Contents

Scientific Personnel

Name	Role	Affiliation
Elaine McDonagh	Principal Scientist / LADCP	JRD-NOC
Ute Schuster	Carbon System – Leader	UEA, Norwich
Pete Brown	Carbon System	UEA, Norwich
Gareth Lee	Carbon System / CFC	UEA, Norwich
Marie-Jose Messias	CFC – Leader	UEA, Norwich
Noam Bergman	CFC	UEA, Norwich
Sinhue Torres – Valdes	Nutrients – Leader	GDD-NOC
Tim Lesworth	Nutrients / Atmospheric Sampling	UEA, Norwich
Rhiannon Mather	Nutrients / Organic Nutrients / SAPS	Liverpool
Brian King	Watchkeeper / CTD / FOG'S / ADCP	JRD-NOC
Susan Leadbetter	Watch Leader / FOG'S	Liverpool
Hannah Longworth	Watch Leader / CTD	SOES-NOC
Paula McLeod	Watch Leader / VMADCP	JRD-NOC
Claire Powell	Watchkeeper / CTD	JRD-NOC
Jeff Benson	Technical Liaison / Instrumentation	UKORS-NOC
Bob Keogh	Instrumentation / Mechanical Engineer	UKORS-NOC
Dave Teare	Instrumentation	UKORS-NOC
Jeff Bicknell	Computing	UKORS-NOC

LADCP- Lowered Acoustic Doppler Current Profiler;
VMADCP – Vessel Mounted ADCP
CTD- Conductivity, temperature depth; SAPS- Stand Alone Pumps;
FOG'S- Fibre Optic Gyros
NOC – National Oceanography Centre, Southampton; JRD – James Rennell Division;
GDD – George Deacon Division; SOES – School of Ocean and Earth Sciences;
UKORS – UK Ocean Research Services; UEA – University of East Anglia;
Liverpool – University of Liverpool;

Ship's Personnel

Phil Gauld	Master
Peter Newton	Chief Officer
Malcolm Graves	2nd Officer
Kieron Hailes	3rd Officer
Kishor (Jet) Jethwa	Chief Engineer
Alex Greenthorn	2nd Engineer
Gary Slater	3rd Engineer
Jim Bills	3rd Engineer
Dean Hurren	ETO
Glenn (Tiny) Pook	CPO (Deck)
Martin Harrison	CPO (Scientists)
Phil Allison	PO (Deck)
Gary Crabb	S1A
Mark Moore	S1A
Andrew Pearce	S1A
Stuart Cook	S1A
Carl Moore	POMTR
Clive Perry	SCM
Peter Lynch	Chef
Wally Link	Assistant Chef
Graham Mingay	Steward

Background and Objectives

The main aim of the 36°N project was to complete a full-depth transatlantic hydrographic section at that latitude. In addition a section was made across the Gulf Stream and deep western boundary current to the north of the main section at the beginning of the trip and, at the end of the cruise a section was made across the Gulf of Cadiz.

Even though the North Atlantic is relatively well observed, there are major problems in our knowledge of its present state and how it might evolve. At present, it is unclear as to the extent of subtropical warming, how phytoplankton growth is sustained over the subtropics, and the rate at which the ocean uptakes carbon dioxide.

In terms of the historical context, the pair of transatlantic hydrographic sections at 24°N and 36°N were taken in 1981 by Roemmich and Wunsch (1985), including CTD stations, nutrient measurements, but lacking carbon, CFC measurements and acoustic current profiling. The 24°N transatlantic section was repeated in 1992 during WOCE, and in 2004 (Cunningham, 2005) both occupation included carbon and CFC sampling, but only the 2004 section included acoustic current profiling. There is a crucial gap in the WOCE coverage (highlighted in the review by Wunsch, 2002) in there being no 36^{o}N section during WOCE leaving 36°N unsampled since 1981.

A recent analysis of historical data suggests that the warming over the N. Atlantic is concentrated over the tropics and subtropics (Lozier and Moore, 2003). Over the subtropical gyre, there appears to be a loss of inorganic nutrients (Rintoul and Wunsch, 1991) and it is unknown how the nitrogen, phosphorus and carbon budgets are closed. In addition, recent observations (Lefèvre et al., 2004; Rosón et al., 2003) suggest that there is less uptake of CO_2 than expected over the N. Atlantic (with an implied outgassing of anthropogenic CO_2) compared with predictions from models.

Thus the data collected on this cruise will contribute to knowledge of how physical and biological cycling operates within the subtropical North Atlantic. Specifically the program will determine the heat transport across 36°N and identify the extent of

warming over the subtropical North Atlantic. The project will also determine the nitrogen and phosphorus budgets in the subtropical North Atlantic and identify the relative importance of the transport and cycling of dissolved organic nitrogen and phosphorus. In addition we will determine the carbon transport across 36°N and identify whether the subtropical North Atlantic is taking up or outgassing anthropogenic carbon.

In total 144 CTD (conductivity-temperature-depth) stations were occupied (Figure 1 and Table 1). A 24-bottle rosette was used to take water samples at these CTD stations. An ADCP (acoustic doppler current profiler) was mounted on the rosette frame. At the site of 13 of these CTD stations SAPs (stand-alone-pumps) were deployed. Hull-mounted ADCP, thermosalinograph (TSG), meteorological and pCO_2 measurements were made underway. Continual atmospheric sampling was carried out for aerosols and gas phase ammonia and rain samples were taken at every opportunity.

References

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Itinerary

Depart St. Georges, Bermuda, 1st May 2005 – arrive Lisbon, Portugal, 15th June 2005

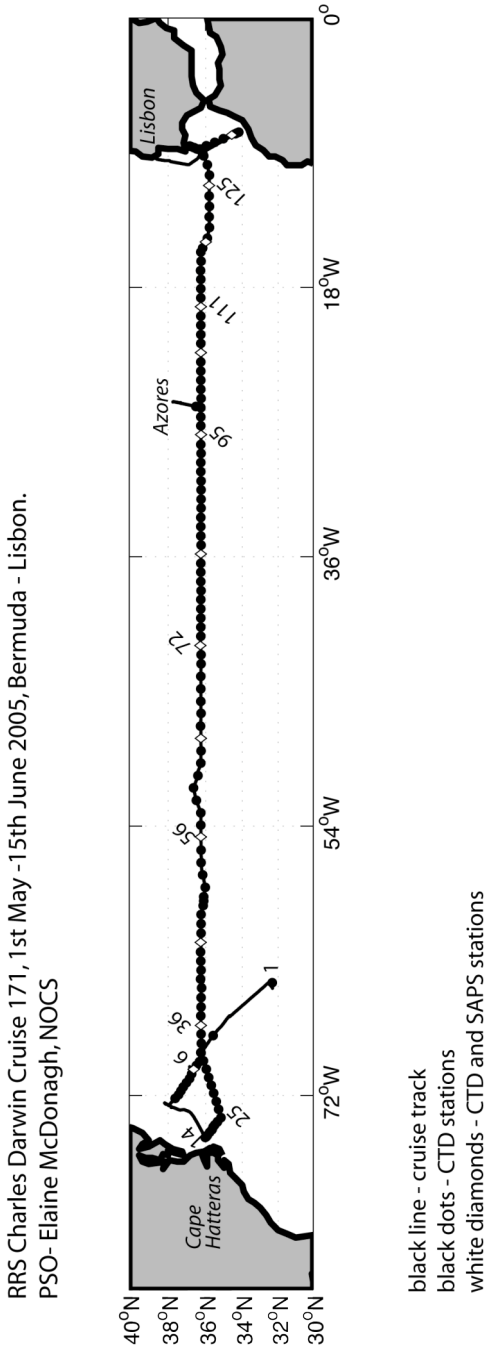

Figure 1: Cruise Track and CTD Stations for CD171

Table 1: List of station positions for CD171

Sta num	Date ddd hhmm	Latitude deg min	Longitude deg min	Water depth (m)	Sampling							
					HeTr	CFC	O_2	CO_2	DOM	Salt	Nuts	SAPs
1	122 1814	34 42.51 N	66 42.89 W	5251		X	X	X	X	X	X	
2	123 0737	35 35.62 N	67 59.99 W	5099		X	X	X		X	X	
3	123 1716	36 13.85 N	69 08.44 W	4563			X	X	X	X	X	
4	124 0116	36 19.42 N	69 44.44 W	4529		X	X			X	X	
5	124 0729	36 29.80 N	70 00.38 W	4466			X			X	X	
6	124 1435	36 38.41 N	70 15.75 W	4422	X	X	X	X	X	X	X	X
7	125 0252	36 44.31 N	70 33.53 W	4385		X	X			X	X	
8	125 0828	36 51.99 N	70 52.14 W	4260			X	X	X	X	X	
9	125 1348	37 01.92 N	71 09.24 W	4125			X		X	X	X	
10	125 1909	37 11.03 N	71 25.96 W	4005	X		X	X	X	X	X	
11	126 0021	37 19.36 N	71 40.75 W	3610		X				X		
12	126 0632	37 26.57 N	71 57.08 W	3249			X	X	X	X	X	
13	126 1220	37 36.66 N	72 12.10 W	3363	X		X	X	X	X	X	
14	128 1040	36 00.89 N	74 48.77 W	124			X		X	X	X	
15	128 1150	35 59.66 N	74 47.76 W	208			X	X	X	X	X	
16	128 1258	35 58.63 N	74 46.43 W	515			X			X	X	
17	128 1437	35 57.13 N	74 44.24 W	1052			X	X	X	X	X	
18	128 1715	35 54.71 N	74 40.53 W	1511			X			X	X	
19	128 2057	35 46.40 N	74 27.51 W	1937			X	X		X	X	
20	129 0103	35 38.96 N	74 16.75 W	2516			X		X	X	X	
21	129 0603	35 30.67 N	73 59.16 W	3035			X	X	X	X	X	X
22	129 1129	35 21.18 N	73 44.50 W	3437			X			X	X	
23	129 1938	35 35.82 N	74 07.02 W	2831			X			X	X	
24	130 0059	35 21.71 N	73 46.16 W	3418			X		X	X	X	
25	130 0652	35 09.52 N	73 28.21 W	3837			X	X	X	X	X	
26	130 1239	35 17.71 N	72 56.09 W	4165			X			X	X	
27	130 1857	35 25.10 N	72 24.43 W	4263	X	X	X	X	X	X	X	
28	131 0141	35 33.94 N	71 51.52 W	4251		X	X			X	X	
29	131 0836	35 41.96 N	71 19.75 W	4349		X	X		X	X	X	
30	131 1500	35 49.98 N	70 47.97 W	4431	X	X	X	X	X	X	X	
31	131 2158	35 58.05 N	70 14.82 W	4478		X	X			X	X	
32	132 0451	36 06.79 N	69 41.63 W	4540			X		X	X	X	
33	132 1104	36 15.37 N	69 07.74 W	4562			X	X	X	X	X	
34	132 1718	36 13.58 N	68 30.91 W	4637			X			X	X	
35	133 0005	36 14.04 N	67 54.16 W	4749			X			X	X	
36	133 0751	36 15.13 N	67 19.19 W	5016	X	X	X	X	X	X	X	X
37	133 1936	36 15.35 N	66 40.45 W	5052			X			X	X	
38	134 0251	36 14.82 N	66 05.14 W	4883			X			X	X	
39	134 0952	36 14.09 N	65 27.37 W	4936		X	X	X	X	X	X	
40	134 1704	36 13.09 N	64 49.14 W	5019			X			X	X	
41	135 0217	36 15.86 N	64 13.78 W	5019			X			X	X	
42	135 0933	36 14.74 N	63 37.52 W	5044		X	X	X	X	X	X	
43	135 1640	36 15.09 N	63 00.66 W	5039			X			X	X	
44	136 0014	36 15.70 N	62 24.39 W	4967			X			X	X	

45	136 0805	36 15.52 N	61 46.35 W	4958	X	X	X	X	X	X	X	X
46	136 1957	36 14.54 N	61 09.85 W	4787			X			X	X	
47	137 0310	36 14.81 N	60 31.77 W	4887			X		X	X	X	
48	137 1000	36 14.52 N	59 54.53 W	5059		X	X	X		X	X	
49	137 1649	36 07.95 N	59 19.00 W	4906			X			X	X	
50	137 2127	36 06.64 N	59 00.17 W	5198		X	X	X		X	X	
51	138 0133	36 05.85 N	58 42.75 W	4556			X			X	X	
52	138 0844	36 00.63 N	58 04.97 W	5204		X	X	X	X	X	X	
53	138 1637	36 10.09 N	57 15.23 W	4842			X			X	X	
54	139 0042	36 14.10 N	56 26.25 W	5377		X	X	X	X	X	X	
55	139 0924	36 14.65 N	55 36.50 W	5399			X			X	X	
56	139 2120	36 14.98 N	54 43.59 W	5107	X	X	X	X	X	X	X	X
57	140 0533	36 15.23 N	53 56.49 W	5447			X			X	X	
58	140 1340	36 14.93 N	53 06.78 W	5468		X	X	X		X	X	
59	140 2247	36 29.29 N	52 16.64 W	5459			X			X	X	
60	141 0747	36 38.83 N	51 26.35 W	5453		X	X	X	X	X	X	
61	141 1623	36 25.12 N	50 37.23 W	5384		X	X			X	X	
62	142 0102	36 15.01 N	49 47.74 W	4957		X	X	X		X	X	
63	142 0947	36 14.62 N	48 58.01 W	5339		X	X			X	X	
64	142 2212	36 14.98 N	48 07.74 W	5417		X	X	X	X	X	X	X
65	143 0727	36 15.87 N	47 18.61 W	5215		X	X			X	X	
66	143 1612	36 14.88 N	46 28.20 W	5076		X	X	X	X	X	X	
67	144 0100	36 15.05 N	45 39.31 W	5168			X			X	X	
68	144 0912	36 15.21 N	44 49.48 W	4849		X	X	X	X	X	X	
69	144 1732	36 15.17 N	43 58.87 W	4829			X			X	X	
70	145 0206	36 14.80 N	43 08.95 W	4835		X	X	X		X	X	
71	145 0849	36 14.82 N	42 32.60 W	4125			X			X	X	
72	145 1847	36 17.01 N	41 55.94 W	4132	X	X	X	X	X	X	X	X
73	146 0145	36 15.13 N	41 18.61 W	4417			X			X	X	
74	146 0830	36 14.98 N	40 41.80 W	4417		X	X	X		X	X	
75	146 1657	36 15.13 N	40 05.95 W	3876			X		X	X	X	
76	146 2350	36 15.17 N	39 28.90 W	3562		X	X	X		X	X	
77	147 0616	36 14.94 N	38 51.81 W	3753			X			X	X	
78	147 1229	36 14.60 N	38 16.15 W	3536		X	X	X	X	X	X	
79	147 1927	36 15.11 N	37 38.79 W	3597			X			X	X	
80	148 0126	36 15.04 N	37 02.05 W	2998		X	X	X		X	X	
81	148 0657	36 14.95 N	36 25.92 W	2995			X			X	X	
82	148 1556	36 14.97 N	35 48.92 W	2770	X	X	X	X	X	X	X	X
83	148 2116	36 14.76 N	35 12.26 W	2159			X			X	X	
84	149 0239	36 14.88 N	34 36.27 W	2273		X	X	X		X	X	
85	149 0805	36 15.01 N	33 58.94 W	2842			X			X	X	
86	149 1323	36 15.10 N	33 22.09 W	2120			X			X	X	
87	149 1831	36 14.84 N	32 45.70 W	2228		X	X	X	X	X	X	
88	150 0001	36 14.79 N	32 08.88 W	2728			X			X	X	
89	150 0540	36 14.84 N	31 31.91 W	2826			X			X	X	
90	150 1103	36 14.76 N	30 56.08 W	3038		X	X	X	X	X	X	
91	150 1645	36 14.99 N	30 19.03 W	3001			X			X	X	
92	150 2237	36 15.00 N	29 42.02 W	3288		X	X	X		X	X	
93	151 0448	36 14.79 N	29 05.73 W	3469			X			X	X	
94	151 1040	36 14.90 N	28 29.11 W	3283			X			X	X	
95	151 2011	36 14.44 N	27 50.11 W	3419	X	X	X	X	X	X	X	X

96	152 0208	36 15.09 N	27 14.84 W	3294			X			X	X	
97	152 0757	36 15.13 N	26 39.06 W	3609			X			X	X	
98	152 1406	36 15.01 N	26 02.03 W	4038		X	X	X	X	X	X	
99	152 1851	36 31.65 N	25 57.51 W	2677		X	X			X	X	
100	153 2110	36 15.20 N	26 02.45 W	4036		X	X	X		X	X	
101	154 0343	36 14.87 N	25 25.17 W	3876		X	X			X	X	
102	154 0930	36 15.01 N	24 49.00 W	3141		X	X	X	X	X	X	
103	154 1520	36 15.06 N	24 12.01 W	3685			X			X	X	
104	154 2130	36 14.95 N	23 34.97 W	4390		X	X	X		X	X	
105	155 0404	36 14.95 N	22 58.85 W	4563		X	X			X	X	
106	155 1357	36 15.00 N	22 21.30 W	5001		X	X	X	X	X	X	X
107	155 2034	36 15.12 N	21 45.14 W	4712			X			X	X	
108	156 0328	36 14.94 N	21 09.09 W	4797		X	X	X		X	X	
109	156 1022	36 14.97 N	20 31.67 W	5077			X		X	X	X	
110	156 1727	36 15.06 N	19 54.82 W	5436		X	X			X	X	
111	157 0517	36 15.26 N	19 17.64 W	5488	X	X	X	X	X	X	X	X
112	157 1319	36 14.99 N	18 41.64 W	5529		X	X			X	X	
113	157 2130	36 15.13 N	18 04.97 W	4760		X	X	X		X	X	
114	158 0619	36 15.30 N	17 28.00 W	5127		X	X		X	X	X	
115	158 1406	36 15.52 N	16 51.60 W	4587			X	X	X	X	X	
116	158 2124	36 14.85 N	16 15.09 W	4263		X	X	X		X	X	
117	159 0445	36 15.18 N	15 37.91 W	3958			X			X	X	
118	159 0854	36 09.03 N	15 22.25 W	1848		X	X	X		X	X	
119	159 1702	35 59.59 N	14 57.50 W	2224	X	X	X	X	X	X	X	X
120	159 2119	35 54.03 N	14 42.06 W	3541			X			X	X	
121	160 0440	35 47.57 N	13 59.43 W	4747		X	X	X	X	X	X	
122	160 1127	35 48.15 N	13 17.45 W	4863		X	X			X	X	
123	160 1903	35 47.74 N	12 35.65 W	4868		X	X	X		X	X	
124	161 0229	35 48.01 N	11 53.93 W	4863			X	X		X	X	
125	161 1256	35 48.55 N	11 11.62 W	4863	X	X	X	X	X	X	X	X
126	161 1954	35 47.74 N	10 29.70 W	4810		X	X	X		X	X	
127	162 0313	35 53.93 N	09 48.23 W	4472		X	X	X	X	X	X	
128	162 0938	36 06.37 N	09 12.79 W	3993		X	X			X	X	
129	162 1340	36 08.99 N	09 04.00 W	3521			X			X	X	
130	162 1719	36 11.97 N	08 56.27 W	3019		X	X	X		X	X	
131	162 2144	36 25.61 N	08 45.63 W	2544			X			X	X	
132	163 0104	36 26.85 N	08 45.02 W	2048			X			X	X	
133	163 0338	36 28.38 N	08 44.25 W	1539		X	X	X		X	X	
134	163 0625	36 35.72 N	08 40.64 W	998		X	X	X		X	X	
135	163 0826	36 38.37 N	08 39.68 W	772		X	X	X	X	X	X	
136	163 1109	36 47.02 N	08 34.94 W	489		X	X	X		X	X	
137	163 1304	36 51.87 N	08 33.07 W	209		X	X	X		X	X	
138	163 2002	35 57.59 N	08 31.66 W	2612		X	X	X		X	X	
139	164 0119	35 30.48 N	08 18.37 W	2197		X	X	X		X	X	
140	164 0625	35 02.96 N	08 03.84 W	2289		X	X	X		X	X	
141	164 1437	34 34.97 N	07 49.22 W	2295	X	X	X	X	X	X	X	X
142	164 1753	34 22.94 N	07 43.94 W	1485		X	X	X		X	X	
143	164 2024	34 18.06 N	07 40.85 W	995								
144	164 2159	34 12.03 N	07 36.98 W	549		X	X	X		X	X	

Narrative

We arrived in Bermuda on Tuesday 26th April and spent the next four days mobilising the cruise in St. George (twinned with Lyme Regis, Dorset). Shore leave ended at 8am local time on Sunday 1st May and we sailed at 9am local time. Bermuda local time is GMT -3hours, all time are in GMT unless otherwise stated. Most of the rest of the day was spent bunkering. We left the bunkering wharf and headed towards the section at 36°N, dropping the pilot at about 2000. The scientists retired to their cabins to adjust and prepare.

Monday 2nd May started with preparations for the work ahead and an emergency muster and boat drill at 1330. A full-depth test station was occupied at 1620. We remained hove to while sampling this station - the sea was rough and the rain cold. Tuesday May 3rd brought much calmer seas and sunshine. A second test station, where all of the bottles were fired at one depth (1000m), was occupied at 0700. The first station on the section (station 3) commenced at 1545

Wednesday 4th May – Station 6 was occupied – the surface currents were the strongest yet encountered, up to 3 kts. After the CTD cast the first SAPs station was completed. We were 200 km east of the Gulf Stream's mean position and were initially unsure whether we had passed through the current proper or a cold-core ring. Satellite data sent from home confirmed that we had passed through the eastern edge of a meander on the Gulf Stream.

Thursday 5th and Friday 6th May the weather began to deteriorate – CTD's 11, 12 and 13 were sampled on station because it was too rough to be working on deck whilst the ship was moving. When we arrived at the waypoint for the next station the weather had deteriorated (atmospheric pressure was still dropping), we moved towards the next waypoint to reassess the situation. We arrived at this waypoint at 1700 and remained hove to whilst the bad weather continued with winds gusting to 50 kts.

Saturday May 7th – at 1500 – we reviewed the weather forecasts. The storm that had been affecting us was moving northeastward up the eastern seaboard of the United

States. The forecast predicted that at our current position the weather would remain sufficiently bad for work to remain stopped on the 8th and be marginal on the 9th. The decision was taken to abandon the first crossing of the Gulf Stream section and move to the beginning of the second crossing of the Gulf Stream and the beginning of the transatlantic section. At 15.30 we began sailing southwestward, away from the storm and towards a more promising forecast

Sunday May 8th - We arrived at the western end of our planned transatlantic section at 1030. The weather was good and we proceeded with CTD station 14. At approximately 2230 the bridge observed a tide line on the water's surface – we were between CTD stations 19 and 20.

Monday May 9th – We passed through the high velocities associated with the Gulf Stream at ~0400. Station 21 was occupied in the centre of these high velocities. Station 22 at the eastern flank of the Gulf Stream was aborted at 1128 while there was 3425m of wire out because of an electrical problem. The electrical retermination of the wire and load testing were completed by 1715. While the wire was being reterminated we steamed to a position between station 20 and 21 – the next station (23) was occupied here to improve our resolution of the Gulf Stream. Station 24, which commenced at 2345 was a repeat of the aborted station 22.

After station 25 was completed at 0530 on May 10th we commenced with 30nm (nautical mile) station spacing. The stations had been closer than that in the boundary current.

Thursday 12th May – station 33 was completed at 1300 hours. This station was a repeat of station 3 – the first station occupied on the section. The completion of this station marked the end of the Gulf Stream box. Subsequent to this we headed due east.

Saturday 14th May – Electrical problems in the control room meant that the ship's engine lost power at around 2100. Power was restored and the ship was moving again by 2345.

Sunday 15th May – Ship's clock advanced by one hour at 0200 (ship's time).

Tuesday 17th May – At 2200 we completed station 50. This station was added between two stations at 30nm spacing. The cast went to 910 dbar where all bottles were fired. A CFC minimum occupied this depth and the samples were used by the transient tracer group to estimate the background concentration in the niskins or bottle blanks.

Wednesday 18th May 2005 –. This morning it was confirmed that we would divert to Punta Delgada on the Azores to collect the lube oil that we had not been able to get in Bermuda. It was estimated that the diversion would take 24 hours. After station 52 was completed at 1100 the decision was taken to increase the station spacing from 30nm to 40nm to accommodate this unscheduled delay. This took immediate effect and station 53 was occupied 40nm along the track from station 52.

Sunday 22nd May – Ship's clock advanced by one hour at 0200 (ship's time).

Wednesday 25th May - A station spacing of 40 nm had been maintained for 7 days and 18 stations. We reverted to the 30nm spacing after station 70 had been completed at 0400.

Sunday 29th May 2005 – Ship's clock advanced by one hour at 0200 (ship's time).

Wednesday 1st June - Station 98 was completed at 1600. We broke off work here as this was the closest approach of the section to Punta Delgada in the Azores. We completed station 98 slightly earlier than anticipated so had time for an additional CFC bottle blank station (station 99) where all of the bottles were fired at 2600 m. This was completed at 1900 on the steam between the section and Punta Delgada. We also completed two 360-degree turns in opposite directions. These manoeuvres were designed to help with the calibration of the fibre optic gyrocompasses that were being trialled on board.

Thursday 2nd June - We met the pilot for Punta Delgada at 0700 and moved alongside to take on water, lube oil and other supplies. We also collected another workhorse

ADCP that had been shipped to us from NOCS. We left the dock and the pilot at 1100 and headed back to the section. We enjoyed a barbeque on the after deck that evening and were back on the section at 2000. Our first station back on the section (station 100) was a repeat of station 98.

Sunday 5th June – Ship's clock advanced by one hour at 0200 (ship's time).

Monday 6th June – station 112 was completed at 1540. This was the deepest station on the section with a maximum CTD pressure of 5628 dbar. The good weather that we enjoyed for the majority of the cruise meant that we easily completed all of the deep stations on the section without having to resort to a more heavy-duty wire.

The good weather to which we had become accustomed broke at the beginning of the week. The wind rose and the swell grew. The increased sea state slowed our progress between stations but did not affect our capacity to complete those stations.

12th June we completed the transatlantic section with Station 137 at 1330. We steamed south to occupy some stations across the Gulf of Cadiz. These stations would allow us to better characterise the Mediterranean influence on the North Atlantic.

13th June No bottles were fired on Station 143 in order that the station could be completed in as timely a way as possible. Station 144, the last of this cruise, was completed at 2230 off the coast of Morocco. We steamed towards Lisbon as the final data was analysed, samples were run and stored and demobilisation commenced. We arrived in Lisbon on the morning of Wednesday 15th June and spent the day demobilising and backing up data. The final samples were packed in dry ice and freighted home on Thursday 16th. On Friday 17th June the majority of the science party flew back to the UK after a successful trip.

Elaine McDonagh

1. CTD System Operation

A total of 144 CTD casts were completed on the cruise utilising this 24-way frame arrangement, with the following configuration:

Sea-Bird 9/11+ CTD
Sea-Bird 24 position Carousel
Sea-Bird 35 Deep Ocean Standards Thermometer
Chelsea fluorometer
Chelsea transmissometer
RD Instruments Workhorse LADCP (downward looking)
RD Instruments Workhorse LADCP (upward looking)
SOC LADCP battery pressure case
WETLabs scattering meter
Tritech altimeter
SOC 10KHz beacon
Sonardyne High Frequency Marker beacon
SOC/Sea-Bird Breakout Box
24 by 20L Ocean Test Equipment water samplers

The configuration for the CTD was as follows:

Sea-Bird 9+ underwater unit, s/n 09P-34173-0758
Sea-Bird 3 Premium temperature sensor, s/n 03P-4105 (frequency=0)
Sea-Bird 4 conductivity sensor, s/n 04C-2571 (frequency=1)
Digiquartz temperature compensated pressure sensor, s/n 90074 (frequency=2)
Sea-Bird 3 Premium temperature sensor, s/n 03P-4151 (frequency=3)
Sea-Bird 4 conductivity sensor, s/n 04C-2580 (frequency=4)
Sea-Bird 5T submersible pump, s/n 05T-3962 (primary)
Sea-Bird 5T submersible pump, s/n 05T-3607 (secondary)
Sea-Bird 24 position Carousel, s/n 32-37898-0518
Sea-Bird 35 DOST, s/n 35-34173-0048
Sea-Bird 11+ V2 deck unit, s/n 11P-24680-0587

The configuration for the A/D channels was as follows:

V1 = Sea-Bird 43 dissolved oxygen sensor, s/n 43-0363
V2 = Tritech PA-200 altimeter, s/n 6196.118171
V3 = Chelsea Aquatracka MKIII fluorometer, s/n 88/2050/095
V6 = WETLabs scattering meter, s/n BBRTD-169
V7 = Chelsea Alphatracka MKII transmissometer, s/n 04-4223-001

The configuration for the remaining instruments was as below:

RD Instruments Workhorse Monitor 300 KHz, s/n 5414 (downward-looking)
RD Instruments Workhorse Monitor 300 KHz, s/n 5415 (upward-looking)
SOC stainless steel battery pressure case, re-chargeable cells, s/n 02
SOC/Sea-Bird Breakout Box, s/n BO119201
SOC 10KHz Beacon, s/n B0
Sonardyne HF Marker beacon, 12000 metre, s/n 233

Sensor Changes:

1) Cast 001---The RDI Workhorse (upward-looking) LADCP flooded, and was removed from the frame
2) Cast 003---Altimeter not working, replaced with Benthos PSA-916T, s/n 1040
3) Cast 005---Shift in secondary conductivity sensor, replaced with s/n 04C-3054
4) Cast 037---Scattering meter not working properly, replaced with s/n BBRTD-182
5) Cast 039---Failed connector on BreakOut Box, scattering meter output changed from V6 to V4
6) Cast 055---BreakOut Box leaked under pressure, replaced with s/n BO19109T
7) Cast 055---Change in 'BOB' connector configuration resulted in fluorometer output change from V3 to V6
8) Cast 059---Change altimeter output from V2 to V3
9) Cast 067---Noise/spiking in secondary conductivity sensor, change to s/n 04C-3502
10) Cast 077---Continual noise/spiking in secondary conductivity sensor, change back to s/n 04C-3054

11) Cast 113---Jump in secondary conductivity sensor, replaced with s/n 04C-3052
12) Cast 119---Replaced BreakOut Box with s/n BO19110 for testing purposes; altimeter output changed from V3 to V2

The noise present on many casts in secondary sensors was finally traced to an intermittent fault in the pump 'Y' cable, on the connector to the pump. The cable was replaced for cast number 077.

The 20L OTE water samplers were problematic throughout the cruise, in regards to not properly closing and sealing in the sample. Various configurations for preparing the samplers were attempted, as well as tightening the external springs. A total of 273 closing failures were logged, an average of 1.9 per cast. On past cruises, the average for closing failures was 2.5 per cast. At the earliest possible convenience, the sampler lanyard system will be re-configured following testing for the best design, and the spring tension will also be tested and springs replaced where necessary.

Jeff Benson
Bob Keogh
Dave Teare

2. CTD Data Processing and Calibration

Raw CTD files from the logging PC were transferred to a networked PC on which SEASOFT modules below were run manually and the output files transferred to the unix system.

2.1. Seabird Processing

Data Conversion (DatCnv)

Input files: CD171{nnn}.dat, CD171{nnn}.CON, CD171{nnn}.BL.
Output files: CD171{nnn}.cnv, CD171{nnn}.ros
The raw CTD data file (CD171{nnn}.dat) is calibrated and output to CD171{nnn}.cnv using calibration coefficients set in configuration file CD171{nnn}.CON. Output parameters (Table 2.1) are set in the DatCnv specification file, DatCnv.psu. A rosette summary file is also created (CD171{nnn}.ros) from the raw CD171{nnn}.BL file with one record for each bottle fire.

Number	Parameter	Unit
1	Pressure, Digiquartz	db
2	Temperature	ITS-90, deg C
3	Conductivity	mS/cm
4	Temperature, 2	ITS-90, deg C
5	Conductivity, 2	mS/cm
6	Pressure Temperature	deg C
7	Time, Elapsed	Seconds
8	Oxygen, SBE 43	µmol/Kg
9	Fluorescence, Chelsea Aqua 3 Chl Con	µg/l
10	Beam Transmission, Chelsea/Seatech/Wetlab Cstar	%
11	Altimeter	M
12	Flag	

Table 2.1: Output from SeaBird data conversion module DatCnv.

Align CTD

Input and Output File: CD171{nnn}.cnv

Alignment of data streams to reduce spiking or hysteresis. We advance oxygen by 6 sec relative to pressure to account for sensor delay. Coefficients for temperature and pressure are set to zero.

Wild Edit

Input and Output File: CD171{nnn}.cnv

The mean and standard deviation of each parameter are separately calculated for blocks of 500 cycles. Points that lie outside two times the standard deviation are temporarily excluded for recalculation of the standard deviation. Points outside ten times of the new standard deviation are replaced by a bad flag. This is applied to temperature, conductivity pressure temperature, oxygen, transmission and altimeter height.

Cell Thermal Mass

Input and Output File: CD171{nnn}.cnv

Removes conductivity cell thermal mass effects with a recursive filter permitting salinity accuracy greater than 0.01 in regions of steep gradients. In such regions the correction may be of the order 0.005 but is otherwise negligible. The thermal anomaly amplitude (α) is 0.03 and the thermal anomaly time constant ($1/\beta$) is 7.0.

Filter

Input and Output File: CD171{nnn}.cnv

Low pass filter pressure with $\tau = 0.15$s

Translate (Trans)

Input and Output File: CD171{nnn}.cnv

Creates an ASCII version of the binary .cnv file.

2.2. Pstar Processing

2.2.1 CTD data files

The following routines process CTD data from resolution of 24hz to 2db and annotate the header accordingly.

ctd0 *Input file: CD171{nnn}.cnv Output file: ctd171{nnn}.24hz*

Writes 24hz ascii data from CD171{nnn}.cnv into pstar format; ctd171{nnn}.24hz. Header information extracted from the .cnv file and position manually input from deck logs.

ctd1 *Input file: ctd171{nnn}.24hz Output files: ctd171{nnn}.1hz, ctd171{nnn}.10s*

In the deck unit, fin sensor data is input through the secondary channel and frame sensor data through the primary. When possible (see section 2.3) fin sensors are used as the primary and temp/temp2 and cond/cond2 names are swapped accordingly. Data is averaged into 1s and from this 10s intervals (ctd171{nnn}.1hz and ctd171{nnn}.10s respectively). Additional variables are derived; t2-t1, c2-c1, salin, salin2, potemp, potemp2, sigma0 and sigma2.

ctd2 *Input file: ctd171{nnn}.1hz Output files: ctd171{nnn}.ctu, ctd171{nnn}.2db*

The 1hz data cycles from the downcast start to upcast end are saved in ctd171{nnn}.ctu. The 2db file is obtained from the downcast cycles sorted on pressure and missing levels filled with linear interpolation. Individual cycles from the start of the downcast, at the maximum pressure and at the end of the upcast are written into ctd2.exec.

fir0 *Input file: ctd171{nnn}.ros Output file: fir171{nnn}*

Writes seabird ascii ctd171{nnn}.ros file into pstar. CTD variables at the bottle stops are extracted from the 10s file by merging on time to give fir171{nnn}. Winch data is read into pstar and saved in win171{nnn}.

sam0 *Input file: sam.masterCD171 Output file: sam171{nnn}*

The sam file format is defined in sam.masterCD171. CTD data are pasted into a copy of the master file from fir171{nnn} and sample data subsequently added (section 2.2).

add_positions.exec: *Input files: abnv1711, ctd2.exec Output file: {nnn}.position*

GPS latitude and longitude from file abnv1711 are merged with the CTD times at the start of the downcast, maximum pressure and end of upcast (in ctd2.exec) and written into {nnn}.position. The corrected position (relative to deck log) is written into headers of the 24hz, 1hz, 10s, ctu, 2db and sam files.

add_ladcpdepth.exec*: Input files: ctd171{nnn}.2db, ctd2.exec, proc.dat (ladcp)*
Maximum instrument depth determined from maximum CTD pressure in 2db file and water depth from Visbeck processing of LADCP data. Both are written into headers of the same files as add_positions.exec.
add_simdepth.exec*: Input files: ctd171{nnn}.2db, ctd2.exec, 171sim*
Water depth is extracted from the simrad record if the cast was not deep enough for the LADCP to resolve water depth, otherwise same procedure as add_ladcpdepth.exec

2.2.2 Sample Files

Analysed sample data for each measured variable (var) - oxygen (oxy), nutrients (nut), salinity (sal), and deep ocean standards thermometer (sbe) - as available are saved on a mac in excel text files and transferred to the unix system by ftp. Problems with bottle closure during CD171 resulted in the use of bottle flag and sample flags flowing the convention of 2 = good, 3 = suspect, 4 = bad and 9 = absent. Variable flags are initially assigned by the analyst in the text file with good as default and ultimately carried in the sam171{nnn} file. Subsequent comparison of bottle salinity and oxygen to CTD measured values in the sam171{nnn} file identifies suspect bottles that are flagged as 3. These, although appearing fine when the CTD landed on deck, have oxygen and salinities consistent with the bottle having leaked or closed at an unexpected depth. Sample number, station number and bottle flag are all set in the salinity sample files. After ftp transfer, **{var}.exec** reads the text file, {var}171{nnn}.txt, into a pstar file - {var}171{nnn}. **pas{var}** then pastes data cycles into the sam file - sam171{num}. Cableout is extracted from the win171{num} files at times of bottle firing and pasted into the sam file using **wire.exec**.

2.2.3 Data Treatment

Significant wake effects were observed in the frame temperature and conductivity sensor pair due to the 20 litre Niskin bottles, hence the fin sensors are preferentially used as the primary pair. Numerous casts before station 80 had unsatisfactory noise in temperature and conductivity from the fin sensor, after which improved data quality was attributed to a pump change on the fin. Spikes in regions of small gradients were edited out, or if this was judged to result in loss of property resolution either the fin

temperature and conductivity were substituted with those from the frame pair (incorporating sensor offset) over the affected data cycles or the frame sensor pair were used as the primary over the full cast. Table 2.2 summarises all editing performed and records the primary/secondary sensor choice in the final data set. All edits were applied to the 1hz files, salinity and other dependent variables were re-computed (as in ctd1), and the 10s, ctu, 2db, fir and sam files updated accordingly.

Stat	Sensor Serial Number				Fin ?	K	Notes See explanatory notes following table
	1ºT	1ºC	2ºT	2ºC			
001	4105	2571	4151	2580	N	1.00006	*Jumps in 2580 conductivity on stations 001, 003 and 004, use frame set as primary for 001 to 004 for consistency in calibration.*
002							
003							
004							
005	4151	3054	4105	2571	Y	1.00006	Spikes - T: D2081±5, D2425±1.5 C: D2111±37 D2673±9 D2344±3 D2438±24 U2439±19
006							Removed duplicate depths resulting from winch stop. Spikes – C: D1781±17, D2016±25, U2127±5
007							-
008							-
009							-
010							-
011							Spikes – T: D2044±5, C: D2076±38
012							-
013							-
014	4105	2571	4151	3054	N	1.00006	*Salinity spikes over full depth from fin sensors so use frame as primary.*
015							

016	4151	3054	4105	2571	Y	1.00006	Swap D52-90
017							Spikes – T&C: D315.5±3.5 D296±2
018							-
019	4105	2571	4151	3054	N	1.00006	*Fin conductivity unstable with spikes, use frame*
020							
021							*Salinity spikes at surface and D1500-2500 (021), D1700-2300 (022), use frame sensors.*
022							
023	4151	3054	4105	2571	Y	1.00006	Spikes: T: D1774±2; C: D307.5±1.5 D1799±25
024							Spikes – C: D1390±16, D1511±24 Swap U136-376, D136-376.
025							Spike – C: D407±1.5
026							Swap D64-327, U219-180
027							-
028							Swap D122-406, U365-30
029							Swap D73-415
030							-
031							Swap D53-443, U251-206
032							Spikes – T: D1573.5±1.5, C: D1592±20 Swap D9-438
033							Spikes – T: D1308±2 C: D1170±11 D1325±20 D1591±5 Swap D28-460
034							Spikes – C: U219±10 U192±4 Swap D12-289, U185-70
035							Swap D162-463, U183-0

036							Spike – T: U90±1
037							Spike – C: U209±2
038							Swap D128-391
039							Spike – C: D240±2. Swap D94-367
040							Swap D301-421
041							Spikes – C: D326±2, D1218±3 D1226±3, D1390±2. Swap D1041-1102, D1208-1285, D1381-1428, D1457- 1499
042	4105	2571	4151	3054	N	1.00001	-
043	4151	3054	4105	2571	Y		Swap D348-457, D556-731, U260-96
044							-
045							-
046							-
047						1.00006	-
048							-
049							-
050							Swap D9-517db
051						1.00004	-
052							Swap D0-470db
053							-
054							Swap D11-469
055							Swap D82-512
056							Swap D10-546
057							Swap D36-395

058							Swap D103-519
059							Swap D4-507
060							-
061							Swap D11-173, D326-427
062	4105	2571	4151	3054	N	1.00000	Swap D4-507
063	4151	3054	4105	2571	Y	1.00006	Swap D39-456
064							Swap D10-499
065							Swap D11-426
066	4105	2571	4151	3054	N	1.00000	-
067	4151	3052	4105	2571	Y	1.00003	Swap D11-421
068							Spike – C: D368±2
069							Swap D11-473
070	4105	2571	4151	3052	N	0.99999	*Salinity spikes with frame sensors significant – use frame sensors*
071							
072							
073							
074							
075							
076	4151	3052	4105	2571	Y	1.00005	Numerous T, C spikes removed U 3500 – 2300, U1154±3, U1145±7. Swap 1-36. See N076 below.
077	4105	2571	4151	3054	N	0.99999	*Salinity spikes with frame sensors significant – use frame sensors*
078							
079							
080	4151	3054	4105	2571	Y	1.00005	-

to 097							
098 to 103	4151	3054	4105	2571	Y	1.00007	-
104 to 111	4151	3054	4105	2571	Y	1.00005	-
112	4105	2571	4151	3054	N	0.99999	*Fin conductivity unstable, use frame*
113 to 144	4151	3052	4105	2571	Y	1.00006	-

Table 2.2 CTD temperature and conductivity sensor information with editing performed.

NOTES

T = temperature, C = conductivity. 1º or 2º refers to final primary and secondary sensor choices as justified in italics*. Editing detailed in regular type.*

Station 076 Frame T signal intermittent over cast. Fin C has bad spikes on downcast, final cast constructed from upcast of fin sensors, still deemed of bad quality.

Spike Removal "Spike – T/C D/U pressure±deltaP" indicates that T or C spikes were replaced with absent data values from pressure minus deltaP to pressure plus deltaP (in dbar) on the down (D) or up (U) cast. This is done only if linear interpolation over the absent data range is deemed acceptable, otherwise the "swap" method is followed. Spikes spanning a pressure range less than 2db are not recorded.

Sensor Swap "Swap D/U pressure1-pressure2". 1ºC is replaced by 2ºC minus $offset_C$*, and 1ºT replaced by 2ºT minus* $offset_T$ *with offsets decided after consideration of the mean over station groups, entrainment effects in the frame noted. On the downcast* $offset_C$ *= 0.01 mS/cm,* $offset_T$ *= 0.001 ºC, while on the upcast ,* $offset_C$ *= 0 mS/cm,* $offset_T$ *= 0 ºC except for station 41 (both offsets = 0 for up and down cast) and 076 (*$offset_C$ *= -0.05 mS/cm,* $offset_T$ *= -0.02 ºC).*

2.3. CTD Calibration and Evaluation

2.3.1 SBE35 Deep Ocean Standards Thermometer

The deep ocean standards thermometer fitted to the CTD fin, with a nominal initial accuracy of 0.001ºC and stability of 0.001ºC/year, provides a reference for evaluating performance of the primary and secondary CTD temperature sensors.

SBE35 Data acquisition and calibration

Sensor 0048 was used throughout CD171. At the end of each CTD station, a file is uploaded from the SBE35's EEPROM, saved in an ascii file (SBE35_{nnn}.cap) and transferred to the unix system, file format in Table 2.3.1.

Column	Description
1	Sample number
2	Date (DD MMM YYYY – day, month year). The month is a 3-character alphabetic abbreviation; e.g., Jan, feb, mar, etc).
3	Time (HH:MM:SS – hour, minute, second)
4	Bn=bottle position number
5	Diff=(maximum – minimum) raw thermistor reading during a measurement (provides a measure of the amount of variation during the measurement)
6	Val=average raw thermistor reading, corrected for zero and full scale reference readings
7	T90=average corrected raw thermistor reading, converted to engineering units (°C[ITS-90])

Table 2.3.1 Format of SBE35_{nnn}.cap files

Full details of the thermometer may be found in Cunningham (2005). At each bottle fire 8 cycles of SBE35 data (at intervals of 1.1s) are averaged and temperature computed from sensor raw output (calibration coefficients $a0$, $a1$, $a2$, $a3$, $a4$ of Table 2.3.2).

$$T90 = \left(\frac{1}{a0 + a1\ln(n) + a2\ln^2(n) + a3\ln^3(n) + a4\ln^4(n)} \right) - 273.15$$

Coefficient	Date	Value
a0	07/11/03	$4.21014933 \times 10^{-3}$
a1		$-1.12827756 \times 10^{-3}$
a2		$1.74012910 \times 10^{-4}$
a3		$-9.73030909 \times 10^{-6}$
a4		$2.09032576 \times 10^{-7}$
slope	17/03/05	1.000017
offset		-0.001128

Table 2.3.2 SBE35 0048 calibration coefficients

To account for sensor drift, a slope and offset correction is applied:

T90 = *slope x* T90 + *offset [degC, ITS-90]*

The ascii file is treated as other sample files; **sbe.exec** reads Diff, Val and T90 into a pstar file (sbe35171{nnn}) with variable names maxdiff, av and t_35 then **passbe** pastes the SBE35 T90 records into the sam171{nnn} file, one record per bottle fire.

Comparison of SBE35 and CTD temperatures

Bottle blank stations (50 and 99) are excluded from the following evaluation of CTD temperature sensor performance (Figure 2.3.3, Table 2.3.4) since the interval between bottle fires was less than 10s – the required wait after bottle firing to ensure the 8.8s of averaged SBE35 data correspond to the CTD 10s average as recorded in the sam file. Additionally CTD data that has not been corrected for spikes is excluded (stations 70-78 fin sensor). Note CTD temperature sensor 4015 is the frame sensor and 4151 the fin sensor throughout the cruise regardless of primary/secondary distinctions made in Table 2.2.

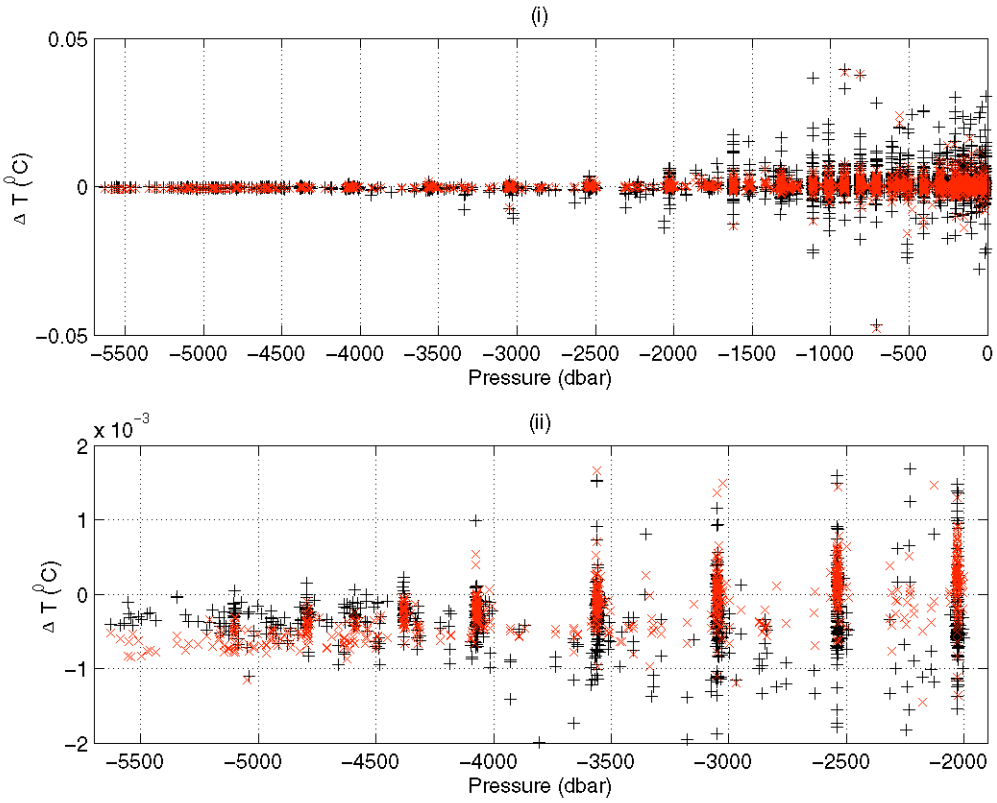

Figure 2.3.3 SBE35 - CTD temperature (ΔT) as a function of pressure for frame CTD sensor (black +) and fin sensor (red x) for (i) the full water column after rejection limit 1 and (ii) deeper than 2000m and rejection limit 2. Limit 1: reject |ΔT| > ± 0.05ºC, compute mean and standard deviation of ΔT and reject ΔT outside μ±2σ, repeat latter. Limit 2: Select only ΔT from below 2000 dbar, then reject |ΔT| > ±0.005ºC, and ΔT outside the resulting μ±2σ, repeated twice (Table 2.3.4).

Below 2000 dbar where spatial and temporal variability of water properties are anticipated to have only a small effect on the temperature difference between the SBE35 and CTD sensor, ΔT (μ±σ) is less than 0.001 with fin and frame sensor both reading warm relative to the SBE35. This is within the nominal accuracy of the CTD sensor and therefore no attempt at calibration of either CTD sensor is made. Variability of ΔT for the frame sensor is almost two times higher than that for the fin over the whole water column, this is attributed to effects of entrainment by the CTD frame, noting that the SBE35 is positioned on the fin.

	Limit 1: ± 0.05ºC, ± 2σ, ± 2σ				Limit 2: P>2000 dbar, ± 0.005ºC, ± 2σ, ± 2σ			
CTD sensor	N_{tot}	% reject	μ(ºC x10^{-3})	σ (ºC x10^{-3})	N_{tot}	% reject	μ (ºC x10^{-4})	σ(ºC x10^{-4})
Frame	192848	0.3	0.73	3.69	59620	0.1	-3.82	4.35
Fin	179831	0.2	0.30	1.96	57489	0.1	-1.61	3.61

Table 2.3.4: SBE35–CTD temperature residuals (ΔT) after application of limit 1 or 2 NOTES. Notice different units in columns 4 and 5 compared to 8 and 9. Rejection limits explained in legend of Figure 2.3.3. N_{tot} is the number of residuals before selection in limit 1, and the number at pressures greater than 2000 dbar in limit 2. % reject is the percent of N_{tot} rejected after limits applied. μ and σ are the mean and standard deviations of the remaining ΔT.

A possible pressure effect is noted in the sensor 4151 (fin) with a warm bias of approximately 0.0007ºC at 5500 dbar decreasing with pressure and not detectable above 3000 dbar. Since we do not know whether the signal is also present on the downcast (upcast-downcast comparisons are too noisy) and it is within the nominal sensor accuracy we do not correct for it.

2.3.2 Conductivity Calibration

CTD conductivities are calibrated by comparing them to bottle conductivities derived from salinity samples obtained during the CTD upcast. The CTD upcast is calibrated and applied to the downcast: the downcast and upcast must be free from hysteresis for this to be valid - discussed below.

Method

Calibrated CTD conductivity (C_{corr}) is obtained by applying a slope correction (K) to account for sensor drift;

$C_{corr} = K*C_{CTD}$ where $K = <C_{bot}/C_{CTD}>$

C_{bot} is bottle conductivity obtained from measured bottle salinity and C_{CTD} upcast CTD conductivity for the 10s at the time of the bottle fire - K is the mean ratio of

bottle to CTD conductivity over a group of stations. To compute K, only bottle salinities flagged as good and from bottles flagged as good are used. $C_{diff} = C_{bot} - C_{CTD}$ and $C_{ratio} = C_{bot}/C_{CTD}$ are computed and samples not satisfying $|C_{diff}| < 0.1$ and $0.9998 < C_{ratio} < 1.0002$ are rejected along with those outlying $\mu \pm 2\sigma$, repeated twice for the remaining C_{diff} and C_{ratio}. The station K value is the mean C_{ratio} of the remaining samples. This procedure is to remove the influence of outlying bottle salinities resulting from poor sample collection, analysis or the effect of spatial and temporal variability in water properties at the time of bottle firing. Problems with the autosal (refer to Section 3) meant that apparent variability in K computed between stations was checked against the deep ocean potential temperature – salinity (θ-S) relationship. For the vast majority of stations groups (selected on geographical location) the CTD showed a tighter curve than the bottle samples. Under the assumption that the deep ocean properties are stable, it was decided not to vary the calibration on a station-by-station basis as suggested by the bottle salts, instead a mean K was taken over as many stations as considered feasible.

The Frame Sensor (2571)

Assigning a K value for stations in which the frame sensor pair was used as the primary (Table 3.2.1) on the above basis introduced inconsistencies in the deep θ-S relationship when calibrated fin and frame stations were compared. A pressure shape in conductivity residuals showed high CTD conductivities at the surface - C_{diff} of approx. -0.005, decreasing to zero offset by 1500 dbar and $C_{diff} < \pm 0.001$ below this. Using the full depth to compute K, introduced a bias to low values. Comparison of fin and frame downcast conductivity (for stations when the fin sensor was good) showed any possible pressure effect on the downcast of sensor 2571 was more probably due to entrainment – the magnitude of which was estimated from the fin-frame sensor temperature difference shape with pressure and background stratification. The pressure effect in the upcast of 2571 is therefore not corrected for, since there is no evidence that it is present in the downcast. The K value applied was computed from bottle samples below 1000 dbar only to prevent the shallow samples from giving an artificially low K – this procedure removed the inconsistencies noted previously in the deep θ-S relationship.

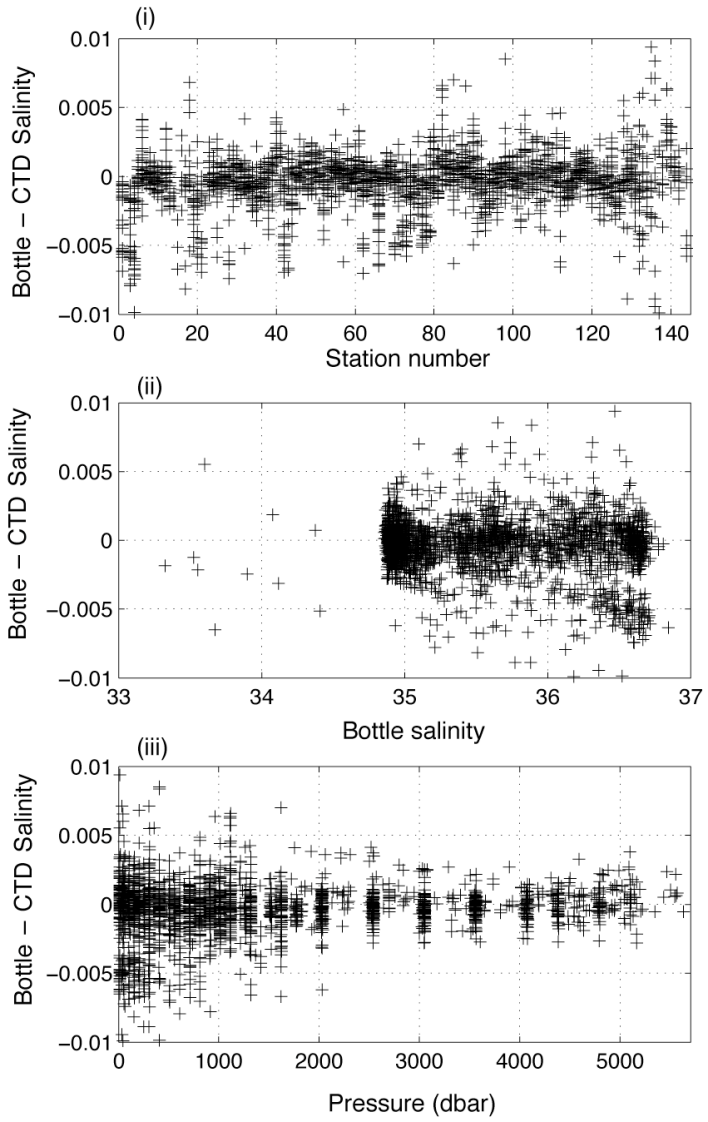

Figure 2.3.5a: Bottle – CTD salinity versus (i) station number, (ii) bottle salinity and (iii) pressure. Selection limits are $|S_{bot} - S_{CTD}| < 0.1$, $\mu \pm 2\sigma$, $\mu \pm 2\sigma$.

Calibration Application and Evaluation

ctdcondcal.exec applies the K value calibration to the primary conductivities in the 1hz file, dependent variables are recomputed (salin, potemp, sigma0 and sigma2) and the 10s, ctu, 2db, fir and sam files updated.

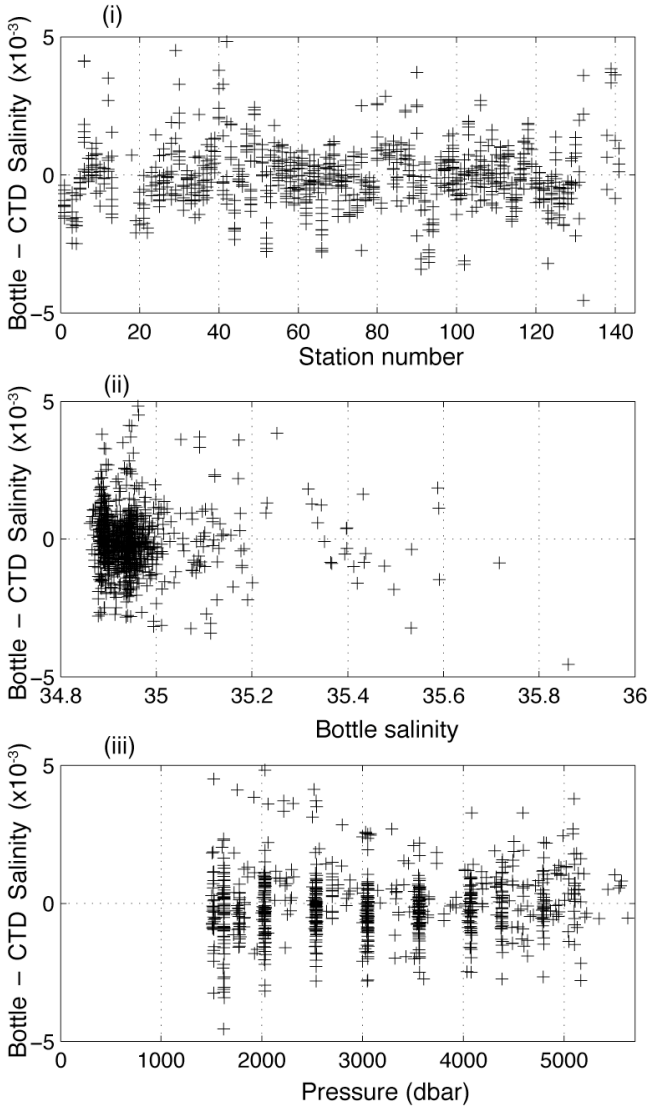

Figure 2.3.5b: Bottle – CTD salinity versus (i) station number, (ii) bottle salinity and (iii) pressure. Selection limits are pressure > 1500db, $|S_{bot} - S_{CTD}| < 0.05$, $\mu \pm 2\sigma$, $\mu \pm 2\sigma$.

In assessment of calibrated salinities against bottle salinities (Figures 2.3.5a and 2.3.5b, Table 2.3.6) the above points must be considered. The bottle minus upcast CTD salinity residuals appear low on some stations when the frame sensor pair were used (Figures 2.3.5a (i) 2.3.5b (i)), but part of this is argued to be due to hysteresis and would not be observed on the downcast. This also explains the cluster of residuals at –0.005 in Figures 2.3.5a (ii) and (iii). Performance of the autosal was disappointing during the cruise and for many stations a large mean salinity residual in the calibrated data set is attributed to calibration problems of the autosal rather than indication of a

need for different calibration. Comprehensive evaluation of sensor performance over the deep pat of the θ-S curve led us to conclude that the sensors were essentially stable over the cruise and we are confident of the calibration applied to ±0.001 in salinity even though the standard deviation of the bottle-CTD salt residuals are larger than this (Table 2.3.6).

Limits	μ	σ	N_tot	N	%
±0.1, ±2σ, ±2σ	-0.0004	0.0026	2840	2478	12.7
P > 1500db, ±0.05, ±2σ, ±2σ	-0.0001	0.0016	1013	950	6.2

Table 2.3.6: Bottle-CTD salinity residual mean (μ) and standard deviation (σ). N_tot is the total number of good flagged bottle salinities and N those used to compute the mean. % is the percent rejected after application of limits.

References

Cunningham, S. A. et al. 2005 RRS "Discovery" Cruise 279 April-May 2004, pp 199, Cruise Report no. 54, Southampton Oceanography Centre, Southampton.

Hannah Longworth

2.3.3 Oxygen Calibration

The CTD Oxygen calibration was reworked at NOC after the cruise. CTD oxygen data were compared with bottle sample oxygen values in units of μmol/kg.

The requirement is to produce a set of CTD downcast oxygen profiles which are in agreement with the bottle samples collected on the upcast.

Pstar program pbotle was used to identify the data cycle from the downcast 2db file that corresponded with the upcast bottle closure. Matching was done on potential temperature. If potential temperature was multivalued on the downcast so that there were several matching cycles, the cycle was chosen to be the one nearest in pressure.

The results of pbotle were inspected station-by-station to ensure that the automated process produced 'sensible' results.

The CTD data from the deck unit (the 'raw' data = O_{ctd_raw}) had been converted from engineering units to dissolved oxygen units using parameters supplied by the manufacturer.

An initial bulk calibration was estimated from stations 51 to 58. The form of the calibration was a scaling of the oxygen concentration, plus a fit to residuals of an offset and a dependence on pressure and potential temperature. Thus
$O_{ctd\_bulk} = 1.2 * O_{ctd\_raw} – 0.0042 * P – 0.50 * \theta – 15.8$ μmol/kg.

The bulk calibration was applied to all stations, and residuals between bottle samples and matched CTD cycles were calculated.

The residuals were examined on a station by station basis. For each bottle,
$R_1 = O_{samp} – O_{ctd\_bulk}$.

It was found that some stations had systematic residuals with non-zero mean. Two forms of fit and adjustment were considered. Either a mean offset for each station, or a mean scaling factor for each station. Thus for each station number n, coefficients A_n or B_n are determined by least squares fit to the relationship:
$R_1 = A_n + B_n * O_{ctd\_bulk}$.

The residuals could be fitted equally well by an offset term, A_n, or a scaling term, B_n. Significance of fit was not improved by including both of the A_n and B_n terms. The scaling term was chosen in preference to the offset, because it seemed a more natural representation of the performance (sensitivity) of the sensor.

For each station, a scaling factor B_n was determined by least squares fit to the residuals $O_{samp} – O_{ctd\_bulk}$. The further set of residuals ($R_2 = R_1 – B_n * O_{ctd\_bulk}$) was examined to decide whether each bottle should be included in the determination of B_n for that station. Large values of R_2 indicated either a bad bottle sample (leaky Niskin bottle or bad titration), or a region of strong vertical property gradient in which the

bottle sample was good but did not match the CTD value because of bottle flushing distance or because of mismatch between the upcast sample and the downcast CTD. Iterative visual inspection and exclusion of large values of R_2 was performed for each station until a satisfactory determination of B_n was made. Bottles excluded from the fitting procedure were noted.

A value of B_n was determined for each station for which sufficient bottle data were available. Of these values for B_n, 51 were the most statistically significant (F statistic for reduction of variance greater than 7). These significant values of B_n were then divided into five groups of stations by visual inspection (1:16; 17:62; 63:98; 99:116; 117:144). In each group, a linear fit (B_{smooth})to the individual station values of B_n was made to produce a complete time series of piecewise-linear, slowly-varying station adjustments. On the main 36°N section (stations up to 137) the amplitude of this slowly-varying scaling factor varied between -0.007 and +0.014.

The above procedure was applied so that the CTD data for station n become
$O_{ctd\_adj}(n) = O_{ctd\_bulk}(n) * B_{smooth}(n)$.

The mean station offsets of the sample data compared with the adjusted CTD data have rms of order 2 μmol/kg. This is comparable to the confidence in the bottle samples, so the smoothed adjustment $B_{smooth}(n)$ is chosen in preference to a station-by-station adjustment of CTD data to bottle data.

The new set of residuals
$R_3 = O_{samp} - O_{ctd\_adj}$
was inspected and found to have a small residual shape in deep water. Accordingly a final empirical adjustment O_{offset} was determined and applied to all stations.
for Pressure < 3000 dbar: $O_{offset} = 0$
for Pressure > 3000 dbar: $O_{offset} = (P-3000) * 1.4 * 10^{-3}$ μmol/kg
and the final CTD data for station n are calculated as
$O_{ctd\_cal}(n) = O_{ctd\_adj}(n) + O_{offset}$

Brian King

3. Water Sample Salinity Analysis

Sampling

Water samples for the analysis of salinity were drawn from each Niskin at every station into 200ml glass sample bottles. Each bottle was rinsed twice and then filled to just below the neck. The rim of each bottle was wiped to prevent salt crystals forming and then each bottle was sealed with a clean, dry, disposable plastic stopper and a screw lid. Duplicate samples were drawn from the lower bottles whenever there were enough sample bottles to do so. Crates of salinity samples were then allowed to equilibrate to room temperature in the constant temperature (CT) lab for 24 hours before analysis.

Laboratory Set-up

Two salinometers were set up in the CT lab. After the engineers made an adjustment to the cooling system it was possible to maintain the temperature of the lab between 19-20°C by keeping the door open. The slight drawback was that the air handling system did not drain properly whilst on station owing to the ship's listing to the starboard side and as a result up to half and inch of water would collect in the corner at each station. The temperature of both salinometers was set to 21°C.

Both the JRD and UKORS salinometers were the Guideline 8400A model. At first only the UKORS salinometer was used, up to the analysis of samples from station 33 when we found that the case vent fan had failed resulting in irregular cycling of the heater. Consequently the results from station 33 have been regarded with great caution. The JRD autosal was used was used as a replacement for the UKORS machine.

Initially the brand new peristaltic pump provided by UKORS would not run smoothly due to the gear mechanism either being over tightened or misaligned. After adjusting the mechanism and mounting the pump performed well. However readings were very difficult to make due to a large amount of bubbles being introduced to the samples. This lessened over time and we feel that it may have been due to pockets of air

remaining in the new pump / long inactivity of the unit as a whole. As a result the readings it gave were still less stable so we reverted to using the UKORS machine as soon as a replacement fan was found, just after the analysis of station 54.

The peristaltic pump on the UKORS autosal also incurred problems. At around station 75 the tubing between the pump and the inlet started leaking, introducing bubbles to the sample and making consistent readings difficult. The new pump (see above) was swapped in while the tubing was replaced. Later (station 106) the peristaltic tubing in the pump itself developed a leak, so the whole pump was replaced.

Further problems were incurred during the analysis of station 96 when the cell arms would not fill correctly. It was found that drops of water had formed in the capillaries above. These were syringed out with air. It is possible that the air pump is not producing enough backpressure during cell filling. The pump valve was lubricated with a little oil, but little change was observed. We believe the problem was caused by incomplete flushing of the cell: a small amount of sample enters the capillaries each time the cell is filled, but this should be flushed out with each cell flush. The problem has been avoided by making sure the cell is thoroughly flushed after each sample.

Analysis

Analyses were performed by Brian King, Claire Powell, Elaine McDonagh, Hannah Longworth, Paula McLeod, Dave Teare, Bob Keogh and Susan Leadbetter (in short everyone related to the physics team pitched in). Samples were standardized using Ocean Scientific International IAPSO standard seawater, batch P145 (Date:15 July 2004, K_{15}:0.99981)

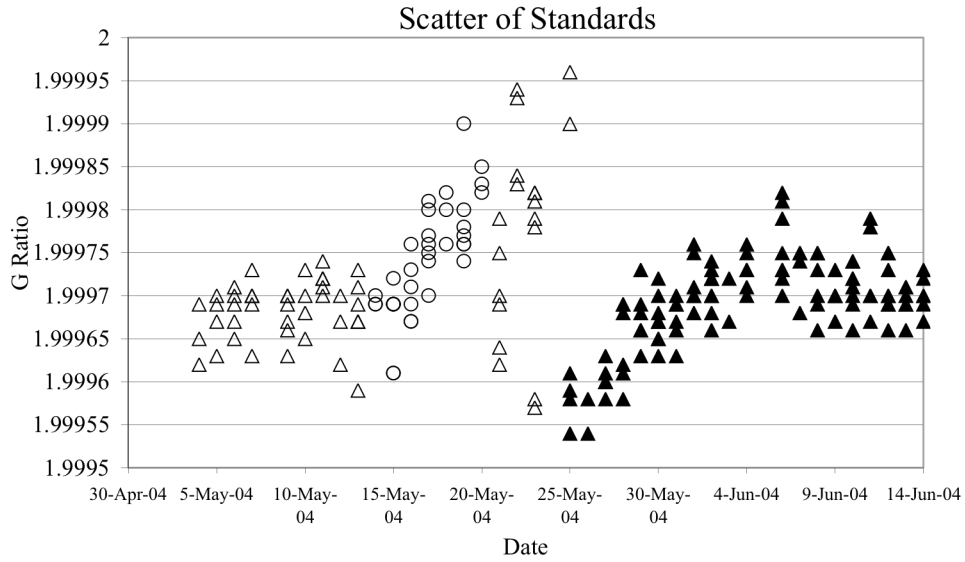

Figure 3.1: The measurement of the g-ratio for each bottle of standard seawater used. Triangles indicate that the UKORS instrument was used (filled triangles for samples after the standard reset dial was adjusted) and circles for the JRD instrument. A total of 2910 samples were used for 144 stations and 9 crates of TSG samples.

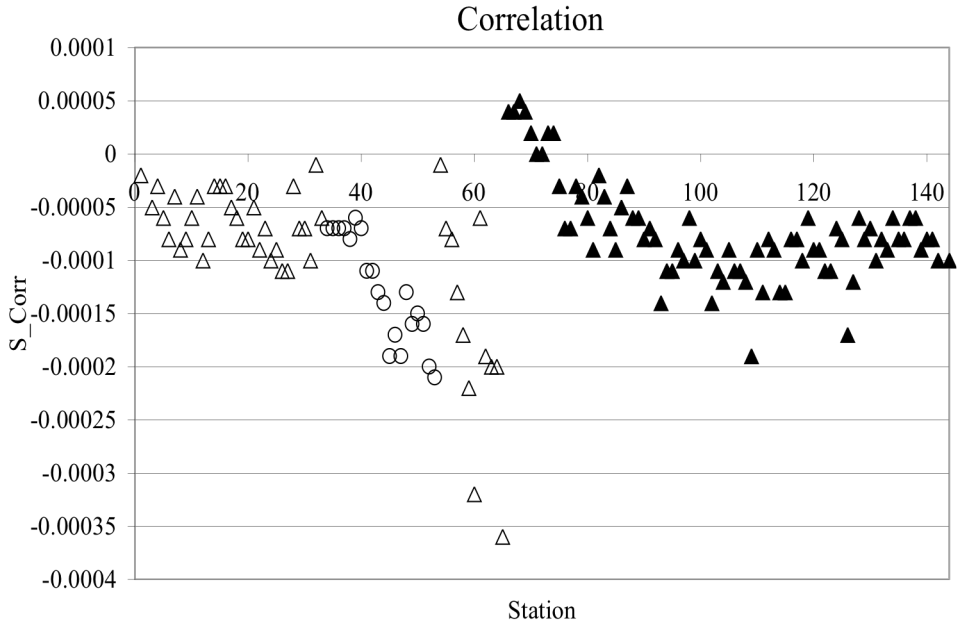

Figure 3.2: The correction ratio used for the analysis of each station. The symbols used indicate which instrument was used as detailed in figure 3.1.

Standard seawater readings were taken at the beginning and end of the analysis of each crate. These readings have drifted upwards over the course of the cruise (figure

3.1) to the point where the standard reset dial on the UKORS autosal was changed from 354 to 296 on 27th May, before the analysis of station 72. As a result the g-ratio correction applied to each crate (figure 3.2) should be considered as 3 time series: JRD autosal and the UKORS autosal before and after this change.

It was also noted that the g-ratio readings of the standard seawater would often vary during the analysis of a crate of samples (figure 3.3). At first it was assumed that a simple average of the two values would suffice but after the analysis of station 50 it was decided that analysis of a 'secondary standard' was necessary after every eight bottles. Standard seawater could not have been used for this purpose, as there would not have been enough so entire crates of 24 samples were drawn from the bottom Niskin at sporadic intervals. These secondary standards were then equilibrated for 24 hours before use. Use of the secondary standards showed that discrepancies between standard seawater measurements were often trivial and a simple average could be taken. In other cases, where the difference was greater the secondary standards showed that especially after a period of inactivity, the autosal had a spin up time so the first standard reading should be disregarded and the values for the first two niskins regarded with caution.

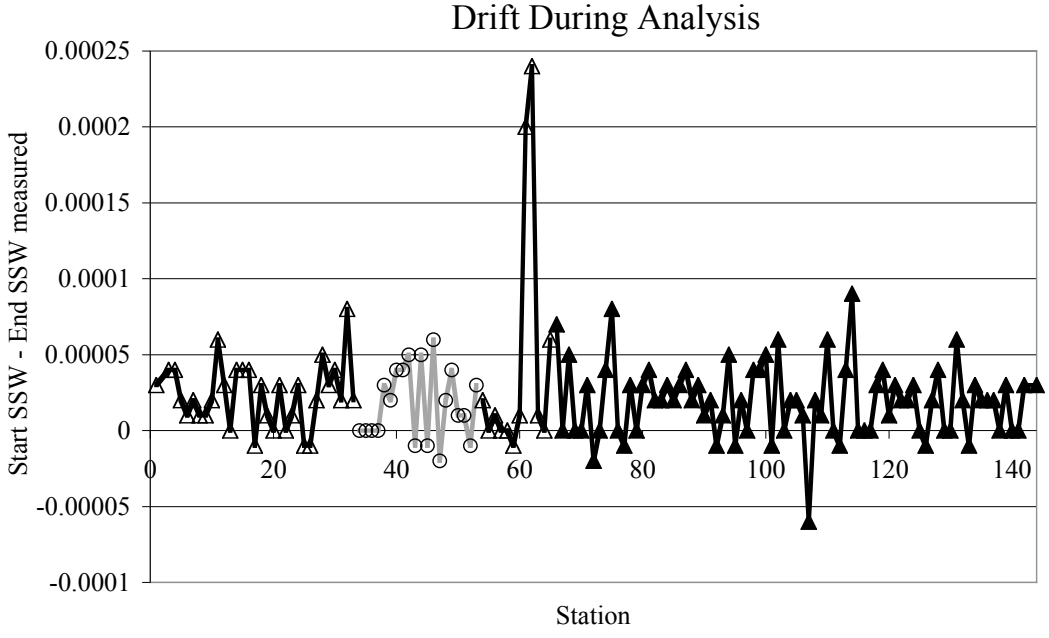

Figure 3.3: The drift during analysis (ssw start – ssw end) for the analysis of each station. The key to symbols is the same as for figure 3.1.

Processing

Following standard practice the salinity values were obtained from conductivity ratio measurements using an excel spreadsheet, which corrects for offsets from standard readings. These results were transferred to unix in the form of a windows text file containing the variables statnum sampnum botlnum botsala botsalb botsal as well as botlflag salflag, which pertain to whether or not the bottle fired correctly and whether or not the sample was analysed for salinity in a satisfactory manner.

Assessment

The 8400A machines are capable, with great care, of producing reproducible data good enough for the calibration of CTD data although much of the data needs to picked over for faults. However we feel that the overall drift and stability is not as good as we have come to expect from 8400B.

In conclusion, whilst the 8400A is adequate, due to its stability over time, it should be used more as a back-up to an 8400B than as a stand-alone instrument. Particularly on a cruise like this one where the demands placed on it are heavy.

Claire Powell

4. Dissolved Oxygen

4.1 Sampling

Seawater for dissolved oxygen determinations was collected from Niskin bottles directly into pre-calibrated glass bottles using a silicon rubber tube. Before the sample was drawn, the water was allowed to flush out of the glass bottle for several seconds. The temperature of the sample was then recorded and the fixing reagents (i.e. manganese chloride and sodium hydroxide/sodium iodide solutions) immediately added and mixed. Bottles were kept in the dark and were mixed for a second time after the precipitate settled to more than 50% of the bottle volume (30 to 40 min). All titrations were carried out within 2 to 3 hours of sample collection. Sampling for oxygen was done before any other sample was taken or, after samples for He and / or CFC's were collected. All CTD casts from station 3 were sampled.

4.2 Analysis

Dissolved oxygen in seawater samples was measured using a Winkler Ω-Metrohm titration unit (716 DMS Titrino) with an amperometric system to determine the end point of the titration (Culberson & Huang, 1987). Chemical reagents were prepared according to Dickson (1994) and recommendations given by this author and by Holley & Hydes (1994) were adopted. Thiosulphate calibrations were carried out every 4-6 days (see Table 4.1) and consisted of the analysis of 5 blanks[1] and 5 standards. Blanks were prepared by pipetting 1 mL of either a 1.696 mM prepared KIO_3 standard (for stations 3 to 11) or a 1.667 mM certified OSIL iodate standard (from station 12 onwards) into 70 ml of Milli-Q water. The analytical standard was prepared by pipetting 10 ml of the above, prepared or certified standards, into 70 ml of Milli-Q water. Averaged blank and standard titration volumes from every calibration were adopted for computing oxygen concentrations. Oxygen concentrations were facilitated by the use of an excel-spreadsheet provided by Richard Sanders. 3 sets of 24+1 oxygen sampling bottles were used and a spreadsheet was generated for each set with the respective oxygen bottle labels and pre-calibrated

[1] Except from the first calibration, which consisted of only 3 blanks.

volumes. Whenever a bottle was accidentally broken and replaced, the bottle label and volume were updated in the respective spreadsheet. In addition to replicate Niskin bottles, at least one sample per cast was analysed in duplicate and whenever a Niskin bottle misfired, spare oxygen bottles were used to produce 2 or 3 replicates from randomly chosen samples.

4.3 Observations

Problems encountered and troubleshooting

The first thiosulphate solution prepared for the cruise (02 May) was standarised with a prepared 1.696 mM potassium iodate solution (0.3631 g of KIO_3 in 1 L of Milli-Q water). However, later calibrations (from 06 May) using certified standards and oxygen analysis results from station 12 onwards, suggested that the molarity of the prepared KIO_3 solution was not accurate (i.e. volumes of thiosulphate used to titrate 10 ml of prepared and certified standards were very similar, see Table 4.1). This problem was further complicated due to an abrupt change in the volumes of thiosulphate solution used to titrate certified standards (see Table 4.1).

Calibration No.	Date (2005)	Blk (ml)	STD (ml)	Thio (M)
1	02 May	0.054	0.517	0.215
2	06 May	0.054	0.512	0.218
3	10 May	0.051	0.524	0.211
4	15 May	0.051	0.504	0.220
5	19 May*	0.051	0.504	0.220
6	23 May	0.051	0.504	0.220
7	26 May	0.052	0.503	0.221
8	31 May	0.051	0.504	0.220
9	04 June*	0.052	0.502	0.222
10	09 June	0.051	0.502	0.221

Table 4.1: CD171 O_2 determinations; dates on which thiosulphate calibrations were carried out, mean blank titre volume (blk), standard titre volume (STD) and molarity of thiosulphate solution (Thio). Denote dates when new thiosulphate solutions were prepared. NB: A prepared KIO_3 standard was used for calibration No. 1 and certified OSIL KIO_3 standards were used for calibrations 2-10.*

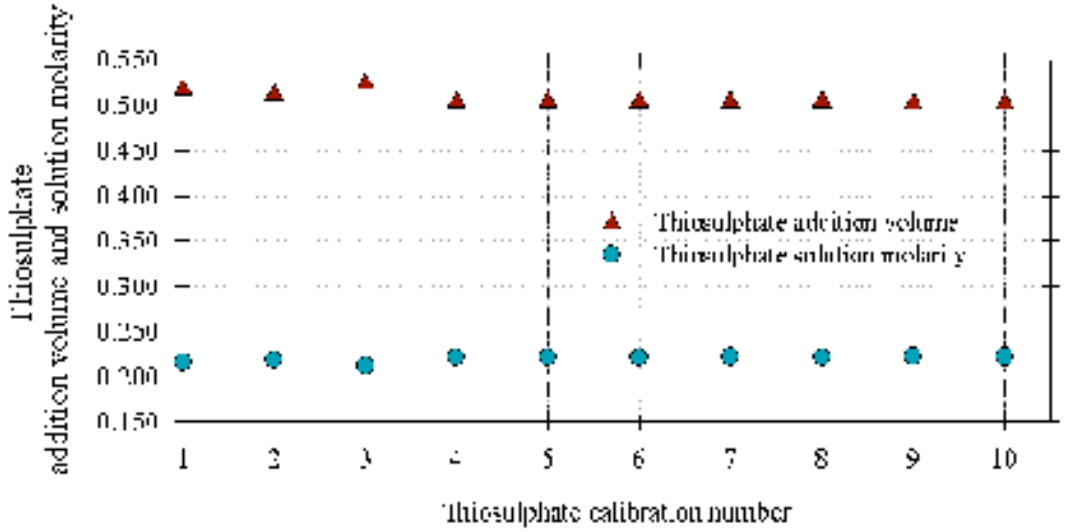

Figure 4.1: Volume of thiosulphate solution added (ml) to titrate 10 ml of a 1.667 mM iodate standard and molarity of the thiosulphate solution during the CD171 cruise. Black dashed lines indicate when a new thiosulphate solution was prepared.

The average volume of the thiosulphate used to titrate blanks and standards, and the thiosulphate molarity calculated from standardisations was overall constant throughout the cruise, suggesting therefore that the thiosulphate solutions prepared were stable over the period they were used (Table 4.1, Figure 4.1). Nonetheless the first 3 calibrations showed slight differences when compared with the rest of the calibrations (i.e. calibrations 4 to 10). These variations, in the order of 10-20 µl of added thiosulphate solution, produced significant deviations in the dissolved oxygen calculations from the expected values. Given that the same thiosulphate solution was used during calibrations 1 to 4, with the 4th being similar to calibrations 5 to 10 (Table 4.1, Figure 4.1), it would appear that the reason for the change observed (from calibration 3 to 4) in the volume of thiosulphate needed for the titration was not related to the chemistry involved in the analysis. The problem may have been related to the Milli-Q water used during the first calibrations or to the bottles used for the calibrations not being clean enough. Thus, the calculation of dissolved O_2 concentrations of all samples before station 44 will need to be reviewed at NOCS.

NB: After discussing the problems encountered with the oxygen analysis, Brian King suggested to correct all oxygen calculations 'affected' by using calibrations 1 to 3. The correction was done by replacing the blank titre and standard titre volumes in the spreadsheets of the 'affected' stations, by the blank titre and standard titre volumes of

calibration number 4. Few days before the end of the cruise every single spreadsheet was twice reviewed, once by Tim Lesworth and a second time by myself. As far as I could see, there were no errors left uncorrected in the reviewed files. Finally, all corrected files were passed on to Hanna Longworth for her to compile the O_2 data set. It was further discovered that the tubing and burette of the titration unit were letting air into the system and were therefore replaced after station 53. If the air getting into the tubes was constant, it would appear that the thiosulphate volume required was larger than needed (although this situation was not observed with seawater samples).

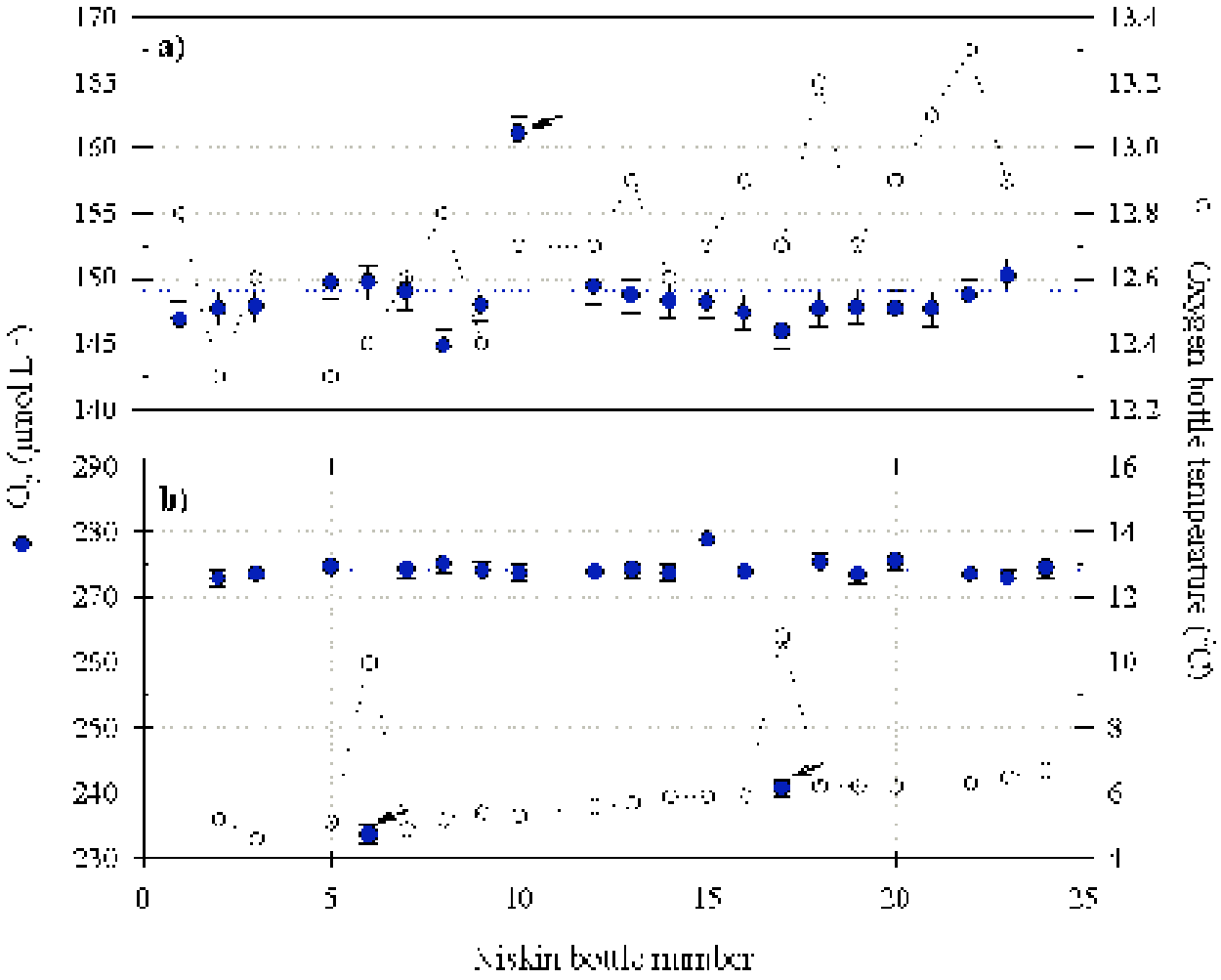

Figure 4.2: Niskin bottle depth-repeats; a) station 50 (average O_2 = 148 ± 1.3 µM, dashed line), and b) station 99 (average O_2 = 274.3 ± 1.3 µM, dashed line). Error bars show the standard deviation of replicates. Data from symbols indicated by arrows was not considered for calculating average values. The temperature of the sample is also shown.

Oxygen analysis reproducibility

Although problems caused by improper mixing of reagents resulted in few profiles with inconsistent data, reproducibility of oxygen measurements was overall satisfactory. Results from two test stations in which all Niskin bottles were fired at the same depth are presented in figure 4.2. The variability of all data points showed on each figure represent less than 1% of the mean value. Large deviations of concentration values were due to misfired bottles (also evident in the temperature).

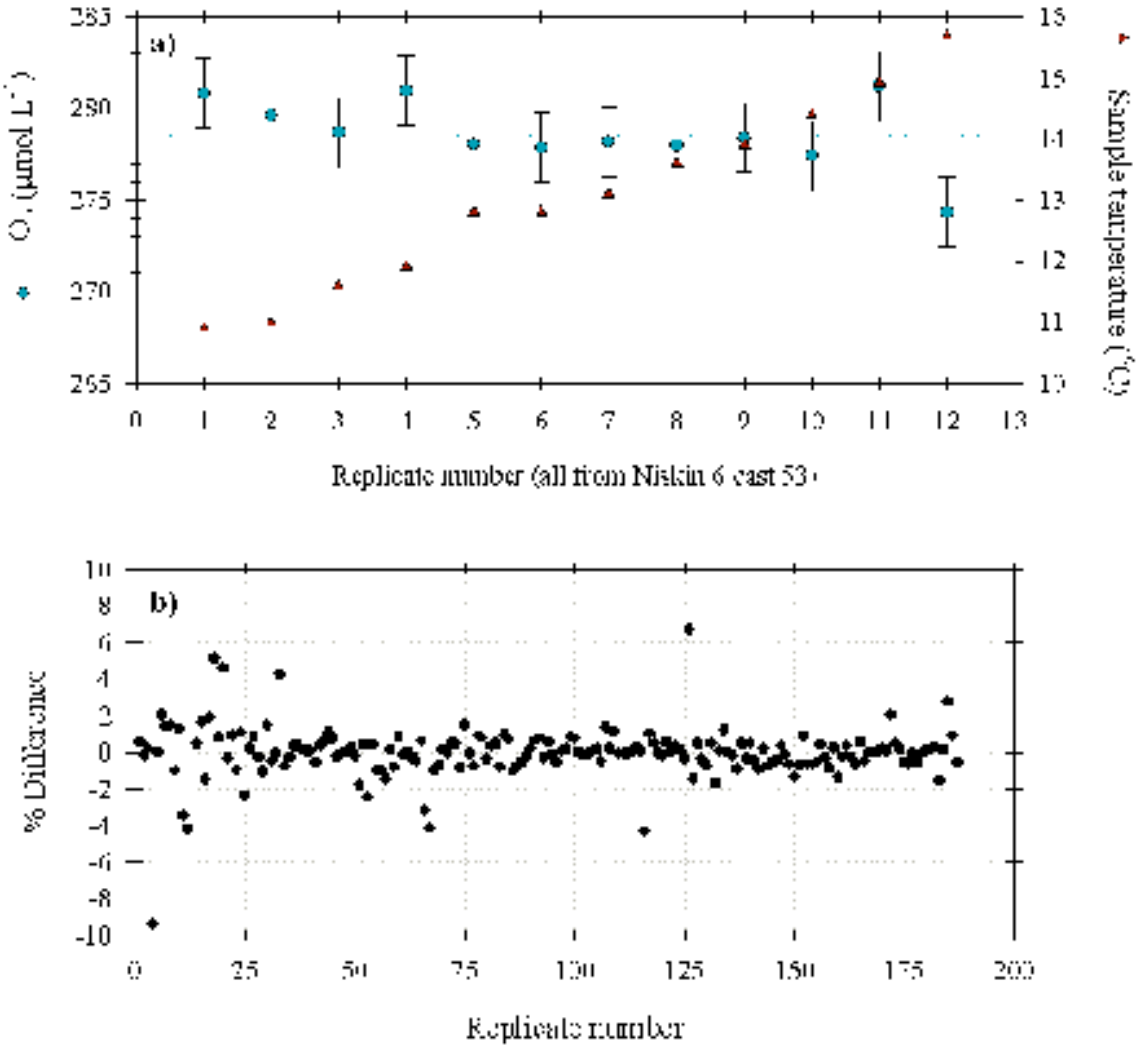

Figure 4.3: a) Replicate measurements from Niskin 6, station 53 (mean O_2 = 278.6 ± 1.9 µM, dashed line). Error bars show standard deviation of replicates. Temperature of the samples is also shown. b) Percent difference of replicate determinations expressed as: %Difference = 100 x (replicate2 – replicate1)/replicate1.

Replicate measurements were also carried out from a single Niskin bottle and showed good reproducibility too, with a variability of less than 1% of the mean oxygen concentration (figure 4.3, a). Percent differences of replicates averaged 0.88% (see figure 4.3, b) and the variation of triplicate measurements represented 0.70% of the mean value.

References

Culberson C H & S. Huang (1987) Automated amperometric oxygen titration. Deep-Sea Research, 34:875-880

Dickson A G (1994) Determination of dissolved oxygen in seawater by Winkler titration. WOCE Operations Manual. Report No. 69/91, Revision 1 November 1994

Holley S E & D J Hydes (1994) Procedures for the determination of dissolved oxygen in seawater. Internal Document, James Rennell Centre for Ocean Circulation.

Sinhue Torres
Tim Lesworth
Rhiannon Mather

5. Inorganic Nutrients

5.1 Sampling

Samples for inorganic nutrient analysis ($NO_3^- + NO_2^-$, PO_4^{3-} and $Si(OH)_4$) were taken from each CTD cast from station 3. Seawater was collected into 30 ml coulter counter vials after samples for CFC's, He, oxygen, CO_2, alkalinity, organic nutrients and salinity were drawn. Vials and lids were rinsed several times with seawater before sample collection. Samples were stored in a fridge and analysed within 1 to 8 hours.

5.2 Analysis

Inorganic nutrients were measured by segmented continuous-flow using a Skalar San^{plus} autoanalyser. This system is set up for analysis and data logging with the Flow Access software package version 1.2.5. The analysis was calibrated with a set of 4 working standards containing nitrate, silicate and phosphate within a concentration range as shown in table 5.1. The calibration range however, was modified for silicate analysis after station 114 in order to verify that concentrations higher than 40 μM were within a linear calibration range. Standards number 1 and 2 were thus replaced by a concentration of 60 and 40 μM respectively. 5 mM stock solutions were used to prepare working standards every 4 to 5 days. Stock standards were prepared with Milli-Q water, but working standards were prepared in a saline matrix (40 g NaCl/1 L Milli-Q water also referred to as artificial seawater), which was also used as the diluent for the analysis and analytical wash cups. The standards were stored in a fridge when not in use. Most CTD casts were analysed in single runs, which consisted of a set of standards, wash and drift cups, certified low nutrient sea water in order to test for contamination of the matrix and samples. The efficiency of the nitrate reduction column (i.e. cadmium column) was tested on a regular basis (2 to 5 days) by measuring and comparing prepared and certified nitrate and nitrite standards. Finally, the autoanalyser tubing was changed every 7-10 days.

	NO_3^-	$Si(OH)_4$	PO_4^{3-}
Std 1	40	40	4
Std 2	30	30	3
Std 3	20	20	2
Std 4	10	10	1

Table 5.1 Set of calibration standards used for nutrient analysis on CD171. Concentration units are μM.

5.3 Observations

Problems encountered and troubleshooting

On the 3rd day of the CD171 cruise the computer connected to the autoanalyser stopped retrieving baseline and peak signals from the integrator. This caused a delay with the nutrient analysis and samples from casts 3 to 7 were analysed after a day of collection. Although the actual reason for this malfunction was not found, the problem appeared to be related with the Skalar Flow Access software since after being re-installed communications between detectors, integrator and computer re-established. On several occasions the nitrate and phosphate signals exhibited noisy baselines. In the case of nitrate, the main reason for this to happen was that fine cadmium granules from the reduction column entered the cell. This was easily resolved by removing the cell (while covering the light source) and allowing some bubbles in for 30-60 seconds. The cell was then placed back and the baseline checked before starting a run. In the case of the phosphate line the noise seemed to be due to chemicals sticking into cell. This problem was solved by washing the cell with 10\% Deacon, Milli-Q water and artificial seawater (\i.e. saline matrix) using a 60 ml syringe. It was also observed that when bad weather conditions persisted the signal of the three nutrients presented noisy baselines.

Quality control

The consistency of the analysis was monitored by recording the baseline (digital units, DU) and calibration slope (DU/[STD]) of the three nutrients measured over time. The

baselines of the three nutrients showed variations with an overall tendency to increase as the cruise progressed (Figure 5.1a). The slope of all calibrations changed from run to run with no particular trend (Figure 5.1b), even when the same batch of artificial seawater and the same set of analytical reagents were used. The slope of the phosphate calibration changed more than 30 units after a new batch of reagents was prepared (prior to analysis of station 92), and varied around similar values for the rest of the cruise (Figure 5.1b, Table 5.2). Although this change was also observed in the slope of the other two nutrients, their slope further varied around values observed before the change (Figure 5.1). Mean values and standard deviations of baselines, calibration slopes and correlation coefficients are presented in Table 5.2. The variations observed throughout the cruise seemed to be within the analytical error of the method and did not affect the quality of the results in general.

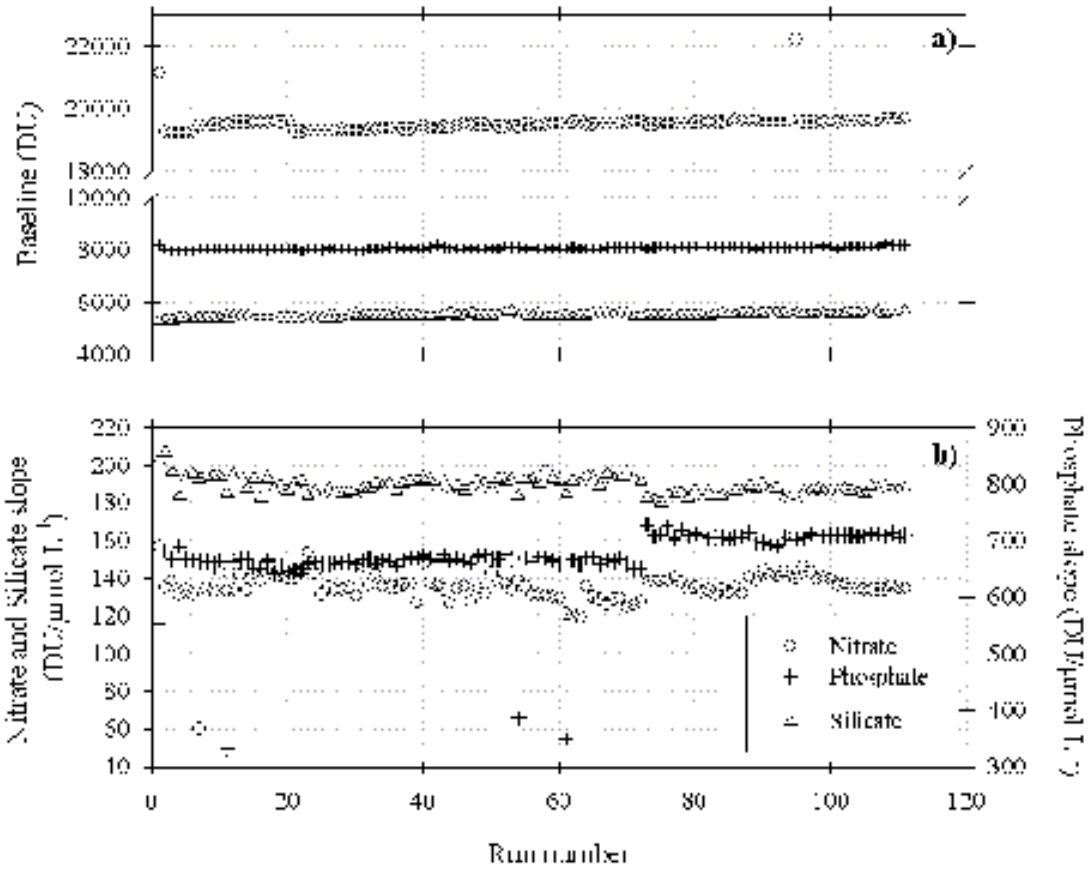

Figure 5.1 CD171 nitrate, phosphate and silicate analysis quality control; calibration slope and baseline time series (DU = digital units).

	NO_3^-	$Si(OH)_4$	PO_4^{3-}
Baseline	**19528** ±324	**5474** ±80	**8079** ±54
Calibration Slope	**135** ±9	**188** ±4	**679** ±22
Correlation Coefficient (r^2)	**0.9887** ±0.0025	**0.9995** ±0.0004	**0.9994** ±0.0006

Table 5.2 Nutrient analysis; basic statistics of analytical parameters (mean in bold characters and standard deviation). Baseline values are digital units (DU) and the slope is given by DU / [STD]. Although the mean value of the complete set of data is shown, the averaged calibration slope of phosphate was 663±7 before analysis of station 91 and 707±7 after analysis of station 92.

The consistency of the analysis was also tested by measuring (in most runs) aliquots of deep seawater collected from CTD cast 1 at 5345 m depth. A total of 130 aliquots of deep seawater were measured and showed mean values of 20.6 ±0.5, 43.7 ±0.8 and 1.43 ±0.03 μM of nitrate, silicate and phosphate respectively, and a mean N:P of 14.4 ±0.5 (Figure 5.2). The standard deviation of the mean deep seawater nutrient concentrations represents variations of less than 2.5%.

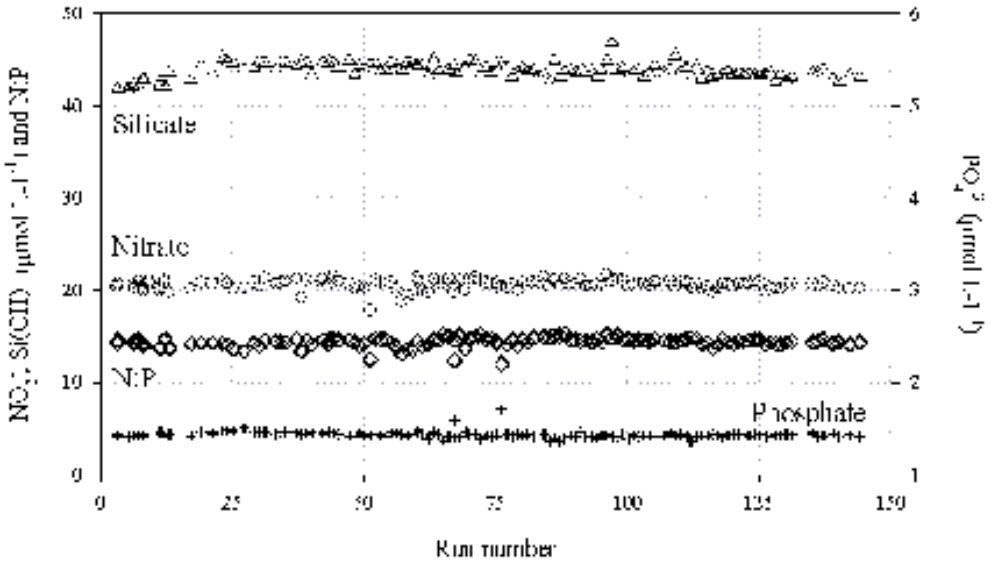

Figure 5.2 Nutrient concentrations of deep seawater collected from CTD cast 1 at 5345 m depth, and N to P ratio.

To gain further insight into the precision of the method, the variation of the complete set of measured standards can be analysed. The results of the more than 200 measurements carried out per calibration standard are summarised in Table 5.3 and shown in Figure 5.3. Although the data plotted in Figure 5.3, particularly higher standards, appeared to suggest better precision of the analysis at low standard concentrations (i.e. variability seems to be higher at higher concentrations), the variability of measurements throughout the cruise represents a precision equal to or better than 1.5\% (Table 5.3).

Results from 2 CTD depth-repeat casts are presented in Figure 5.4. Data shown in this figure suggests that the repeatability of measurements from a given CTD cast had a variation equal to or better than 1.7%. That is, the precision of measurements when comparing samples from replicate Niskin bottles was likely better than 1.7%.

	NO_3^-	Prec.	PO_4^{3-}	Prec.	$Si(OH)_4$	Prec.
Std 1	40.26 ±0.59	1.5%	3.98 ±0.03	0.7%	40.01/60.07[a] ±0.20/0.34	0.5%/0.5%
Std 2	29.83 ±0.30	1.0%	3.02 ±0.02	0.6%	30.1 ± 0.14	0.5%
Std 3	19.98 ±0.22	1.1%	2.02 ±1.02	1.0%	19.96 ±0.08	0.4%
Std 4	10.00 ±0.14	1.4%	1.02 ±0.02	1.9%	9.98 ±0.06	0.6%

Table 5.3 Mean value and variation of all standards measured, and precision of the analysis. Concentration units are μM. [a]Silicate calibration range was changed on the 07 June, just before analysis of station 114

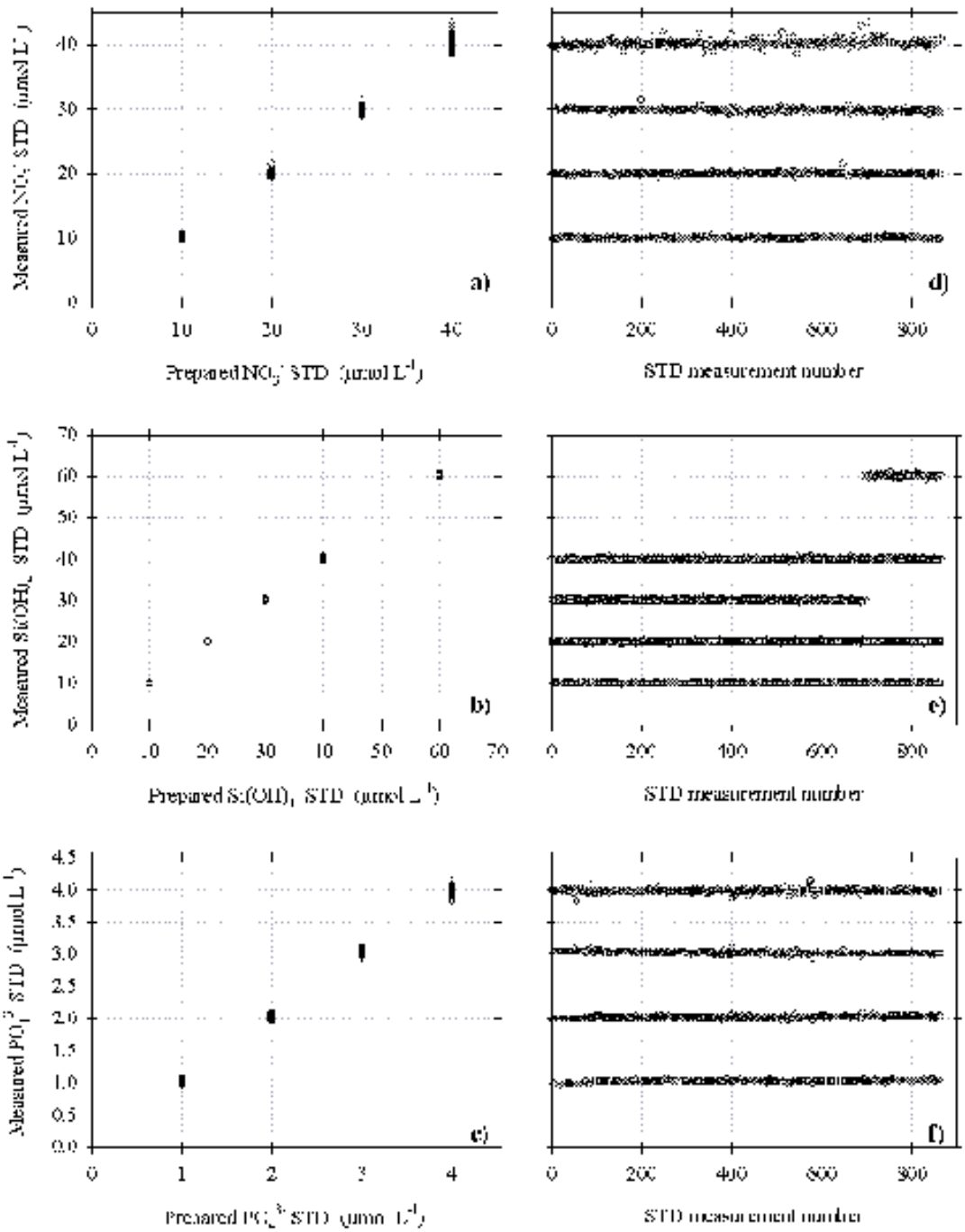

Figure 5.3 Complete set of `measured' standards plotted against the `prepared or intended' concentration (a, b and c). `Measured' standards plotted against respective analysis number (d, e and f). Y-axis on left side panels are the same as Y-axis on right side panels.

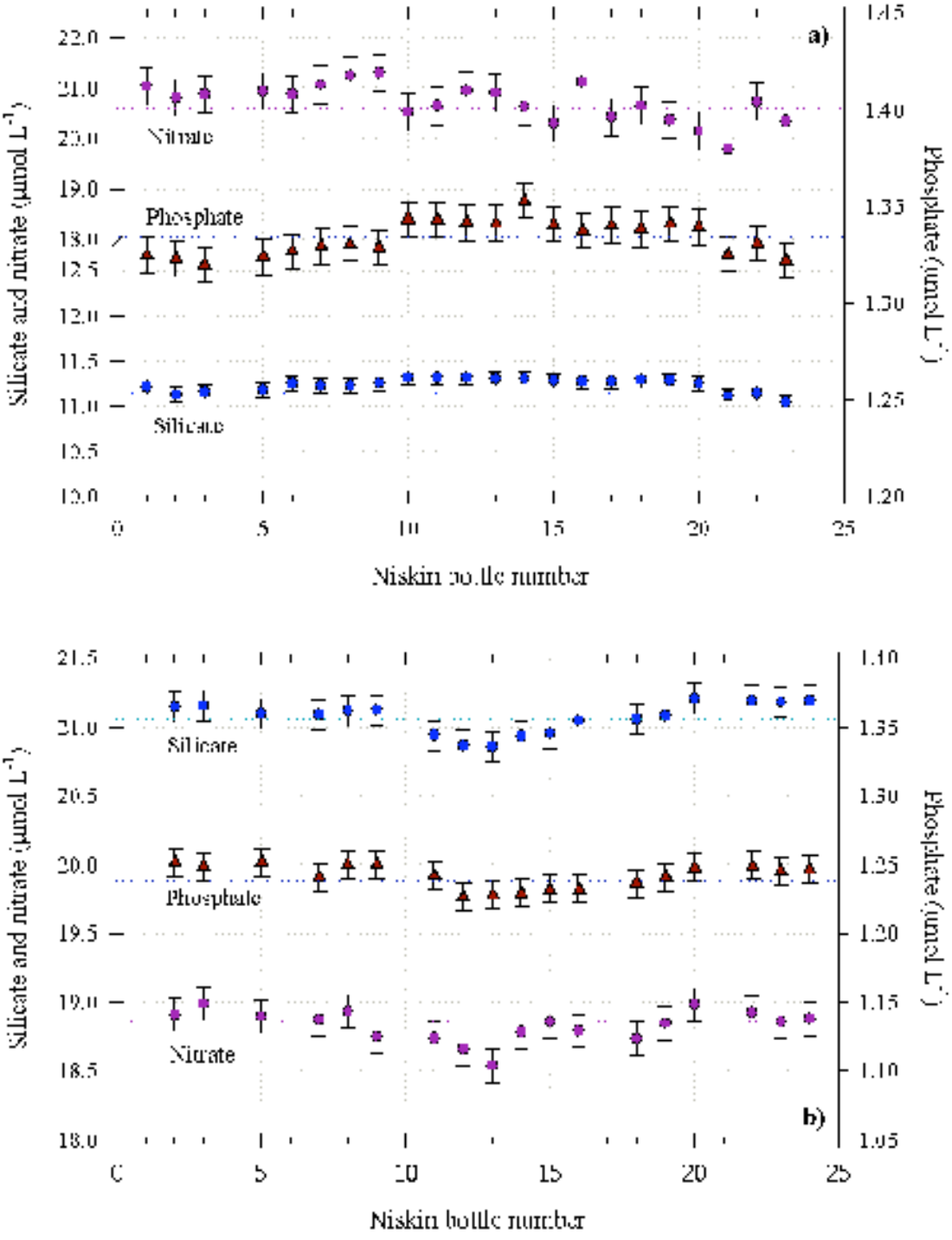

Figure 5.4 Niskin bottle depth-repeats; ***a)*** *station 50 (average nutrient concentrations;* NO_3^- *= 20.72 ± 0.37,* $Si(OH)_4$ *= 11.23 ± 0.07 and* PO_4^{3-} *= 1.33 ± 0.008 μM, dashed lines), and* ***b)*** *station 99 (average nutrient concentrations* NO_3^- *= 18.83 ± 0.11,* $Si(OH)_4$ *= 21.07 ±0.11 and* PO_4^{3-} *= 1.24 ± 0.008 μM, dashed lines). Error bars show the standard deviation of the whole set of replicates.*

In a previous cruise report (Bryden *et. al.,* 2003) it was pointed out that whereas nitrate duplicate samples exhibited random variations (i.e. the fact of a second replicate producing a relative higher or lower concentration was not systematic), duplicate samples of phosphate and silicate showed systematic variations. In the CD171 cruise, results showed that differences of triplicate measurements were random in the case of nitrate and in most cases silicate and particularly phosphate showed no variations (i.e. triplicate measurements produced the same result).

The accuracy of the analysis was tested by measuring a set of OSIL certified standards in two separate runs, prepared at a concentration of 20 μM for nitrate and silicate and 1 μM for phosphate. Certified standards however, are prepared with distilled water and are usually of a comparatively low concentration (e.g. 1000 μM $Si(OH)_4$ and NO_3^-, and 100 μMPO_4^{3-}). Thus, this analysis may have slight errors, since in order to prepare the desired concentrations, relatively large volumes of certified standards are diluted with artificial seawater, therefore changing the characteristics of the daily used analytical matrix. The first set of standards (n=7) were measured on the 11 June and produced the following results: NO_3^-=19.87 ±0.11, $Si(OH)_4$=21.60 ± 0.04 and PO_4^{3-}=1.03 ± 0.003 μM. This represents an accuracy of 99.4%, 106.3% and 103.0% for nitrate, silicate and phosphate respectively. The second set of standards (n=10) were measured on the 12 June and produced the following results: NO_3^-=20.47 ±0.14, $Si(OH)_4$=21.60 ±0.05 and PO_4^{3-}=1.01 ±0.006 μM, which in turn represents an accuracy of 102.3%, 108.0% and 101.0% for nitrate, silicate and phosphate respectively.

References

Bryden, H L (2003) RRS Charles Darwin Cruise 139 (01 Mar – 15 Apr 2002. Trans-Indian Hydrographic Section across 32°S) Tech. Rep. 45, National Oceanography Centre, Southampton.

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6. Carbon Parameters

The CO_2 parameter analytical equipment was set up in the seagoing laboratory container of the Laboratory for Global Marine and Atmospheric Chemistry (LGMAC), University of East Anglia (UEA), Norwich, UK. Discrete CTD samples were analysed for total inorganic carbon (TIC), total alkalinity (TA), and partial pressure of CO_2 (pCO_2). Additionally, a continuous, automated instrument for the analysis of sea surface pCO_2 and atmospheric pCO_2 was run throughout the cruise.

Due to the length of time needed for the analyses, generally every second station was sampled, apart from the western and eastern boundary currents, where more frequent stations were sampled. When a station was sampled, all depths were sampled, with the exception of stations 118 and 134, where only the bottom depths were sampled.

Three samples were drawn from each Niskin sampled: a 250 ml and a 500 ml reagent bottle for discrete TIC and/or discrete TA, and a 500 ml volumetric flask for discrete pCO_2. Discrete seawater samples were taken according to Standard Operating Procedure 1 (SOP 1) outlined in DOE (1994). Samples were drawn from the Niskin bottles immediately after the oxygen samples were taken. All seawater samples were taken with Tygon tubing into pre-cleaned bottles and flasks. These were rinsed once, filled from the bottom, and overflown once. They were then stoppered without any gas bubbles entrapped. The samples were fixed by creating a headspace and adding saturated mercuric (II) chloride ($HgCl_2$) solution according to DOE (1994). Samples were fixed and stored at ambient temperature in the laboratory container, until prior to analysis, when they were brought to 25^{o}C for TIC and TA, and 15^{o}C for pCO_2. All stations sampled were analysed on board, together with replicates. Only a few samples were stored for post-cruise analysis back at UEA.

Replicates samples were taken for all discrete analyses from random Niskin bottles at several stations, and run on board for TIC, TA, and pCO_2. Additional replicates were taken from the ship's non-toxic seawater supply.

6.1 Discrete total inorganic carbon (TIC)

Total inorganic carbon was analysed by coulometry. All inorganic carbonate is converted to CO_2 (gas) by addition of excess phosphoric acid (1 M, 8.5%) to a calibrated volume of seawater sample. Oxygen-free-Nitrogen (OfN) gas passed through soda lime, to remove any traces of CO_2, is used to carry the evolving CO_2 to the coulometer cell. In the coulometer cell, all CO_2 is quantitatively absorbed forming an acid, which is coulometrically titrated. During CD171, the coulometer was set to integrate the titration as counts (CTS), and titration endpoint is set to 4 times 50 CTS per 60 sec.

Two systems for the analysis of TIC were on board: a stand alone TIC analyser (TIC_1), and a combined system for TIC and TA (TIC_2), called Versatile Instrument for the Determination of Titration Alkalinity (VINDTA, Marianda, Kiel, Germany). Both TIC systems use a coulometer (model 5100, UIC Inc, USA), with the maximum current adjusted to 50 mA.

TIC_1: The stand-alone TIC analyser consisted of a coulometer and a CO_2 extraction unit based on the Single Operator Multiparameter Metabolic Analyzer (SOMMA), developed by Kenneth Johnson (Johnson et al. 1985, 1987, 1993; Johnson 1992), and modified at UEA.

TIC_2: Within the VINDTA system, the analytical method for TIC is the same as the stand-alone one, but combined with the analysis of TA (described below).

The accuracy of the TIC analyses was determined regularly by measuring certified reference material (CRM), supplied by Dr. A. Dickson of Scripps Institution of Oceanography (SIO), Batch #69. No certified values for batch #69 were available at the time of completion of the cruise; hence only relative values could be computed. Post-cruise work will involve the calculation of absolute TIC values. The CRM results are shown in Figure 6.1.

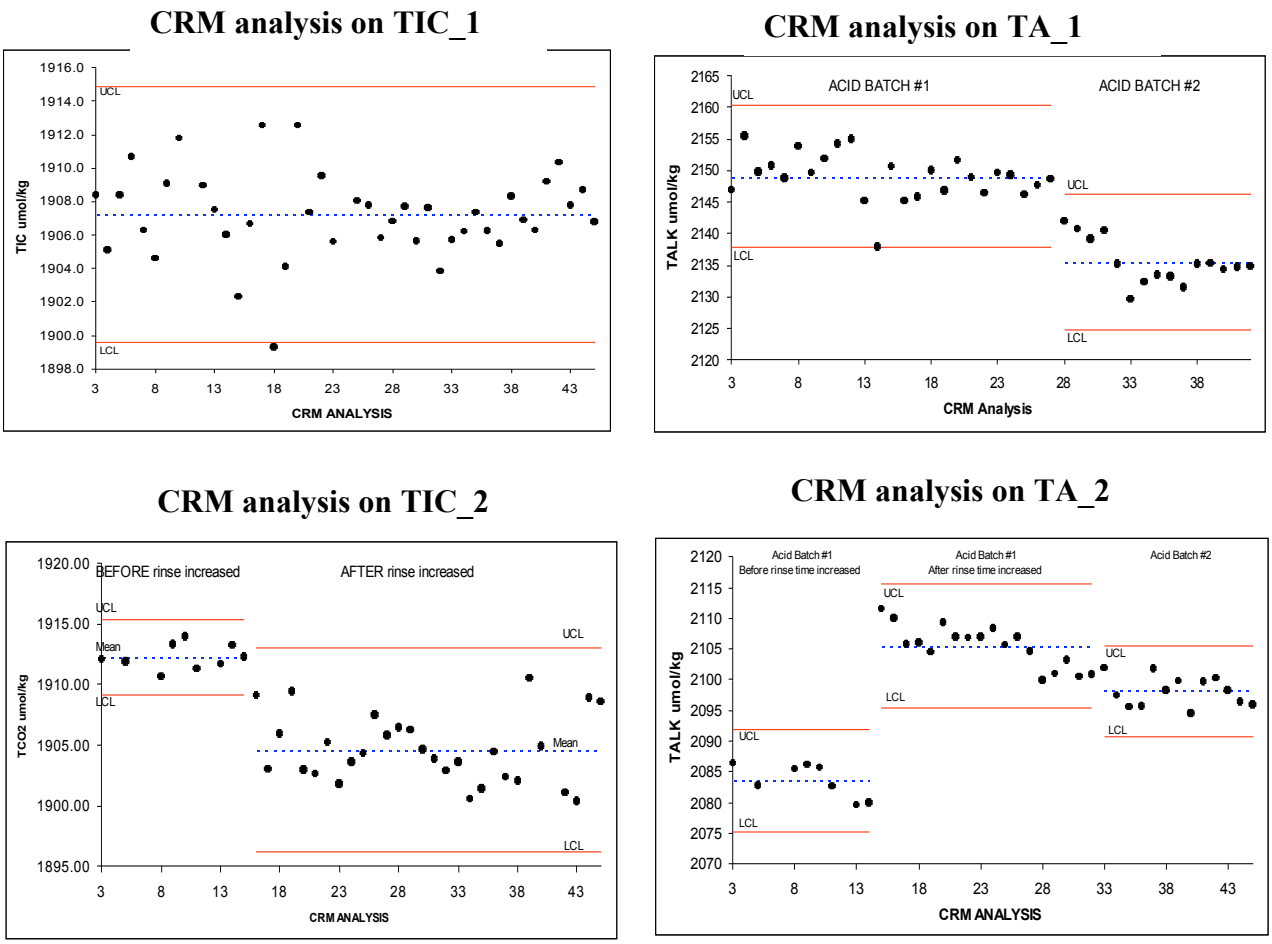

Figure 6.1: Results of the TIC analysis of CRM batch 69 throughout the cruise. TIC_1 and TA_1 were stand-alone instruments, whilst TIC_2 and TA_2 were a combined system.

Post-cruise work will involve the analysis of the stored samples, which could not be analysed on board. A post-cruise calibration of the temperature sensor and the pipette volume will also be done, and the sample results recalculated if necessary.

Problems encountered during CD171:

- a sample memory effect was encountered during the initial stages of the cruise on the VINDTA system (TIC_2). This resulted in analyses being affected by the previous sample result. Tripling the rinsing time led to the elimination of this problem.

6.2 Discrete total alkalinity (TA)

Total alkalinity was determined by the titration of a calibrated volume of seawater, equilibrated to 25ºC. Titration was achieved with a strong acid (HCl). The s-shaped titration curve produced by potential of a proton sensitive electrode shows two inflection points, characterising the protonation of carbonate and bicarbonate, respectively. The acid consumption up to the second point is equal to the titration alkalinity. From this value, the carbonate alkalinity is calculated by subtracting the contributions of other ions present in the seawater, i.e. nutrients.

For this analysis, two VINDTA were used, one working in combined mode with TIC analysis (see TIC_2 above). They are an open cell titration system, with sample delivery via a thermostated calibrated pipette. Sample handling and titration is program controlled. The titration is carried out using a Titrino (Model 719 S, Metrohm, Switzerland). The results are calculated using a non-linear curve fitting approach, comparing a calculated curve to the data points and making use of the best-fit coefficients for alkalinity calculation.

TA_1: VINDTA serial number #4, designed for combined analysis with TIC. However, during CD171, it was run only for TA.

TA_2: VINDTA serial number #7, running in combined mode with TIC (TIC_2). The software of this system has been rewritten in VisualBasic 6.0 by Alex Etchells (UEA), for easier handling and running of the system.

During CD171, two solutions of 0.1M hydrochloric acid were made up for the titrations. Sub-samples of this acid were taken for post-cruise analysis to determine the exact concentration. The correct concentration will then be used to recalculate the results.

Alkalinity data was calibrated with CRMs, shown in Figure 6.1. However, the calculation method is dependent on a realistically estimated ratio of acid factor and pipette calibration, since the same calibration factor can also be obtained with various combinations of these two parameters, but the quality of the curve fit will be different.

Therefore a re-calibration of the pipette and exact calculation of the acid factor will be processed post cruise. Changes that would exceed the mean standard deviation of the method are not likely. A number of early stations were analysed using an inaccurate acid factor. These stations have an incorrect concentration at the end of the cruise. Recalculation is required post cruise to enter the correct acid factor and thus obtain a corrected result. The nutrient and salinity data will also be included in the post cruise processing, together with back calculation of rejected samples.

For the calculation of carbon alkalinity from total alkalinity, the phosphate and silicate alkalinity has to be known. This can be done using the separately determined nutrient concentrations. However, the contribution is low, for phosphate about equal to the phosphate concentration (i.e. 0-3 µmol/kg for open ocean waters), a factor of 10 lower for silicate. Nutrient data was not available immediately during this cruise and therefore not included in the calculations. This will be part of the post-cruise recalculation.

Encountered problems:

- For TA analysis, a problem of sample memory effect was also encountered during the initial stages of the cruise. This resulted in analyses being affected by the previous sample result. Tripling of the rinsing time led to the elimination of this problem.

6.3 Discrete partial pressure of CO_2 (discrete pCO_2)

The partial pressure of CO_2 in seawater was determined by infrared absorption of CO_2 in a gas stream that was equilibrated with CO_2 in a seawater sample at 15°C. The system was built at UEA prior to cruise, its design based on the one described by Waninkhof & Thoning (1993).

A headspace was created in the 500 ml volumetric flasks by replacing a volume of seawater with a gas of a CO_2 concentration close to that of the seawater. Six gas standards (10 litre, BOC, UK) were available with different CO_2 concentrations, which had been calibrated against primary National Oceanographic and Atmospheric Administration (NOAA) gas standards prior to the cruise. The headspace gas was circulated through the seawater sample and the IR detector (LiCor model 6262,

LiCor, Inc., USA) until equilibrium was reached, generally after 20 min, whilst maintaining close to atmospheric pressure within the loop. If equilibration had not been reached, the sample was re-equilibrated.

All gas standards were run after each 12 to 15 samples, in order to calibrate the LiCor detector. The precision of the analysis was determined by running replicate samples, taken either from Niskin bottles or the ship's non-toxic seawater supply.

6.4 Continuous partial pressure of CO_2 (continuous pCO_2)

The partial pressure of CO_2 in surface seawater was determined by infrared absorption of CO_2 in a gas stream being continuously equilibrated with the CO_2 of surface seawater. The system used was built at UEA, its design based on the one described by Cooper et al (1998).

Seawater from the continuous non toxic supply of RRS Charles Darwin was tee-ed off from a high flow (>50 litres/min) bypass, passed through a perculator type equilibrator at 5 litres/min. A counter-flow of air was continuously circulated through the equilibrator and the detector (LiCor model 7000, LiCor, Inc., USA). At least once per hour, the system analysed CO_2 in air, pumped in from the foremast.

Gas standards (10 litre, BOC, UK) of CO_2 in air were measured throughout the cruise, in order to calibrate the LiCor detector. These standards had been calibrated against primary National Oceanographic and Atmospheric Administration (NOAA) gas standards prior to the cruise.

Under controlled conditions in the laboratory, and during a pool side international intercomparison in Japan in 2003, the type of instrument used for this cruise gave a precision of ± 0.7 ppm CO_2.

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Ute Schuster

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7. Chlorofluorocarbons (CFC's) and sulfur hexafluoride (SF_6)

7.1 Sample collection and technique

Water samples were collected from 20-L bottles used on the cruise to allow for the larger volume needed for the CFC-SF_6 (~2 litres) sampling in comparison for the classical volume needed for CFC's (~300ml) sampling. The bottles had been cleaned prior to the cruise using isopropanol and packed in foam-free boxes for the transport. Nitrile 'O' rings were washed in isopropanol and baked in a vacuum oven for 24 hours. The trigger system of the bottles was external stainless steel springs. Water samples were collected in 500 ml ground glass stoppered bottles. The bottles were filled from the bottom using a tygon tube and overflowed by ~1 litre to expel all water exposed to the air. Immediately after sampling, the glass bottles were immersed in a cool box of clean cold deep water until analysed. Ices packs were added as necessary to keep the samples cold and prevent degassing. The cool boxes were housed in the wet lab whereas the extraction/analysis system was housed in the nearby main lab.

For air sampling, a ¼" OD Dekabon tubing was run from the system to the mast of the ship. The air was pump through the line using a DA1 SE Charles Austen pump.

The samples were analysed on board as soon as possible using a coupled SF_6 and CFC's system. The design of the coupled system was proposed by Bill Smethie [LDEO, 2004, personal communication]. The method combines the LDEO CFC method [Smethie et al., 2000] and the PML SF_6 method [Law et al. 1994] tied together with a common valve for the introduction of gas and water samples. This system has the advantage of a simultaneous analysis of SF_6 and CFC's from the same water sample. The water sample flows through and fills a small calibrated volume (25 cm^3) for CFC's and large calibrated volume (300 cm^3) for SF_6. Then there is a separate purge and trap system for CFC's and SF_6. Each purge and trap system is interfaced to an Agilent 6890 gas chromatograph with electron capture detector (GC-ECD). The samples were stripped with N_2 and the CFC's and SF_6 were respectively trapped at ~ -80°C on a Unibeads and aPorapak Q cold trap immerged on the headspace of liquid nitrogen. Then the traps were heated to 105°C for CFC's and 90°C for SF_6 and injected into the respective gas chromatograph. The SF_6 separation

was achieved using a molecular sieve packed 2m main column and 1m buffer column. The CFC's separation was achieved using a 1m Porasil B packed pre-column and a 1.5m carbograph AC main column. The carrier gas was pure nitrogen, which was cleaned by molsieve (13X mesh 80/100).

	Tank AAL-70508		
	Mixing ratio	Std Dev	Scale
SF_6	9.78 ppt	0.08	2000
CFC-12	534.48 ppt	1.2	2001
CFC-11	253.4 ppt	0.6	1992
CFC-113	80.6 ppt	0.2	2002
CCl4	95.4	0.3	2002

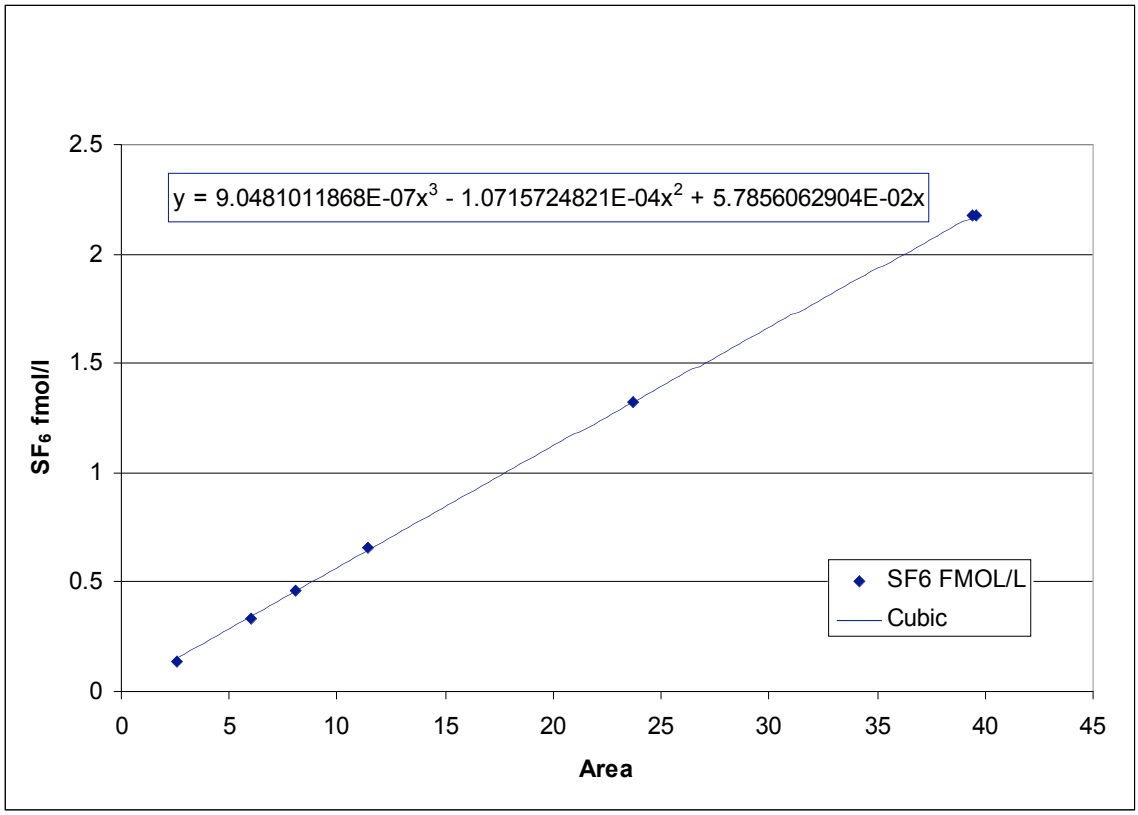
Table 7.1

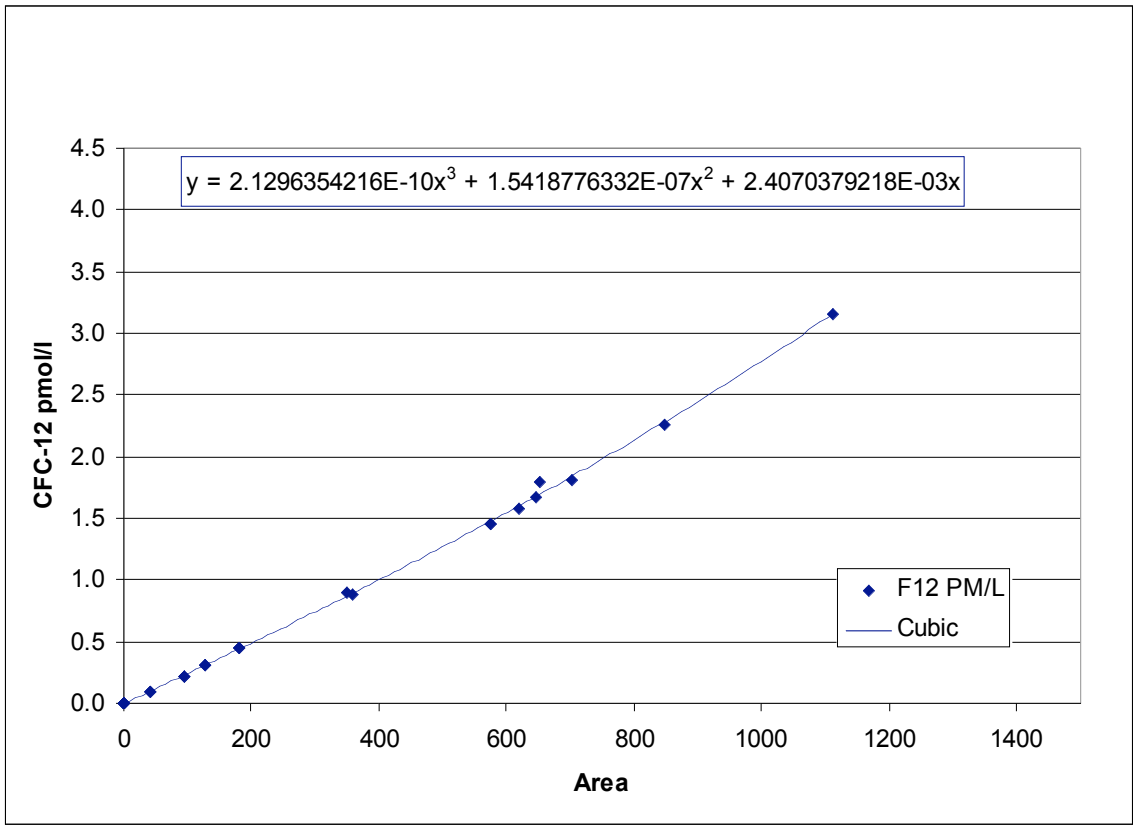
7.2 Calibration

The CFC's/SF_6 concentrations in air and water were calculated using an external gaseous standard. The standard supplied by NOAA (Brad Hall, February 2005) corresponds to clean dry air slightly enriched in SF_6, in 29L Aculife-treated aluminum cylinders (Table 7.1). The calibration curves were made by multiple injections of different volumes of standard that span the range of tracers measured in the water. Examples of fitting calibration data are given Figure 7.1. Complete calibration curves were made approximately every 2 days whereas the changes in the sensitivity of the systems were checked by measuring a fixed volume of standard gas every 10 runs (Figure 7.2). The temporal drift of the ECD between two calibration curves was assumed to be linear in time.

7.3 Contamination and blank correction

The blank correction is to compensate for any trace CFC's/SF_6 originating from the sampling bottles, handling and from the measurements procedure. This correction is normally estimated from the samples collected in waters that would be very likely free of CFC's. Zero CFC water was not observed in the Western Basin and it was not possible to determine a sample bottle blank until we reached the water~ 5000m deep


y = 9.0481011868E-07x3 - 1.0715724821E-04x2 + 5.7856062904E-02x
SF6 FMOL/L
Cubic
SF6 fmol/l
Area
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
35
40
45


y = 2.1296354216E-10x3 + 1.5418776332E-07x2 + 2.4070379218E-03x
F12 PM/L
Cubic
CFC-12 pmol/l
Area
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
200
400
600
800
1000
1200
1400

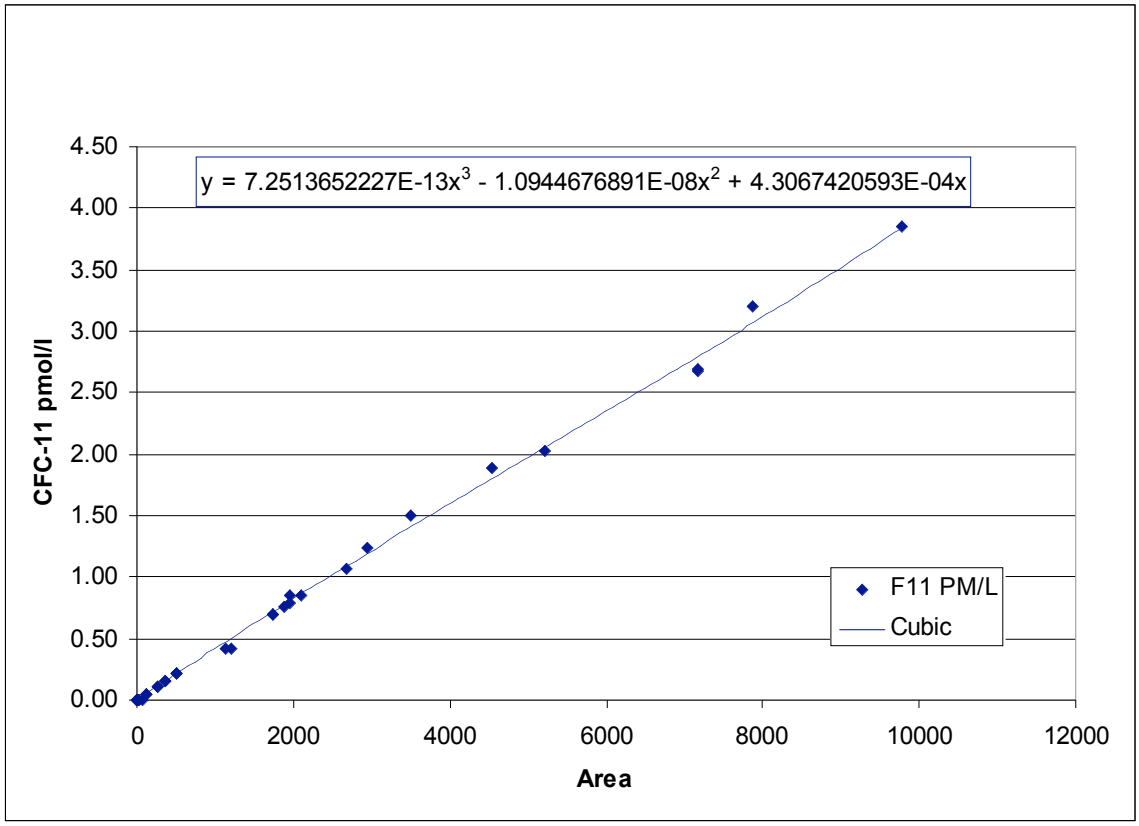


Figure 7.1: Examples of calibration curves (14/06/2005) to convert the ECD signal (peak area) in concentrations.

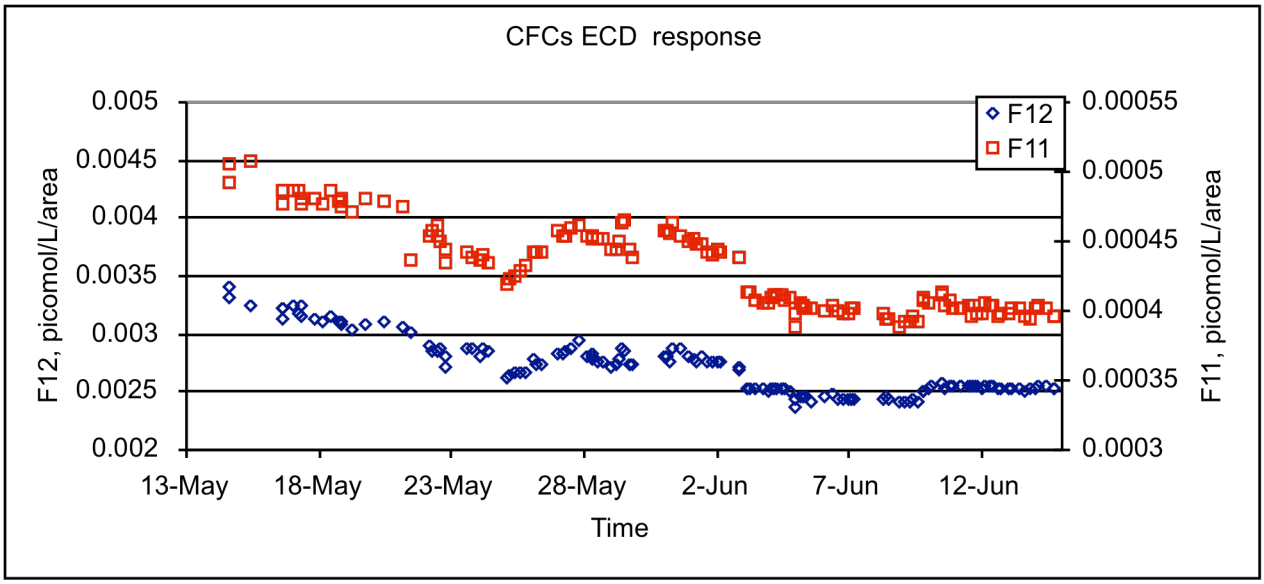
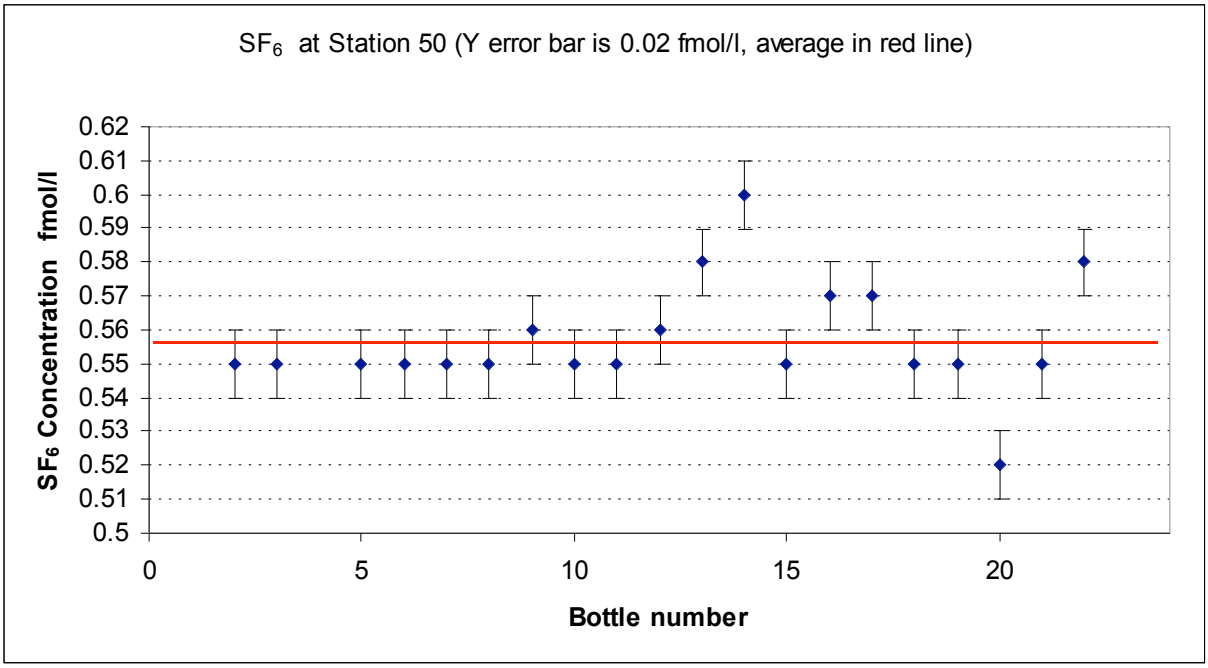
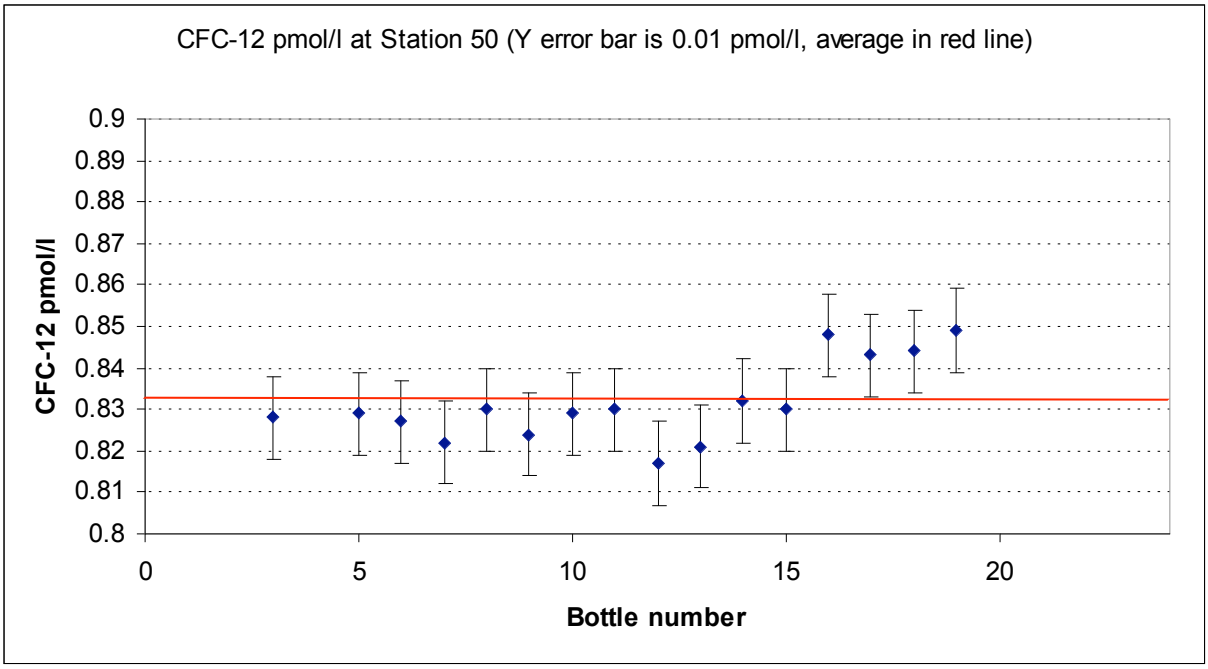
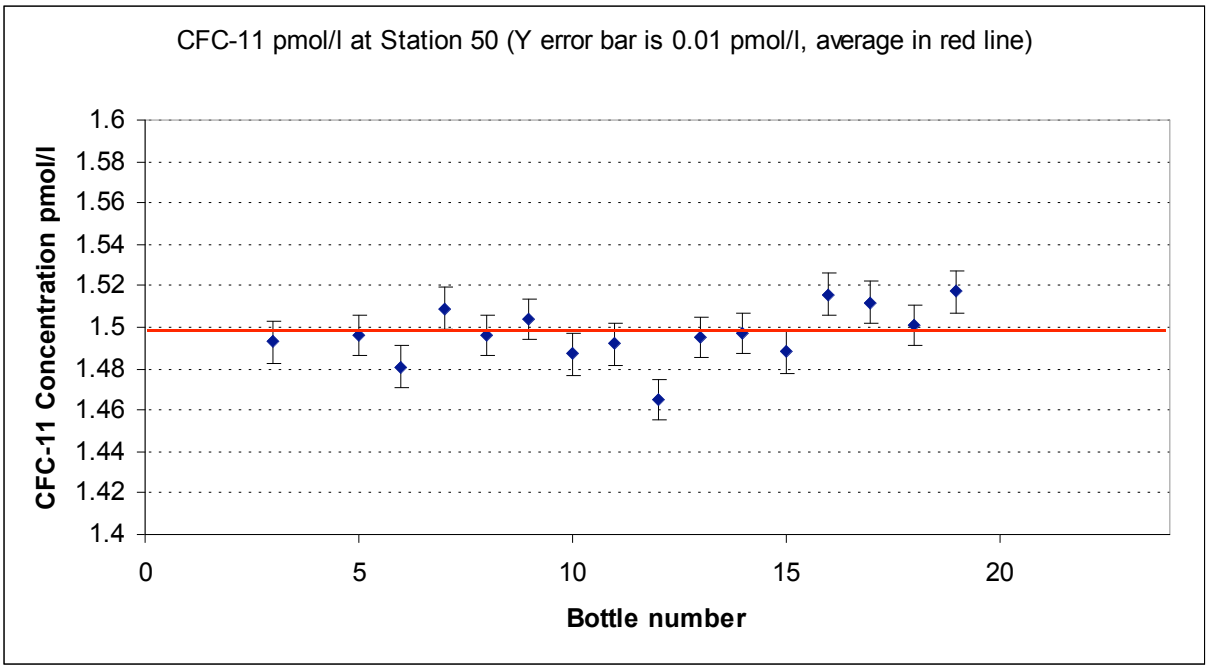


Figure 7.2: The temporal evolution of the CFC's ECD-response during the cruise for the 1.5 ml volume

at stations 112-114 in the Eastern Basin. The tracer levels found there were 0.01-0.02 pm/kg for CFC-11 and CFC-12 and below detection limit for SF_6. These levels were the lowest of the all cruise and they were use as the background bottle blank for all the bottles and the entire cruise. They could be an over-estimate and this needs to be studied in more detail.







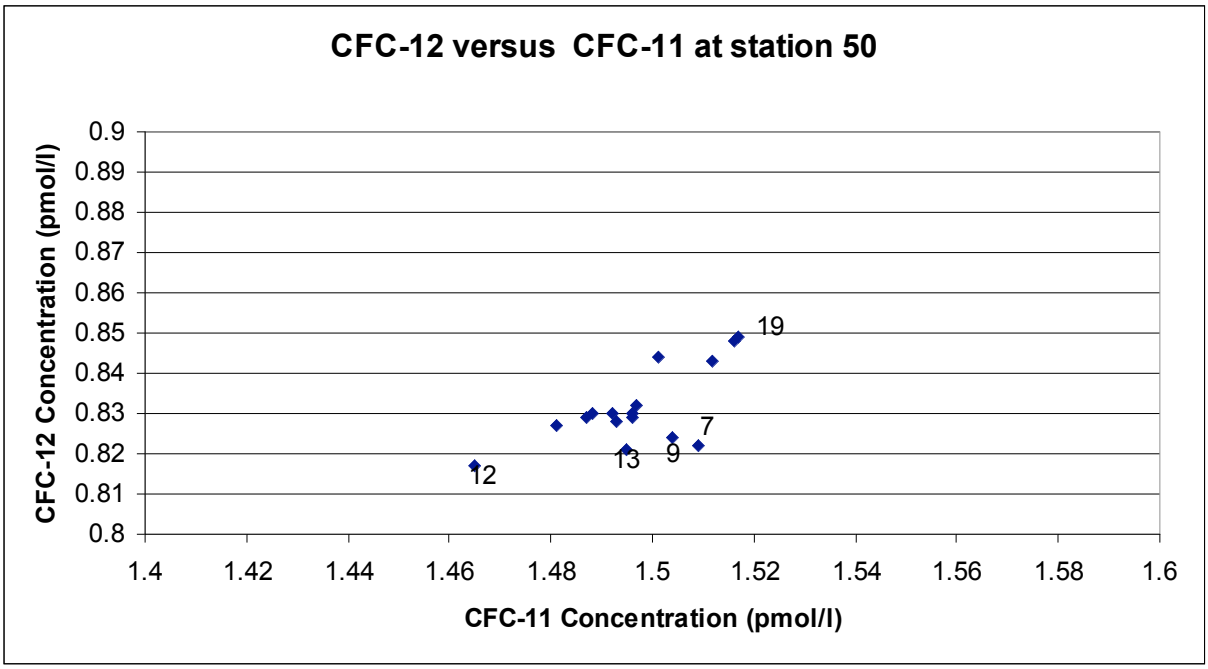


Figure 7.3: Relative bottle contamination for each Niskin estimated by stripping the entire rosette at a single depth at station 50 near the 900m tracers minimum.

Relative bottle contamination for each Niskin was estimated by stripping the entire rosette at a single depth at station 50 (Fig. 7.3) near the 900m CFC's minimum and by samples drawn from neighbouring Niskins closed at the same depth.

From station 76, the use of an old RS contact spray on the CTD cables lead to CFC's contamination of the nearby hydrographic bottles. It mostly affected the bottles

number 8 and 9 placed just above the cables, and in decreasing levels as we go further from the cables, the bottles 7-6 and 10-11. Due to this activity, several profiles (mostly Station-No. 76, 78, 80) were badly disturbed, primarily in CFC-113, then CFC-12 and CFC-11. By firing suspected contaminated bottles and uncontaminated bottles at the same depth, we tried to follow and estimate the contamination. It showed that after the incident, the contamination decreased slowly with the number of stations. Before station 87 the O'rings of the contaminated bottles were replaced however it did not erase the contamination problem.

7.4 Precision

The precision of the measurements was determined from duplicate samples drawn on the same Niskin. The average standard deviation for 43 pairs of duplicates was 0.006 fmol/kg for SF_6 and 0.004 pmol/kg for both CFC-11 and CFC-12.

7.5 Instruments interference

The radiowaves of the VHF used in the main lab to communicate with the deck appeared to affect the signal of the electron capture detectors. It resulted in negative peaks of the ECD baseline. This activity affected mostly the SF_6's ECD placed around 4 meters away from the CTD controls. Luckily, CFC's ECD was shielded behind the other GC. To avoid this interference we tried to time an elution of the SF_6 peak outside the time of use of the VHF. However 2% of the SF_6 data were lost due to this problem.

7.6 Performance

The setting up of the new SF6- CFC's system encountered several problems and the first reliable SF6- CFC's analysis could be carried out at CTD station 17. During the rest of the cruise, the system worked nearly continuously (2 stops of 48 hours where due to a failure of the liquid nitrogen generator and a stop of 24 hours to a failure of the CFC's system). In total, 1386 water samples were analysed on 82 CTD stations.

Marie-José Messias

Noam Bergman

8. Helium and Tritium

8.1 Introduction

In order to complement other transient tracer measurements along 36N it was decided to collect samples for the measurement of helium and tritium. Tritium is the common name for hydrogen-3 (^{3}H), which is a radioactive isotope of hydrogen. Tritium is a transient tracer that occurs naturally in the ocean in concentrations of *0.2-0.5 TU* (*one tritium unit (TU) equals 1 tritium (T) atom in 10^{18} hydrogen (H) atoms or 1 TU = $1*10^{-18}$(T/H)*), although much larger amounts entered the ocean during the bomb tests of the 1950s and 1960s. In order to improve the quantitative accuracy of tritium measurements they can be combined with simultaneous measurements of tritium's daughter product helium-3 that is only found in non-zero concentrations in the interior of the ocean. Thus a 'tracer age' can be determined which can be determined which is the equal to the length of time since the water was last at the surface (Jenkins and Clarke, 1976).

To make best use of available resources it was decided to sample intensively in the western boundary region and then one station every second or third day across the remainder of the section.

8.2 Method

Helium

Glass and plastic are permeable to helium so samples for helium analysis were collected in soft coil dehydrated copper pipe. Prior to arrival on station 70cm long pieces of copper pipe[2] were cut from a 20m coil and dented 14cm either side of the centre point. On station samples for helium analysis were drawn immediately after those drawn for CFC's and before those drawn for oxygen. Water was drawn from the

[2] Although initially cut to 70cm it was later found that by using 68cm of pipe it was possible to cut 29 pieces of copper from a 20m coil rather than 28.

Niskin bottles through a piece of tubing attached to the end of the pipe and then allowed to drain through a second piece of tubing attached to the top of the copper pipe. In order to fill the pipe smoothly, and to flush out bubbles, the pipe and tubing were initially held higher than the water level in the Niskin before being lowered slowly. Any remaining bubbles were removed by massaging the tubing and tapping pipe with a wooden bat. The tubing was then clamped approximately 10cm from either end of the copper pipe using metal clamps. Whilst holding the tubing onto the pipe the ends and middle of the copper pipe were crimped using a hydraulic pump effectively creating three cold welded ends and producing two 29.5cm samples. These were then re-rounded to create a partial vacuum before being wrapped in bubble wrap and stored for analysis ashore.

Tritium

One-litre bottles were used for the collection of samples for tritium analysis. These were prepared the previous December in Liverpool by baking them in an argon atmosphere after which the bottle lids were taped on to prevent loosening during travel.

Tritium was the last sample to be drawn from the Niskins and samples were taken from each bottle where a helium sample had been taken. Tubing was inserted into the mouth of the bottle and the bottles were filled to within a few centimetres of the top so that some of the argon atmosphere remained. The bottle lids were re-taped and the bottles packed for analysis ashore.

Each sample was labelled with the cruise number, the station number and the Niskin bottle number from which it was drawn. The two copper pipes were additionally labelled A and B for easy identification. One duplicate sample (1 bottle and 70cm copper pipe) was drawn at each station and these were labelled with successive letters of the alphabet.

Care was taken to ensure that nobody in the sampling region wore luminous dial watches, which contain tritium and are thus a severe contamination risk. However it

was noted that there was a tritiated emergency sign at one end of the wet lab, where copper preparation and bottle taping took place.

8.3 Samples

In total 19 stations were sampled for helium and tritium involving the collection of 234 complete samples (see Table 8.1 for details). Nine of these were 'deep' stations (the first sample being drawn from a depth of over 2000m). In the western boundary samples were taken every day and attempt was made to locate two in the Gulf Stream and one in the Deep Western Boundary Current. After station 30 stations were sampled every two-three days with the sampling taking place during the 20:00 – 00:00 or the 00:00 – 04:00 watch. 12 helium samples had to be discarded due to leaking copper pipes and tubing 'popping' off the end of the pipe and 5 tritium samples were not completed due to the Niskin running out of water. After station 6 all the samples were drawn by Susan Leadbetter who had been given about 2 hours training in March by Claire Postlethwaite. All physics watch keepers assisted with the cold welding and re-rounding of the pipes.

References

Jenkins, W.J., and W.B. Clarke, The distribution of ^{3}He in the western Atlantic Ocean, *Deep-Sea Res.,* **23***,* 481-494, 1976

Station	Latitude (N)	Longitude (W)	Depth of deepest Sample	Number of Complete Samples	Additional part samples	Comment
6	36 35.08	070 18.85	4044	14	3pip 4bot	Deep
10	37 11.13	071 26.02	4063	17		Deep
13	37 36.33	072 17.04	3405	15		Deep
21	35 29.80	074 01.30	3031	15		Deep
27	35 24.99	072 24.99	4324	17	1pip 1bot	Deep
30	35 49.91	070 48.02	4500	15	2pip 1bot	Deep
36	36 14.90	067 19.10	2031	12		
45	36 16.16	061 45.82	2019	12		
56	36 14.90	054 42.20	2029	11	1pip 1bot	
64	36 15.05	048 07.99	5512	16	1pip 1bot	Deep (W Atl.)
72	36 17.97	041 56.02	2014	12		
82	36 14.95	035 48.68	2797	10	8pip	MAR
95	36 14.08	027 50.11	2026	12		
106	36 14.90	022 21.16	2031	11		
111	36 15.51	019 17.04	5587	15	3pip 3bot	Deep (E Atl.)
119	35 59.77	014 58.00	2024	11	2pip	
125	35 48.56	011 11.60	2028	11	2pip	
133	36 28.34	008 44.28	1523	11	1pip 1bot	
141	34 35.10	007 49.50	2316	12		Med outflow
			TOTAL	234		

Table 8.1: List of Sampled Stations for Helium and Tritium

Key: pip refers to one 22cm length of copper pipe

bot refers to one 1l sample for tritium analysis

Susan Leadbetter

9. Organic Nutrients

Introduction

The North Atlantic Ocean consists of a double-gyre system, a sub-polar and a subtropical gyre, driven by wind forcing. Over the subtropical gyre it is unknown how the nutrient budgets of nitrogen (N), phosphorus (P) and carbon (C) are closed.

It has long been recognised that inorganic nutrients such as nitrate and phosphate are essential in maintaining primary production within the world's oceans, and are required by phytoplankton to build biomolecules such as proteins. Nitrogen and phosphorous also occur as dissolved "organic" species, often in higher concentrations than their inorganic counterparts. Dissolved organic nutrients comprise material ranging in size from simple monomeric molecules to complex macromolecules, and chemically from labile monomers, such as urea and amino acids to refractory macromolecules (Jackson and Williams, 1985). The nutritive properties of dissolved organic nitrogen (DON) and dissolved organic phosphorus (DOP) depend on the chemical composition of the pools. It is necessary to characterise the components of these pools in order to assess their importance in the nutrient budgets. Furthermore, to close these budgets the supply of nutrients must also be investigated. In common with N and P, the transport of dissolved organic carbon (DOC) might be important in closing the C budget over the North Atlantic.

Objectives

In order to help close the nutrient budgets, the concentrations of DON, DOP and DOC must be determined. To characterize part of the DON pool, samples will be analysed for amino acids, with the ratio of the D- and L- enantiomers examined. The sources of organic nutrients will be investigated through the use of stable nitrogen isotopes.

Sampling

Samples were collected for TON, TOC, TOP, DON, DOC, DOP, amino acids and Stand Alone Pump (SAP) filters at the following stations (Table 9.1).

Station	Date	Lat (°N)	Long (°W)	SAPs
Test Station	02/05/2005	34.4296	-66.4158	No
3	03/05/2005	36.1397	-69.0724	No
6	04/05/2005	36.3508	-70.1885	Yes
8	05/05/2005	36.5249	-70.5209	No
9	05/05/2005	37.0194	-71.0885	No
10	05/05/2005	37.1054	-71.2519	No
12	06/05/2005	37.269	-71.57	No
13	06/05/2005	37.3619	-72.1208	No
14	08/05/2005	36.0082	-74.4882	No
15	08/05/2005	35.597	-74.4776	No
17	08/05/2005	35.5704	-74.4451	No
20	08/05/2005	35.3837	-74.1608	No
21	09/05/2005	35.3152	-73.5649	Yes
24	09/05/2005	35.2324	-73.4372	No
25	10/05/2005	35.1016	-73.2677	No
27	10/05/2005	35.2547	-72.2252	No
29	11/05/2005	35.4213	-71.2002	No
30	11/05/2005	35.4997	-70.4795	No
32	12/05/2005	36.0783	-69.3977	No
33	12/05/2005	36.1619	-69.0605	No
36	13/05/2005	36.1537	-67.1922	Yes
39	14/05/2005	36.147	-65.278	No
42*	15/05/2005	36.1538	-63.3832	No
45	16/05/2005	36.166	-61.4752	Yes
47	17/05/2005	36.1448	-60.3181	No
52	18/05/2005	35.0051	-58.0488	No
54	19/05/2005	36.1241	-56.2645	No
56*	19/05/2005	36.1489	-54.4196	Yes
60	21/05/2005	36.388	-51.2607	No
64	22/05/2005	36.1498	-48.0792	Yes
66	23/05/2005	36.1498	-46.2802	No
68	24/05/2005	35.1538	-44.4975	No
72	25/05/2005	36.1798	-41.56	Yes
75	26/05/2005	36.1529	-40.0569	No
78*	27/05/2005	36.1458	-38.1635	No
82	28/05/2005	36.149	-35.4868	Yes
87	29/05/2005	36.147	-32.4539	No
90	30/05/2005	36.1467	-30.5623	No
95	31/05/2005	36.1405	-27.5012	Yes
98	01/06/2005	36.1519	-26.0191	No
102*	03/06/2005	36.15	-24.4909	No
106	04/06/2005	36.1501	-22.212	Yes
109	05/06/2005	36.1502	-20.3195	No
111	06/05/2005	36.1506	-19.1803	Yes
114	07/06/2005	36.149	-17.28	No
115	07/06/2005	35.1557	-16.5174	No
119	08/06/2005	35.5979	-14.5803	Yes
121	09/06/2005	35.4763	-13.5881	No
125	10/06/2005	35.486	-11.1161	Yes
127*	11/06/2005	35.5445	-9.4754	No
135*	12/06/2005	36.3839	-8.3972	No
141	13/06/2005	34.3493	-7.4924	Yes

Table 9.1: Stations sampled for organic nutrients.

**denotes stations where duplicate samples taken*

Methods

Dissolved and Total Organic Nutrients and Amino Acid Collection and Storage

Samples were collected directly from the CTD Niskin bottles into prepared 500ml wide mouthed Nalgene bottles, after rinsing 3 times with the sample water. Samples were filtered using an all glass single flask filtration unit and 47mm 0.7μm GF/F filters. These filters were retained for possible further analysis at the National Oceanographic Centre (NOC). The subsequent filtrate was transferred into a 60ml prepared polypropylene pot and placed in a -80°C freezer until analysis using a Skalar San^{Plus} autoanalyser at NOC. Samples for DOC and DON analysis were transferred into a muffled 20ml glass ampoule and fixed with 20μl of 50% HCl before flame sealing. These will also be analysed at the NOC using a High Temperature Oxidation (HTO) machine. Samples for TOP, TOC and TON were treated in the same manner with filtering excluded. TOP samples were stored in 60ml sterilin pots and TOC/TON samples stored fixed in flame sealed 5ml glass ampoules. Samples were taken from six to twelve depths at each station, with higher resolution in the surface waters.

Six to twelve amino acid samples from varying depths were collected at stations corresponding to those where SAPs were deployed. These samples were filtered in the same way as the organic nutrient samples and collected in 28ml muffled glass vials. Samples were then placed in a -80°C freezer. These will be transferred to the University of Liverpool for analysis by High Performance Liquid Chromatography (HPLC).

Stand Alone Pumps (SAPs)

SAPs were deployed at a frequency of approximately every third day throughout the cruise. Three SAPs were pumped for 2 hours at each station at depths of 50m, 100m, and 150m with the intention of being able to capture the chlorophyll maximum. Filter beds were loaded with muffled 293mm 0.7μm GF/F filters (c.f. Section 11 Instrumentation). Once recovered the filters were placed in muffled foil, and dipped in liquid nitrogen to enable pigment analysis. Samples were then placed in a -80°C freezer. Filters will be transferred to the University of Liverpool to investigate

nitrogen isotopes, pigments, and for C and N analysis. A total of 13 stations were sampled along the transect.

Results

No results are currently available, as water samples for organic nutrients will be stored until analysis at the NOC. Analyses of SAP filters collected and amino acid water samples will take place at the University of Liverpool. Data analysis will hopefully be completed within a year.

References

Jackson G. A. and Williams P. M. (1985) Importance of dissolved organic nitrogen and phosphorus to biological nutrient cycling. *Deep-Sea Research* **32**(2), 223-235.

Rhiannon Mather

10. Atmospheric Sampling

Introduction

Atmospheric sampling on CD171 was carried out for aerosols and gas phase ammonia along 36N between 1st May and 15th June 2005. Aerosols (particulates suspended in the atmosphere ranging in size from 0.1-100 μm diameter) were sampled using two high volume (1 m^3 min^{-1}) samplers. Gas phase ammonia was sampled using a low volume vacuum pump with filter packs. Rainwater was also collected at every opportunity to assess wet deposition.

Sampling Procedure

Two separate high volume samplers were used to sample aerosols: one sampler was loaded with paper substrates for major ion analysis of aerosols, the other loaded with quartz fibre substrates for analysis of organic carbon and nitrogen. In preparation for the cruise the quartz fibre filters were ashed in a muffler oven at 400°C for four hours to remove any organic substances that may have initially been on the filters, they were then packed in aluminium foil for transport and storage. Paper filters were taken straight form the manufacturers packaging.

Sampling of aerosols was done using slotted filers and backup filters with a six-stage cascade impactor. For normal sampling on CD171, only plates three and four of the cascade impactor were used. This was in order to split the size range of aerosol particles collected, with the > 1 μm fraction being collected on the slotted filters between the impactor plates and the < 1 μm fraction being collected on the backup filter. Filters were handled, loaded in to and removed from the cascade impactors whilst wearing gloves in a laminar flow hood situated in the ship's main laboratory to prevent dust contamination. They were sealed in zip-loc bags for transportation to the samplers (located on the wheelhouse roof).

The samplers were fitted with a chart recorder for recording flow rate and duration and also have an analogue count that counts as long as the motor is running. A new chart was fitted at the beginning of each 20-24 hour sampling period and the count

recorded, time, date and position were also noted. Recording the number on the analogue count was done so that if a motor failed, there was a record of how long the sampler was active for (this is also replicated on the chart recorder). The samplers were calibrated to give a flow rate of 1 m^3 min^{-1}, calibration was performed twice during the cruise, once at the start (31st April, day 120) and once half way through (24th May, day 144).

Ammonia sampling was performed using a low volume vacuum pump with filter-packs (Figure 10.1). Each filter-pack holds three filters and is fitted with a cyclone separator for separating out large particles. The filters used with the filter packs are 4.7 cm diameter, the first of the three filters is a 1 µm PTFE filter for the removal of large particles, the second an third filters are paper filters soaked in a 0.1M oxalic acid solution. The filters are soaked in the acid, loaded in to and unloaded from the filter-packs in a glove box, which is supplied with air filtered through an additional acid soaked filter in an attempt to eliminate contamination from background ammonia in the lab. The glove box was set up in the main laboratory and the filters were transported between the main lab and low volume system in sealed zip-loc bags.

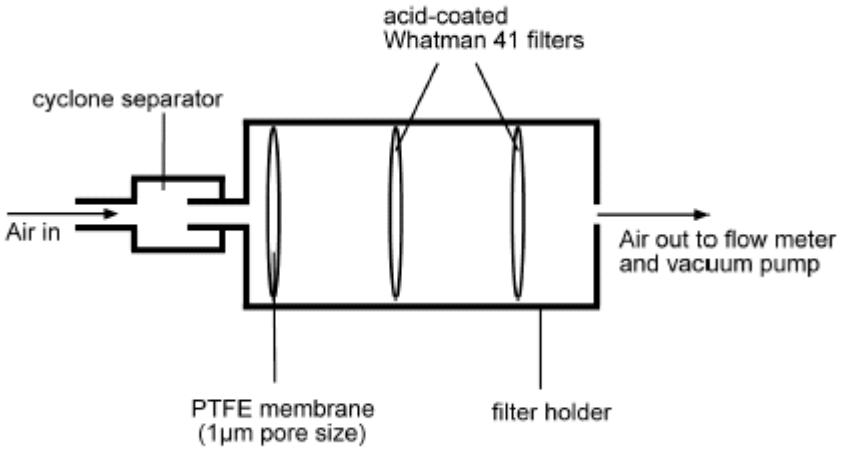


Fig 10.1. Filter-pack used for ammonia sampling

Initially an electrical flow meter was used with the ammonia system, however after three days this became clogged with the oxalic acid solution and was damaged beyond repair. It was replaced with a mechanical flow meter.

After sampling the paper aerosol filters were folded in two and sealed in zip-loc bags and the same procedure was applied to the quartz samples, which were re-wrapped in aluminium foil to prevent contamination from the organics in the bags. All the filters from the ammonia system were placed individually in 15ml centrifuge tubes and sealed in two zip-loc bags. All filters were stored frozen in a -20ºC chest freezer for later analysis at UEA.

Rainwater was simply collected using a funnel and frozen for analysis at UEA.

Equipment Set-up and Progress

Main Lab

Equipment used in the main lab was a glove box (supplied by UEA), a laminar flow cabinet (supplied by UKORS) and a fume cupboard (supplied by UKORS). The glove box and flow cabined were used as described above. The fume cupboard was used for making the oxalic acid solution from oxalic acid, methanol and glycerol. The fume cupboard was used once a week to make a new batch of acid solution. Also in the main lab there was a repeater monitor for the ship's surfmet system, which was useful for monitoring wind direction.

Monkey Island (Wheelhouse roof)

All the samplers were set up on the monkey island. They run of a 240V power supply and to be used were insulated to IP65 standard. They were plugged in inside the scientific plot and extension leads were lead through a duct on the wheelhouse roof. For this kind of work onboard *RRS Charles Darwin* it is necessary to bring sufficient extension lead to be able to plug in up to four electrical components up to 40m away from their power supply. The samplers are situated on the monkey island because this is the highest point of the ship and receives the cleanest air. If there was a relative following wind, the samplers were switched off to avoid contamination from the ship's funnel. One thing that was noted during the cruise is that the galley and bow thrust exhausts are both forward of the monkey island, the contamination effects of this are unknown at present. Access to the monkey island is by vertical ladder, on the orders of the ship's Master this meant the samplers could not be accessed in the dark and turning them off could only be done by pulling the plugs in the ship's plot.

Rainwater Sampling

Rainwater sampling was performed by lashing a length of drainpipe to the ship and securing a funnel and a sample bottle in it whenever it rained. Because of limited access to the monkey island and the difficulty of carrying a funnel up a ladder, two pieces of drainpipe were lashed behind the bridge wings, allowing for sampling on either side of the ship depending on the direction of the wind. The sample bottles and funnel were stored in the ship's plot so as to be close at hand. Using this setup there was still the potential for water to drip from the ship's superstructure in to the sample bottles. A list of rainwater samples taken can be seen in Table 10.1.

Sample	Julian Day	Time (GMT)	Latitude	Longitude
1	BLANK			
2	ABANDONED DUE TO LIGHT RAIN			
3	124	0505	36 25.48	69 57.21
4	124	1405	36 38.08	70 16.78
5	124	1932	36 44.52	70 09.34
6	126	1440	37 36.08	72 12.00
7	ABANDONED DUE TO BAD WEATHER			
8	140	0321	36 28.92	50 18.56
9	140	0331	36 28.92	50 18.56
10	140	0350	36 28.92	50 18.56

Table 10.1 Positions of Rainwater Samples Taken

Progress on CD171

Progress on CD171 was very satisfactory. In order to ensure clean air enters the samplers, sampling can only be carried out when the wind approaches the ship forward of the beam. When on station this was not generally a problem as the ship was hove-to head to wind at the vast majority of stations. Underway sampling was problematic for the first two weeks of the cruise as we experienced westerly winds. The situation improved over the last four and a half weeks of the cruise as we experienced southeasterly and northeasterly winds, providing a headwind all the time.

A total 34 days sampling of at least 19 hours were achieved over the cruise's 45 day duration. Duration and dates of these samples can be seen in below in Figure 10.2.

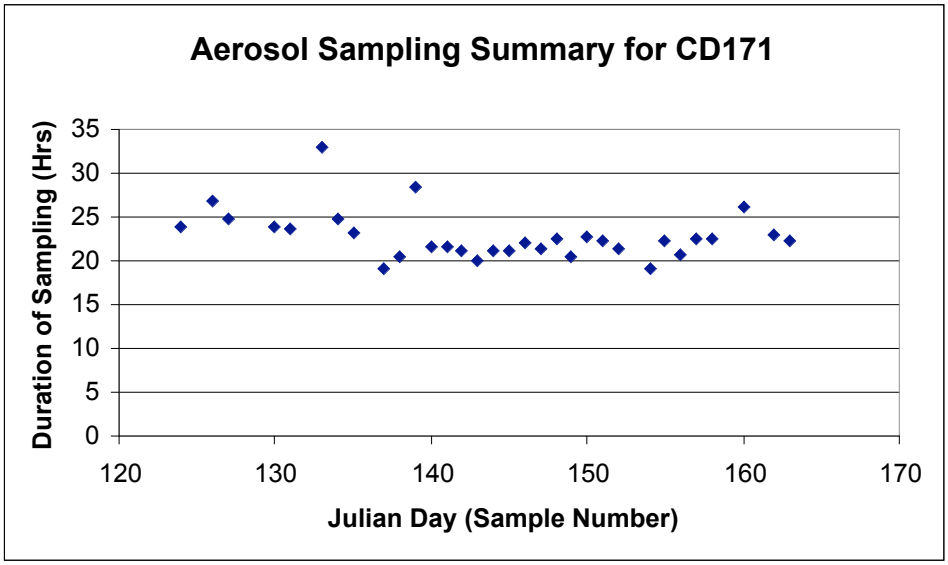


Fig10.2. Plot of days on which samples were collected and duration of sampling.

Tim Lesworth

11. Instrumentation

11.1Miscellaneous

11.1.1 Salinometer

Two Guildline Autosals, model 8400A, s/n 56747 (UKORS/NMEP) and one from JRD were used throughout the trip. A total of 2910 salinity samples were analysed. The salinometers were sited in a temperature-controlled lab, with an ambient temperature setting of approximately 20°C. Unfortunately the CT Laboratory controller was unable to fix the ambient temperature without leaving the door to the lab open, resulting in some variability to the air temperature. The cooling/exhaust fan on s/n 56747 failed during the cruise, and was replaced with a similar unit loaned from RSU. Spare fans were ordered for the following trip. Several minor repairs (tubing replacement, etc.) were carried out to the peristaltic pumps.

11.1.2 RO and Milli-Q water systems

OED system serial numbers 003 and 004 were installed in the wet lab prior to sailing, and were operated with minimal problems for the duration of the cruise. Two chlorine cleaning cycles were performed, and 4 pre-filters used. On JD125 the RO12 pre-treatment pack began to leak, and upon investigation it was discovered a pressure fitting had cracked. No replacement fitting was on board, thus a temporary repair was initiated by applying gasket sealant to the threads, which halted the leak. One-half of the installed RO pack was consumed and turned around for replacement, and one-half of a new pack was installed at the end of the trip.

11.1.3 Stand Alone Pumps

A total of 13 SAP casts were completed on the trip, consisting of the following configuration:

SAP s/n 002-02: pump time = 2 hours, typical depth 50 metres
SAP s/n 03-02: pump time = 2 hours, typical depth 100 metres
SAP s/n 03-03: pump time = 2 hours, typical depth 150 metres

Throughout the trip the individual SAP's were alternated at random to pump at the three different depths, in order to track specific pump performance. The SAP's were deployed from the starboard gantry, utilising the hydrowinch and wire. The Rexroth "tugger" winch was engaged for lifting the pumps on and off the wire. All pumps ran properly according to the pre-set timer and delay boards; volumes filtered were appropriate to the depths, filters and time operated, with the exception of a timer board failure (vibration caused the board to loosen) on s/n 002-02 for cast 056, and a pump operating failure for cast 064, cast 106 and cast 141. This specific SAP is operated by the newest version timer board, and requires that the timer delay has been properly begun prior to deploying.

11.1.4 Liquid Nitrogen Generator

Installed in the air gun annexe prior to sailing. The nitrogen generator supplied between 4 and 12 litres of liquid nitrogen per day as required, and functioned satisfactorily throughout the cruise, with two notable exceptions.

Firstly, about one week into the cruise, the nitrogen gas regulator was found to have been tampered with. The whole regulator body had been unscrewed, presumably in an attempt to adjust the locked regulator hand wheel. This caused the helium compressor to be running whilst there was no or insufficient nitrogen gas supply to the Dewar.

The regulator was re-assembled and correctly adjusted, but on re-starting the machine the liquid nitrogen level gauge was found to be no longer functioning. It is assumed that ice had formed in the level gauge tubes due to air entering the Dewar whilst the nitrogen gas supply was interrupted.

Due to the constant demand for liquid nitrogen it was not possible to allow the Dewar to warm up in order to clear the blockage in the level gauge. The liquid nitrogen level was monitored daily from this point, and the helium compressor started manually to produce liquid nitrogen as required.

In the second instance the burst disc, which protects the Dewar, was found to have failed. There were no obvious signs of over pressurisation due to incorrect nitrogen regulator adjustment, and the pressure relief valve was found to be in working order. The burst disc was removed, and replaced with a solid plug.

The above incidents resulted in the loss of liquid nitrogen supply for approximately twenty-four hours on each occasion.

On future cruises suitable spare flasks could be used to store excess liquid nitrogen production, thus allowing maintenance and repairs to be performed without interrupting the supply of liquid nitrogen to the scientists. It should be noted that the nitrogen generator can take two or three days to cool to working temperature when first started. An alternative supply to cover this start up period may be required on some cruises. A degree of "tamper proofing" to the compressed air and nitrogen regulators should be considered.

11.2. Fixed Equipment

11.2.1. Simrad EA-500

The echo sounder had no working problems; the HP colour printer was tested and operated normally during the cruise. Serviced a cooling fan in the deck unit. Spare fans ordered.

11.2.2 PES towed body

The "fish" was deployed from the beginning of the cruise, and operated successfully throughout. Three lengths of fairing were torn and replaced.

11.2.3. Chernikeeff EM Log

The EM Log was operated throughout the cruise with no apparent problems, after recalibration by B. King by applying calculated speeds from the VMADCP (see Section16.6).

11.2.4. VMADCP

VM-DAS was installed with the cruise specific parameters modified upon departure. The air breather pipe work is damaged at the through-hull installation, and the ball valve may be corroded internally. Air was bled from the system by opening the pipe coupling fitted to the top hat. Suggest pipe work be replaced with stainless steel fittings. The data quality was compromised by not being able to properly bleed air, moisture and debris from the system. Beam 3 failed during the cruise, and Beam 1 is weak. A separate report has been compiled regarding the Beam failures (see Section 16.2).

11.3 SurfMet

The SurfMet system was installed for this cruise in the following configuration:
TSG system:

housing temperature FSI OTM s/n 1361
remote temperature FSI OTM s/n 1370
housing conductivity sensor FSI OCM s/n 1358
flow-through 20cm transmissometer WetLabs/SeaTech s/n T-1019D
flow-through fluorometer WETLabs s/n WS3S-134

All the above sensors are calibrated with the exception of temperature and conductivity that have their calibration stored internally. Rhopoint DGH converters are used to give +/- 5 volts for the transmissometer and fluorometer data. The transmissometer and fluorometer were cleaned at weekly intervals throughout the cruise, with air and blank values recorded pre- and post-cleaning to monitor sensor drift.

Met system:

air temperature/relative humidity Vaisala HMP44L s/n S504004
barometric pressure Vaisala PTB100A s/n S3440009
port PAR sensor Didcot/ELE DRP-5 s/n 5143
starboard PAR sensor Didcot/ELE DRP-5 s/n 5144
port TIR (pyranometer) sensor Kipp & Zonen s/n 962276
starboard TIR (pyranometer) sensor Kipp & Zonen s/n 962301

anemometer Vaisala WAA s/n P22306
wind vane Vaisala WAV s/n R21213

The wind speed and direction are not calibrated; all other meteorological sensors have calibrations. The wind direction is oriented with 180 degrees on the bow; this is to ensure averages over the thirty-second period are not affected by fluctuations between 0 and 360 degrees whilst on station. Met system data is collected through a Vaisala QLI50 sensor collector. All SurfMet data is polled once every second; a thirty second average is then taken and sent to the OED shipboard data collection for application of calibration constants. In addition, salinity is calculated using the housing temperature and conductivity sensors, and calibrated throughout the cruise by salinity samples.

Sensor Changes:

The humidity sensor gave erratic readings and eventually failed. The sensor was investigated during the port-call in the Azores, and replaced with s/n S5040001.
The TSG conductivity sensor was changed on day 129 19:00, s/n 1358 was removed and s/n 1341 was fitted.

Jeff Benson
Bob Keogh
Dave Teare

12. Underway Salinity Samples

Sampling

Unless the ship was on station samples were taken every four hours, ship's time, from the ship's underway water supply. The supply was allowed to run for at least a whole minute before each sample was drawn in order to flush water through the system. The sample was then bottled as described in Section 3. The time and date at which each sample was taken was duly recorded.

TSG sensor

Initially the TSG conductivity sensor (serial number 1358) was calibrated by a constant offset, i.e. the instrument itself was calibrated. Although this calibration was found to be sufficient to begin with, on crossing the Gulf Stream we entered a regime of low conductivity surface water and the constant offset was found to be inadequate at this conductivity range.

As a result the sensor was replaced with serial number 1341 on Julian day 129 (9th May) at 19:13 ship's time. This sensor was, and remained throughout the cruise, uncalibrated. Details of the calibration applied to the data from this instrument are given below.

Processing

The pstar routines navexec0, navexec1, surexec0 and surexec1 were used to obtain the TSG data from the ship's surfmet data along with corresponding navigation data. These routines were executed daily. The pstar program plxyed was used to examine and then despike where necessary the conductivity record produced by surexec0 before salinity was calculated in surexec1 as this made calibration easier.

Since the conductivity sensor was uncalibrated it was necessary to run two versions of surexec1: one that left the data as it was and another that included a calibration determined after the second crate of 24 surface salinity samples had been analysed.

Calibration

Due to the temperature dependence of salinity, calibration of the TSG data against the bottle samples was done by comparing conductivity to the 'bottle conductivity'. This quantity is derived from the 1983 equation of state using the temperature of the TSG housing and the measured bottle salinity.

Firstly the conductivities were compared for the sensor that was replaced. Figure 12.1 shows the calibration curve for this sensor, along with the residuals. It was felt that in this case a linear fit, i.e. a slope adjustment and constant offset, were sufficient to fit the range of conductivities encountered.

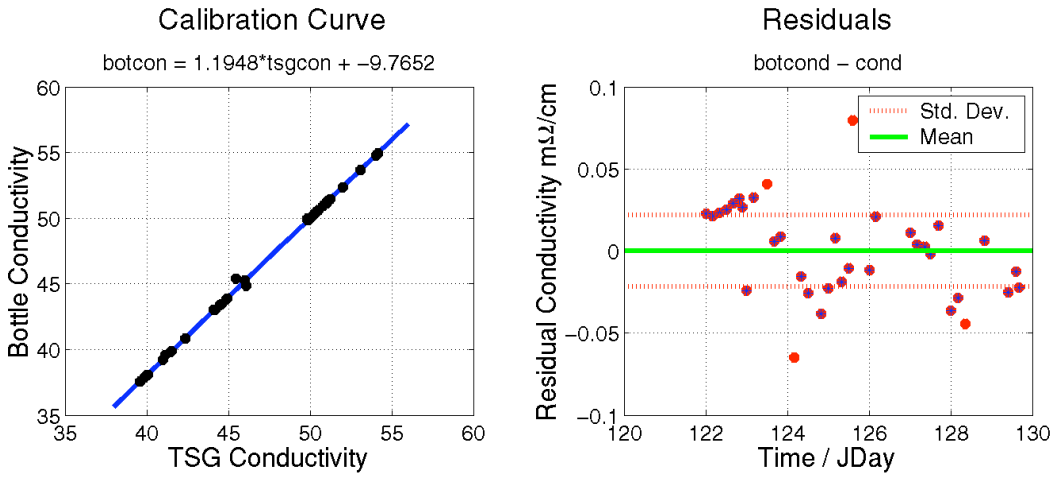


Figure 12.1: Calibration Curve and Residuals for Instrument 1358

Comparing conductivities for the data produced by the second sensor yields the calibration curve as shown in Figure 12.2. Although a fit was executed every time a crate of 24 samples was analysed, the fit obtained after the second crate was used. In the interests of calibrating the instrument for the future this seemed to fit the lower salinity water slightly better and it may be that over a wider range of salinities a parabolic fit would be better. For the purpose of this cruise we felt that applying the linear fit along with a slowly varying offset was fine as shown in Figure 12.2, along with the calibrated sea surface salinity and sea surface temperature time series.

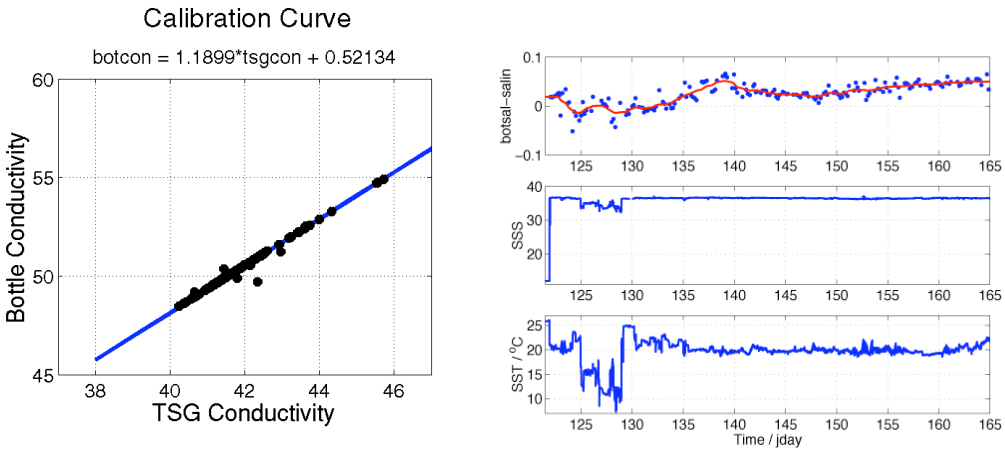


Figure 12.2: Calibration curve and residuals for instrument 1341. The residuals are shown in salinity space, with a line showing the slowly varying offset that was then applied. The plots blow this show the calibrated sea surface salinity (SSS) and sea surface temperature (SST)

Claire Powell

13. Bathymetry

Bathymetry data was collected from a simrad ea500 echo sounder and stored directly onto a paper printout. The signal was also digitized and stored on the Darwin 171 archive.

This data was processed and calibrated by Jeff Bicknell (Section 14). Although the paper record is very clear when examined by eye, the digitization process can sometimes misinterpret the data it receives. For this reason the calibrated data was plotted in four-hour sections using matlab from where it could be compared to the paper record. Any differences occurred when the ship was on station, due to the CTD interfering with the echo sounder. Since in principal the ship does not move when on station it was possible simply to eliminate these bad points from the digital record.

The completed set was then averaged into 5 and 2 minute bins using the matlab binavg routine. Navigation data, acquired when processing the TSG data (see Section 12), was then added to the averaged bathymetry data using the pstar routine pmerge.

Claire Powell

14. Computing

Data Logging

Data was collected via the ABC data logging computer system. The following data streams were collected during CD171

Data Grabber	Instrument	
GPS_4000	Trimble GPS 4000	MkII Level A
GPS_ASH	Ashtec ADU	MkII Level A
GPS_NMEA	Trimble GPS 4000	MkII Level A
GPS_G12	SeaStar G12 (DGPS)	MkII Level A
SURFMET	On board surfmet system	Direct to Level B
ADCP	150Khz ADCP	Direct to Level C
WINCH	CLAM system	Direct to Level B
LOG_CHF	Chernikeeff Log	MkII Level A
GYRONMEA	Ships Gyro	MkII Level A
EA500D1	Ships Echo sounder	MkII Level A

Level A

There was no real problems with the fitted Level As but when they were reset after a clock jump the gps_ash needed to have its input/output data path set to 4800 baud to ensure it continued to work the dates and times of these incidents were :-

Day 122 22:12:56 to 23:01:55

Day 129 17:31:12 to 18:43:42

Day 151 00:25:32 to 00:54:29

Level B

The Level B had no problems during the cruise and logged continuously the backup tapes had a problem when one of the tapes failed to be recognised after being formatted this was downloaded, erased and reformatted all worked well from then on.

ADCP

The 150 KHz ADCP was logged directly to the Level C workstation. It was also logged internally on the pc to enable records to be given for analysis by the scientists as required, the computer locked up on three occasions no apparent fault was noted but a suspicion of over heating was thought to be the probable cause. The day and time of these incidents is as :
Day 144 15:13:21 to 17:57:59
Day 148 15:25:29 to 16:14:39
Day 154 22:44:41 to Day 155 01:04:31

Processed Data Fields

The data files were processed during the cruise bestnav (using gps_4000, relmov), prodep is the processed bathymetry file which is produced from rawdep and using the carter tables for the relevant area of work produces a corrected depth for each input from the rawdep file. rawdep is produced by taking the raw echo-sounder data removing all duplicate times and then removing all transient spikes from the data using a program called rvsedit this then produces the rawdep file. relmov is used to calculate the ships relative motion taking inputs from the ships log and gyro these are then fed to the bestnav file to give ships position along with the gps _4000 data file

General Computing

Several computers were attached to the ships network during the cruise using the DHCP service on board. There was a problem with the network appearing to be slow this was traced to a cron program running on Darwin3ng after stopping the cron program the network speeded up considerably. The wireless network gave full coverage to the main Lab, with a limited signal quality to the accommodation and worked reasonably well only needing to be reset twice during the cruise

Email

The email system worked well all through the cruise

Jeff Bicknell

15. Lowered Acoustic Doppler Current Profiler (LADCP)

The ship departed from Bermuda with two WH300 ADCPs. The uplooking instrument failed on the first cast, and took no further part in the cruise. The opportunity was taken of the mid-cruise call in the Azores to pick up a replacement instrument. Unfortunately, this instrument had a weak beam, and so it did not provide any additional measurement capability, although data were acquired from it for stations 110 and following.

The remaining downlooking WH300 was used throughout the cruise, and performed as well as could be expected. Its performance was similar to that of the WH300 instruments on CD139 in the subtropical Indian Ocean: Reasonable data were acquired in the upper ocean and main thermocline, with significant reduction in quality below about 2000 metres depth. Fortunately this instrument maintained performance during the cruise, so that the unavailability of a second uplooking instrument did not compromise the cruise.

Configuration

The number of bins was set to 16, and reduced to 10 from station 110 onwards, since it was apparent that the distant bins were not acquiring any useful data. The bin size and pulse length was 10 metres for stations 1 to 65. This was increased to 16 metres for stations 66 onwards, in the hope that the increased power input to the water and increased averaging in each bin would improve the instrument performance in the poor scattering regions. This was thought to have been moderately successful, and the configuration was kept for the remainder of the cruise.

Data processing

The UH and LDEO software suites were configured. The UH suite was used as the primary source for water column profiles. The LDEO suite was used as the most convenient way to extract bottom-tracked ADCP data and package height-off-bottom data. The data processing paths were unchanged from recent cruises, e.g. CD139.

Brian King

16. Navigation and Vessel Mounted ADCP

An RDI vessel mounted Acoustic Doppler Current Profiler (VM-ADCP) was operated on RRS *Charles Darwin* throughout cruise 171 (see also Section 11). Data were logged continuously and compared with navigation data to provide absolute water velocities, ships velocities and heading.

16.1 Navigation

Data from three navigational instruments installed on *RRS Charles Darwin* were processed. The data were obtained from the Trimble 4000 GPS receiver (position), Ashtech XII 3DF GPS receiver (heading and attitude), and the Arma Brown MK10 Gyrocompass (heading). All instruments were logged to the RVS level A system before being transferred to the RVS level C system. The scripts used to process the navigation data are described in the section titled 'VM-ADCP and Navigation Processing Scripts'. The data were processed in 24 hours periods and corresponding files stored under the label of year day (jday).

The Trimble GPS receiver provided a continuous data stream throughout the duration of the cruise. There were no issues with data quality or gaps.

Heading

Heading is calculated from both the ships gyrocompass and the Ashtech GPS data. The most continuous information on ship's heading is available from the gyrocompass. It is used in both ADCP and meteorological data processing. The Ashtech data is used to correct the inherent error in the gyrocompass, oscillations which can continue for several minutes after a manoeuvre. The heading (and attitude) data can then be combined with the ADCP data stream to calculate absolute ship and water velocities.

The Ashtech GPS coverage was generally good throughout the cruise. Gaps in the data stream longer than one minute are listed in Table 16.1.

Time Gaps:	05 122 22:12:56	to	05 122 23:01:55	(48.98 minutes)
(yr,day, hh:mm:ss)	05 124 10:25:05	to	05 124 10:27:06	(2 minutes)
	05 129 17:31:12	to	05 129 18:43:42	(1.2 hours)
	05 135 17:09:01	to	05 135 17:10:41	(100 seconds)
	05 137 13:57:36	to	05 137 13:59:29	(113 seconds)
	05 151 00:25:32	to	05 151 00:54:29	(28.95 minutes)

Table 16.1: Gaps in the Ashtech GPS data logging stream. All times are in GMT.

16.2 VM-ADCP

The VM-ADCP is mounted in a recess within the ships hull. It is offset from the ships' fore/aft direction by 45°. This offset is corrected for during initial data processing stages (adpexec0). The 150kHz ADCP, RDI transducer serial number 302, was logged using IBM Data Acquisition Software (DAS) version 2.48, profiler software (firmware) version 17.10.

Data from the VM-ADCP was initially set to record in 64 x 8m bins, in ensembles of two minutes duration. On day 150 this was altered to 40 x 8m bins due to poor signal return. This alteration increased the data return from less than 60 pings per bin, over a two minute averaging interval, to greater than 80. No other parameters were altered besides changes between water and bottom track modes. The 'blank beyond transmit' was set to 8m, and the transducer depth (hull depth) to 5m. With a pulse length of 8m, this gives the centre of the first bin as 21m. These settings are documented in the water track and bottom track configuration files: cd171wat.cnf and cd171bot.cnf.

The ADCP data were logged continuously by the level C RVS computer. The data acquisition software was run on an IBM-type 300 MHz PC. From there, they were transferred in daily sections to pstar format and processed using the pstar scripts as described below. Logging was without major event although on several occasions data logging either crashed or was stopped. Gaps in the ADCP data stream longer than 5 minutes are listed in Table 16.2. Following identification of a problem with the number three transducer head a parallel RVS data-stream was started, collecting data relating to spectral width, raw amplitude and statistics for each beam.

The system was set to record in water track mode for the majority of the cruise. The exception is for a period of 2.2 hours when bottom track data were recorded whilst on the Western basin shelf (depth < 500m).

Time Gaps:	05 120 17:10:51	to	05 120 17:45:27	(34.5 minutes)
(yr,day, hh:mm:ss)	05 144 15:13:21	to	05 144 17:57:59	(2.75 hours)
	05 148 15:27:59	to	05 148 16:14:39	(40.7 minutes)
	05 150 09:11:27	to	05 150 09:32:35	(21.1 minutes)
	05 150 09:32:35	to	05 150 09:46:42	(14.1 minutes)
	05 152 20:16:29	to	05 152 21:04:05	(47.5 minutes)
	05 154 22:44:41	to	05 155 01:04:31	(2.3 hours)
	05 157 19:30:31	to	05 157 20:03:30	(33 minutes)
	05 159 10:35:29	to	05 159 10:52:59	(17.5 minutes)
	05 160 05:10:59	to	05 160 05:22:32	(11.5 minutes)

Table 16.2: Gaps in the VM-ADCP data stream. All times are in GMT.

Computer Crashes and Other Gaps

On a number of occasions the logging PC completely froze. Communications were restored only after rebooting the computer. It was hypothesised that this was due to overheating of the logging unit. This idea was refuted after the door to the cupboard was tied open and the computer continued to crash. We are no wiser as to why the computer crashing occurs. If this problem is experienced on future cruises the viability of the logging PC should be investigated. Gaps in the data stream were minimised onwards of day 159 due to a warning program written by Brian King. When gaps in the ADCP data stream exceed 240 seconds, as indicated by comparison of the data stream time-stamps from the ADCP and GPS_4000 data streams, a large message was posted to all computers connected to the main scientific unix hub-*SOHYDRO6*. This alerted attention and a rapid response ensued on each occasion. It is highly recommended that use of this program be continued on future cruises.

Depth of Penetration and Resulting Change in Bin Numbers

On day 150, it was noticed that the number of data exceeding the percentage good return threshold was virtually zero. This was causing large gaps in the data stream. It was suggested that the low return was due to a lack of scatterers in the water column. Inspection of data to that date showed that, excluding days 125-128, there was effectively zero return below bin 30. The solution to was to decrease the number of bins from 64 to 40. This increased the number of 'pings' to each bin, from less than 60 to more than 80, hence increasing the likelihood of a sufficiently good signal return. For inspection purposes, the display threshold was reduced to one percent. Consideration of the variation in scatter within calculated velocities versus percent good return suggested it would be unhelpful to reduce the 'percent good' quality threshold for data processing (in adpexec3, see processing scripts) without very careful consideration of the relative merits of increased data coverage versus a greater standard deviation in velocity measurements.

For the period where depth of penetration was greater than bin 40, days 125-128 corresponding to our time in the Gulf Stream region, the 64 row files were retained. It was reassuring to note that in one of the most complex dynamical regions sampled in the 36N section we have adequate underway data for resolving the ageostrophic velocity field.

On day 159, it was decided that it was not solely a lack of scatterers causing poor signal return. On-station data were good but between station profiles frequently contained no data above the percent good threshold. The ADCP vent pipe was bled on the afternoon of day 159 by Jeff Bicknell and a small amount of air released. The problem was further investigated by Bob Keogh on the morning of day 160. On this occasion a large amount of air was released and the ship's engineers given a brief tutorial on the workings of the bleed valves. It should be noted that bleeding was carried out as close to a last resort. The pipes should actually be bled at least once a week, preferably daily in rough weather. It was noticed that at some point in time the ADCP vent pipe had received some damaged. This was fixed by Bob Keogh who noted on removing the pipe that it was fully blocked by corrosion. The vent pipe is

now working as designed and regular venting should be carried out. The mechanical section of this report contains further information on this matter.

Unfortunately bleeding of vent pipes did not significantly improve data return during steaming periods. On day 161 electronic faults were pursued. The DAS self diagnosis tests were run and no faults were shown. Further investigation of the raw Doppler data showed that beam three was faulty. The nature of this fault is not known and further investigation is required once the ship is in port. In response to the faulty transducer head a three beam solution was adopted. Although this does not allow for calculation of error in velocity measurements it meant that consistent data were now available during steaming periods. Velocity profiles were consistent both within and between ensembles, above a depth of approximately 125m (bin 15).

Changes to the configuration file allowing a three beam solution were saved to the water track configuration file: cd171wat.cnf

Changes to the data recording to output raw Doppler data including spectral width, beam statistics and number of three beam solutions were saved in: c171rec.cnf

Issues with Data Quality

Having identified that beam three was faulty the ADCP data throughout the cruise were investigated. The 'pingdata***' files corresponding to each data ensemble were automatically logged to the PC hard drive but were not being grabbed by the RVS data stream. These files were still available and could be downloaded to floppy disk, at the end of the cruise all available 'pingdata' files were copied to Zip disk for further post-cruise investigation. It is apparent that beam 3 was faulty throughout the cruise. For days 120-129 when the ship was in relatively shallow shelf waters the data quality was not significantly affected. Onwards from day 130 the data becomes increasingly poor, this is most apparent during steaming periods when the ships speed is upwards of 10 knots. Beam one is also not functioning at full capability. This is a possible explanation for very high velocity shear in surface bins. The on-board processed data (i.e. the archived data set) should be treated with caution. Further

processing and investigation to be carried out post-cruise will provide further insight as to the level of confidence that can be had in the data.

The following report was left for any following parties sailing on *Charles Darwin* hoping to make use of the VM-ADCP data:

Notes on shipboard ADCP beam weakness

It was noted that ADCP data return had deteriorated to the point of returning almost no data while steaming between stations. Initially there was the possibility that this was caused by poor scattering conditions. As this explanation became increasingly improbable, various hardware explanations were explored. The sea chest was bled of air several times. Although some air was vented, and problems (blockages) with the air bleed system were identified and rectified, the data stream was not restored.

The DAS was reconfigured to permit 3-beam solutions, and the data return improved immediately. Various raw outputs were activated and grabbed into RVS file 'adcpraw', starting at approximately day 161, 1500 GMT.

Data were analysed for the period 161/1630 to 162/0215, which included an even split of station and steaming time, roughly 5 hours of each.

Analysis and interpretation of the raw data are as follows.

***Individual beam amplitudes (rawampl)*:** This parameter contains data for the last ping in each ensemble. All the station ensembles have been averaged to a single profile (approx 140 ensembles) and all the steaming data have likewise been averaged (also approx 140 ensembles). Beam 3 is consistently weak compared with the others. This beam was evidently to blame for the loss of data. Beam 1 is also weaker than beams 2 or 4, but apparently not fatally so. The Beam 3 signal strength is marginally better on station than while steaming at 10 knots. Evidently the station data are just above the threshold for returning 'good' pings, but 4-beam solutions in the days preceding 161 should be used with caution pending further investigation of

consistency with other estimates of currents. It is possible that biases will have crept in, even though the DAS determined the pings to be 'good'.

Percent good pings (rawgood): For each beam rawgood takes a single value for each 2-minute ensemble. As far as we can tell from the manual, this is the total percent good bins for all bins and all pings on a beam. It doesn't return statistics for each bindepth. Even though beam 1 is weaker than beams 2 and 4, it returns comparable percent good statistics. Beam 3 is clearly well below par. Beam 3 returns a reasonable number of good bins on station, so that DAS returns 4-beam profiles on station, and almost no good bins while steaming.

Raw spectral width (rawspecw): As with rawampl, this parameter also contains the raw data from the last ping in each ensemble. Although we don't know exactly how to interpret this parameter, we infer that this parameter is present if a bin doppler estimate was returned, and takes an absent value (-1) if not. Therefore the percentage of valid returns of this parameter is an approximate measure of the percent of good pings in each bin for each beam. On station, Beam 3 is valid for 50% of the time in bins down to 150 metres, while beams 1, 2 and 4 approach 100% in the same depth range. For steaming data, the data return from beam 3 drops below 20% at all depths, while the other beams decay with depth as expected, dropping to 25% at about 200 metres. The actual values of the spectral width do not show a dramatic contrast between beams. On station, Beam 3 is not distinguishable from the others. While steaming, the spectral width (when returned as valid) is clearly higher than for the other beams, indicative of a poorer signal-to-noise ratio.

Note concerning data logging: We note in passing that it is possible in DAS to save percent 3-beam solutions as one of the 40-bin ensemble parameters. This was activated at the same time as 3-beam solutions were allowed. However, we note that this is not a parameter available to be grabbed into the RVS adcp file. Therefore we believe this parameter will be saved in the pingdata files from day 161 onwards, and could be parsed from them after the cruise if there is sufficient interest. We can be sure that steaming data will be almost 100% 3-Beam solutions. Station data will be a mixture of 3- and 4-beam solutions.

Principal conclusions as at 12 June 2005

1) The shipboard ADCP is not functioning in 4-beam mode. Data from CD171 prior to the activation of 3-beam solutions on day 161 should be reviewed post cruise. Some periods early in the cruise are clearly good, later periods may be suspect.
2) The instrument needs to be investigated as soon as possible. It is possible that one or more beams have become obstructed, or there may be a more serious hardware fault. Beam 3 is definitely returning bad data. Beam 1 is performing less well than 2 and 4, but above the threshold for absent data.
3) The instrument should be operated with 3-beam solutions activated in DAS until the beam issue is resolved. We recommend the continued use of adcpraw as a diagnostic tool until the problems are resolved. We believe good data down to about 200 metres can be collected in this mode.

16.3 ADCP Calibration

Bottom Track Data

The misalignment angle, ϕ_{corr} between the fore/aft directions of the vessel mounted ADCP and the ship, ϕ_{corr}, is given by:

$$\phi_{corr} = \phi_{ship} - \phi_{ADCP}$$

where

$$\phi_{ship} = \tan^{-1}\left(\frac{v_n}{v_e}\right),\ \phi_{ADCP} = \tan^{-1}\left(\frac{v_{bot,\,n}}{v_{bot,\,e}}\right)$$

and ϕ_{ship} is the direction of motion of the ship, calculated from the north- and eastwards components of the ship's velocity, $V=(v_n, v_e)$, ϕ_{ADCP} is the observed direction of motion of the seabed, $V_{bot}=(v_n, v_e)$.

The speed correction is calculated from the ratio of the, known, vessel speed and the measured ADCP speed.

$$A = \frac{|V|}{|V_{bot}|}$$

From Bottom Track Data: $\phi = 3.5°$; A=1.0002

Post-calibration the remaining residuals are: $\phi = 0.1007° \pm 0.3293$, A=1.0000± 0.0056

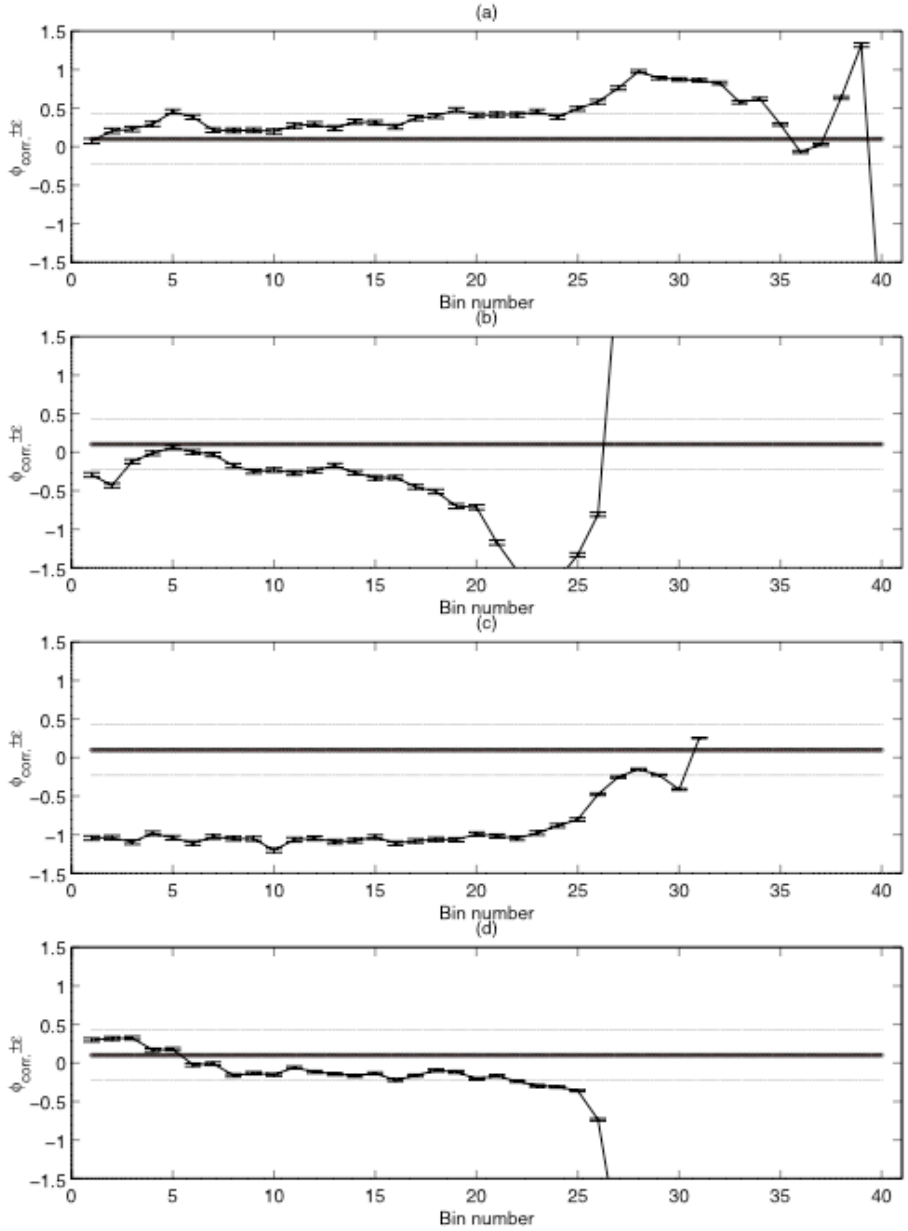


Figure 16.1: Angle of correction between ship's fore/aft direction and that of the VMADCP for days (a) 120-130 (b) 130-140 (c) 140-150 (d) 150-160.

Water Track Data

In addition to the standard calibration using any available bottom track data a comparison calibration was done using water track data. This was restricted to steaming periods where absolute water velocity will be small in comparison to the ships velocity. The angle of motion of the water is assumed random when considered over the period of the calibration.

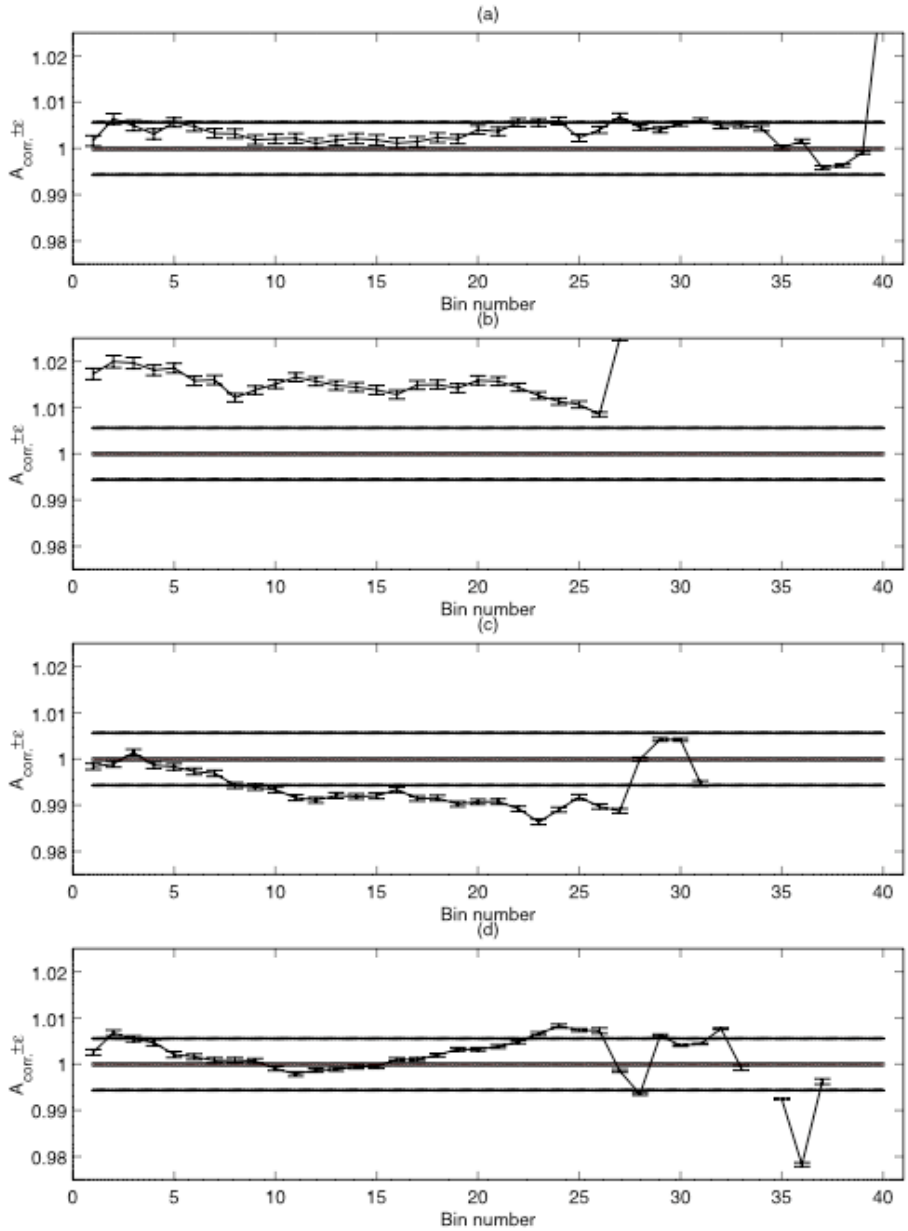


Figure 16.2: Speed correction factor for VMADCP speeds to true speed for days (a) 120-130 (b) 130-140 (c) 140-150 (d) 150-160.

The data were considered both for the entire cruise duration and in sections of 10 days. Smaller time periods were considered but the error on calibration coefficients increased greatly with reducing numbers of data points. Figures 16.1 and 16.2 show the ϕ and A corrections calculated for each bin. When restricting attention to the first 10 day period, while the ship was in relatively shallow western shelf water, the coefficients compare favourably with those for the bottom track data. A deterioration

in the comparison is seen in later periods. Whether this is accurate or a result of poor data quality will be further investigated post-cruise.

16.4 PHINS.

The PHINS fibre optic gyro system was available for trial use. In addition to the usual processing using heading information from the Ashtech GPS system a parallel directory was created and processing steps ashexec 2-4 (described below) were redone using PHINS headings. It is immediately obvious that the PHINS provided a higher resolution (every second as opposed to a 2 minute average), more complete and less noisy heading data set. Calibration was also carried out for the PHINS data and yielded values of: $\phi = 3.0°$, A= 1.0002
Post-calibration the residuals were: $\phi = -0.654° \pm 0.333$, A=1.0000±0.0056

16.5 On and Off Station Positions

The appended 'adpapp.abs' file was split into on and off station sections. The state of the ship was determined from the speed of the ship as determined from the ship velocities in the 'botapp.abs' file. A single averaged file was produced for each station and a 10 minute average for between station/steaming sections.

16.6 Chernikeeff E-M log calibration

Once a calibration for the shipboard ADCP had been established, data from the E-M log were compared with a near-surface bin (bin 3) of the ADCP. The E-M log was found to be displaying values that were high relative to the ADCP, with a positive offset at low speed.

The E-M log had been configured with data from a calibration carried out on CD160. Using the engine revs/E-M log speed from one leg of the CD160 calibration, a new calibration table was prepared, and entered into the E-M log unit in the plot at approx 1300 on 3 May (day 123). Instructions for this procedure are in Section 6 of the Chernikeeff operating manual.

The requirement is for a calibration table that maps E-M log transducer speed ‘a’ into true speed through the water ‘s’.

The calibration table was prepared as follows: First a correction was calculated that would bring E-M log speeds into agreement with the shipboard ADCP. If the speed in the RVS data file (which employed the CD160 calibration table up to day 123) is L, the best fit was S = 0.976 * L – 0.75

This gives the required conversion from the CD160 calibration to a CD171 calibration. The offset is consistent with the observation that the E-M log displayed 0.9 knots while alongside in Bermuda.

Next, a single straight line fit was obtained between transducer speed and true speed for the CD160 calibration. We preferred to use a straight line approximation so that imperfections or nonlinearities in the CD160 calibration table were not propagated into the next calibration. Thus s1 ~= 0.786 * a – 8

Thus the required entries in the calibration table are given by

s2 = 0.976 * (0.786 * a – 8) – 0.75

These values are listed in the table 16.3.

Revs	***Transducer speed ‘a’***	***CD160 true speed ‘s1’***	***CD171 true Speed ‘s2’***
25	180	131	55
50	533	383	326
75	836	686	558
100	1144	909	794
125	1452	1109	1031

Table 16.3 Required Calibration Values

On 12 May (day 132) the calibration was reviewed, with an analysis of all E-M log and ADCP data up to 132/0500. The agreement at high and low speeds was found to be good, with no systematic residuals. However, as the cruise progressed, it became apparent that the E-M log was displaying speeds lower than the true speed.

The calibration was again reviewed on 6 June (day 157). No systematic bias was discerned at low speeds, but there was a clear bias at higher speeds. Examination of the ratio of true (ADCP ship-over-water) speed to RVS-logged E-M log speed shows a drift begins at about day 135. At 6 June (157), the correction factor is 1.12 (median of all data over 8 knots from 155/0000 to 157/0955.

Accordingly a new calibration table was prepared, by scaling s3 = s2*1.12
The resulting values (shown in table 16.4) were entered into the deck unit at 158/0905 by Jeff Bicknell.

Revs	***Transducer speed 'a'***	***CD171 true speed 's3'***
25	180	62
50	533	365
75	836	625
100	1144	889
125	1452	1155

Table 16.4 Scaled Calibration Values

An assessment was made of the new calibration in the days following its application. On days 158 and 159, at speeds of about 8 knots the E-M log seemed to be displaying lower speeds than the ADCP. On days 160 and 161, at speeds of 10 knots, the E-M log agreed with the ADCP. On Day 161 it was noticed that beam 3 on the VMADCP was bad, and had been bad for a considerable time. The VMADCP was switched to 3-beam solutions at 161/1430. VMADCP data collected after this time will need to be reviewed post-cruise for possible post-cruise recalibration. Therefore the E-M log calibration in force at the end of cruise 171 should be considered uncertain at the 3 to 5 percent level. The E-M log data acquired during the cruise should not be used for scientific purposes, due to the time-varying drift of calibration.

16.7 VMADCP and Navigation Processing Scripts

Navigation and Vessel-Mounted ADCP (VMADCP) were processed in daily segments. Appended copies of the processed files were created. The processing scripts used are listed below. All execs are preceded by the '171' cruise identifier. The processing scripts are grouped under the single executables dailynav1 and dailynav2 dealing with the navigation and VMADCP processing steps respectively.

All scripts and file names are preceded by the cruise identifier: 171

dailynav1:

gpsexec0: read in navigation best from the RVS data stream "gps_nmea" to pstar format, calculate the ships velocity and then append onto the master cruise file.

Output: gps{jday}.raw, gps{jday}, gps01 (master).

gyroexec0: read in heading data from the RVS gyro data stream to pstar format, perform a nominal check on data control: unique times, monotonically increasing, headings between 0-360°. Append to master cruise file.

Output: gyr{jday}.raw, gyr01 (master).

ashexec0: read in data from the RVS data stream for the Ashtech XII 3DF GPS receiver. Perform preliminary quality control checks.

Output: ash{jday}.raw.

ashexec1: merge the ashtech data (from ashexec0) with the heading data (from gyroexec0), calculate the difference in headings , ashtech-gyro (a-ghdg).

Output: ash{jday}.mrg

ashexec2: edit the merged ashtech file using the following criteria:

heading	0 < hdg <360°
pitch	-5 < pitch < 5°
roll	-7 < roll < 7°
attitude flag	-0.5 < attf < 0.5
measurement RMS error	0.00001< mrms < 0.01
baseline RMS error	0.00001< brms < 0.1
ashtech-gyro heading	-10 < a-ghdg < 10 °

The data were then averaged to 2 minutes and further edited on pitch. The constraint of the pick was altered during the cruise. Days 119-150 were picked on pitch with 0.5° of the daily mean pitch. This was resulting in large gaps in the data stream (filled by linear interpolation in ashedit.exec). For days 141-145 the pick was increased to within 1.5° of the daily mean pitch. This improved the data coverage but resulted in a very noisy data stream requiring significant user input in the following datapick (ashedit.exec). As a compromise the pick was reduced to within 1° of the daily mean value. This improved the representation of the data and required minimal user input on the data pick.

Output: ash{jday}.edit, ash{jday}.ave

ashedit.exec: any remaining spikes in a-ghdg were manually picked out (plxyed), the data were linearly interpolated between missing values to create a smooth data stream and appended to a master file for merging with ADCP data in adpexec2 (see later).

Output: ash{jday}ave.dspk, ash01.int (master file).

dailynav2:

adpexec0: read in from the RVS level C "adcp" data stream into pstar. The data were split into gridded depth dependent data, placed into "adp" files, and "non-gridded" depth independent data were placed in to "bot" files. Velocities were scaled to cm s^{-1}, the amplitude by 0.43 to db, and the time stamp moved to the centre of each bin. The depth of each bin was determined from user supplied data, delta, the offset of the bin centre.

Delta = Hull depth + Blank after transmit + bin length = 5 + 8 + 8.

On day 150 a change was made to the number of bins. Further explanation of this is made below. This routine required updating to account for the change from 64 bins to 40bins.

Output: adp{jday}d, bot{jday}d

adpexec1: data can be corrected for any drift in the logging PC clock with respect to the RVS data-stream timestamp. With the PC interfaced to GPS the Userexit program four (UE4) is able to correct the PC time using the GPS time. This eliminates the need for clock correction but the step is

retained, with a zero clock correction throughout, so that compatibility of the processing software with other ship's platforms is maintained.

Output: adp{jday}d.corr, bot{jday}d.corr, clock{jday}

adpexec2: the adcp data were merged with the master ashtech navigation data: **adp{jday}d.corr** with **ash01.int**

The east/north adcp velocities were converted to speed and direction, the heading error (a-ghdg) was added to the direction, and velocities converted back to east/north.

Output: adp{jday}d.true, bot{jday}d.true

This processing step forward were carried out in a parallel directory (adp_p) using data from the IXSEA PHINS inertial navigation system.

adpexec3: the data were calibrated for any offset between the adcp unit and the forward axis of the ship. The additional intended offset of 45° is dealt with during the preliminary processing. More details of the VM-ADCP are below. The applied values for the correction angle, ϕ_{corr}, and speed factor, A, are:

ASH: ϕ_{corr}**= 3.5°, A= 1.0002**

PHINS: ϕ_{corr} **= 3.0°, A= 1.0002**

The data were then edited on a threshold percent good of signal return, 25% by default, and velocities for returns below this threshold set to the absent data value.

Output: adp{jday}d.cal, bot{jday}d.cal

adpexec4: the data are merged with the "bestnav" navigation file, gps01. The velocity of the ship is calculated and from this absolute water velocities are calculated.

Output: adp{jday}d.abs, bot{jday}d.abs

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17. Fibre Optic Gyros (FOG's)

The ships heading was measured using four separate instruments, the ship's mechanical gyrocompass, the Ashtech GPS ADU, and two fibre-optic gyro compasses (FOG's), the Octans and the Phins.

17.1 Benchtop evaluation of PHINS and OCTANS FOG's

FOG's

Fibre-optic gyrocompasses use interferometry to determine the difference in phase of two light beams travelling in opposite directions around a fibre-optic coil in order to deduce the speed of rotation through inertial space at the location of the instrument. Thus if the latitude and speed of the vessel are also known the heading can be determined. Two fibre-optic gyrocompasses were employed on CD171. These were attached to the bench on the port side of the plot and orientated in line with the ships own axes. Later in the cruise, the Octans was relocated on the CTD frame, for investigation of the performance of ADCP magnetic compasses. There follows a brief report of the Octans and PHINS performance. A more comprehensive study was undertaken ashore post cruise, the results of which are published in an NOC research report (Prytherch and King, 2006).

Octans FOG

The Octans FOG is contained in a watertight housing capable of being lowered to the ocean floor on the CTD. It was used in initially in the plot but transferred to the CTD for stations 69 to 113. Whilst in the plot lever arm distances were entered in order to compensate for the difference in movement experienced on the bench to that experienced at the GPS antenna (x_1 = 0.0m, x_2 = -5.0m, x_3 = 9.5m). Between the 29th April and 21st May GPS speed and heading information was supplied to the repeater through a serial port. However this led to significant wanderings in the heading lasting for an average of 20mins and occurring three or more times in any 24hour period. Following consultation with the manufacturer IXSEA this serial port feed was removed at 02:30 on 21st May. The problem was that the interface from the Octans to external GPS input was in some sense not robust. It transpired that this was a known

problem prior to the cruise. Once the GPS serial input has been disabled, the regular and substantial Octans heading errors were removed, but it was now necessary to enter speed and direction manually. Since this could not be maintained throughout the cruise, the data acquired during the cruise does not enable an effective evaluation of the performance potential of the Octans.

In order to enable data acquisition from the Octans during the underwater test phase, a data logger (in a separate pressure case) had been prepared at NOC by Jon Cambell and Andy Harris. Octans data messages were stored in the logger in the form of NMEA messages ($HEHDT, $PTHRO). In addition to data logging, the pressure case performed the functions of power management and a communications breakout box. The logger provided a time stamp and was synchronised to GPS time by daily inputs of GPS data. Although most clock adjustments were small (less than 1s) some larger adjustments occurred after the logger had been rebooted. Octans output was set at a frequency of 2Hz and stored in hourly data files (of size approximately 1270KB). The logger had the capacity to store 340 hours of data after which it was necessary to clear its memory. Files from the logger were downloaded daily via a network cable. It was noted however that some of the downloaded data files had missing lines (e.g. time but no heading) or incorrectly formatted lines. This corruption occurred most frequently when files were being downloaded from the logger to the PC.

PHINS

The second FOG Phins operated in a similar manner to the Octans, but contained a larger fibre-optic coil and was suitable for shipboard work only. During the whole cruise GPS speed and latitude were supplied via serial port A to the machine, and time was also configured to be synchronised with the GPS. Whilst still in port and before a GPS input was added, the Phins latitude, speed and therefore heading drifted after setup. Once the GPS input was connected it was necessary to set the GPS configuration to 'Not Active, Always True' in order that the Phins' Kalman filter would not reject the GPS input. This was not changed after the start of the cruise.

Data from the Phins were logged directly on to a PC via a USB cable. This data included time, heading, pitch and roll information and was output at a rate of 1Hz and

stored in hourly files. These files were tab delimited text files containing approximately 360KB each. PHINS data logging was controlled by manufacturer supplied software.

Data Download and Processing

Data from both the Octans and the Phins was downloaded to Unix on an approximately daily basis. The Octans data was first filtered using oct_pro1.exec to retain only time, heading, roll and pitch information and then read into Matlab using oct_pro2.m. It was necessary to build subroutines to check the format of each of these input lines and also reject incomplete sets of lines. The Phins data was read into Matlab using phins_pro.m. Although there were fewer problems with the Phins data files an error line appeared in the files almost every 24hours at 12:29:35 UTC.

Adding or subtracting 360 to the heading removed jumps of 360 degrees every time the heading passed through 360 to 0 or 0 to 360 which removed errors when merging the data sets onto the common time base. The data sets were then linearly interpolated onto an integer second time series. Both these tasks were done in the program threesixty.m. Finally the differences of the two data sets were compared and the difference averaged on a two-minute time step in cfoctphins.m.

The Phins and Octans data sets were then compared to the Ashtech and Gyro data sets which were also linearly interpolated onto the same time base.

The preliminary analyses carried out during CD171 revealed the problems with the Octans, and also suggested that the PHINS was performing at least as well as the Ashtech GPS ADU that had previously been considered to be the best available source of shipboard heading.

17.2 Underwater deployment of OCTANS

Octans deployments on the CTD package

After investigation of the performance of the Octans on the bench, the second phase of the Fibre-Optic Gyro experiment was deployment of the Octans on the CTD frame.

This was to enable evaluation of the heading-pitch-roll sensors of the WH300 ADCP, using the Octans as a reference. An evaluation was made of the sensors on WH300 s/n 5414.

The ADCP is fitted with a magnetic compass, so the reported headings are subject to instrument measurement errors (failure to measure the local magnetic field correctly) and what we refer to as frame-induced errors: distortion of the large-scale Earth's magnetic field by the package so that the local magnetic field observed by the WH300 has a bias compared with the geomagnetic model used to adjust the heading data in post-processing. The frame-induced error can be a combination of two types: magnetic field sources on the package, and distortion of the large-scale field by metal in the package. Both the instrument and the frame errors are expected to vary with heading of the package.

Underwater configuration

The Octans was deployed on the CTD package on station 69. The underwater rig consisted of the Octans, the logger/junction box, and a battery pack. The data logging arrangement was equivalent to the bench setup, except that power was supplied by a battery pack instead of the bench power supply. The Octans was mounted centrally in the frame, between the downlooking WH300 and the CTD, at the same level as the CTD. The forwards direction of the Octans was pointing towards the CTD. The forwards direction of the WH300 (beam 3) had also been aligned in this direction by eye before the start of the cruise. Initially therefore we expected the Octans and WH300 headings to agree, with a possible small mean offset.

The junction/logger box was mounted below the Octans and at right angles to it. The junction box connectors were to the left of the Octans when looking in the Octans forward direction. The battery pack in use was a spare battery pack for the WH300 LADCP system. It occupied a slot to the right of the Octans, above the CTD break-out-box. It was therefore near the fin, and on the opposite side of the frame to the battery pack supplying power to the LADCPs. The trailing lead from the junction box to the battery pack had a connector incompatible with the 2-pin bulkhead connector fitted as standard to the battery pack. A compatible bulkhead connector for the battery

pack was brought with the Octans rig, and had been fitted to the battery pack after leaving Bermuda. The original bulkhead connector was refitted to the battery pack after the rig was taken off the frame, and the spare connector returned to NOC with the set of junction box blanks/connectors.

There was a choice of two leads to connect the Octans to the junction box. These 10-way leads have limited flexibility and had been made with different geometry. One was made up with the lead in-line with the connector, and the other had the lead at right angles. The right-angle lead was more convenient, because there was limited space between the Octans and the CTD.

The battery pack was removed from the frame for stations 79 to 81. There was a problem with noisy CTD data on the fin sensors and all possibilities of disruption to the water flow were being considered. The Octans and junction box remained on the frame, with the power socket on the junction box blanked off. The CTD data problem was resolved elsewhere, and the battery pack refitted for station 82.

Communication and power on deck were via a trailing lead from a laptop on the starboard-side bench. This was equivalent to the shorter lead used for bench tests, and provided power/battery charging, RS232 and ethernet comms to the logger, and RS232 configuration/comms for the Octans. The deck lead split into two 6-way tails, one of each gender. A trailing lead from the junction box also split into two corresponding tails, which were brought to the edge of the frame adjacent to the ADCP tails. The deck lead was connected after each station to recharge the battery. Data were downloaded once per day, on the 00-08 watch. Energy consumption (nominally 12W at 24V) was comfortably within the battery pack capacity.

Problems encountered

Good data were obtained up to station 113. After that, communication with the Octans was lost. Logger files were empty, and communication on deck using the Octans Repeater software on the laptop produced no data. The logger was rebooted several times, and seemed to be working correctly. Power cycling (disconnect and reconnect the battery pack) failed to cure the problem. Since there was no blank for the

bulkhead connector on the Octans, and no means of powering it or communicating other than via the junction box, it wasn't considered possible to investigate the problem with the instruments on the frame. The entire rig was removed after station 115 and investigated on the bench. It was immediately found that the system worked perfectly when using the alternate blue lead from junction box to Octans. The problem in the lead with the right-angle connector was that the power ground pin no longer provided a connection. The other 9 pins seemed to be OK. We were unable to establish in which part of the cable the problem lay.

We note that the cable fault occurred soon after a series of deep stations over 5000 db (5163, 5537, 5589, 5629, 4835 decibars for stations 109 to 113). The Octans had been added to the frame after completion of deep stations in the western basin, so these were the first stations over 5000 metres after crossing the Mid Atlantic Ridge. We also note that some difficulty had been experienced in arranging for the Octans leads to be made up. When used on ISIS, oil-filled pressure-balanced leads are used to connect to the DG O'Brien connector on the Octans. The risk of seepage of oil into the CTD or onto the Niskin bottles meant that an alternative had been sought. Our initial conclusion, pending investigation of the failed lead, is that the mouldings used would not be sufficiently reliable for regular deep use. Therefore if an Octans was to be routinely integrated into a CTD frame, an alternate solution is required. This may require the manufacturer to provide a different bulkhead connector on the Octans. There were no evident problems with the 10- and 12-way connectors on the junction box.

Data and analysis of WH compass errors

Data were logged continuously on the underwater logger. In addition, several segments of data were logged to the laptop while the package was on deck using the Octans Repeater software, so that they could be supplied in manufacturer's format if required.

The report from CD139 gives an analysis of how to separate frame error from instrument measurement error. On any station, the difference is found between reference heading (in this case the Octans) and the ADCP heading. Over a collection

of stations, typically 6 to 10, the random rotation of the package is sufficient to ensure that all parts of the azimuth are explored, so that a complete description is available of heading difference as a function of heading. Once this heading difference has been established, the ADCP is rotated in the frame a new heading difference is established. Assuming the frame error does not change as a result of rotating the ADCP, the 'difference of differences' results entirely from the instrument error. A set of equations describing the calculation of instrument error from successive rotations of the ADCP was given in the CD139 report (Bryden *et al.* 2003). Unfortunately the equations are garbled in the published version, so the theory is reproduced below.

Theory for derivation of WH compass errors from CD139

The following is a reproduction of the theory for estimating WH LADCP magnetic compass errors, as set out in the CD139 cruise report. The published hardcopy of the text from that report had a number of places where equations were garbled, mainly missing minus signs.

The text assumes two WH instruments, each with a magnetic compass. On CD171 there was one WH instrument, and an Octans Fibre-Optic Gyrocompass. The FOG takes the place of the 'uplooker' WH instrument.

We reproduce here the text as it should have appeared on pages 89ff. of the CD139 report (Bryden *et al.* 2003).

Dual Workhorse related compass errors

An investigation was carried out into the magnetic compass errors of the WHs. The motivation is that the heading related and relative compass errors of the two instruments play a large part in resulting velocity profile errors.

From the analysis that follows, we expected to be able to determine the instruments' compass errors. Unfortunately, the results are puzzling, as will be described. The experiment consisted of comparing differences of reported heading between two instruments, with the instruments being rotated in their clamps between casts.

The instrument headings returned by the compasses are subject to errors from two sources. First, distortion of the local magnetic field by the CTD frame and possibly by the instrument itself, and second, instrumental error whereby it fails to measure the local field perfectly. Let the local field error, presumed to be caused chiefly by the influence of the frame, be denoted by F. Let the instrument error be I and the measured heading be H. Then at some instant, the true heading T of the underwater package (e.g. the direction in which the fin was pointing) is given by

$$T = H + O + F + I \qquad (17.1)$$

where O is the offset between beam 3 of the instrument and the nominal true package heading. The sense of F and I is that they are corrections that must be applied. All elements of (17.1) are dependent on time *t*, except for O. We assume that F is a function of T. That is to say, whenever the package points in the same direction, F has the same value. We also assume that I is a function of H: whenever the instrument measures a heading of say 90°, it will be subject to a reproducible error. Thus in full

$$T(t) = H(t) + O + F(H(t)) + I(H(t)) \qquad (17.2)$$

Now (17.2) applies for both uplooker (subscript 1) and downlooker (subscript 2) instruments,

$$T = H_1 + O_1 + F_1(T) + I_1(H_1)$$

$$T = H_2 + O_2 + F_2(T) + I_2(H_2)$$

Taking the difference of the two equations, and noting that the true package heading is the same for both instruments, gives

$$H_1 - H_2 = O_2 - O_1 + F_2 - F_1 + I_2 - I_1 \qquad (17.3)$$

Suppose that $H_1 - H_2$ has been measured for a complete range of headings, with instrument positions we will denote by subscript A. (Note on many casts, the package completes one or more complete rotations, but on some casts this was not the case.) Thus, $H_1 - H_2$ is considered to be known as a function of T. Now suppose that one of the instruments is rotated on the frame, and the new geometry is denoted by B. To preserve generality, we will suppose that each instrument is rotated by an amount δ counterclockwise viewed from above. Of course, for any adjustment we chose to keep either δ_1 or δ_2 as zero, rotating just one instrument. Thus, on cast A

$$T = H_1 + O_{1A} + F_1(T) + I_1(H_1),$$

and on cast B

$$T = H_1 + O_{1B} + F_1(T) + I_1(H_1),$$

where $O_{1B} = O_{1A} + \delta_1$ and similarly $O_{2B} = O_{2A} + \delta_2$.

Consider (17.3) for two casts before and after a rotation. At some true package heading (estimated from the uplooker, for instance, by assuming that F and I are small),

$H_{1A} - H_{2A} = O_{2A} - O_{1A} + F_{2A}(T) - F_{1A}(T) + I_{2A}(H_{2A}) - I_{1A}(H_{1A})$

$H_{1B} - H_{2B} = O_{2B} - O_{1B} + F_{2B}(T) - F_{1B}(T) + I_{2B}(H_{2B}) - I_{1B}(H_{1B})$

Subtract these two equations to discover the change in $H_1 - H_2$. Assuming that the error terms are small, we can write, for example $H \sim T - O$, so $I(H) \sim I(T - O)$,

$(H_{1B} - H_{2B}) - (H_{1A} - H_{2A}) =$

$+\{(O_{2B} - O_{2A}) - (O_{1B} - O_{1A})\}$

$+\{(F_{2B}(T) - F_{2A}(T)) - (F_{1B}(T) - F_{1A}(T))\}$

$+\{I_{2B}(T - O_{2B}) - I_{2A}(T - O_{2A})\}$

$-\{I_{1B}(T - O_{1B}) - I_{1A}(T - O_{1A})\}.$

Now assume $F_{1B}(T) = F_{1A}(T)$ and $F_{2B}(T) = F_{2A}(T)$, i.e. the frame induced error is assumed to be unchanged by rotation of the instrument in the frame, then

$(H_{1B} - H_{2B}) - (H_{1A} - H_{2A}) =$

$\{\delta_2 - \delta_1\}$ + zero

$+\{I_{2B}(T - O_{2A} - \delta_2) - I_{2A}(T - O_{2A})\}$

$-\{I_{1B}(T - O_{1A} - \delta_1) - I_{1A}(T - O_{1A})\}.$

Now, we also assume that the functional form of I(H) has not changed, so I_1 and I_2 do not need subscript A or B. Finally if, for example, δ_1 is zero, then the last line of the above equation is zero, so

$$(H_{1B} - H_{2B}) - (H_{1A} - H_{2A}) = \delta_2 + \{I_2(T - O_{2A} - \delta_2) - I_2(T - O_{2A})\} \qquad (17.4)$$

Thus the double difference (change in heading differences) resulting from the rotation of an instrument in the frame has a mean offset equal to the rotation of the instrument, and a functional form (as a function of T) that arises from a phase shift of I_2.

Next, we observe that the left hand side (LHS) of (17.4), is found to be roughly sinusoidal in shape, with amplitudes up to 5 degrees either side of the mean. If $I = \sin(H)$, then LHS should be described by a sine curve, however this did not fit the results satisfactorily. Therefore assume,

$I(H) = A_1 \sin(H + \phi_1) + A_2 \sin(2H + \phi_2)$.

In principle, the four coefficients A_1, A_2, ϕ_1, ϕ_2 can be determined from a single rotation of amount δ_2. Indeed, it was found that this functional form fitted the measurements very well. The residuals of LHS after fitting were invariably less than 1°. Now

$\sin(H - \delta) - \sin(H) = 2 \cos(H - \delta/2)\sin(-\delta/2)$

and (17.4) becomes

$$LHS - \delta_2 = \qquad (17.5)$$

$$2A_1\cos(T - O_{2A} + \phi_1 - \delta_2/2) \sin(-\delta_2/2)$$

$$+ 2A_2\cos(2(T - O_{2A}) + \phi_2 - \delta_2) \sin(-\delta_2).$$

The unknown coefficients and phases were determined from the lowest two modes of an FFT of $(LHS - \delta_2)$ in Matlab. Note that if δ_2 is exactly 180°, the cos(2H) term cannot be determined.

A series of adjustments to the WH positions was made, as summarised in table L1 on page 92 of the CD139 cruise report, to attempt to solve for the unknown amplitudes and phases of the instrument error.

If all our assumptions were correct, any move of the MWH should enable us to determine the same A and ϕ coefficients for I_2. However, we don't find this to be the case. Instead different coefficients are found for different orientations (A to J) of the two instruments. One or more of the assumptions must be wrong.

The paragraph above ends the extract from the CD139 report.

Results from CD171

The previous section of text describes the conclusions from CD139. The estimates made of the coefficients A_1, A_2, ϕ_1, ϕ_2 were not consistent between the various rotations of the WH ADCPs. This inconsistency remained unexplained.

A much more satisfactory set of data was obtained on CD171.

Compared with CD139, where a WH300 ADCP was used as a reference while the second one was rotated, the situation is simplified. The Octans is regarded as giving true heading of the package, measured with an absolute accuracy significantly better than the ADCP compass errors being investigated.

The ADCP s/n 5414 was set in four orientations, with stations grouped as follows:

Config-uration	Station range	Number of stations in this config-uration	H_1-H_2	O_1	O_2	Total adjustment compared with config A		Nominal alteration
						Octans	WH	
A	69 - 78	10	358	0	358	0	0	0
B	82 - 90	9	274	0	274	0	276	M CW 90
C	91 - 99	9	180	0	180	0	182	M CW 90
D	100 - 113	14	84	0	84	0	86	M CW 90

Table 17.1: Instrument subscript 1 is the Octans, which defines the package heading. M in the final column refers to the Master WH. Headings and differences have been reduced to lie in the range (0,360).

Using the model $I = A_1*\sin(\theta + \phi_1) + A_2*\sin(2* \theta + \phi_2)$ the amplitudes and phases can be determined from 90 degree offsets of the instrument. The A_2 term cannot be determined from a 180 degree offset. Therefore we analyse configuration pairs AB, AD, CB and CD.

The initial analysis was based on finding a mean heading difference for each configuration. Difference data were binned in 20 degree bins, and the median found for each bin. The change in heading difference was calculated for each configuration pair. For each pair, the amplitude and phase of the $\sin(\theta)$ and $\sin(2\theta)$ modes were found as the two lowest modes of the FFT of the left hand side of equation (17.5). There was a pleasing consistency between the A and ϕ values calculated in this way. In order to estimate the uncertainty of the A and ϕ determination from any

comparison pair, the analysis was then performed on a station-by-station basis. Thus each station in set A was compared with each station in set B, to produce many estimates of the unknown A and ϕ. Stations with insufficient data to populate the 20-degree bins were excluded from this analysis. Thus a standard deviation of A and ϕ estimates was made for each comparison pair, as summarised in Table 17.2.

Comparison pair	δ_1	δ_2	Npairs	A_1	Sigma (A_1)	ϕ_1	Sigma (ϕ_1)	A_2	Sigma (A_2)	ϕ_2	Sigma (ϕ_2)	Mean rms Residual (degrees)
B minus A	0	276 (-84)	72	1.85	0.23	-102	10	1.46	0.13	33	6	0.7
D minus A	0	86	126	2.21	0.34	-102	5	1.49	0.14	35	5	0.5
B minus C	0	94	64	2.41	0.30	-109	5	1.50	0.15	38	6	0.8
D minus C	0	264 (-96)	112	2.20	0.17	-97	9	1.52	0.14	39	6	0.3
Average of rows above				2.17	0.26	-103	7	1.49	0.14	36	6	0.6

Table 17.2 Summary of amplitudes and phases of two lowest modes of instrument errors, form station-by station analysis. For each comparison pair, the number of pairs analysed would be the product of the number of stations in each configuration if all stations could be used. The amplitude and phase columns show the mean of Npairs comparisons. Standard deviations of the quantities are shown.

The values of A_1, A_2, ϕ_1, ϕ_2 show reasonable consistency across the four configuration pairs, so we have good reason to believe that this correctly describes the variation of heading error with heading. The absolute offset of instrument error cannot be determined without measuring precisely the misalignment between the Octans and the WH300. We could think of no way of doing this on the frame.

Having established a single best fit for the instrument error, we can now infer the frame error F(H). Again an estimate can be made for each station, and a consistent

picture emerged. The frame error F had a sin(2θ) character varying between +2 and -2 degrees around the azimuth.

The next steps in this investigation would be to establish the impact errors of the magnitudes described above on finally-processed LADCP profiles, and to explore a data path for merging Octans data onto the raw LADCP data.

Pitch and Roll

Limited investigation was undertaken of WH pitch and roll data. To facilitate this investigation post-cruise, we noted the relative attitudes of the Octans and WH instruments. One edge of an engineers' square was placed firmly against the base of the octans, with the other edge leading over the WH. It was found that relative to this Octans line of zero pitch, beam 3 of the WH was below beam 4. The pitch difference was equivalent to 9mm across the 200mm base of the WH pressure case. The Octans had been aligned as nearly as possible by eye with its zero roll line downmost in its clamps. A straight edge was placed across the base of the WH and its height relative to the perforated struts that support the Octans clamps was noted. It was estimated that beam 2 was lower than beam 1, by 10mm across 400mm separation.

References

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