Cruise Report, CLIMODE 2, AT013

18-31 January 2006
R/V Atlantis

Summary

This is the initial winter cruise of the CLIMODE program, an NSF-funded study: CLIvar Mode water Dynamics Experiment (CLIMODE). Our goal is to better understand the air-sea exchange and cross-frontal mixing in the wintertime Gulf Stream where, Eighteen Degree Water is formed in late winter and then recirculates in the subtropical gyre of the N. Atlantic. The first cruise (CLIMODE 1) occurred in November 2005 and was mainly a mooring and float deployment cruise, aboard the R/V Oceanus. This second CLIMODE cruise was mainly concerned with air-sea exchange, cross-frontal mixing, and float/drifter deployments in the Gulf Stream & northern Sargasso Sea.

On AT013 we deployed 52 CTDs, 30 Radiosondes, 13 Bobbers, and 9 surface drifters. The ASIS/FILIS compound spar was deployed, recovered, and gathered data for nearly 9 days. For the first week it seemed to stay in the Gulf Stream, but was entrained into a cold core ring for the last two days of its drift. An attempt to recover the spar was made on the 8th day, Saturday morning, the 28th, but 15 ft. seas breaking onto the mast of the spar and 30-35 kt winds made this impossible. Recovery was made soon after first light on the 29th, and Atlantis steamed westward to service the surface mooring, which had some sensors needing replacement. However, rough seas and an opposing current prevented us getting there until after dark, so an inspection was made under the search lights and the Atlantis headed for home.

The adverse weather on the day of departure, 18 January, with 40+ kt peak winds out of the south, the direction we were headed, slowed us in the beginning of the cruise. But clearing conditions allowed work to proceed until the cold air outbreak on the 26th and 27th, when sustained northerly winds & 20 ft seas slowed station work and eventually caused us to heave to for 12 hours beginning on the night of the 27th. After work resumed the following day, stations were soon stopped so that we could attempt a spar recovery on Saturday the 28th. As noted above, however, this was not possible. In all, probably 5 CTD stations were lost during this period.

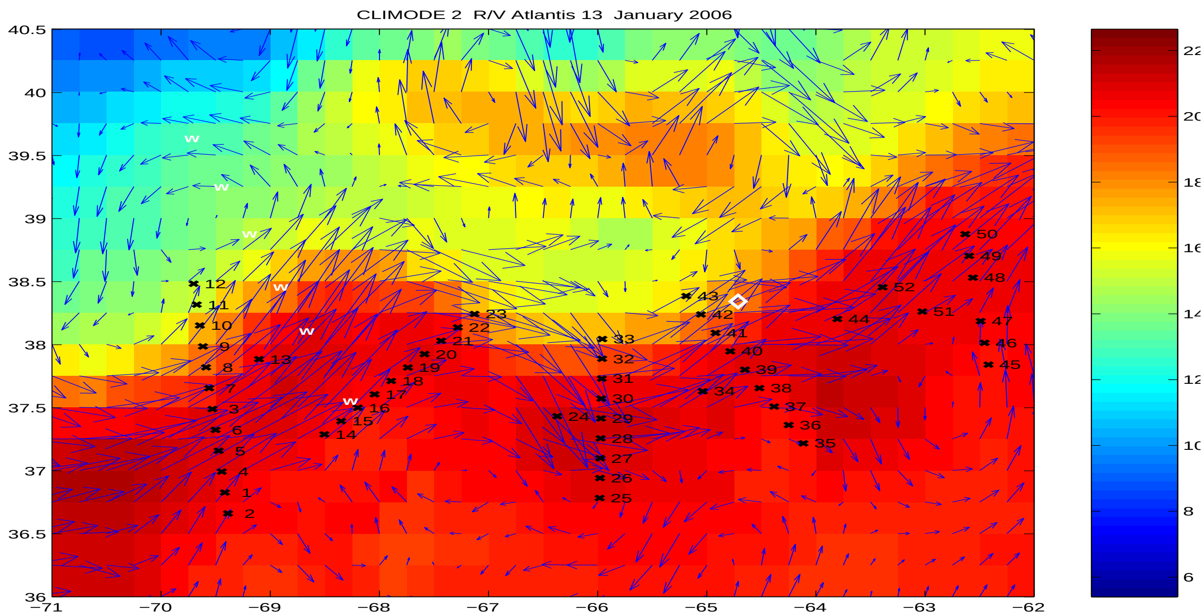
The new ADCP installation on Atlantis worked very well, with profiling routinely down to 700m except in rough seas. Flux sensors on the bow mast worked well too, and overall we have an excellent data set with which to plan our 6 week campaign next year: this includes a great cold air outbreak with 35 kt northerly winds & 5C air temperatures right in the middle of our cruise!

Thanks go out to the Captain Silva, Bo'sun Bailey, Steward Wood and all of the crew of the R/V Atlantis for helping make this a successful cruise. Thanks also go to Kathie

Kelley & her APL/UW team, and Roger Samelson & the OSU group, for providing the satellite and high resolution weather forecasting data we used continuously for planning and interpreting our shipboard measurements. SeaNet was essential in this communication linkage. The 25 members of the scientific party & their duties on the vessel are listed in Table 1. A cruise summary table is found in Table 2.

CTD Hydrography & ADCP (Terry Joyce)

A test station and 52 regular $CTDO_2$ stations were collected with a Seabird 911b CTD system, 24 place rosette, and supported by members of the Scripps ODF team. Four of the stations went to a depth of 2000m, while all the others were to a nominal depth of 1000m. Typically, 20 water samples were collected on each station and analyzed for salinity, dissolved oxygen, nutrients. On some of the stations, samples were collected for dissolved inorganic carbon (DIC) for N. Bates & ^{15}N for D. Sigman. Underway CO2 sampling was carried out by Purinton for N. Bates throughout the cruise. Station locations are given in the event log, Table 2. A complete discussion of the CTD procedures and problems on the cruise can be found in Appendix 1. The overall layout of stations is presented with an overlay of SST and surface geostrophic currents from satellite products for one given day of the cruise (Fig. 1a). For this cruise, a new 75 kHz RDI Ocean Surveyor ADCP system was installed on Atlantis. In addition, the existing Ashtech directional GPS system antennas were relocated on top of the bridge. Some Ashtech problems remained with periods of data dropouts, but enough data were obtained to correct some of the large errors in ship gyro necessary for ADCP processing. The summary of the ADCP data is presented in a similar overall plot (Fig. 1b) to the CTD stations.



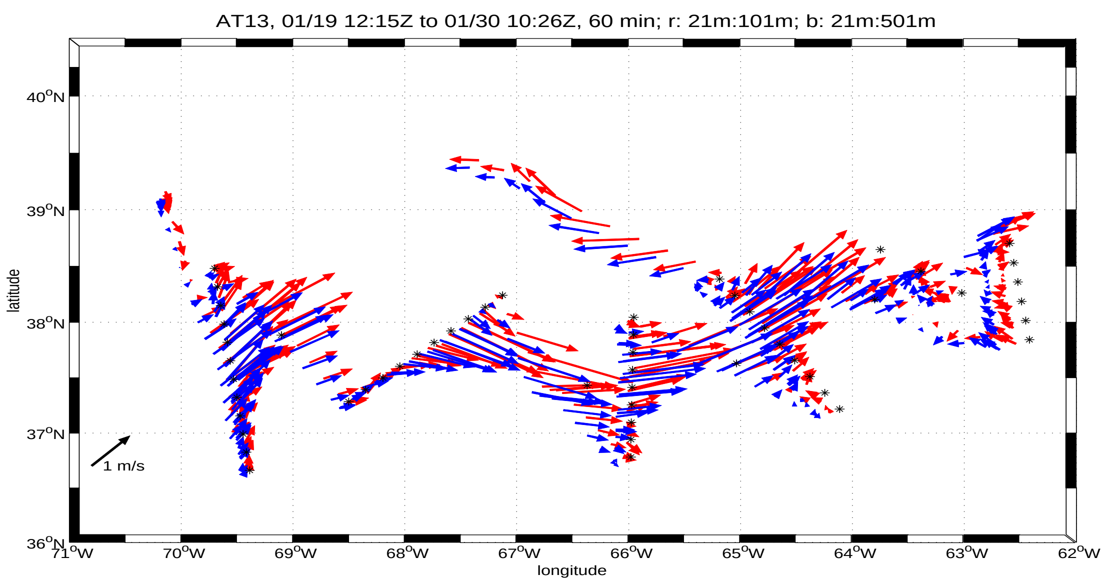
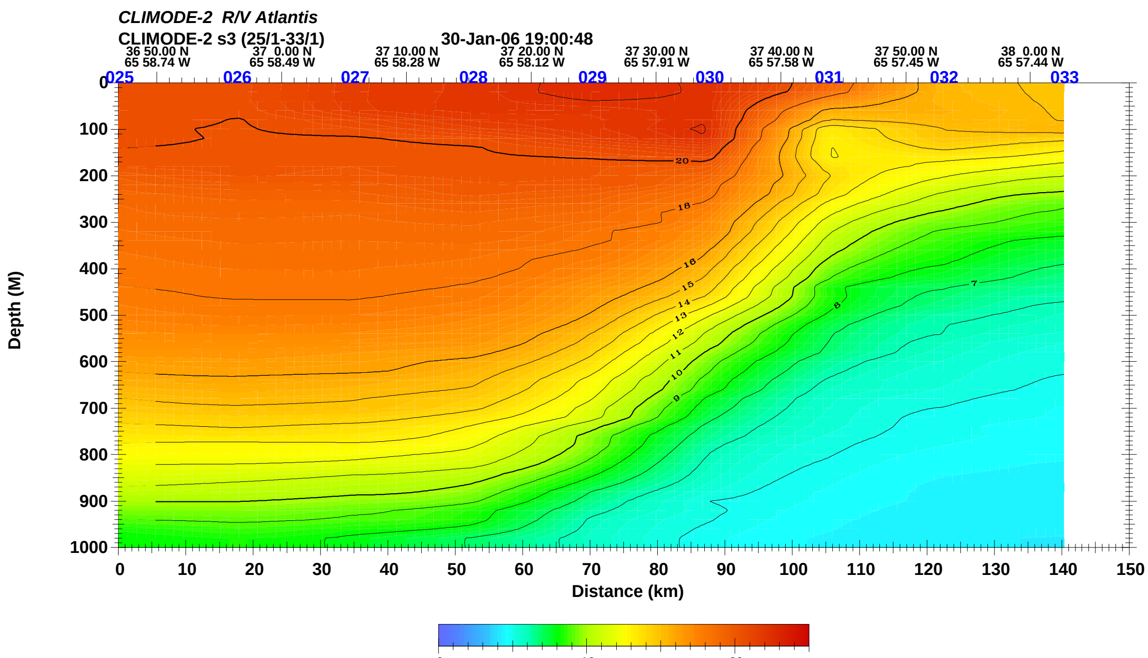
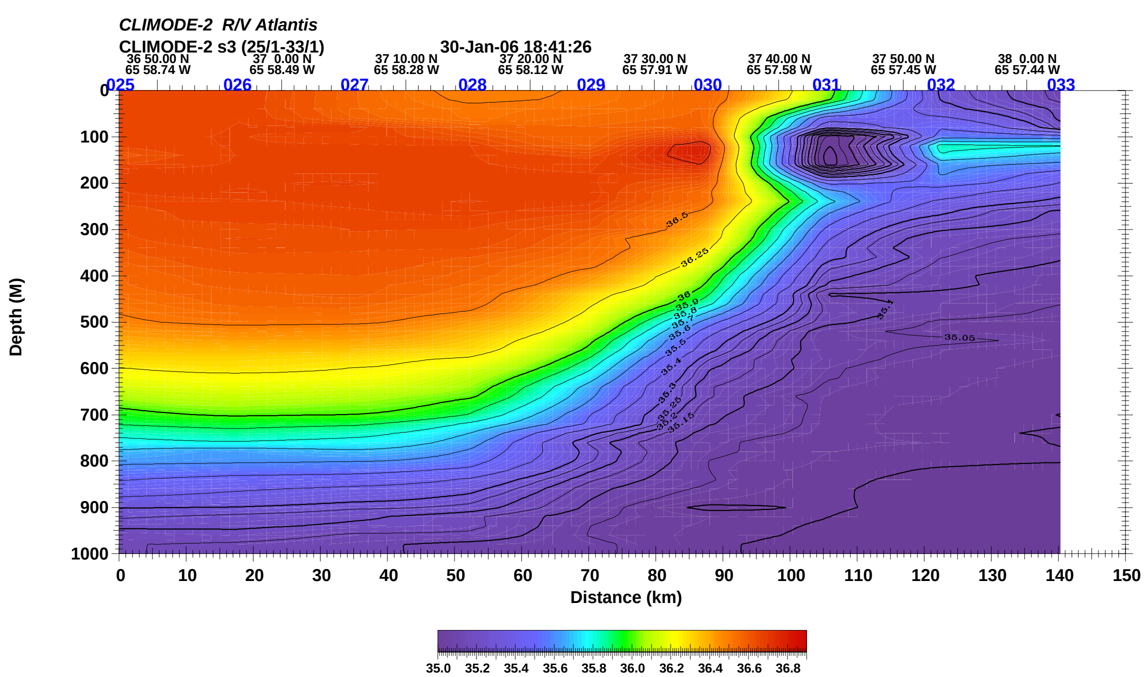


Fig. 1a. Locations of CTD stations (symbols) together with SST and surface geostrophic velocity for 27 January 2006. 1b. ADCP summary for entire cruise showing 21-500m (blue) and 21-100m (red) hourly averages.

Figure 2. Here we show samples from one transect of the Gulf Stream comprising stations 25-33, CTD section 3. This section (north is on the right) cross the Gulf Stream front in the trough of a meander (see Fig. 1a).



Pot Temp (Deg C)



Salt (PSU)

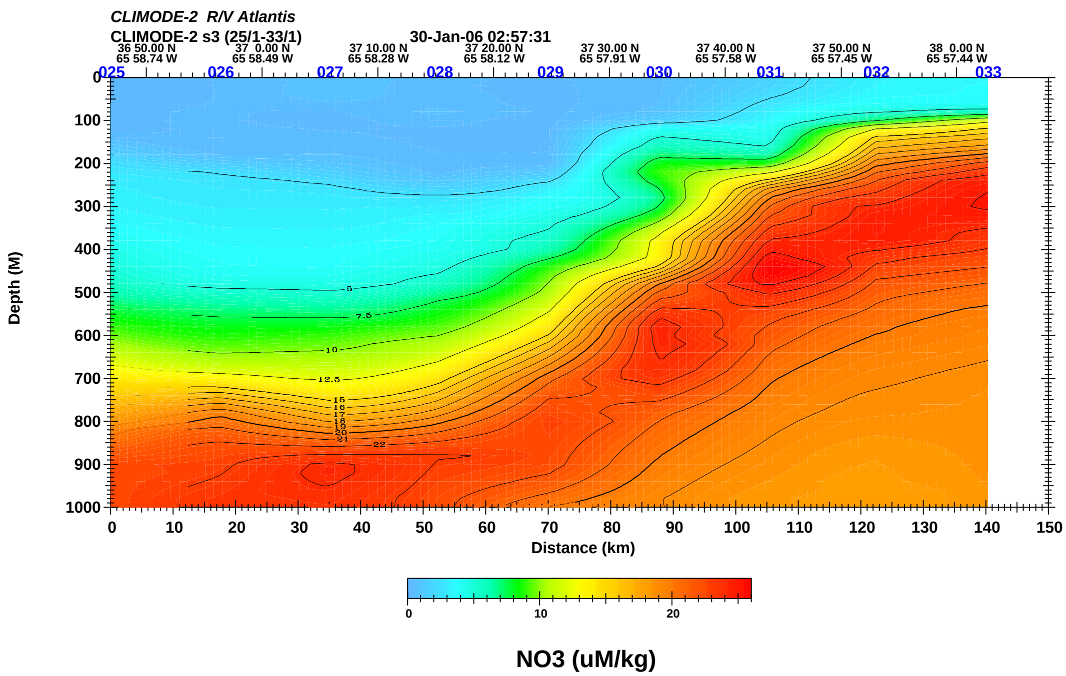
Note the low salinity bolus at station 31. This density surface outcropped to the north of the Gulf Stream on CTD section 1. This subducted layer is essentially saturated in dissolved oxygen and forms one mode of 3-D subduction observed on the cruise. The high salinity maximum to the south of the front is Salinity Maximum Water (SMW) which originates at the surface of the central tropical Atlantic under the region of high net evaporation. It is characterized by low dissolved oxygen. The large T/S gradients in the upper ocean are density compensating to an extent, but large T/S gradients remain on isopycnal surfaces.

Nutrient measurements (Susan Lozier)

Earlier work has suggested that the production and advection of North Atlantic STMW introduces spatial and temporal variability in the subsurface nutrient reservoir beneath the North Atlantic subtropical gyre and that the strength of this nutrient reservoir essentially sets the pattern of primary productivity for the gyre. A working hypothesis for why the STMW is of such importance in setting the nutrient reservoir involves its production and export: As the mode water is formed, its nutrients are depleted by biological utilization. When the depleted water mass is exported to the gyre, it injects a wedge of low-nutrient water below the euphotic zone, essentially reducing the availability of nutrients to the surface. Thus, low productivity surface waters are associated with the age of the subsurface STMW.

The primary goal of this project during the CLIMODE 2 cruise was to assess the cross-stream structure of nutrients in the winter and to ascertain the degree of nutrient depletion in newly-formed mode waters.

During CLIMODE-2/AT13 a suite of nutrients (nitrate, nitrite, phosphate and silicate) were measured at 52 CTD stations, which formed four full sections across the Gulf Stream. These measurements represent the first wintertime cross sections of nutrients in the Gulf Stream. Analyses of the nutrients were made on board by the Oceanographic Data Facility (ODF) at Scripps Institution of Oceanography, under the direction of Frank Delahoyde. A representative section of nitrate (Figure 3a) illustrates the shallow nutricline north of the stream relative to the deep nutricline to the south. Additionally, there is only a weak nitrate gradient along the isopycnals (Figure 3b), in contrast to the quite strong temperature and salinity gradients. The high nitrate bolus at station 30 is associated with an upstream surface feature that was subducted. In addition to an analysis of the downstream and cross-stream structure of the nutrient field in winter, the nutrient data will be analyzed in conjunction with the other hydrographic data and the shipboard ADCP data to evaluate cross-stream nutrient exchange.



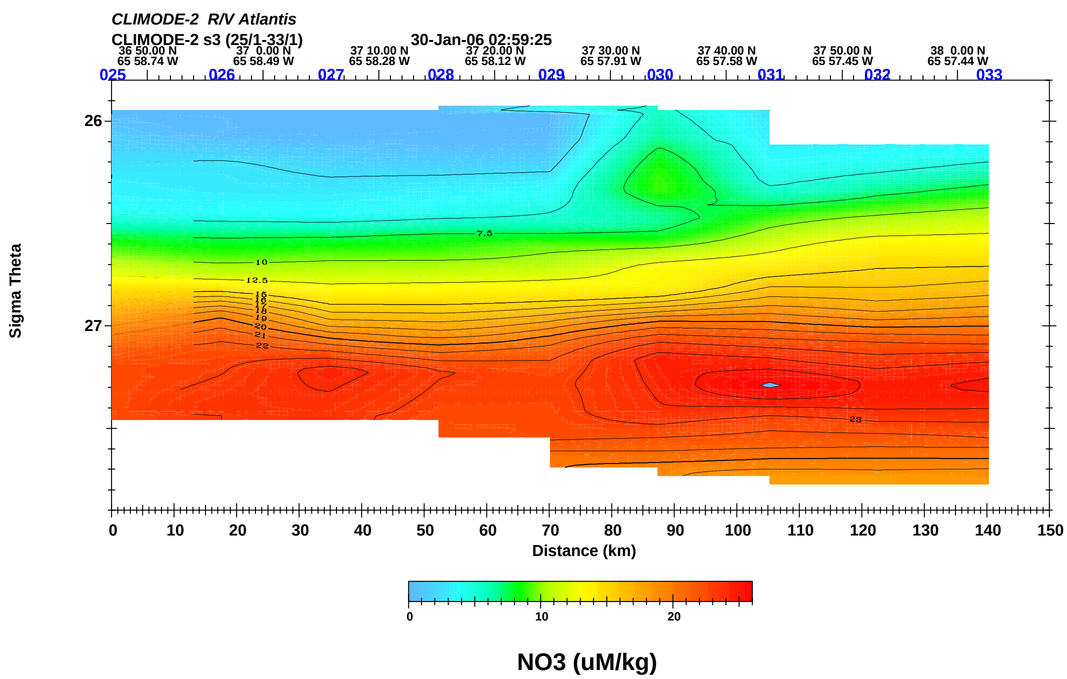


Figure 3. Nitrate section vs depth (upper) and potential density (lower) across the Gulf Stream on section 3.

CO_2 Sampling (Brett Purinton)

There remains much uncertainty about the geographic and temporal variability of ocean carbon dioxide (CO_2) sources and sinks, and their modulation by biological and physical processes, particularly in the ocean basins adjacent to North America. Subtropical mode waters (STMWs) are relatively shallow water masses that ventilate the depths between the seasonal and main thermoclines of the subtropical gyres. It has been estimated that an extra ~0.6-2.8 Pg (1015 g) of CO_2 has accumulated within the STMW (i.e., Eighteen Degree Water, EDW) layer of the North Atlantic subtropical gyre over the last 15 years, a significant and recent change in the ocean sink of CO_2.

As a contribution to CLIMODE, water column sampling and subsequent data syntheses led by Dr. Nicholas Bates (Bermuda Biological Station for Research) will focus on investigating the biogeochemical dynamics of CO_2 during EDW formation. We suspect that the CO_2 signal observed in the STMW (EDW) layer over the last 15 years results from wintertime uptake of CO_2 at the site of EDW formation and the subsequent retention of CO_2 in EDW (due to weak winter mixing and potential coupling to North Atlantic Oscillation variability) during recirculation of the gyre (rather than contributions from the remineralization of organic matter). As part of efforts to understand the role of EDW as a long-term CO_2 sink, water samples for dissolved inorganic carbon (DIC) and alkalinity were collected from 52 stations in the region of EDW formation. In addition, rates of air-sea CO_2 gas exchange in the region of EDW will be determined from measurements of seawater pCO_2 collected from underway, shipboard measurements of the surface layer.

Bobber Floats (Dave Fratantoni & John Lund)

Each Bobber was equipped with a RAFOS hydrophone and a Sea Scan TD (temperature, and pressure) sensor. Bobbers are acoustically tracked under water using the arrival time from several sound sources located on subsurface moorings deployed during the OC419 November 2005 cruise.

The bobbers are programmed to seek the 18.5 degree isotherm and adjust their buoyancy to follow this isotherm. Each day the float listens for 120 minutes starting at 00:00:00 GMT for acoustic pongs from the source moorings. Once every three days the float will bob between the 17 and 20 degrees. Every 30 days the float makes a deep profile from 1000 meters to the surface. While at the surface, position and temperature profile data are transmitted via Argos.

Float serial number 2526 (Argos ID 39476) was modified to surface on a 12 day rather than 30 day cycle.

AT13 Bobber locations

Bobber	Date	Time	SN	LAT	lat	LON	lon	ARGOS ID
1	1/20/2006	14:25	2526	36	39.54	69	23.03	39476
2	1/22/2006	7:14	2525	37	17.87	68	29.41	39475
3	1/22/2006	13:26	2374	37	31.07	68	11.38	38598
4	1/23/2006	2:48	2384	36	46.84	65	58.66	39449
5	1/24/2006	1:40	2373	36	55.28	65	58.09	38597
6	1/24/2006	8:01	2529	37	04.55	65	58.00	39721
7	1/25/2006	5:21	2382	37	12.62	64	07.29	39060
8	1/25/2006	15:09	2383	37	21.65	64	15.00	39448
9	1/25/2006	21:24	2380	37	39.09	64	30.68	38605
10	1/27/2006	10:40	2530	37	51.36	62	27.51	39722
11	1/27/2006	14:36	2521	38	00.87	62	28.62	39471
12	1/27/2006	22:13	2522	38	21.98	62	31.92	39472
13	1/29/2006	13:57	2378	38	15.07	63	02.69	38603

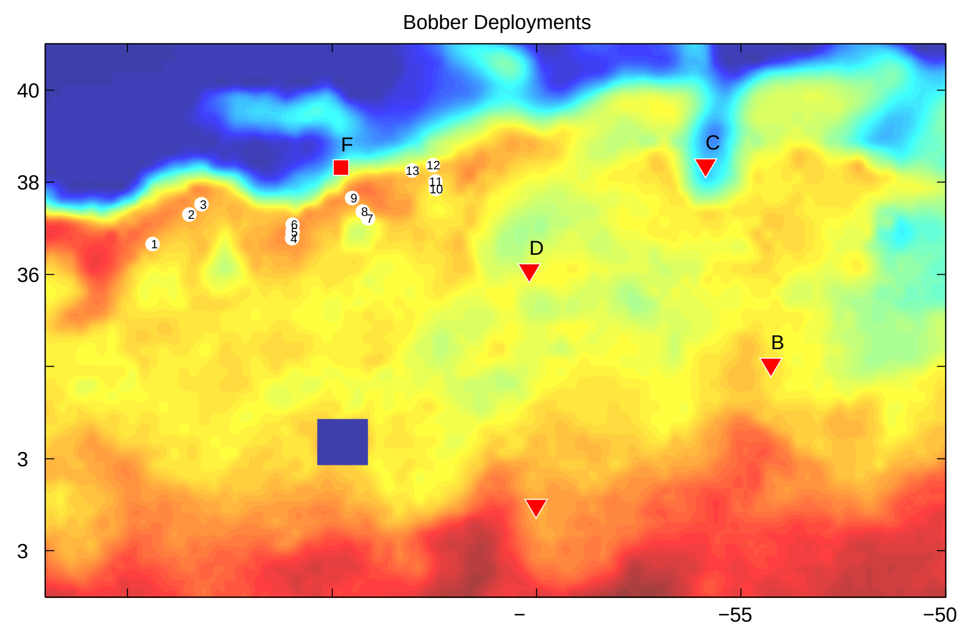


Figure 4. Bobber deployment positions and sequence (numbered white dots) plotted on a smoothed SST from 26 January 2006. Triangles A-D mark the sound source mooring locations and square F the CLIMODE surface mooring deployed during the November 2005 OC419 CLIMODE-1 cruise.

Surface drifter deployments (Rick Lumpkin)

Nine satellite-tracked surface drifting buoys were deployed on AT-13, to measure mixed layer currents and sub-skin SS (Fig. 5)T. Combined, these measurements will allow estimates of eddy heat fluxes across outcropping isotherms. The drifters were “mini” SVP (Surface Velocity Program) drifters, drogued at 15m depth with a holey sock drogue.

One pair of drifters was deployed within one minute of each other on the SST front at the northern edge of the Gulf Stream, at SST values of approximately 17-19°C. Two pairs were deployed immediately south of the front, in the core of the Gulf Stream along the nominal path of the ASIS/FILIS buoy, along with a single drifter at 60°W. Two drifters were launched separately at the southern edge of the Gulf Stream.

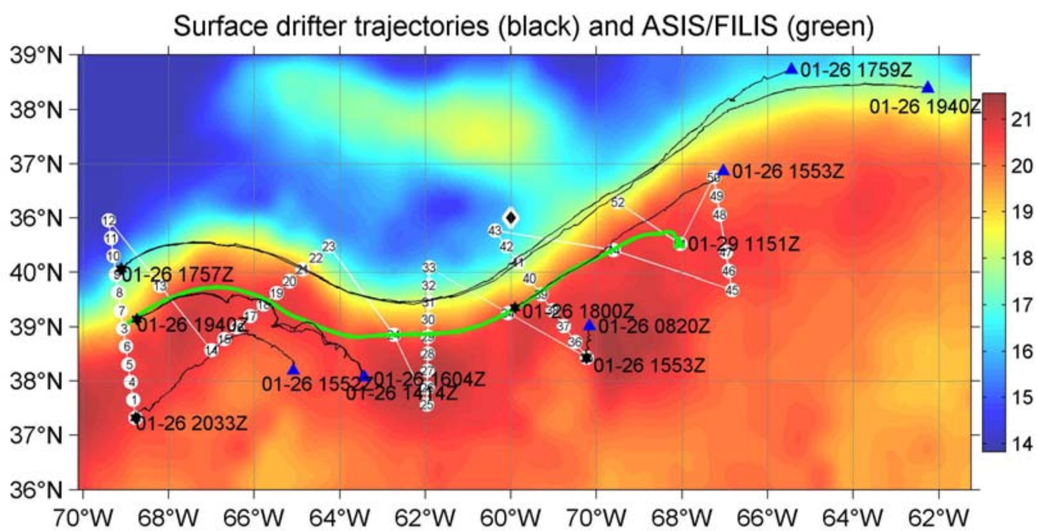


Figure 5. Drifter deployment locations (stars) and subsequent trajectories (black lines), with final Argos fixes as of 27 January 2006. The trajectory of the ASIS/FILIS buoy (green) is shown for comparison, along with the AT-13 casts (numbered white bullets). Background shading is microwave SST (°C) for 27 January 2006.

Air-Sea Exchange (Jim Edson)

The Meteorological/ASIS group on board the Atlantis operated a number of systems during the CLIMODE cruise. The meteorological sensors on the bow mast of the

Atlantis included three direct covariance flux systems (DCFS) to measure momentum, heat, moisture, and radiative (solar and IR) fluxes. The bow sensors also measured mean air temperature, humidity, pressure wind speed, wind direction, and sea surface temperature using a downward looking radiometer. All systems ran continuously from January 18-30. The only exception was a brief power failure lasting from 00-03Z on January 28. The ASIS was successfully deployed on January 20 at 19:00Z. The ASIS was equipped with a DCFS, Nortek current meter, 2 ADCPS, and a suit of sensors to measure air and sea temperature, salinity, humidity, pressure, and directional waves. All systems ran continuously until we stopped data acquisition prior to recovery on January 29 at 12:15Z. The Iridium position finding system worked flawlessly. The ASIS was recovered with only minor damage and all data was successfully offloaded for future analysis. A quick look showed that four of the six capacitance wave-wires survived the entire deployment. All other systems appeared to have functioned normally. The group also launched 32 rawinsondes during the CTD transects, producing 26 profiles of the atmospheric boundary layer and 6 profiles in courage.

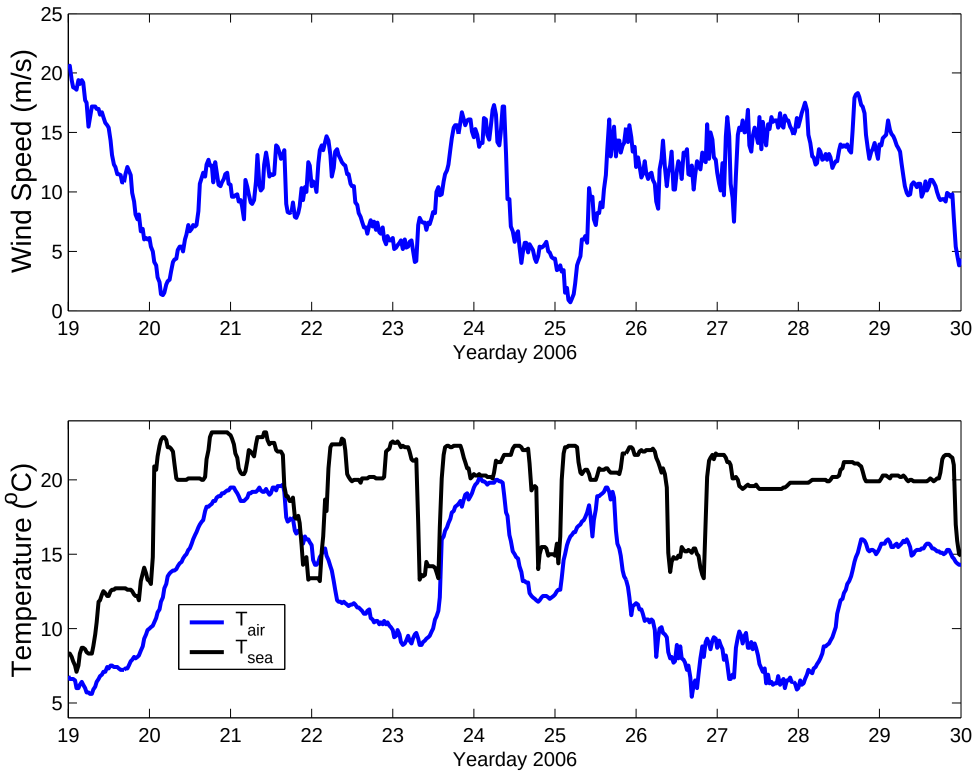


Figure 6. Shipboard record of true wind speed, air and sea temperature for the cruise.

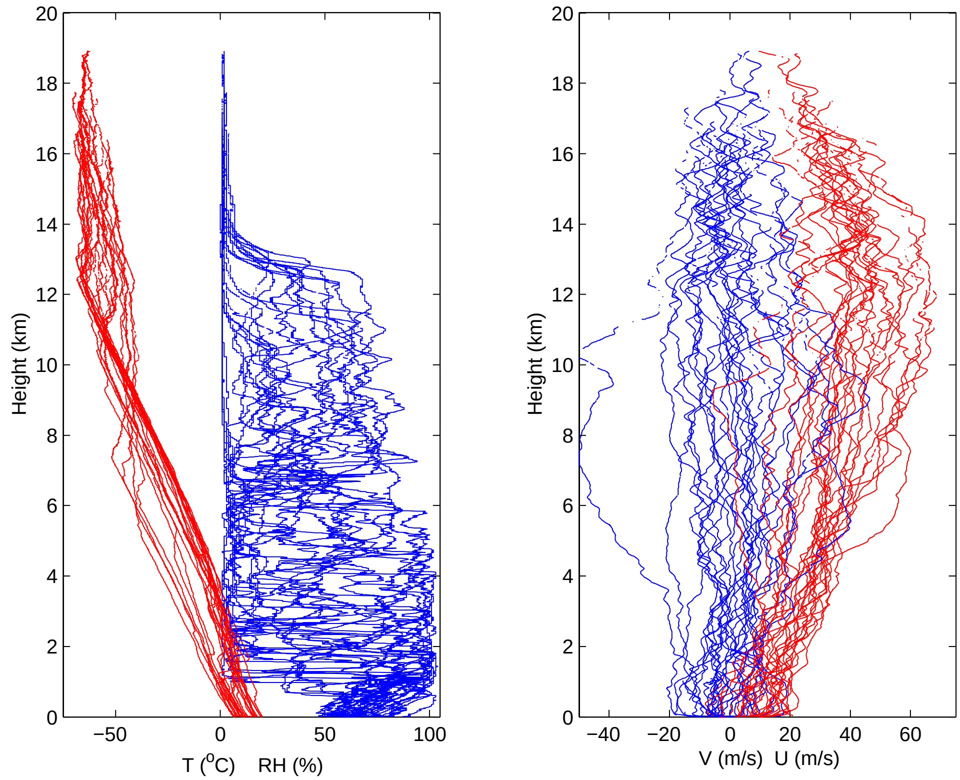


Figure 7. Radiosonde temperature, relative humidity (left) and wind velocity (east red, north, blue).

Tethered Profiler (FILIS, John Toole)

Tethered off the ASIS buoy was an instrument system designed to repeatedly profile the upper ocean's temperature, conductivity and relative velocity structure at fine vertical scale. The assemblage consisted of a WHOI-built Coastal Moored Profiler (CMP) mounted on a 500-m length wire rope segment with distributed buoyancy at the top and a 300 pound ballast weight at the bottom. A Sea-Bird MicroCat CTD was mounted just above the ballast weight and programmed to sample at 5 second interval to quantify the vertical motion of the tether. The distributed buoyancy consisted of a series of 21 11"-diameter plastic floats that was designed to also act like spar buoy. Buoyancy was adjusted so that 2-3 of the floats would lie at the surface in calm conditions. The profiling wire and floatation was attached to the ASIS with a 100-m synthetic rope tether. Small floats were placed along the tether to aid visibility. The CMP was fitted with a Falmouth Scientific, Inc. EMCTD and, for the first time, a Nobska Instruments, Inc. MAVS acoustic current meter (ACM). Foam buoyancy (with stated working depth rating of 750 m) was added to the CMP to compensate for the water weight of the MAVS ACM. A continuous sampling program was entered into the CMP; at the completion of each one-way profile between 12 and 475 dbars, the instrument would archive data to flash memory and immediately cycle in the opposite direction.

Deployment of the system involved first launching the ASIS and then, while slowly steaming into the wind, paying out the surface tether, distributed buoyancy segment, and profiling wire. Midway along that segment, the CMP was fitted to the wire. Lastly the Microcat and ballast weight were shackled to the wire and released overboard. After deployment, the ship rendezvoused with the drifting system once on January 23 (CTD station 24), on January 27 when recovery was planned but aborted due to strong winds and high seas, and then the following day when the instrument system was successfully recovered. At those times, the ASIS buoy appeared to orient downwind/wave from the CMP system. During the first encounter when the winds were strong, 5-10 of the CMP floatation spheres were visible at times in the wave field, suggesting that the ASIS was pulling strongly on the tether.

The CMP and Microcat recorded data internally during the deployment, thus assessment of the data return only took place after return to Woods Hole when the instruments could be debriefed. At that time it was discovered that the CMP and MAVS logged 471 data files (one each per attempted profile). The device successfully profiled from ~475 m to 200 m or shallower a total of 80 times between January 20 20:12 GMT and January 25 16:14. Thereafter, the Profiler never managed to move up from the bottom stop on the wire. On recovery, it was noted that the foam floatation mounted on the CMP to compensate for the water weight of the ACM was compressed. Weighing the system in water after return to Woods Hole it was established that the CMP had lost approximately 285 g of buoyancy during the deployment. This degree of foam compression exceeded the manufacturer's specifications of the material. The added water weight, in combination with wire motion due to waves, are likely explanations for why the CMP failed to cycle later in the deployment. Also disappointing, when the MicroCat CTD was examined in the laboratory after the cruise, it was observed that the batteries were fully exhausted. (This shouldn't have been the case for this length of deployment.) When fresh batteries were installed, no usable data were accessible from the instrument's memory. Pressure data from the CMP during the period that the instrument was stuck at the bottom stop should nevertheless provide information about the wire heave during the deployment.

The recovered data will be evaluated in the coming months to determine if the FILIS system tethered to the ASIS float can be modified so as to insure regular profiles will be obtained during the planned 2007 CLIMODE deployments. Sufficient data was collected to allow evaluation of the MAVS ACM on Moored Profilers.

Table 1, Scientific Party on AT013

NAME (M/F)	INST/Responsibility	EMAIL
Terrence Joyce (M)	WHOI - Chief Scientist,watchleader	tjoyce@ whoi.edu
John Toole (M)	WHOI -FILIS, radiosondes	jtoole@ whoi.edu
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Willie Ostrom (M)	WHOI/ASIS, FILIS boss	wostrom@ whoi.edu
Craig Marquette(M)	WHOI/ASIS,FILIS co-boss	cmarquette@ whoi.edu
Steve Faluotico (M)	ASIS, Ship met,radiasondes	sfaluotico@ whoi.edu
Brett Purinton (M)	DIC	brett@ bbsr.edu
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Marshall Swartz (M)	WHOI - sssg tech	mswartz@ whoi.edu

Table 2, Cruise Event Log

% 1=ctd	2=balloon	3=bobber	4=drifter	5=asis						
%	GMT	lat	latdeg	lon	londeg	event	incrment	comment	who	activity
%										
20060118	1730	41	31.56	-70	40.38	0	0	%	watch	depart whoi
20060119	1453	39	07.31	-70	08.17	0	0	%	ms	start ctd 999 test station
20060119	1455	39	07.3086	-70	08.1726	2	2	%	je	launch balloon, 3 tries
20060119	1630	39	06.17	-70	08.05	0	0	%	tj	end ctd 999
20060120	0008	38	09.23	-69	49.7	2	3	%	je	launch balloon 3
20060120	0930	36	49.536	-69	24.88	1	1	%	lt	start ctd 01
20060120	1046	36	49.69	-69	24.57	0	0	%	lt	end ctd 01
20060120	1211	36	39.60	-69	23.187	1	2	%	lt	start ctd 02
20060120	1330	36	39.52	-69	23.11	2	4	%	jt	launch balloon, nice Wx
20060120	1407	36	39.54	-69	23.06	0	0	%	tj	end ctd 02
20060120	1425	36	39.53	-69	23.03	3	1	%	jl	launch bobber sn2625
20060120	1426	36	39.53	-69	23.03	4	1	%	rl	launch drifter 54421
20060120	1939	37	31.063	-69	30.48	5	1	%	jt	launch ASIS/FILIS
20060120	2039	37	32.82	-69	26.63	1	3	%	tj	start ctd 03
200601202	2201	37	33.5	-69	24.3	0	0	%	sl	end ctd 03
20060120	2204	37	33.5	-69	24.3	4	2	%	rl	launch drifter 54424, asis in sight
20060120	2205	37	33.5	-69	24.3	4	3	%	rl	launch drifter 55128, asis in sight
20060121	0020	37	23.84	-69	25.44	2	5	%	je	launch balloon, 1st x'd, 2nd good
20060121	0303	36	59.43	-69	26.55	1	4	%	sl	start ctd 04
20060121	0420	36	59.44	-69	26.53	0	0	%	sl	end ctd 04
20060121	0543	37	09.37	-69	28.23	1	5	%	lt	start ctd 05
20060121	0702	37	09.98	-69	26.81	0	0	%	lt	end ctd 05
20060121	0815	37	19.19	-69	29.81	1	6	%	lt	start ctd 06
20060121	0940	37	20.057	-69	28.2393	0	0	%	lt	end ctd 06
20060121	1132	37	39.24	-69	33.24	1	7	%	eb	start ctd 07
20060121	1222	37	40.664	-69	31.746	2	6	%	sf/je/jt/jd	balloon 06 mid-transect sounding,not archived
20060121	1257	37	41.684	-69	30.328	0	0	%	lt	end ctd 07

20060121	1403	37	49.26	-69	34.95	1	8	%	tj	start ctd 08
20060121	1532	37	52.28	-69	31.23	0	0	%	tj	end ctd 08
20060121	1640	37	59.03	-69	36.87	1	9	%	tj	start ctd 09
20060121	1730	38	00.46	-69	34.75	2	7	%	je	launch balloon 07, replaces #6
20060121	1804	38	00.46	-69	34.75	0	0	%	tj	end ctd 09
20060121	1805	38	00.46	-69	34.74	4	4	%	rl	deploy drifter 54420, N edge GS
20060121	1805	38	00.46	-69	34.74	4	5	%	rl	deploy drifter 55149, N edge GS
20060121	1910	38	08.97	-69	38.59	1	10	%	tj	start ctd 10
20060121	2029	38	09.96	-69	38.14	0	0	%	tj	end ctd 10
20060121	2133	38	18.932	-69	40.36	1	11	%	sl	start ctd 11
20060121	2237	38	18.90	-69	40.18	0	0	%	sl	end sta 11
20060121	2345	38	28.77	-69	42.01	1	12	%	sl	start ctd 12
20060122	0000	38	28.71	-69	41.88	2	8	%	cm	launch balloon 08, rainy
20060122	0143	38	28.66	-69	41.53	0	0	%	sl	end sta 12
20060122	0630	37	54.23	-69	04.64	2	9	%	df	launch balloon 9, windy & cooling,mid return
20060122	0632	37	53.04	-69	05.79	1	13	%	lt	start ctd 13
20060122	0756	37	54.89	-69	03.70	0	0	%	lt	end ctd 13
20060122	1240	37	17.13	-68	30.14	1	14	%	lt	start ctd 14
20060122	1245	37	17.10	-68	30.10	2	10	%	jt/sf	launch balloon 10, begin transect
20060122	1400	37	17.7	-68	29.5	0	0	%	tj	end ctd 14
20060122	1408	37	17.86	-68	29.41	3	2	%	jl	deploy bobber 2, sn2525
20060122	1511	37	23.43	-68	21.10	1	15	%	tj	start ctd 15
20060122	1633	37	24.41	-68	20.79	0	0	%	tj	end ctd 15
20060122	1736	37	29.79	-68	12.07	1	16	%	tj	start ctd 16
20060122	1859	37	30.39	-68	11.42	0	0	%	tj	end ctd 16
20060122	1903	37	31.068	-68	11.38	3	3	%	jl	deploy bobber 3, sn2374
20060122	1959	37	36.13	-68	02.89	1	17	%	tj	start ctd 17
20060122	2111	37	36.19	-68	02.39	0	0	%	sl	end ctd 17
20060122	2200	37	42.12	-67	54.02	1	18	%	sl	start ctd 18
20060122	2210	37	42.12	-67	54.02	2	11	%	je	launch balloon 11
20060123	0000	37	47.66	-67	45.14	0	0	%	sl	end ctd 18
20060123	0113	37	48.62	-67	44.21	1	19	%	sl	start ctd 19
20060123	0225	37	47.44	-67	39.94	0	0	%	sl	end ctd 19

20060123	0306	37	55.22	-67	35.07	1	20	%	sl	start ctd 20
20060123	0419	37	53.51	-67	31.19	0	0	%	sl	end ctd 20
20060123	0536	38	01.45	-67	25.64	1	21	%	lt	start ctd 21
20060123	0705	37	59.46	-67	21.33	0	0	%	lt	end ctd 21
20060123	0819	38	07.88	-67	16.87	1	22	%	lt	start ctd 22
20060123	0935	38	08.14	-67	16.28	0	0	%	lt	end ctd 22
20060123	1041	38	14.43	-67	07.85	1	23	%	lt	start ctd 23
20060123	1045	38	14.40	-67	08.00	2	12	%	jt	launch balloon 12
20060123	1203	38	15.01	-67	07.31	0	0	%	lt	end ctd 23
20060123	1700	37	24.6	-66	41.20	0	0	%	sci	close encounter with ASIS
20060123	1744	37	24.62	-66	41.99	1	24	%	tj	start ctd 24
20060123	1800	37	24.40	-66	39.3	2	14	%	je	lost balloon 13, 14 ok
20060123	1906	37	24.32	-66	36.46	0	0	%	tj	end ctd 24
20060124	0215	36	48.86	-65	58.67	2	15	%	je	launch balloon 15 from fantail
20060124	0248	36	46.84	-65	58.66	3	4	%	jl	launch bobber #4 sn2384 - sinker
20060124	0124	36	46.91	-65	58.80	1	25	%	sl	start ctd 25
20060124	0239	36	46.88	-65	58.66	0	0	%	sl	end ctd 25
20060124	0520	36	55.28	-65	58.08	3	5	%	jl	bobber #5 sn2373
20060124	0357	36	56.34	-65	58.59	1	26	%	sl	start ctd 26
20060124	0512	36	55.36	-65	58.07	0	0	%	lt	end ctd 26
20060124	0642	37	05.72	-65	58.31	1	27	%	lt	start ctd 27
20060124	0758	37	04.62	-65	57.90	0	0	%	lt	end ctd 27
20060124	0801	37	04.55	-65	58.00	3	6	%	jl	bobber #6 sn2529 - big waves
20060124	0927	37	15.25	-65	58.24	1	28	%	lt	start ctd 28
20060124	1051	37	14.67	-65	56.52	0	0	%	lt	end ctd 28
20060124	1208	37	24.81	-65	57.86	1	29	%	lt	start ctd 29
20060124	1215	37	24.81	-65	57.86	2	16	%	jt	balloon 16, 1st ROV van launch - brilliant
20060124	1318	37	25.04	-65	55.86	0	0	%	tj	end ctd 29
20060124	1433	37	34.19	-65	57.83	1	30	%	tj	start ctd 30
20060124	1552	37	34.64	-65	53.14	0	0	%	tj	end ctd 30
20060124	1707	37	43.76	-65	57.35	1	31	%	tj	start ctd 31
20060124	1837	37	43.48	-65	52.80	0	0	%	tj	end ctd 31
20060124	1954	37	52.9746	-65	57.468	1	32	%	th	start ctd 32

20060124	2119	37	53.28	-65	56.00	0	0	%	sl	end ctd 32
20060124	2214	38	02.25	-65	56.36	1	33	%	sl	start ctd 33
20060124	2230	38	02.25	-65	56.36	2	17	%	je	launch balloon 17
20060125	0025	37	58.114	-65	47.822	0	0	%	sl	end ctd 33
20060125	0430	37	37.98	-65	01.53	2	18	%	jt	launch balloon 18 from fantail, calm
20060125	0417	37	37.78	-65	02.00	1	34	%	sl	start ctd 34
20060125	0531	37	39.17	-64	58.85	0	0	%	lt	end ctd 34
20060125	0532	37	39.30	-64	58.60	4	6	%	rl	drifter #6 54422
20060125	1029	37	12.93	-64	06.85	1	35	%	lt	start ctd 35
20060125	1100	37	12.93	-64	06.85	2	19	%	je/fb	launch balloon 19
20060125	1222	37	12.66	-64	07.14	0	0	%	lt	end ctd 35
20060125	1226	37	12.60	-64	07.30	3	7	%	df	launch bobber #7
20060125	1228	37	12.6	-64	07.30	4	7	%	rl	launch drifter #7 55151
20060125	1343	37	21.80	-64	14.89	1	36	%	tj	start ctd 36
20060125	1503	37	21.70	-64	14.93	0	0	%	tj	end ctd 36
20060125	1509	37	21.65	-64	15.00	3	8	%	df	deploy bobber #8
20060125	1640	37	30.53	-64	22.83	1	37	%	tj	start ctd 37
20060125	1725	37	30.72	-64	22.28	2	20	%	je	launch balloon 20 from fantail, 30 kt winds
20060125	1803	37	30.45	-64	22.30	0	0	%	tj	end ctd 37
20060125	1957	37	39.061	-64	30.777	1	38	%	tj	start ctd 38
20060125	2209	37	42.22	-64	33.65	0	0	%	sl	end ctd 38
20060125	2124	37	39.10	-64	30.678	3	9	%	df	deploy bobber #9
20060125	2353	37	48.35	-64	38.24	2	21	%	je	launch balloon 21 fron fantail, 25kt winds
20060126	0040	37	49.11	-64	37.06	2	22	%	wo	launch balloon 22, 2nd launch at this station
20060126	0041	37	48.16	-64	38.66	1	39	%	sl	start ctd 39
20060126	0147	37	49.23	-64	36.78	0	0	%	sl	end ctd 39
20060126	0313	37	56.70	-64	46.90	1	40	%	sl	start ctd 40
20060126	0509	38	01.67	-64	43.37	0	0	%	sl	end ctd 40
20060126	0700	38	06.30	-64	54.36	2	23	%	cm	launch blloon 23, Fab
20060126	0710	38	05.81	-64	54.78	1	41	%	lt	start ctd 41, after repair to ctd
20060126	0829	38	07.53	-64	52.85	0	0	%	lt	end ctd 41
20060126	1050	38	14.32	-65	03.06	1	42	%	lt	start ctd 42
20060126	1208	38	14.49	-65	02.89	0	0	%	lt	end ctd 42

20060126	1408	38	22.90	-65	11.30	1	43	%	tj	start ctd 43
20060126	1455	38	22.85	-65	11.43	2	24	%	jt	launch balloon 24, 2nd try successful
20060126	1605	38	22.87	-65	11.67	0	0	%	tj	end ctd 43, near mooring F, weller's
20060126	2200	38	20.00	-65	00.00	0	0	%	ms	WHOI NCTD onto rosette for testing
20060126	2200	38	12.34	-63	48.00	2	25	%	je	launch ballloon 25 - failed - failed- snow,hail,sleet
20060127	0036	38	13.29	-63	47.43	1	44	%	sl	start ctd 44
20060127	0119	38	13.27	-63	47.59	2	26	%	je	launch ballloon 26 - failed- snow,hail,sleet
20060127	0216	38	14.5	-63	47.26	0	0	%	sl	end ctd 44
20060127	0910	37	50.53	-62	25.29	1	45	%	lt	start ctd 45
20060127	1037	37	51.28	-62	27.48	0	0	%	lt	end ctd 45
20060127	1039	37	51.35	-62	27.50	3	10	%	df	deploy bobber #10
20060127	1045	37	51.35	-62	27.50	2	27	%	je	launch balloon 27 - wicked
20060127	1245	38	00.74	-62	27.33	1	46	%	lt	start ctd 46
20060127	1429	38	00.73	-62	28.53	0	0	%	tj	end ctd 46
20060127	1436	38	00.27	-62	28.62	3	11	%	df	deploy bobber 11, fun, ice falling from sky…
20060127	1659	38	11.13	-62	29.32	1	47	%	tj	start ctd 47
20060127	1832	38	11.33	-62	31.32	0	0	%	tj	end ctd 47
20060127	1915	38	11.40	-62	32.00	2	28	%	je	launch balloon 28, from fantail, 40kts
20060127	2213	38	21.975	-62	31.918	3	12	%	df	deploy bobber 12, ctd 48 delayed
20060128	0558	38	31.83	-62	33.39	1	48	%	lt	start ctd 48
20060128	0721	38	32.25	-62	33.80	0	0	%	lt	end ctd 48
20060128	0806	38	33.43	-62	33.72	2	29	%	cm	launch balloon 29, improving conditions
20060128	1006	38	42.16	-62	35.63	1	49	%	lt	start ctd 49
20060128	1155	38	42.50	-62	35.44	0	0	%	lt	end ctd 49
20060128	1400	38	52.48	-62	37.52	1	50	%	tj	start ctd 50
20060128	1521	38	53.21	-62	35.41	0	0	%	tj	end ctd 50
20060128	1540	38	53.63	-62	34.64	2	30	%	je	launch balloon 30, looks good
20060128	2125	38	15.80	-63	01.6	4	8	%	rl	deploy drifter #8, 55116
20060128	2125	38	15.80	-63	01.6	4	9	%	rl	deploy drifter #9, 54423
20060128	2205	38	16.0	-63	01.0	1	51	%	sl	start ctd 51
20060128	2321	38	15.71	-63	02.1	0	0	%	sl	end ctd 51
20060129	0358	38	27.2	-63	23.1	1	52	%	sl	start ctd 52
20060129	0518	38	27.3	-63	22.9	0	0	%	sl	end ctd 52

20060129	1200	38	15.3	-63	2.0	5	2	%	jt	begin FILIS recovery
20060129	1345	38	15.11	-63	02.55	0	0	%	jd	ASIS on board
20060129	1357	38	15.07	-63	02.69	3	13	%	jl	deploy bobber #13, sn 38603
20060130	0157	38	20.34	-64	42.78	0	0	%	jd	pass by Mooring F, weller's

Appendix 1, CTD/Hydro

Description of Measurement Techniques

1. CTD/Hydrographic Measurements Program

The basic CTD/hydrographic measurements consisted of salinity, dissolved oxygen and nutrient measurements made from water samples taken on CTD/rosette casts, plus pressure, temperature, salinity, dissolved oxygen and fluorometer from CTD profiles. A total of 53 CTD/rosette casts were made usually to 1000 meters (4 casts were made to 2000 meters). No major problems were encountered during the operation.

1.1. Water Sampling Package

CTD/rosette casts were performed with a package consisting of a 24-bottle rosette frame (ODF), a 24-place pylon (SBE32) and 24 2.5-liter Bullister bottles (ODF). Underwater electronic components consisted of a Sea-Bird Electronics SBE9*plus* CTD (ODF #777) with dual pumps, dual temperature (SBE3*plus*), dual conductivity (SBE4), dissolved oxygen (SBE43) and fluorometer (SeaPoint); an SBE35RT Digital Reversing Thermometer and a Simrad altimeter.

The CTD was mounted vertically in an SBE CTD frame attached to the bottom center of the rosette frame. The SBE4 conductivity and SBE3*plus* temperature sensors and their respective pumps were mounted vertically as recommended by SBE. Pump exhausts were attached to inside corners of the CTD cage and directed downward. The entire cage assembly was then mounted on the bottom ring of the rosette frame, offset from center to accommodate the pylon, and also secured to frame struts at the top. The SBE35RT temperature sensor was mounted vertically on the SBE9*plus* equidistant between the T1 and T2 intakes. The fluorometer was mounted horizontally along the rosette frame adjacent to the CTD. The altimeter was mounted on the inside of the bottom frame ring.

The rosette system was suspended from a new UNOLS-standard three-conductor 0.322" electro-mechanical sea cable. This sea cable had been relubricated at WHOI and the lubricant was initially dripping from the wire (onto the rosette). The lubricant had no discernable effect on the hydrographic measurements. A single sea cable retermination served for the entire cruise.

The R/V Atlantis' starboard-side Markey winch was used for all casts. The winch sliprings were replaced prior to departure.

Cast 51/1 was aborted at 51m on the downcast because the CTD primary pump had shut down. The problem was traced to the primary conductivity UW cable which was replaced.

The deck watch prepared the rosette 10-15 minutes prior to each cast. The bottles were cocked and all valves, vents and lanyards were checked for proper orientation. Once stopped on station, the CTD was powered-up and the data acquisition system in the computer lab started when directed by the deck watch leader. The rosette was unstrapped from it's tiedown location on deck. Tag lines were threaded through the rosette frame, and syringes were removed from the CTD intake ports. The winch operator was directed by the deck watch leader to raise the package, the squirt boom and rosette were extended outboard and the package quickly lowered into the water. The tag lines were removed and the package was lowered to 10 meters, by which time the sensor pumps had turned on. The winch operator was then directed to bring the package back to the surface (0 winch wireout) and to descend to 50 meters. At 50 meters the winch operator transfered control to a winch station in the computer lab. The deck watch leader operated the winch for the remainder of the down cast and the up cast to 50 meters. Control was then returned to the winch operator for package recovery.

Each rosette cast was usually lowered to 1000 meters, using the CTD pressure to determine distance.

During the up cast the deck watch leader was directed to stop the winch at each bottle trip depth. The CTD console operator waited 15 seconds before tripping a bottle to insure the package wake had dissipated and the bottles were flushed, then an additional 15 seconds after receiving the trip confirmation to allow the SBE35RT temperature sensor time to make a measurement. This procedure was modified prior to cast 38/1, extending the initial waiting period to 30 seconds to attempt to reduce the variance of CTD residual differences with check samples and secondary sensors. Once a bottle had been closed, the deck watch leader was directed to haul in the package to the next bottle stop.

Standard sampling depths were used throughout CLIMODE-2. These standard depths were staggered every other station.

Recovering the package at the end of the deployment was essentially the reverse of launching, with the additional use of poles and snap-hooks to attach tag lines. The rosette was secured on deck under the block for sampling. The bottles and rosette were examined before samples were taken, and anything unusual noted on the sample log.

Each bottle on the rosette had a unique serial number. This bottle identification was maintained independently of the bottle position on the rosette, which was used for sample identification. No bottles were replaced on this cruise, but various parts of bottles were occasionally changed or repaired.

Routine CTD maintenance included soaking the conductivity and DO sensors in fresh water between casts to maintain sensor stability. Rosette maintenance was performed on a regular basis. O-rings were changed as necessary and bottle maintenance was performed each day to insure proper closure and sealing. Valves were inspected for leaks and repaired or replaced as needed.

1.2. Underwater Electronics Packages

CTD data were collected with a SBE9*plus* CTD (ODF #777). This instrument provided pressure, dual temperature (SBE3), dual conductivity (SBE4), dissolved oxygen (SBE43), fluorometer (SeaPoint) and altimeter (Simrad 807) channels. The CTD supplied a standard SBE-format data stream at a data rate of 24 frames/second.

Sea-Bird SBE32 24-place Carousel Water Sampler	S/N 3239801-0527
Sea-Bird SBE35RT Digital Reversing Thermometer	S/N 3528706-0035
Sea-Bird SBE9*plus* CTD	S/N 09P21561-0777
Paroscientific Digiquartz Pressure Sensor	S/N 88907
Sea-Bird SBE3*plus* Temperature Sensor	S/N 03P-4307 (Primary)
Sea-Bird SBE3*plus* Temperature Sensor	S/N 03P-2322 (Secondary)
Sea-Bird SBE4C Conductivity Sensor	S/N 04-3057 (Primary)
Sea-Bird SBE4C Conductivity Sensor	S/N 04-2819 (Secondary, 1/1-8/1)
Sea-Bird SBE4C Conductivity Sensor	S/N 04-2765 (Secondary, 9/1-52/1)
Sea-Bird SBE43 DO Sensor	S/N 43-0060
SeaPoint Fluorometer	S/N SCF2748
Simrad 807 Altimeter	S/N 9604051

Table 1.2.0 CLIMODE-2 Rosette Underwater Electronics.

The CTD was outfitted with dual pumps. Primary temperature, conductivity and dissolved oxygen were plumbed on one pump circuit and secondary temperature and conductivity on the other. The sensors were deployed vertically. The primary temperature and conductivity sensors (T1 #03P-4307 and C1 #04-2322) were used for reported CTD temperatures and conductivities on all casts. The secondary temperature and conductivity sensors were used for calibration checks.

The SBE9*plus* CTD and SBE35RT temperature sensor were both connected to the SBE32 24-place pylon providing for single-conductor sea cable operation. The sea cable armor was used for ground (return). Power to the SBE9*plus* CTD (and sensors), SBE32 pylon, SBE35RT and Simrad 807 altimeter was provided through the sea cable from the SBE11*plus* deck unit in the main lab.

1.3. Navigation and Bathymetry Data Acquisition

Navigation data were acquired at 1-second intervals from the ship's Trimble P-Code GPS receiver by one of the Linux workstations beginning January 18.

Bathymetric data from the ship's multibeam echosounder system (Seabeam 2100) were also logged and archived independently.

1.4. CTD Data Acquisition and Rosette Operation

The CTD data acquisition system consisted of an SBE-11*plus* (V2) deck unit and two networked generic PC workstations running Fedora Core Linux. Each PC workstation was configured with a color graphics display, keyboard, trackball and DVD+RW drive. One of the systems also had 8 additional RS-232 ports via a Comtrol Rocketport PCI serial controller. The systems were connected through a 100BaseTX ethernet switch, which was also connected to the ship's network. These systems were available for real-time operational and CTD data displays, and provided for CTD and hydrographic data management and backup.

One of the workstations was designated the CTD console and was connected to the CTD deck unit via RS-232. The CTD console provided an interface and operational displays for controlling and monitoring a CTD deployment and closing bottles on the rosette.

CTD deployments were initiated by the console watch after the ship had stopped on station. The watch maintained a console operations log containing a description of each deployment, a record of every attempt to close a bottle and any pertinent comments. The deployment and acquisition software presented a short dialog instructing the operator to turn on the deck unit, examine the on screen CTD data displays and to notify the deck watch that this was accomplished.

Once the deck watch had deployed the rosette, the winch operator would begin the descent. The rosette was lowered to 10 meters, raised back to the surface then lowered to 50 meters. This procedure was adopted to allow the immersion-activated sensor pumps time to start and flush the sensors. At 50 meters winch control was transfered to the deck watch leader in the computer lab.

Profiling rates were frequently dictated by sea conditions but never exceeded 60m/minute.

The progress of the deployment and CTD data quality were monitored through interactive graphics and operational displays. Bottle trip locations were transcribed onto the console and sample logs. The sample log would later be used as an inventory of samples drawn from the bottles.

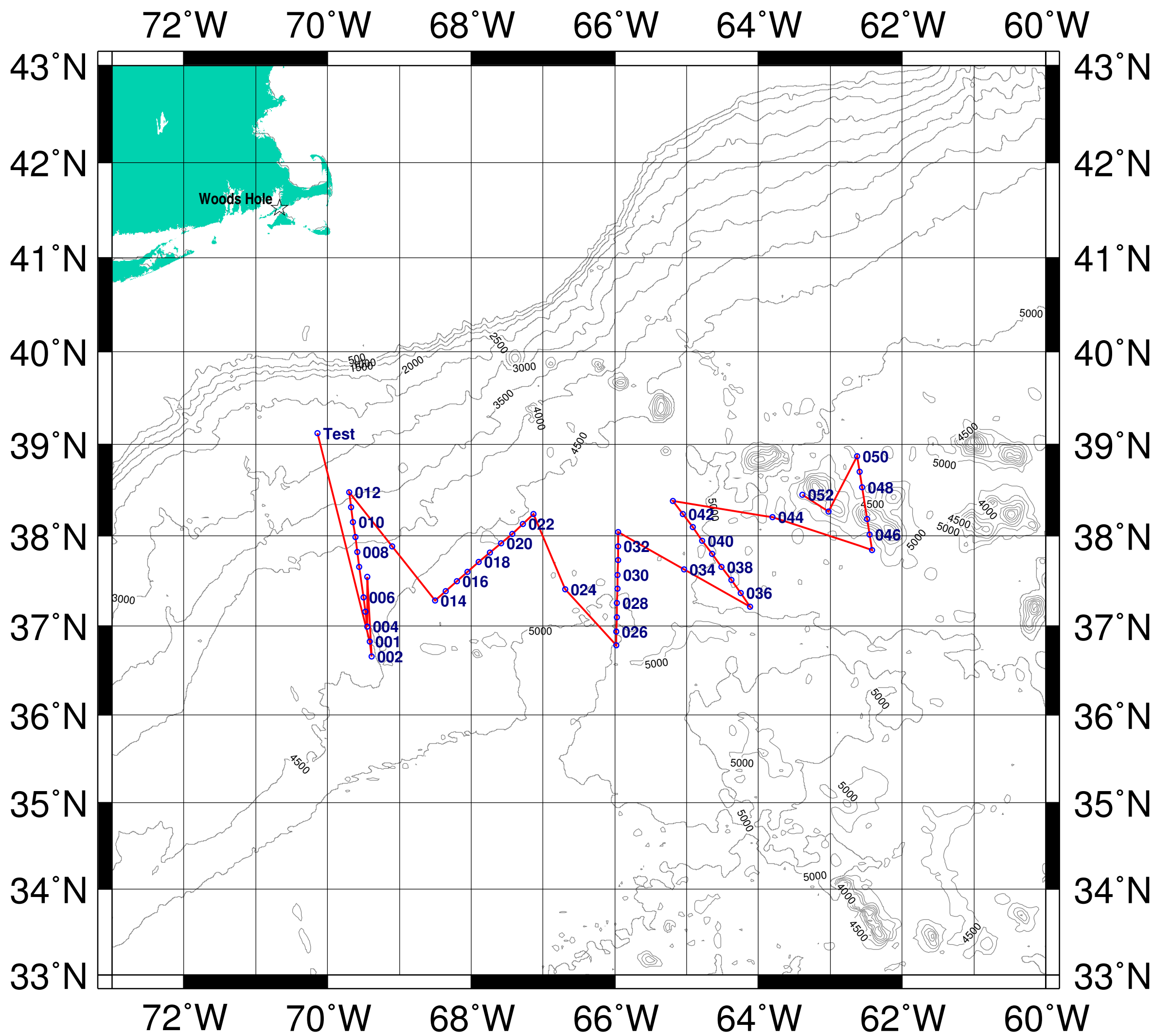
Bottles were closed on the up cast by operating an on-screen control. The deck watch leader was given a target wire-out for the bottle stop, proceeded to that depth and stopped. Bottles were tripped at least 15 seconds after stopping to allow the rosette wake to dissipate and the bottles to flush. This wait time was extended starting with cast 38/1 to 30 seconds to attempt to reduce the variance of CTD residual differences. The deck watch leader was instructed to proceed to the next bottle stop at least 10 seconds after closing bottles to allow the SBE35RT temperature sensor time to make a measurement.

At 50 meters on the up cast control was returned to the winch operator for package recovery. After the last bottle was closed, the console operator directed the deck watch to bring the rosette on deck. Once on deck, the console operator terminated the data acquisition, turned off the deck unit and assisted with rosette sampling.

1.5. CTD Data Processing

The shipboard CTD data acquisition was the first stage in shipboard processing. The raw CTD data were converted to engineering units, filtered, response-corrected, calibrated and decimated to a more manageable 0.5 second time-series. The laboratory calibrations for pressure, temperature and conductivity were applied at this time. The 0.5 second time-series data were used for real-time graphics during deployments, and were the source for CTD pressure and temperature associated with each rosette bottle. Both the raw 24hz data and the 0.5 second time-series were stored for subsequent processing.

At the completion of a deployment a series of processing steps were performed automatically. The 0.5 second time-series data were checked for consistency, clean sensor response and calibration shifts. A 2 decibar pressure-series was then generated from the down cast. Both the 2 decibar pressure-series and 0.5 second time-series data were made available for downloading, plotting and reporting on the shipboard cruise website.



climode2 Cruise Track 2006-01-29 05:19

CTD data were routinely examined for sensor problems, calibration shifts and deployment or operational problems. The primary and secondary temperature sensors (SBE 3) were compared to each other and to the SBE35 temperature sensor. CTD conductivity sensors (SBE 4) were compared and calibrated by examining differences between CTD and check-sample conductivity values. The CTD dissolved oxygen sensor data were calibrated to check-sample data. Additional TS and theta-O_2 comparisons were made between down and up casts as well as with adjacent deployments. Vertical sections were made of the various properties derived from sensor data and checked for consistency.

Few CTD acquisition and processing problems were encountered during CLIMODE-2. Casts 16/1 and 17/1 had problems with the primary pump turning off during the downcast that was traced to an intermittent O2 sensor cable. The up cast data were processed for these casts. Cast 40/1 had a problem in T1 and T2 when entering the water that was traced to the primary conductivity UW cable. The graphics display on the CTD acquisition system froze during 48/1 and was traced to a graphics card driver which was subsequently updated. The CTD data acquisition was unaffected.

A total of 54 casts were made (including 1 test cast and 1 aborted cast). The 24-place 2.5-liter rosette and CTD #777 were used on all casts.

1.6. CTD Sensor Laboratory Calibrations

Laboratory calibrations of the CTD pressure, temperature, conductivity, dissolved oxygen and the SBE35RT Digital Reversing Thermometer sensors were performed prior to CLIMODE-2. The calibration dates are listed in table 1.6.0.

Sensor	S/N	Calibration Date	Calibration Facility
Paroscientifi c Digiquartz Pressure	88907	12-January-05	SIO/ODF
Sea-Bird SBE3*plus* T1 Temperature	03P-4307	12-December-05	SIO/ODF
Sea-Bird SBE3*plus* T2 Temperature	03P-2322	12-December-05	SIO/ODF
Sea-Bird SBE4C C1 Conductivity	04-3057	7-December-05	SBE
Sea-Bird SBE4C C2 Conductivity	04-2819	29-December-05	SBE
Sea-Bird SBE4C C2 Conductivity	04-2765	29-December-05	SBE
Sea-Bird SBE43 Dissolved Oxygen	43-0060	N/A	SBE
Sea-Bird SBE35RT Digital Reversing Thermometer	3528706-0035	18-May-05	SIO/ODF

Table 1.6.0 CLIMODE-2 CTD sensor laboratory calibrations.

1.7. CTD Shipboard Calibration Procedures

CTD #777 was used for all CLIMODE-2 casts. The CTD was deployed with all sensors and pumps aligned vertically, as recommended by SBE. The primary temperature and conductivity sensors (T1 & C1) were used for all reported CTD data on all casts, the secondary sensors (T2 & C2) serving as calibration checks. The SBE35RT Digital Reversing Thermometer (S/N 3528706-0035) served as an independent calibration check for T1. *In-situ* salinity and dissolved O_2 check samples collected during each cast were used to calibrate the conductivity and dissolved O_2 sensors.

The variability of the environment that was observed on most deployments made sensor and check sample comparisons somewhat problematic. Since no deep check samples were collected, metrics of variability had to be inferred from sensor comparisons.

1.7.1. CTD Pressure

The Paroscientifi c Digiquartz pressure transducer (S/N 88907) was calibrated in January 2005 at the SIO/STS Calibration Facility. Calibration coeffi cients derived from the calibration were applied to raw pressures during each cast. Residual pressure offsets (the difference between the fi rst and last submerged pressures) were examined to check for calibration shifts. All were < 0.5db, and the sensor exhibited < 0.2 db offset shift over the period of use. No additional adjustments were made to the calculated pressures.

1.7.2. CTD Temperature

A single primary temperature sensor (SBE 3, S/N 03P-4307) and secondary temperature sensor (SBE 3, S/N 03P-2322) served the entire cruise. Calibration coefficients derived from the pre-cruise calibrations were applied to raw primary and secondary temperatures during each cast.

Two independent metrics of calibration accuracy were examined. The primary and secondary temperatures were compared at each rosette trip, and the SBE35RT temperatures were compared to primary and secondary temperatures at each rosette trip.

Calibration accuracy was first examined by tabulating T1-T2 over a range of pressures (bottle trip locations) for each cast. These comparisons are summarized in figure 1.7.2.0.

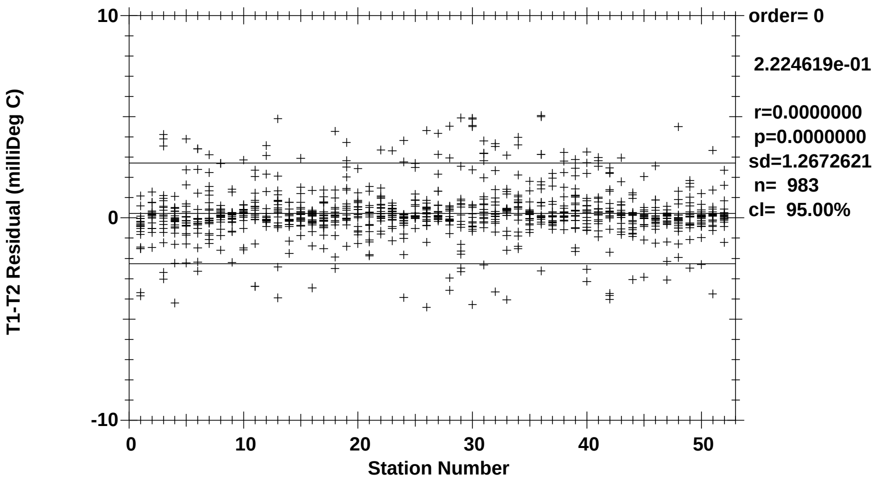


Figure 1.7.2.0 T1-T2 by station.

The 95% confidence limit for the mean of the differences is ±0.0025° C. The variance is relatively high in spite of the small spatial separation of the sensors (<0.5 meters) because of the gradients, current velocities and sea states encountered during deployments.

The SBE35RT Digital Reversing Thermometer is an internally-recording temperature sensor that operates independently of the CTD. It is triggered by the SBE32 pylon in response to a bottle trip. According to the Manufacturer's specifications the typical stability is 0.001° C/year. The SBE35RT on CLIMODE-2 was set to internally average over approximately one ship roll period (8 seconds). It was located equidistant between T1 and T2 with the sensing element aligned in a plane with the T1 and T2 sensing elements. The differences between the SBE35RT and T1 (primary CTD temperature) are summarized in figure 1.7.2.1, and between the SBE35RT and T2 (secondary CTD temperature) in figure 1.7.2.2.

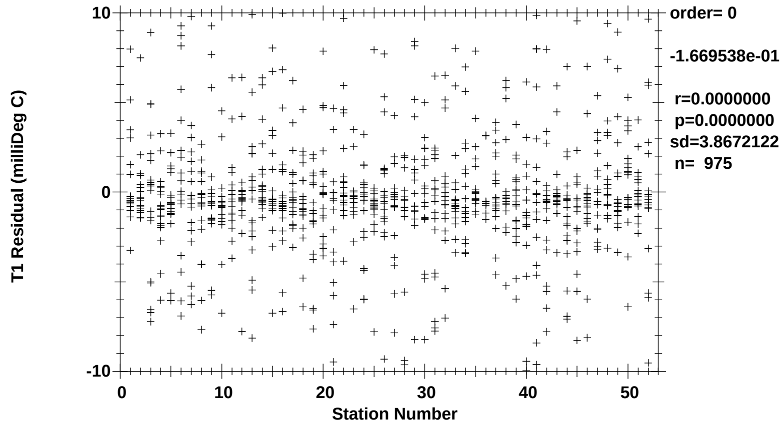


Figure 1.7.2.1 SBE35RT-T1 by station.

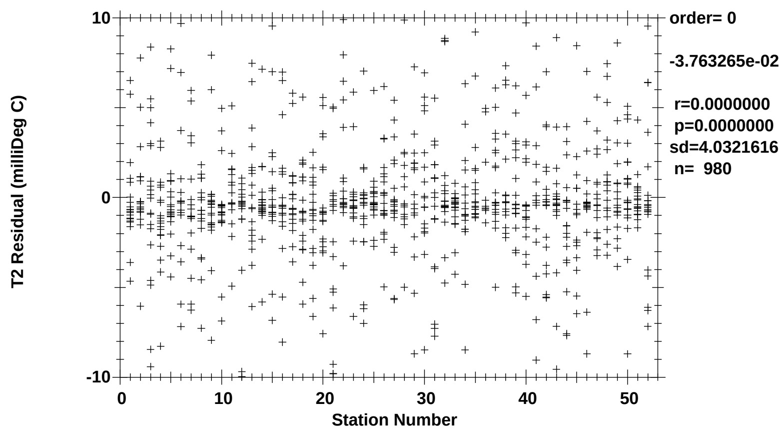


Figure 1.7.2.1 SBE35RT-T2 by station.

Post-cruise calibrations for all the temperature sensors are pending.

1.7.3. CTD Conductivity

A single primary conductivity sensor (SBE 4, S/N 04-3057) and two secondary conductivity sensors (SBE 4, S/N 04-2819 1/1-8/1, S/N 04-2765 9/1-52/1) served the entire cruise. Conductivity sensor calibration coeffi cients derived from the pre-cruise calibrations were applied to raw primary and secondary conductivities.

Comparisons between the primary and secondary sensors and between each of the sensors to check sample conductivities (calculated from bottle salinities) were used to derive conductivity corrections. The fi rst secondary sensor (04-2819) had a 0.02 mS/cm offset relative to C1 initially, and may have been damaged or dropped. This offset grew to 0.03 mS/cm by cast 8/1 and the sensor was replaced. None of the sensors exhibited a secondary pressure response over the pressure range encountered on CLIMODE-2.

Since no deep check samples were collected, T1-T2 at bottle trip locations was employed as a metric of environmental variability to qualify the selection of salinity check samples used for calibration fi tting. The coherence of this relationship is illustrated in fi gure 1.7.3.0.

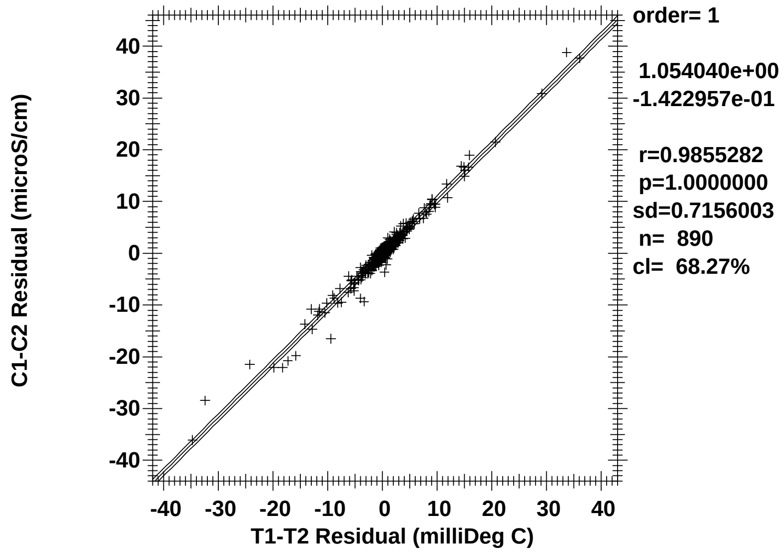


Figure 1.7.3.0 C1-C2 by T1-T2, all points.

C1 was determined to have a slight drift amounting to a +0.0019 mS/cm offset over the cruise.

The comparison of the primary and secondary conductivity sensors by cast after applying shipboard corrections is summarized in figure 1.7.3.1. The first (unstable) C2 (casts 1/1-1/8) was not used for this comparison.

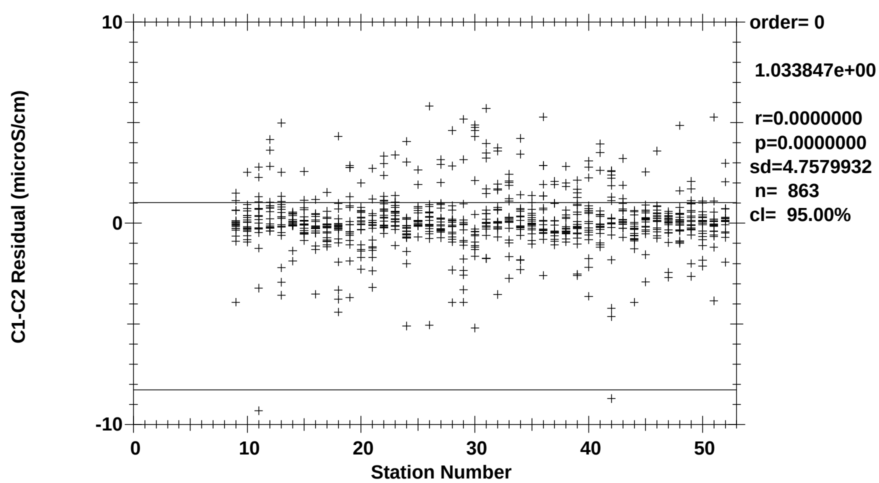


Figure 1.7.3.1 C1 and C2 conductivity differences by cast (-0.005° C≤T1-T2≤0.005° C).

Salinity residuals after applying shipboard T1/C1 corrections are summarized in figures 1.7.3.2 through 1.7.3.4.

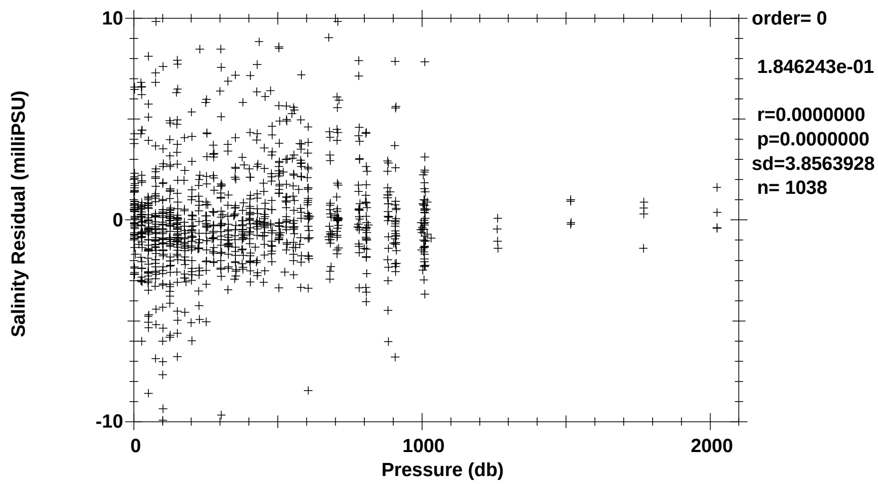


Figure 1.7.3.2 salinity residuals by pressure (all points).

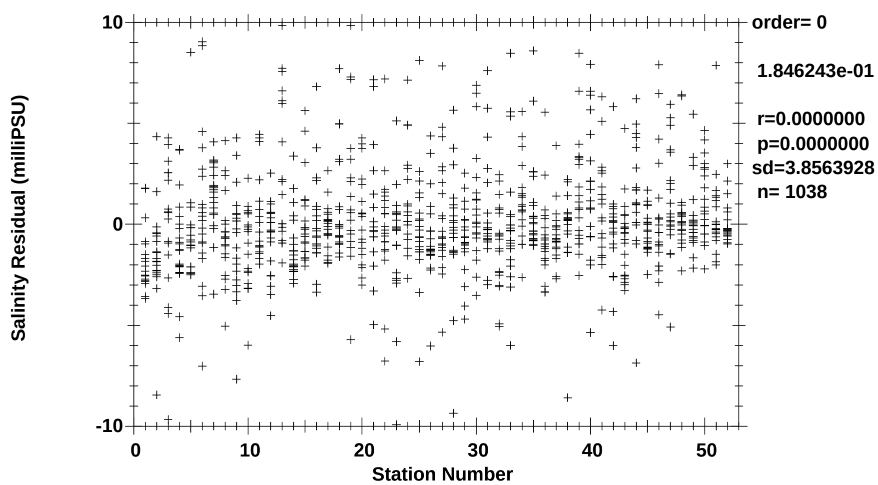


Figure 1.7.3.3 salinity residuals by cast (all points).

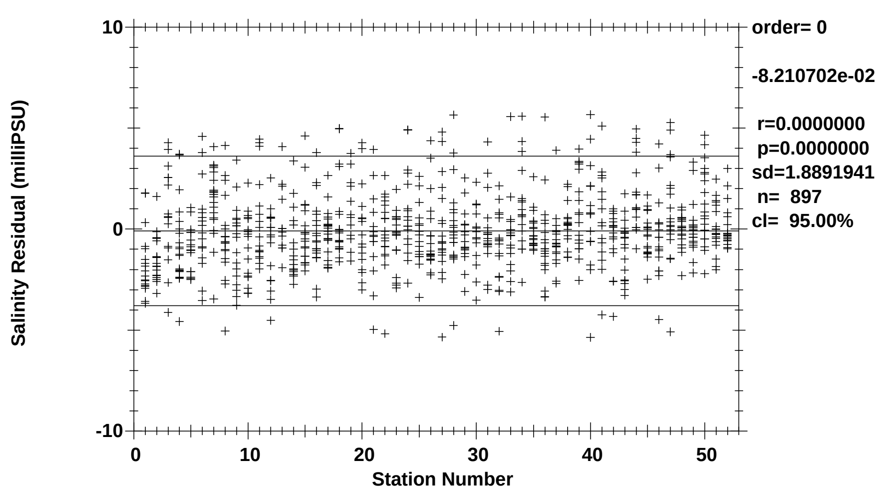


Figure 1.7.3.4 salinity residuals by cast (-0.005° C≤T1-T2≤0.005° C).

Figure 1.7.3.4 represents an estimate of the salinity accuracy on CLIMODE-2. The 95% confidence limit is ±0.0035 PSU relative to the bottle salts.

1.7.4. CTD Dissolved Oxygen

A single SBE43 dissolved O_2 (DO) sensor was used during this cruise (S/N 43-0060). The sensor was plumbed into the primary T1/C1 pump circuit after C1.

The DO sensors were calibrated to dissolved O_2 check samples at bottle stops by calculating CTD dissolved O_2 then minimizing the residuals using a non-linear least-squares fitting procedure. The fitting procedure determined the calibration coefficients for the sensor model conversion equation, and was accomplished in stages. The time constants for the exponential terms in the model were first determined for each sensor. These time constants are sensor-specific but applicable to an entire cruise. Next, casts were fit individually to check sample data. The resulting calibration coefficients were then smoothed and held constant during a refit to determine sensor slope and offset.

Standard and blank values for bottle oxygen data were smoothed and the bottle oxygen recalculated prior to the final fitting of CTD oxygen.

The residuals are shown in figures 1.7.4.0-1.7.4.2.

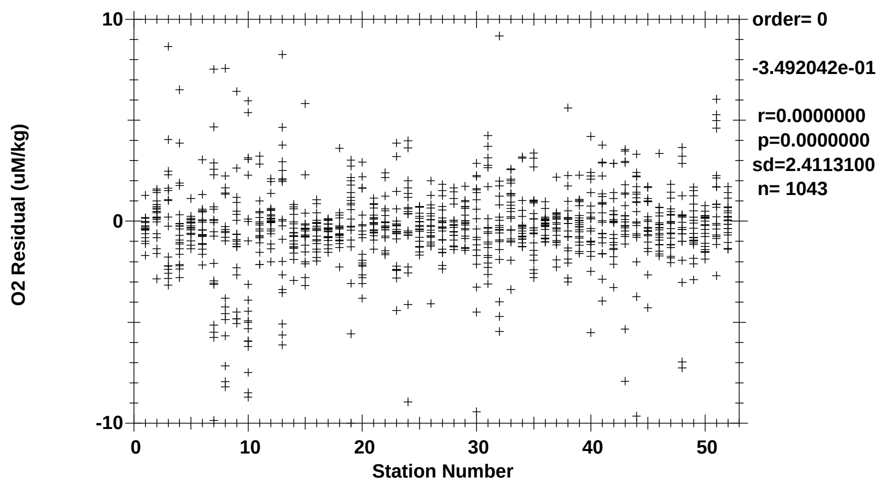


Figure 1.7.4.0 O_2 residuals by cast (all points).

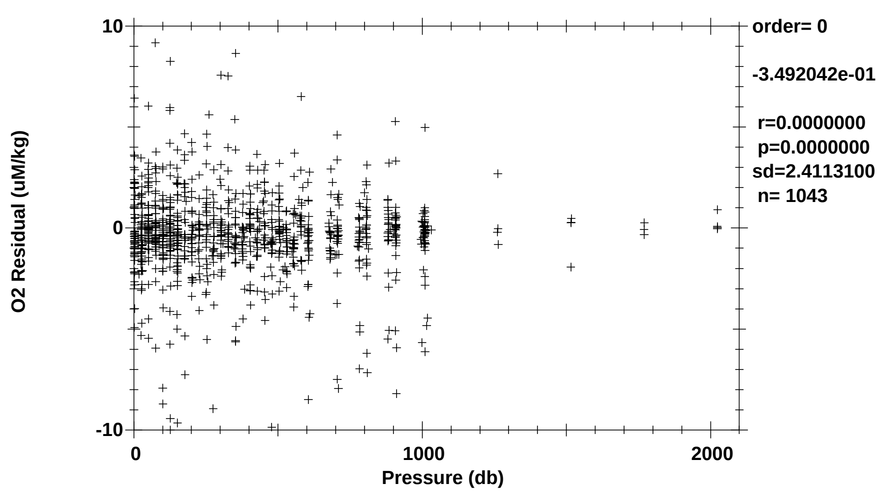


Figure 1.7.4.1 O_2 residuals by pressure (all points).

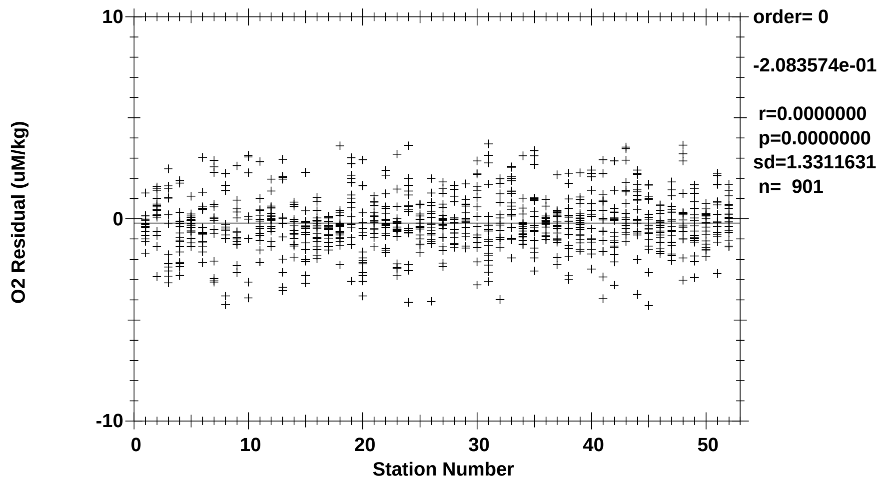


Figure 1.7.4.2 O_2 residuals by cast (-0.005° C≤T1-T2≤0.005° C).

The standard deviations of 2.41 uM/kg for all oxygens and 1.33 uM/kg for low-gradient oxygens are only presented as general indicators of goodness of fit. ODF makes no claims regarding the precision or accuracy of CTD dissolved O_2 data.

The general form of the ODF O_2 conversion equation for Clark cells follows Brown and Morrison [Brow78] and Millard [Mill82], [Owen85]. ODF models membrane and sensor temperatures with lagged CTD temperatures and a lagged thermal gradient. *In-situ* pressure and temperature are filtered to match the sensor response. Time-constants for the pressure response τ_p, two temperature responses τ_{Ts} and τ_{Tf}, and thermal gradient response τ_{dT} are fitting parameters. The thermal gradient term is derived by low-pass filtering the difference between the fast response (T_f) and slow response (T_s) temperatures. This term is SBE43-specific and corrects a non-linearity introduced by analog thermal compensation in the sensor. The O_c gradient, dO_c/dt, is approximated by low-pass filtering 1st-order O_c differences. This gradient term attempts to correct for reduction of species other than O_2 at the sensor cathode. The time-constant for this filter, τ_{og}, is a fitting parameter. Dissolved O_2 concentration is then calculated:

$$O_{2ml/l} = [c_1 O_c + c_2] \cdot f_{sat}(S,T,P) \cdot e^{(c_3 P_l + c_4 T_f + c_5 T_s + c_6 \frac{dO_c}{dt} + c_7 dT)} \qquad (1.7.4.0)$$

where:

$O_{2ml/l}$	= Dissolved O_2 concentration in ml/l;
O_c	= Sensor current (μamps);
$f_{sat}(S,T,P)$	= O_2 saturation concentration at S,T,P (ml/l);
S	= Salinity at O_2 response-time (PSUs);
T	= Temperature at O_2 response-time (° C);
P	= Pressure at O_2 response-time (decibars);
P_l	= Low-pass filtered pressure (decibars);
T_f	= Fast low-pass filtered temperature (° C);
T_s	= Slow low-pass filtered temperature (° C);
$\frac{dO_c}{dt}$	= Sensor current gradient (μamps/secs);
dT	= low-pass filtered thermal gradient (T_f - T_s).

1.8. Bottle Sampling

At the end of each rosette deployment water samples were drawn from the bottles in the following order:

- O_2
- Dissolved Inorganic Carbon (DIC)
- N_{15}
- Nutrients
- Salinity

The correspondence between individual sample containers and the rosette bottle position (1-24) from which the sample was drawn was recorded on the sample log for the cast. This log also included any comments or anomalous conditions noted about the rosette and bottles. One member of the sampling team was designated the *sample cop*, whose sole responsibility was to maintain this log and insure that sampling progressed in the proper drawing order.

Normal sampling practice included opening the drain valve and then the air vent on the bottle, indicating an air leak if water escaped. This observation together with other diagnostic comments (e.g., "lanyard caught in lid", "valve left open") that might later prove useful in determining sample integrity were routinely noted on the sample log. Drawing oxygen samples also involved taking the sample draw temperature from the bottle. The temperature was noted on the sample log and was sometimes useful in determining leaking or mis-tripped bottles.

Once individual samples had been drawn and properly prepared, they were distributed for analysis. Oxygen, nutrient and salinity analyses were performed on computer-assisted (PC) analytical equipment networked to the data processing computer for centralized data management.

1.9. Bottle Data Processing

Water samples collected and properties analyzed shipboard were managed centrally in a relational database (PostgreSQL-8.0.3) run on one of the Linux workstations. A web service (OpenAcs-5.2.2 and AOLServer-4.0.10) front-end provided ship-wide access to CTD and water sample data. Web-based facilities included on-demand arbitrary property-property plots and vertical sections as well as data uploads and downloads.

The Sample Log (and any diagnostic comments) was entered into the database once sampling was completed. Quality flags associated with sampled properties were set to indicate that the property had been sampled, and sample container identifications were noted where applicable (e.g., oxygen flask number).

Analytical results were provided on a regular basis by the various analytical groups and incorporated into the database. These results included a quality code associated with each measured value and followed the coding scheme developed for the World Ocean Circulation Experiment (WOCE) Hydrographic Programme (WHP) [Joyc94].

Various consistency checks and detailed examination of the data continued throughout the cruise.

1.10. Salinity Analysis

Equipment and Techniques

A single Guildline Autosal Model 8400A salinometer (S/N 48-263), located in the forward analytical lab, was used for all salinity measurements. The salinometer was modified by ODF to contain an interface for computer-aided measurement. The water bath temperature was set and maintained at a value near the laboratory air temperature (24° C).

The salinity analyses were performed after samples had equilibrated to laboratory temperature, usually within 6-8 hours after collection. The salinometers were standardized for each group of analyses (usually 1-2 casts, up to ~40 samples) using at least two fresh vials of standard seawater per group. Salinometer measurements were made by computer, the analyst prompted by the software to change samples and flush.

Sampling and Data Processing

1072 salinity measurements were made and approximately 100 vials of standard water (SSW) were used.

Salinity samples were drawn into 200 ml Kimax high-alumina borosilicate bottles, which were rinsed three times with sample prior to filling. The bottles were sealed with custom-made plastic insert thimbles and Nalgene screw caps. This assembly provides very low container dissolution and sample evaporation. Prior to sample collection, inserts were inspected for proper fit and loose inserts replaced to insure an airtight seal. The draw time and equilibration time were logged for all casts. Laboratory temperatures were logged at the beginning and end of each run.

PSS-78 salinity [UNES81] was calculated for each sample from the measured conductivity ratios. The difference (if any) between the initial vial of standard water and the next one run as an unknown was applied as a linear function of elapsed run time to the data. The corrected salinity data were then incorporated into the cruise database.

Insufficient sample equilibration times were sometimes a problem as was having to collect samples on deck. The estimated accuracy of bottle salinities run at sea is usually better than ±0.002 PSU relative to the particular standard seawater batch used. The 95% confidence limit for residual differences between the bottle salinities and calibrated CTD salinity relative to SSW batch P-145 was ±0.007 PSU for all salinities, and ±0.0035 PSU for salinities collected low gradients.

Laboratory Temperature

The temperature in the salinometer laboratory varied from 23.2 to 26.1° C, during the cruise. The air temperature change during any particular run varied from -1.6 to +1.2° C.

Standards

IAPSO Standard Seawater Batch P-145 was used to standardize for casts 1/1-2/1 and 8/1-52/1. Batch P146 was used to standardize for 3/1-7/1.

1.11. Oxygen Analysis

Equipment and Techniques

Dissolved oxygen analyses were performed with an ODF-designed automated oxygen titrator using photometric end-point detection based on the absorption of 365nm wavelength ultra-violet light. The titration of the samples and the data logging were controlled by PC software. Thiosulfate was dispensed by a Dosimat 665 buret driver fitted with a 1.0 ml buret. ODF used a whole-bottle modified-Winkler titration following the technique of Carpenter [Carp65] with modifications by Culberson *et al.* [Culb91], but with higher concentrations of potassium iodate standard (~0.012N) and thiosulfate solution (~55 gm/l). Pre-made liquid potassium iodate standards were run once a day approximately every 4 stations, unless changes were made to system or reagents. Reagent/distilled water blanks were determined every day or more often if a change in reagents required it to account for presence of oxidizing or reducing agents. The auto-titrator performed well.

Sampling and Data Processing

1073 oxygen measurements were made. Samples were collected for dissolved oxygen analyses soon after the rosette was brought on board. Using a Tygon and silicone drawing tube, nominal 125ml volume-calibrated iodine flasks were rinsed 3 times with minimal agitation, then filled and allowed to overflow for at least 3 flask volumes. The sample drawing temperatures were measured with a small platinum resistance thermometer embedded in the drawing tube. These temperatures were used to calculate uM/kg concentrations, and as a diagnostic check of bottle integrity. Reagents were added to fix the oxygen before stoppering. The flasks were shaken twice (10-12 inversions) to assure thorough dispersion of the precipitate, once immediately after drawing, and then again after about 20 minutes.

The samples were analyzed within 1-4 hours of collection, and the data incorporated into the cruise database.

Thiosulfate normalities were calculated from each standardization and corrected to 20° C. The 20° C normalities and the blanks were plotted versus time and were reviewed for possible problems.

The blanks and thiosulfate normalities for each batch of thiosulfate were smoothed during the cruise and the oxygen values recalculated.

A noisy endpoint was occasionally acquired during the analyses, usually due to small waterbath contaminations. These endpoints were checked and recalculated using STS/ODF designed software.

Volumetric Calibration

Oxygen flask volumes were determined gravimetrically with degassed deionized water to determine flask volumes at STS/ODF's chemistry laboratory. This is done once before using flasks for the first time and periodically thereafter when a suspect volume is detected. The volumetric flasks used in preparing standards were volume-calibrated by the same method, as was the 10 ml Dosimat buret used to dispense standard iodate solution.

Standards

Liquid potassium iodate standards were prepared in 6 liter batches and bottled in sterile glass bottles at STS/ODF's chemistry laboratory prior to the expedition. The normality of the liquid standard was determined at ODF by calculation from weight. Two standard batches were used during CLIMODE-2. Potassium iodate was obtained from Acros Chemical Co. and was reported by the supplier to be 98% pure. The second standard was supplied by Alfa Aesar and has a reported purity of 99.4-100.4%. Tests at ODF indicate no difference between these 2 batches. All other reagents were "reagent grade" and were tested for levels of oxidizing and reducing impurities prior to use.

1.12. Nutrient Analysis

Equipment and Techniques

Nutrient analyses (phosphate, silicate, nitrate and nitrite) were performed on an ODF-modified 4-channel Technicon AutoAnalyzer II, generally within one to two hours after sample collection.

The methods used are described by Gordon *et al.* [Gord92]. The analog outputs from each of the four colorimeter channels were digitized and logged automatically by computer (PC) at 2-second intervals.

Silicate was analyzed using the technique of Armstrong *et al.* [Arms67]. An acidic solution of ammonium molybdate was added to a seawater sample to produce silicomolybdic acid which was then reduced to silicomolybdous acid (a blue compound) following the addition of stannous chloride. Tartaric acid was also added to impede PO_4 color development. The sample was passed through a 15mm flowcell and the absorbence measured at 660nm.

A modification of the Armstrong *et al.* [Arms67] procedure was used for the analysis of nitrate and nitrite. For the nitrate analysis, the seawater sample was passed through a cadmium reduction column where nitrate was quantitatively reduced to nitrite. Sulfanilamide was introduced to the sample stream followed by N-(1-naphthyl)ethylenediamine dihydrochloride which coupled to form a red azo dye. The stream was then passed through a 15mm flowcell and the absorbence measured at 540nm. The same technique was employed for nitrite analysis, except the cadmium column was bypassed, and a 50mm flowcell was used for measurement.

Phosphate was analyzed using a modification of the Bernhardt and Wilhelms [Bern67] technique. An acidic solution of ammonium molybdate was added to the sample to produce phosphomolybdic acid, then reduced to phosphomolybdous acid (a blue compound) following the addition of dihydrazine sulfate. The reaction product was heated to ~55° C to enhance color development, then passed through a 50mm flowcell and the absorbence measured at 820nm.

Explicit corrections for *carryover* in nutrient analyses are not made. In a typical AutoAnalyzer system, sample to sample carryover is ˜ 1-2% of the concentration difference between samples. This effect is minimized by running samples in order of increasing depth such that concentration differences between samples are minimized. The initial surface samples could be run twice or a low nutrient sea water sample run ahead of the surface sample since these samples generally follow standard peaks.

Sampling and Data Processing

1049 nutrient samples were analyzed.

Nutrient samples were drawn into 45 ml polypropylene, screw-capped "oak-ridge type" centrifuge tubes. The tubes were cleaned with 10% HCl and rinsed with sample 2-3 times before filling. Standardizations were performed at the beginning and end of each group of analyses (typically one cast, up to 36 samples) with an intermediate concentration mixed nutrient standard prepared prior to each run from a secondary standard in a low-nutrient seawater matrix. The secondary standards were prepared aboard ship by dilution from primary standard solutions. Dry standards were pre-weighed at the laboratory at ODF, and transported to the vessel for dilution to the primary standard. Sets of 7 different standard concentrations were analyzed periodically to determine any deviation from linearity as a function of absorbence for each nutrient analysis. A correction for non-linearity was applied to the final nutrient concentrations when necessary. A correction for the difference in refractive indices of pure distilled water and seawater was periodically determined and applied where necessary. The pump tubing was changed 1 time.

After each group of samples was analyzed, the raw data file was processed to produce another file of response factors, baseline values, and absorbences. Computer-produced absorbence readings were checked for accuracy against values taken from a strip chart recording. The data were then added to the cruise database.

Nutrients, reported in micromoles per kilogram, were converted from micromoles per liter by dividing by sample density calculated at 1 atm pressure (0 db), *in situ* salinity, and a per-analysis measured laboratory temperature.

Standards

Primary standards for silicate (Na_2SiF_6) and nitrite ($NaNO_2$) were obtained from Johnson Matthey Chemical Co.; the supplier reported purities of >98% and 97%, respectively. Primary standards for nitrate (KNO_3) and phosphate (KH_2PO_4) were obtained from Fisher Chemical Co.; the supplier reported purities of 99.999% and 99.999%, respectively. The efficiency of the cadmium column used for nitrate was monitored throughout the cruise and ranged from 99-100%.

No major problems were encountered with the measurements. The temperature of the laboratory used for the analyses ranged from 23.5° C to 26.5° C, but was relatively constant during any one station (±1.5° C).

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