fishing lines. Dragging for the mooring was considered but was not allowed by the Bridge because of the close proximity to an underwater cable. Moorings P1 and P2 were then recovered without problems.

Attempts to Relocate the IES's, the old M2 and Release M1B

On the following days, repeated attempts to relocate the two IES's were made. Finally a fax from the University of Rhode Island solved the puzzle: the IES's had been set to automatically release after 180 days of deployment. This explains both their relocation at the beginning of the mooring operations (10th of April) and the failure to relocate and recover them (15th April), for they had released 8 to 16 hours before we had arrived to recover them. Therefore both of the IESs must be adrift.

It was also hoped that M1B would become disentangled by the tidal currents and come to the surface. During our subsequent visits to M1B on the 17th and 18th of April, however, the release could be relocated and monitored. Repeated attempts to communicate with the old (lost) M2 mooring were also unsuccessful.

Problems

Notably, the spherical buoyancy elements of M2 and M1A floated with the Argos beacon beneath the water surface. Apparently, the torque of the Argos beacon is enough to roll the buoy over and submerge the antenna making Argos communications sporadic at best. This may explain the failure of Argos transmissions to locate the old M2 when it surfaced. A counterweight on the mooring chain might rectify such submergence of the antenna.

The cautious approach of *Discovery* to the floating moorings was also of note. It seems that *Discovery* is excessively large for this type of operation as experience with smaller vessels (*Malaspina, Tofino, Poseidon*) indicates that the approach to the floating buoys can be done more quickly on a smaller vessel.

Data Recovery

The data from the moored instruments were downloaded on board *Discovery*. A major disappointment was the failure of the BBADCP on mooring M2 to record more than 17 hours of data: it switched itself off after 17 hours in the water and switched itself back on during the recovery operations. The cause for the switching off is unknown. The failure of the rotors of the current meters on two of the instruments of M1A after a few hours and after a few weeks in the other instrument essentially reduces the current meter data at the Camarinal sill to those recorded by the bottom current meter at mooring M1A. The pressure gauges at the north and south sides of the sill yielded nearly complete data records.

Conclusions

Instrument recovery was very successful. All moorings were relocated and only M1B could not be recovered. The errors in the setting of the two IES's were frustrating but were not within our purview. The failure to relocate the IES's after they had gone adrift was beyond our capability as the cruise period was effectively over before we understood what had happened.

Data recovery was disappointing. Even before quality control of the data, the failure of the current meters on M1A and the BBADCP on M2 essentially nullifies the attempt to directly measure the exchange at the sill section during this deployment period from October 1997 to April 1998. Hopefully the data from the pressure gauges will be sufficient to overcome the problem.

I. Waddington, M. N. Tsimplis, and K. Goy

Table 3. Mooring Information

Mooring	Latitude	Longitude	Depth	Deployment	Recovery	
	N	W	(m)	Date	Date	
Western Section						
M1B	35°56.68	5°45.70	287	14/10/1997	Bottom Part not Recovered	
P1	35°58.72	5°44.23	194	16/10/1997	16/4/1998	
P2	35°53.28	5°44.76	196	16/10/1997	16/4/1998	
M2	35°54.56	5°44.43	277	16/10/1997	16/4/1998	
M1A	35°56.90	5°45.92	280	16/10/1997	16/4/1998	
Eastern Section						
I1	36°03.02	5°24.27	205	17/10/1997	15/4/1998	
I2	35°55.91	5°21.03	205	17/10/1997	15/4/1998	
U1	35°01.02	5°23.64	614	17/10/1997	15/4/1998	
U2	35°58.40	5°22.44	844	17/10/1997	15/4/1998	
IES75	36°02.96	5°24.48	258	17/10/1997	Not Found	
IES77	35°55.93	5°20.80	192	17/10/1997	Not Found	

Table 4. Instrumentation on Recovered Moorings

Mooring	Instrument (Serial No)	Recovered	Condition	Data recovered
P1	RCM-7 (10277)	Yes	Clean and Good	deployment period
	WLR-8 (1684)	Yes		145 days
P2	RCM-7 (9967)	Yes	Clean and Good	deployment period
	WLR-8 (1682)	Yes	Clean and Good	145 days
M2	BBADCP	Yes	Good and Clean	17 h
M1A	RCM-7 (10275)	Yes	Clean - No Rotor	4 records then currents stop. Restart 1/1/98 and then intermittent and stop again.
	RCM-7 (10278)	Yes	Clean - No Rotor	Currents for 15 days.Other sensors full deployment period
	RCM-7 (10280)	Yes	Clean	deployment period
I1	RCM-7 (11677)	Yes	Fouling and fishing lines	Full deployment.
	RCM-7 (10856)	Yes	Severe fouling and Rotor Broken.	Currents to 11/2/98. Then intermittent failing 18/2/1998. Other sensors full deployment period
	RCM-7 (12293)	Yes	Severe fouling and Rotor Broken.	Full deployment period, rotor probably broken on recovery.
I2	RCM-7 (11678)	Yes	Fishing line. Fouling. No Rotor.	Currents until 12/11/97.Other sensors full deployment period.
	RCM-7 (12302)	Yes	Fishing line around rotor. Fouling.	Currents until 17/11/97.Other sensors full deployment period.
	RCM-7 (12297)	Yes	Fouling.	Deployment period-intermittent current data, stalled and failed 23/1/1998.
U1	RCM-5 (6122)	Yes	Clean and Good	Deployment Period
	RCM-5 (8727)	Yes	Clean and Good	Deployment Period
	RCM-5 (7658)	Yes	Clean and Good	Deployment Period
U2	RCM-5 (6121)	Yes	Clean and Good	Deployment Period
	RCM-5 (8728)	Yes	Clean and Good	Deployment Period
	ACM (1375A)	Yes	Clean and Good	Not Checked.

Table 5. Instrumentation on Partially Recovered and Unrecovered Moorings

Mooring	Instrument (Serial No)	Recovered	Condition	Data recovered
M1B	RCM-7 (10273)	Yes	Recovered after the top part broke free.	30 days
	RCM-7 (9968)	Yes	Recovered after the top part broke free.	30 days
	RCM-7 (10278)	No		None. Released but did not surface. Assumed to be held down by fishing lines or by its own wire.
IES75	AIES-75	No	Adrift	Released automatically after 180 days
IES77	AIES-77	No	Adrift	Released automatically after 180 days

CHASING THE BORE

Introduction

The exchange flow between the Mediterranean and the Atlantic through the Strait of Gibraltar is strongly modulated by the tide. This is especially true at springs when the inflow of Atlantic water at the surface can be arrested or even reversed. When the net flow is out of the Mediterranean, the dense Mediterranean water occupies a thick layer as it flows out over the Camarinal sill. As the flow reverses (at about the time of high water at Tarifa) the shallow surface layer of Atlantic water deepens dramatically and begins to flow into the Mediterranean. This depth change propagates to the east as a moving hydraulic jump or bore.

Observational Strategy

The main technique used for observing the bore was to occupy fixed stations (shown in Figure 1b), observing the bore as it passed, and then to move faster than the bore to the east to occupy another station. In this way we tried to observe the bore at two or three locations (and in addition passed over the bore in between stations) in the early morning hours of three days. This stop-and-chase technique was only possible in the southern part of the Strait because of the traffic regulations. In addition we occupied a fixed station for a 12 hour period on 12-13 April, and also observed the bore while we were stationary or steaming westward in the northern part of the Strait on four or five additional occasions. The encounters are summarised in the table below.

Encounters

YearDay, Date	HW Tarifa (UTC)	Stations bore encountered
100, 10/4/98	0054	L4, L5
	1309	L6N
101, 11/4/98	0125	L4, L5, L6E
	1340	
102 12/4/98	0154	L4E, L5E
	1411	L6N
103 13/4/98	0223	L4E (12 hour station)
	1443	L5N
104 14/4/98	0254	L4E, L6

Instrumentation

The principal instruments for measuring the bore were the vessel-mounted (or underway) ADCP for current profiles and the EK500 for backscatter profiles, which could be used when underway or stationary, and a tow-yo package which was used while steaming slowing into the strong currents so the measuremetns were nearly stationary. The tow-yo had a CTD and either an optical plankton counter (OPC) or a towed undulating bio-Acoustic Sonar (TUBA). The CTD's used were Shallow 1 and Shallow 2. Both had problems: Shallow 1 had a conductivity sensor damaged and a board dislodged on a test deployment, and Shallow 2 had a leak leading to dodgy pressure measurements. The tow-yo, deployed aft using a small winch with approximately 300m of wire, measured the variations in depth of the 37 to 38 isohalines which define the interfacial region between inflowing Atlantic water and outflowing Mediterranean water.

Summary

We observed strong undular bores with vertical excursions in the interface between the Atlantic and Mediterranean water in excess of 100m over three minutes or less. The sampling strategy should allow us to build up an understanding of the speed and development of the Bore as it moves through the Strait. An especially valuable feature of the experiments is the range of simultaneous measurements undertaken.

Recommendations

A longer wire for the tow-yo system would have allowed us to sample the Mediterranean water better at a number of stations.

Recorded radar images would have enhanced our understanding of the three-dimensional structure of the Bore and associated waves. Even a video image of the Bridge radar screen would have proved useful

G. Lane-Serff, B. King, N. Crisp, L. Redbourn and S. Watts

SIMRAD EK500 Echosounder

EK500 Installation

The SIMRAD EK500 scientific echosounder is a self-contained, portable system comprising a winch with fixings for a 1m matrix of deck boltdown points and a tow-fish on 50 m of cable, housing the 3 transducers operating at frequencies of 38, 120 and 200 kHz. 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 winch system was installed on the port side of the ship, beside the cover to the after hold, with the transducer cables from the winch drum passing through a goose-neck in the Boson's locker, and then to the system electronics which were installed (with the printer) on a bench in the Hangar. Previously on *Discovery* we had installed the system electronics, monitor and printer in the deck lab. But this required the use of 20 m extension cabling to reach the winch, which introduced extra noise to the system. For ease of use, and comparison with other instruments (ADCP, EA500) during this cruise, the EK500 Monitor was installed in the Main Lab. The cables for the monitor (video and remote-control signals) were initially routed via junction boxes to the electronics in the hangar, although these were later replaced by dedicated shielded cables after the routing via junction boxes was found to be responsible for noise contamination.

After the initial trial of the system on the passage leg south from Southampton to the Strait of Gibraltar, the winch cable was removed and replaced with a new design which incorporates both a stainless steel sheath just below the polyurethane outer sheath for extra protection of the cable against long-lines and also a haired fairing which replaces the 1.5m lengths of solid rubber fairing which were used previously on the old cable. The haired fairing greatly simplifies, and speeds up the deployment and recovery procedures as it is no longer necessary to ensure correct orientation of the fairing as it passes through the sheave, or as it goes onto the winch drum.

The tow-fish was first deployed on the new cable just before 13:00 on 9 April off the Iberian coast, and the ship's speed was increased at 15 minute intervals by 2 knots until 10 knots speed was reached. The initial behaviour of the cable even at low speeds was of some concern as there was significant strumming, causing vibration in components of the winch, and the drag of the cable was much higher than that of the rubber-faired cable. With the fish deployed on 25m of cable (from the sheave), and therefore at a depth of about 18 m when vertical, it was at a depth below the sea surface of only a few metres, and as far aft as the 'A' frame with a wire-angle of over 60 degrees when steaming at 8 knots. The behaviour of the cable improved significantly during the first 24 hours of use, however, as the 'hairiness' of the fairing increased (reducing the drag) as the strings making up the fairing unravelled, and finally a speed of 8 knots was set as the maximum speed for use of the tow-fish. The fish was inspected for mechanical integrity at regular intervals and required no maintenance during the cruise.

Interference from Ship's 38 kHz Echosounder

On the evening of 10 April when the EK500 was deployed at the start of station 13374, a steady source of interference with the 38 kHz channel was eventually traced to a 38 kHz echosounder recently installed on the Bridge. From approximately 0800 on 11 April, the Bridge echosounder was turned off during EK500 deployments for the remainder of the cruise, except for a short (< 1 hr) deployment west of the Camarinal sill on the 16 April.

Calibration

The calibration procedure for the EK500 was carried out in the Bay of Gibraltar on the morning of 17 April. The three SIMRAD standard calibration spheres were hung from the fish, at distances of approximately 9, 12, and 15 m. The 200 kHz sphere closest to the fish, and the 38 kHz sphere furthest away (15 m is the manufacturers minimum recommended distance for the calibration procedure). For the split beam transducers, calibration is 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.

Due to the relatively strong current shear and high volume of shipping in the bay, it was not possible to keep the ship on station for long periods of time. Acoustic visibility of the calibration spheres was consequently intermittent allowing only the 38 kHz channel to be calibrated. The calibration data will be tidied up and analysed in the laboratory enabling a comparison with other recent calibrations. According to SIMRAD, drift in the instrument is minimal and once a good calibration has been made, only checks at yearly intervals are necessary. A quick look at the 38 kHz data, however, does show an offset of < +1 dB compared with +3.91 dB from the calibration during *Charles Darwin* Cruise CD104a.

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) + 2aR, where R is range and a, frequency dependant absorption coefficient) and estimated values of the noise floors at each frequency. Further processing at the laboratory will include the analysis and application of calibration data and corrections for in-situ sound absorption (using data from the tow-yo, and CTD stations) for which default values have been assumed during the cruise.

Operations

The EK500 was generally used to monitor the arrival of the bore and nonlinear waves generated near the sill regularly just after high tide. Simultaneously with the EK500, we were using the underway ADCP measurements to profile the variations in currents associated with the waves and we were towing a CTD up and down to monitor the variations in the depth of the interface between Atlantic and Mediterranean waters in the Strait associated with the waves. The EK500 images of backscatter, particularly at 38 kHz, provided the best real-time images of the arrival of the waves (Figure 2). A principal scientific objective for the cruise was to determine whether the backscatter signal is caused by turbulence or by biology. After the initial passage of the waves, the backscatter signal was found to evanesce, sometimes to rise toward the surface and sometimes to just disappear, so that the later wave crests and troughs were not reliably seen in the EK500 backscatter measurements.

Recommendations

With each installation of the EK500, even when on the same vessel, some work has to be done to minimise the noise in the system. In order to alleviate this problem, we should consider semi-permanent installations for ships on which the system is frequently installed. Such installations would 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 incidence of interference between the Bridge echosounder and the EK500 each operating at 38 kHz highlights the need for future pre-cruise planning meetings to identify any such conflicts in the use of scientific and ship's equipment. During this cruise we gratefully acknowledge the officers on the bridge for their co-operation in turning off the Bridge echosounder during EK500 deployments.

N. Crisp

NAVIGATION

This report describes the processing and quality of navigation data during cruise D232. Accurate navigation is particularly important for measurements of ocean currents using both Vessel-Mounted and Lowered ADCP's.

Differential GPS400

Differential GPS4000 navigation data (ship position, heading, speed over ground, satellite fix parameters) were acquired every second throughout the cruise, giving the ship's position to within about 5 m, based on positions gathered while *Discovery* has been tied up at the pier. Daily processing included three steps:

a. Acquisition of GPS4000 data from RVS files using the gpsexec0 program;

b. Quality control of data, in which data are deleted wherever poor positioning accuracy is indicated by satellite fix parameters;

c. Averaging ship velocity data into 2-minute (or 1-minute after 12 April) bins in preparation for subsequent merging with ADCP data.

In terms of data quality, the percentage of 'good' data acquired during a 24 hour period ranged from a minimum of 97.5% on JD 108 (18 April) to a maximum of 99.8% on JD 103 (13 April).

Ship's Gyrocompass

Two S.G. Brown gyrocompass units are installed on the bridge. Ship heading was logged every second via a level A microprocessor. Daily processing effectively consisted of acquisition of gyro heading data from RVS files using the gyroexec0 program. In terms of data quality, the percentage of 'good' data acquired during a 24 hour period ranged from a minimum of 99.1% on JD 96 to a maximum of over 99.9% on JD 99.

Ashtech 3DF GPS Attitude Determination

The Ashtech ADU2 (Attitude Detection Unit 2) GPS is a system comprising four satellite receiving antennae mounted on the boat deck with a receiver unit on the Bridge. The ADU2 is superior to the earlier GPS 3DF receiver as 12 satellites are tracked on each of the four antennae providing much improved data return. Every second, the Ashtech measures ship attitude (heading, pitch, roll) and these data are used in post-processing to correct ADCP current measurements for "heading error". This post-processing is necessary because in real-time the ADCP uses the less accurate but more continuous ship's gyro headings to resolve east and north components of current. In post-processing, small drifts and biases in the gyro headings are corrected using the Ashtech heading measurements. With each attitude acquired are measures of the maximum measurement error, rms error, and the maximum baseline rms error, which then allow poorly determined attitudes to be flagged during processing.

Daily processing consisted of five steps:

a. Acquisition of Ashtech data from RVS files using the ashexec0 program;
b. Quality control of Ashtech data using ashexec1;
c. Averaging into 2-minute (or 1-minute) bins to be compatible with ADCP data;
d. Determining the 'a-ghdg' parameter (the correction applied to gyro headings) using ashexec2;
e. Plotting daily time series of 'a-ghdg' and manually editing out any remaining outliers using 'plxyed' (PSTAR program) and ashexec3.

In terms of data quality, the percentage of 'good' data acquired during a 24 hour period ranged from a minimum of 87.7% on JD 107 to a maximum of 98.3% on JD 103. Manual editing was required on JD's 103, 104, 105, 107 and 108 with a maximum of 9 one-minute averaged data points being removed on JD 107. The largest gap in a-ghdg data was also on JD 107 and lasted approximately 2 hours.

L. Redbourn

VESSEL-MOUNTED ACOUSTIC DOPPLER CURRENT PROFILER

Initial Setup

The vessel-mounted acoustic Doppler current profiler (VM-ADCP) was troublesome right from the start of the cruise. The transducer had been returned to RDI for repair/refurbishment, and there had been trouble with its reinstallation, apparently to do with the mounting stalk. However, the transducer was eventually installed shortly before sailing. Difficulties were then experienced with commissioning the transducer. A variety of attempts were made to identify the problem, including at one stage installing the deck unit from Charles Darwin which happened to be docked at SOC at the time. The fault-finding work was hampered by several hours of unavailability of the lab power supply, related to problems in the engine room. Eventually the system was restored to apparent operation with level-C data logging, although some of the self-diagnostics were not passed, in particular one diagnostic indicated "low current error". In the absence of further information, this were attributed to the fact that the ship was alongside in shallow water.

The work plan in the Strait called for real-time monitoring of VM-ADCP, preferably in contoured vertical sections. We had therefore intended to use the RDI Transect software, whose real-time displays are more user-friendly than the earlier Data Acquisition System (DAS) software. However, the difficulty with commissioning the ADCP system left no time to experiment with Transect, especially data logging aspects, before leaving port. We therefore decided to revert to DAS as the primary ADCP operation software.

First Problems

Shortly after departing Southampton, bottom-track (BT) data were logged for transducer alignment calibrations. These data produced consistently incomprehensible results. Further investigation eventually led to the conclusion that Beam 3, the forward-looking beam, was faulty. Examination of the automatic gain control (AGC), beam by beam, showed that signal return strength on that beam was more or less independent of depth, rather than decaying to background noise with depth as usual. It was concluded that the beam was 'dumb' but not 'deaf'. Since DAS had been operated in a mode where 3-beam WT solutions were not allowed (they are normally expected to be inferior to 4-beam solutions) all the VM-ADCP data prior to this time were almost certainly rubbish. There being no possibility of repair, DAS was switched into a mode in which three-beam water-track (WT) solutions were permitted. This produced reasonable

WT data, and checks were kept to ensure that DAS was in fact returning solutions based on the three good beams.

It was believed that there is no mechanism in DAS for calculating 3-beam BT solutions, so all BT data for the cruise are presumed to be bad.

There was now a question of whether or not to address Transect data logging, and to swap to Transect for the remainder of the cruise. In the absence of firm information about how Transect handled 3-beam solutions, the decision was taken to stick with DAS. (Later information was that Transect automatically computes a 3-beam solution if the diagnostics indicate one beam is bad, outside of user control.) Further experiments were conducted with Transect only after leaving the critical work area of the Strait.

Transducer Alignment

The question of transducer alignment could not therefore be addressed for BT data. On the run to Tenerife, a series of zig-zag manoeuvres, 20 minutes on each leg, was completed for this purpose. After processing the measurements from these zig-zag manoeuvres, it was concluded that the nominal alignment used during the cruise should be adjusted by 2.6°, so that the nominal forward direction was in fact 2.6° to starboard. The zig-zag calibration also indicated the speed measured by the VM-ADCP should be multiplied by 0.991 to obtain the true speed. For the final VM-ADCP data set these corrections have been applied.

DAS Configuration

A general configuration of 100 times 4 metre bins was used. An initial averaging interval of 120 seconds was used, which has been the default time on previous cruises. However, after the initial attempts at observing the tidal bore in the Strait, this was seen to be too long to resolve the phenomenon adequately so the time averaging was reduced to 60 seconds at 0908 on 12 April.

'Real-time' Analysis

An attempt was made to simulate some of the features of Transect within pexec processing. While computationally rather inefficient, the availability of fast processing with the new Ultra workstation made it just about feasible. A series of unix scripts was written which, with a single command, undertook the following steps:

Check the time of latest ADCP data that has already been read into pstar

Check whether any more ADCP data are available in level-C

If more data available, read it into pstar, ensuring no gaps or overlaps.

Adjust reference level to chosen bin (~100 metres depth).

Rotate velocity to be 'along Strait'

Produce time-depth contour plot of along-Strait velocity component.

Most of this was straightforward, except for two 'tricks' required.

Most of the processing was run on the new Ultra (discovery7, running Solaris). But all functions requiring RVS software (not yet built for Solaris) or access to RVS level-C data files (not cross-mounted on discovery7) needed to be run as remote shells on discovery5 (running sunos4). Thus 'lookc' to get state of RVS file and 'listit' to extract new data could not be run on discovery7.

Inevitably, the level-C adcp file is rather large. For some reason, 'datapup' took unacceptably long to read in a small amount of data from the end of the file. Clearly datapup needs, in some sense, to scan the entire file. Thus it might take 10 minutes to read in one minute's worth of data. However, the 'listit' program works almost instantaneously. Obviously it has a different mechanism for scanning time stamps. Therefore data were extracted from RVS format to ascii using 'listit' and then read into pstar using 'pascin'.

The resulting series of scripts was unpolished, but acceptably quick. Data accrued in the RVS file once per minute. They could be displayed in contoured sections on discovery7 within 15 to 20 seconds of acquisition. This quick-and-dirty (and essentially disposable) processing was quite independent of routine 24-hour ADCP processing, which provided the master dataset for the cruise.

In conclusion, the effort put into commissioning discovery7 before leaving Southampton paid handsome dividends, both in processor speed and extra available disk space.

Routine Processing

Routine processing was completed once per 24 hours, following established routes documented in previous reports (e. g., Leach and Pollard, 1998). Data were read in, clock corrections applied, Ashtech heading corrections applied, and absolute velocities computed from the real-time differential Global Positioning System (DGPS) navigation.

Experiments with Transect

Once *Discovery* had left the work area of the Strait, attention returned to the use Transect. In particular, data logging was addressed. Two possibilities seem to exist:

1) Average (e.g.-120 second) data are logged to Transect PC hard drive. Files subsequently could be moved to a different PC, where they are replayed to ascii and read into other formats. Presumably the specification for the binary format is available and could be read directly. Transfer of files off the PC requires interruption to data logging. There is no obvious way of sending these out of a serial port in real time.

2) 'Raw ensembles' are output in real time from Transect, and can be sent on serial output. For test purposes these were captured using kermit on the nearby PC normally reserved for GPS-ADU2 (Attitude Detection Unit 2) communications. A 'raw' ensemble here consists of about 4 pings worth of data, so data volumes are large. The ascii format is different to the format for ascii replay of average data.

One drawback is that the content of both types of ascii file can be varied by the user, which makes automatic logging more difficult. Furthermore, data output may consist of absolute velocities referenced to navigation (if available) rather than velocities relative to ship, so user corrections (e.g. heading correction) are more difficult to apply. Scope for mistakes by inexperienced users is therefore greater than with DAS.

Table 6 shows the times when Transect was in use. All other periods weree covered using DAS acquisition except for short periods of 'no data' when work on the PC was taking place.

Observations of the Bore

While the EK500 presented real-time images of the Bore and associated large-amplitude waves, the VM-ADCP provided quantitative estimates of the velocity signatures of these nonlinear phenomena (Figure 3) with only a short delay. A revelation came from the contour plots of vertical velocity (Figure 4) from the VM-ADCP which exhibited downward and upward velocities up to 50 cm s^{-1} corresponding to the descents and ascents of the layer of maximum backscatter and of the interfacial layer simultaneously measured by the tow-yo system. As the cruise progressed, we relied more and more on the VM-ADCP measurements of the Bore and waves because the horizontal and vertical velocity signatures of the waves were apparent even when the backscatter signal had disappear after their initial passage. Finally, we tried to use the VM-ADCP measurements to define the depth of the interface between Atlantic and Mediterranean waters by contouring the vertical shear in alongstrait current and determining the depth of maximum shear.

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Table 6. Periods during which Transect was used to acquire Vessel-Mounted ADCP data. All other periods were effectively covered by DAS procedures. **Transect Filename** indicates that the ADCP data were acquired on the dedicated PC used for the VM-ADCP. **Log Files** indicate attempts to transmit the Transect data over a serial connection to be recorded on another PC in real time so that the data could be examined without stopping VM-ADCP acquisition.

TRANSECT FILENAME	**START DATE & TIME**	**STOP DATE & TIME**
D232000T.000	15/04/98 15:40:38	
D232000T.001		
D232000T.002		
D232000T.003		
D232000T.004		
D232000T.005		16/04/98 00:08:40
D232001T.000	17/04/98 12:55:52	
D232001T.001		17/04/98 14:49:56
D232002T.000	17/04/98 14:51:46	
D232002T.001		
D232002T.002		
D232002T.003		
D232002T.004		17/04/98 21:27:48
D232003T.000	17/04/98 21:52:44	
D232003T.001		
D232003T.002		
D232003T.003		
D232003T.004		
D232003T.005		
D232003T.006		
D232003T.007		
D232003T.008		
D232003T.009		
D232003T.010		
D232003T.011		
D232003T.012		
D232003T.013		18/04/98 20:30:48
LOG FILES	**START DATE & TIME**	**STOP DATE & TIME**
d232_1.log	15/04/98 20:06:37	15/04/98 20:57:48
d232_2.log	16/04/98 00:10:37	16/04/98 00:27:28
d232_3.log	empty	
d232_4.log	16/04/98 09:26:45	16/04/98 09:33:11
d232_5.log	16/04/98 10:44:39	16/04/98 15:27:17
d232_6.log	17/04/98 12:49:35	18/04/98 20:31:33

TOWYO CTD

In order to be able to observe the vertical motions of the interface between Atlantic and Mediterranean water during the passage of the tidal bore, a second CTD system was prepared; it was referred to as the 'towyo' system.

The towyo system consisted of a NBIS MkIIIb CTD with duplicate conductivity sensors installed in shallow-rated (600dbar) pressure case, mounted in a cuboidal frame, and deployed over a block suspended under the aft A-frame. Two CTD's Shal01 and Shal02 (generally used in the IOSDL/SOC SeaSoar vehicle) were used. The frame was attached to 400 metres of cable, with 7 conducting cores. The cable was spooled with a portable hydraulic winch mounted on the aft deck. Electrical connection was via slip rings. In addition to the CTD, a Chelsea aquatracker 0.25m path transmissometer was mounted on the frame, and interfaced to the CTD. Furthermore, either of the Optical Plankton Counter (OPC) or Towed Undulating Bioacoustic Sonar (TUBA) was mounted, using spare conductors for power and communications.

The CTD data were monitored from the main lab, and verbal instructions were given to the winchman to enable profiling through the interface. Strategy was modified slightly on the various deployments, but generally a salinity threshold of 36.8‰ was taken to define the top of the interfacial layer and a salinity threshold of 38.1‰ defined the bottom of the interfacial layer. As soon as the package reached the threshold salinity, the winch was reversed so that the characteristics of the interfacial region were repeatedly sampled. Occasionally, a profile from the surface to 300 m depth was taken to establish the characteristics of the inflowing upper layer Atlantic waters and of the outflowing lower layer Mediterranean waters. Generally, the rate of profiling was sufficient to resolve the motions of the interface and its stratification. This was not the case, however, when sampling the leading edge of the internal bore, where vertical motions of the interface could exceed 50 cm s^{-1}. Inevitably there are times when the sampling is aliased due to the limited speed of the winch and the streaming angle of the wire: in these situations the vertical profiles cannot be expected to represent the stratification accurately. The problem was particularly noticeable when trying to overtake a fast downward moving interface with a towyo downcast. Indeed, in one instance the downward motion of the interface overtook the package. It is unlikely that such severe vertical motions could ever be tracked satisfactorily with a profiling package. Rather, some sort of vertical chain, able to make simultaneous measurements at many depths, is needed.

Most of the towyo stations were conducted on nights when the intention was to sample the bore in several different locations. Stations were between one and three hours duration to observe the characteristics of the leading edge of the bore and of the crests and troughs of the trailing wave train.

After steaming downstream past the leading edge, the cycle was repeated. In addition, one 12-hour station was completed to cover a complete tidal cycle.

Two CTD systems were taken on the cruise and both were used. Shal01 was used on casts 01 and 02, but was replaced after that due to sporadic bad data frames. A loose internal connection was later found and fixed. Shal02 was used on casts 03 to 08. After cast 08 the deck pressure was found to be -9 to -11 dbar. The instrument was replaced by Shal01, and investigated. The internal pressure was clearly greater than atmospheric, since air escaped when the pressure case was opened. Also, a small amount of seawater was found inside, but not sufficient volume to account for the excess pressure. The electronics seemed undamaged, and the instrument performed normally after maintenance. Casts 09 to 11 used the restored Shal01.

B. A. King

Cast	Time (ddd hhmmss)	Lat (degrees)	Lon (degrees)	Duration (minutes)	Comment
01	097 153122 097 163451	43 46.44 43 46.60	-9 44.47 -9 46.40	63	373 Test Station
02	101 012800 101 025600	35 55.37 35 55.36	-5 42.42 -5 42.47	88	376 - L4
03	101 041129 101 050806	35 55.69 35 55.89	-5 36.79 -5 35.65	56	377 - L5
04	101 062355 101 085500	35 57.89 35 57.82	-5 27.73 -5 24.70	151	378 - L6E OPCa
05	102 021729 102 040515	35 55.47 35 55.57	-5 39.66 -5 39.40	107	379 - L4E OPCb
06	102 045522 102 065436	35 56.94 35 57.51	-5 32.14 -5 30.07	119	380 - L6 OPCc
07	102 220948 103 100658	35 55.48 35 55.56	-5 39.38 -5 39.91	717	385 - L4E OPCd
08	104 024900 104 053351	35 55.45 35 55.66	-5 39.75 -5 39.33	164	388 - L4E TUBA
09	104 062506 104 084113	35 57.47 35 57.55	-5 30.33 -5 30.30	132	389 - L6 TUBA
10	105 031928 105 060144	36 05.14 36 05.18	-5 18.04 -5 18.32	162	398 TUBA
11	108 033046 108 061302	35 53.69 35 54.69	-5 49.09 -5 44.56	162	409 TUBA

TUBA (TOWED UNDULATING BIO-ACOUSTIC) SONAR

Background

The Towed Undulating Bio-Acoustic (TUBA) Sonar unit measures the spectral responses at seven different frequencies (ranging from 175 kHz to 2.4 MHz) to provide an estimate of zooplankton abundance, and ultimately for modelling the size and types of scatterer in the sampling volume. It is primarily designed to be towed under SeaSoar, the SOC towed undulating vehicle. This cruise was the third opportunity we have had to try this prototype instrument at sea.

Prior to this cruise modifications had been carried out to improve co-channel harmonic interference and to sharpen the in band responses. This involved redesigning and rebuilding most of the receiver circuitry. In this trial TUBA was attached to the tow-yo frame and deployed over the stern. The frame was repeatedly lowered and raised through the upper 250m of the water column.

The spectral zooplankton profile recorded showed some correlation with the EK500 records confirming correct operation, although in general it was difficult to see any improvement to the harmonic interference as there were so few scatterers present during the tow-yo sections. However, looking at the spectral response of the individual return echoes showed some improvement in the sharpness.

Data Processing

The transmit trigger pulse from the Deck unit is aligned with the CTD data frame such that the TUBA receive signals are sent during a 'quiet' period between frames. The analogue signal returns, which are transmitted up the cable within a 250 kHz bandwidth, are sampled at 769 kHz to avoid any aliasing ploblems using a 16-bit PC-compatible acquisition and digital signal processing (DSP) card. The DSP card performs fast-Fourier-transform functions and passes the results to the PC, which runs a graphical user interface for control of the acquisition and data logging and display of the data in both raw and spectral forms. These spectra and the raw digital amplitude data are transferred to the PC where frequency dependant absorption losses are applied and the relative returned energy at each frequency calculated over a bandwidth appropriate to the selected transmit pulse duration.

Currently, compensation for absorption losses and change in scattering volume with range are calculated during post-processing using standard pexec software. The absorption losses are calculated using the equations of Francoise and Garrison (1982) after merging the data with contemporaneous temperature and salinity and depth data from the tow-yo CTD or SeaSoar.

Development Issues

As mentioned above, correlation of the 175 kHz channel with the EK500 record was very promising. Other channels, apart from 1.6 and 2.4 MHz, showed similar returns with much lower amplitudes. In its present state, however, the instrument is uncalibrated, and compensations must be applied in order to compare signal returns from different frequencies.

A. Harris and N. Crisp

TUBA Deployment Periods During RRS *Discovery* Cruise 232

Strait of Gibraltar, April 1998

14 April	02:53:42	to	05:34:53	Station L4E ToYo 388
14 April	06:55:57	to	08:51:38	Station L6, ToYo 389
15 April	03:12:35	to	06:03:23	east of Point Europa, ToYo 398
18 April	03:26:46	to	06:12:58	west of sill, ToYo 409

LONGHURST-HARDY PLANKTON RECORDER (LHPR)

The LHPR was fished twice during this cruise. This instrument is used to take biological samples at fine depth resolutions of a few metres, using a 280 micron mesh net with a 200 micron cod-end. It is fished on the conducting *deep-tow* cable and so constant monitoring of the net is possible on board the ship. The intention of the tows was to sample the large-amplitude waves formed at 100-150 m depth following the tidal bore. Unfortunately the gear being so light and hence sensitive to changes in ship's speed and in currents, it proved impossible to control the depth of the net accurately. However, both tows sampled Mediterranean and Atlantic water, as indicated by temperature and salinity, above and below the wave form. Both of the tows finished within one hour of sunset and so may be affected by migration of animals towards the end of the sampling period.

Station 13384 at L6N (Figure 2) took 94 samples and station 13387 at N3 took 86 samples, each one minute in duration. Initial observations before preservation indicate that there were no large animals (>5mm) in the catches, there being no bulges or distortions in the mesh on the take-up spool. The spools were preserved whole for later examination in the laboratory. Salinity, temperature and depth were sampled routinely throughout the deployments.

Some problems were experienced with the gear prior to the first deployment. At some stage between leaving SOC and arrival at the work site electrical tracks on the power supply board of the deck unit had broken. There were indications of tracking and sparking so this problem may have been a progressive failure. Some joints were resoldered and a number of tracks were bridged before the problem could be solved. No further problems were encountered.

B. Boorman

CTD MEASUREMENTS DURING HYDROGRAPHIC STATIONS

Equipment

The cruise was equipped with two MkIIIc CTDO's (Neil Brown Mark IIIc Conductivity-Temperature-Depth-Oxygen) instruments from SOC's Ocean Technology Division (OTD): numbers Deep03 and Deep04. Deep03 was used throughout the cruise. The underwater package included CTD, altimeter, Lowered ADCP (described in the following section), 24-place FSI (Falmouth Scientific Instruments) pylon and 24 x 10-litre water bottles. 18 of the bottles were standard, internally-sprung with epoxy-coated steel springs (FSI bottles which had most recently been used on *James Clark Ross* Cruise 27), 6 were externally-sprung lever action Niskins (referred to in cruise logs as LAN), supplied by Dr. N. Morley, and intended principally for trace metal sampling. The closing mechanism of the LAN's was high on the outside of the bottles, and would have fouled on the standard OTD CTD frames. In order to accommodate this, one of the frames had been modified by cutting and extending the upright supports of the top ring prior to the cruise.

The FSI Pylon has the facility that the firing positions can be addressed in any order. The LAN's were therefore installed in positions 19 to 24, with no need to rearrange bottles on the pylon in order to achieve required depths for trace metal sampling. Unfortunately, the pylon persistently failed to fire in certain positions. As a result, the LAN in position 24 was moved to position 18. Certain other pylon positions were consistently avoided, once they had been identified as unreliable. Although various attempts were made to rectify the pylon problems, none was entirely successful. Since the deepest station was only 900 metres, however, there was not a shortage of available bottles for sampling different depths. A spare FSI pylon also gave problems on deck and was not used underwater. After completing stations in the Strait of Gibraltar, the pylon in use was overhauled in the lab, but a final equipment test station en route to Tenerife showed no improvement. Because of his greater familiarity with the equipment, the pylon problems were left for J. Smithers to address on the following cruise. In addition, a spare GO pylon was shipped out to Tenerife, in case neither of the FSI pylons could be made to work satisfactorily. Bottle samples were identified by a combination of station number and rosette position, regardless of bottle firing order. For example, sample 41206 was from station 13412, position 06.

For all hydrographic stations, the package was deployed from the amidship gantry. Because the station depths ranged only from 81 to 900m, the 10mm winch cable was used throughout.

Sampling Strategy

A total of 29 hydrographic stations were taken. Two test stations were made in the Bay of Biscay during transit from Southampton to the Strait of Gibraltar to assess instrument performance. In the Strait, two approximately north-south sections consisting of 11 stations were taken across the eastern and western entrances to the Strait; two stations were made over the positions of the Inverted Echo Sounders; two stations were taken in the narrowest part of the Strait close to the start positions for the Longhurst-Hardy Plankton Recorder (LHPR) tows; and one of the stations at the western entrance to the Strait was repeated to assess the temporal variability between finishing the northern half of this section and starting the southern half (Figure 1c):

Hydrographic Station Positions in the Strait of Gibraltar during RRS Discovery Cruise 232

Location	Station	Latitude	Longitude
E12	374	36.0522	-5.3915
E13	375	35.9391	-5.3391
E11	381	36.1753	-5.3109
E10	382	36.1661	-5.2753
E9	383	36.1340	-5.2310
N3	386	35.9630	-5.5384
E8	390	36.1067	-5.1878
E7	391	36.0685	-5.1781
E6	392	36.0234	-5.1557
E5	393	35.9761	-5.1299
E4	394	35.8980	-5.0929
E3	395	35.8767	-5.1611
E2	396	35.8569	-5.2100
E1	397	35.8480	-5.2730
N2	399	35.9865	-5.5481
W11	400	36.0833	-5.8846
W10	401	36.0477	-5.9213
W9	402	35.9978	-5.9701
W8	403	35.9620	-6.0184
W7	404	35.9386	-6.0173
W1	405	35.8030	-5.9455
W2	406	35.8272	-5.9557
W6	407	35.9194	-5.9984
W7	408	35.9403	-6.0137
W5	410	35.9048	-5.9979
W4	411	35.8794	-5.9854
W3	412	35.8534	-5.9731

Each Station consists of continuous CTD and LADCP profiles of temperature, salinity, oxygen and east and north velocities as well as water samples at discrete depths.

The two sections across the eastern and western entrances represented an attmept to estimate the biogeochemical fluxes through the Strait of Gibraltar. Because of aliasing problems particularly associated with semidiurnal tidal variations, it may not be possible to reliably determine such fluxes. Nevertheless, the combination of vertical CTDO profiles with simultaneous profiles of velocity from the LADCP and with vertically dense water sample analyses for nutrients, trace metals, CFC's, and dissolved and total organic carbon offered a unique opportunity to try to estimate biogeochemical exchange between the Mediterranean Sea and the Atlantic Ocean.

Data Capture

Data from the CTD deck unit were logged using both RVS (Research Vessel Services) level A and the Data Acquisition and Processing System (DAPS) developed in SOC's George Deacon Division. On previous cruises on *Discovery* and *James Clark Ross*, the RVS level A had seemed unable to keep up with the 25 Hz data rate provided by the MkIIIc CTD. The symptom was that most of the 1-second data output by the level A was an average of many fewer than 25 frames. Also, the level A had been inclined occasionally to hang altogether, resulting in loss of data that needed to be rectified by a slow, tedious process of recovery from raw files on the deck unit PC. These effects are documented in more detail in other cruise reports (e.g., Heywood and King, 1996). The decision was therefore taken before the cruise to use the DAPS as the primary data capture for CTD and bottle firing events, with the hope that the cruise might provide scope for investigation of the level A problems. Curiously, spot checks on the level A data stream suggested that it was performing perfectly, capturing the full CTD data rate. No further investigation could therefore be pursued. Thus there are still unresolved doubts about the level A reliability. The DAPS data files were read directly into pstar files and then processed in the usual way. The DAPS variables include the 1-second temperature difference (deltaT) variable normally produced in the level A.

Bottle firing events were logged both in DAPS and on a 'bottles' level A data stream. For stations 13405 – 13408 inclusive, the data from the DAPS bottle log was lost, but the information was retrieved from the RVS system. Winch data, including wire out, were also logged via a level A data stream.

The use of DAPS has two slight weaknesses, each of which could perhaps be addressed in the future:

(i) DAPS data are time-stamped with the time of the Sun workstation's clock. This is able to drift relative to ship master clock (synchronised to UTC), so it must be monitored and corrected if errors grow to more than a couple of seconds. It is ultimately desirable that DAPS should have an interface to GPS or ship master clock time messages.

(ii) The level-B archive of CTD data is bypassed. There seems no reason in principle why the DAPS workstation could not produce level-B messages of its 1-Hz averages, for shipboard archive under the RVS system. A number of other systems, for example the underway meteorological measurements, simulate level-A output in this way.

Data Processing

For each station, the CTD data were processed in as close to real time as possible in order to check that all sensors were functioning within acceptable ranges. Raw data were read in for CTD, winch and bottle events. Data were merged using time stamps. Initial conductivity calibration was chosen after the first test station to give a sensible deep T-S (temperature-salinity) value in the Bay of Biscay, based on historical data. While rather crude, the large salinity signal in the work area meant this was acceptable for an initial salinity calibration. Initial oxygen calibration was meaningless. Oxygen sample data were only merged with CTD data right at the end of the cruise, so calibration of CTD oxygen had to wait for post-cruise processing at SOC.

Working files on board ship consisted of cleaned and de-spiked 1 Hz data, and extracted downcast data, sorted, averaged to 2 db and interpolated to fill any gaps. It was noted that the apparent T-S relation was drifting more than would be considered acceptable for highest-quality deep hydrography. This was attributed to a failing conductivity cell. However, the effect was not so great that the drift could not be satisfactorily monitored from the sample salinities. Deep03 with a single conductivity cell was kept in use until then end of this cruise, and the need for the cell to be changed prior to the next cruise was noted. Data cycles that define the downcast portion of the 1 Hz file were checked in post-cruise processing, and a few errors corrected.

Salinity Calibration

The shortness of the working time (8 days) for CTD measurements during D232 meant that rather little shipboard calibration work was done. Initial comparisons between sample and CTD salinities revealed the problem with the conductivity cell, which was due to be changed for cruise 233. Detailed comparisons were carried out post-cruise by Dr. King at SOC. CTD bottle firing data were extracted by time and compared with sample salinity. Since the stations are relatively shallow and the temperature range is relatively small, a simple salinity offset was identified for each station, rather than attempting a more complicated fit between CTD and sample conductivity. The complete data processing path was then repeated automatically, so that CTD data from bottle firing events was extracted from the new 1 Hz files and passed into the sample files. This was necessary to ensure that correct CTD salinities were available for all bottles, including, for example, trace metal bottles from which salinity samples had not been drawn.

Care was needed to exclude unsuitable salinity samples from the calibration process. Strong vertical gradients in salinity, as large as 1 ‰ over 10 metres in the vertical, are not well sampled by 10-litre Niskin bottles. Estimates from previous cruises (e.g. Saunders et al., 1993) suggest that the vertical flushing distance of the bottles is 5 metres or more. Thus sample minus CTD discrepancies up to, or even greater than, 0.1 can arise from this source of error. As individual stations were examined, large residuals in regions of strong gradient were noted and excluded from the calibration. However, these sample data were not flagged as bad, since there is no reason to suspect that either the sample capture or the sample analysis were faulty.

Residuals between final CTD and the subset of sample salinities used in the calibration showed a typical standard deviation of less than 0.004, for up to 8 sample salinities per cast. This represents the sum of CTD salinity errors, sample analysis errors, and sample/CTD mismatches arising from smaller vertical gradients that have not already been excluded. Final CTD data were produced for the 27 stations in the work area.

Oxygen Calibration

No oxygen calibration was attempted at sea, because the sample data were not available until close to the end of the cruise in Tenerife. Post-cruise at SOC, CTD oxygen was calibrated station by station by Dr. King. Up to 5 oxygen parameters (S_1 to S_5) were fitted for each station, using the following expression;

$$O_2 = \mathrm{Osat}(T,S) * S_1 * (\mathrm{Oxyc} + S_4) * \exp(- S_2 * P - S_3 * (S_5 * \mathrm{Tctd} + (1-S_5) * \mathrm{Oxyt}))$$

The requirement is to fit downcast CTD oxygen data from the 2 dbar file, which are the reported CTD oxygen data, to the samples collected on the upcast. Accordingly, it is necessary to extract downcast values of Oxyc, Oxyt, press, temp and salin, that correspond to the upcast water sample. On some previous cruises this has been done by selecting data cycles at matching pressure. However, significant vertical migration of material surfaces (revealed by comparison between up and down T and S profiles), coupled with strong vertical property gradients, even within the short time of these stations, made this an unreliable technique. Accordingly an option was used in the pexec program 'pbotle' which allowed matching on potential density, the assumption being that this was a more reliable marker of a material surface. Density data were referenced to the nearest 500 dbars for the purposes of such matching. The matching selected by this process was still judged to be imperfect, so that on six stations a hybrid matching combining density and pressure was used. A certain amount of analyst's judgement is involved here, but the result is considered acceptable for the present dataset.

The result of fitting the oxygen algorithm parameters was examined on each station. On some stations, the distribution of sample values and CTD values made the fitting problem ill-conditioned, so that one or more of the parameters could not be determined. In these cases, subjective judgement was used and those parameters were fixed at values representative of nearby stations. Remaining parameters were then fitted to the available data. As with salinity calibration, outliers were identified and excluded from the fitting procedure, which was then repeated. Where the outlier was attributed to a bad sample analysis, the sample flag was set to 'bad'. Typical rms residuals per station in the finished dataset are less than 3.5 umol/l. where the mean residual is calculated using number of degrees of freedom = Number of samples - 5.

Some final fixes were required. On some stations, near-surface CTD oxygen data were bad, arising from the CTD being soaked at 10 metres, but then not being returned to surface before commencing the downcast. Near-surface data, acquired before soaking, were deleted and replaced by the shallowest good data. Therefore the 2db CTD oxygen data on these stations (13375, 381, 382, 392, 395, 396, 397, 406, 407) do not correspond to the oxyc data in the files. In addition, a few residual spikes were removed by manual editing. At station 408, no oxygen samples were drawn because it was a repeat of station 404. Appropriate 'fake' sample data at bottle closing depths were invented by examining T-O relation on station 404, so that CTD oxygen could be calibrated.

Lastly, CTD oxygens were fitted to sample oxygen reported in umol/l. At the time of this report, sample and CTD oxygen data are still stored as umol/l. These should subsequently be converted to umol/kg, using a density based on the recorded temperatures at the time of fixing the samples.

B. A. King, K. M. White and S. Watts

LOWERED ADCP MEASUREMENTS (LADCP)

Equipment

SOC has two RD Instruments 150 kHz BroadBand Acoustic Doppler Current Profilers adapted for Lowered use (LADCP's), subsequently referred to as SOC-01 and SOC-02, each with a pressure case rated to 6000 metres and each with 4 downward facing transducers. SOC-01 has a 20-degree beam angle, and was initially purchased as a phase II instrument in a full-length, 6000-metre pressure case, suitable for moored use. It has since been upgraded to phase III, and the pressure case shortened so that it fits more conveniently into the SOC CTD frames. In the present SOC configuration, the instruments are powered by external battery pack. SOC-01 has worked flawlessly on at least seven previous cruises. SOC-02 was purchased specifically for lowered use in November 1996, as a phase III instrument in a short pressure case with a 30-degree beam angle. It has been troublesome on previous occasions, most recently when it failed completely on D230 (Bacon, 1998).

The LADCP is mounted vertically in the centre of the CTD frame. A separate battery pack is mounted horizontally near the bottom of the frame. Two new battery pressure cases had been ordered for this cruise. Unfortunately, one failed a pressure test shortly before the cruise. The fault was believed to be in the material rather than the design. The second was tested only to 2000 meters, and hence given a safe working depth of 1000 meters, adequate for the work area in the Strait of Gibraltar. The new pressure cases took four 12-volt rechargeable lead-acid gel cells connected in series to give 48 volts. The battery pack pressure case is fitted with a recharge plug and a tight screw at the end cap of the case to release gas during the recharge. A short lead was left permanently attached to the LADCP unit and tied to the frame to enable the external power and communications lead to be connected pre- and post-deployment. A backup arrangement was to use older pressure cases filled with alkaline battery packs. Two 15 meter communications and power leads were connected to a dedicated PC and to a DC power supply located in the Deck Lab.

During set-up prior to a cast and for downloading data, external power was supplied to the unit via the communications lead. Prior to each cast the instrument was subjected to a checklist and sent a configuration command-file, which determines the mode of operation. One of the tests set the internal clock of the instrument to the ship's clock. The test results and pre-deployment files were recorded for each cast. The instrument was set to Water and Bottom Tracking Mode with 10 times 16-meter bins for the whole cruise. The battery pack was connected for recharge when the power level dropped below 44 volts to avoid potential data loss.

Data Processing

The LADCP measures instantaneous relative velocities of scatterers in the water column and these can be converted into profiles of absolute currents by an elaborate processing path. The scatterer velocities are measured by utilising the Doppler frequency shift, phase changes and correlation between coded pulses transmitted and received by four transducers. The raw data are scaled to velocity units by taking into account the velocity of sound, as estimated from CTD data. The directions of the currents are inferred from calculations in which the geometry of the transducer set, the orientation of the package and the magnetic variation are taken into account. The depth of the instrument is first calculated by integrating the measured vertical velocity and later fine-tuned by matching to the CTD pressure and time data.

In order to remove relative velocities introduced by the motion of the package during the cast, shear profiles were computed by differentiating the velocities within each of the ensemble 16-bins. Then, the data is integrated up over the cast to produce a shear profile with a zero net velocity. This process also removes the barotropic component of the velocities, which must be reinstated either from the ship displacement (determined from differential GPS data) or from the relative motion of the package over the sea floor (Bottom Tracking). The final velocity profile is the sum of the baroclinic and barotropic components.

The processing of LADCP data is achieved using software developed by Eric Firing's group at the University of Hawaii. The software uses a combination of 'perl' scripts and MATLAB '.m' files to process the data. The version used on this cruise was downloaded from Hawaii on 24 September 1997. The main processing steps are:

1) Extract binary ADCP files from instrument.; copy raw file (.000) to sun workstation.

2) scanbb.prl to get start, stop times of cast.

3) loadbb.prl to load into CODAS database file.

4) domerge.prl. The perl script 'domerge' calculates mean shear profiles (the baroclinic component of the current) and applies corrections and editing options which were kept constant throughout the cruise.

5) The MATLAB script 'do_abs' calculates absolute velocities and produces a standard set of profiles. In this step the uncorrected data (down, up and mean profiles) were viewed and plotted as unreferenced shear profiles with the depth-average set to zero.

This is the first logical stopping place, and can be achieved within minutes of downloading the cast data. Depending on the availability of navigation and CTD data, the order of the following steps can be varied.

6) Read in CTD data to matlab. (di9804ts.m)

7) Run fd.m, which provides automatic registration of CTD and LADCP data. If the automatic procedure fails, or does not produce well-matched results, there are manual procedures.

8) add_ctd.prl adds CTD depth and soundspeed to the database.

9) domerge.prl recalculates shear profiles for modified data.

10) When a matlab nav file becomes available, do_abs.m can be run to include GPS navigation, to produce absolute water velocities.

Problems Encountered

SOC-02 had failed to work on its previous cruise (D230), and had been back to RDI for repair. Repairs included a replacement beam, followed by repainting of the transducer head, the significance of which became apparent. The intention at the start of the cruise was to use it as the primary instrument, thereby giving it a thorough testing.

Unfortunately, SOC-02 leaked on the first cast, which was a test cast to 5000 metres. Upon recovery, data were downloaded, and showed loss of meaningful signal part way through the downcast, even though a complete record was recorded in memory. When the instrument was removed from the frame and opened in the lab, it was found to contain enough seawater to run out of the (now horizontal) pressure case. Eyewitness estimates ranged from 'less than a cupful' to 'less than a pint'. Fortunately, the RDI staff on board to work with the ACCP were familiar with BroadBand ADCP and were able to offer invaluable assistance. The instrument was stripped down as quickly as possible, and all components washed several times in RO (reverse osmosis) water, and left to dry. Visual inspection of the components showed no visible damage to any of the circuits or other components.

The leak was particularly discouraging because SOC has had no previous experience with leaks with ADCP pressure cases, and the cause of the leak was sought. Upon close examination of the seal between the transducer head and the pressure case, G. Murdock noticed traces of black paint in the O-ring grooves. The only possible explanation for this seemed to be that paint had got there when the transducer head was repainted at RDI.

Later in the cruise, SOC-02 was reassembled, and seemed to be working normally. We were hopeful that no damage had accrued from the flooding. The traces of paint in the grooves were removed with a soft wooden cocktail stick. One remaining puzzle was that when pinging on deck, the audible 'tick' was much quieter than on SOC-01. This has always been the case with SOC-02 since it was first delivered. RDI had been asked to check the performance of the high-power module during the recent repair and had reported nothing wrong. However, the opportunity was taken while three of SOC's BroadBand ADCP's were together to substitute a high-power module from the BroadBand ADCP recovered from a mooring. An much louder 'tick' was then achieved, comparable to SOC-01, apparently confirming that SOC-02's high-power module has been defective since first delivery.

A further test station was conducted en route to Tenerife late in the cruise, and SOC-02 was deployed. Thankfully the instrument did not leak, confirming the paint as the cause of the problem. However, the deployment was not a success from the data point of view. Beam returns and correlations were lower than expected for an instrument working normally, and a further beam failure was suspected. Investigation was deferred until after return to shore, when RDI could be asked to examine the data file and advise. SOC-01 was left as the working instrument for the following cruise.

Station Data

Data from 20 out of 27 stations were downloaded and appear to be of fine quality. Five stations (381, 397, 401, 405, 410) were too shallow (depths of less than 150 m) to have any useful data. Station 371 experienced the failure of SOC-02, described above. Station 382 was lost because the wrong data were downloaded from instrument memory and the problem was not noted until after the instrument memory had been cleared.

B. King, A. Benabdeljelil, K. White and N. Crisp

WATER SAMPLE ANALYSES

Salinity

Two salinometers were carried on D232, the IOS Guildline Autosals 8400A, used exclusively for sample analysis on this cruise, and the 8400, carried as backup, which was modified by the addition of Ocean Scientific International peristaltic-type sample intake pumps. Processing was carried out in the usual manner (e.g., Bacon, 1998) and to WOCE standards (0.001 in salinity). Conversion from measured Guildline conductivity ratio was via in-house software (Excel 5.0 spreadsheet 'Salinity Master' v.2). A total of 342 samples were analysed. Two batches of standard seawater were used: P130 (21/03/1996) and P133 (11/11/1997), of which 14 and 4 ampoules were consumed, respectively. Analysis of duplicate and replicate samples from the only deep station (13372 where all bottles were closed at 4000 m) show for 19 duplicates a standard deviation of 0.0008, excluding one outlier; and for 3 replicates, all differences were ±0.0002.

K. White, G. Lane-Serff and S. Bacon

Oxygen

Oxygen samples were drawn from each Niskin bottle following the collection of samples for CFC analysis. Duplicate samples were taken on each cast, usually from the two deepest bottles. Samples were drawn through short pieces of silicon tubing into clear, wide-necked pre-calibrated glass bottles and fixed on deck with manganese chloride and alkaline iodide dispensed using precise repeat Anachem bottle top dispensers. Samples were shaken on deck for approximately half a minute, and again in the constant temperature (CT) laboratory 15 minutes to half an hour after sampling. The samples were then stored under water until analysis. The temperature of each sample was taken on deck using a hand-held electronic thermometer probe and was used to calculate any temperature dependant change in the sample bottle volume.

Samples were analysed in the CT laboratory starting two hours after sample collection. The Winkler whole bottle titration method with amperometric endpoint detection was used (Culberson and Huang, 1987). Equipment used included the Metrohm Titrino unit and control pad, exchange unit with 5 ml burette (unit 3) to dispense thiosulphate in increments of 1 µl, and an electrode for amperometric endpoint detection. The spin on the stir bar was occasionally disturbed by the movement of the ship and also by the uneven bases on some of the glass bottles, leading to less effective stirring of the sample and thus longer titration times, although this probably did not effect the accuracy of the endpoint detection.

The thiosulphate normality was checked on each run against an in-house potassium iodate standard. Although the thiosulphate reservoir was never topped up, two different standards of potassium iodate were used during the cruise. The exact weight of each standard and the calibration of the volumetric flask used in its preparation, along with the calibration of exchange unit 1a used to dispense it, were recorded into a spreadsheet used in the calculation of final oxygen concentrations. Variable standardisation on the first batch of potassium iodate standard was found to be caused by the presence of bubbles in the thiosulphate supply unit so the exchange unit was replaced after the first four stations.

The introduction of oxygen with the reagents and impurities in the manganese chloride were corrected by blank measurements made on each run, as described in the WOCE Manual of Operations and Methods (Culberson, 1991). The iodate standards were added to the excess reagents in the flask used for blank measurements.

Absolute duplicate differences for each station are shown in Table 7. Duplicate differences > 1.0 μmol l^{-1} accounted for 13.2% of the total number of duplicates. The mean duplicate difference was 0.45±0.63 μmol l^{-1} (0.23±0.34% full scale precision). Ignoring these high duplicate differences the mean was 0.25±0.26 μmol l^{-1}. The data quality may be affected by the amount of time that the Niskin bottles were open and warming up on deck prior to sampling.

R. Boscolo and E. K. Oikonomou

Nutrients

Sampling Procedures

Water samples for the analysis of dissolved inorganic nutrients: dissolved silicon (also referred to as silicate and reported as SiO_3), nitrate and nitrite (referred to as nitrate or NO_2+NO_3) and phosphate (PO_4), were collected after CFC, oxygen, and carbon samples had been taken. All samples were taken into 30 ml "diluvial" sample cups, rinsed 3 times with sample before filling. The samples were then stored in a refrigerator until analysis, between 1 and 6 hours after collection. A total of 24 casts were sampled for nutrients during the cruise (a total of 255 samples). Samples were transferred into individual 8 ml samples cups, mounted onto the sampler turntable and analysed in sequence. The nutrient analysis was performed using the SOC Chemlab Auto-Analyser type II (AAII) coupled to a Digital-Analysis Microstream data capture and reduction system. Each sample was analysed in duplicate to ensure accuracy and to increase precision.

Calibration

The primary calibration standards for dissolved silicon, nitrate and phosphate were prepared from sodium hexaflurosilicate, potassium nitrate, and potassium dihydrogen phosphate, respectively. These salts were dried at 110°C for 2 hours, cooled and stored in a dessicator, then accurately weighed to 4 decimal places prior to the cruise. The exact weight was recorded aiming for nominal weight of 0.960 g, 0.510 g and 0.681 g for dissolved silicon, nitrate and phosphate respectively. When diluted using Milli-Q water, in calibrated 500 ml glass (or polyethylene for silicate) volumetric flasks these produced 10 μmol l^{-1} standard stock solutions. These were stored in the refrigerator to reduce deterioration of the solutions. Only one standard stock solution was required for each nutrient for the duration of the cruise, and it was checked daily against OSI (Ocean Scientific International) standards.

Mixed working standards were made up once per day in 100 ml calibrated polyethylene volumetric flasks in artificial seawater (40g l^{-1} NaCl). The working standard concentrations, were corrected for the weight of dried standard salt and calibrations of the 500 ml and 100 ml volumetric flasks. Before correction working standard concentrations were as follows: 40, 30, 20, and 10 μmol l^{-1} for nitrate and silicate, and 2, 1.5, 1 and 0.5 μmol l^{-1} for phosphate. A set of working standards was run in duplicate on each analytical run to calibrate the analysis.

Reagents for each of the nutrients analysed were made up as and when required from pre-weighed salts. The autoanalyser required some maintenance. Position 38 on the rotating table occasionally was not sampled. This was temporarily eliminated by keeping the autostop switch off. The chart recorder also had a tendency to stop and start, resulting in some loss in chart records which did not affect the data output.

Silicon

Dissolved silicon analysis followed the standard AAII molybdate-ascorbic acid method with the addition of a 37°C heating bath (Hydes, 1984). The colorimeter was fitted with a 50 mm flow cell and a 660 nm filter.

Nitrate

Nitrate (and nitrite) analysis followed the standard AAII method using the sulphanilamide and naphtylethylenediamine-dihydrochloride with a copperised-cadmium filled glass reduction column. A 15 mm flow cell and 540 nm filter was used. Nitrite standards equivalent in concentration to the third nitrate standard were prepared each day to test the efficiency of the column.

Phosphate

For phosphate analysis the standard AAII method was used (Hydes, 1984) which follows the method of Murphy and Riley (1954). A 50 mm flowcell and 880 nm filter were used.

V. Hart

ChloroFluoroCarbon (CFC) Tracers

The main aim of the halocarbon work on D232 was to collect a comprehensive tracer data set for CFC-11, CFC-12, CFC-113 and carbon tetrachloride in order to characterise and age the two water masses found in the Mediterranean Sea and also to determine their outflow and spread into the North Atlantic Ocean. This study will attempt to combine the results of CO2 from the next cruise to calculate the anthropogenic carbon dioxide that the Mediterranean outflow introduces into the North Atlantic Ocean.

Sample Collection

Samples were drawn from 10 litre Niskin bottles directly into 100 ml ground glass syringes, flushed three times before taking the sample and then stored under a continuous flow of surface sea water to keep gas tight integrity. Most samples were analysed within 12 hours of collection. When a delay did develop due to equipment failure there was no evidence of sample degradation up to a further 12 hours.

Analysis

Halocarbon analyses were carried out using a modified version of the Gas Chromatograph-Electron Capture Detector (GC-ECD) system described in Boswell and Smythe-Wright (1996). Sharper chromatography was achieved by using liquid nitrogen and 10 cm x 19 gauge outside diameter traps filled with glass beads for the cryogenic trapping of compounds. After a few initial problems, the system worked well giving high quality measurements throughout the cruise. Measurements were made on a total of over 180 samples from 22 stations from nearly all depths thus achieving the CFC tracer aims of the cruise.

Two major problems occurred during the cruise. Firstly the automated valve system which controls the opening and closing of the trap and detector developed a problem resulting in the gases not being trapped. This was overcome by throwing the valves manually. Secondly and more importantly, the precolumn in the GC-ECD snapped twice, causing the flow to stop in one of the channels. This was resolved by replacing the complete length of precolumn in the detector, which needed an entire day to complete and resulted in 2 CTD stations (E5 and E6) not being sampled. Thanks go to the ship engineers, especially K. Jethwa, for their invaluable assistance with the precolumn replacement.

Calibration and Precision

CFC tracers are usually calibrated using a 20 point calibration from a gas standard prepared by the NOAA Climate Monitoring and Diagnostics Laboratory in Boulder which is calibrated to the Scripps Institurion of Oceanography (SIO) 1994 scale. However, due to time contraints a calibration was not run on D232, but CFC calibration is planned prior to the start of the next cruise. Duplicate measurements were made at a number of stations and showed good accuracy and precision. Standards and blanks were run after every six water samples to monitor the baseline and retention times of all the CFC tracers.

I. Soler Aristegui and R. Davidson.

Trace Metals

For the purposes of trace metal sampling, D232 forms part of a series of cruises carried out for the CANIGO project. As with the three previous visits to the area the sampling strategy is intended to establish end member concentrations within the boundaries of the region for the variously sourced waters passing through the Strait of Gibraltar. As a result of adverse weather on the previous mission in February 1998, D232 provided the only opportunity within CANIGO to obtain trace metal samples during winter/early spring, when input to the source waters, in particular terrestrial and sedimentary supplies, may differ significantly from those found in summer conditions. The deep mixing observed at the western transect, the result of westerly winds combined with the limited warming of the upper water column, is also likely to affect trace metal distributions, while relatively small temperature variations make distinction between separate water masses in terms of temperature-salinity characteristics more problematical than is the case for summer conditions. As normal internal spring or rubber Niskin bottles are not suitable for trace metal sampling, lever action Niskin bottles with external closure mechanisms were used for trace metal samples, with 6 units being available on the Rosette throughout D232.

A total of 61 samples were obtained and filtered on board, with both filters and filtrate being retained for future analysis. Samples were split so that several laboratories could analyse them for various trace metals as follows:

SOC	1 l	Dissolved Cd, Co, Cu, Fe, Mn, Ni, Pb, Zn
	Filters	Particulate Cd, Cu, Fe, Mn, Pb, Zn (Co and Ni bdl)
GBE	0.5 l	Dissolved As, Ba, U

In addition, 15 samples were taken for later Os analysis by GCE and two for dissolved and total Nd in the Mediterranean waters by the CNES laboratory in Toulouse.

SOC	School of Ocean and Earth Science, Southampton Oceanography Centre, UK
GBE	Laboratoire Geofluides, Bassins et Eaux, CNRS, Univ Montpellier, France
GCE	Laboratoire Geochimie et Cosmochimie, Universite Paris, France

N. H. Morley

Total and Dissolved Organic Carbon

Samples for total and dissolved organic carbon (TOC and DOC, respectively) were taken from all depths on all CTD stations after CFC and oxygen samples were collected. All samples for TOC analysis were taken into 10 ml glass ampoules and for DOC measurements into 1 litre glass bottles. Before the cruise all glassware were precombusted at 450°C for at least 6 hours. During sampling, seawater was allowed to flow directly from the Niskin stopcock without the stopcock touching the bottles and ampoules to reduce the chance of contamination.

Samples for DOC analysis were filtered through precombusted (450°C, 6 hours) Whatman glass fiber (fine) (GF/F), collected in duplicate into 10 ml glass ampules, poisoned by addition of $HgCl_2$ (2 mg l^{-1}), sealed, and stored in the dark (similar protocol was used for TOC samples collection). In order to test for contamination during filtration, we have taken samples for TOC analysis.

Samples will be analysed in the Laboratory of Marine Microbiology (CNRS UPR 223, Marseille, France) where we use the commercially available Shimadzu instrument Model TOC-5000 Total Carbon Analyzer with quartz combustion column in the vertical position filled with 1.2% platinum silica pillows. Prior to analysis, subsamples will be acidified with 10 ml of 85% H_3PO_4 and sparged for 10 min at a flow rate of 50 ml min^{-1} with CO_2-free pure air to purge inorganic carbon. 100 ml injection will be repeated 3 to 4 times for each sample. For standardisation we use potassium hydrogen phthalate diluted in Milli-Q water (4 concentrations) prepared just before sample analyses each day. The system blank determination is from analysis of ampoules of low carbon water provided by J. Sharp (University of Delaware) and it was found to range from 6 to 10 μmol l^{-1} C.

E. V. Dafner

Table 7. Oxygen Duplicates

A flag value of 2 indicates good determination, flag value 3 indicates questionable value

Sample Num	Station Num	Bottle Temp°C	BotOxya µm/l	BotOxya Flag	BotOxyb µm/l	BotOxyb Flag	BotOxy µm/l	BotOxy Flag	Difference µm	%
37401	13374	14.0	183.80	2	186.12	2	183.80	2	2.32	1.26
37403	13374	13.9	199.16	2	199.69	3	199.16	2	0.53	0.27
37406	13374	13.9	200.02	2	200.40	2	200.02	2	0.38	0.19
37415	13374	14.5	216.09	3	214.23	2	214.23	2	1.86	0.86
37501	13375	12.9	188.76	2	189.59	3	188.76	2	0.83	0.44
37503	13375	12.8	186.63	2	185.28	3	186.63	2	1.35	0.72
37504	13375	12.9	183.56	2	183.84	3	183.56	2	0.28	0.15
38101	13381	13.8	183.66	2	183.68	2	183.66	2	0.02	0.01
38103	13381	13.5	184.49	2	187.71	3	184.49	2	3.22	1.75
38201	13382	13.6	176.53	2	176.21	2	176.53	2	0.32	0.18
38205	13382	13.6	176.03	2	174.40	2	176.03	2	1.63	0.93
38301	13383	13.4	182.18	2	182.25	2	182.18	2	0.07	0.04
38303	13383	13.2	181.86	2	181.93	2	181.86	2	0.07	0.04
38603	13386	13.2	185.50	2	184.92	2	185.50	2	0.58	0.31
38607	13386	13.2	179.78	2	180.01	2	179.78	2	0.23	0.13
38613	13386	13.9	197.81	2	197.85	2	197.81	2	0.04	0.02
39006	13390	12.9	183.88	2	183.89	2	183.88	2	0.01	0.01
39101	13391	13.4	192.03	2	191.90	2	192.03	2	0.13	0.07
39113	13391	14.7	216.41	2	215.36	2	216.41	2	1.05	0.49
39201	13392	13.6	190.36	2	190.03	2	190.36	2	0.33	0.17
39210	13392	14.0	207.07	2	207.17	2	207.07	2	0.10	0.05
39301	13393	13.4	182.14	2	182.04	2	182.14	2	0.10	0.05
39307	13393	13.2	178.11	2	177.92	2	178.11	2	0.19	0.11
39401	13394	13.3	184.63	2	184.85	2	184.63	2	0.22	0.12
39406	13394	13.1	181.39	2	180.51	2	181.39	2	0.88	0.49
39413	13394	15.9	246.42	2	246.35	2	246.42	2	0.07	0.03
39501	13395	13.0	187.16	2	187.04	2	187.16	2	0.12	0.06
39509	13395	13.4	195.45	2	195.64	2	195.45	2	0.19	0.10
39601	13396	13.0	185.42	2	185.56	2	185.42	2	0.14	0.08
39607	13396	13.0	180.41	2	180.36	2	180.41	2	0.05	0.03
39701	13397	15.0	221.10	2	221.83	2	221.10	2	0.73	0.33
39703	13397	15.1	226.62	2	226.49	2	226.62	2	0.13	0.06
39901	13399	13.5	185.92	2	186.00	2	185.92	2	0.08	0.04
39911	13399	13.2	176.57	2	175.89	2	176.57	2	0.68	0.39
40001	13400	14.4	212.58	2	212.90	3	212.58	2	0.32	0.15

40101	13401	14.2	207.98	2	208.01	2	207.98	2	0.03	0.01
40201	13402	13.9	201.51	2	201.44	2	201.51	2	0.07	0.04
40206	13402	14.6	218.06	2	217.94	2	218.06	2	0.12	0.06
40301	13403	13.9	194.18	2	193.36	2	194.18	2	0.82	0.42
40401	13404	13.6	184.65	2	184.60	2	184.65	2	0.05	0.03
40410	13404	14.3	207.71	2	207.71	2	207.71	2	0.00	0.00
40501	13405	14.4	209.50	2	209.93	2	209.50	2	0.43	0.21
40504	13405	16.0	242.20	2	242.30	2	242.20	2	0.10	0.04
40504	13405	16.0	242.20	2	242.30	2	242.20	2	0.10	0.04
40601	13406	13.9	205.01	3	205.16	2	205.16	2	0.15	0.07
40701	13407	13.9	205.78	2	205.94	2	205.78	2	0.16	0.08
40706	13407	15.0	228.53	2	228.56	2	228.53	2	0.03	0.01
41001	13410	13.7	206.76	3	205.86	2	205.86	2	0.90	0.44
41004	13410	13.7	207.57	2	207.74	2	207.57	2	0.17	0.08
41101	13411	13.2	184.36	2	184.57	2	184.36	2	0.21	0.11
41107	13411	13.1	191.49	2	191.51	2	191.49	2	0.02	0.01
41201	13412	13.2	185.53	2	185.30	9	185.53	2	0.23	0.12
41205	13412	13.3	194.76	2	193.75	9	194.76	2	1.01	0.52
								Mean	0.45	0.23
								stndev	0.63	0.34
							Mean	< 1 µmol/l	0.25	0.13
							stdev	< 1 µmol/l	0.26	0.13

Table 8. Trace Metal Samples: Stations and Recorded Bottle Pressures

Analysis of the 1 litre samples for dissolved Cd, Co, Cu, Fe, Mn, Ni, Pb, Zn and of the filters for particulate Cd, Cu, Fe, Mn, Pb, Zn (Co and Ni bdl) will be carried out at Southampton Oceanography Centre. Analysis of the 0.5 litre samples for dissolved As, Ba, U will be made at the CNRS Laboratoire Geofluides. In addition, 15 samples were taken for later Os analysis by the Laboratoire Geochimie et Cosmochimie and two samples for dissolved and total Nd in the Mediterranean waters by the CNES laboratory in Toulouse.

Station	Pressures of Samples Taken					
D13374	10	75	201	255		
D13375	13	76	246	330		
D13381	13	23	52	110		
D13382	350	200				
D13383	18	77				
D13386	13*	53*	102*	202*	330*	604*
D13390	400	780	(Bulk sample for Nd)			
D13394	10	439				
D13396	12	102	350*			
D13397	12					
D13400	12*	32	42*	52	74*	
D13401	16	47	69	100		
D13404	20	76	119	160	200	265
D13405	15*	80	100			
D13406	10	55	120	195		
D13411	27*	102*	152*	202*	275	414

* Os sample also taken

ACOUSTIC CORRELATION CURRENT PROFILER

Background

The Acoustic Correlation Current Profiler (ACCP) is a pre-production instrument from RD Instruments, San Diego that was first installed on RRS *Discovery* in February 1995 for cruise 214. While some oceanographic data have been gathered with the instrument and a number of engineering evaluation papers and articles have been written, its performance as a current profiler on *Discovery* has been disappointing. In particular, it has not been able to achieve its specified current profiling range under even moderate ship speeds. The ACCP is still an experimental instrument, only three exist, and the other two units, one with RDI and one with the US Navy on the USS *Dolphin* research submarine have proved less problematic.

The passage from Southampton to Algeciras at the start of this cruise provided the perfect opportunity for two of RDI's staff intimately familiar with the ACCP signal processing and hardware to witness the poor performance and to find solutions. The dreadful weather on leaving port hampered to some extent the shallow water trials on the UK continental shelf, but we were able to establish unequivocally that the poor performance was not due to electrical interference, it was neither broadband electrical noise nor narrow band interference. This in itself was a major step forward.

Operations

Overnight on day 6-7 April, near 45° 29' N 8° 15' W in the Bay of Biscay, we demonstrated that the ACCP could bottom track in 4840 m of water at speeds of 0 to 4 kt. Clearly the transmitter and signal processing algorithms were functioning correctly. We believe this to be a range record for any type of velocity log in bottom track mode.

From first switching on the ACCP at Empress Dock in Southampton, the high signal level from the receivers was of concern to the RDI staff. Signal level is displayed as 'Received Signal Strength Indicator' (RSSI) in logarithmic units (counts) of 0.42 dB. In RDI's experience the instrument noise level should be below 14 counts, with any external acoustic noise received by the transducer from any source adding to this baseline. At Empress Dock the level was 40 - 60 counts. This high level did not drop when the ship left dock, rather it increased. It soon became clear that there was not a single reason for the counts being so high, rather a number of factors contributed to the high noise. In turn, the high noise was the cause of the instrument's poor profiling range. If we can understand and minimise the sources of noise then our conclusion is that the instrument has the inherent ability to meet its specification - the installation and environment rather than the instrument are the main limiting factors.

Noise Sources

Over the five day passage we identified a number of acoustic noise sources and classified them as internal to the instrument, ship generated, or external (from the ocean). Our observations are summarised in Tables 9 and 10. Although not a complete analysis of the noise problems in the installation we can conclude with some confidence that:

a) The instrument, signal processing, electronics and electrical installation work well and are likely to meet their specifications under ideal operating conditions.

b) These ideal operating conditions are not present on RRS *Discovery*; the ship has several internal sources of noise that preclude the ACCP meeting its specification. While some of these noise sources can be switched off, some can not. The winch noise is especially troublesome in that it degrades ACCP performance on station, when other sources such flow noise and ship motion should be substantially reduced.

Results

While the major objective for this cruise was a thorough investigation of the ACCP operating environment we did gather water profiling and bottom track data continuously from 11 - 19 April when in the study area (Griffiths, Bradley and Murdock, 1999). Bottom track data were compared daily with ship velocity computed from differential Global Positioning System (DGPS) positions over a range of bottom types and ship speeds from zero to 14 kt over the ground. Daily data return depended on bottom type and much of the Strait provided near specular reflections rather than true backscatter. Unfortunately, ACCP signal processing cannot compute the peak of the correlation function with accuracy when it is very broad as happens under specular reflection. Thus, daily returns varied from 47% to 88% of possible one minute ensembles with an average of 66%. Specular reflection also reduced data return when we attempted a bottom track run over the Seine abyssal plain at 4300 m on day 19 April.

A simple regression of the bottom track speed from the ACCP against DGPS over 5110 one minute ensembles from day 96 to 105, in water depths from 100 to 4800 m yielded:

$$S_{\text{accp}} = 0.9883\ S_{\text{dgps}} - 3.11 \qquad \text{(speed in cm/s)}$$

with a standard error of the slope of ± 0.00089, a standard error of the intercept of ± 0.36 and a correlation coefficient of 0.9979.

Bottom track was maintained far more frequently than on *Discovery* cruise 224 in the Alboran Sea. An irrecoverable bottom track loss only happened once. Compared to the Simrad EA500 precision echo sounder the depth readings from the ACCP showed a higher variation, but there were a number of occasions when the ACCP provided better performance than the EA500.

The ACCP deck unit connects to the synchro gyro signals to obtain heading for conversion of ship-relative to earth velocity components. The output east and north velocities therefore include any gyro error as well as any static misalignment of the transducer in its well. In bottom tracking mode it should be possible to compare the heading inferred from the ACCP with that from DGPS and to compare the difference between the two to the gyrocompass error determined from the Ashtech ADU2 GPS receiver. By limiting the data to a narrow band of latitude (35 - 37°) and speeds above 200 cm/s we were able to compare the two estimates of gyro error as a function of heading. While the heading from the ACCP is far noisier than from the ADU2, with a standard error of the mean in 30° bins of 0.2° in contrast to less than 0.05° for the ADU2, the characteristics of the heading dependent error were observed. The correlation coefficient between the two estimates was 0.655 which was significant at the 5% level for a set of observations with 11 degrees of freedom. The static misalignment was estimated to be 2.8° counter-clockwise of true.

Further work ashore will be needed on the water track data to estimate their accuracy. The data set will inevitably be limited by the problem in the upper 200 m and the range reduction due to the noise sources tabulated here.

G. Griffiths, S. Bradley and G. Murdock

TABLE 9 Ship noise sources affecting the ACCP and their characteristics.

Noise source	Characteristic	Effect / amplitude
CTD winch hydraulics	Raised RSSI level from broadband continuous interference	Effect depends on mode: a) Winch on, wire at rest - gives an RSSI increase of ca. 10 counts b) Paying out - RSSI increases with wire out, from ca. 20 count increase at 100 m to a 50 count increase at 5000 m at 1 m/s. Slower payout reduces noise. Data return & quality greatly degraded. c) Hauling produces a near constant noise increase of ca. 30 counts at 1 m/s irrespective of wire out. Data return degraded but usable.
Bow thruster	Raised RSSI from broadband noise	Noted on station as ca. 4-8 count increase above ambient when winch noise was not present. Lower than winch noise.
Propeller	Noise varying with blade frequency (rpm*no. blades/60)	Apparent at times of low noise, not easy to separate from ship motion induced noise underway.
Bridge echo sounder	Periodic narrowband spikes, several per second. The Skipper GDS101 operates at 38 kHz with 1kW.	ca. 25 count - degrades performance. Can be switched off unless required for navigation. Also interferes with EK500.
EA500 echo sounder	Periodic narrowband spikes - carrier at 10 kHz, less frequent pulses, transducers further away in a towfish so less important that the bridge echo sounder.	ca. 50 count spikes when superimposed on a ca. 30 count baseline, but performance not greatly reduced. Cannot be switched off - essential data source.

Roll stabiliser	Pulses at varying spacing of several per second, often grouped, correlating with the audible 'bang-bang' of the roll stabiliser.	Significantly degrades performance, pulses last for 10's to 100's of milliseconds, amplitudes to ca 30 counts were frequent. Roll stabiliser can be switched off.
Ship motion through a wave field.	Raised RSSI, strongly interacts with sea noise due to waves breaking, bubble clouds etc.	A significant effect - complicated through interaction with the sea state - would require a project in own right to quantify.
Oceano release transmitter	Short spikes in a group giving rise to long decay times, even when transmitted from the towfish.	Degrade data quality, levels of up to 100 counts above ambient; very.
Water, fuel and stabiliser tanks.	While these are not active noise sources, we believe that these part full tanks of water or fuel may be acting as broadband echo chambers. Since its installation, this ACCP has suffered from poor performance in the upper 200 m, unknown in the other two units/installations.	We suspect that the transmission pulse of the ACCP couples to these broadband echo chambers which in turn leak a signal to the receivers for a significant time after the transmission pulse has ended. The ACCP sees this 'echo' of the transmission signal (at zero Doppler) decaying with time as a decaying signal in range. It is an observed characteristic of this peculiar interference that the correlation matrix at delay τ shows each transducer element to be receiving a broadband signal but totally uncorrelated with its neighbours. We do not yet understand this behaviour

TABLE 10 Environmental Noise

Noise source	Characteristic	Effect / amplitude
Empress Dock - alongside	Raised RSSI, slowly varying, industrial sources most likely and ship generated acoustic noise reverberating the shallow water.	30 - 60 counts rather than the < 14 counts achievable from RDI experience in a quiet environment.
Sea noise	breaking waves bubble clouds Langmuir	These sources (a) act as noise sources capable of increasing RSSI to 90+, thereby preventing any signal reception because of noise masking and (b) can result in a (thin?) bubble layer close to the transducer face that completely masks any received signal during that ping and, possibly, for a number of subsequent pings. In this case, the RSSI can read low (ca 20 counts for instance), as the bubble layer screens the transducer from other external noise sources.
Sea noise interacting with the ship	Ship interaction with sea noise is complex and variable.	Ship pitching down seems to be correlated with lower numbers of 'valid' pings, possibly with a lag, from bubbles generated that flow across the transducer face. This may be predisposed by the presence of large bubble clouds ahead of the ship's track.

Shipping	At 22 kHz local shipping is a source of noise. During calm conditions, at times of low ship noise (no winch, thruster etc.) and low speed in the Strait of Gibraltar the minimum RSSI remained above 30 counts. We presume due to a background noise from the heavy shipping through the Strait. A dramatic decrease in the noise level (minimum achievable RSSI) was observed when we departed the working area towards Tenerife, this occurred on crossing the 500 m iso- bath to the west of Morocco at ~ 35 43'N 6° 36'W.	Raised RSSI limiting profiling range. This fall of ca. 50 counts happened: - at a steady speed of 12 kt during a steady course - as bottom depth increased from 500 m to 1000 m - further increase in bottom depth to 4000 m had little additional effect. When we requested a reduction in ship speed to 3 kt the minimum RSSI was found to be 14 counts - exactly as observed by RDI in the quiet deep waters off San Diego.
Rain	Likely to be a source of noise but could not be quantified on this occasion.	

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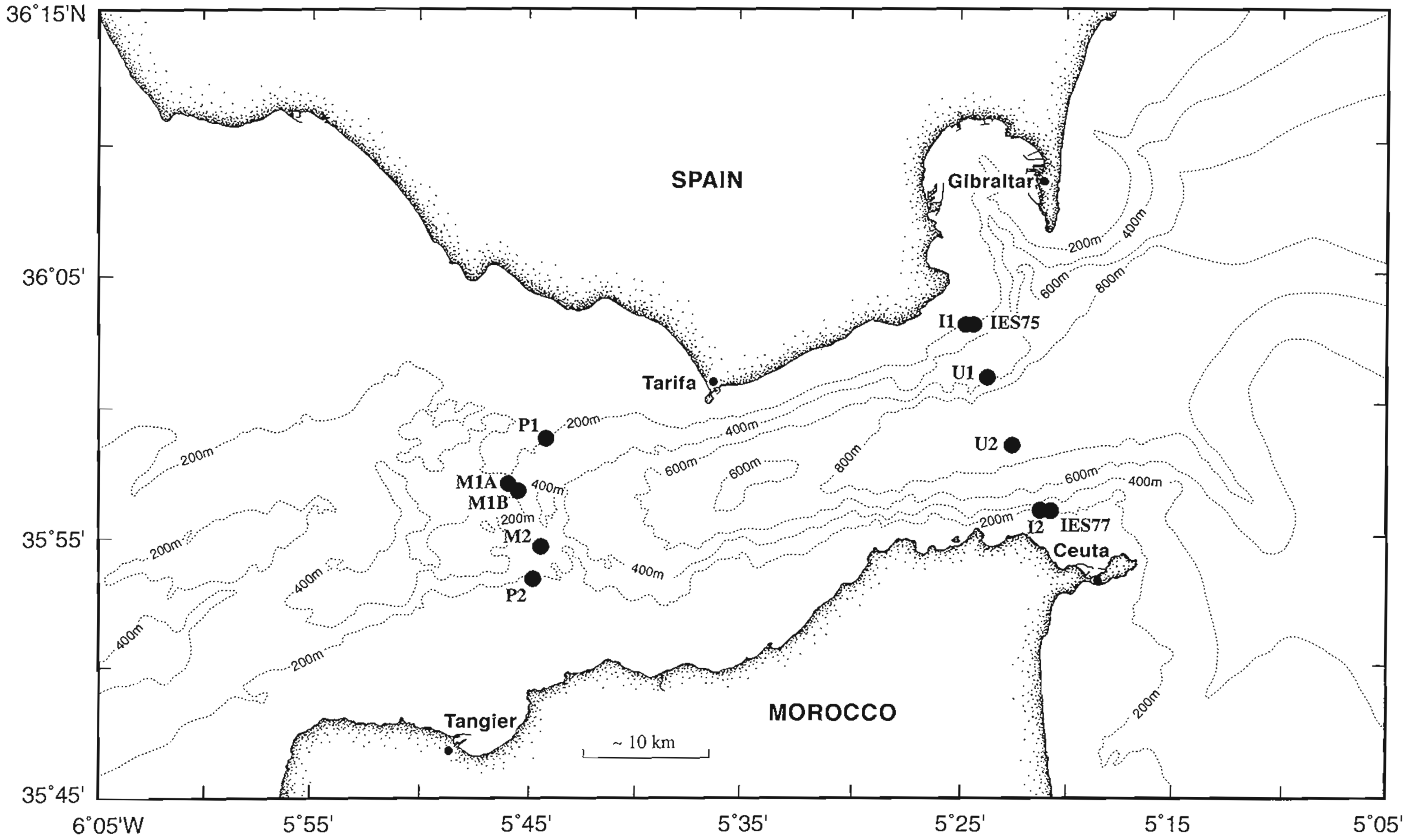

Figure 1a. Location of Moorings for Recovery during *Discovery* Cruise 232 April 1998

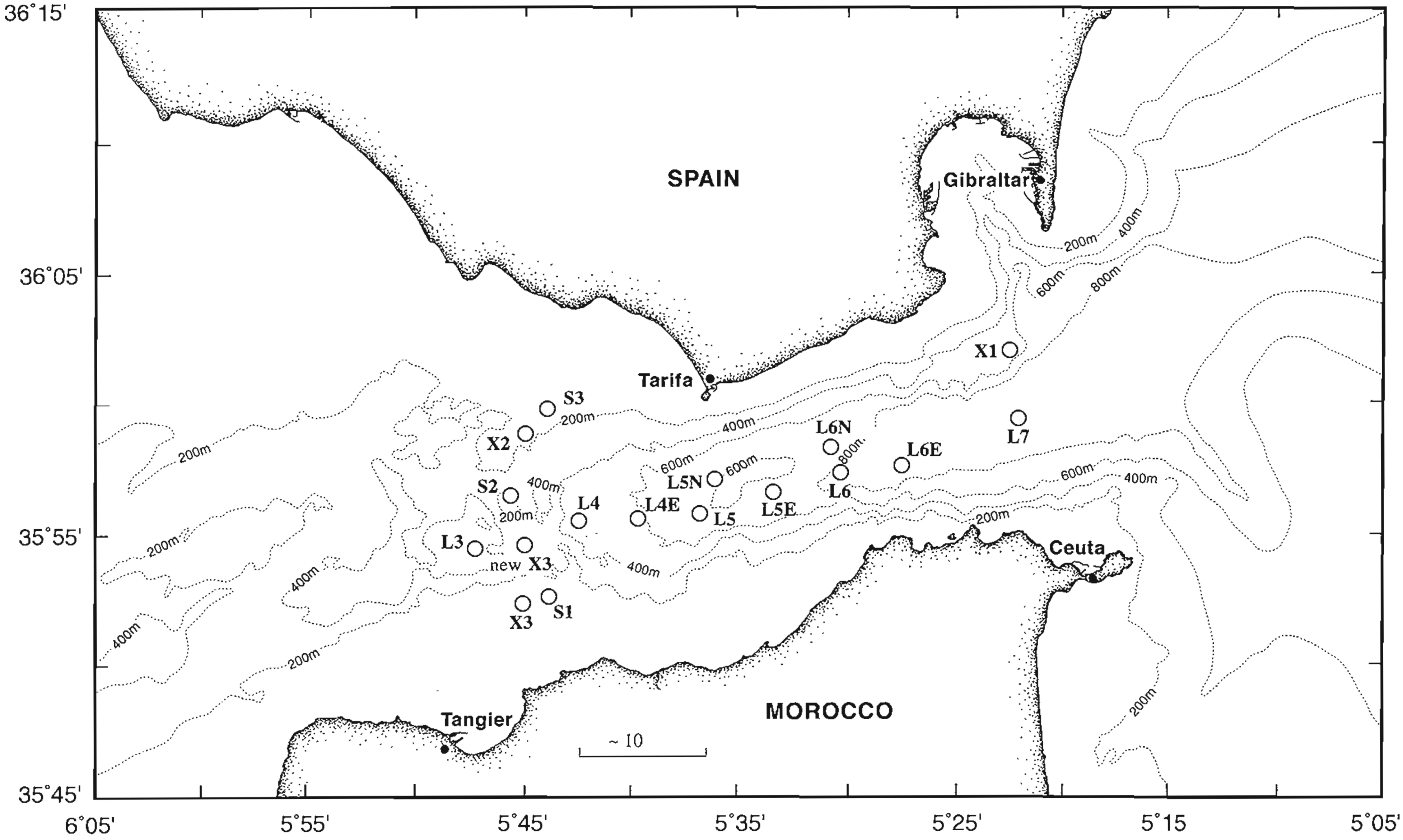

Figure 1b. Location of Underway Profiling Stations during *Discovery* Cruise 232 April 1998

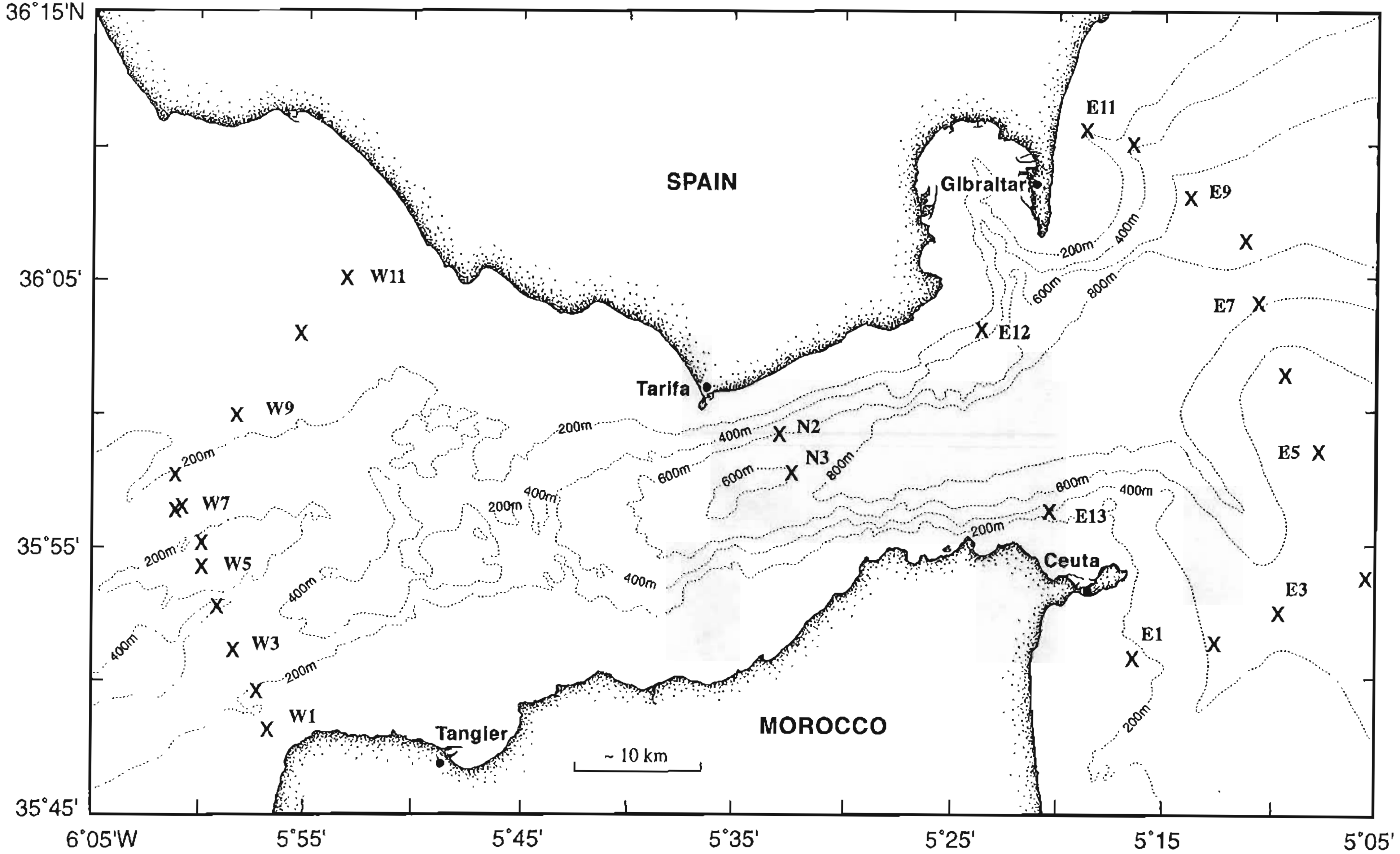

Figure 1c. Location of Hydrographic Stations during *Discovery* Cruise 232 April 1999

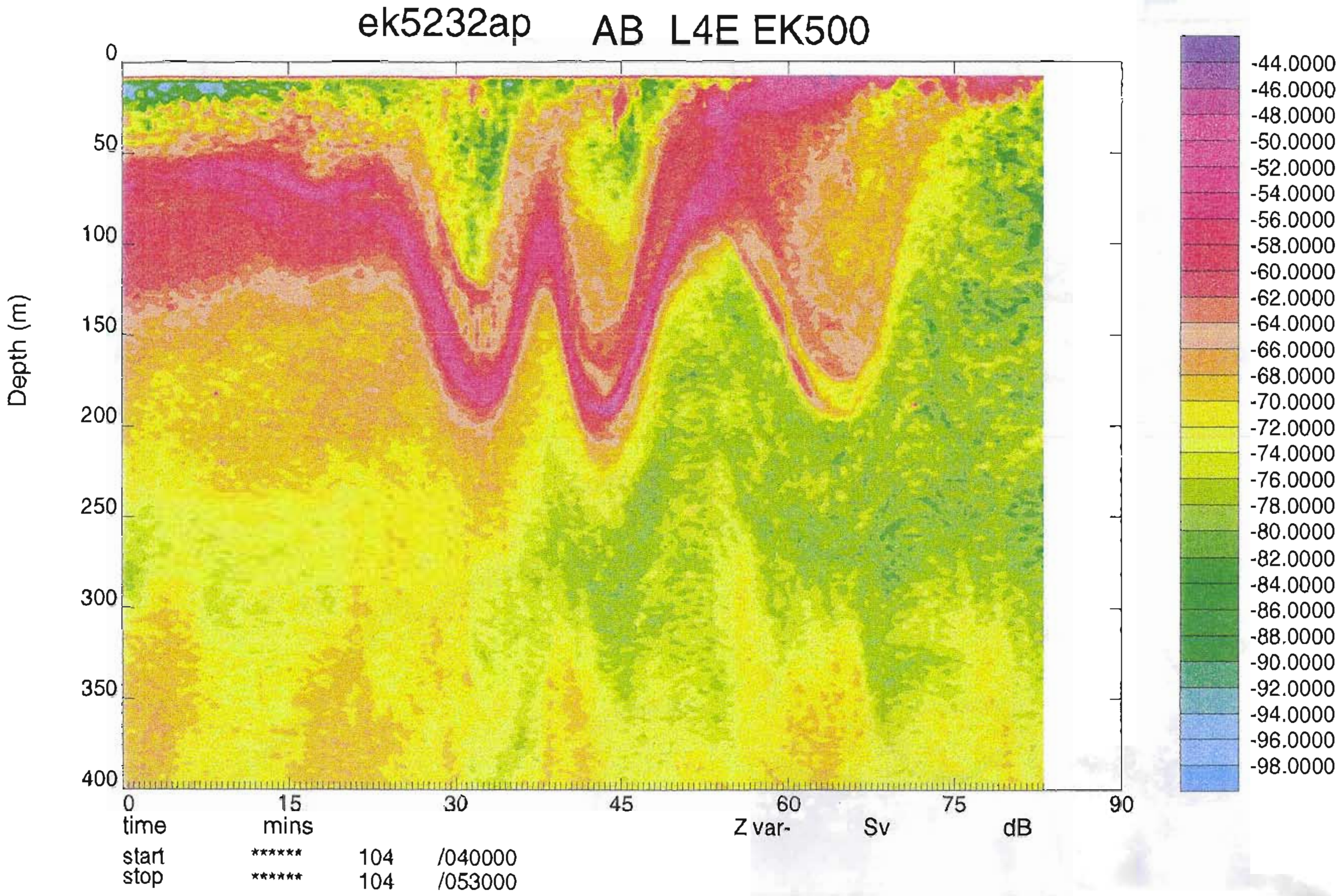

Figure 2. Backscatter intensity (dB) for 38 KHz EK500 underway sampling in the Strait of Gibraltar at L4E on 14 April between 0400 and 0530.

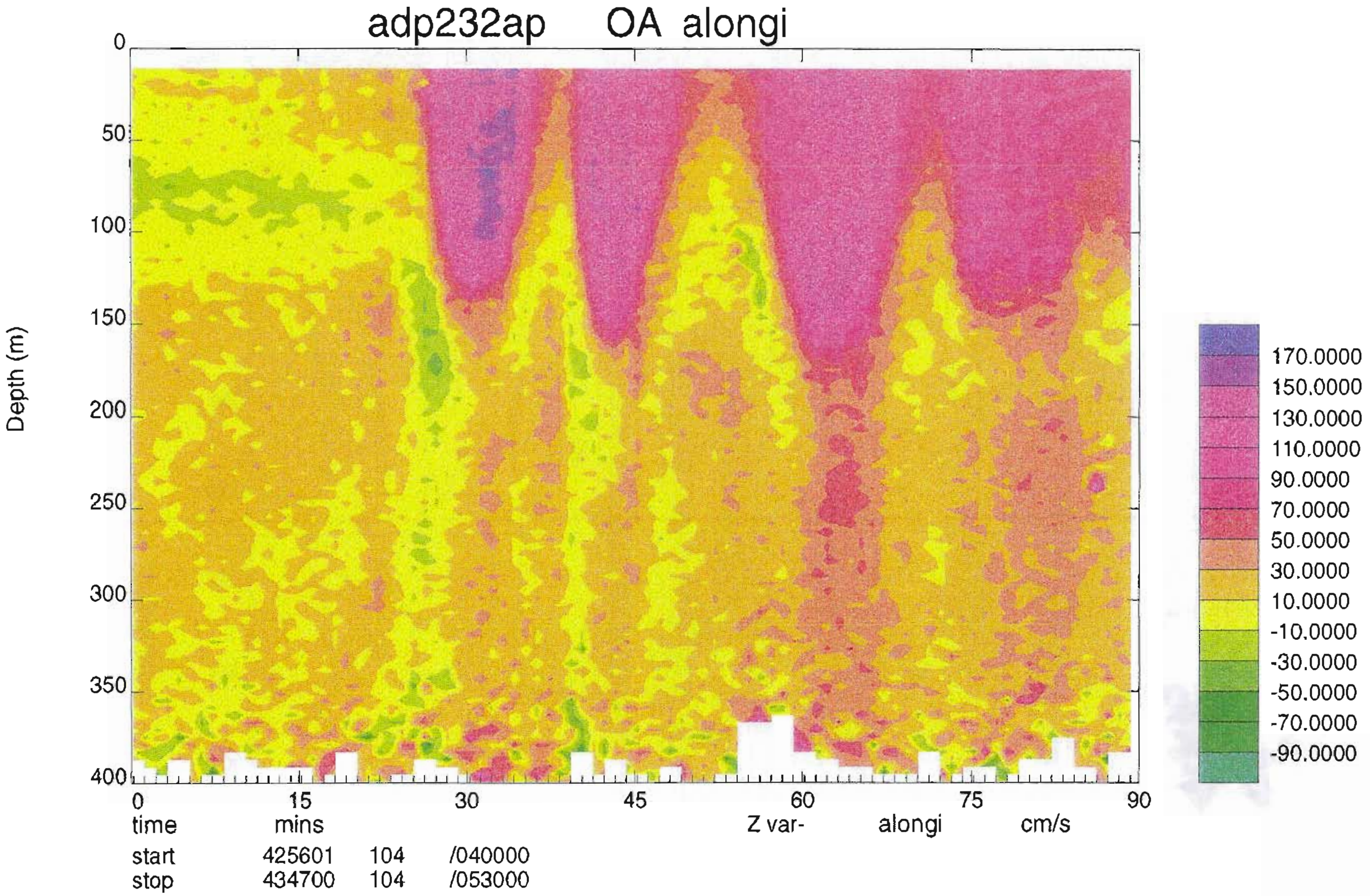

Figure 3. Alongstrait (77°T) Velocity (cm/sec) from underway ADCP sampling in the Strait of Gibraltar at L4E on 14 April between 0400 and 0530.

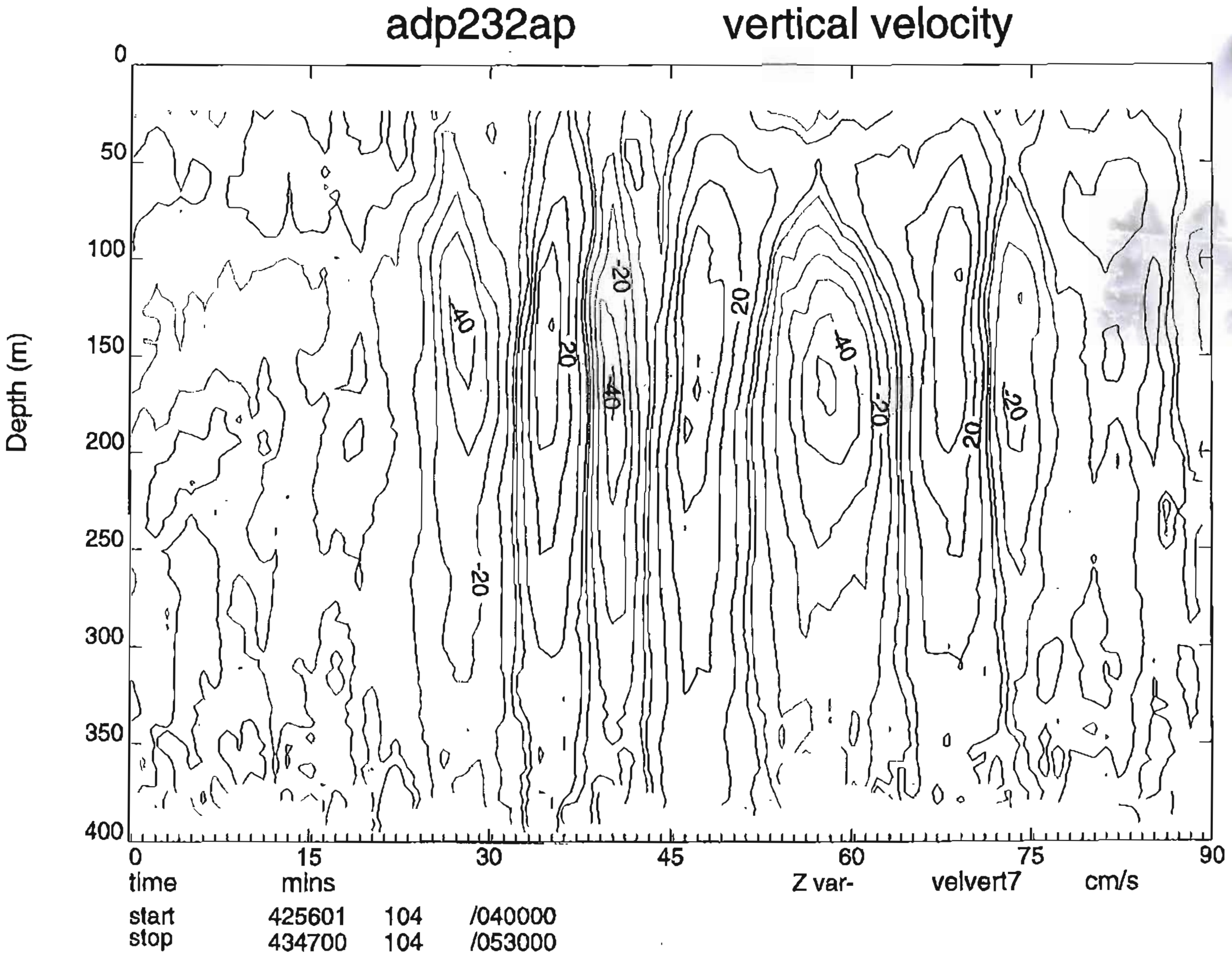

Figure 4. Vertical Velocity (cm/sec) from underway ADCP sampling in the Strait of Gibraltar at L4E on 14 April 1999 between 0400 and 0530