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RRS *DISCOVERY* CRUISE 214
26 FEB-09 MAR 1995

Agulhas Current Experiment

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ABSTRACT

Six moorings with a total of 26 current meters were deployed in the Agulhas Current as it flows southwestward in the Indian Ocean along the continental slope off South Africa. The moorings were specifically designed to maintain their integrity in strong currents with faired wire, large (rather than distributed) buoyancy elements and heavy, fluked anchors. Two of the moorings in the strongest parts of the Current included Acoustic Doppler Current Profilers (ADCP's) at approximately 400m depth to profile upward the currents at 8m intervals throughout the upper 400m of the water column.

A closely spaced CTD section consisting of 14 stations (plus one test station) within 220 km of the African coast was taken in order to determine the geostrophic transport of the Agulhas Current. A novel aspect of the CTD stations was the mounting of an ADCP on the CTD frame so that the velocities at each station could be measured directly from surface to bottom and back to the surface. This technique, called Lowered ADCP or LADCP, resulted in full-depth velocity profiles for each of the 14 CTD stations.

To provide reference level velocities for geostrophic calculations, continuous underway measurements using the ship-mounted ADCP were carried out to measure the currents in the upper 300m of the water column. During the cruise, these underway ADCP measurements were combined with Global Positioning Satellite (GPS) navigation to determine velocities at 10-minute intervals with an error of approximately 10 cm s^{-1}.

A pre-production instrument, called an Acoustic Correlation Current Profiler (ACCP), was mounted in *Discovery's* hull in Durban and extensive tests of its profiling capabilitites were carried out during the cruise. Early comparisons with underway ADCP measurements and with LADCP measurements during CTD stations suggests that the ACCP has the potential to profile accurately down to depths of approximately 1200m.

KEYWORDS

ACCP
ACOUSTIC CORRELATION CURRENT PROFILER
ADCP
AGULHAS CURRENT
COUNTRYGB
CRUISE 214 1995
CTD OBSERVATIONS
"DISCOVERY"
LADCP
LOWERED ADCP
MOORINGS
WOCE

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Table 1a. Scientists participating aboard RRS *Discovery* Cruise 214 and their affiliations.

Name	Institution
BRYDEN, H. L.	James Rennell Centre
BACON, S.	James Rennell Centre
BEAL, L.	Southampton University
BONNER, R. N.	Institute of Oceanographic Sciences
BRANDON, M.	Scott Polar Research Institute
COOPER, J.	University of Cape Town
CRISP, N. A.	Institute of Oceanographic Sciences
CUNNINGHAM, S. A.	James Rennell Centre
DUPEE, B.	James Rennell Centre
FORRESTER, T. N.	James Rennell Centre
GOY, K. M.	Institute of Oceanographic Sciences
GRIFFITHS, G.	Institute of Oceanographic Sciences
GRIFFITHS, M. J.	James Rennell Centre
HARTMAN, M. C.	Institute of Oceanographic Sciences
KEENE, S. B.	Institute of Oceanographic Sciences
MASON, P.	Research Vessel Services
NGUYEN, T.	RD Instruments
PHIPPS, R.	Research Vessel Services
ROUAULT, M.	University of Cape Town
SUPER, B.	Sea Fisheries Research Institute
SPAIN, P.	RD Instruments
TAYLOR, A.	Research Vessel Services
TOKMAKIAN, R.	Naval Postgraduate School
VALENTINE, H.	University of Cape Town
WADDINGTON, I.	Institute of Oceanographic Sciences
WATSON, G.	Kyoto University
WYNER, J.	Research Vessel Services

Table 1b. Personnel aboard RRS *Discovery* Cruise 214 and their ranks.

Name	Rank
LONG, G. M.	Master
CHAMBERLAIN, R. J.	Chief Officer
SYKES, S.	2nd Officer
CROFT, M.	3rd Officer
DONALDSON, B.	Radio Officer
ADAMS, A. P.	Chief Engineer
MCDONALD, B. J.	2nd Engineer
BELL, S. J.	3rd Engineer
PARKER, P. G.	Electrician
POOK, G. A.	CPO(D)
LEWIS, T. G.	PO(D)
PERKINS, J. R.	S1A
OLDS, A. E.	S1B
HEBSON, H. R.	S1A
AVERY, R. W. G.	S1A
CRABB, G.	S1A
ELLIOTT, C. J.	SCM
SWENSON, J. J. E.	Chef
SMITH, L. V.	SM
ROBINSON, P. W.	Steward
DUNCAN, A. S.	Steward
BRIDGE, A. M.	MM

ITINERARY

Depart Durban, 26 February 1995 - Arrive Cape Town 9 March 1995

OBJECTIVES

The Agulhas Current is the thermocline western boundary current for the South Indian Ocean. The Agulhas Current has long been considered to be the strongest of the Southern Hemisphere western boundary currents and perhaps second only to the Gulf Stream in transport among all western boundary currents. Direct measurements of its size and temporal variability, however, have never been made; and arguments over the appropriate choice of reference level for geostrophic transport estimates from hydrographic sections have led to a range of transport values from 35 to 95 Sv for the region where it closely follows the African continental slope. An accurate estimate of the transport of the Agulhas Current represents a key for defining the large-scale circulation of the Indian Ocean including its heat and fresh-water fluxes and the size of its meridional overturning circulation.

During 1995, there is an intense international programme to study the circulation of the Indian Ocean as part of the World Ocean Circulation Experiment (WOCE). As a U.K. contribution to this international Indian Ocean programme, we developed a plan to deploy an array of moored current meters across the Agulhas Current in order to measure the transport of the Agulhas Current and its temporal variability over a year-long period. Thus, the primary objective for *Discovery* Cruise 214 was to deploy this array of moored current meters.

The second objective of the cruise was to make a hydrographic section across the Agulhas Current in order to determine the geostrophic transport of the Current. To avoid the problems of choosing a reference level that have confounded previous synoptic estimates of the Agulhas Current transport, we made an effort to utilise new and developing acoustic profiling methods to measure directly the velocity structure of the Agulhas Current during the cruise. The new method that provided the fundamental velocity measurements is underway ADCP profiling utilising GPS navigation, which Saunders and King (1995) used to such advantage on the transatlantic section A11. After the cruise, we hoped to utilise data from nearby land stations to postprocess the GPS measurements using differential GPS (DGPS) techniques to increase the accuracy of the underway ADCP measurements by an order of magnitude to less than 1 cm s^{-1} for 10-minute average velocities, following the methods pioneered by King, Alderson and Cromwell (1995). Thus, with these underway ADCP measurements and DGPS navigation techniques, we hoped to have accurate enough measures of the velocity structure in the upper 300m of the water column to make an accurate estimate of the synoptic geostrophic transport of the Agulhas Current for the first time.

In addition, for this cruise we prepared two developmental acoustic profiling techniques to help define the velocity structure of the Agulhas Current. First, we prepared a mounting for an ADCP on the CTD/Rosette frame so that surface-to-bottom lowered ADCP (LADCP) velocity measurements could be obtained at each CTD station. Secondly, we collaborated with RD Instruments to obtain and install in *Discovery's* hull just prior to the cruise a pre-production instrument called an Acoustic Correlation Current Profiler (ACCP). The specifications for the ACCP indicated that it may be able to profile continuously down from the surface to a depth of approximately 1200m. Testing and intercomparing the three new and developing acoustic profiling techniques made up the third objective for *Discovery* Cruise 214.

References

Griffiths, G., B. Dupee, G. Watson, P. Spain and T. Nguyen. 1995. Trials and evaluation of an RD Instruments Acoustic Correlation Current Profiler in the Agulhas Current on RRS Discovery Cruise 214, Institute of Oceanographic Sciences Internal Document 349, 61p.

King, B. A., S. G. Alderson and D. Cromwell. 1995. Enhancement of shipboard ADCP data using DGPS position and GPS heading measurements, *Deep-Sea Research*, submitted.

Saunders, P. M., and B. A. King. 1995. Bottom currents derived from a shipborne ADCP on WOCE cruise A11 in the South Atlantic, *Journal of Physical Oceanography*, 25, 329-347.

NARRATIVE

While moored in Durban harbour, navigation data were collected for the purpose of inspecting the noise baseline of the onboard satellite positioning systems. RRS *Discovery* left Durban on 26 February 1995 (JDAY 057) at 1300 Z about a day behind schedule, the delay being due to the late arrival of essential air freight. The work area was a section at a bearing of 130°T starting on the South African continental shelf near Port Edward, about 80 nm south-westwards down the coast from Durban. The run down the coast was used for ADCP calibration in bottom-tracking mode in water depths between 50 m and 200 m and was taken in a nearly straight line from off Durban (1400 Z) to off Port Edward (2030 Z). The ship was then turned inshore until a water depth of about 50 m was reached, when an acoustic survey offshore along the work line was begun. The purpose of this survey was to provide in-situ bathymetry and ADCP and ACCP current profiles across the Agulhas Current to define the structure of the current core for accurate positioning of the moorings. In order to ensure high quality acoustic current profiles, ship speed was maintained at a steady 5 kn over the ground. This line survey began at 2100 Z and continued until 2100 Z the following day (058, 27 Feb.), after which the first two CTD/LADCP casts were carried out (stations 1 and 2) as systems tests, ending about 0330 Z (059, 28 Feb.).

The ship then made for the first mooring site (mooring F), arriving about 0700 Z. Deployment and position fixing was completed by 1400 Z, after which there were four hours of acoustic current profiling close by the mooring position (1430-1820 Z). CTD stations 3 and 4 were carried out during night on the offshore and inshore sides (respectively) of mooring F, to enable intercomparison of ACCP, ADCP profiles around the site of mooring F with geostrophy and LADCP across the mooring and, ultimately, with the mooring itself. This work started about 1945 Z (059, 28 Feb.) and concluded about 0340 Z (060, 1 Mar.), when way was made for the site of mooring E. Mooring E was laid during the morning and fixed with 2 beam passes in increasingly foul weather, which curtailed the third beam pass before completion. The strong winds prevented further work that day. About 0230 Z the following day (061, 2 Mar.), course was set to return to the work line, when a profiling run was made across the site of mooring D, which was laid and fixed in the late morning and afternoon of that day. During the night between about 1910 Z until 0215 Z (062, 3 Mar.), two more CTD profiles were carried out (numbers 5 and 6), bracketing the previous day's mooring position (E) as before. Immediately following these stations was an ACCP calibration run, executed in what were intended to be reciprocal paths but the track more resembled a butterfly shape due to the strong current. This test finished about 0440 Z, when way was made to the site of mooring C, the laying and fixing of which finished in mid-afternoon. Two more ACCP calibration runs followed, for speed and bottom tracking, which began about 1525 Z and finished about 2215 Z. CTDs 7 and 8 were carried out overnight, between about 2335 Z (062, 3 Mar.) and 0735 Z (063, 4 Mar.), bracketing mooring D. During the day, mooring B was laid and fixed; in the evening, station 9 was completed (2020 - 2300 Z), followed by station 10 (0255 - 0500 Z, 064, 5 Mar.), bracketing mooring C.

During the day (064, 5 Mar.), the last mooring (A) was laid and fixed. This was followed by an intensive period of CTD/LADCP stations, in which 5 casts (11-15) were completed between 1145 Z and 1230 Z the next day (065, 6 Mar.) to bracket the remaining moorings and to fill in the CTD section for geostrophic transport estimates. The last activity in the work area was a water-track ADCP zig-zag of 3 hours duration in 6 legs, finishing at 1530 Z, after which course was set for Cape Town. The ADCP was switched to bottom track when over the shallow water of the Agulhas bank at 0910 Z (066, 7 Mar.). *Discovery* arrived outside Cape Town harbour at 0600Z on 9 March ((068) and docked at 0800Z.

The weather had been fine and warm, with sea surface temperatures about 26°C and hot days, apart from 16 hours of high winds and foul weather. The participating scientists and ship's personnel are listed in Table 1. A brief chronology of daily events is included as Table 2. Figure 1a shows the overall cruise track for *Discovery* Cruise 214 and Figure 1b shows the detailed cruise track back and forth along the work line. Finally, Figure 2 shows the bathymetry, current meter mooring configuration and CTD/LADCP station positions on the principal section perpendicular to the South African coast off Port Edward.

Table 2. Brief chronology for *Discovery* Cruise 214, 26 February to 9 March 1995

26 February	Depart Durban 1300Z ADCP Bottom Track Calibration
27 February	Acoustic Profiling across Agulhas Current CTD Test Stations 1 and 2
28 February	Mooring F Deployment ADCP/ACCP Profiling near Mooring F CTD3 and CTD4 either side of Mooring F
1 March	Mooring E Deployment Sudden storm halts CTD operations
2 March	Mooring D Deployment CTD5 and CTD6 either side of Mooring E
3 March	ACCP Reciprocal Course Test Mooring C Deployment ACCP Speed Calibration Test CTD wire pinched, 50m cut off and reterminated ACCP Boomer Test
4 March	CTD7 and CTD8 either side of Mooring D Mooring B Deployment Acoustic Profiling across the core of the current
5 March	CTD9 and CTD10 on either side of Mooring C Mooring A Deployment CTD 11, 12, and 13 up onto the shelf Acoustic profiling across Agulhas Current
6 March	CTD14 and CTD15 at offshore edge Zig Zag deep water ADCP orientation test Steam to Cape Town began at 1500Z
7 March	Steaming toward Cape Town Underway ADCP and ACCP Profiling One XBT at inshore edge of Agulhas Current
8 March	Steaming toward Cape Town Underway ADCP and ACCP Profiling until 1800Z
9 March	Arrive Cape Town 0800Z

MOORINGS

I. Waddington and K. Goy

Six moorings were to be deployed for the experiment (Figure 3). The topography was determined on the outward run from Durban along a transect into deep water after which the positions and depths for all moorings were planned.

The moorings had been designed at IOSDL (ACE Technical Report 1, IOSDL Internal Report to be produced) and equipment purchased from UK and US sources. WHOI provided the majority of mooring lines and fittings and IOSDL provided the adjustment lines and instrument fittings. The IOSDL mooring team and ships crew carried out all deployments with the ship's crew preparing wires for the next mooring as required. An assortment of extra wire lengths was made up to enable depth adjustments to be made just before final deployment. All navigation was taken from the ships GPS system using the bridge plotter when deploying and renavigating over the mooring after deployment. Deployment plots were obtained from the ship's RVS-best navigation with depths plotted as available.

Deployment commenced on day 59 with **Mooring F** (Figure 4f, Table 3f), planned for deployment on flat topography. The mooring was deployed buoy first from the IOSDL double-barrel Capstan with the fairing attached to the wire outboard of the deployment sheave. An attempt was made to pre-attach the fairing beneath the subsurface buoy before deployment. This was not satisfactory as the fairing became detached due to the line bend as the line was hand-deployed. Deployment followed standard IOSDL techniques developed over the previous three years with the exception of the anchor drop, as the anchor was a WHOI Mace type. The anchor was lifted outboard using the starboard crane with a YOYO hook. The technique worked well; however, with the YOYO attached in the crane hook, as the load was released the hook came out of the crane hook and catapulted back onto the deck . This was later found to be a failure of the crane hook latch. Mooring descent was monitored on an IOSDL Waterfall display and touchdown and bottom separation observed. The ship then steamed various courses monitoring the pinger to obtain best position from beam-ons. With the best position established, the vessel proceeded to the position and lay to whilst all remote acoustic functions were tested. On completion of the tests, all acoustics were turned off as the vessel left the area.

Table 3a. Checklist for deployment of ACE Mooring A

ACE MOORING 800 metre check list and deployment sheet				**Mooring A**
Deployed RRS Discovery	**Day 64 - 1995**	**5th March 1995**		
Item	Type	Length	Time In	Comment
IOSDL Steel Sphere	50" Dia Yellow/brown		6:26	Dacron tether
Chain	2m of 1/2" WHOI			
Swivel	S/S IOSDL			
Faired mooring wire	WHOI 3/16"	20m		white
FSI ACM Coastal	1351		6:33	
Faired mooring wire	WHOI + Endeco fair	100m		white
FSI Coastal	1349		6:46	
Faired mooring wire	WHOI + Endeco fair	200m		white
Aanderaa IOS7	10852		7:12	Rf 0655
Mooring Wire	WHOI	300m		
Aanderaa RVS8	11615			Rf 0721
Swivel	S/S			
Chain	1/2"	1m		
RT661 + B2S doubler	RT 235 & 232			RT232 Ping on
Mooring Wire	WHOI 1/4"	70m		
Nylon	WHOI Plait	20m		
Chain	1/2" LL	15m		
ANCHOR	WHOI + MACE 2000	2000 lbs	8:14	75 kg drag
Anchor Drag	Danforth on 3/8" ch			chain
Anchor observed on bottom	Water depth 813.5m	uncorrected	8:18+50	
Release Details				
RT661 - 235	Ping on 95BD	Off 95B3		
RT661 - 232	Ping on 82AD	Off 82A3		
Checked in lab and on mooring all pinger functions OK				
Anchor deploy position	**31 04.73 S**	**30 22.26 E**	GPS	
Release best acoustic	**31 05.03 S**	**30 22.08 E**	GPS Plotter	
WD best acoustic	**849 m**	**height off**	**106m**	

Table 3b. Checklist for deployment of ACE Mooring B

ACE MOORING 1700 metre check list and deployment sheet				**Mooring B**
Deployed RRS Discovery	**Day 63 - 1995**	**4th March 1995**		
Item	Type	Length	Time In	Comment
Flotech Syntactic Buoy	49" Dia N0.			
fitted with:				
RDI BBADCP	1184	1184		
ARGOS - Mk2 IOSDL	90 sec rep rate	23830	10:57	
Light	Novatech			
Chain	2m of 3/8" WHOI			
Swivel	S/S IOSDL			
FSI ACM + HACTD	1348		10:58	
Faired mooring wire	WHOI + Endeco fair	200m		white
Swivel + chain	1m 3/8" chain			
Subsurface CRP	3453/3		11:20	
Swivel + chain	IOS + 2m 3/8"			
Faired mooring wire	WHOI + Endeco fair	200m		white
FSI Coastal	1350		11:46	
Faired mooring wire	WHOI + Endeco fair	400m		black
				white
Aanderaa RVS7	11654		12:37	Rf 1151
Mooring Wire	WHOI	200m		
Aanderaa RVS8	11616		12:55	Rf 1241
Swivel	S/S			
Chain	1/2"	1m		
RT661 + B2S doubler	RT 229 & 61			RT61 Ping on
Mooring Wire	WHOI 1/4"	50m		
Nylon	WHOI Plait	20m		
Chain	1/2" LL	15m		
ANCHOR	WHOI + MACE 3000	3000 lbs	13:19	
Anchor Drag	Danforth on 3/8" ch			
Anchor observed on bottom	Water depth 1509 m	uncorrected	13:29	
Release Details				
RT661 - 229	Ping on 82BD	Off 82B3		
RT661 - 61	Ping on 20BD	Off 20B3		
Checked in lab and on mooring all pinger functions OK				
Anchor deploy position	**31 05.32 S**	**30 26.01 E**	GPS	
Release best acoustic	**30 26.01 S**	**30 25.44 E**	GPS Plotter	
WD best acoustic	**1480 m**	**height off**	**86m**	

Table 3c. Checklist for deployment of ACE Mooring C

ACE MOORING 2700 metre check list and deployment sheet				Mooring C
Deployed RRS Discovery	**Day 62 - 1995**	**3rd March 1995**		
Item	Type	Length	Time In	Comment
CRP Syntactic Buoy	49" Dia			
fitted with:				
RDI BBADCP	1185			
ARGOS - Mk2 IOSDL	90 sec rep rate	23829	8:23	
Light	Novatech			
Chain	2m of 3/8" WHOI			
Swivel	S/S IOSDL			
Aanderaa IOS7	10862		8:23	Rf 0819
Faired mooring wire	WHOI + Endeco fair	200m		white
Swivel + chain	1m 3/8" chain			
Subsurface CRP				
Swivel + chain	IOS + 2m 3/8"		8:54	
Faired mooring wire	WHOI + Endeco fair	200m	9:15	white
FSI Coastal	1347		9:19	
Faired mooring wire	WHOI + Endeco fair	400m		black
Repaired at 300m				
Aanderaa RVS7	11656		10:15	Rf 1004
Mooring Wire	WHOI	2 x 400m		
Aanderaa RVS8	11627		10:41	Rf 1026
Swivel	S/S			
Chain	1/2"	1m		
RT661 + B2S doubler	RT 230 & 234		10:41	
Wire	WHOI 3/16	400m	10:59	
	WHOI 1/4"	50m		
Nylon	WHOI Plait	20m		
Chain	1/2" LL	15m		
ANCHOR	WHOI + MACE 3000	3000 lbs	12:53	
Anchor Drag	Danforth on 3/8" ch			
Anchor observed on bottom	Water depth 2515 m	uncorrected	13:04	
Release Details				
RT661 - 230	Ping on 82CD	Off 82C3		
RT661 - 234	Ping on 95DD	Off 95D3		
Checked in lab and on mooring all pinger functions OK				
Anchor deploy position	**31 10 .23S**	**30 32 .55E**	GPS	
Release best acoustic	**31 10.38 S**	**30 32 .22E**	GPS Plotter	
WD best acoustic	**2498m**	**height off**	**550 m**	

Table 3d. Checklist for deployment of ACE Mooring D

ACE MOORING 3000 metre check list and deployment sheet				**Mooring D**
Deployed RRS Discovery	**Day 61 - 1995**	**2nd March 1995**		
Item	Type	Length	Time In	Comment
CRP Syntactic Buoy	49" Dia N0.	34532	9:10	
Faired mooring wire	WHOI + Endeco fair	35m		white
Aanderaa IOS7	10856		9:19	Rf 0903
Faired mooring wire	WHOI + Endeco fair	400m		white
Aanderaa RVS7	11657		10:17	Rf 1011
Faired mooring wire	WHOI + Endeco fair	400m		black
Aanderaa RVS7	11673		10:59	Rf 1052
Mooring Wire	WHOI	2 x 400m	11:20	Towing
			11:59	Restart
Glass spheres Benthos	17" Flange RM	18 off		Yellow
Swivel	S/S			
Chain	1/2"	1m		
Aanderaa IOS8	11626		12:03	Rf 1114
Mooring Wire	WHOI	400m		
RT661 + CR200	RT 57 & CR 2521			
Wire	WHOI 3/16	200+200m		
	Polyester	100m		
Nylon	WHOI Plait	20m		
Chain	1/2" LL	15m		
ANCHOR	WHOI + MACE 2500	2500 lbs		
Anchor Drag	Danforth on 3/8" ch		12:50	
Anchor observed on bottom	Water depth 2900m	uncorrected		
Release Details				
RT661 - 57	Ping on 62AD	Off 62A3		
CR200 - 2521	316 - 325 1.08 sec			
Anchor deploy position	**31 20.58 S**	**30 47.01E**	GPS	
Release best acoustic	**31 20.55 S**	**30 46.46E**	GPS Plotter	

Table 3e. Checklist for deployment of ACE Mooring E

ACE MOORING 3200 metre check list and deployment sheet				**Mooring E**
Deployed RRS Discovery	**Day 60 - 1995**	**1st March 1995**		
Item	Type	Length	Time In	Comment
CRP Syntactic Buoy	49" Dia N0.	3453/1		
Faired mooring wire	WHOI + Endeco fair	35m	6:10	
Aanderaa RVS7	11677		6:18	Rf 0604
Faired mooring wire	WHOI + Endeco fair	400m		
Aanderaa RVS7	11674		7:15	Rf 0712
Faired mooring wire	WHOI + Endeco fair	400m	8:25	
Aanderaa RVS7	11675		8:09	Rf 0802
Mooring Wire	WHOI	2 x 400m	8:25	Towing
Glass spheres Benthos	17" Mix	18 off		Mix see notes
Swivel	S/S			
Chain	1/2"	1m		
Aanderaa IOS8	9967		10:34	Rf 0825
Mooring Wire	WHOI	400m	10:45	
RT661 + CR200	RT 55 & CR 2519			
Wire	WHOI 3/16	400m		
	Polyester	100m	11:08	
Nylon	WHOI Plait	20m		
Chain	1/2" LL	15m		
ANCHOR	WHOI + MACE 2500	2500 lbs	add100k	Tow @1115
Anchor Drag	Danforth on 3/8" ch		11:24	
Anchor observed on bottom	**Water depth 2900m**	uncorrected	11:40	
Release Details				
RT661 - 55	Ping on 42BD	Off 42B3		
CR200 - 2519	316 - 324 1.14 sec			
Anchor deploy position	**31 34.24 S**	**31 06.38 E**	GPS	
Release best acoustic	**31 34.46 S**	**31 06.00 E**	GPS Plotter	
No best depth due to storm conditions - unable to return to site				
No best depth on Day 65 due to skew on RT55 unable to detect beam ons.				

Table 3f. Checklist for deployment of ACE Mooring F

ACE MOORING 3500 metre check list and deployment sheet				**Mooring F**
Deployed RRS Discovery	**Day 59-1995**	**28th Feb 1995**		
Item	Type	Length	Time In	Comment
CRP Syntactic Buoy	49" Dia 3453/4			
Faired mooring wire	WHOI + Endeco fair	35m		black 1m
Aanderaa RVS7	11678		6:56	Rf 06:52
Faired mooring wire	WHOI + Endeco fair	400m		white 2ft
Aanderaa RVS7	11676		8:12	Rf 0813
Faired mooring wire	WHOI + Endeco fair	400m		Black
Aanderaa RVS7	11682		9:27	Rf 0923
Mooring Wire	WHOI	2 x 400m		
Glass spheres Benthos	17" (3 off orange)			SRM
Chain	3/8"	2m		
Aanderaa IOS8	9968		11:24	Rf 1045
Swivel	S/S			
Chain	1/2"	1m		
RT661 + CR200	RT 60 & CR 2499		11:24	
Wire	WHOI 3/16	400m		
Wire	IOS 6mm Blue	400m	11:47	
Line	Kevlar 12mm	411m	12:03	
Wire	WHOI 3/16	200m		
Nylon	WHOI Plait	20m		
Chain	1/2" LL	15m		
ANCHOR	WHOI + MACE 2500	2500 lbs	1236	100 kg chain
Anchor Drag	Danforth on 3/8" ch			
Anchor observed on bottom	water depth 3446m	uncorrected	1257+30	
Release Details				
RT661 - 60	Ping on 20AD	Off 20A3		
CR200 - 2499	316 - 321 1.12 sec			
Anchor deploy position	**31 54.4 S**	**31 28.00 E**	GPS	
Release best acoustic	**31 54.51 S**	**31 28.24 E**	GPS Plotter	

Mooring E (Figure 4e, Table 3e) was deployed on day 60 using the same basic techniques, the only modifications being the upper fairing being attached with the subsurface sphere overside and streaming astern. The fairing was then easily attached and slid down the wire to the subsurface buoyancy. Attachment of the anchor release YOYO hook was modified and was securely chained to the crane, thus preventing the previous catapult effect. There was one difficulty, however: after deployment as the mooring was being acoustically navigated, a severe storm blew up and no best position could be determined. The mooring was revisited on day 65 but due to skew on the RT661 pinger the best position was not correctly renavigated.

Mooring D (Figure 4d, Table 3d) was deployed on day 61 using the standard techniques described above. Adjustments were required in the mooring line lengths to correct for a slightly shallower bottom depth than had been anticipated. After deployment accurate acoustic navigation was obtained.

Mooring C (Figure 4c, Table 3c) was deployed on day 62 in a significant surface current of approximately 3 knots. After the mooring had been streamed aft, it was necessary for the vessel to steam across the current in a 2 hour tow before anchor drop. The echosounder was run continuously throughout deployment and topography determined and this was later plotted as a site survey.

Mooring B (Figure 4b, Table 3b) was deployed on day 63 with the vessel stemming a significant surface current. For this deployment, it was decided to begin nearly at the mooring position and just hold position while steaming into the surface current and against the wind. The final positional adjustment was made by slipping across current to the correct depth for anchor release. As with mooring C, an echosounder record was obtained as a site survey.

Mooring A (Figure 4a, Table 3a) was deployed on a steeply sloping topography with the vessel again maintaining essentially final position while stemming the surface current and then adjusting for anchor drop by slipping across the current into deeper water. The echosounder record was again used as a site survey.

A summary schematic of all instruments deployed on the six-mooring array is given in Figure 5 and summary position information for all moorings is listed in Table 4.

Table 4. ACE Mooring position and details of instrumentation on each of the 6 moorings

Mooring Deployments 'ACE' RRS Discovery Cruise 214						
Mooring	**A**	**B**	**C**	**D**	**E**	**F**
Position	31 05.03S	31 05.30S	31 10.38S	31 20.55S	31 34.46S	31 54.51S
	30 22.08E	30 25.44E	30 32.22E	30 46.6E	31 06.00E	31 28.24E
Item/depth	50"steel buoy	49"Syntactic Buoy	49"Syntactic Buoy	49"Syntactic Buoy	49"Syntactic Buoy	49"Syntactic Buoy
	115.5m	BBADCP 1184	BBADCP 1185	316m	316m	350m
		ARGOS 23860	ARGOS 23829			
	CM1351FSI	382m	399m			
	138m					
		CM +HACTD 1348	CM10862RCM7	CM10856RCM7	CM11677RCM7	CM11678RCM7
	CM1349FSI	384m	403m	353m	353m	388m
	238m					
		49"Syntactic Buoy	49"Syntactic Buoy			
	CM10852RCM7	588m	606m			
	439.5m					
		CM1350FSI	CM1347FSI	CM11657RCM7	CM11674RCM7	CM11676RCM7
	CM11615RCM8	790m	809m	753m	753m	789m
	740.5m					
		CM11654RCM7	CM11656RCM7	CM11673RCM7	CM11675RCM7	CM11682RCM7
		1190m	1209m	1154m	1154m	1189m
		CM11616RCM8	CM11627RCM8	CM11626RCM8	CM9967RCM8	CM9968RCM8
		1391m	2010m	1963m	1963m	1997m
Acoustic	RT661 235	RT661 229	RT661 230	RT661 57	RT661 55	RT661 60
Releases	RT661 232	RT661 61	RT661 234	CR200 2521	CR200 2519	CR200 2499
				2363m	2363m	1995m
Water depth	849m	1480m	2498m	2900m	2900m	3446m

All the IOSDL-supplied winches and ship's equipment functioned well throughout the operations and the ship's crew obtained experience with the IOSDL winching systems, aiding the operations considerably. No problems were encountered in the operation of the deck or overside systems. Sincere thanks are extended to the ship's officers and crew for their enthusiasm, professionalism, and advice in vessel manoeuvring during deployment operations.

Acoustic releases

All the acoustic releases (Table 5) were prepared during Cruise 213 by David White of IOSDL. Modifications were made to the doubled RT661 units with insulating bushes being inserted in the drop link and top link to isolate the stainless steel from the galvanised steel shackles. Further attention will be required to optimise the design for this drop-link bushing. The CR200 release bushes were all re-machined onboard to allow the use of increased diameter shackle pins throughout the moorings.

BROADBAND ACOUSTIC DOPPLER CURRENT PROFILERS

N. Crisp

Two self-contained RDI BroadBand ADCPs (BBADCPs) were incorporated into Agulhas moorings B and C. These units were identical 4-beam 150kHz systems with 20 degree beam angles (rather then the more common 30 degrees) for increased profiling range, and full length (1000 dbar) pressure cases enabling 6 RDI battery packs to be installed.

BroadBand ADCPs have a major advantage over the conventional narrow band ADCPs: through an improvement in the post processing algorithms which determine the Doppler shift of the returned echo, the standard deviation of the velocity measurement from a single ping (which is dependant on the setup of the ADCP) has been reduced by up to a factor of ten. This means that fewer pings are required per ensemble to obtain a good velocity standard deviation (say 0.5 cm s^{-1}) and so less power is required enabling much longer deployments.

Table 5 Acoustic Releases Used on ACE Deployments

Mooring	Release type	Serial No.	Mech/pyro	Tests	Ping on	Ping off	Command	Period
A	RT661 MORS	RT235	Mech B2S pair	Full function	95BD	95B3	N/A	N/A
	RT661 MORS	RT232	Mech B2S pair	Full function	82AD	82A3	N/A	N/A
B	RT661 MORS	RT229	Mech B2S pair	Full function	82BD	82B3	N/A	N/A
	RT661 MORS	RT61	Mech B2S pair	Full function	20BD	20B3	N/A	N/A
C	RT661 MORS	RT230	Mech B2S pair	Full function	82CD	82C3	N/A	N/A
	RT661 MORS	RT234	Mech B2S pair	Full function	95DD	95D3	N/A	N/A
D	RT661 MORS	RT57	PYRO Firing	Full function	62AD	62A3	N/A	N/A
	CR200 IOSDL	2521	PYRO Firing	Full function	N/A	N/A	316 - 325 Hz	1.08 s
E	RT661 MORS	RT55	PYRO Firing	Full function	42BD	42B3	N/A	N/A
	CR200 IOSDL	2519	PYRO Firing	Full function	N/A	N/A	316 - 324 Hz	1.14 s
F	RT661 MORS	RT60	PYRO Firing	Full function	20AD	20A3	N/A	N/A
	CR200 IOSDL	2499	PYRO Firing	Full function	N/A	N/A	316 - 321 Hz	1.12 s

Release frequencies and codes not shown in this table .

The first step in the preparation of the instruments was the installation of the latest firmware (version 4.20) and an updated power timing IC (version cd53). Together these fix a bug which had prevented the ADCP from pinging under certain temperature-related conditions and introduce some improved operating modes. Installation was fairly straightforward and both instruments were successfully tested and taken through dummy deployments as a further check on their operational integrity.

The RDI software BBSETUP was used to determine the best trade-offs for bin-length, number of bins, pings per ensemble, ensemble period and standard deviation per ensemble against memory capacity and available battery power (with 6 alkaline packs). The capacity of our 6 alkaline packs was estimated by considering the temperature that the packs would experience in the deployed unit (taken from CTD contour plots of the mooring line from data collected on the previous cruise (*RRS Discovery* cruise 213) and using a curve of Watt-hour capacity against temperature for a single pack. The RDI program BBSETUP gives an estimate of the energy required for a deployment given the operating parameters. These can be tweaked until the desired energy estimate is given.

The best set of operating parameters found using this software are given below (based on a deployment duration of 450 days or 15 months).

ADCP parameter	**Quantity**
Pings per ensemble	10
Depth cell size	8 metres
Number of depth cells	64
Blank after transmit	4 metres
Time per ensemble	30 minutes

Predictions

Velocity standard deviation	0.64 cm/s
Recording space required	35.6 MB
Energy required (450 days)	1743 Wh

Finally the real-time clocks were set to GMT (see times below), the battery packs installed and the instruments set-up with the parameters given above. The end-cap O-rings were checked (and replaced as necessary), greased and the end-cap installed. At this stage the units were incorporated into the syntactic foam buoys ready for deployment later in the cruise. The timing details for the individual BBADCPs are given below. Actual deployment times will be found above on the checklists for moorings B and C (Tables 4b, 4c). All times are given in GMT.

BBADCP Ser No.	Real-time clock set:	Logging started at:
1184	08:37:00 24/02/1995	09:30 24/02/1995
1185	08:35:00 25/02/1995	11:30 25/02/1995

AANDERAA CURRENT METERS

K. Goy

A total of 19 Aanderaa Current meters were deployed on the 6 moorings. Of these, 14 were supplied new from RVS and had been prepared and calibrated at RVS prior to shipment for the Cruise. The remainder were IOSDL instruments which had been recovered from previous ADOX - SWINDEX deployments.

Where a combination of fine scale temperature and pressure were required the instruments were reconfigured to record pressure on channel 2 and temperature on channel 4. This has, however, the disadvantage of not allowing a wider range temperature channel should the scaling prove incorrect. Data from a CTD section across the Agulhas Current taken on the previous cruise were checked to ensure fine temperature ranges were satisfactory and the conductivity range of 30 - 45 mmhos/cm selected for the top instruments was correct.

All instruments were rechecked onboard prior to deployment and fitted with 13 ampere hour lithium cells allowing a sampling interval of 30 minutes with the extended DSUs.

ACM 10852 was deployed on mooring 1 due to failure of one of the new FSI acoustic instruments. The conductivity range of 22 - 67 mmhos/cm was scaled using spare resistors carried on the cruise and calibrated onboard. The pressure sensor was fitted from ACM 5204, recovered from SWINDEX *Discovery* Cruise 213 and this pressure sensor will require calibration post recovery.

FSI CURRENT METER PREPARATION FOR ACE

M. Hartman and N. Crisp

Delivery of 7 current meters from Falmouth Scientific Inc. (FSI) was taken at the outset of the cruise, two of these units incorporated FSI high-accuracy CTD sensors whilst the remaining 5 were coastal units with standard pressure and temperature sensors. All are capable of operating at full ocean depth.

Communication with the units was via a terminal emulator available with Microsoft windows running on a PC connected via RS 232 to an interface supplied by FSI, which was also capable of supplying power to the current meter if it had no battery.

Of the 7 instruments supplied, one of the CTD units and one of the coastal units were unserviceable due (probably) to a firmware problem. An additional firmware bug was discovered: if the clock was set and then subsequently checked, the time would either be displayed as not initialised or would be incorrect by several minutes. This problem was overcome by setting the time after setting all other logging parameters and then saving immediately to EEPROM.

The following pre-deployment procedure applies to the coastal units. Each current meter was removed from its frame and the pressure case opened. Lithium batteries were installed. The kick start button was pulled out and the dummy lead replaced with the communication cable. The unit (if behaving correctly) powers up in run mode; ***O changes it to open mode so that communication with the unit is possible. The unit was configured to record the following parameters: three components of velocity (in earth co-ordinates), compass reading, battery voltage, temperature, pressure and time. The sampling interval was set to 30 minutes, with the instrument making one 5-minute vector average during this period. The memory was zeroed, the hardware pointer reset and the logging bit set to 'on'. Finally the time and date were checked and corrected. This information was written to EEPROM so that in the event of battery bounce or other inadvertent temporary powering down of the unit, logging would recommence when power was re-applied.

Information from FSI stated that writing to EEPROM could corrupt the calibration file. Thus, after powering down and then up again, the logging parameters and calibration file were checked. The instruments were then set to run for a few hours, the data checked and finally set to log for the year-long deployment. All 'O' ring faces were cleaned and greased, silica gel was placed in the case which was then reassembled and placed in its frame. Zinc anodes were placed on the thread of the end cap retaining clips, the clips themselves were coated with tectyl.

For the instrument with the CTD attachment, the CTD was hooked up directly to the terminal and observed to output data. However, when connected via the current meter, the data logged from the pressure sensor consisted of zeros. A method was devised whereby pressure could be applied to the sensor continually over a period of logging, this yielded non-zero values. The unit was then set up as above for the coastal units but with 'CTD = on' and 'SPRES = off' (these units do not have the standard sea-pressure (SPRES) sensor installed). The frame was fitted with a vane, and the unit placed so that the hole through the conductivity cell would be aligned with the current flow

NAVIGATION

M. Griffiths

bestnav - PSTAR abnv files

The main navigation was provided via the RVS data stream, bestnav, which is constructed using the RVS stream 4000_av. The latter is derived using one second data from the new GPS 4000 Trimble, which are then sub-sampled to 30 seconds, and filtered over 11 data cycles (equivalent to 5 minutes). We were unsure of the effects of the 5 minute filtering on the velocities, so an alternative bestnav (called bestnav1) was created which used the one second GPS 4000 Trimble (RVS file gps_4000) data as the primary input file, and sub-sampled every 30 seconds. Data from the GPS ASHTECH (RVS file gps_ash) were nominated for the secondary input file, to be used if no good data were received from the GPS 4000 for more than 120 seconds. If good data were not received from the GPS ASHTECH for more than 300 seconds then the old GPS TRIMBLE would be used. Smaller gaps in the data were filled using dead reckoning with data from the ship's GYRO and the Chernikeeff (Electromagnetic) log, (RVS files gyrosync and log_chf). Data from both bestnav files (bestnav and bestnav1) were at 30 second intervals. For each set of navigation data, a separate file was created with smoothed velocities. For the 5 minute filtered GPS 4000 derived navigation, the velocities were filtered over 11 data cycles (i.e. 5 minutes). For the GPS 4000 30-second subsampled navigation the velocities were smoothed over 21 data cycles (i.e. 10 minutes).

Finally, an extra variable was created as a measure of distance from the start of the section, 'distoff'. The reference point at the shore was taken to be -30.9966°S 30.3000°E. distoff is then the distance from this reference along the axis directed toward 130°T, perpendicular to the coastline.

Summary of the files created:

abnv2141	- derived from 4000_av (5 minute smoothed gps_4000)
abnv2141.av	- as above with despiked and smoothed (5 minutes) velocities
abnv2142	- derived from gps_4000
abnv2142.av	- as above with despiked and smoothed (10 minutes) velocities
abnv2143.av	- as above, with distoff variable added.

Towards the end of the cruise, the abnv2142 files were found to have jumps as the receiver switched from one satellite constellation to another. These jumps were smoothed out in the abnv2141 versions. No remedy was found during the cruise for these problems. It is hoped that post-processing of the gps_4000 data will improve the quality.

GPS 4000, GPS ASHTECH, ship's gyro

Master files were created for the GPS 4000 (gps_4000), GPS ASHTECH (gps_ash) and ships gyro (gyrosync) - all at 1 second intervals. Gyro was edited for headings outside the 0-360° range. Data from the gyro were merged with the GPS ASHTECH master file, and used to calculate a difference between the headings derived from each instrument (a-ghdg). GPS 4000 was edited for pdop greater than 4. On occasions, we noted that s (taken to be svc - number of satellites used) was less than 3, yet pdop was good (i.e. less than 4). In these cases, the existing execs would delete data, so routines were modified to look only at pdop. Data quality for the GPS ASHTECH was based on :

hdg accept data between 0°,360°
pitch accept data between -5°,5°
roll accept data between -5°,5°
mrms accept data between 0.00001,0.008
brms accept data between 0.00001,0.09
attf accept data between -0.5,0.5
a-ghdg accept data between -5°,5°

Data in a-ghdg were then despiked by hand using the pstar routine 'plxyed'. Finally, a smoothed version of the data was created, using the pstar routine 'pfiltr', over 11 data cycles. This final version was not used for merging with the ADCP data, but should be used during post-processing.

Problems

Problems occurred in regions of strong currents, when running bestnav. If the drift was too great, then data was lost. Rerunning bestnav with coarser limits cured the problem.

Plots of the 1 second GPS data (from both 4000 and ASHTECH) would indicate that some sort of smoothing is still taking place on the data before reaching the level C.

Quality

Positions were logged in port at the start of the cruise, the standard deviation for the position error was found to be 0.0002° (i.e. about 20m) for both latitude and longitude for the GPS 4000.

Using the RVS 'gaps' utility at the end of cruise, the following time gaps in navigation were found:

time gap : 95 059 05:30:10 to 95 059 05:32:02 (112 s)
time gap : 95 060 05:46:30 to 95 060 05:47:09 (39 s)
time gap : 95 060 17:34:27 to 95 060 17:35:39 (72 s)
time gap : 95 062 05:43:56 to 95 062 05:45:51 (115 s)

time gap : 95 065 17:06:44 to 95 065 17:09:41 (3.0 mins)
time gap : 95 065 17:38:53 to 95 065 17:39:51 (58 s)
time gap : 95 065 23:12:46 to 95 065 23:14:03 (77 s)
time gap : 95 065 23:14:14 to 95 065 23:15:06 (52 s)
time gap : 95 065 23:15:11 to 95 065 23:15:47 (36 s)
time gap : 95 065 23:16:28 to 95 065 23:17:32 (64 s)
time gap : 95 065 23:17:37 to 95 065 23:18:15 (38 s)
time gap : 95 065 23:19:24 to 95 065 23:20:19 (55 s)
time gap : 95 065 23:22:32 to 95 065 23:23:14 (42 s)
time gap : 95 065 23:23:25 to 95 065 23:24:14 (49 s)
time gap : 95 066 05:41:04 to 95 066 05:42:20 (76 s)
time gap : 95 066 06:02:08 to 95 066 06:03:57 (109 s)
time gap : 95 066 08:42:33 to 95 066 08:43:28 (55 s)
time gap : 95 066 11:44:26 to 95 066 11:46:01 (95 s)
time gap : 95 066 17:34:37 to 95 066 17:36:02 (85 s)
time gap : 95 067 08:19:24 to 95 067 08:21:37 (2.2 mins)
time gap : 95 067 08:30:04 to 95 067 08:30:41 (37 s)
time gap : 95 067 08:30:42 to 95 067 08:32:18 (96 s)
time gap : 95 067 11:17:50 to 95 067 11:19:47 (117 s)
time gap : 95 067 11:53:48 to 95 067 11:54:38 (50 s)

Heading data

While positions were logged in port at the start of the cruise, the standard deviation of the heading angle (as measured from the GPS ASHTECH) was found to be 0.4531°, while the mean difference between the GPS ASHTECH and the ship's gyro was 0.4251° (sd=0.5454).

ECHOSOUNDING

A. Taylor and M. Griffiths

The bathymetric equipment aboard RRS *Discovery* for cruise 214 comprised a hull-mounted transducer, a Precision Echo Sounding (PES) 'fish' transducer, and a Simrad EA500 hydrographic echosounder. For most periods the

PES fish was deployed over the port side of the ship; for short times just at the beginning and end of the cruise, bathymetry data was obtained via the hull-mounted transducer. There were three outputs from the echo sounder; a visual screen display of the return signal, a continuous printer output, and a depth reading which was calculated by the echo sounder and passed to an RVS level A interface. Data were sent to the level A once every return echo, the period of which is determined by the depth. Data from the level A were then passed to level B/C. Every day the raw data were subsampled at a thirty second interval and Carter corrected (a correction due to the speed of sound in water not being a constant 1500 m s^{-1} as the echosounder assumes, but varying with the properties of seawater). Data were inspected for dubious values by comparing the logged data with the echosounder printout. This processing was accomplished routinely by RVS. Suspect data were flagged, and the processed data were placed in a level C data stream. The data were transferred to pstar format in daily chunks, and merged with navigation data to obtain latitude, longitude and distance run at each point.

COMPUTING

M. Griffiths

In the main lab there were 3 Mac Classics, 1 Quadra, and 1 IIsi all networked with the shipboard computers. MacSat in the plot room was networked for some of the time. A PowerPC was networked from the chemistry lab and an additional Mac Classic was networked from the deck lab used for current meter setup and mooring operations. Finally, an ethernet connection was made to the PSO's office, allowing a PowerBook to be networked from there, although the PSO did not bring a computer along for the short cruise.

For printing and plotting, we had an HP Paintjet, an Apple LaserWriter, and also made use of the new RVS colour postscript printer. The latter performed well, and produced good quality plots, although using the 'hcposta4' driver took considerably longer than the trusty Paintjet.

AIR SEA INTERACTION

M. Rouault

The parameters monitored by the shipboard meteorological system are: wind speed and wind direction (R.M Young anemometer), air pressure (Vaisalla barometer), wet and dry air temperature (two Vector psychrometers), photosynthetically active radiation (two Didcot radiometers), total solar radiation (two Kipp and Zonen radiometers) longwave radiation (two Eppley radiometers) and sea surface temperature (hull mounted resistance thermometer). Data are recorded as 1 minute averages and stored with ship speed, heading and position. These data allow the wind stress, the sensible and latent heat flux, the radiative flux, and the net heat budget at the sea surface to be calculated using standard bulk formulae.

A sonic anemometer was added to the system. This device samples the three components of wind speed (u,v,w) 20 times per second. For every 1024 recordings, a fast Fourier transform of the deviation from the last averaged value is performed to calculate the turbulence spectrum. This allows a calculation of the wind stress almost directly using the inertial dissipation method. To complete the system, the surface wave spectra is recorded by a Mk 2 shipborne wave recorder

Problems

The port psychrometer was giving bad values of the wet air temperature. This may have been due to a calibration problem. The port dry air temperature appeared to be correct. The starboard psychrometer was changed on day 56 prior to the start of the cruise. During the storm on day 60, the entire system worked erratically for an hour at the peak of the storm. Bad data on most devices apparently alternated with a small amount of good data.

Weather

The weather was generally good with prevailing northeasterly winds in the same direction of the Agulhas Current, cumulus formation and the odd thundershower mostly at night. The wind seemed unusually strong for a high pressure dominated weather system.

On the afternoon of day 60, the ship came under the influence of a coastal low which lasted until the morning of day 61 bringing cloudy conditions, rain and strong winds. At the start of the storm, in less than 10 minutes the wind increased from 5 to 25 m s^{-1} and the direction shifted abruptly from NNW to SSE (Figure 6). The air temperature dropped by 4°C, the latent heat flux varied from -100 W m^{-2} to -550 W m^{-2} and the sensible heat flux from -20 W m^{-2} to -150 W m^{-2}. There was also a drop of 0.3° C in the sea surface temperature.

CTD STATIONS

S. Cunningham, S. Keene and M. Brandon

CTD package configuration and deployment operations

Fourteen full depth CTD stations were occupied (Table 6) during RRS *Discovery* cruise 214 to the Agulhas Current. Several of the stations were made in extreme operating conditions: steep bathymetry, 2.5 m s^{-1} surface currents and large vertical shears, high winds and marginal swell conditions. It is to the full credit of all those involved that the data are of top quality and were collected without incident and in a thoroughly professional manner.

The old IOS Aluminium CTD Frame was used with the addition of a new stainless steel skirt mounted below the CTD frame. This allowed a lowered acoustic Doppler current profiler (LADCP) to be fitted in the centre of the frame directly below the CTD pylon. This increased the height of the package to about 2.5 m. A full set of lead weights was used at the bottom of the CTD frame, anticipating the extra drag on the package due to the surface area of the LADCP.

The mechanical part of the termination was tested three times during the cruise. Pull tests were completed satisfactorily at 2.1 tonnes for 2 minutes. The electrical termination was done twice during the cruise: first prior to the first

Table 6. CTD Station Positions

Stn no.	Cast no.	Date yymmdd	JDAY	start GMT	bottor GMT	end GMT	lat deg. S	lon deg. W	uncdpth m	cordpth m	ca	ht.off m	wire m	P max dbar	depth m	Sm no.	Note
12777	1	950227	058	2151	2213	2240	-32.3159	32.1502	3564.0	3571.1	68	n/a	0500	0507.5	0502	00	Test cast
12778	1	950228	059	0003	0111	0323	-32.3095	32.1459	3565.0	3572.2	68	22.2	3540	3604.2	3558	48	
12779	1	950228	059	1959	2102	2240	-31.9263	31.5924	3515.0	3521.7	68	10.5	3507	3564.0	3519	36	
12780	1	950301	060	0033	0140	0335	-31.8054	31.4330	3340.5	3345.4	68	10.9	3327	3383.3	3342	36	
12781	1	950302	061	1923	2023	2157	-31.6309	31.1846	3115.5	3119.0	68	17.9	3090	3141.8	3116	31	
12782	1	950302	061	2333	0040	0213	-31.5165	31.0204	2893.0	2895.0	68	18.7	2873	2912.5	2893	36	
12783	1	950303	062	2344	0040	0210	-31.4040	30.8674	2921.5	2918.0	69	19.0	2900	2942.0	2922	30	
12784	1	950304	063	0449	0552	0735	-31.2897	30.7015	2946.0	2942.5	69	15.2	2950	2971.6	2947	29	
12785	1	950304	063	2029	2125	2257	-31.2346	30.6134	2808.5	2805.0	69	23.8	2860	2825.2	2774	24	
12786	1	950305	064	0305	0346	0456	-31.1102	30.4544	1695.0	1694.6	69	94.6	1750	1631.1	1694	24	
12787	1	950305	064	1152	1223	1319	-31.0976	30.3951	1329.5	1331.7	69	45.6	1420	1295.6	1330	15	
12788	1	950305	064	1631	1633	1651	-31.0333	30.3477	0071.5	0071.5	69	11.5	0060	0062.6	0071	08	
12789	1	950305	064	1743	1744	1800	-31.0149	30.3329	0049.0	0049.0	69	18.4	0030	0031.9	0049	06	
12790	1	950306	065	0243	0345	0518	-31.7186	31.3143	3220.5	3224.2	68	17.2	3245	3254.1	3213	24	
12791	1	950306	065	0942	1050	1229	-32.1140	31.8710	3560.0	3567.1	68	17.4	3555	3604.2	3560	28	N tot. samp = 151

ca is the Carter Area correction region
Sm is the number of samples drawn on the cast

station, the second time after an electrical conductor failure in the cable. Fifty meters were pulled from the drum and a damaged section of cable was found and cut away. The damaged section exhibited characteristics typical of the cable snatching in a block.

The LADCP had compass and tilt sensors fitted. This gave information on the attitude and rotation of the package during deployment. The LADCP was operated in a self contained mode and had no effect on CTD measurements other than its physical presence in the frame and a likely increase in wake effects.

The CTD was deployed from the amidships gantry and hauled via the 10T winch. Because of the height of the package the shipboard bulwarks were removed and replaced by wire rails which were removed at the time of each deployment and recovery. Deck operations were undertaken by deck crew and scientists. Three lines were used to maintain close control of the package during deployment and recovery. However, the winch drivers were able to maintain close control on the package and no serious problems were encountered due to their skill. Gantry and winch worked satisfactorily throughout the cruise. The cable was a torque balanced, armoured 10 mm single core conductor Rochester cable. It was found to be in very poor condition showing considerable rust throughout its length.

An old GO 24 position pylon was used and found to perform poorly. Although misfires appeared to be rare, inspection of the sample and reversing data revealed about 4 double trips per cast. Water bottles were a mixture of GO and FSI design and gave no serious difficulties. One water bottle was damaged after jumping its mount, possibly during deployment in heavy swell. It was saved by the securing line and replaced by our single spare bottle.

The following instruments were fitted to the underwater package:

1. Neil Brown Mk IIIc WOCE CTD (DEEP04) with a Beckman dissolved-oxygen sensor. CTD data frequency is 32 Hz;
2. 24 x 10 litre GO rosette;
3. Five SIS digital reversing thermometers and one SIS precision reversing pressure meter;
4. Altimeter for near bottom navigation;
5. Transmissometer (s/n 0035), but no data are reported due to a failure of this instrument.

In the shipboard laboratory, the acquisition and processing equipment consisted of:

1. CTD deck unit, 1401;
2. Two IBM 486 33 MHz computers running the EG&G CTD data acquisition firmware, version 5.1 Revision 9, for real time display and listing of data. Raw data backup was done by dumping disk files to a tape streamer.
3. Primary data acquisition was via the shipboard Level ABC system.

Data capture

CTD data were passed from the CTD Deck Unit to the Level A (acquisition) dedicated microcomputer. In real time the data were median despiked and averaged to one second values. The time rate of change of temperature was also computed over the one second values. Data are subsequently passed to Level B (logging) and C (processing). Details of the system may be found in [*Voss et al.*, 1986] and [*Pollard et al.*, 1987]. A new parameter recorded was the number of data frames being averaged to the one second values.

Problems had been reported on earlier cruises that the new CTD Level A had difficulty coping with a 32 Hz data frequency, leading to serial overruns and Level A crash. However, we found the Level A to work satisfactorily during this cruise.

Calibrations

Temperature

CTD temperature was calibrated at IOSDL on 13 Oct. 1994 (Issue No. IT0043) at 11 temperatures between 0°C and 30°C. The transfer standard had been calibrated at the triple points of Mercury and water, and at the melting point of Gallium. The following calibration was applied:

$$T = 0.1326 + 0.99933 \times T_{raw} \quad (1)$$

This calibration was in degrees C on the ITS-90 scale, which was used for all temperature data reported from this cruise. For the purpose of computing derived oceanographic variables, temperatures were converted to the ITS-68 scale, using:

$$T68 = 1.00024 \times T90 \quad (2)$$

as suggested by [*Saunders*, 1990]. The standard deviation of temperature differences for this fit was 1.35×10^{-4} °C.

The mismatch between the time constant of the temperature and conductivity sensors is minimised using a time constant, $\tau = 0.45s$ in:

$$T = T + \tau \times \Delta T \quad (3)$$

where ΔT is the time rate of change of temperature over a one second temperature sample computed in the Level A, as described in the SCOR WG 51 report [*Crease and al*, 1988].

Pressure temperature was calibrated using the following:

$$T_{press} = 86.539 - 2.2711 \times T_{praw} + 3.648E - 4 \times T_{praw}^2 \quad (4)$$

The CTD was fitted with a fast response temperature probe. The data were logged but not utilised as part of the calibration. The following calibration was applied:

$$T_{fast} = -1.0312 + 1.0522 \times T_{fraw} - 5.0818E - 3 \times T_{fraw}^2 + 1.0207E - 4 \times T_{fraw}^3 \quad (5)$$

Future investigation of how to utilise this measurement will be undertaken.

Pressure

CTD pressure was calibrated at IOSDL on 10 Oct. 1994 (issue no. IP0016) at 16 pressures between 0 and 5500 dbar, and at temperatures of 20°C, 9.65°C and 0.16°C. The calibration was performed using a dead-weight tester in series with a Paroscientific digiquartz model 240 portable transfer standard; the Digiquartz was taken as the standard. The resulting calibration data were analysed for temperature dependence and hysteresis between calibrations at increasing and decreasing pressures.

The pressure was calibrated with respect to the temperature calibration at 9.65°C by the following:

$$P = -38.32 + 1.07365 \times P_{raw} + 3.0E-8 \times P_{raw}^2 \qquad (6)$$

A static pressure correction was determined from:

$$P_{stat} = (0.075 - 0.0 \times P_{raw}) \times (T_{press} - 10.000) \qquad (7)$$

so that (7) adds 0.75 dbar per 10 degrees temperature change and the final pressure is given by:

$$P = P + P_{stat} \qquad (8)$$

A final adjustment to pressure is to make a correction to up-cast pressures for hysteresis in the sensor. This is calculated on the basis of laboratory measurements of the hysteresis at 9.65 °C. The hysteresis after a cast to 5500 m (denoted by $dp5500(p)$) is given in Table 7. Intermediate values are found by linear interpolation. If the observed pressure lies outside the range defined by the table, $dp5500(p)$ is set to zero. For a cast in which the maximum pressure reached is $p_{\max}$, the correction applied to the up cast CTD pressure (p_{in}) is:

$$p_{out} = p_{in} - \left(dp5500(p_{in}) - \left((p_{in}/p_{\max}) \times dp5500(p_{\max})\right)\right) \qquad (9)$$

Conductivity

The following nominal calibration was applied to the conductivity data:

$$C_{new} = 0.0 + 1.0 \times C_{old} \qquad (10)$$

Table 7. Pressure Hysteresis

P dbar	dp(5500(P)) dbar
0	0.0
3000	0.7
5500	0.0

Table 8. Conductivity Coefficients

Stn. No.	A	B
12777	-0.00468	0.96785
12778	-0.00468	0.96785
12779	-0.00468	0.96785
12780	-0.01122	0.96795
12781	-0.00881	0.96785
12782	-0.01120	0.96756
12783	-0.01185	0.96722
12784	-0.01754	0.96703
12785	-0.00641	0.96672
12786	-0.00700	0.96659
12787	-0.01440	0.96676
12788	-0.05300	0.96760
12789	-0.05300	0.96760
12790	-0.00939	0.96655
12791	-0.01279	0.96653

cond = A + B x cond

This was followed by the cell material deformation correction:

$$C_{new} = C_{old} \times \left[1 + \alpha \times (T - T_0) + \beta \times (P - P_0)\right] \tag{11a}$$

where the coefficients for the cell material are:

$$\alpha = -6.5E^{-6} {}^\circ C^{-1} \tag{11b}$$
$$\beta = 1.5E^{-8} dbar^{-1} \tag{11c}$$
$$T_0 = 15^\circ C \tag{11d}$$
$$P_0 = 0 dbar \tag{11e}$$

and P, T and C_{old} are CTD pressure, temperature and conductivity.

The conductivity cell was found to have a drift between casts of the order of 0.02 mmho/cm. Coefficients for (10) were determined on a station by station basis by matching up-cast CTD conductivities to bottle conductivities in the normal fashion, where the normal fashion is concisely explained in [*Millard and Yang*, 1993]. Those coefficients may be found in Table 8. Figures 7a and 7b show the trends of the conductivity offset and slope coefficients on a station by station basis.

Salinity

At five stations a systematic depth dependence in the salinity residuals was found. This was likely due to the conductivity coefficients in (10) being in error. For these stations a final salinity calibration was done by fitting the salinity residuals with:

$$dsalin = a + b \times P + c \times T \tag{12}$$

The corrections at P_{min} and P_{max} are given in Table 9.

The final (bottle - CTD) salinity difference is -0.0001 with a standard deviation of 0.0019 for 277/291 samples for all differences within 2.8 standard deviations of the mean.

Table 9. Salinity Calibration

D214 salcal calibration deltaS = a + bP + cT

stn	Pmax	T(Pmax)	Pmin	T(Pmin)	a	b	c	cr Pax	cr Pmin
12777	507	13.9120	11	25.2227					
12778†	3605	1.3620	1	25.2128	-3.044	0.000380	-0.025792	-0.0017	-0.0037
12779†	3563	1.6517	1	26.1704	2.348	-0.000155	-0.194970	0.0015	-0.0028
12780	3383	1.8430	1	26.7271	1.789	-0.000492	-0.099133	-0.0001	-0.0009
12781	3141	1.9612	7	26.1240	0.862	-0.000283	-0.064316	-0.0002	-0.0008
12782	2913	2.0834	1	26.0958	0.204	-0.000080	-0.004263	0.0000	0.0001
12783	2943	2.0938	5	26.2192	2.481	-0.001069	-0.132981	-0.0009	-0.0010
12784†	2971	2.1431	7	26.7593	0.640	-0.001407	-0.016511	-0.0036	0.0002
12785	2825	2.2045	5	26.5412	1.780	-0.000526	-0.112708	0.0000	-0.0012
12786	1631	2.8164	-1	25.9434	2.857	-0.001736	-0.168705	-0.0004	-0.0015
12787	1295	3.2342	5	25.0695	1.712	-0.000703	-0.027830	0.0007	0.0010
12788	63	18.0571	1	23.6554	8.776	-0.040886	-0.350191	-0.0001	0.0003
12789†	31	20.3305	1	21.1178	3.500	0.000000	0.000000	0.0035	0.0035
12790†	3255	1.9734	1	25.2015	1.667	0.000137	-0.092233	0.0019	-0.0007
12791	3605	1.5070	1	25.1478	0.596	-0.000294	-0.038274	-0.0005	-0.0004

dsalin = a + bP + cT

† dsalin correction applied for this station

Altimeter

An altimeter was fitted to the CTD frame for near bottom navigation. The altimeter worked successfully through the cruise. The following calibration equation was applied:

$$alt = -227.06 + 6.91 \times alt - 2.70E - 4 \times alt^2 \qquad (13)$$

Reversing pressure and temperature measurements

Six reversing instruments were available: one SIS RPM and five RTM's. Of these RTM's, one died after 7 casts. Statistics for the differences from the CTD measurements have been formed for all data over all casts. This makes it impossible to monitor CTD drift: there are not enough samples to form significant statistics over the cruise. Bearing this in mind the post-cruise calibration of the CTD will be of importance. Independent additional temperature measurements, for example by fitting Falmouth Scientific Instruments temperature probes, should be considered essential on future deployments.

Differences are formed eliminating samples outside 2.8 times the standard deviation of the mean. For a normally distributed process this has a 0.5 % chance of eliminating good data.

Reversing Pressure Measurements

Rosette position	Pressure Meter
1	P6075S

The mean difference (P6075S - CTD) was -14.22 dbar with a standard deviation of 10.1 dbar for 9/14 samples. Note that the pressure meter data are uncalibrated. The utility of this measurement is as confirmation of the depth at which bottle 1 was fired.

Reversing Temperature Measurements

Rosette position	Temperature Meter
(Casts 777 to 782)	
3	T399
11	T219 & T255
18	T253 & T892
(Casts 783 to 792)	
9	T253
11	T219 & T255
18	T892

The following calibrations were applied:

$$T_{T219} = -0.0249 + 0.9998 \times T \quad (14)$$
$$T_{T253} = 0.0078 + 1.00012 \times T \quad (15)$$
$$T_{T255} = -0.00266 + 0.99978 \times T \quad (16)$$

In the following the first number within parentheses is temperature and the second is the correction to be added. Linear interpolation was used between calibration points.

$$T_{T892}(-2.0,-0.003),(5.0,-0.003),(10.0,-0.002),(19.5,-0.002) \quad (17)$$
$$T_{T399}(-2.0,0.001),(0.0,0.000),(5.0,0.001),(10.0,0.000),(15.0,-0.001),(19.5,0.000) \quad (18)$$

The mean temperature difference (RTP - CTD) is 0.0229 °C with a standard deviation of 0.0385 °C for 36/41 samples.

Oxygen

The oxygen calibrations for this cruise were carried out slightly differently from methods used on previous IOS/JRC cruises. Previous cruises used the following algorithm to calibrate the Beckman dissolved-oxygen probe:

$$O_2 = \left[rho \times O_c\right] \times oxysat(S,T) \times e^{\left(\alpha\left(CTD \times f + oxyt(1-f)\right) + \beta P\right)} \quad (19)$$

and in (19), *rho* is the slope, O_c is the oxygen probe current, oxysat is the oxygen saturation at a salinity S and a temperature T, α is the temperature correction and β is the pressure correction for the oxygen probe. Because the oxygen probe has a very slow thermal response we correct for this in equation (19), and f is the fraction of the CTD temperature (CTD) and the oxygen probe temperature ($oxyt$) we use to calculate the oxygen values in (19).

Work at the Rennell Centre [*Cunningham*, 1995] based on work at Woods Hole [*Owens and Millard*, 1985] suggested that we should modify equation (19) to include a correction for the oxygen diffusion through the membrane of the Beckman probe and for the oxygen current bias, thus O_c would become:

$$O_2 = \left[rho \times \left(O_c + \tau \times \frac{dO_c}{dt} \right) + \chi \right] \times oxysat(S,T) \times e^{(\alpha(CTD \times f + oxyt(1-f)) + \beta P)} \qquad (20)$$

and χ is the current bias and τ is a time constant. $\frac{dO_c}{dt}$ was calculated from one second values over a time interval of 3 seconds. From [Owens and Millard, 1985] this was believed to be an appropriate time for the diffusion of oxygen across the membrane of the Beckman sensor. These coefficients were minimised with the new pstar program, *oxycal5*, to give the calibrations listed in Table 10.

The final (bottle - CTD) oxygen difference is -0.9 $\mu mol/l$ with a standard deviation of 6.8 $\mu mol/l$ for 268/277 samples for all differences within 2.8 standard deviations of the mean.

References

Crease, J., and e. al, The acquisition, calibration and analysis of CTD data, *Unesco Technical Papers in Marine Science, 54*, 96pp, 1988.

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Millard, Jr., R. C., and K. Yang, CTD calibration and processing methods used at Woods Hole Oceanographic Institution, *WHOI-93-44*, WHOI, 1993.

Owens, W. B., and R. C. Millard, Jr. A new algorithm for CTD oxygen calibration, *J. Phys. Oceanogr., 15(5)*, 621-631, 1985.

Table 10. Oxygen Coefficients

CTD station	rho	alpha	beta	chi	tau	f	residual squares error
12777†							
12778	1.5462	0.01938	-0.0001942	0.01924	2.9761	0.3577	2.6
12779	1.6320	0.02071	-0.0001732	0.00836	2.9716	0.1022	2.7
12780	1.6420	0.02105	-0.0001896	-0.00506	2.9923	0.2833	1.7
12781	1.6818	0.02308	-0.0001870	-0.00108	3.0103	0.4285	2.2
12782	1.5975	0.03230	-0.0001725	0.03230	3.0332	0.3124	4.4
12783	1.6440	0.02200	-0.0001934	-0.00330	3.0025	0.4568	2.6
12784	1.8510	0.02517	-0.0001672	-0.01875	2.9967	0.0000	3.7
12785	1.6511	0.02229	-0.0002127	-0.01735	3.0040	0.3983	2.8
12786	1.6944	0.02290	-0.0002152	-0.03049	3.0133	0.3343	2.4
12787	1.5455	0.01782	-0.0004035	-0.07184	3.0125	0.5492	2.0
12788	1.2586	0.01172	-0.0001284	0.03763	2.9938	0.3993	1.3
12789	1.2123	0.00622	-0.0001088	-0.02947	3.0012	0.4207	0.4
12790	1.6889	0.02259	-0.0001872	-0.01082	3.0142	0.3226	3.1
12791	1.4992	0.01776	-0.0001847	0.03185	2.9902	0.4401	3.5

† No Oxygen samples drawn

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SAMPLE SALINITY MEASUREMENT

T. Forrester

Sampling

Water samples were drawn from each CTD Niskin bottle into 200 ml glass sample bottles closed with disposable plastic inserts and screw-on caps. A procedure of rinsing the bottles and caps twice with sample water before filling to the base of the neck and sealing was employed for each sample. Before the plastic caps were inserted, the bottle necks were wiped dry to reduce the risk of salt crystals forming and contaminating samples. Samples for each CTD station were encased in wooden crates and allowed to equilibrate to ambient temperature in a constant temperature room for at least 12 hours before being analysed.

Analysis

A Guildline Autosal model 8400 fitted with an Ocean Scientific International peristaltic sample intake pump was used to analyse the samples. To minimise errors in the readings, a mains power supply filter was fitted. The Autosal was found to be in good working order, it had been used extensively and maintained during the preceding cruise. The IOSDL Autosal model 8400A was also on board and operable as a standby instrument. The salinometers were situated in the constant temperature laboratory with a room temperature set at 22.6°C and the salinometer water-bath temperature was set at 24°C, so that intermittent heating by the two heater lamps was required. All analyses were carried out by Tom Forrester who had no previous experience at salinity analysis but had attended a salinity course run by Ocean Scientific Int. before the cruise and was conversant with current practises.

Standardisation was achieved by use of IAPSO standard sea water ampoules. The primary cruise standard was batch P125 (57 ampoules). After the first set of analysis of the test CTD cast samples (12778), the Autosal was re-standardised using standard sea water (batch P125) and the Rs value adjusted to give a correct reading to within 0.0004 or 0.0008 Salinity Equivalent (SE). Standardisation of the samples was carried out before and after each set of 24 samples were analysed and a mean correction value used. The standard sea water corrections values are shown in Figure 8, the mean of the corrections was 0.0004 SE with a standard deviation of 0.0002 SE.

Duplicates (samples drawn from different Niskins closed at the same depth) and replicates (two or more samples drawn from the same Niskin bottle) were often made at the bottom and at other depths for the shallower casts. These repeat firings were "blind" to the samplers and to the analyst. The mean difference between the duplicates was 0.0001 SE with a standard deviation of 0.0011 and the mean difference between the replicates was 0.0000 SE with a standard deviation of 0.0015.

SAMPLE OXYGEN MEASUREMENT

H. R. Valentine and J. Cooper

Method

Oxygen samples were drawn from every bottle before the collection of samples for salinity analysis. A test station (12778) was used for training and as a check on the oxygen bottle calibrations. Duplicate samples were taken on each cast, generally from the first four bottles. Samples were drawn into clear, wide necked calibrated glass bottles and fixed on deck with reagents dispensed using Anachem bottle top dispensers. Samples were shaken on deck for half a minute. Checks were made at this stage to tighten the stoppers and look for bubbles. The samples were shaken and checked again in the constant temperature laboratory 1/2 hour after collection.

Bottle temperatures were taken, following the sampling for oxygen, using a hand held electronic thermometer probe. The temperatures were used to calculate the temperature dependant changes in the sample bottle volumes.

Samples were analysed in the constant temperature laboratory (21 to 22°C), starting one hour after sample collection, following the Winkler whole bottle titration with an amperometric method of endpoint detection, as described by Culberson and Huang (1987). The equipment used was supplied by Metrohm and included the Titrino unit and control pad to dispense the thiosulphate in increments of 1ul, with an electrode for amperometric end point detection.

A software error occurred on station 12779 resulting in the Titrino parameters not being saved to a file. Otherwise the equipment worked well. The Anachem dispenser for the NaI/NaOH had to be replaced at station 12784. The NaI/NaOH was being topped up and there were problems drawing the solution up into the dispenser so a new one was used. The new one used was B35, D.

Air bubbles were found in bottles 23 and 24. These bottles were checked very carefully when sampled and no bubbles were found. It was only after the second shaking that the air bubble was noticed. It has been suggested that the bubbles may be due to nitrogen coming out of solution. These bottles usually corresponded with the 50 and 10 m depths; where the sea water was above 24°C.

Oxygen sampling bottle used to sample Niskin 17 was found to be a mixture of sample bottle 124 (bottom) and sample bottle 157 (top). This then means that the volume is incorrect. This was identified at station 12785; so oxygen values for bottle number 17 for stations 12778, 12779, 12780, 12781, 12782, 12783, 12784 and 12785 are questionable. Maybe the volume can be recalculated later using this combination of sample bottles.

Standardisations

The thiosulphate normality was checked at the beginning of each run; every time the reservoir was topped up; and when fresh iodate standard was prepared (table 2). The exact weight of this standard, the calibration of the 10 ml exchange unit (driven by a Metrohm Dosimat) and the 1L glass volumetric flask used to dispense and prepare the standard, were accounted for in the Mac worksheet, used to calculate the oxygen values. These calibrated volumes are shown in Table 11.

Table 11. Calibrated volumes of various dispensers used for the standardisations.

Dispenser	**Nominal Vol (ml)**	**Calibrated Vol (ml)**
Exchange unit 2	10	9.96225
Eppendorf	5	4.99558
Volumetric flask	1000	1000.09

The thiosulphate normality was checked on 3 occasions against a commercially prepared standard (Sagami chemical company, Japan) dispensed using an Eppendorf 5 ml positive displacement pipette. On each occasion the thiosulphate normality calculated to be exactly the same using the iodate working standard and that supplied by Sagami (Table 12).

Table 12. Thiosulphate normality determined using the Sagami standard.

Station Number	**Iodate weight**	**Vstd (ml)**	**N(thio)**
12784	0.35666	0.498	0.100
12784	0.35666	0.500	0.100
12787	0.3531	0.493	0.100

Blanks

The introduction of oxygen with the reagents and impurities in the manganese chloride were corrected for by blank measurements made on each station, as described in the WOCE Manual of Operations and Methods (Culberson, 1991). Blank measurements were made at the beginning of each run and when new chemicals were used (Table 13).

Table 13. Iodate weight, mean blank volume (Vblk), mean standardisation volume (Vstd) and N(thio).

Station Number	**Iodate weight**	**Vblk (ml)**	**Vstd (ml)**	**N(thio)**
12778	0.35666	0.0002	0.99300	0.100
12779	0.35666	0.0010	0.99467	0.100
12780	0.35666	-0.0007	0.99545	0.100
12781	0.35666	0.0005	0.99475	0.100
12782	0.35666	0.0003	0.99600	0.100
12783	0.35666	0.0003	0.99567	0.100
12784	0.35666	0.0015	0.99400	0.100 (0.100) *
12785	0.35666	0.0022	0.99467	0.100
12786	0.3531	0.0002	0.98158	0.100 **
12787	0.3531	0.0002	0.98108	0.101 (0.101)
12788	0.3531	0.0020	0.98067	0.101
12789	0.3531	0.0020	0.98067	0.101
12790	0.3531	0.0018	0.98017	0.101
12791	0.3531	0.0013	0.97841	0.101

* New batch of acid and alkaline iodide used
** New batch of MnCl2 and IO3 used

Duplicate analyses

The mean difference and standard deviation (absolute differences) between duplicate samples was found to be 0.671 umol l^{-1} +/- 0.631 umol l^{-1} for 51 observations. The mean difference and standard deviation of the duplicates (absolute) taken on Discovery cruise D213 are 0.845 +/- 0.762 umol l^{-1} for 411 observations.

Also mean difference and standard deviation of oxygen samples taken from duplicate firings (more than one bottle triggered at same depth) were calculated (Table 14).

Table 14. Mean differences and STD of duplicate samples and duplicate firings.

	Mean difference	**Standard Deviation**
Duplicate samples		
(sample - duplicate)	-0.291	+/- 0.878
(absolute)	0.671	+/- 0.631
Duplicate firings		
(1st - 2nd)	0.115	+/- 1.399
(absolute)	0.961	+/- 1.015

Data comparisons

Preliminary data comparisons were made against Discovery cruise D213 data. The following station was compared : D213 station 12681 with D214 station 12791. The bottom water oxygen value was 224.88 umol l-1 for 12681 and 224.48 umol l^{-1} for 12791; a difference of 0.40 umol l^{-1}.

References

Culberson, C.H. and S.Huang, 1987. Automated amperometric oxygen titration. *Deep-Sea Research*, 34, 875-880.

Culberson, C.H. 1991. 15pp in the WOCE Operations Manual (WHP Operations and Methods) WHPO 91/1, Woods Hole.

THERMOSALINOGRAPH

T. Forrester

Instrumentation and technique

Continuous underway measurements of surface salinity and temperature were logged using a Falmouth Scientific Inc (FSI) thermosalinograph (TSG) mounted onboard ship with:

a) An FSI Ocean Temperature Module (OTM) (1340) mounted near the non-toxic intake in the forward hold, at a depth of 5 m.
b) FSI Ocean Conductivity Module (OCM)(1331) and OTM (1339) sensors mounted in a polysufanone housing.

A header tank was used to provide a constant flow of de-bubbled non-toxic water. The data was sampled at 1Hz and averaged over 20 s periods before logging on the level B system. The instrument was run continuously throughout the cruise.

Calibrations

The OCM and OTM's were pre-calibrated using laboratory standards and calibration data to obtain four polynomial coefficients.

Salinity calibration samples were drawn from the non-toxic water supply at two hourly intervals when underway, and when on station (from March 2 1995) samples were taken every four hours. Water samples were drawn into 200ml glass sample bottles closed with disposable plastic inserts and screw-on caps. A procedure of rinsing the bottles and caps twice with sample water before filling to the base of the neck and sealing was employed for each sample. Before the plastic caps were inserted, the bottle necks were wiped dry to reduce the risk of salt crystals forming and contaminating samples. The samples were encased in wire crates and allowed to equilibrate to ambient temperature in a constant temperature room for at least 12 hours before being analysed.

Samples were analysed on a Guildline 8400 using a similar technique described for the sample salinity measurement.

Data processing

The TSG conductivity measurements at 20 s interval were de-spiked, records being rejected if salinity differed by more than 0.05 from a 5 point median. Conductivity values were then determined at a pressure of 0 bar and temperature at the housing OTM. The data were than averaged over two minute periods and merged with the navigation data to include latitude and longitude. The 2 minute averaged conductivity values were then de-spiked using a maximum difference of 0.01 mmho/cm.

In order to calibrate the TSG salinity values, the data were merged with salinity values from the two hourly bottle samples. The bottle conductivities were calculated assuming pressure of 0 bar and temperature at the housing OTM. Then the TSG conductivities were calibrated using a linear fit of the differences between the bottle and TSG conductivities over time:

$$TSG = 2.5966899 + 0.9104599 * time$$

These calibrated conductivities were then used to calculate calibrated TSG salinities which were merged with the bottle salinities to give the final residuals, which were smoothed with a top hat filter of half width 6 hours. The TSG salinities were then corrected by adding the filtered differences. The mean difference between the bottle and TSG salinities was -0.0026 with a standard deviation of 0.0154.

LOWERED ACOUSTIC DOPPLER CURRENT PROFILER (LADCP)

N. Crisp, R. Tokmakian and L. Beal

Instrument set-up

This is the first JRC/IOSDL cruise where an ADCP has been used routinely as part of a lowered package on CTD stations. To enable the ADCP to be lowered in conjunction with the CTD, an extension to the CTD frame was designed. This extension is the same diameter as the bottom of the current CTD frame and is clamped underneath it. The package was assembled whilst in port by first clamping the ADCP in the centre of the new frame and then lowering (by crane) the standard CTD frame onto it. The top end of the ADCP fits centrally into the old frame about 18cm below the rosette firing mechanism allowing space for the turn radius of the end-cap cable.

The ADCP is an R. D. Instruments 150kHz BroadBand unit with a 6000m pressure case and 20 degree beam angles. The ADCP was installed with the latest versions of CPU and power timing firmware (4.20 and c5d3 respectively) at the start of the cruise. The power timing upgrade fixed a bug which occasionally caused the instrument to stop pinging, although we had not come across the problem with any of our BroadBand ADCP test lowerings or deployments. The unit was powered with three 32V (24 Ampere-hour) lithium battery packs which were designed to last the entire cruise. These were simply standard BroadBand battery packs but with the alkaline 'C' cells replaced with lithium 'C' cells. The voltage of these was checked before and after each deployment, and despite a drop of about 0.3V after each cast, the batteries recovered to a constant voltage throughout the 15 casts undertaken during the cruise.

This initial set-up with a full length BroadBand ADCP mounted within the CTD frame is far from ideal since it lengthens the CTD package making it more cumbersome and difficult to handle in rough conditions. However, no serious problems were encountered during this cruise. A re-design of the package will be undertaken back at the laboratory and will most likely constitute a shortening of the ADCP pressure case so that it contains only the electronics. This should enable a modified CTD frame of standard height to house the instrument. We also intend to design our own rechargeable battery packs to go in separate pressure cases which would enable continuous operation of the ADCP on longer cruises.

Data recovery from the ADCP was carried out after each cast, using a baud rate of 38,400 to minimise the recovery period. On this short cruise, however, the 40MByte internal PCMCIA memory was large enough to store all casts undertaken during the cruise with 6MB to spare.

LADCP data processing: overview

As others in the field of lowered ADCP have already developed a substantial package for processing these data, it seemed sensible to make use of this on our first cruise rather than try to develop our own methods. The software employed was obtained from Eric Firing (at the University of Hawaii) by ftp.

Despite detailed documentation provided by Firing and others, getting the software to work smoothly and understanding exactly what it is doing takes some time: knowledge of MATLAB, PERL, and CODAS software is an advantage and the latter two were new to us (CODAS is in-house database software developed at the University of Hawaii). However, the processing of LADCP data is not inherently difficult and is summarised below:

Initially the data are loaded into a CODAS database with added station information such as position and magnetic compass correction. The LADCP clock is corrected if necessary. The CTD profile data are used to estimate the variation of depth and speed of sound with time. The LADCP derived velocities can then be modified accordingly with the changing sound speed through the water column.

The profiles are edited to remove bottom interference, bad profiles and bad bins. In order to remove the package motion through the water, a mean vertical shear profile is calculated by differentiating the ADCP velocity profiles. This velocity is found either by using the CTD depths against time (if available) or by integrating the LADCP vertical data to obtain approximate depths. With position fixes at the start and end of station, the depth-averaged velocity components can be calculated and the integrated shear profile can be plotted as an absolute velocity profile (for example, Figure 9 for station 3).

The final step is to contour the velocity components and plot statistics such as up-cast minus down-cast shear. These shear plots can help to decide whether or not package wake on the up-cast is biasing the data. Such post-processing will be carried out back at the laboratory in addition to looking at the echo amplitude data to look at the distribution of scatterers with depth and their effect on the ADCP's profiling range.

Processing steps

The following is an outline of the steps in the analysis procedure and E. Firing's notes must be consulted to understand the editing and the exact function of the programs.

On the PC:

1. The raw profile data were loaded onto a PC and programs *scanbb* and *loadbb* were run to assimilate ancillary station data (position, cast number etc.) and the ADCP profile data into the CODAS database.

2. The database files were then transferred to the SUN network using PC-NFS.

On the SUN:

Processing to get fully corrected velocity profiles is carried out in two passes. The first pass involves:

1. Converting the PC CODAS database files to SUN CODAS database files.

2. Differentiating the velocity profiles and averaging the results into 5m bins over the profile depth.

3. Integrating the shear profiles into separate down and up-cast velocity profiles - taking into account the depth-averaged velocity component if GPS position fixes are available (these GPS data are usually incorporated for the second pass)

Second pass processing additionally involves:

1. Assimilating CTD data for the cast into the database. This enables accurate sound speed to be calculated for each profile and also gives a better estimation of the depth of the package.

2. Editing the ADCP profiles to remove any bottom interference and other bad profiles or bins. Note these are flagged as bad, rather than replaced with absent data.

3. Incorporating GPS data for the start and end times of the cast. Smoothed navigation is used for this.

Plots that are generated as a matter of course during the above processing steps include (in addition to velocity and shear profiles) ADCP heading and tilt which are very useful for monitoring the behaviour of the entire CTD package, the first time that such data have been collected by IOSDL. These will be useful not only in our redesign of the CTD/ADCP package but also to RVS for investigating for example the package-spin and whether or not it is a potential problem for the winch cable.

ACOUSTIC DOPPLER CURRENT PROFILER

S. Bacon

The physical installation of the ADCP on RRS *Discovery* is described elsewhere (Saunders, 1993; see also Griffiths, 1992) and will not be repeated here, with the exception of noting that the total of transducer depth below waterline plus 'blank-beyond-transmit' is now taken as 9 m. The Cruise Narrative section above gives details of ADCP calibration runs conducted during the cruise; and the Navigation section above gives details of on-board navigation processing and data which is integral to ADCP processing. While in bottom–tracking mode, the ratio of bottom–track to water–track pings was set at 1:1.

The first piece of processing which was necessary was the provision of a working heading correction ϕ and amplitude scaling factor A (for description of terms see Pollard and Read, 1989). The processing of the first bottom–track calibration run will be described next, followed by a description of the routine ADCP processing route employed on the data thereafter. If one takes the position error in one-second GPS navigation as 100 m, then a straight run of 100 km involves a heading error derived from that navigation data of 10^{-3} radians or ca. 0.05°, which is acceptable by reason of comparability with the best heading accuracy available from the Ashtech 3DGPS (King and Cooper, 1993). So firstly a long section of the navigation data is sought throughout the calibration run which has nearly continuous good data, both GPS position from the Trimble 4000 and heading from the Ashtech. Endpoints are identified and a mean heading and speed over the ground are calculated from GPS endpoint times and positions. These values are assumed to be 'truth' against which the ADCP bottom-track data over the same time interval are to be compared.

Now the ADCP uses the ship's gyro for its heading input because gyro heading is continuous in time. The ADCP heading is first corrected using the navigation variable 'a-ghdg' (Ashtech minus gyro heading). The misalignment angle, which must be established to enable processing to be referenced to true ship's fore-and-aft direction, is the sum of the misalignment of the Ashtech antenna array (with respect to true ship's fore-and-aft direction) and the misalignment of the ADCP transducer head (similarly). Then the ADCP bottom-track must be processed to give a mean heading and speed between the same two endpoints identified as above. That this processing detailed below appears cumbersome is due to the need to switch between rectangular and polar coordinates. The clock correction (as *adpexec1*, described below), is taken as done.

For Bottom–track processing, nn and mm are ADCP and navigation processing serial numbers; botew and botns are initially uncalibrated bottom velocities in rectangular coordinates, and vars indicates the relevant variables in each processing step:

(i) merge files bot214nn.corr (vars. time, botew, botns) and ash214mm.mrg (vars. time, a-ghdg) on time (PMERGE). Output file bot214nn.cal1.

(ii) PCOPYA to extract data between selected endpoints. Output file bot214nn.cal1a.

(ii) PCMCAL on vars. botew, botns in bot214nn.cal1, to convert to vars. speed, dirn. Output file bot214nn.cal2.

(iii) PARITH on vars dirn and a-ghdg in bot214nn.cal2, to create new variable adphdcor. Output file bot214nn.cal3.

(iv) PCMCAL on speed and adphdcor to create new vars ebotcor, nbotcor. Output file bot214nn.cal4.

(v) ALLAV on ebotcor and nbotcor to produce one mean speed from each series of velocity components. Output file bot214nn.cal5.

(vi) PCALIB on ebotcor and nbotcor, to multiply by -1, to obtain "ship-going-forwards" vels, rather than "bottom-going-backwards" vels.

(vii) PCMCAL to convert single ebotcor and nbotcor values to speed and dirn.

These last two values are compared with their navigation-derived equivalents. On the first calibration run (the only one processed at sea), values of $\phi = 2.315°$ and A = 1.006 were obtained. All calibration data will be re-processed on land after the differential correction has been applied to GPS position data.

Next the processing route for the routine ADCP data is described.

(i) *adpexec0.* Extract raw ADCP data from RVS acquisition, put into PSTAR. Output files bot214nn, adp214nn.

(ii) *adpexec1.* Apply manual correction (determined daily) to ADCP pc clock time to align with GPS time. Output files bot214nn.corr, adp214nn.corr.

(iii) *adpexec2.* Apply A and ϕ calibration values. Perform basic editing (remove bad values of bottom vels., water vels., vertical vels., backscatter amplitude), make 10-minute averages. Output files bot214nn.work (appended to master bot file bot214), adp214nn.av.

(iv) *adpexec2a.* Apply Ashtech heading correction to gyro heading (a-ghdg). Output file adp214nn.true.

(v) *adpexec4.* Merge ADCP data with navigation (bestnav) data. Output file adp214nn.abs.

Execs 3 and 5 produced diagnostic plots and were used as appropriate. Final plots of daily east and north true current vector components were produced with UCONTR. A contoured section of the alongcoast velocity (230°T) versus distance offshore for the initial transit across the Agulhas Current is shown in Figure 10.

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ACOUSTIC CORRELATION CURRENT PROFILER

G. Griffiths, P. Spain, T. Nguyen, B. Dupee and G. Watson

The Acoustic Correlation Current Profiler offers the potential to profile currents underway to far greater ranges than is possible with the Doppler technique. RD Instruments built a prototype instrument in 1990/1 which showed promise. We placed a contract with RDI for delivery of an ACCP, but 'our' system could not be delivered in time for the cruise, instead RDI provided the prototype instrument and two staff to operate it.

The principle of operation of a correlation profiler is far more complex than a Doppler profiler. To summarise in one sentence ... "Thus the objective, in the correlation system, is to transmit two identical signals separated by a known time interval and then to search for a separation vector and a time delay for which the correlation (*of the received signal*) is a maximum.", from Dickey and Edward (1978), p. 257.

Transducer, system electronics and interfaces

The transducer was installed by divers into the pre-prepared sea chest on the hull of *Discovery* on 23 February, 1995. There was no clear orientation mark on it. No sound absorbing material was fitted to the sea chest, and no acoustic window was fitted. The hardware of the ACCP is based on electronics and signal processing technology developed at RDI for the Broadband range of ADCPs. As such, it uses a pseudo-random binary sequence (of '0' and '1', encoded as 0° and 180° phase) to modulate the carrier frequency (22 kHz). By increasing the time-bandwidth product, more energy is put into the water, while maintaining an acceptable spatial resolution, by time compressing the received signal using a correlator. Raw signal outputs from the ACCP deck electronics are sent to a Pentium PC fitted with an Intel iapx860 RISC co-processor. This PC could process the data from a 2 second receive window (to 1500 m) in some 30 s. Alternatively, the PC could pre-process the data and store it on disk for offline processing by a second identical machine. The second stage processing involving a maximum likelihood (ML) technique took most time.

The display on the PC focused on engineering and signal processing information. Graphical views of the spatial correlation functions as received (at lags of 0 and t_c) and after ML processing were very helpful indicators of data quality. The numeric display of signal parameters was low-key, signal quality indicators were readable, but the velocity readouts Vx, Vy and Vz were difficult to track from ping to ping.

The data acquisition system recorded ASCII files either to the hard disk of the PC, or to a Panasonic 1 GByte read/write optical disk on a SCSI port. The files contain individual ping data, rather than the ensemble averages as in the ADCP DAS. File sizes were typically tens of MBytes. The PC was not connected to Ethernet. The optical (or 1.4 MByte floppy for small files) disk written by the ACCP was transferred to a PC connected to the shipboard Ethernet network and the ASCII files copied to the Unix Level C computer. Files varied in duration from minutes to some 10 hours. A typical day would include files of different types, (resolution settings were superboomer, boomer, coarse, medium and fine) each with a different number of vertical bins. For experimental and evaluation purposes, this was necessary, but when used for routine data collection, there will be a need to minimise changes, and to use file sizes of up to 24 hr.

The level C ASCII files were read into the Pstar processing system for post processing, the data following a similar path to those from the ADCP. As with our ADCP data, some element of manual editing and quality control will be needed with the ACCP. The ASCII files were also read into Matlab for rapid evaluation of data quality, calibration etc. At this stage occasional errors consisting of spurious spaces in the ASCII files were detected and edited manually.

The ACCP prototype electronics does not provide for a heading input from the ship's gyrocompass. As heading is essential for converting the velocities from ship- to earth- coordinates, this is a serious omission. Merging the ACCP data with heading at the post-processing stage is definitely second-best. There is also no navigation input to the ACCP. This is less of a concern to us as it is our practice to merge ship-relative velocities with GPS at the post processing stage.

Data quality and calibration

We experienced far higher standard deviations of velocity than were observed in sea trials of the instrument off San Diego. Our values varied from 200 cm s^{-1} (and higher) in the near surface bins to 20 - 60 cm s^{-1} at mid depths (250 - 900 m) Velocities above 130 m were often unacceptable, standard deviations were above 1 m s^{-1}, and there was a consistent bias toward zero velocity as the surface was approached. In practice we discounted much of the data above 200 m. As this is the region of strongest signal return, the reason for poor performance is not clear.

At depths greater than about 1000 m, most of the data points were flagged as invalid by the RDI processing software (although values were still being produced). However, as in the near-surface bins, these were very scattered and did not show any consistent correlation with expected flow speeds. It was concluded that these data should also be discarded. It was also apparent from time series plots of data values at each depth that a significant number of data values that had been flagged as valid, were so far from the mean as to be highly suspect. A spike filter was implemented so that any points that were more than 3 standard deviations from the local median were eliminated.

Contrary to our preconceptions, the performance on-station for CTD casts was, for the most part, poorer than underway at slow speeds. It was clear that this was due to noise (acoustic or electrical?) from the winch system, with its hydraulic power packs and electric motors, which occupies the same machinery space as the ACCP transducer.

Interference from the Simrad EA500 echo sounder operating at 12 kHz was present, shown on the ACCP echo trace as an uncorrelated spike. Although the correlation technique provided some immunity to noise, a method of synchronising the transmission of the ACCP to the Simrad would be an advantage.

For initial calibration we used a north - south pair of tracks, and considered 7 depth cells from 236 m to 543 m on the 'fine' setting and took 5 minute averages of the ACCP velocities. Using a modified Pollard and Read (1989) technique we found the misalignment angle ϕ to be -2.88°, and the amplitude scaling factor was 0.96787.

A second, more controlled calibration exercise was performed on March 3rd consisting of four half hour legs in each of the four cardinal directions. Analysis of these runs yielded a value of $\phi = -4.1^\circ$ (to starboard of astern) and 1.04 +/- 0.02 for the amplitude scaling factor. The angle agrees quite well with that deduced from the initial calibration, but the scaling factor is 7% higher. This needs to be re-checked since such a large uncertainty is unacceptable. Data from a third calibration, run at speeds of 2, 4, 6, 8 and 10 kt may help to resolve this question.

Initial comparisons with the lowered ADCP and the ship-mounted ADCP on CTD station 3 were encouraging (Figure 12). Except for the problems above 200 m the ACCP profile agreed with the LADCP and ADCP profiles within one standard error of the mean (typically 1.2 - 3 cm s^{-1}) at each depth cell in the east and north components. The ACCP averaged out to some extent the fluctuations in the profile with vertical wavelengths of less than some 300 m (fluctuations due to internal-inertial waves).

The ACCP trial was highly successful, and a more detailed report has been compiled which includes recommendations to RDI on how the instrument could be improved (Griffiths, Dupee, Watson, Spain, and Nguyen, 1995).

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CONCLUSIONS

Six moorings with a total of 26 current meters were deployed in the Agulhas Current as it flows southwestward in the Indian Ocean along the continental slope off South Africa. The moorings were specifically designed to maintain their integrity in strong currents with faired wire, large (rather than distributed) buoyancy elements and heavy, fluked anchors. These moorings are planned to be recovered in Spring, 1996, after a full year-long deployment period.

Two of the moorings in the strongest parts of the Current included Acoustic Doppler Current Profilers (ADCP's) at approximately 400m depth to profile upward the currents at 8m intervals throughout the upper 400m of the water column.

A closely spaced CTD section consisting of 14 stations (plus one test station) within 220 km of the African coast was taken in order to determine the geostrophic transport of the Agulhas Current.

A novel aspect of the CTD stations was the mounting of an ADCP on the CTD frame so that the velocities at each station could be measured directly from surface to bottom and back to the surface. This technique, called Lowered ADCP or LADCP, resulted in full-depth velocity profiles for each of the 14 CTD stations.

To provide reference level velocities for geostrophic calculations, continuous underway measurements using the ship-mounted ADCP were carried out to measure the currents in the upper 300m of the water column. During the cruise, these underway ADCP measurements were combined with Global Positioning Satellite (GPS) navigation to determine velocities at 10-minute intervals with an error of approximately 10 cm s^{-1}. It is expected that utilising Differential GPS techniques with nearby land-station data in a post-processing mode will ultimately reduce the uncertainty in velocities measured during the cruise by an order of magnitude.

A pre-production instrument, called an Acoustic Correlation Current Profiler (ACCP), was mounted in *Discovery's* hull in Durban and extensive tests of its profiling capabilities were carried out during the cruise. Early comparisons with underway ADCP measurements and with LADCP measurements during CTD stations suggests that the ACCP has the potential to profile accurately down to depths of approximately 1200m. High noise levels during periods of heavy ship roll and in the upper 250m of the water column appeared to be the principal limiting factors in ACCP performance during this cruise.

ACKNOWLEDGMENTS

We thank the officers and crew of RRS *Discovery* for their expert help in meeting the cruise objectives, and especially for their invaluable assistance during mooring deployment operations.

NERC support under the UK WOCE Capital Fund enabled us to acquire the ACCP and ADCPs which proved to be essential for defining the character of the Agulhas Current and determining its transport. The creative partnership between IOS and RD Instruments worked out between Gwyn Griffiths of IOS and Steve Bradley and Peter Spain of RDI provided a novel opportunity to collaborate on the development of the new acoustic profiling technique embodied in the ACCP.

We particularly thank Robin Tokmakian for her insights into the LADCP processing that allowed access to the top-to-bottom velocity profiles during the cruise; Rob Bonner, Keith Goy and Dave White for installing the ACCP cable during the previous cruise; Henry Valentine and Jackie Cooper for taking responsibility for oxygen determinations at a late stage in cruise planning; Mark Brandon for his help with CTD measurements; and Sheldon Bacon for organising pre-cruise logistics for the scientific personnel.

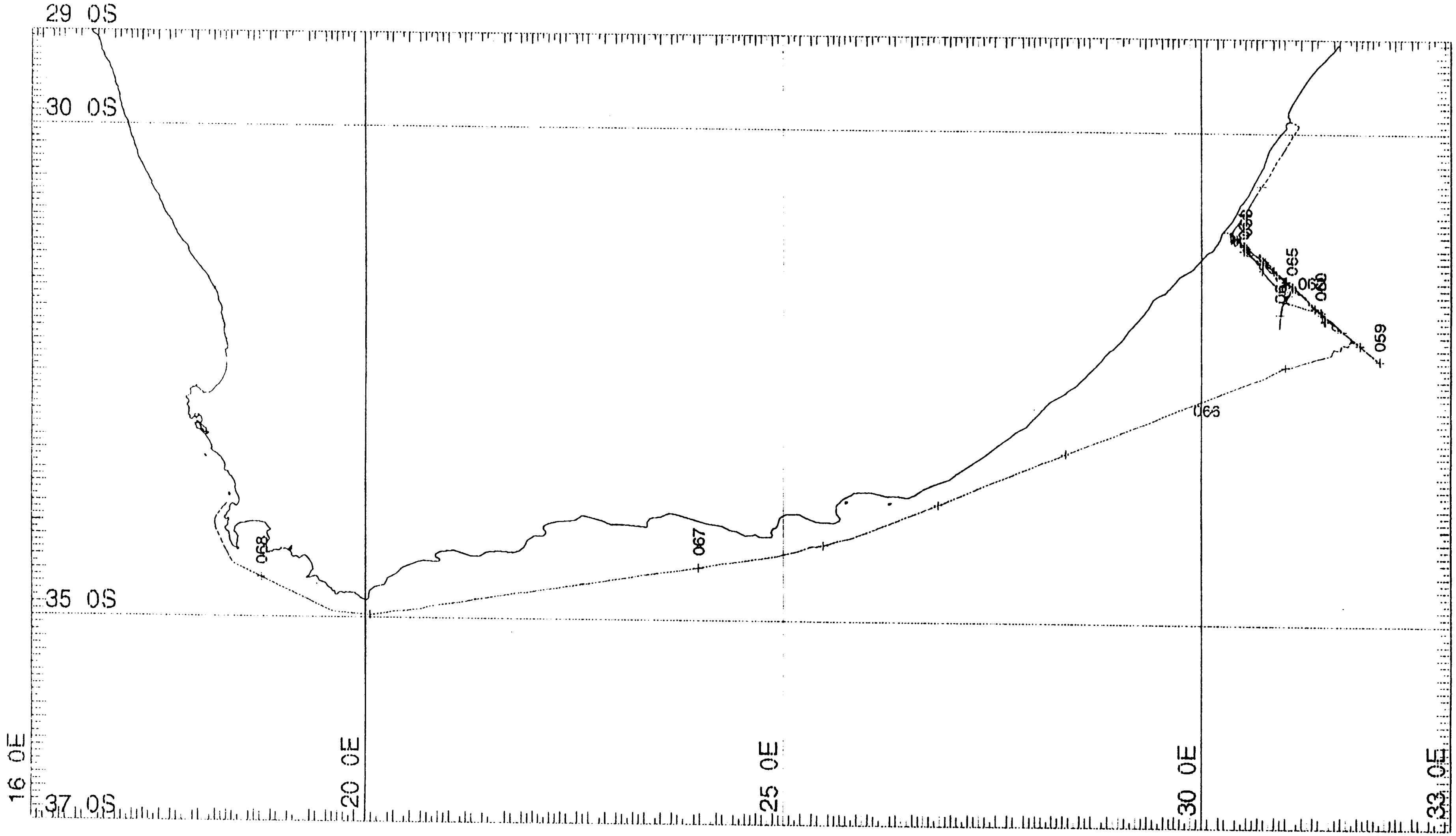


Figure 1a. Overall cruise track for *Discovery* 214, Durban to Cape Town, 26 February to 9 March 1995

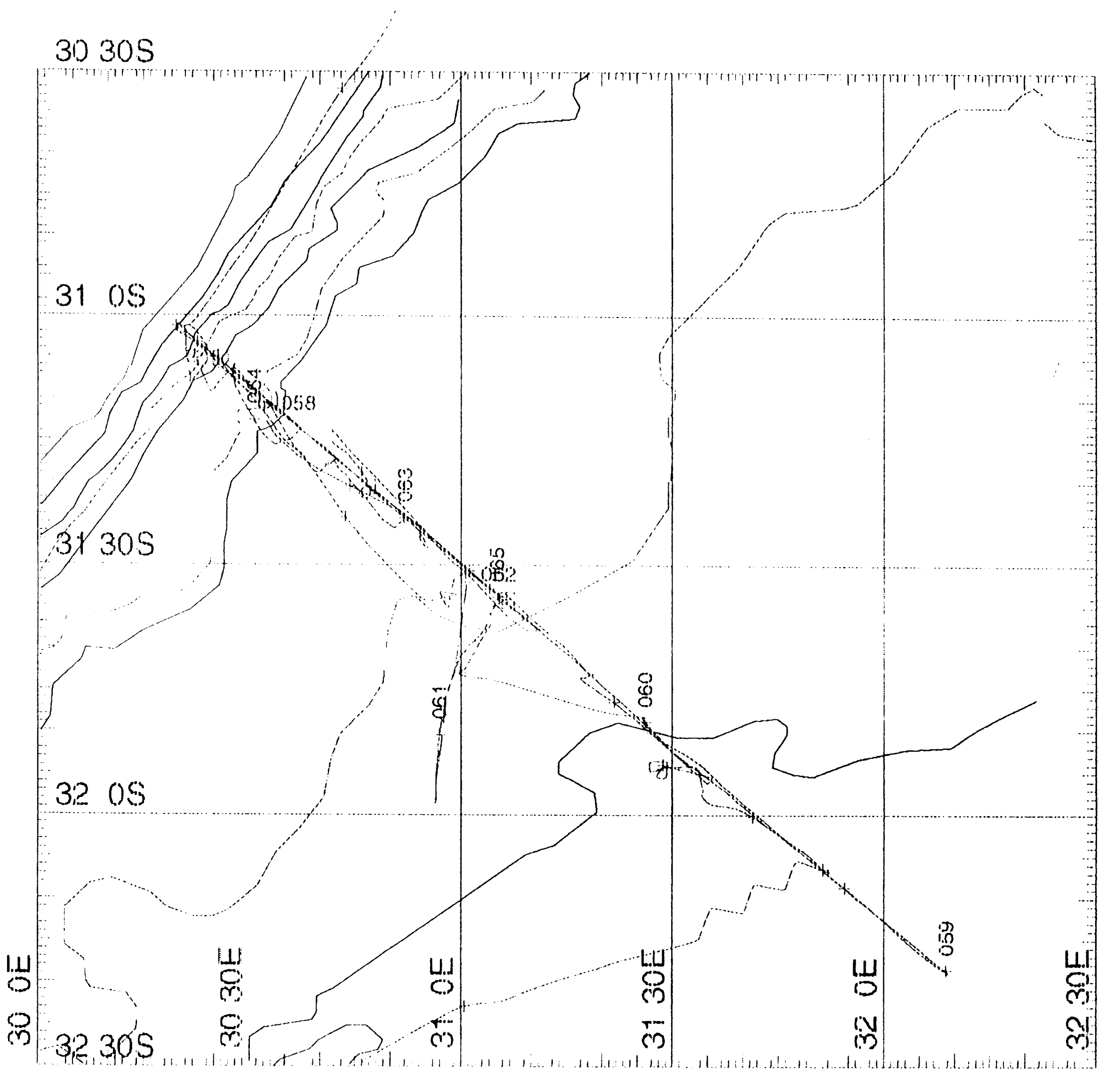


Figure 1b. Detailed cruise track for ACE work aboard RRS *Discovery* 214 on the section across the Agulhas Current offshore of Port Edward

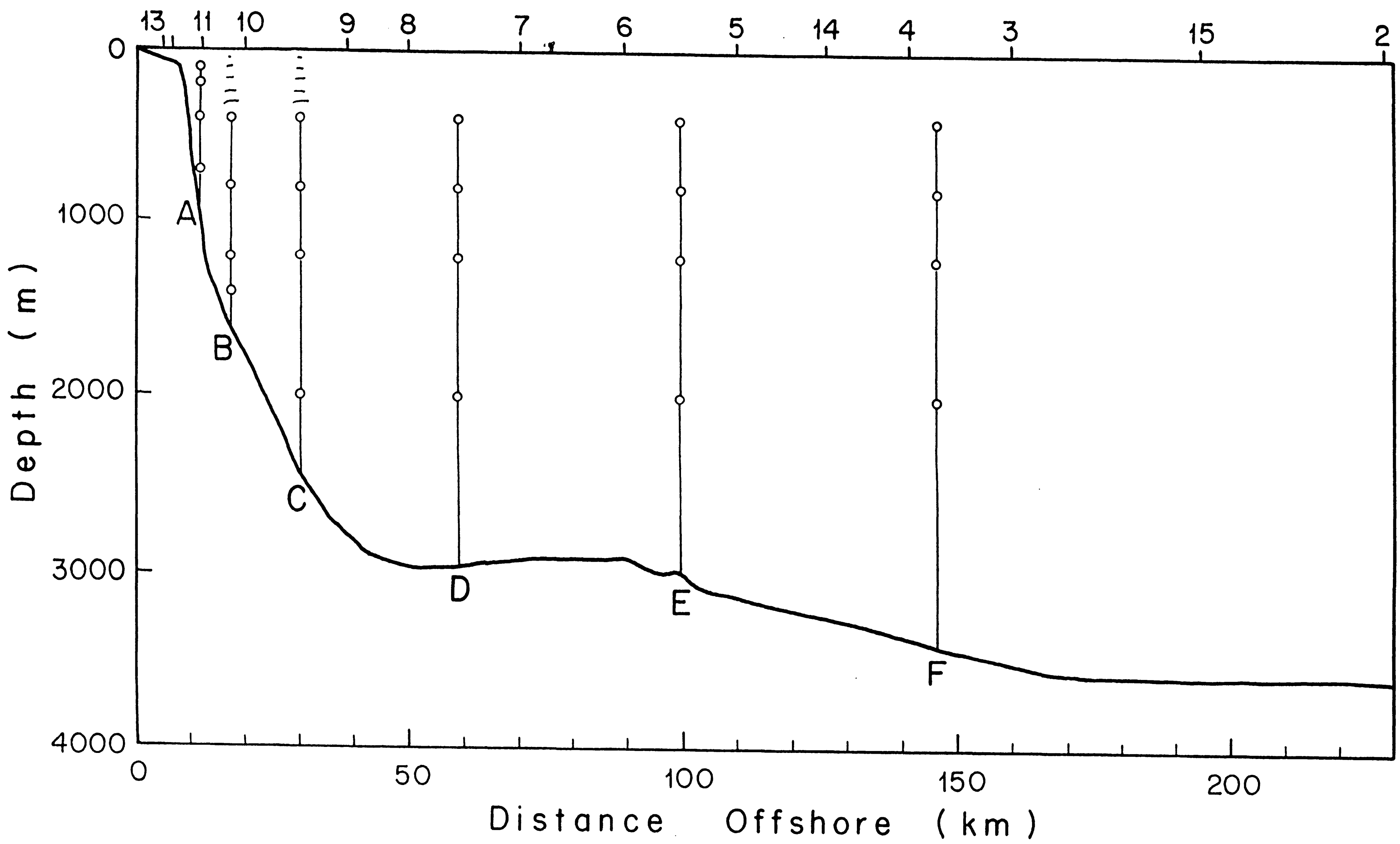


Figure 2. Configuration of the year-long ACE current meter array with CTD/LADCP station locations on the section across the Agulhas Current off Port Edward. The bathymetry is taken from *Discovery's* initial transit across this section.

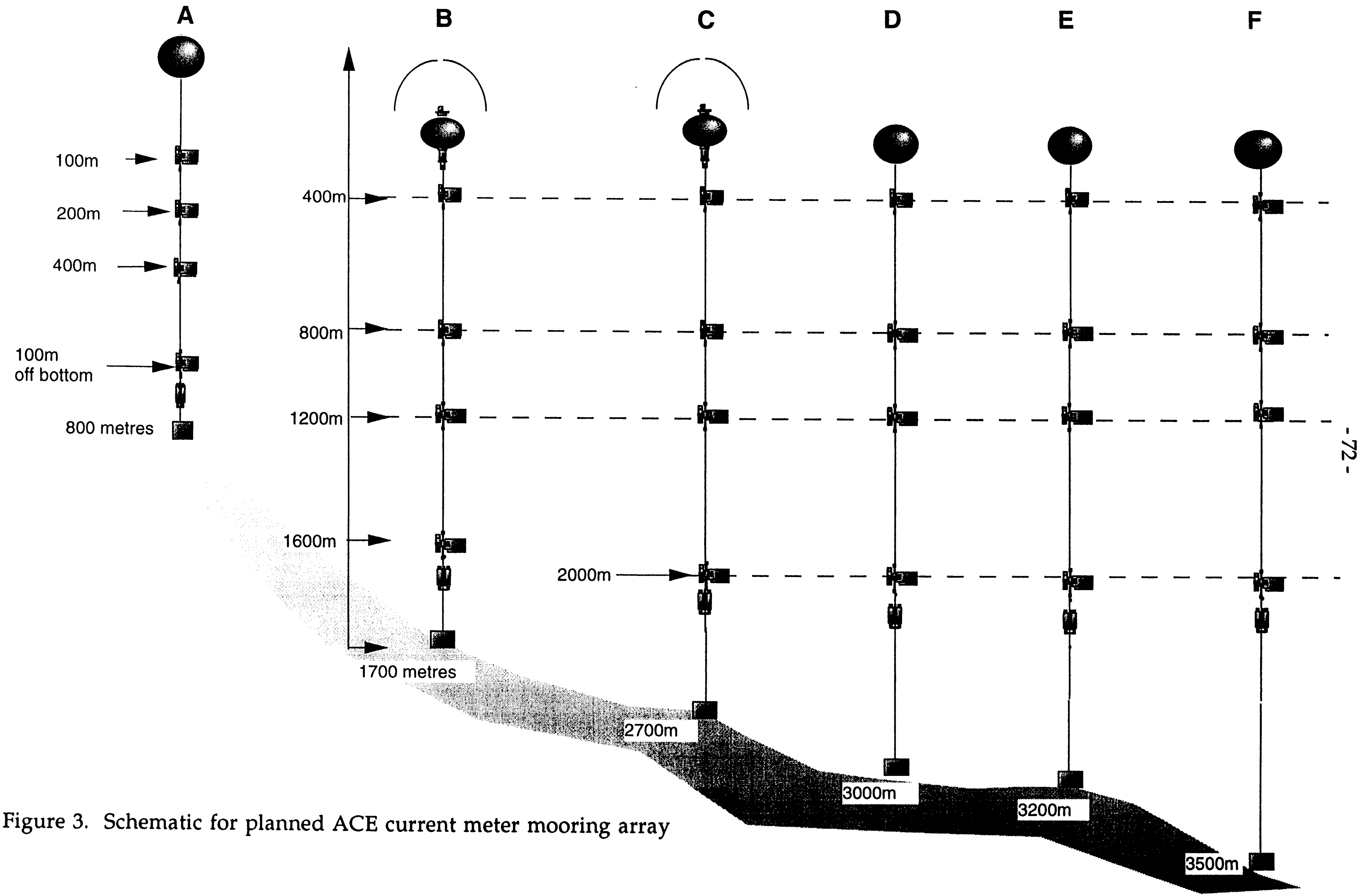


Figure 3. Schematic for planned ACE current meter mooring array

Figure 4a. Details for ACE Mooring A

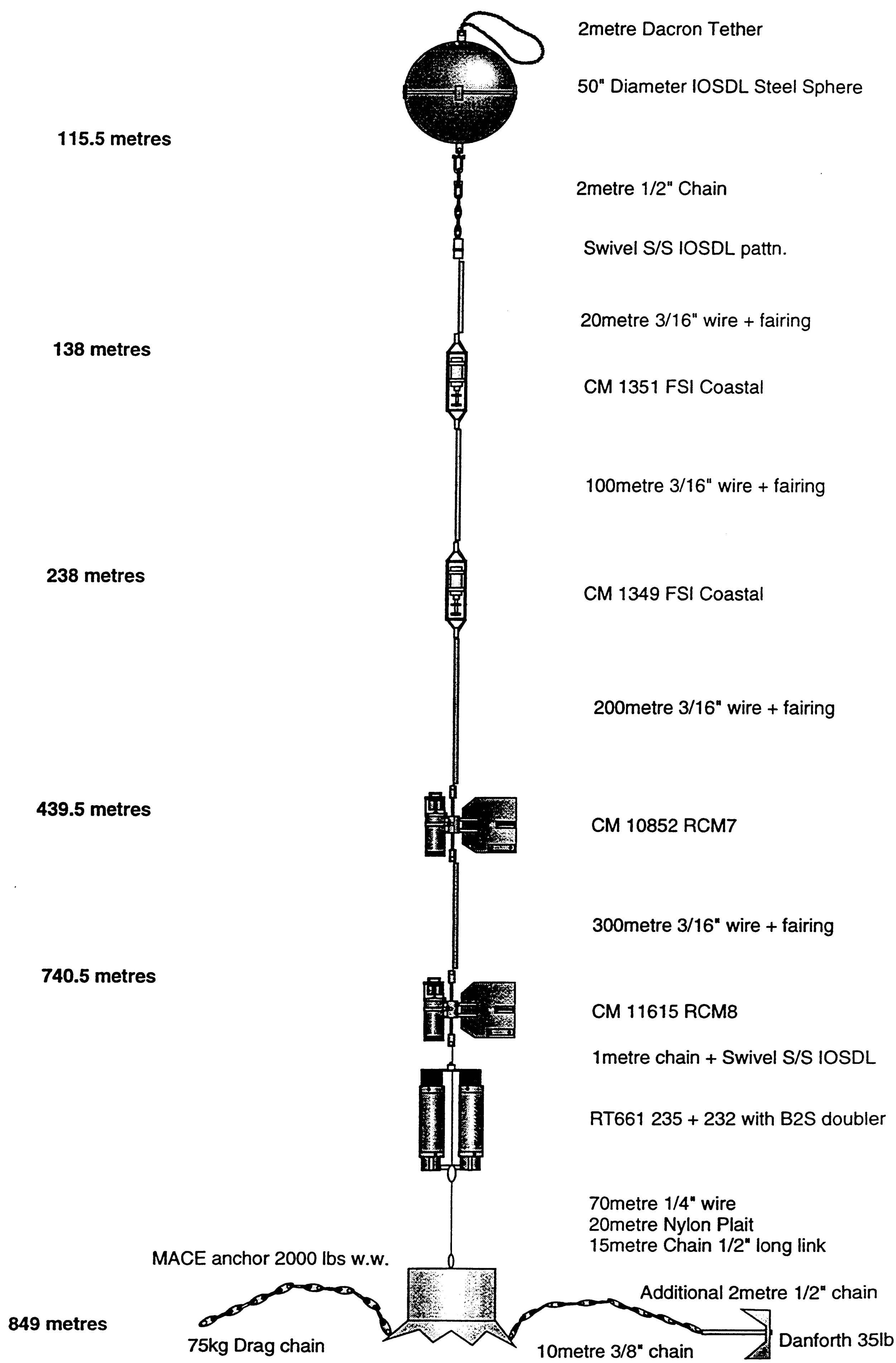


Figure 4b. Details for ACE Mooring B

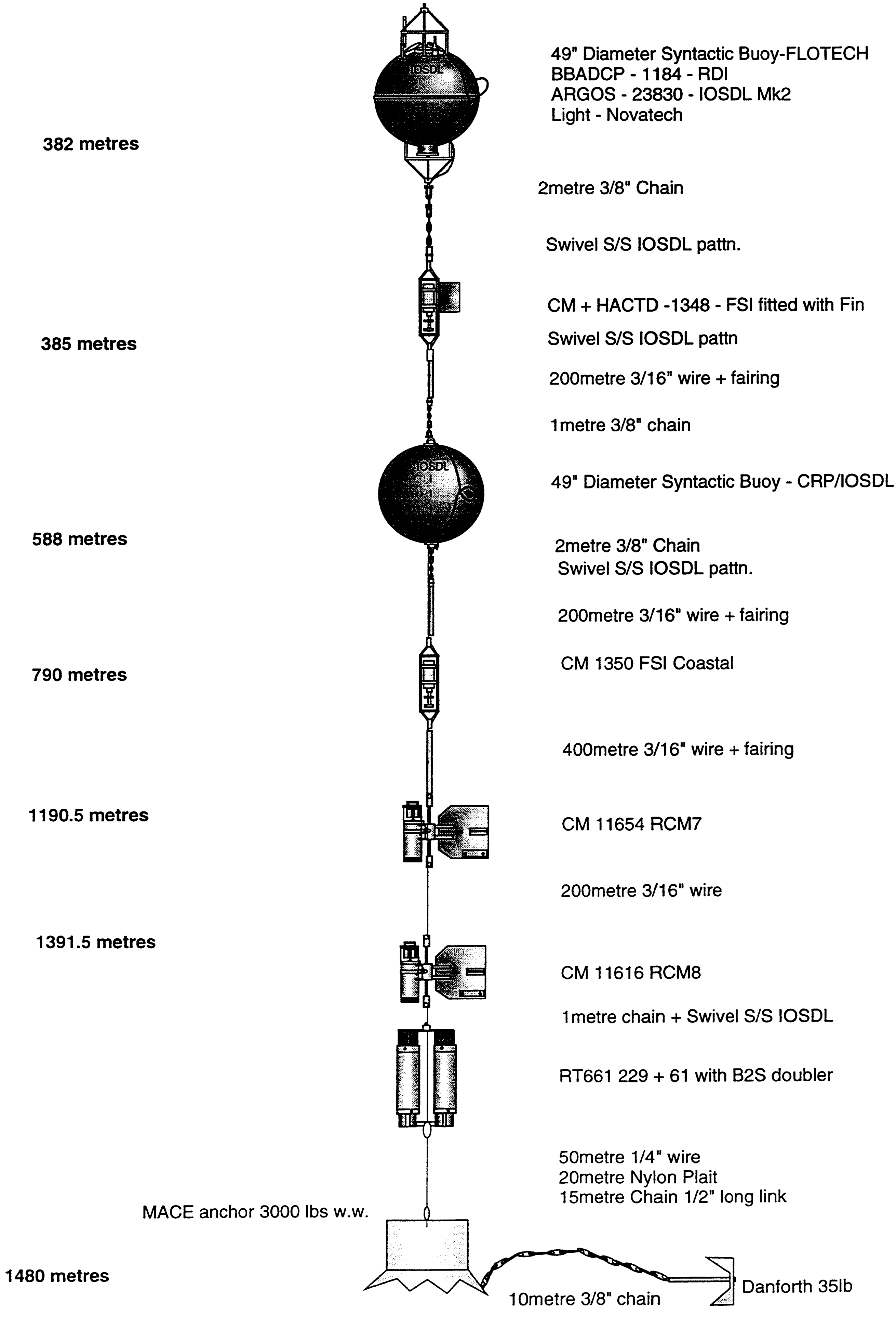


Figure 4c. Details for ACE Mooring C

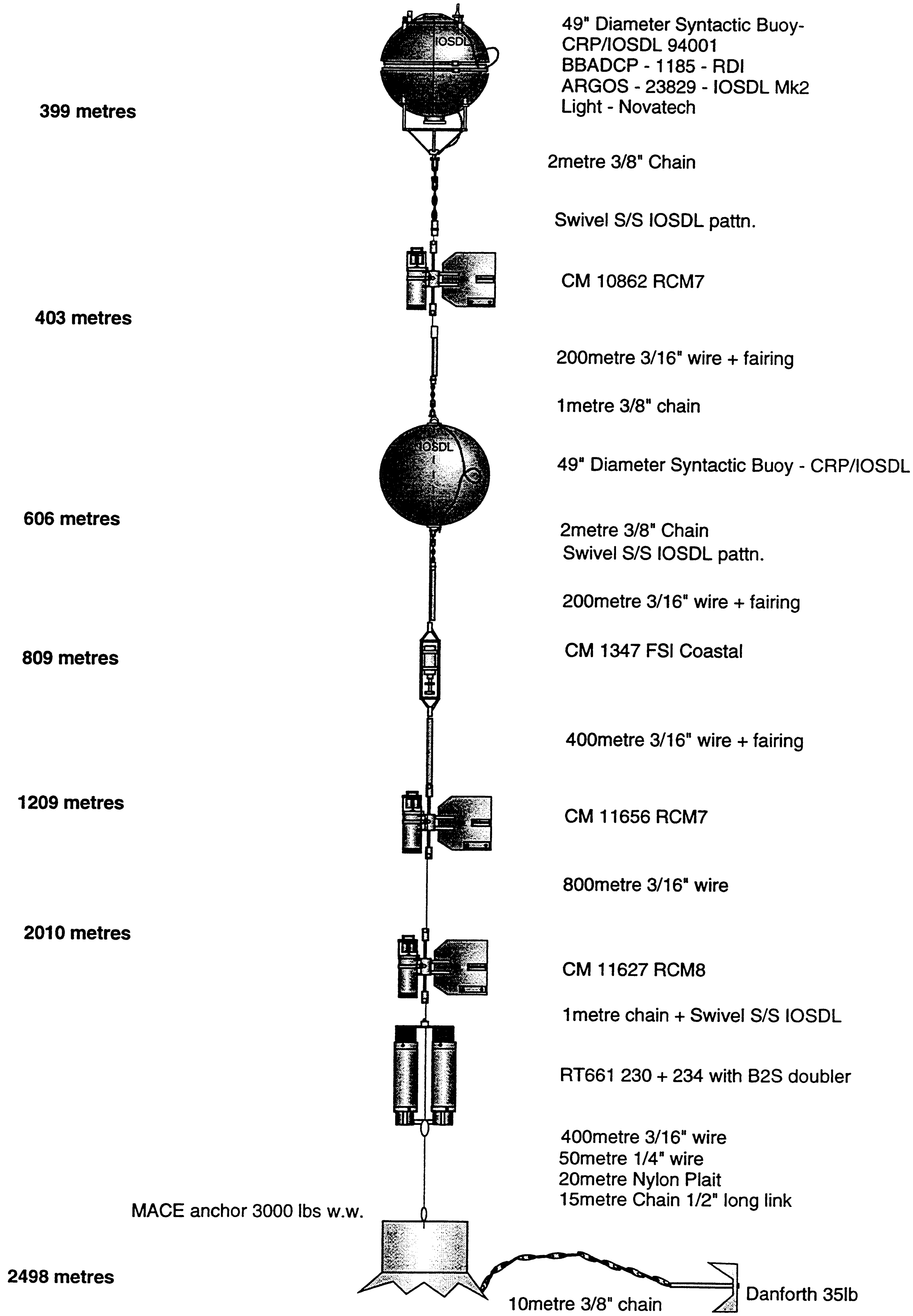


Figure 4d. Details for ACE Mooring D

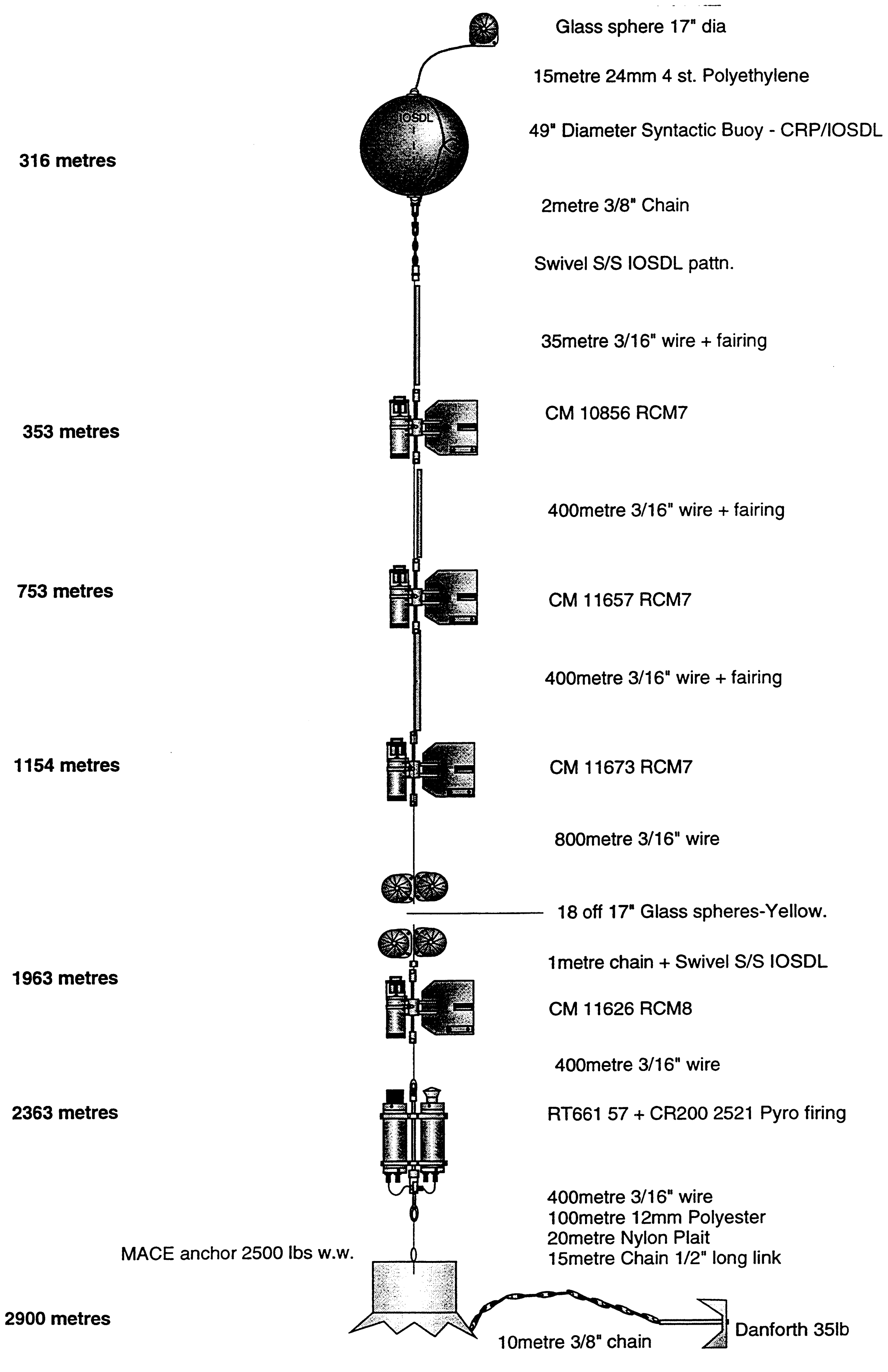


Figure 4e. Details for ACE Mooring E

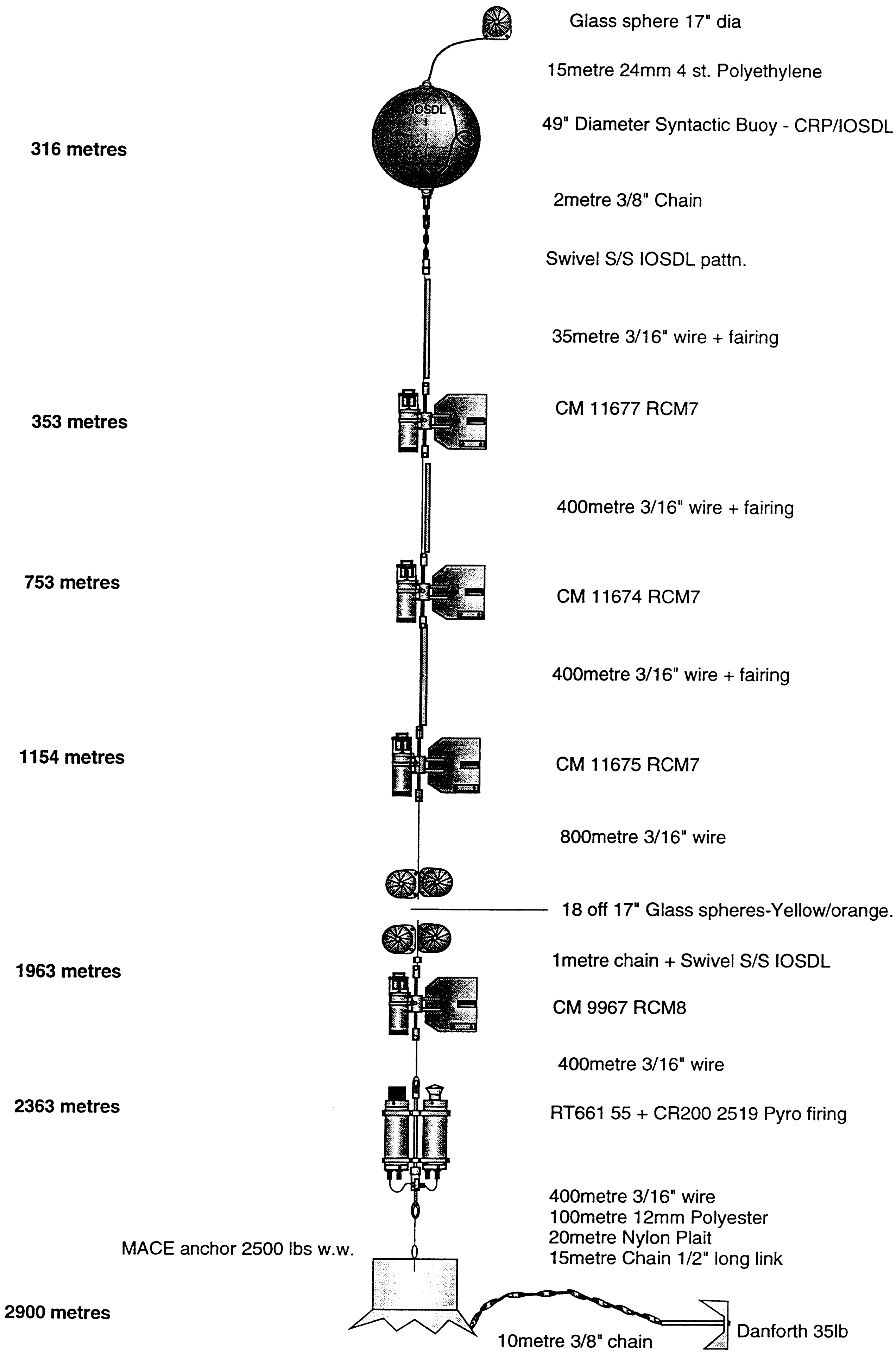
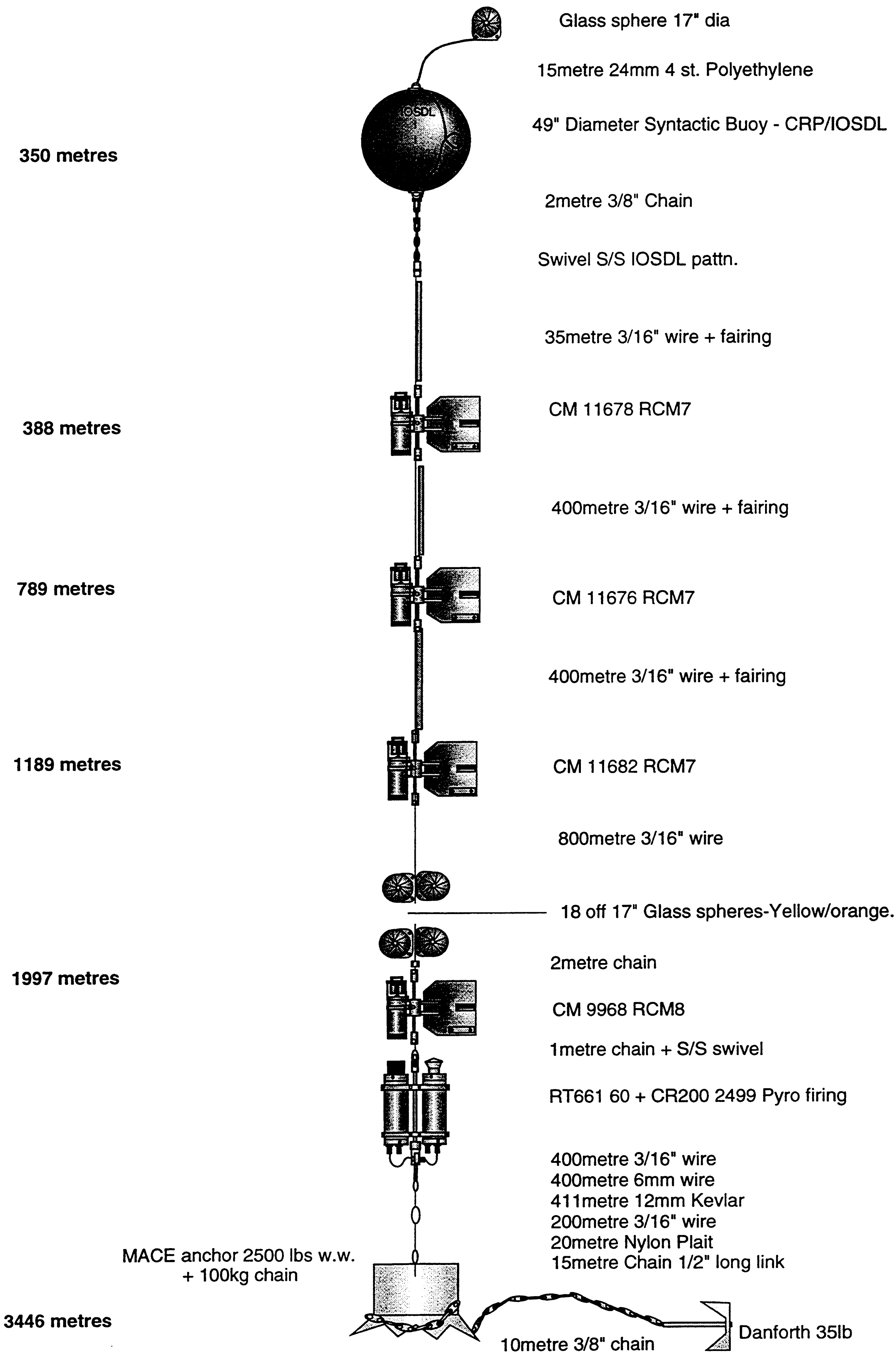
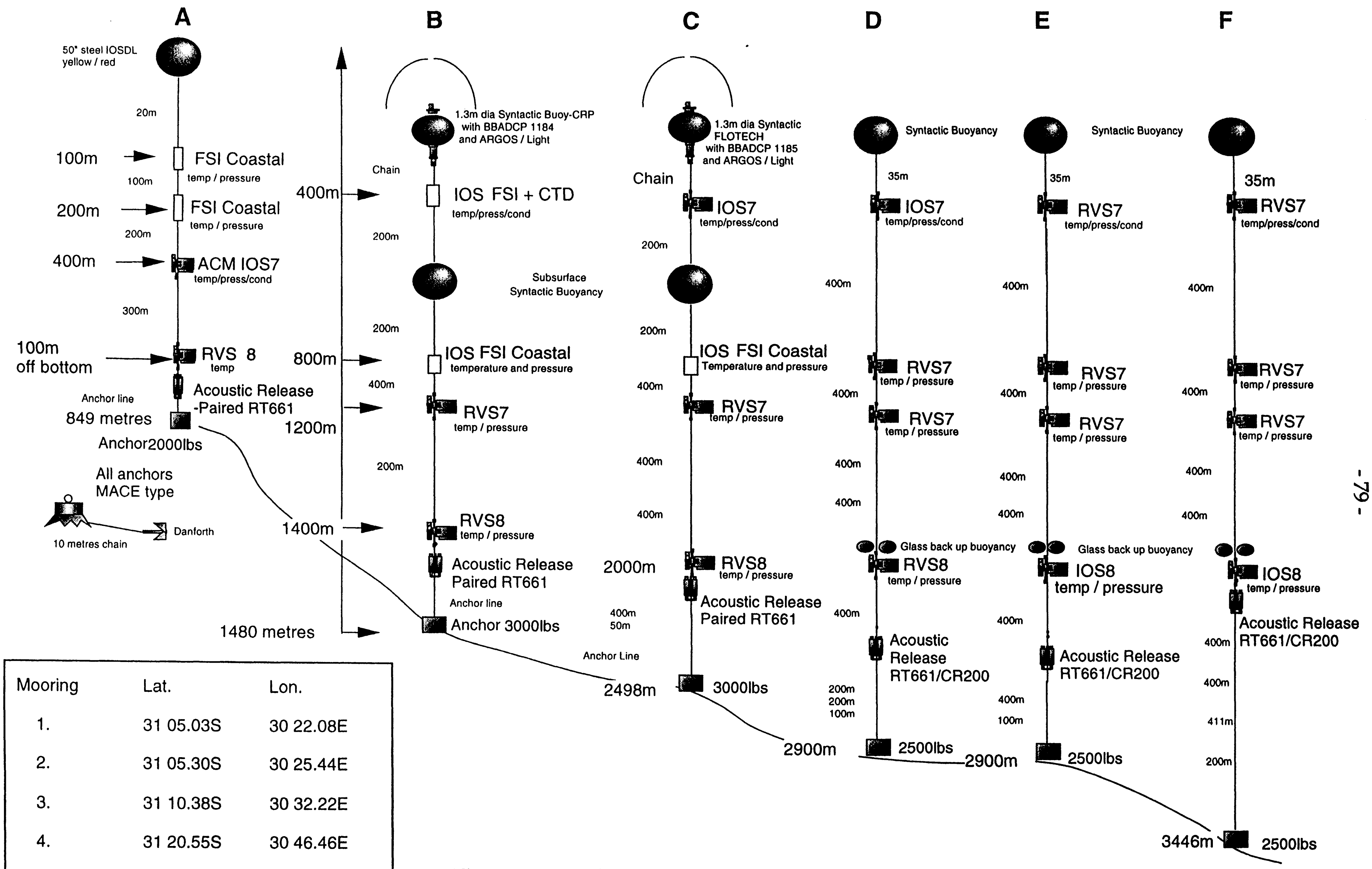


Figure 4f. Details for ACE Mooring F

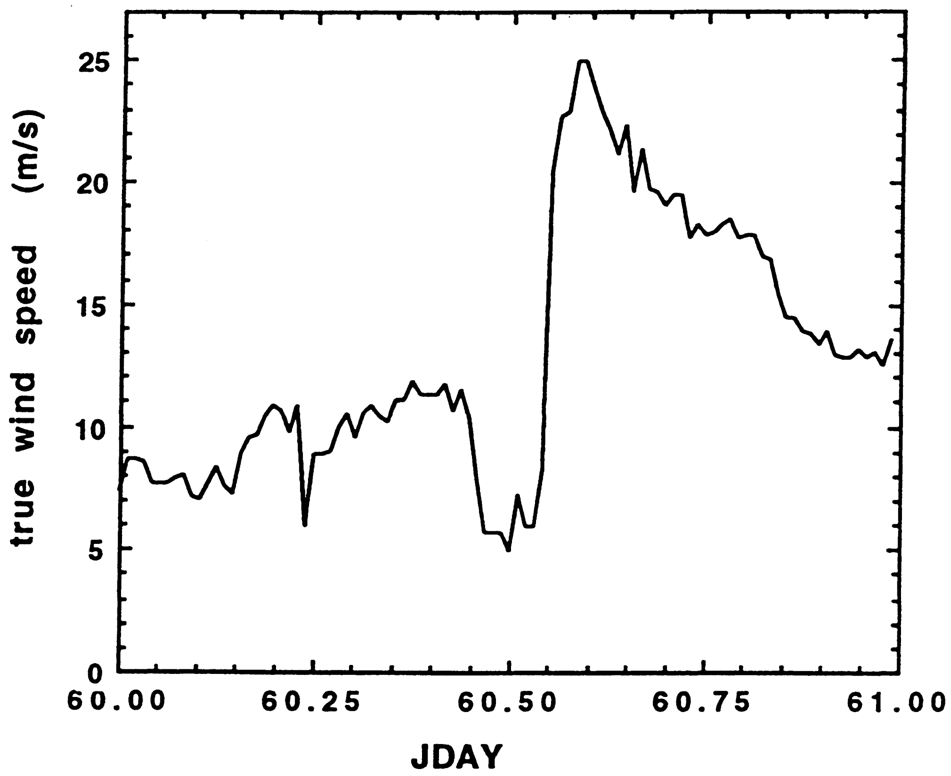




Mooring	Lat.	Lon.
1.	31 05.03S	30 22.08E
2.	31 05.30S	30 25.44E
3.	31 10.38S	30 32.22E
4.	31 20.55S	30 46.46E
5.	31 34.46S	31 06.00E
6.	31 54.51S	31 28.24E

Figure 5. Configuration of instrumentation on ACE mooring array as deployed February-March 1995 from RRS *Discovery*

Figure 6. Wind speed and wind direction during the passage of the coastal low on 1 March 1995 (JDAY = 60)



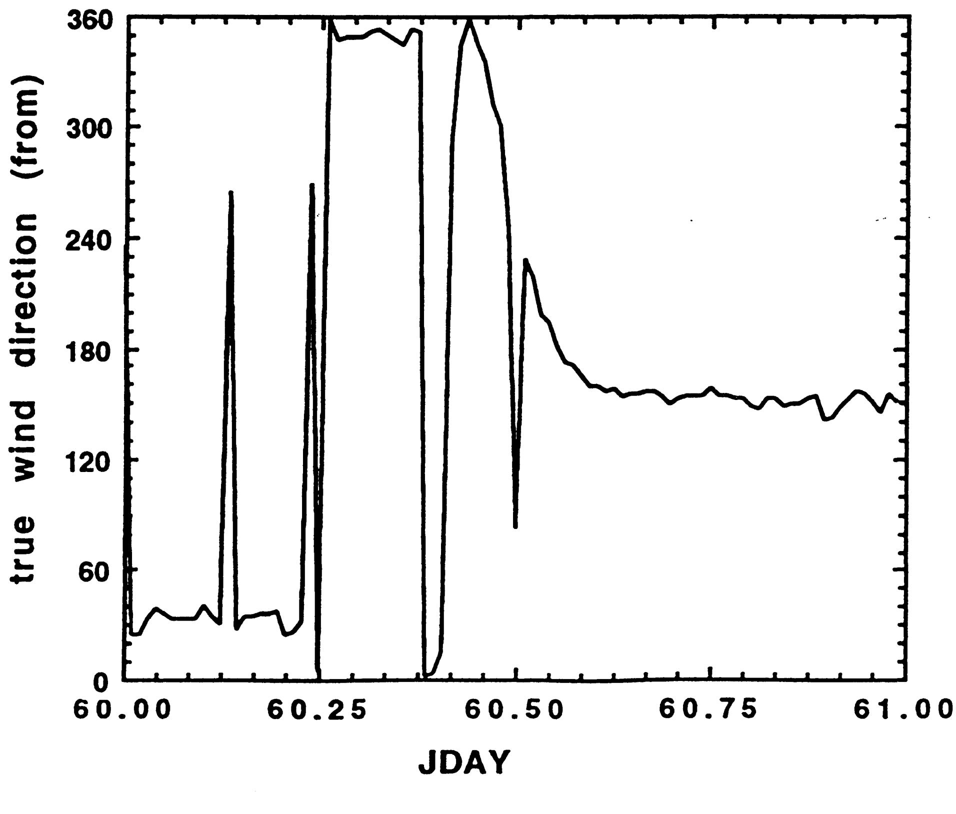


Figure 7a. Conductivity offset versus Station

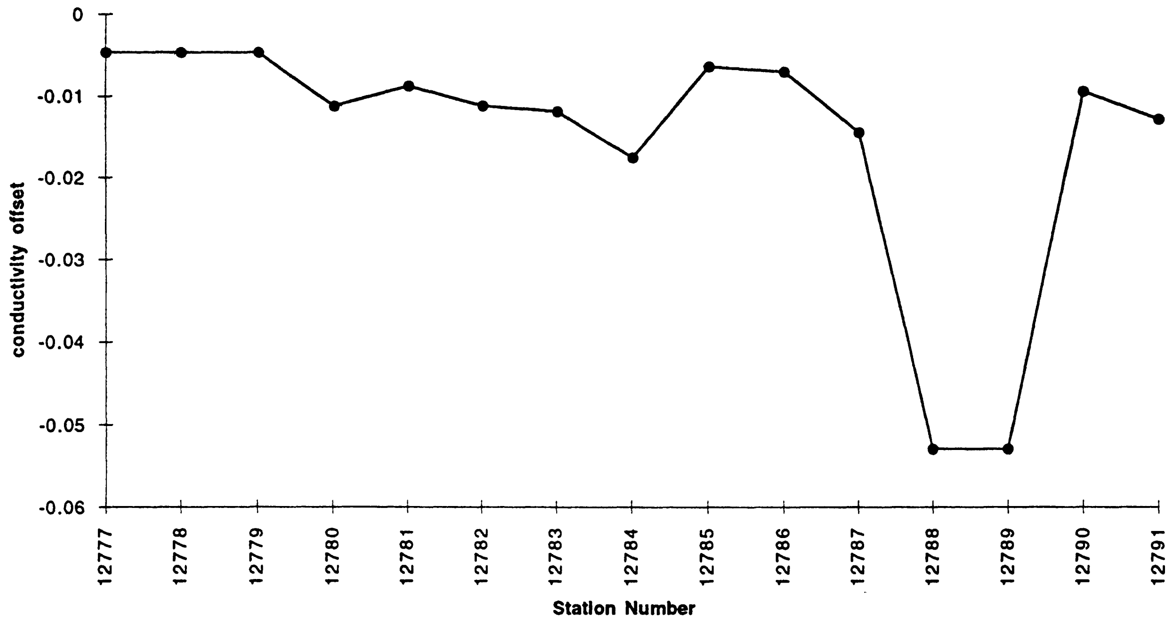
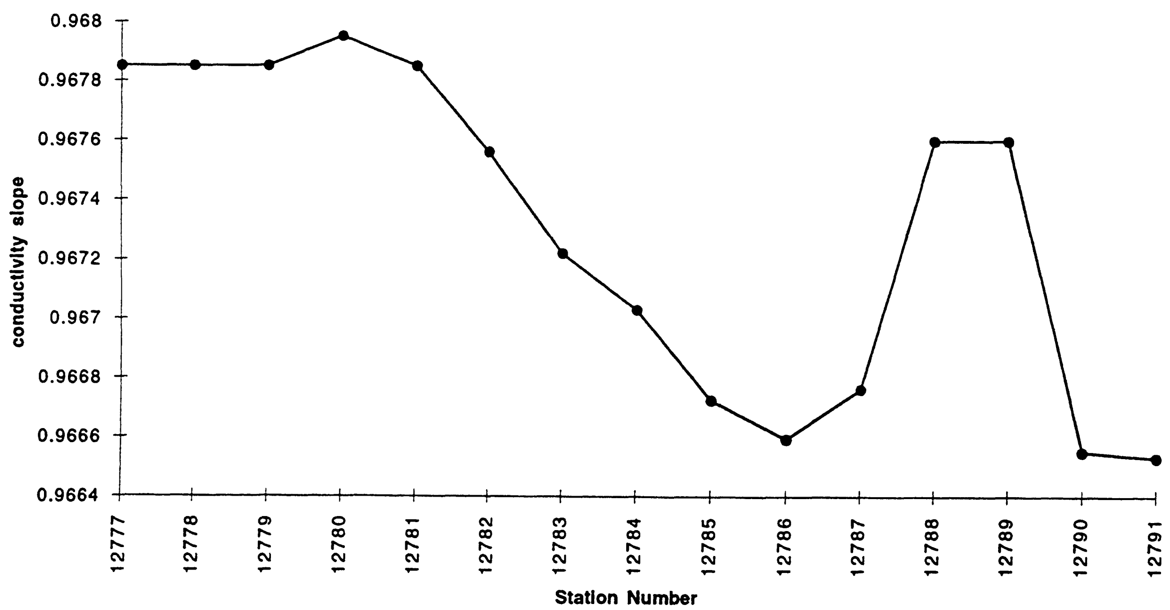


Figure 7b. Conductivity slope versus Station



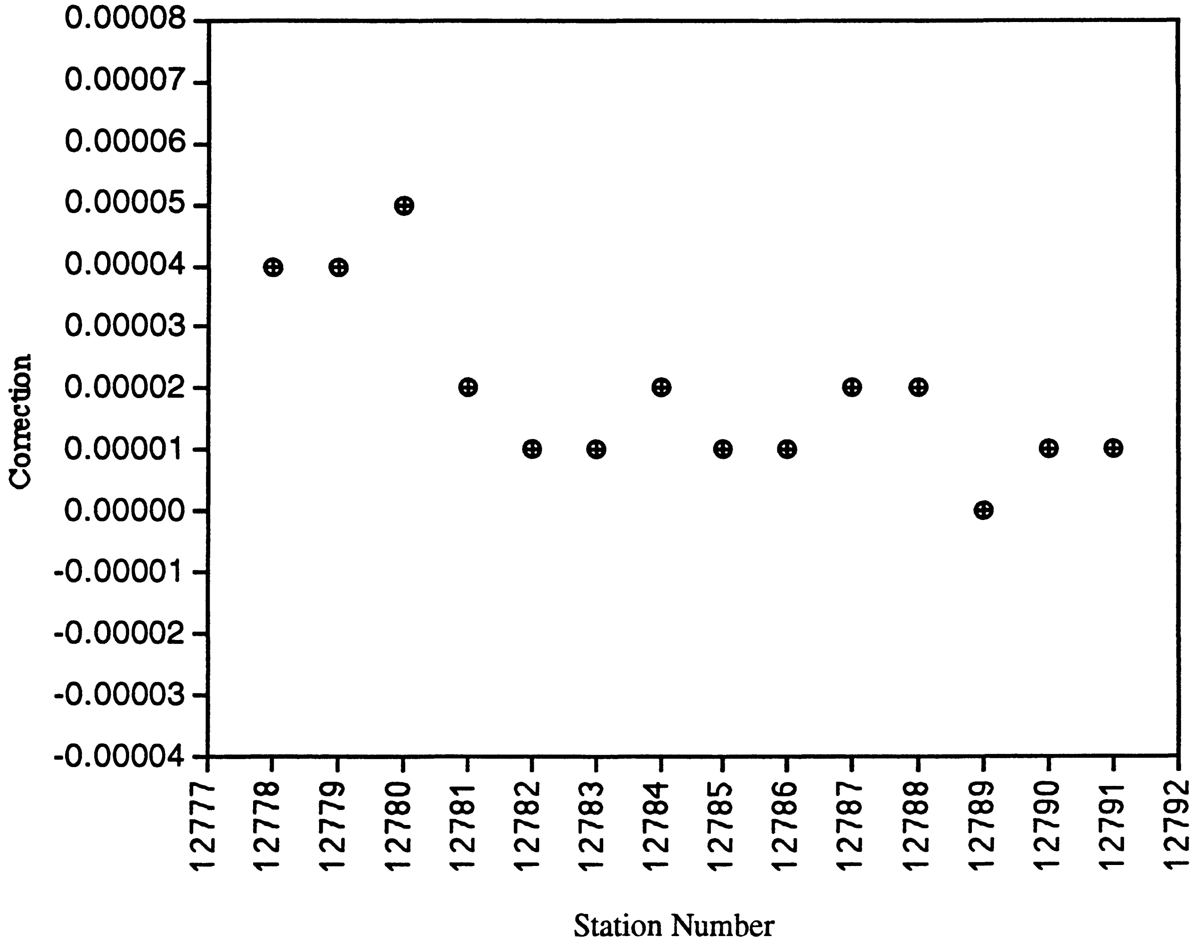


Figure 8. The Standard Sea water corrections (actual) applied to the salinometer readings for the salinity samples at each station.

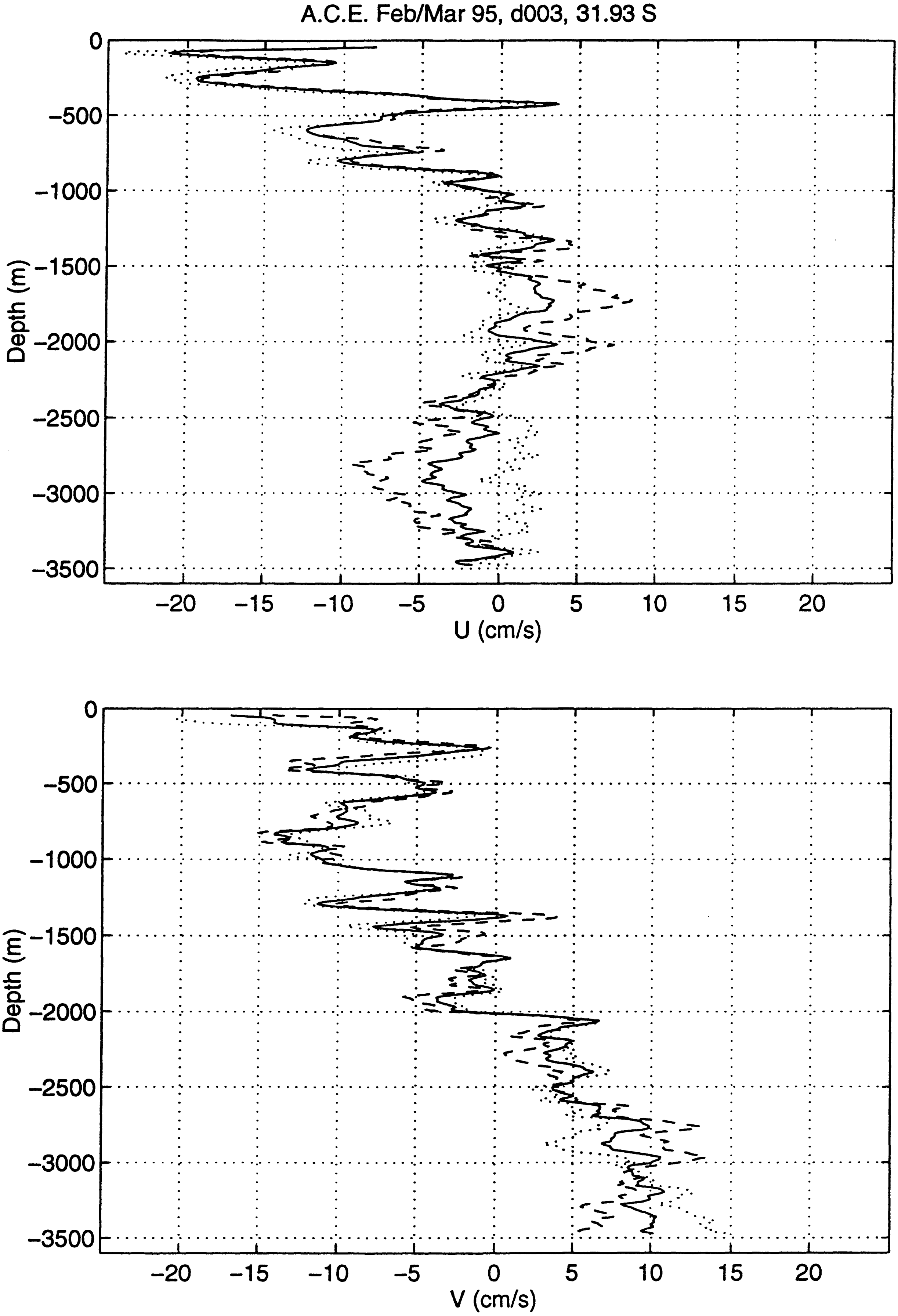


Figure 9. East (U) and North (V) velocity profiles for LADCP station 3. The down profile is shown as a dashed line, the up profile as a dotted line, and the average up and down profile as a solid line.

Figure 10. Contoured Section of along-coast velocity (220°T) in the upper 300m across the Agulhas Current off Port Edward, South Africa from underway ADCP measurements. The horizontal axis is distance offshore from the coast at 30° 59.8'S 30° 18'E along a line running toward 130°T; the vertical axis is depth below the sea surface; and velocities are in cm s^{-1}

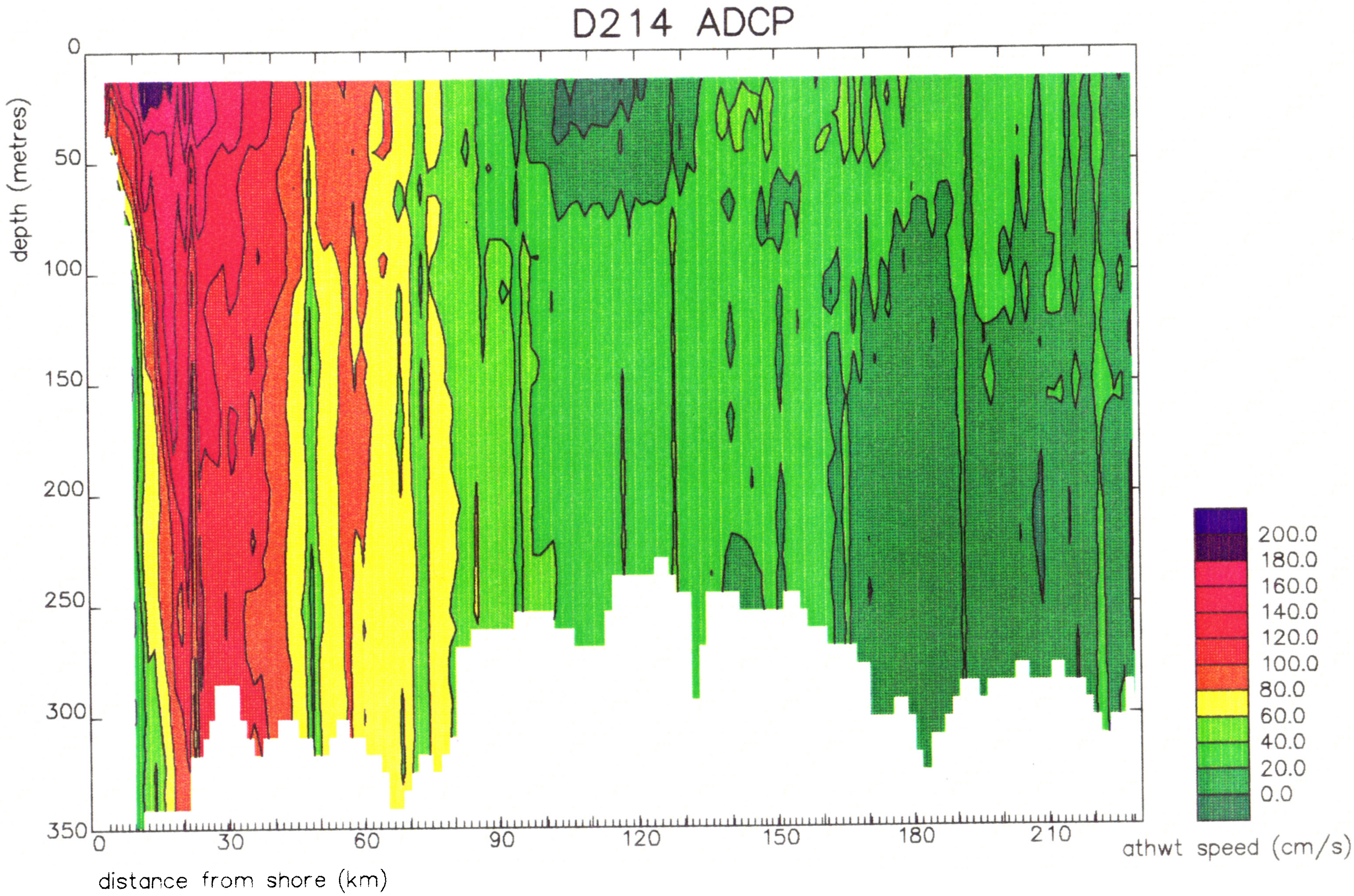


Figure 11. North current component from three acoustic current profiling instruments deployed on the Agulhas Circulation Experiment, February 1995.

Station L003 Day 59 1950 - 2240Z Lat: 31.9°S Lon 31.59°E