Cruise report: *R/V Oceanus* cruise no. 411

Woods Hole to Woods Hole
April 26 – May 4, 2005

Station W: Continuing the measurement program

Background

R/V Oceanus cruise number 411 contributed to a sustained research program funded by the U.S. National Science Foundation that is investigating the characteristics and consequences of interannual variations in the Northwest Atlantic's Deep Western Boundary Current. The overturning circulation of the Northwest Atlantic Ocean at mid-latitude involves poleward transport of warm water by the Gulf Stream and equatorward flow of colder intermediate and deep waters. Comprehension of how these limbs of the global current system and their associated regional recirculations vary on decadal time scale is incomplete. In particular, we lack understanding of how interannual variations in air-sea exchange and water mass modification at high latitudes are transmitted equatorward, and what impacts or feedbacks such signals may have for the Atlantic- wide circulation. Limiting advance in understanding is the lack of long, well-resolved records to document interannual signals in water properties, stratification, and transport of the Deep Western Boundary Current (DWBC) system. Importantly, anomalies created at subpolar latitudes may be profoundly altered or even blocked by the Gulf Stream. Conversely, subpolar anomalies may influence the position, strength, and/or stability of the Stream, and in turn affect patterns of air-sea exchange throughout the North Atlantic. These basic questions motivate the present research effort to observe the DWBC south of New England. Our study is documenting for an initial four-year period, the temperature, salinity, tracer, and velocity variations of the DWBC upstream of its Gulf Stream cross-under point by maintaining a 5-element moored array over the slope south of Woods Hole, and occupying a hydrographic section along this line semi-annually (Figure 1). A companion research program by U.K. investigators is sampling bottom pressure variability at each of our mooring sites (plus a shallower site) and along two additional measurement lines to the north. The array south of New England (named Station W in memory of L. Valentine Worthington) will quantify changes in DWBC water properties, stratification (potential vorticity), and transport. The high-spatial-resolution sampling possible from the ship will help verify that the array resolves interannual signals as well as return water samples for at-sea and shoreside tracer analyses. In addition to raw observations, value-added products such as time series of core properties and transport by water mass will be produced and distributed. We are furthermore encouraging other researchers to build on the Station W infrastructure to augment the fields being sampled. Equally important, as the program continues, the recovered data will be examined to determine whether a subset of the array is sufficient to index water property and transport variations in this area, and thus contribute to a long-term ocean observing system.

The full moored array was deployed during *R/V Oceanus* cruise 401 in April-May, 2004 during which a line of hydrographic stations along the array and extending south across the Gulf Stream was collected. The section was reoccupied from the *R/V Cape Hatteras* in September 2004. The goals of cruise Oc411 included recovery and redeployment of three moorings in the array, deployment of a 4th mooring along the measurement line in the axis of the Gulf Stream (an activity supported by WHOI's Ocean and Climate Change Institute), and reoccupation of the hydrographic section. Mooring and station positions are displayed in Figure 1 with details provided in Tables 1 and 2.

The three moorings serviced on Oc411 supported Moored Profiler instruments as well as fixed-depth current meters (near the bottom) and temperature/conductivity sensors (top and bottom of the profiler depth ranges). The adopted sampling scheme for the Profilers (burst sampling with 4 one-way profiles per burst, profiles in a burst starting every 9.5 hours and bursts spaced in time by 5 days) fully utilizes their battery supply in about one year, thus the requirement for annual servicing. The other two moorings in the array are fitted with discrete current meters and T/C recorders capable of operating for 2 years, as are the bottom pressure gauges. (Those systems will be turned around in 2006.) During Oc411 a new element in the array was deployed – a 6th conventional current meter mooring sited along Line W at the mean axis of the Gulf Stream. This mooring, proposed by Dr. Michael McCartney and named GUSTO-05, was funded by WHOI's Ocean and Climate Change Institute.

Under the Station W program, the parameters sampled at the hydrographic stations include continuous profiles of temperature, salinity and dissolved oxygen (obtained from the CTD system), velocity (from a shipboard and Lowered Acoustic Doppler Current Profiler systems) discrete water samples analyzed for salinity and oxygen (used to calibrate the CTD sensor data) and CFC's (F11, F12 and F113), and underway surface ocean and atmosphere parameters. In addition, water samples were collected and stored for subsequent shipment to Dr. John Smith (BIO, Canada) for analysis of I^{129} concentration.

Science party:

Chief scientist: J. Toole (WHOI)

Hydrographic sampling: R. Curry, M. Cook, J. Dunworth-Baker, M. Swartz, D. Wellwood, M. Hudspeth, (WHOI) Eugene Gorman and Guy Mathieu (LDEO);

Mooring operations: S. Worrilow, B. Hogue, L. Costello (WHOI); Andrew Cookson (UW/APL);

Observer: D. Murphy (author)

Cruise narrative:

R/V Oceanus arrived back at the WHOI pier on April 21 and loading of equipment for the Station W cruise began the following day. Loading was largely complete by 1700 on April 25, setting the stage for a 10 AM departure on April 26. [Note: all events in this section are reported in local Eastern Daylight Time.] After a very windy Monday, Tuesday dawned sunny and mild with weak winds. Lines were cast off at 10:15, a slight delay to give the Martha's Vineyard ferry time to clear the channel. The safety lecture was given by Chief Mate Diego Mello as we steamed south in Vineyard Sound. During the transit, the first mooring was wound on the deployment winch. Operationally, the plan was for each recovered mooring wire to be wound on top of the new wire for the replacement mooring. The used wire would then be off-spooled, leaving the winch ready to deploy the new mooring wire. This scheme was used for all three mooring turn-arounds conducted during Oc411.

Sea surface temperature imagery for the week prior to the cruise revealed a large southward meander in the Gulf Stream roughly aligned with the Line W moored array, with several more meanders visible to the east, figure 2. This structure persisted through the cruise, making for a rather anomalous cross section of the Gulf Stream as documented by our hydrographic data.

Sampling was initiated just after dinner with the first set of CTD stations (numbers 1-7) that extended from the 90-m isobath across the shelf break to 2100 m water depth. Conditions were fine for work through the night and into the morning of April 27, but increasing winds were forecast. *R/V Oceanus* arrived at the site of Mooring #1 at 0600 and recovery operations were initiated. The mooring and associated instrumentation were safely aboard by 1030. Operations then transitioned to deploying the replacement mooring. The buoyancy sphere and mooring chain were reused since they were all still in good condition. Based on an estimate of the local currents (weak), wind direction and the 3 hours required to payout the mooring, the ship was positioned 3.75 nm north of the target anchor site. The deployment began at 14:30 and was completed with anchor launch at 1812. During the deployment, the forecast front passed our position - winds increased to 30-35 knots causing a very steep and confused sea. With *Oceanus* riding low in the water, sea water frequently washed over the working deck making conditions for the mooring crew difficult. Due to their great skill, all the mooring instrumentation made it safely over the side. The mooring anchor was tracked acoustically (by ranging on the releases) until it settled on the bottom. Ironically, the winds and sea state relaxed shortly thereafter. Fatigued, cold and wet, the mooring team opted to wake early the following morning to wind the new wire for mooring # 3.

CTD operations resumed at 2000 with station 8, followed by occupation of stations 9 and 10 which put us on site for recovery of mooring # 3 at 0900 on April 28. As planned, the mooring team wound the new wire and made ready for the recovery and redeployment. The release was fired at 0946 and all of the gear was aboard by 1200. The original plan was to occupy CTD # 11 between the recovery and redeployment of mooring # 3. However, it was decided to conduct a test lowering of the acoustic releases needed for the remaining moorings during this period. Concurrent with the release test lowering, the used mooring wire was off-spooled from the winch and the instrumentation prepared. To establish the standoff position to begin the mooring deployment, a trial was conducted during which the vessel was pointed into the wind/seas at the desired 1-1.5 knots through the water and the velocity over the ground determined. Based on the estimated current set, *Oceanus* was positioned 5 nm west of the target anchor position to begin redeployment of mooring # 3. Seas were a bit lumpy and confused but much better than the day before. The deployment went smoothly; anchor over occurred at 2130.

Again, the mooring team opted to defer winding new wire until the following morning. CTD operations resumed by occupying station 11 adjacent to mooring 3 and then station 12. In order to position the ship close by mooring # 5 by mid-morning on April 29th, it was decided to skip station 13 until our return north. *Oceanus* arrived at the mooring site at 0930. One of the acoustic releases on the mooring failed to respond to deck unit interrogation signals, but the other performed as expected and was activated to effect recovery. (All of the Line W moorings are fitted with dual releases for safety.) Immediately after recovery of the mooring, CTD #14 was occupied; to save time, no repositioning was done. As done for the prior mooring, tests were conducted to establish the stand off position to begin the deployment. A site 6 nm NW of the target anchor spot was agreed to. However, shortly after the deployment operations began, it was discovered that the current set was significantly stronger than was estimated (opposing progress towards the target anchor site). Being limited to a safe tow speed of 1-2 knots through the water, a long deployment operation resulted. In the end, the anchor was dropped 2.7 nm from the target location (but in acceptable water depth). CTD operations continued overnight with stations 15 and 16.

April 30th dawned with weak winds (10-12 knots) and small seas. *Oceanus* arrived at the designated site for the Gusto-05 mooring deployment at 1000. As before, the mooring team got going early that morning to wind wire on the deployment winch and assemble all the other components. Despite the large number of discrete instruments on the mooring, the assembly and payout of the mooring went very smoothly; anchor launch was at 1623. After tracking the anchor to the bottom and disabling the releases, Oceanus was directed to CTD station 17.

With the mooring work completed, the science party transitioned to round-the-clock CTD work. Details of the station work completed on Oc411 are given in Table 2. Based on the ~400 nm track distance back to Woods Hole, it was decided to terminate the section with Station 22 at Lat.36.6^{o} N in order to return to port on May 4 as scheduled. The shipboard ADCP data suggested we had spanned the high velocity core of the Gulf Stream and Station 22 had a well-developed Eighteen Degree Water layer indicative of Sargasso Sea stratification. Terminating at Station 22 left sufficient time to occupy Station 13 during the return transit, which was completed just after breakfast on May 2. Arrival at the Woods Hole pier was at 815 on May 4.

Table 1: The Line W moored array, Spring 2005 – Spring 2006

Mooring 0: BPR

Lat: 38 44.3 N
Lon: 69 48.8 W
Bottom Depth: 1800 m

Mooring 1: MMP & BPR

Lat: 39 36.260 N
Lon: 69 42.997 W
Bottom Depth: 2244 m

Mooring 2: VACM's & BPR

Lat: 39 13.003 N
Lon: 69 26.699 W
Bottom Depth: 2737 m

Mooring 3: MMP & BPR

Lat: 38 50.698 N
Lon: 69 10.963 W
Bottom Depth: 3240 m

Mooring 4: VACM's & BPR

Lat: 38 25.466 N
Lon: 68 54.159 W
Bottom Depth: 3691 m

Mooring 5: MMP & BPR

Lat: 38 08.597 N
Lon: 68 37.601 W
Bottom Depth: 4125 m

Mooring 6: VACM's GUSTO-05
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Lat: 37 31.159
Lon: 68 16.998
Bottom Depth: 4676

* bottom depths have been corrected based on depth-averaged sound speed for adjacent CTD stations

MMP denotes a mooring supporting a McLane Moored Profiler instrument
VACM denotes a mooring fitted with multiple fixed-depth current meters
BPR denotes a bottom pressure gauge deployed separately at the site

Table 2: List of hydrographic stations occupied on Oc411

						POSITION		UNC	HT ABV	WIRE		# OF
		STN	DATE	TIME		LAT	LONG	DEPTH	BOTTOM	OUT	PMAX	BOTTLES
32OC411	W	1	042605	2303	BE	40 16.95 N	070 11.89 W					
32OC411	W	1	042605	2308	BO	40 16.93 N	070 11.82 W	93.6	10.2	82	82.6	1
32OC411	W	1	042605	2321	EN	40 16.86 N	070 11.59 W					
32OC411	W	2	042705	0031	BE	40 08.68 N	070 06.21 W					
32OC411	W	2	042705	0035	BO	40 08.76 N	070 06.28 W	120.4	10.2	109	109.8	6
32OC411	W	2	042705	0043	EN	40 08.63 N	070 06.38 W					
32OC411	W	3	042705	0158	BE	40 00.60 N	070 00.19 W					
32OC411	W	3	042705	0204	BO	40 00.66 N	070 00.22 W	164.6	9.2	153	154.6	7
32OC411	W	3	042705	0214	EN	40 00.79 N	070 00.30 W					
32OC411	W	4	042705	0313	BE	39 54.01 N	069 55.96 W					
32OC411	W	4	042705	0331	BO	39 54.02 N	069 56.34 W	595.6	6.5	656	639.9	11
32OC411	W	4	042705	0352	EN	39 53.97 N	069 56.81 W					
32OC411	W	5	042705	0443	BE	39 51.53 N	069 54.14 W					
32OC411	W	5	042705	0506	BO	39 51.67 N	069 54.49 W	995.0	7.0	1023	1007.0	13
32OC411	W	5	042705	0535	EN	39 51.88 N	069 54.89 W					
32OC411	W	6	042705	0632	BE	39 47.42 N	069 51.02 W					
32OC411	W	6	042705	0706	BO	39 47.46 N	069 50.77 W	1462.0	11.0	1459	1465.0	16
32OC411	W	6	042705	0745	EN	39 47.47 N	069 50.58 W					
32OC411	W	7	042705	0848	BE	39 41.99 N	069 48.01 W					
32OC411	W	7	042705	0932	BO	39 41.92 N	069 48.35 W	2096.0	8.7	2085	2094.3	20
32OC411	W	7	042705	1025	EN	39 41.70 N	069 48.60 W					
32OC411	W	8	042805	0013	BE	39 28.52 N	069 38.52 W					
32OC411	W	8	042805	0106	BO	39 28.36 N	069 38.28 W	2421.0	8.4	2435	2423.2	21
32OC411	W	8	042805	0205	EN	39 27.89 N	069 38.01 W					
32OC411	W	9	042805	0345	BE	39 15.55 N	069 29.44 W					
32OC411	W	9	042805	0447	BO	39 15.62 N	069 29.48 W	2660.0	9.7	2642	2660.0	22
32OC411	W	9	042805	0558	EN	39 15.48 N	069 29.53 W					
32OC411	W	10	042805	0818	BE	39 00.74 N	069 20.21 W					
32OC411	W	10	042805	0922	BO	39 00.60 N	069 21.25 W	3070.0	10.0	3218	3097.0	22
32OC411	W	10	042805	1046	EN	39 01.30 N	069 22.10 W					
32OC411	W	11	042905	0136	BE	38 47.65 N	069 11.03 W					
32OC411	W	11	042905	0246	BO	38 48.33 N	069 10.72 W	3261.0	10.0	3335	3290.2	22
32OC411	W	11	042905	0403	EN	38 49.07 N	069 10.15 W					
32OC411	W	12	042905	0613	BE	38 33.66 N	069 01.39 W					
32OC411	W	12	042905	0730	BO	38 33.99 N	069 01.07 W	3461.0	6.6	3464	3497.4	22
32OC411	W	12	042905	0845	EN	38 33.93 N	069 00.90 W					
32OC411	W	13	050305	0858	BE	38 19.98 N	068 51.76 W					
32OC411	W	13	050305	1009	BO	38 20.41 N	068 51.74 W	3805.0	8.7	3834	3846.0	21
32OC411	W	13	050305	1128	EN	38 20.78 N	068 51.75 W					
32OC411	W	14	042905	1653	BE	38 02.17 N	068 43.05 W					
32OC411	W	14	042905	1824	BO	38 01.79 N	068 42.87 W	4122.0	9.0	4148	4182.0	22
32OC411	W	14	042905	1954	EN	38 01.69 N	068 43.18 W					
32OC411	W	15	043005	0346	BE	37 51.17 N	068 32.59 W					
32OC411	W	15	043005	0528	BO	37 51.24 N	068 32.42 W	4349.0	8.6	4419	4418.0	22
32OC411	W	15	043005	0709	EN	37 51.07 N	068 32.03 W					
32OC411	W	16	043005	0910	BE	37 37.29 N	068 22.63 W					
32OC411	W	16	043005	1049	BO	37 37.94 N	068 23.09 W	4572.0	8.4	4653	4657.0	22
32OC411	W	16	043005	1228	EN	37 37.77 N	068 23.87 W					
32OC411	W	17	043005	2221	BE	37 22.90 N	068 13.00 W					
32OC411	W	17	050105	0002	BO	37 22.69 N	068 13.22 W	4729.0	10.0	4865	4819.0	22
32OC411	W	17	050105	0144	EN	37 22.49 N	068 12.90 W					
32OC411	W	18	050105	0430	BE	37 08.42 N	068 03.64 W					
32OC411	W	18	050105	0619	BO	37 08.37 N	068 03.68 W	4885.0	10.4	5014	4986.0	22
32OC411	W	18	050105	0808	EN	37 08.19 N	068 03.60 W					
32OC411	W	19	050105	1126	BE	36 54.01 N	067 53.71 W					
32OC411	W	19	050105	1312	BO	36 55.34 N	067 52.11 W	4914.0	7.3	5038	5021.0	22
32OC411	W	19	050105	1458	EN	36 56.29 N	067 51.60 W					
32OC411	W	20	050105	1921	BE	36 39.68 N	067 44.12 W					
32OC411	W	20	050105	2139	BO	36 41.17 N	067 39.14 W	4925.0	14.4	6382	5040.8	22
32OC411	W	20	050105	2342	EN	36 42.09 N	067 36.27 W					
32OC411	W	21	050205	0444	BE	36 12.34 N	067 27.16 W					
32OC411	W	21	050205	0641	BO	36 12.55 N	067 26.23 W	4936.0	4.8	5049	5082.0	22
32OC411	W	21	050205	0831	EN	36 12.00 N	067 24.19 W					
32OC411	W	22	050205	1304	BE	35 42.52 N	067 09.63 W					
32OC411	W	22	050205	1504	BO	35 41.56 N	067 10.69 W	5044.0	9.0	5519	5178.0	21
32OC411	W	22	050205	1659	EN	35 41.27 N	067 12.17 W					

Figure 1. Map of the Station W field program elements. Shown are the locations of the moored instrumentation (white stars - sites numbered 0 to 6) and hydrographic stations (red dots) superimposed on the bathymetry of the region.

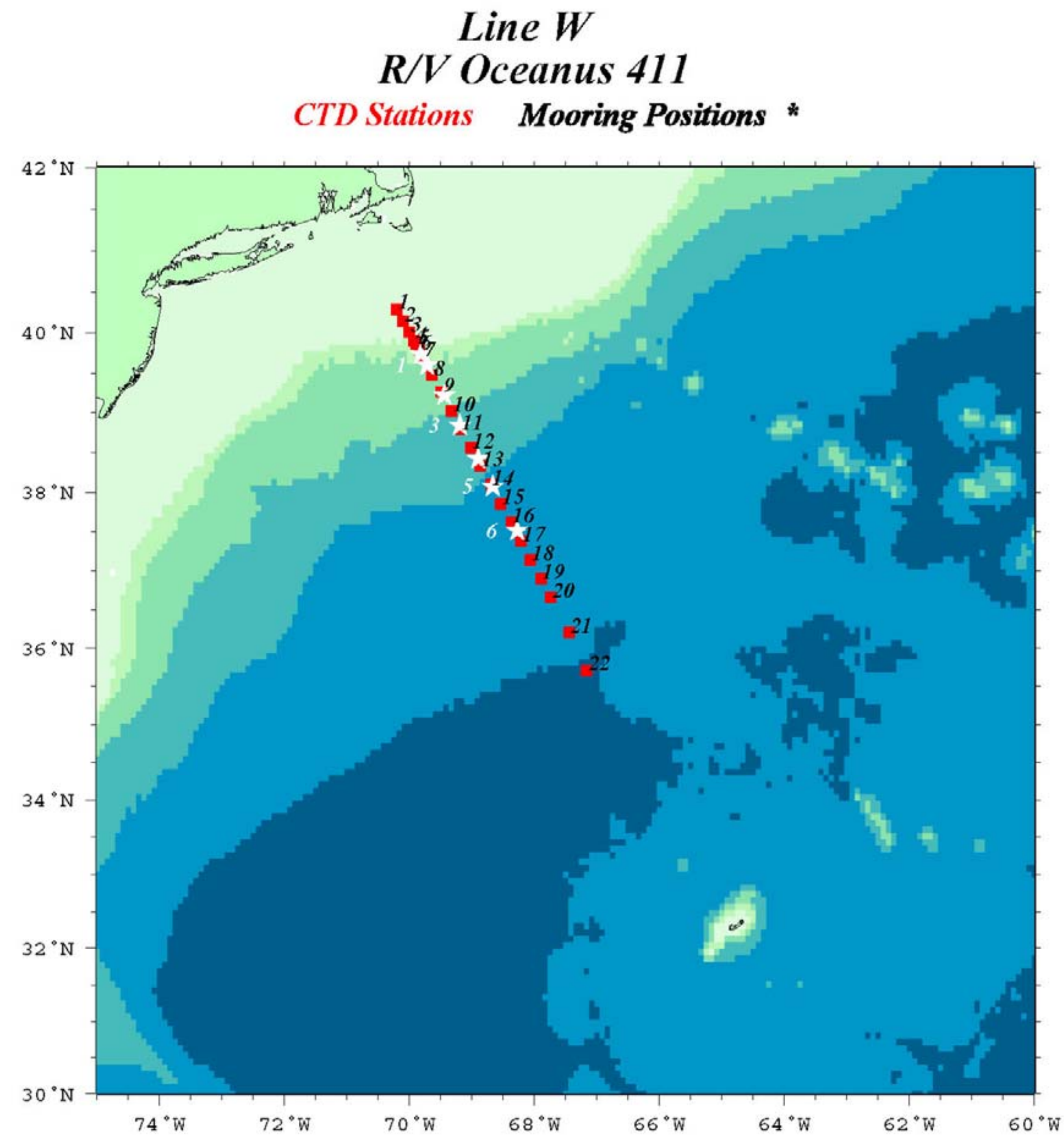
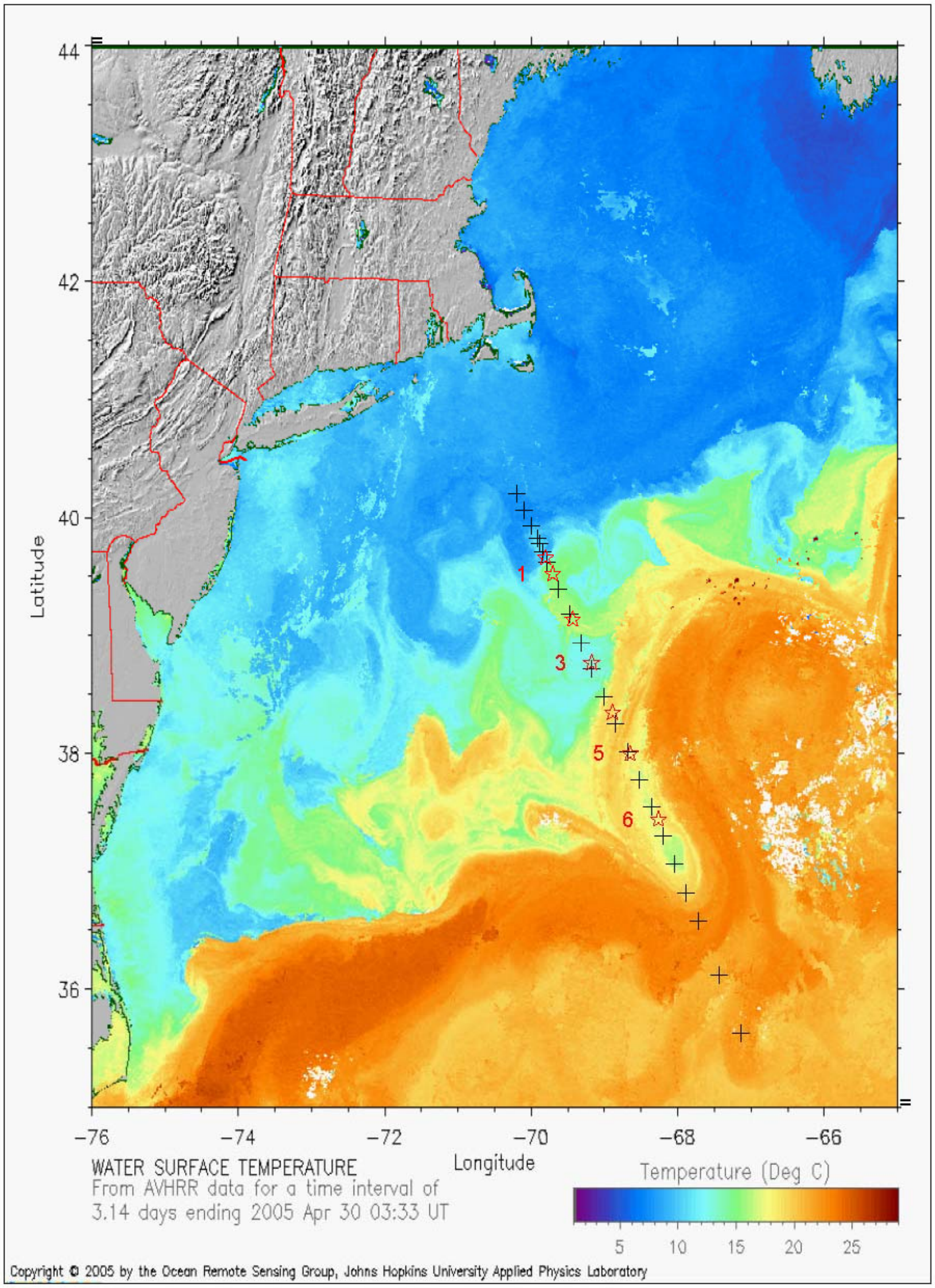


Figure 2. A sea surface temperature (SST) composite for the three-day period about April 29 during Oc411. Note the large southward meander of the Gulf Stream that lay along the Line W line at the time of the cruise. Station and mooring positions are indicated. (SST figure from the JHAPL remote sensing laboratory: http://fermi.jhuapl.edu/avhrr/gs_n/averages/05apr/gs_n_05apr30_0333_multi.png.)



Initial assessment of Moored Profiler performance: April/May 2004-2005

Three McLane Moored Profilers (MMP's) were recovered during Oc411 after one-year deployments at Station W sites 1, 3 and 5 (see Table 1). All three were programmed to burst sample with 4 one-way profiles spaced 9.5 hours apart, with a burst starting every 5^{th} day of the deployment. MMP # 121 at Site 1, cycling between 85 and 2178 db, returned data from 285 one-way profiles with the last file logged on April 26, the day Oc411 departed Woods Hole. Virtually all profiles spanned the depth interval between top and bottom stops on the wire. The total vertical travel distance accumulated by this instrument was 592 km. Although still operating when recovered, the battery voltage was down, suggesting it was nearly exhausted. It is unclear why the energy consumption was greater than normal (typical endurance on a battery has been approximately 800 km).

The FSI sensors on MMP 121 performed well. Apart from occasional profiles during which the conductivity sensor was fouled temporarily by biological material, derived salinities on deep water potential temperature surfaces have a spread of approximately 0.02 pss, comparable to the spread sampled by a Microcat T/C sensor positioned just below bottom stop of the MMP profiling interval. That both instruments documented this salinity variability suggests that much of the salinity variation was due to real water mass changes. The ACM on MMP 121 also functioned well. Preliminary ocean velocity profiles derived during the cruise describe a mean flow at depth to the west, consistent with the Deep Western Boundary Current. MMP # 104, deployed on the replacement mooring, was programmed with the same sampling schedule as MMP # 121.

MMP 122 at Site 3 also successfully cycled between the top and bottom mooring stops for the vast majority of its operation. The chief exception was the burst on Oct 2, 2004 (profiles 117-120) when the MMP was "stuck" near 320 m depth. ACM data show strong currents at this time accompanied by significant high-frequency noise. Wire strumming caused by Gulf Stream ring currents is suspected to have somehow prevented the MMP from moving on the wire. This will be investigated further. MMP 122 exhausted its battery and stopped profiling on March 16, 2004 after accumulating 736 km of vertical profiling. Early termination of this system was anticipated based on the programmed sampling plan. In light of the lower than expected endurance of MMP 121 and desire to sample over a full year period, the replacement instrument MMP # 105 was programmed to initiate a burst of 4 one-way profiles every 7.5 days. This scheme should mean that this instrument will sample for at least a 400 day period and that every other burst will be synchronous with MMP # 104 at Site 1.

Sensor performance on MMP 122 was also good, comparable to that seen on MMP 121. Salinities on deep isotherms exhibited a spread of around 0.01 pss apart from the occasional fouled profile. The ACM also worked well; the preliminary ensemble-mean velocity profile is westward and rather barotropic in character.

MMP 123 was deployed at Site 5 and programmed to cycle between 1000 and 4110 db. (To minimize current forces from the Gulf Stream on this mooring, the subsurface floatation was placed down at 800 m with a 200 m wire shot from there to the top of the profile interval. The MMP cycled regularly between its programmed depths for ~ 5 months (profile 120) but thereafter, reached down to ever shallower depth until, at time of recovery, it was reaching only 1500 m. Due to its decreased profiling interval, the MMP was still operating at time of recovery; total profile distance accumulated was 637 km. The difficulty reaching the bottom stop might have been due to a ballasting error – down-going motor current drain was much higher than up-going for this deployment. Again, this will be researched further. In anticipation that the replacement MMP (#106) will properly cycle for its full mission, the sampling schedule was set to match that of MMP 105 at site 3 (start a burst every 7.5 days) to better insure a full year-long record will be obtained.

Sensor data on MMP 123 was good. Salinity variations on deep isotherms were less than 0.01 pss; all channels of the ACM functioned acceptably. The ensemble-mean velocity profile derived from the preliminary data is eastward above ~2500 m (increasing speed with height) indicating Gulf Stream flow, and westward with increasing speed toward the bottom, indicating the DWBC.

The general good performance of these MMP units and good quality data that they returned is most encouraging. Also rewarding was the safe recovery of all the instrumentation. Design of these moorings with (heavy) Vector Averaging Current Meters deployed between the bottom stop of the MMP and the backup buoyancy may have contributed to the elimination of damage seen on previous recoveries when MMP's were struck by the glass balls during recovery.

In the weeks following completion of Oc411 the CTD sensors recovered from the moorings will be calibrated in the laboratory. With this information, final data from the moored instrumentation will be generated and made available on the Station W web site to be accessible under the main WHOI web page: http://www.whoi.edu/.

Acknowledgements

The success of the Spring 2005 cruise to Station W aboard R/V Oceanus is attributable to the hard work by everyone involved. The WHOI mooring team of Scott Worrilow, Brian Hogue and Larry Costello - ably assisted by Andrew Cookson, the irreplaceable Jeff Stolp, the deck crew, the skipper and mates of *R/V Oceanus* all worked long hours in at times trying conditions to complete 7 mooring ops (recovery or redeployment) in 3 ½ days. The Hydrographic team of Marshall Swartz, Maggie Cook, Jane Dunworth, Eugene Gorman and Guy Mathieu under the leadership of Ruth Curry with the assistance of Marisa Hudspeth, together with the ship's personnel, safely deployed, recovered and sampled the CTD/rosette package through rough as well as calm conditions. Patrick Rowe effectively kept the shipboard sampling systems operating and logging. Thanks to all of these folks and the shoreside support we received before and after the cruise, an excellent data set was obtained. The Station W program is supported by the National Science Foundation through grant no. OCE-0241354 to the Woods Hole Oceanographic Institution. The study contributes to the U.S. CLIVAR program and the U.K. RAPID study.