Cruise report: *R/V Oceanus* cruise no. 421

Woods Hole to Woods Hole
April 5 – 15, 2006

Line W: Continuing the measurement program

Background

R/V Oceanus cruise number 421 contributed to a joint Woods Hole Oceanographic Institution and Lamont Doherty Earth Observatory 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 6^{th} mooring (funded by WHOI's Ocean and Climate Change Institute), located near the mean axis of the Gulf Stream, extends the array southward an additional 30 nmi. A companion research program by U.K. investigators from the Proudman Oceanographic Laboratory 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 Line 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 analysis. 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 was collected along the array and extending south across the Gulf Stream. Three of the moorings support 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. Mooring #6 was deployed in fall 2005 and will not be recovered until spring, 2008.

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 are collected and stored for subsequent shipment to Dr. John Smith (BIO, Canada) for analysis of I^{129} concentration.

After the moored array was installed, the Line W hydrographic section section was reoccupied from the *R/V Cape Hatteras* in September 2004. Then in April/May 2005, the three Profiler moorings were recovered and redeployed and the hydrographic section reoccupied during cruise Oc411. The section was again occupied in October 2005 on cruise Oc417. The goals of Oc421 included recovery and redeployment of all 5 Line W moorings, recovery and redeployment of the 6 bottom pressure gauges, and occupation of the hydrographic section. In addition, two days of ship time were added to the cruise to permit repair work to be carried out on meteorological sensors mounted on a surface buoy deployed in the Gulf Stream east of Line W as part of CLIMODE (the CLIVAR, Mode Water Experiment). Mooring and station positions are displayed in Figure 1 with details provided in Tables 1 and 2.

Science party:

Chief scientist: J. Toole (WHOI)

Hydrographic sampling: R. Curry, J. Dunworth-Baker, F. Bahr and D. Wellwood (WHOI), W. Smethie and E. Gorman (LDEO);

Mooring operations: S. Worrilow, J. Lord, B. Hogue, and P. Fraser

Bottom pressure gauge operations: P. Foden and S. Mack, (POL)

Photograph of the science party for *R/V Oceanus* cruise number 421.

Cruise narrative:

R/V Oceanus was loaded with Line W scientific equipment between March 30 and April 4 and departed Woods Hole at 10 AM April 5. [Note: all events in this section are reported in local Eastern Daylight Time.] Sea surface temperature imagery for the week prior to the cruise revealed an extremely large northward meander in the Gulf Stream roughly aligned with the Line W moored array, Figure 1. This structure persisted through the cruise, making for a rather anomalous cross section of the continental slope and Gulf Stream. Sampling was initiated just after dinner with the first set of CTD stations (numbers 1-6) that extended from the 90-m isobath across the shelf break to approximately 2000 m water depth. Around dawn on April 6, the station work was terminated and the vessel was positioned for recovery of the bottom pressure gauge (BPR) at site W0. Foden and Mack successfully communicated acoustically with the instrument and initiated its anchor release procedure. Approximately 90 minutes later the instrument's radio signal was detected. It was quickly sighted and brought aboard. *R/V Oceanus* was then directed to mooring site W1 for recovery of the first Moored Profiler mooring, which was accomplished before lunch. The BPR at W1 was then recovered and we proceeded to mooring site W2.

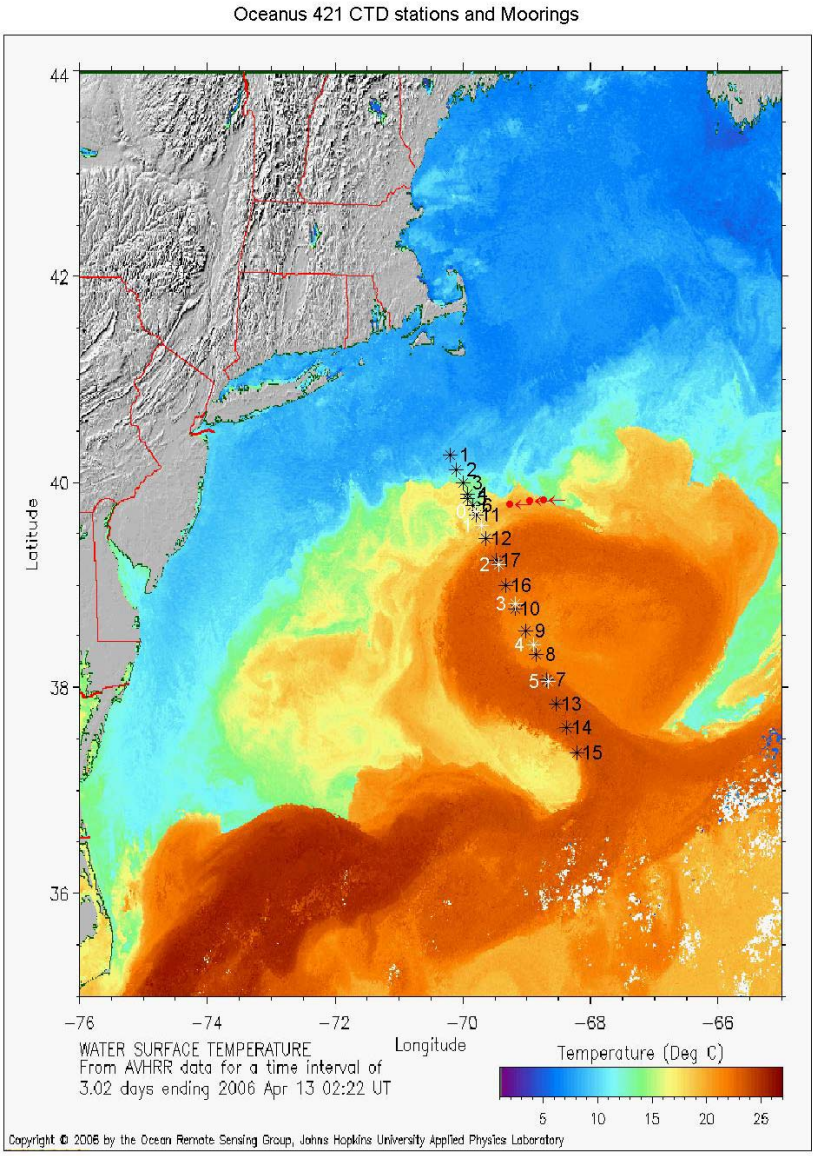

Figure 1. SST map with mooring (white numbers) and station positions (black numbers) marked. The CLIMODE surface mooring was just east of this image's boundary (38^{o} 19' N, 64^{o} 47' W). The red symbols mark the position and course of the *Spray* glider in the days just prior to its recovery.

Due to the time of day and lack of night-time recovery aids on the BPR, it was decided to first try and recover BPR #2. Although acoustic communications with the instrument were successful and the BPR indicated that it had released its anchor, it failed to lift off

from the sea floor. Ultimately it was concluded that the BPR was stuck and we proceeded to the mooring recovery at site W2. The mooring recovery operation was completed by 10 PM. We then transited southeast along the line to mooring site W5 as planned, arriving on station at 6 AM on April 7. The POL team was up first to attempt recovery of BPR 5. Unfortunately, no acoustic returns were received from the instrument and at 9:30 it was decided to transition to mooring recovery activities. Mooring W5 was brought aboard by early afternoon and, while preparing to redeploy the mooring, the hydrographic station at this site was occupied (designated station site 9014). With winds building towards forecast gale strength, it was decided nevertheless to proceed with the mooring deployment. Anchor over occurred at 10 PM in winds over 30 knots and waves washing the deck. Despite the rough conditions, hydrographic station work was carried out through the night and, because it was too rough for mooring operations, into the following day, working back north along Line W. By dinner time, the hydrographic team was exhausted and so it was decided to hove to over night. (The cruise plan originally called for mooring work in daytime and station work at night, thus requiring just one team of each.) Station work was resumed early on April 9, still in gale conditions. The planned occupation at site 9009 was abandoned when, due to the misalignment of the wind, seas and strong Gulf Stream currents it proved impossible to orient the vessel to control wire angle. Thus we transited north to pick up some of the more northern stations yet occupied. After completion of stations at sites 9007 and 9008 around dinner time, it was decided to again hove to for 12 hours.

April 10 dawned with improving conditions although with significant seas remaining. Given the forecast of good weather for the next three days, it was decided to complete recovery of the remaining instruments, then transit to the CLIMODE surface buoy. The two days required to transit to and from the buoy and effect repairs would allow the WHOI mooring team to prepare for the mooring redeployments. First, the POL team attempted to communicate with the BPR at site W3 but failed to receive any acoustic responses. Eventually the instrument was given up as lost and we proceeded to recovery the W3 mooring (which was aboard by lunch time). Lastly *R/V Oceanus* was positioned at site W4. By this time the winds had dropped to 10 knots and the seas had laid down greatly. Again, Foden and Mack failed to make acoustic contact with the BPR at this site so we moved on to the mooring recovery. All mooring components were brought aboard by 10 PM.

The CLIMODE surface buoy operations (requiring deployment of a small boat and technicians boarding the buoy) were constrained to occur in daytime. Given the time of day and 190 nmi distance to the CLIMODE mooring, it was decided to defer departure for the buoy until the next afternoon. Thus the morning and afternoon of April 11 were devoted to extending the hydrographic section south past mooring #6. Departure for the CLIMODE buoy occurred at 5 PM. Adverse currents delayed arrival at the CLIMODE surface buoy from the expected 8 AM to noon on April 12. However, conditions were ideal: winds were less than 10 knots with small seas and swell. Lord and Bahr, accompanied by Coxswain Cacho and Engineer Kadlec made two trips in the small boat between *Oceanus* and the buoy, ferrying new sensors out and returning the damaged

ones. By connecting a laptop computer to the buoy data logger, they verified that the new sensors were operating properly and by 3 PM we were heading back to Line W.

Sensor repair work underway on the CLIMODE surface buoy.

Thanks to the quick work at the CLIMODE buoy, *R/V Oceanus* arrived at the W4 mooring site at 5 AM on April 13. Deployment of the mooring at W4 proceeded smoothly and we proceeded immediately to W3. (Given the poor performance of the BPR instruments at these deeper depths, no free-standing gauge was deployed at W4 or W3. However, as an engineering exercise, a pressure gauge was affixed to the WHOI mooring just above the acoustic releases.) Again, the mooring deployment operation was efficient and effective; anchor over occurred at 7 PM. Through the night, the two remaining station sites yet sampled (9009 and 9010) were occupied and we were on the W2 mooring site at dawn on April 14. Both mooring and BPR deployments proceeded uneventfully in the morning and we pressed on to site W1. Due to the Gulf Stream meander, site W1 was experiencing a 3 knot surface current to the east, opposing a light southerly wind. The setup point selected to begin mooring operations proved to be too far south, but thanks to skillful maneuvering of the vessel by Chief Mate Mello and quick deck work by Worrilow and the mooring team, the anchor was launched very close to the target location and desired isobath. The mooring work was completed by deploying BPRs at sites W1 and W0.

The final operation on the cruise was recovery of the "*Spray*" glider for fellow WHOI scientist Breck Owens. The *Spray* had been deployed 4 months earlier and in that time, performed 6 transects of the Gulf Stream Under instructions from Owens (sent to the glider via Iridium phone), *Spray* went into recovery mode before dawn on April 15. *R/V Oceanus* was positioned at 39^{o} 52' N, 69^{o} 17' W (estimated glider position for the morning of April 15), awaiting an updated position report (from the glider, to Owens to *Oceanus*). Immediately on powering up the ARGOS transmitter RDF at 4:30 AM, signals from *Spray* were received. Two subsequent position updates from Owens (the last at 05:50 AM) directed us to the glider (which was first sighted at ~200 m range just off the starboard bow). The instrument was recovered at 06:20 AM at 39^{o} 52.491' N, 69^{o} 14.295' W. With insufficient time available to extend the hydrographic section further south, R/V Oceanus was directed towards Woods Hole with arrival at the pier around 7 PM on April 15.

Despite several days of gale conditions during the cruise, the major cruise objectives for the U.S. science team were completed. In addition to the expert work by the science team, significant credit for the cruise success is due to the efforts of Captain L. Bearse, mates A.D. Mello and P. Carty, Chief Engineer R. Morris, Bos'n K. Rand, Shipboard Science Technician P. Rowe, and the other crew of *R/V Oceanus*. We thank them for their consistently fine work. The most disappointing element of the cruise was the poor performance of the Proudman Laboratory's BPRs in deep water with 4 systems lost. Hopefully lessons learned from this experience will result in improved system reliability in future.

Acknowledgements

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Table 1: The Line W moored array, Spring 2006 – Spring 2007

Mooring 0: BPR

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

Mooring 1: MMP & BPR

Lat: 39 35.821 N
Lon: 69 41.710 W
Bottom Depth: 2227 m

Mooring 2: VACM's & BPR

Lat: 39 12.962 N
Lon: 69 26.564 W
Bottom Depth: 2740 m

Mooring 3: MMP & BPR

Lat: 38 50.690 N
Lon: 69 10.224 W
Bottom Depth: 3245 m

Mooring 4: VACM's & BPR

Lat: 38 26.843 N
Lon: 68 54.508 W
Bottom Depth: 3644 m

Mooring 5: MMP & BPR

Lat: 38 10.696 N
Lon: 68 34.001 W
Bottom Depth: 4102 m

Mooring 6: VACM's GUSTO-05

Lat: 37 31.159
Lon: 68 16.998
Bottom Depth: 4676

* bottom depths are uncorrected.

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 Oc421

Line_W R/V Oceanus 421 April 2006

Sta	Cst	UTC	POSITION	Dpth	HAB	Pmax	comments
1	1	040506 2306	BE 40 16.99 N -70 12.45 W GPS	93			
1	1	040506 2310	BO 40 16.99 N -70 12.45 W GPS		9	83	
1	1	040506 2317	EN 40 16.99 N -70 12.45 W GPS				
2	1	040606 0021	BE 40 08.41 N -70 06.19 W GPS	123			
2	1	040606 0028	BO 40 08.31 N -70 06.05 W GPS		10	112	
2	1	040606 0033	EN 40 08.22 N -70 06.01 W GPS				
3	1	040606 0131	BE 40 00.39 N -70 00.39 W GPS	163			
3	1	040606 0139	BO 40 00.16 N -70 00.32 W GPS		11	154	
3	1	040606 0149	EN 39 59.92 N -70 00.41 W GPS				
4	1	040606 0307	BE 39 53.85 N -69 55.93 W GPS	701			
4	1	040606 0327	BO 39 53.52 N -69 55.94 W GPS		10	720	
4	1	040606 0354	EN 39 52.99 N -69 56.17 W GPS				
5	1	040606 0514	BE 39 51.43 N -69 54.29 W GPS	1183			
5	1	040606 0544	BO 39 50.85 N -69 54.55 W GPS		10	1181	
5	1	040606 0624	EN 39 50.08 N -69 55.06 W GPS				
6	1	040606 0747	BE 39 47.24 N -69 51.38 W GPS	1650			depth recorder not working
6	1	040606 0819	BO 39 46.72 N -69 51.95 W GPS		200	1440	
6	1	040606 0901	EN 39 46.10 N -69 52.75 W GPS				
7	1	040706 1716	BE 38 06.12 N -68 36.66 W GPS	4137			releases tested at 3k
7	1	040706 1840	BO 38 06.05 N -68 35.92 W GPS		10	4155	
7	1	040706 2029	EN 38 05.72 N -68 35.05 W GPS				
8	1	040806 0503	BE 38 19.85 N -68 51.99 W GPS	3780			no trip confirm 14-22
8	1	040806 0611	BO 38 19.56 N -68 52.37 W GPS		10	4155	
8	1	040806 0734	EN 38 19.02 N -68 52.02 W GPS				
9	1	040806 1207	BE 38 33.19 N -69 01.36 W GPS	3457			
9	1	040806 1306	BO 38 33.03 N -69 01.01 W GPS		10	3433	
9	1	040806 1423	EN 38 32,72 N -69 00.92 W GPS				
10	1	040806 1734	BE 38 17.34 N -69 10.89 W GPS	3262			
10	1	040806 1834	BO 38 18.34 N -69 09.49 W GPS		9	3295	
10	1	040806 1952	EN 38 19.52 N -69 08.20 W GPS				
11	1	040906 1419	BE 39 42.28 N -69 48.03 W GPS	2084			
11	1	040906 1457	BO 39 42.74 N -69 48.33 W GPS		11	2053	
11	1	040906 1548	EN 39 43.31 N -69 48.77 W GPS				
12	1	040906 1846	BE 39 28.82 N -69 38.39 W GPS	2384			
12	1	040906 1932	BO 39 29.96 N -69 38.73 W GPS		10	2555	
12	1	040906 2035	EN 39 31.27 N -69 38.98 W GPS				
13	1	041106 0613	BE 37 50.93 N -68 32.89 W GPS	4306			
13	1	041106 0734	BO 37 51.27 N -68 35.56 W GPS		10	4548	
13	1	041106 0906	EN 37 51.86 N -68 38.09 W GPS				
14	1	041106 1131	BE 37 37.59 N -68 23.05 W GPS	4545			releases tested at 3k,
14	1	041106 1253	BO 37 38.99 N -68 24.98 W GPS		9	4652	forgot to fire surface bottle
14	1	041106 1454	EN 37 40.73 N -68 26.33 W GPS				
15	1	041106 1730	BE 37 23.09 N -68 13.22 W GPS	4702			
15	1	041106 1855	BO 37 24.67 N -68 15.68 W GPS		12	4867	releases tested at 3k
15	1	041106 2052	EN 37 26.20 N -68 17.37 W GPS				
16	1	041406 0101	BE 39 00.89 N -69 20.19 W GPS	3059			
16	1	041406 0157	BO 39 00.95 N -69 20.20 W GPS		10	3035	
16	1	041406 0310	EN 39 00.79 N -69 20.39 W GPS				
17	1	041406 0615	BE 39 15.56 N -69 29.29 W GPS	2654			
17	1	041406 0705	BO 39 17.27 N -69 29.27 W GPS		8	2647	
17	1	041406 0810	EN 39 14.69 N -69 28.73 W GPS				