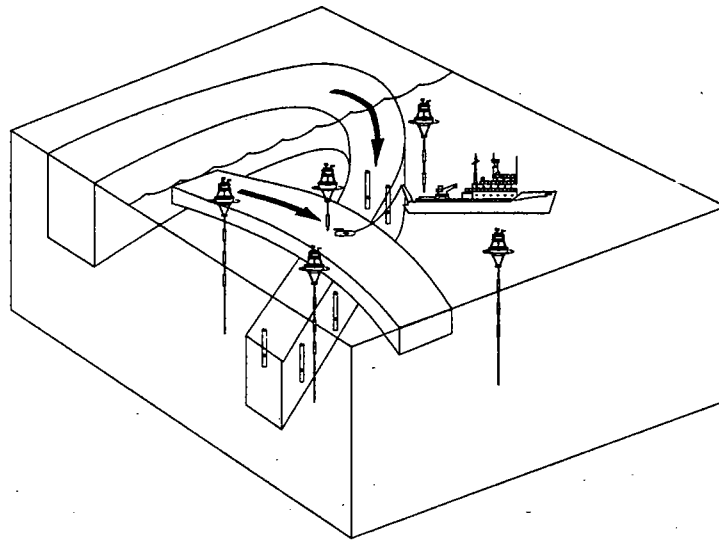




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## The Subduction Experiment



**Cruise Report**  
**RRS *Charles Darwin***  
**Cruise Number 73**  
**Subduction 3 Mooring Deployment and Recovery Cruise**  
**30 September – 26 October 1992**

by

Richard P. Trask  
William Jenkins  
Jeffrey Sherman  
Neil McPhee  
William Ostrom  
Richard Payne

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Upper Ocean Processes Group  
UOP Technical Report 93-3

**WHOI-93-18  
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March 1993

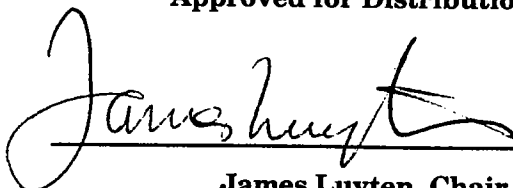
**Technical Report**

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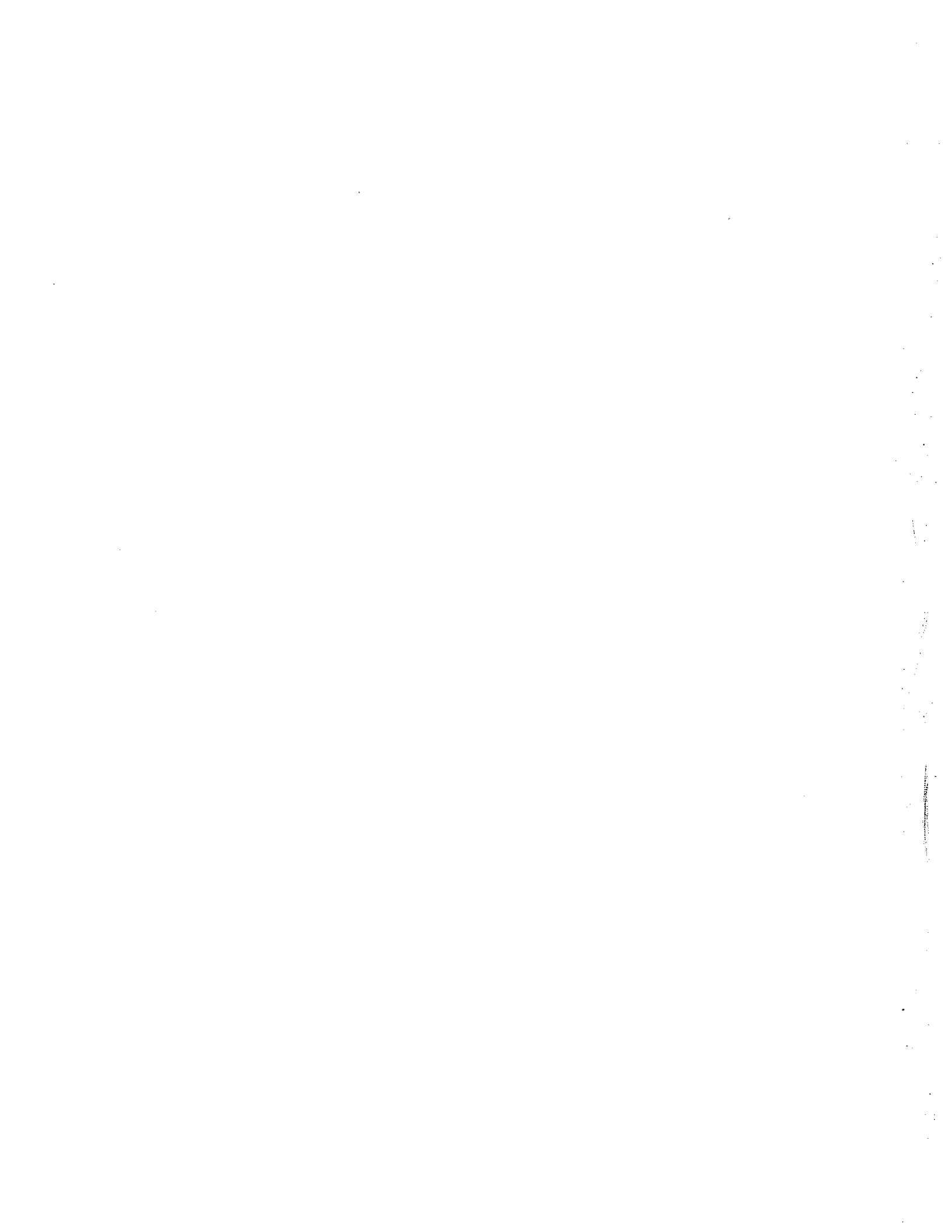
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**James Luyten, Chair**  
Department of Physical Oceanography





## Abstract

Subduction is the mechanism by which water masses formed in the mixed layer and near the surface of the ocean find their way into the upper thermocline. The subduction process and its underlying mechanisms were studied through a combination of Eulerian and Lagrangian measurements of velocity, measurements of tracer distributions and hydrographic properties and modeling.

An array of five surface moorings carrying meteorological and oceanographic instrumentation were deployed for a period of two years beginning in June 1991 as part of an Office of Naval Research (ONR) funded Subduction experiment. Three eight month deployments were planned. The moorings were deployed at 18°N 34°W, 18°N 22°W, 25.5°N 29°W, 33°N 22°W and 33°N 34°W.

A Vector Averaging Wind Recorder (VAWR) and an Improved Meteorological Recorder (IMET) collected wind speed and wind direction, sea surface temperature, air temperature, short wave radiation, barometric pressure and relative humidity. The IMET also measured precipitation. The moorings were heavily instrumented below the surface with Vector Measuring Current Meters (VMCM) and single point temperature recorders.

Expendable bathythermograph (XBT) data were collected and meteorological observations were made while transiting between mooring locations. In addition a series of 59 CTD stations were made and water samples taken to be analyzed for tritium levels, salinity and dissolved oxygen content.

This report describes the work that took place during RRS Charles Darwin cruise number 73 which was the third scheduled Subduction mooring cruise. During this cruise the second setting of the moorings were recovered and redeployed for a third eight month period. This report includes a description of the instrumentation that was deployed and recovered, has information about the underway measurements (XBT and meteorological observations) that were made including plots of the data, includes a description of the work conducted in conjunction with the tracer/hydrography program and presents a chronology of the cruise events.

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# Section 1: Introduction

The RRS Charles Darwin departed Funchal, Madeira at 0910 UTC on Wednesday, 30 September, 1992 for a joint Physical Oceanography and Chemistry cruise. This was the third of four scheduled mooring cruises planned for this experiment (figure 1). The purpose of this cruise was to recover and redeploy five surface moorings deployed in February 1992 as part of the ONR funded ASTEX and Subduction experiments. In conjunction with the mooring work a series of 59 CTD stations were made and water samples taken to be analyzed for tritium levels, salinity and dissolved oxygen content. Hourly XBTs and meteorological observations were also made.

The cruise involved personnel and equipment from both the Woods Hole Oceanographic Institution (WHOI) and Scripps Institution of Oceanography (SIO). Appendix 1 lists the cruise participants. Figure 2 shows the cruise track and the mooring locations. The moorings recovered during this cruise were the second setting of the array and were known as Subduction 2. Table 1 lists the Subduction 2 mooring positions and the dates they were deployed and recovered. Table 2 lists the deployment positions and dates for the moorings deployed during this cruise which is the third setting, known as Subduction 3. For completeness the Subduction 1 mooring positions and deployment dates are included in Table 3. Figure 1 shows the mooring cruise schedule for the entire Subduction experiment. (See Trask and Brink, 1993 and Trask et al., 1993 for information about the first and second Subduction mooring cruises, respectively.)

This report has in addition to this introduction three sections. The second section describes the mooring program including the instrumentation that was deployed and recovered, as well as the underway measurements that were made including XBT profiles and meteorological observations. The third section describes the tracer/ hydrography program and the fourth section is a chronology of the entire cruise.

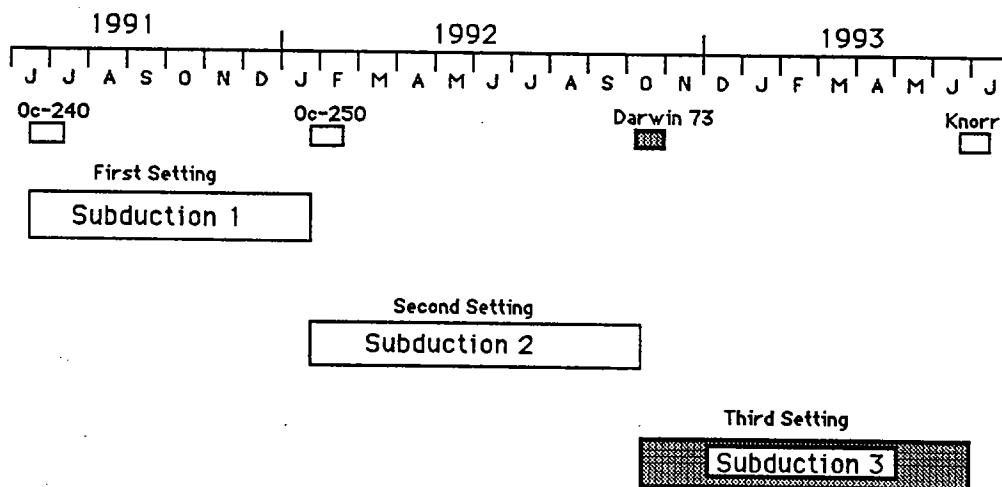
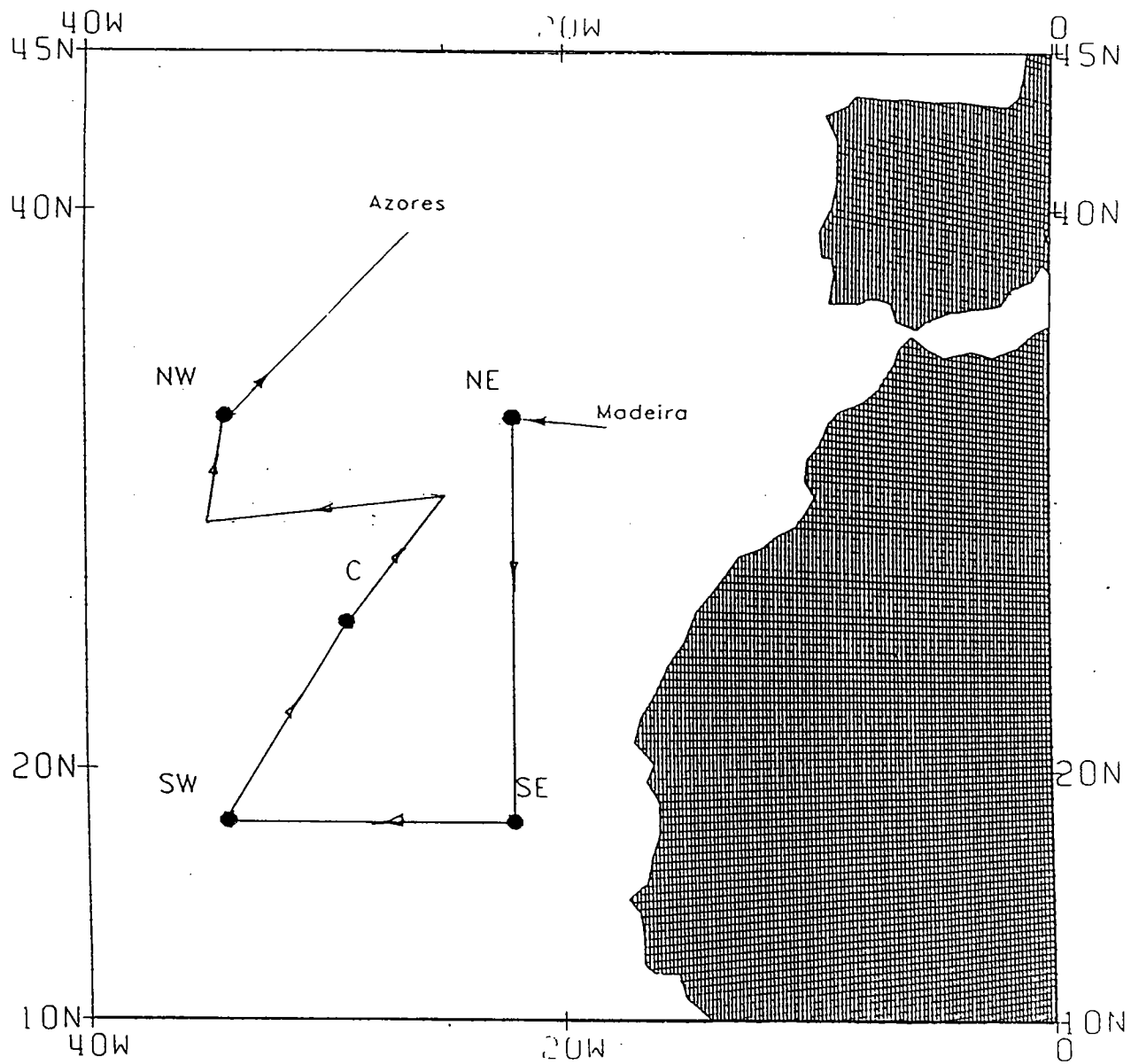


Figure 1. Mooring Cruise Schedule

Figure 2. Darwin 73 Cruise track and mooring positions.



**Table 1**  
**Subduction 2 Mooring Deployment Dates and Positions**

Buoy	Mooring Number	Deployment Date and Time (UTC)	Recovery	Position (GPS)
SW*	924	5 Feb 92 @1318		17°59.93'N 34°00.65'W
SE	925	9 Feb 92 @ 0244	6 Oct 92 @1759	17°59.72'W 22°00.29'W
C	926	12 Feb 92 @ 1915	14 Oct 92 @1203	25°31.95'N 28°57.23'W
NE	927	20 Feb 92 @ 1547	1 Oct 92 @ 1857	33°01.98'N 22°00.27'W
NW	928	23 Feb92 @ 2328	23 Oct 92 @ 0912	32°54.42'N 33°53.35'W

\*SW Parted 4 June 92, Toroid with upper instrument cage recovered 17 July 92  
Unsuccessful dragging attempt during DARWIN cruise 73.

**Table 2**  
**Subduction 3 Mooring Deployment Dates and Positions**

Buoy	Mooring Number	Deployment Date and Time (UTC)	Position (GPS)
SW	954	11 October 1992 @ 1846	18° 05.57'N 33° 53.97'W
SE	953	7 October 1992 @ 1157	17° 57.71'W 22° 02.77'W
C	955	15 October 1992 @ 1023	25° 31.93'N 28° 56.52'W
NE	952	2 October 1992 @ 1449	33° 01.80'N 21° 59.39'W
NW	956	24 October 1992 @ 0017	32° 54.38'N 33° 53.58'W

**Table 3**  
**Subduction 1 Mooring Deployments and Positions**

Buoy	Mooring #	Deployment Time (UTC)	Recovery Time (UTC)	Position(GPS)
NE	914	18 Jun 1991 1642	14 Feb 1992 2315	33° 00.07'N 21° 59.75'W
C	915	23 Jun 1991 0026	11 Feb 1992 1120	25° 31.90'N 28° 57.17'W
SW	916	25 Jun 1991 1312	2 Feb 1992 0727 4 Feb 1992 1844 *	18° 00.03'N 33° 59.96'W
SE	917	29 Jun 1991 0137	30 Oct 1991 0000 8 Feb 1992 0843**	18° 00.13'N 22° 00.00'W
NW	918	3 Jul 1991 1323	15 Sept 1991 2035 23 Feb 1992 1022***	32° 54.61'N 33° 53.50'W

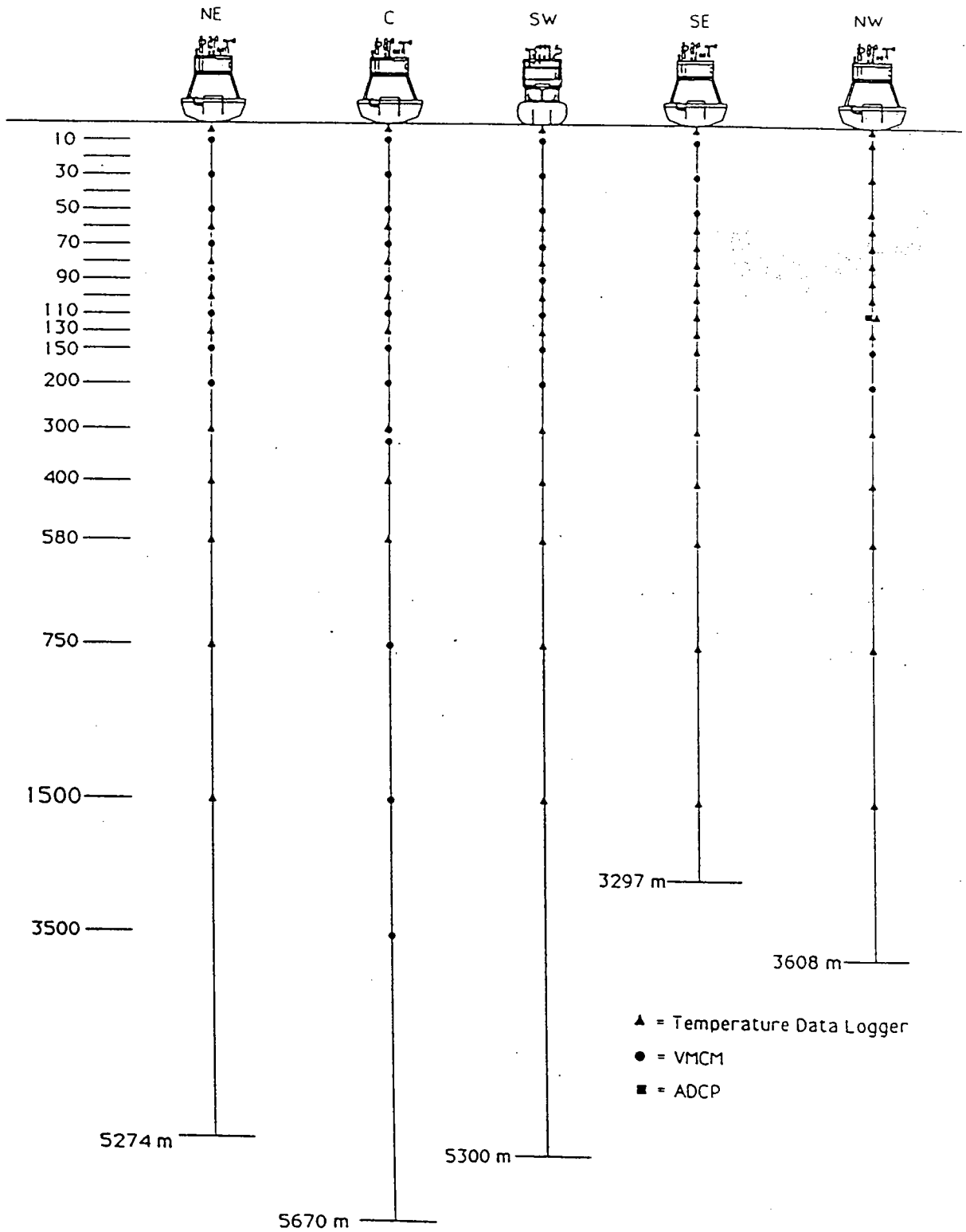
- \* SW Mooring broke free on 3 November 1991. Top 110m recovered 2 February 1992  
remainder of mooring recovered 4 February 1992.
- \*\* SE Mooring broke free on 10 October 1991. Top 50m recovered on 30 October 1991  
remainder of mooring recovered 8 February 1992
- \*\*\* NW Mooring broke free on 3 August 1991. Top 400m recovered 15 September 1991  
remainder of mooring recovered 23 February 1992

## Section 2: The Mooring Program

### A. Mooring and Buoys

The goal of the mooring program conducted during Darwin cruise number 73 was to recover five moorings that were deployed during R/V Oceanus cruise number 250 in February 1992 and deploy replacement moorings. The five surface moorings deployed in February included two WHOI moorings designated Central and Northeast and 3 SIO moorings designated Southeast, Southwest and Northwest. The Central, Northeast, Southeast and Northwest moorings were deployed with WHOI 10' diameter discus buoys and the Southwest mooring had a SIO 7'6" diameter toroid buoy. Additional buoyancy was provided to the toroid by means of a large boat fender that was inserted in the center hole of the toroid and inflated. Figure 3 schematically shows all five moorings and the distribution of the Subduction 2 and 3 subsurface instrumentation.

Figure 3. Subduction 2 and 3 Mooring Instrument Placements



Meteorological instrumentation was mounted on both toroid and discus buoys. A two part aluminum tower was attached to both buoy types. The top half, which has the meteorological sensors, marine lantern and satellite antennae was the same for both buoy types so as to minimize the differences between buoys and to facilitate assembly. The lower half was specific to the buoy type and acted as an interface between the buoy hull and tower top. The tower tops were separate assemblies so that they could easily be replaced with new units containing freshly calibrated sensors when the moorings were recovered and redeployed.

On 4 June, 1992 the Southwest mooring parted and the toroid buoy went adrift. The buoy was tracked via satellite and eventually recovered by NOAA vessel Malcolm Baldrige on 12 July 1992. The only component suspended below the buoy at the time of recovery was a damaged load cage from the uppermost current meter. The cage had apparently failed causing the toroid buoy to go adrift. The cause of the cage failure is unknown. Since cage failures are uncommon one can speculate that the mooring may have been tampered with or inadvertently became entangled with fishing gear and pulled beyond its load capability.

Attempts to recover the portion of the failed Southwest mooring still on station were unsuccessful during Darwin cruise 73. The acoustic release on the mooring would not release when commanded. The release could be interrogated without difficulty; however, when a release command was sent it would not release the mooring nor return confirmation of release. A dragging attempt was made but without success. The location of the mooring was surveyed carefully in the event that a future attempt at dragging is possible. Details of the dragging attempt during Darwin cruise 73 can be found in the cruise chronology section of this report.

## **B. Instrumentation**

A total of 102 recording instruments were deployed on the five Subduction 3 moorings. There were 9 meteorological packages, 34 current meters, 58 temperature data loggers, and one Acoustic Doppler Current Profiler. The specific instrumentation deployed during the third setting of the Subduction array is shown in table 4. For reference purposes the instrumentation on the first and second settings are shown in tables 5 and 6 respectively.

### **Meteorological Instrumentation**

Each discus buoy was outfitted with two separate meteorological instruments. One system was a Vector Averaging Wind Recorder (VAWR) which recorded measurements of wind speed and direction, air temperature, relative humidity, barometric pressure, sea surface temperature, short wave radiation, and long wave radiation. Additional information about the VAWR can be found in Trask et al. (1989). The other meteorological package was an IMET system which made measurements of the same variables as the VAWR plus precipitation. The IMET systems on the second Subduction deployment did not measure longwave radiation but it was included on the third deployment. Both the VAWR and IMET systems individually recorded all data internally as well as telemeter their data via Argos. The VAWR stored its data on cassette tape every 15 minutes, and the IMET system recorded on optical disk every minute.

**Table 4.**  
**Subduction 3 Instrumentation**

Depth	NE	C	SW	SE	NW
VAWR IMET	V-721WR	V-121WR	V-720WR	V-704WR	V-722WR
1	W-3283	W-3279	W-3297	W-3305	W-3262
10	VM-038	VM-032	SVM-02	SVM-06	S-3306
30	VM-021	VM-018	SVM-22	VM-022	W-3341
50	VM-012	VM-024	SVM-07	SVM-20	W-4492
60	W-4488	W-3303	S-2432	W-4481	W-2541
70	VM-033	VM-030	SVM-23	S-2418	W-2537
80	W-3259	W-4489	W-2539	S-2436	W-3665
90	VM-037	VM-028	SVM-13	S-2428	W-2533
100	W-4485	W-3265	W-4487	S-2422	W-3274
110	VM-041	VM-039	SVM-4	S-2420	ADCP-185
130	W-4482	W-3280	S-2421	S-2424	W-3309 S-3710
150	VM-015	VM-009	SVM-24	S-2437	VM-014
200	VM-016	VM-034	SVM-19	S-2433	SVM-03
300	W-4493	VM-035	S-2435	S-2425	S-3270
310		VM-027			
400	S-3302	W-4491	S-3295	S-3312	S-3314
580	S-3311	W-3662	W-2542	W-4490	S-3307
750	S-3378	VM-036	S-3292	S-3275	S-3708
1500	S-3281	VM-011	W-4483	W-3271	S-3304
3500		VM-045			

W-# = WHOI Brancker Temperature Recorder  
S-# = SIO Brancker Temperature Recorder  
VM-# = WHOI Vector Measuring Current Meter  
SVM-# = SIO Vector Measuring Current Meter

**Table 5**  
**Subduction 1 Instrumentation**

Depth	NE	C	SW	SE	NW
VAWR IMET	V-704WR	V-722WR	V-720WR	V-721WR	V-121WR
10	VM-041	VM-035	SVM-04	SVM-12	S-3285
20	TEST STING1				TEST STING2
30	VM-021	VM-033	SVM-07	VM-007	S-3315
40	TEST STING3				
50	VM-039	VM-024	SVM-06	SVM-16	S-3294
60	W-3274	W-3309	S-3314	W-3297	W-3262
70	VM-032	VM-012	SVM-22	S-3282	S-3313
80	W-3265	W-3308	W-3279	S-3270	S-3260
90	VM-022	VM-038	SVM-02	S-3298	S-3261
100	W-3288	W-3296	W-3303	S-3284	W-3258
110	VM-030	VM-009	SVM-05	S-2425	ADCP
130	W-3269	W-3280	S-2427	S-2432	S-3277 S-2434
150	VM-028	VM-037	SVM-20	S-2418	SVM-11
200	VM-018	VM-016	SVM-13	S-2424	SVM-10
206	COND				
300	W-3300	W-3289	S-2435	S-2433	S-2421
400	W-3305	W-3283	S-2437	S-2422	S-2431
580	W-3268	W-3271	W-3341	W-3290	W-3272
750	W-3286	VM-015	S-2436	S-2426	S-2420
1500 3490 3500	W-3293	VM-034 TENS 1029 VM-011	W-3287	W-3259	W-3273

W-# = WHOI Brancker Temperature Recorder  
 S-# = SIO Brancker Temperature Recorder  
 VM-# = WHOI Vector Measuring Current Meter  
 SVM-# = SIO Vector Measuring Current Meter



**Table 6**  
**Subduction 2 Instrumentation**

Depth	NE	C	SW	SE	NW
VAWR IMET	V-380WR	V-712WR	V-713WR	V-707WR	V-717WR
1	W-3507	W-3506	W-3665	W-3704	W-3508
10	VM-034	VM-002	SVM-01	SVM-03	S-3709
30	VM-027	VM-023	SVM-16	VM-010	W-3274
50	VM-036	VM-020	SVM-08	SVM-17	W-3288
60	W-2539	W-2541	S-3285	W-3279	W-3296
70	VM-014	VM-013	SVM-15	S-3707	W-3309
80	W-2542	W-2534	W-3263	S-3261	W-3269
90	VM-045	VM-019	SVM-14	S-3706	W-2536
100	W-3280	W-2537	W-3291	S-3714	W-2540
110	VM-035	VM-008	SVM-12	S-3710	ADCP-195
130	W-3265	W-2538	S-3310	S-3294	W-2535 S-3313
150	VM-009	VM-026	SVM-11	S-3715	SVM-09
200	VM-011	VM-025	SVM-18	S-3708	SVM-21
300	S-3260	VM-017	S-3713	S-3712	S-3276
310		VM-031			
400	S-3711	W-2533	S-2430	S-2423	S-3277
580	S-3298	W-3262	W-3299	W-3303	S-3316
750	S-2426	VM-029	S-2429	S-2434	S-3282
1500	S-2427	VM-001	W-3258	W-3341	S-3284
3500		VM-003			

W-# = WHOI Brancker Temperature Recorder  
 S-# = SIO Brancker Temperature Recorder  
 VM-# = WHOI Vector Measuring Current Meter  
 SVM-# = SIO Vector Measuring Current Meter

For both the discus and toroid buoys the VAWR sensors (except sea temperature) and electronics with battery pack were attached to the tower top. The sea surface temperature sensors for both the VAWR and IMET systems were attached to the buoy bridle approximately 1 meter below the surface. All the other meteorological sensors were placed at the same heights on the tower tops as in Subduction 1 and 2 (Trask and Brink, 1993). During the second and third Subduction settings the Southwest toroid did not have an IMET system. The IMET sensors on all the discus buoys were configured the same and mounted on the tower top. The IMET electronics and rechargeable batteries were housed in the discus buoy water tight instrument well. Details regarding the IMET performance during the second setting can be found in Appendix 2.

### Current Meters

A total of 34 Vector Measuring Current Meters (VMCM) provided by both WHOI and SIO were deployed on the five Subduction 3 surface moorings. The 23 WHOI VMCMs were a modified version of the EG&G Sea Link instrument whereas the 11 SIO VMCMs were built by Scripps personnel. The sampling interval for the WHOI VMCMs was 7.5 minutes, and for the SIO VMCMs it was 15 minutes

The WHOI VMCMs incorporated several changes to the standard EG&G Sea Link product. These included different propeller bearings, a different plastic for the propeller blades, an external temperature pod for faster temperature response, and a redesign of the instrument cage. The cage redesign and external temperature pod is described in Trask et al. (1989) as is some historical information on propeller bearings and blade materials.

For the Subduction experiment the WHOI VMCMs in the upper 100 meters were outfitted with cages that had 3/4" diameter cage rods. The deeper instruments had cages with 1/2" cage rods. All cages had a single cross brace to support the sting between the two sets of propellers.

An alternative propeller bearing chosen for use in the Subduction experiment was an all silicon nitride ball bearing (SiNi balls and races with a Duroid ball retainer) available from Miniature Precision Bearing (MPB), of Keene, New Hampshire as part number J0001-809. This was selected over the typical stainless steel bearing based on previous test results, actual deployments and the fact that the eight month Subduction deployment would be 30% longer than most previous deployments.

The VMCM propellers used in the Subduction experiment were made of an unpigmented Delrin 100 ST which is impact modified.

The Subduction 2 VMCMs that were recovered during Darwin cruise number 73 were in excellent condition with respect to propeller bearings and blades. None of the propellers had broken blades and the silicon nitride bearings were like new. Two instruments (VM009 and VM011) that were recovered during this cruise had been in the water during both Subduction 1 and Subduction 2 with their original stings (propeller sensor assemblies). These instruments had a total deployment time of 16 months and were found to still be in excellent condition. VM009 and VM011 were both redeployed on the Central mooring at 150 and 1500 meters depth respectively for an additional eight months.

Appendix 3 has a complete listing of all the VMCMs used during the three Subduction settings. The listing shows the mooring and depth where each instrument was deployed for each of the three settings.

## Temperature Loggers

A total of 58 temperature data loggers manufactured by Richard Brancker Research Ltd. were provided by both WHOI and SIO for the five Subduction moorings. The locations of the loggers are shown in figure 3 and table 4. The loggers provided by WHOI were attached to the mooring line using a hinge type clamp that was tightened around the wire. The SIO clamping arrangement consisted of two 2-piece monel blocks which have been machined to accept the mooring wire. The two pieces were clamped around the wire with .25" hardware.

Several different temperature recorder models were deployed. The SIO 2000 series instruments sampled at 30 minute intervals. The WHOI 2000 series instruments which were modified for extra memory sampled at 15 minutes, and both the SIO and WHOI 3000 series instruments sampled at 15 minutes. The SIO 2000 series instruments had SIO fabricated pressure cases and endcaps. The WHOI 4000 series instruments were rebuilt XX-105 units that flooded during Subduction 1 and had new EPROMS. The sampling interval for the 4000 series instruments was the same as the 3000 series units.

A total of 15 temperature loggers recovered from the first Subduction setting during Oc-250 leaked a small quantity of water, and their data could not be read. In response to this problem while at sea the instruments that were deployed for the second setting had a vacuum drawn during assembly to better seat the O-rings. This procedure was adopted from SIO whose nearly identical temperature loggers did not display the problem as severely. In addition, the endcaps were tightened considerably more than previously deployed using a large adjustable wrench. The procedures adopted during Oc-250 proved worthwhile since none of the 25 WHOI instruments recovered during Darwin cruise 73 showed any signs of leaking.

In preparation for the third setting of instruments several changes were made to the Brancker temperature loggers. In addition to tightening the endcaps and drawing a vacuum, a new flexible nut assembly was incorporated into all the temperature loggers prepared in Woods Hole. The intent of the flexible nut was to correct for an out-of-square condition between the removable endcap and its threaded rod used to secure the endcap to the pressure case. The preparation of instruments also included spray coating all electronic boards with DOW Corning 1-2577 conformal coating to offer some resistance to moisture should the instruments leak a small quantity of water. The following Brancker serial numbers were modified to have the flexible nut assembly, and coated electronics boards: 3662, 4491, 4489, 3283, 4488, 3259, 4485, 4487, 3297, 3305, 4481, 4482, 4493, 4490, 4483, 3271, 4492, 3665.

Appendix 4 has a complete listing of all Brancker temperature recorders used during the three Subduction settings. The listing shows the mooring and depth where each instrument was deployed for each of the three settings.

## ALACE Float

One SIO Autonomous LAgrangian Circulation Explorers was deployed during Darwin cruise 73. It was deployed at position 25°19.36'N, 29°05.79'W on 14 October 1992 at 0508 UTC. A description of that instrument can be found in Appendix 5 of this report.

## C. Underway Measurements

### Expendable Bathythermographs (XBT)

Two hundred XBTs were deployed during Darwin cruise 73. The T-7 probes were purchased from Spartan of Canada. XBT data was logged on a NEC APC IV with a Spartan data acquisition microprocessor card. The digital data was simultaneously logged in memory and plotted on the screen. Problems with a drifting calibration were encountered early on resulting in XBT surface temperatures which differed from those taken by the bucket thermometer. After numerous attempts to find the cause of this problem the cable on the ship's hand held launcher was replaced with a new shielded cable. With this change the calibration became stable and the surface temperatures agreed with the surface bucket temperatures. Once the cable was replaced there were very few probes that failed to produce reasonable data. Unfortunately the first 48 probes were used prior to correcting the calibration problem. The last XBT drop occurred at 1100 UTC on 19 October 1992 at position 29° 06.36'N, 33° 56.17'W.

Hourly XBTs were taken on the hour while the ship was underway. If a scheduled XBT occurred within a half hour of a CTD station then the XBT was not taken. XBTs were also suspended when the ship was within 10 miles of a surface mooring. XBT positions and overplots of the XBT data can be found in Appendix 6.

### Meteorological Measurements

The primary source of high quality meteorological data on Darwin 73 was a Multimet system installed by Peter Taylor's group from Rennell Centre, Southampton. The Multimet sensors were installed on a foremast about 4 meters aft of the peak of the bow with most of the sensors located at a height of about 15 meters above the water line. Sensors on the foremast included an R.M. Young AQ anemometer, an Eppley pyrgeometer, two aspirated wet/dry bulb aspirated temperature units, and two Kipp and Zonen short wave pyranometers. All three radiation measuring sensors were mounted on gimbals. The pyrgeometer was near the top of the mast where it was unaffected by neighboring objects. The two pyranometers were located about 2 meters to port and starboard from the mast. The larger value was selected in the processing with the assumption that the larger had not been affected by the mast's shadow. The barometric pressure sensor was in the top lab with the processing and recording electronics package. The output of the ship's gyro was also recorded.

All parameters were averaged over the first 50 seconds of each minute. The time assigned to these values was that of the beginning of the minute. These one minute values of undecoded data were recorded on EPROM within the electronics package and on the ship's Sun-based data logging system.

All appropriate sensors were calibrated before and after the cruise. The calibrations were applied to the raw data in off line processing using a set of programs developed by the Taylor group. The processing used the navigation data recorded by the ship's logging system to correct the measured wind speed and direction for ship movement. The logged outputs of the ship's thermosalinograph were added to the final data files.

Manual meteorological observations were taken hourly on the half hour. The manual observations consisted of recording the time, position, ship's speed, ship's heading, wind speed and wind direction from the bridge readout, barometric pressure using an AIR hand held barometer, air temperature and relative humidity using a hand held Vaisala sensor, sea surface temperature and salinity as measured by the thermosalinograph (pumped from 5 meters depth), cloud type and cloud coverage in octas and bucket temperature. In addition the corresponding Multimet data was also recorded by hand.

Hourly on the hour in conjunction with XBTs the time, position, sea surface temperature and salinity from the thermosalinograph and bucket temperature were recorded.

## **Section 3: The Tracer/Hydrography Program**

### **A. Introduction and Purpose**

The purpose of this part of the cruise was to obtain a large scale mapping of the distribution of tritium-helium age, oxygen, salinity and temperature over the area of study. The tritium-helium age, deduced from the distributions of both tritium (the heaviest isotope of hydrogen) and its stable daughter product helium-3, can be regarded as a measure of elapsed time since water was at the ocean surface, and hence is a direct measure of the subduction rates of different water masses. By subduction, we mean the process by which water resident at the ocean surface enters the subsurface circulation of the great, subtropical ocean gyres. Subduction apparently takes place in several ways. The first is called Ekman Pumping, whereby water is forced downward by wind driven convergence of surface waters. The second is a form of "thermodynamic underthrusting", where southward flowing water at the base of the previous winter's mixing layer is buried under warmer, less deeply convecting surface layers. The third, associated with secondary vertical processes and mixing at current fronts (in particular, the Azores Front), we refer to as "frontal subduction". The first is computable from the large scale wind fields, coupled with more-or-less well understood upper ocean physics. The limitation of this calculation is the quality and availability of good wind observations over the ocean (hence the need for the meteorological moorings in the Subduction Experiment). The second has only recently been recognized as an important process, and has been estimated by a combination of upper ocean circulation fields and the topography of the winter mixed layer depths. The third is by far the most difficult to assess and predict, and is probably only addressable from tracer and tritium-helium age measurements. We suspect that all three processes play an important role in subduction. Indeed, this is supported by observations of tracer distributions and the tritium-helium age fields. The goal of the Tracer/Hydrography component of the Subduction Experiment is evaluate the relative contributions of these mechanisms, and to characterize the subsurface circulation and mixing.

## B. Sampling Scheme

The stations sampled are shown in figure 4. A total of 59 stations were taken. Logistically, we were constrained to sample largely on the cruise tracks between the mooring sites, but a central "Z" shaped excursion was included to obtain mapping across important tritium-helium age gradients and flow lines. Because the overall goals and subject study of the mooring programme are the same as the tracer/hydrography programme, the cruise track is close to optimal for our purposes. The track may be divided into four major sections:

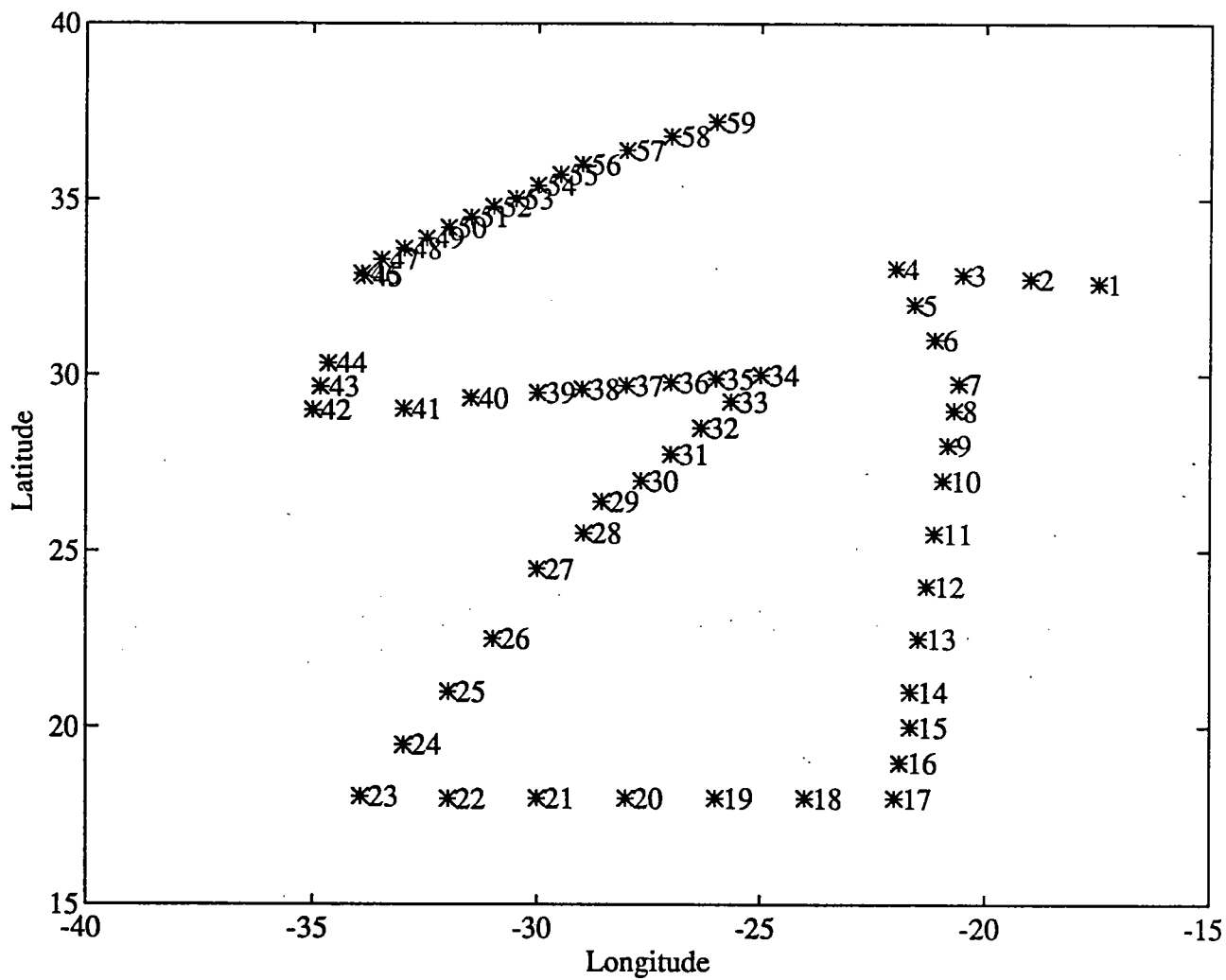
- a meridional section along 22 W (stations 4-17) cutting through the large scale flow stagnation point and penetrating into the confluence between southward flowing subtropical and northward flowing tropical waters
- diagonal section (stations 23-34) extending "upstream" into the tongue of subducting waters
- two sections (stations 34-42, and stations 45-59) transecting the southward veering subtropical gyre circulation

The last of these sections is perhaps the most critical, in that it provides the only means or directly assessing the frontal subduction component. The means by which this can be done is by determining the directional rotation of tritium-helium age isochrons relative to the mean streamlines.

## C. Sampling Procedures and Techniques

Water samples were obtained from a 12 place, 10 litre Niskin Bottle rosette sampler with a Neil Brown CTD. Typical stations were to 500 metres depth, with occasional sampling to 1000 or 2000 metres. Sampling was primarily done over the potential density anomaly range of 26.0 to 26.9 kg/m<sup>3</sup>, with "supporting sampling" done above and below these levels. Salinity, oxygen, helium and tritium samples were drawn from the Niskins on deck. Salinity samples were measured using a Guildline AutoSalinometer bridge calibrated with IAPSO standard water ampoules. Oxygen measurements were by high precision Modified Winklet Titrations using an automated dosimat with electrode end point determination. The helium and tritium samples were drawn into 90 cc stainless steel sample cylinders with O-ring sealed plug valves on either end. The helium was extracted into 25 cc glass ampoules (Corning type 1724, low He-permeability aluminosilicate glass) using a hot-extraction technique in an all metal UHV vacuum system. Tritium samples were degassed in 200 cc glass flasks (again Corning type 1724 glass) on a separate UHV system. Both UHV systems were cryo- and diffusion pumped, instrumented with convectron and ion vacuum gauges, and operated with computer controlled solenoid/pneumatic valves. The subsequently obtained samples are being returned to WHOI for shore-based mass spectrometric analysis of helium and tritium. The tritium will be determined by helium-3 regrowth techniques, after an incubation period of one year.

Figure 4. Tracer/Hydrography Station Plan



## D. Preliminary Hydrographic Results

Since they require shore-based analytical procedures, the tritium-helium data are currently unavailable. We do, however, have some preliminary hydrographic (temperature, salinity and dissolved oxygen) data. Figure 5, for example, is a contour plot of temperature vs depth along the central (diagonal) section, with north on the right. The isotherms, particularly warmer than 18 degrees, show the dominant southward deepening associated with subduction. Surface waters show a banded structure, with front-like southward increases in temperature at about the 1600 and 200 km positions. At the extreme southward end, the deep isotherms turn upward, characterizing the westward flowing limb of the subtropical gyre circulation.

The zonal banding is even more evident in the salinity distribution shown in figure 6, which is a surface plot of salinity vs depth and distance along the same section. Aside from the 100-200 km oscillation, the shallow salinity is domes upward in the middle of the section due to the high salinity cell created by the high E-V trade winds. A subtle subsurface bulge in the salinity surface (most evident at about 100-150 metres in the southern end of the section) is an imprint of the subducting waters, known further west as the Subtropical Underwater. Deeper down, the influence of Antarctic Intermediate water can be seen in the southern end of the section at 500 metres (note how the surface dips downward).

The southern water influence is also seen in the oxygen surface (figure 7) for this section, where the deep oxygen concentrations dip to about 2 ml/l. This is an artifact of the large tongues of low oxygen water protruding from the coast of Africa. A striking feature of the oxygen distribution shown here is the subsurface photosynthetic oxygen maximum at about 60-100 metres. This feature attenuates southward and eastward, reflecting geographic variations in new primary production, which result from changing patterns of nutrient recycling.

## Section 4: Cruise Chronology

The RRS Charles Darwin left Funchal Madeira on 30 September 1992 at 0910 UTC. While enroute to the Northeast mooring, one deep (3000 meter) and 2 shallow (500 meter) CTD stations were taken.

### Northeast Mooring

The Darwin arrived at the Northeast buoy at 1420 UTC on Thursday 1 October 1992 at position 33°01.81'N, 21° 59.52'W. Figure 8 is a schematic of the Northeast Subduction 2 mooring (WHOI mooring number 927) as deployed in February 1992. As the ship passed by the buoy it appeared in good condition and photographs were taken. The ship then moved to a position .25 miles downwind of the surface buoy and remained there for four hours while meteorological observations were recorded every five minutes. With the meteorological observations completed the ship moved into position for recovery. The discus buoy was alongside and hooked into at 1912 UTC. At this point the buoy had to be led aft around to the stern gantry. The ship took too long to pass by the buoy and as a result the buoy got caught under a shelf on the starboard quarter outboard of the rail. Repeated contact with the ship as it slowly passed aft caused excessive damage to the buoy



