OC404-1 Cruise Report
Draft – July 20, 2004

Contents:

1. Objectives

Voyage 404-1 of R/V *Oceanus* was the first cruise of the EDdy Dynamics, mIxing, Export, and Species composition (EDDIES) project. A detailed description of the EDDIES science plan is contained in the original proposal, available on the project web site[1]. The specific objectives of this cruise "Survey 1" were to:

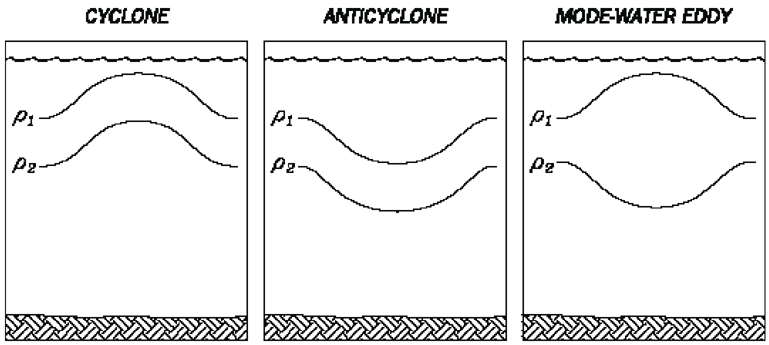
1. Select several candidate eddy features on the basis of satellite altimetry and ocean color.
2. Obtain precise determinations of eddy centers for each of the candidate eddy features (XBT, ADCP).
3. Occupy transects through the center of each of the candidate features (XBT, CTD/Rosette, MOCNESS, VPR, Light probe)
4. Choose target feature based on the results of (3)
5. Conduct detailed grid survey of target feature
6. Repeat (4) as time allows to assess temporal evolution of the target feature
7. Coordinate with R/V *Weatherbird II* in joint sampling operations (last 10 days)

2. Selection of the candidate features

Prior experience suggests that there are at least three different types of mid-ocean eddies in the Sargasso Sea (Figure 1): cyclones, anticyclones, and mode-water eddies (MWEs). Cyclones and MWEs are of interest to this project, as both tend to displace upper ocean isopycnals toward the surface, causing nutrient input into the euphotic zone. Whereas cyclones are identifiable in satellite altimetry by virtue of their negative sea level anomaly (SLA), MWEs are not distinguishable from anticyclones on the basis of altimetry alone because both result in positive SLA. In principle, satellite-based SST could distinguish these two, as anticyclone and MWEs would be characterized by warm and cold SST anomalies, respectively. However, given the

[1] http://science.whoi.edu/users/mcgillic/eddies/EDDIES_Project.html

paucity of reliable SST imagery in the Sargasso Sea during summer, we had to rely on in situ measurements to unequivocally distinguish MWEs from anticyclones.



	Cyclone	Anticyclone	Mode-water Eddy
Temperature Signal			
near-surface	cold	warm	cold
main thermocline	cold	warm	warm
Sea Level Anomaly	low	high	high
Rotation	counterclockwise	clockwise	clockwise

Figure 1. Three different types of eddies in the Sargasso Sea.

Eddy age is another key issue. Whereas an intensifying cyclone will have upwelling in its center, the isopycnals in the interior of a decaying cyclone will be downwelling. The earlier phase of the eddy's lifetime will be when nutrient injection and the associated biological response occur.

Summary of desirable characteristics for the target eddies:

1. Young
2. Strong imprint on upper ocean physics, biology, and chemistry
   (not necessarily a large amplitude SLA in the case of a MWE).
3. Intensifying
4. Chemical impact discernible in real time
5. Biological impact discernible in real time
6. Cyclone versus MWE?
   a. unequivocal satellite determination favors cyclones
   b. trapping of near-inertial motions and possible enhanced mixing favors MWEs
   c. some of the big events at BATS have been MWEs
      Jenkins (1988) Summer 1986 event
      McNeil et al. (1999) July 1995 eddy
7. Proximity to BBSR: must be within 1 day's steam for *Weatherbird II*

Clearly, it was necessary to sample several eddies during the first survey cruise prior to making a decision on which feature to target with more detailed sampling.

Eddy statistics from prior years (Figure 2) provided some guidance with respect to expected eddy trajectories over the course of the planned sampling activities (June-August). With respect to the logistics of the joint operations with the Weatherbird II, the ideal eddy would be slightly east of BATS in the beginning (ca. 62W), and slightly west of BATS at the end (ca. 66W).

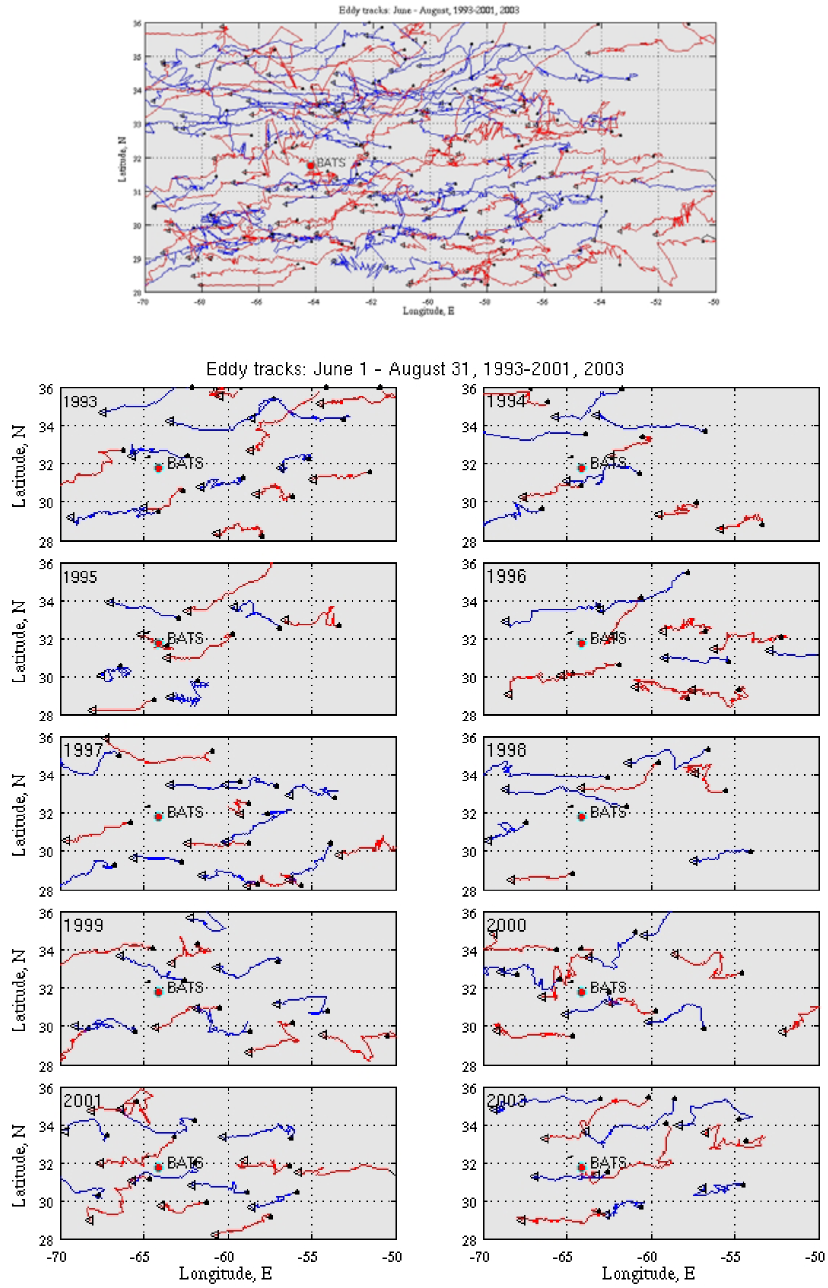


Figure 2. Eddy tracks for June through August, 1993-2001, 2003. Cyclones are in blue, and anticyclones are in red.

Eddy features of interest were identified prior to the cruise using satellite altimetry from CCAR[2] and the Navy[3]. MODIS ocean color imagery was also made available courtesy of David Siegel and Toby Westberry (UCSB). Five candidate features were selected (Figure 3): three anticyclones (A1,A2,A3) and two cyclones (C1,C2). All five features were tracked in the satellite data archive to determine their trajectories and recent history of SLA extrema (Figure 4). A1 is a persistently strong feature, with SLA extremum greater than 20cm dating back to the beginning of this particular record (February 1). A2 underwent gradual strengthening beginning April 1. A3 has strengthened dramatically since late April. C1 intensified significantly during May. C2 intensified in late Feb, and has fluctuated with a 10-20cm extremum since then.

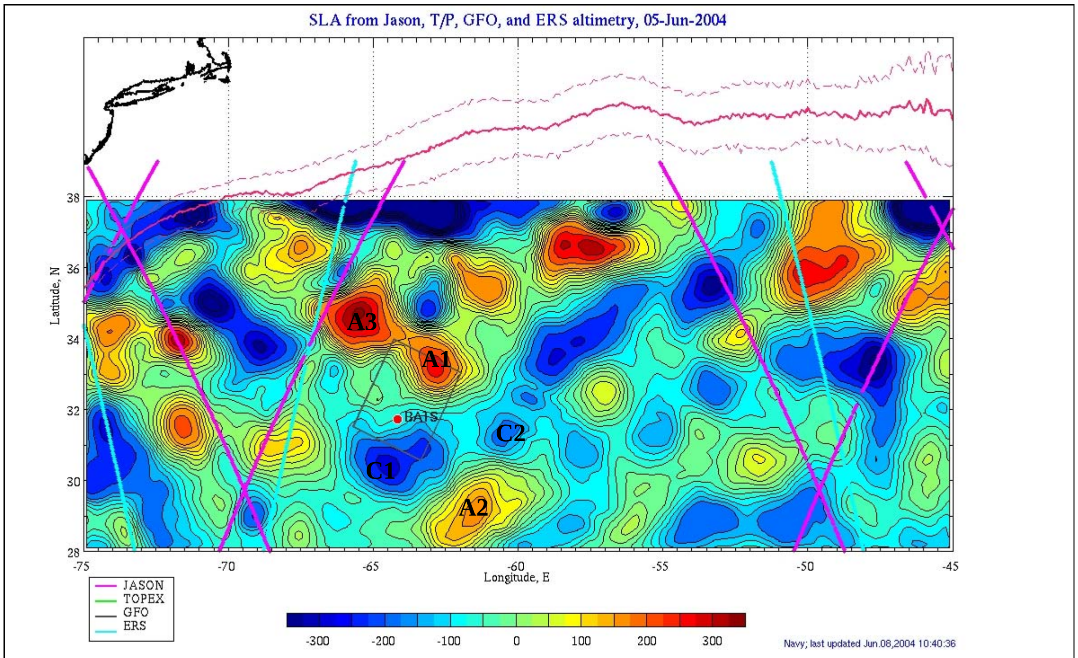


Figure 3. Objective analysis of sea level anomaly (mm) for June 5, 2004. Data source: see footnote (3). Five candidate features are indicated: A1, A2, A3, C1, C2. The solid magenta line indicates the mean path of the Gulf Stream, and the dashed lines the one standard deviation meander envelope.

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[2] http://www-ccar.colorado.edu/~realtime/nwatlantic-real-time_ssh

[3] http://www7300.nrlssc.navy.mil/altimetry/

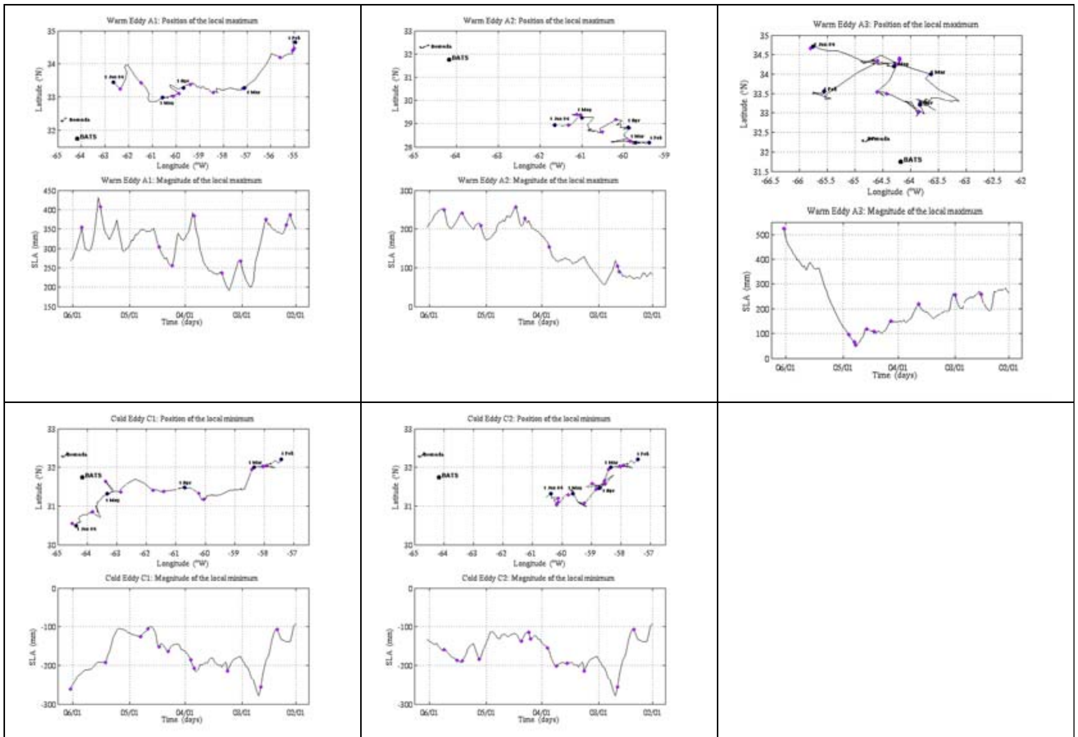

Figure 4. Recent trajectories and histories of SLA extrema for the five candidate features: A1 (upper left), A2 (upper middle), A3 (upper right), C1 (lower left), and C2 (lower middle). Dots on the SLA histories indicate a satellite overpass of eddy center.

3. Transects through the candidate features

All five candidate features were sampled during the cruise (Figure 5).

Underway XBT operations commenced south of the Gulf Stream, in transit toward a large anticyclone A3 at (34 30.0N, 66 30.0W). XBT data revealed this feature is a regular anticyclone, not a mode water eddy (Figure 6). Feature A3 is therefore not a contender for future study, but a single hydrocast (CTD 2) was deployed at eddy center for comparison purposes.

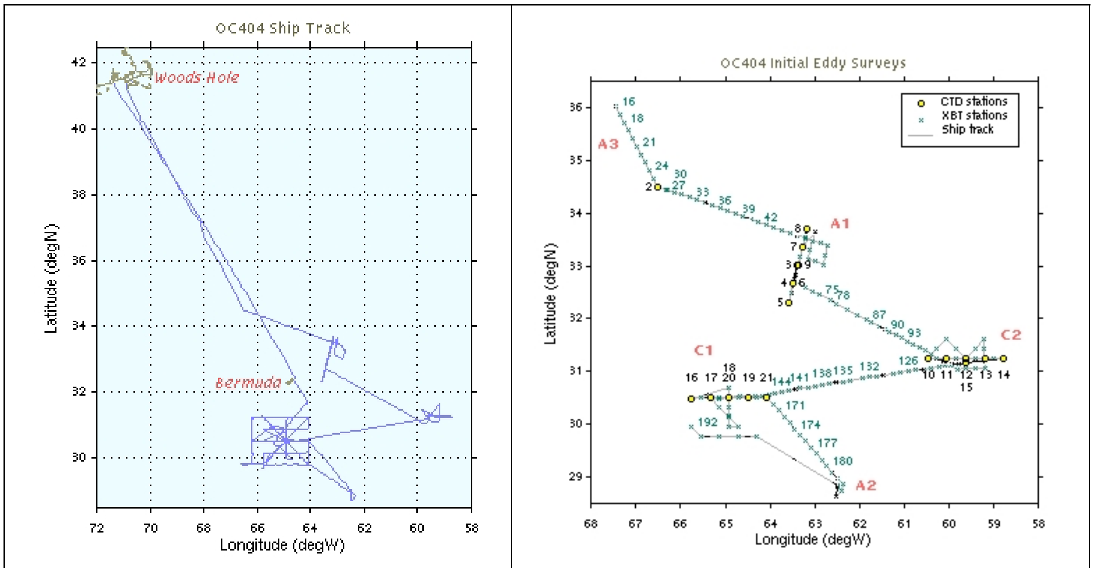

Figure 5. OC404-1 cruise track (left) and station positions for initial survey of candidate features.

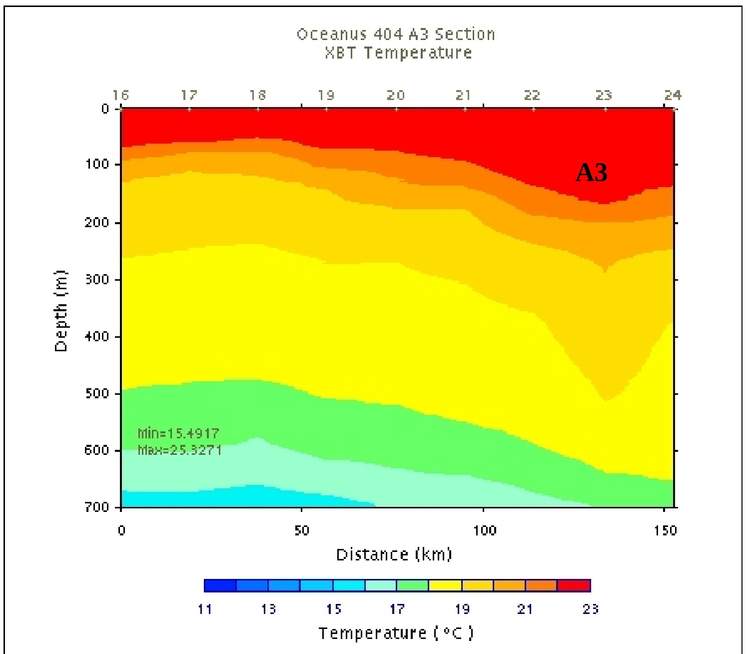

Figure 6. Alongtrack XBT section through anticyclone A3.

Transited to anticyclone A1 at (33 22.2N, 63 42.0W), and conducted an XBT search for eddy center (Figure 7, left panel). A cross section based on XBT data (Figure 7, right panel) reveals this feature is a bolus of 16 degree water, as opposed to the thick lens of 18 degree water characteristic of mode water eddies in this region. After locating its center, a cross section of 5 CTD stations was occupied (Figure 8), including a midnight MOCNESS tow at eddy center (Table 1). Significant biological perturbations were evident in the southern flank of A1. Based on MODIS imagery (Figure 9), these aspects may be associated with a streamer spiraling inward toward eddy center. The fluorescence maximum, typically at 100m in the background waters, was raised to ca. 60m, with a secondary peak at 120-140m. FRRF measurements indicated high variable fluorescence in the uplifted fluorescence maximum at 60m (Bibby, Koblizek, Wyman). Low-level nutrient measurements indicate nutrient enhancement at 60m, with measurable nitrate as shallow as 40m (Li). Water was collected from this feature for growout experiments (Bibby) and oxygen incubations (Mourino). Further hydrographic analysis of the eddy cross-section revealed thinning of the 18 degree water at eddy center, with a bolus of 16 degree water below containing a distinctive salinity anomaly. It is clear from the transects that the vertical extent of these aspects were not captured fully by the 0-700m data being collected. Therefore, a 1500m CTD (including nutrient, oxygen, and helium samples) was occupied at eddy center to obtain more information about the vertical structure and water mass characteristics of the anomalous feature.

MOCNESS Tow #	Date	Time	Eddy Feature
1	6/15/04	Night	A1 center
2	6/18-19/04	Night	C2 center
3	6/21-22/04	Night	C1 center
4	6/23-24/04	Night	C1 SW corner “outside”
5	6/24/04	Day	C1 SW corner “outside”
6	6/25-26/04	Night	C1 center
7	6/26/04	Day	C1 center
8	6/28/04	Night	C1 NW corner “outside”

Table 1: Summary of MOCNESS tows.

The water mass characteristics in eddy A1 was found to contain an unusual layer of water between 560 and 666 m (in situ T, 16.45-16.50 C; potential T, 16.34-16.41 C; salinity, 36.34-36.35 per mille; sigma theta, 26.7 kg/m3; oxygen, 5.0 ml/l). The World Ocean Atlas 2001 was searched to find water masses that had the same potential temperature and salinity. Properties on the 33 standard levels of the Atlas were linearly interpolated vertically to 1 m intervals, and searched for the entire North and South Atlantic (90 S-90 N, 100 W-40 E). In the Annual Mean climatology, the only water in the Atlas that had the same potential temperature and salinity was between the Canary Islands and Gibraltar (Figure 10). Of this water, only that between 31-34 N, 13-11 W had oxygen in excess of 5.0 ml/l (viz 5.05-5.24 ml/l; depth 108-131 m; sigma theta = 26.7) to be the possible source water mass. This may be Madeira Mode Water.

The monthly climatologies were also searched, and it was found that seasonally a few other locations also had potential temperature and salinity in this range, most notably near the Gulf Stream in March, May, July, September and October (Figure 11). However it was found that the oxygen content of these waters near the Gulf Stream is in the range 4.27-4.71 ml/l, too low to be the source water mass. Water in the central of the basin (28-33 N, 30-50 W) in September also had too low oxygen (4.51-4.89 ml/l) to be the source. Thus the monthly climatologies also suggest the source water as coming from around Madeira.

The location of eddy A1 has been tracked with altimetry back to February 2004, at which time it was at 34 N, 55 W (Figure 4). This agrees with the notion that the eddy has moved in from the east. Retrospective analysis of the altimetric data archive is taking place to determine whether or not the eddy did originate in the vicinity of 31-34 N, 13-11 W.

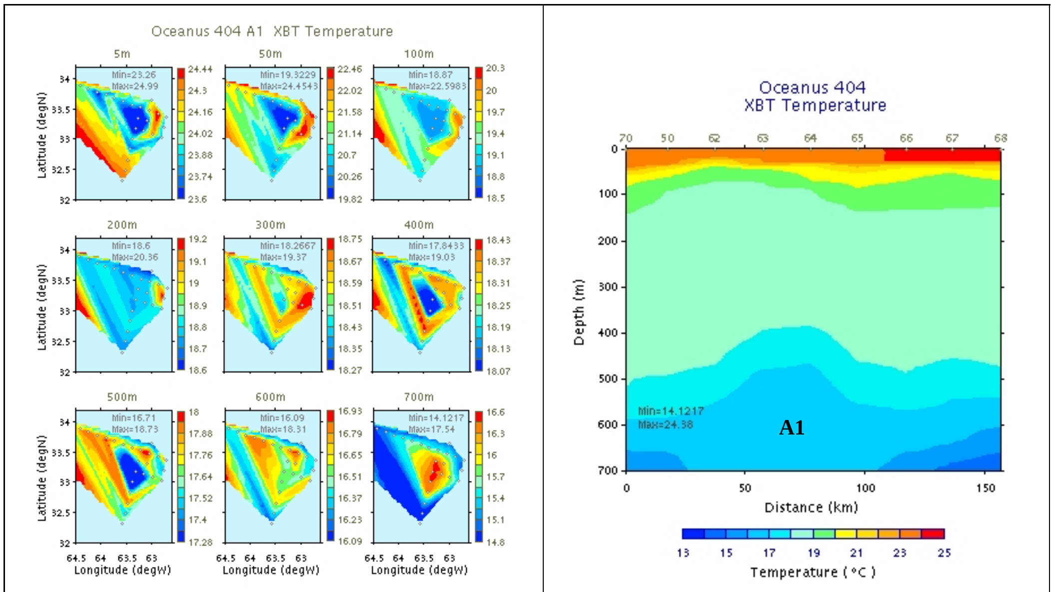

Figure 7: XBT survey (left) and cross section through anticyclone A1 (right).

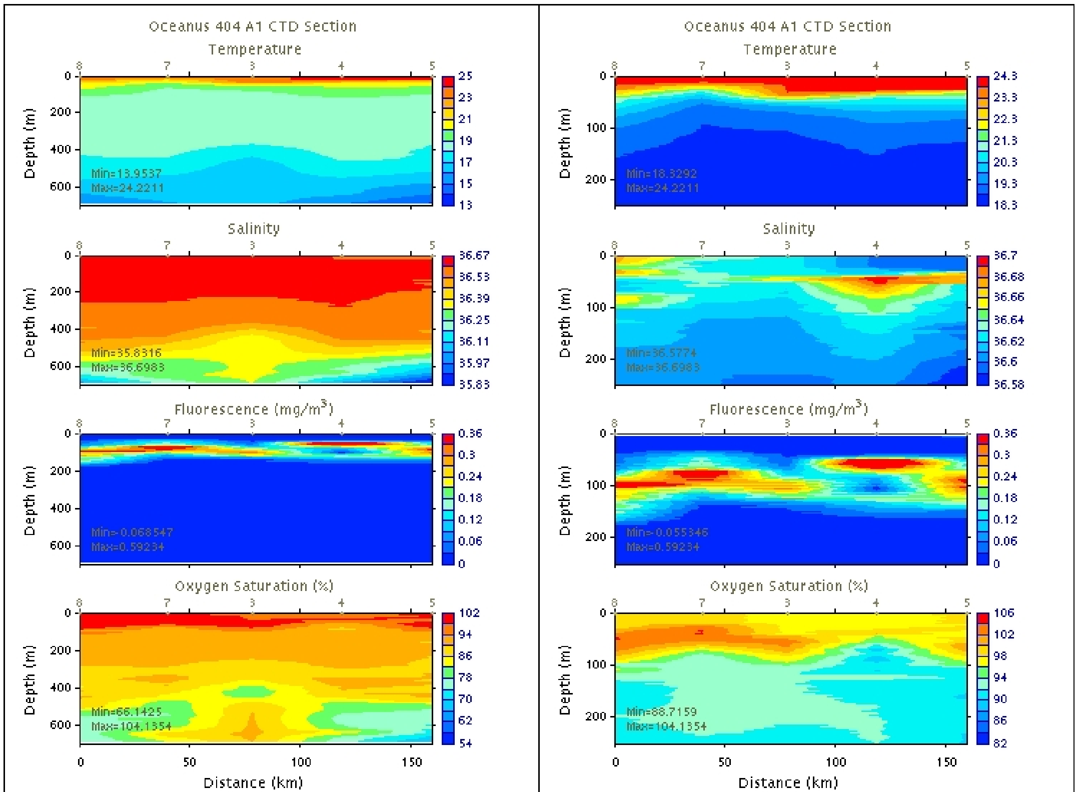

Figure 8. Temperature, salinity, fluorescence, and oxygen saturation across A1. Left: 0-700m; right: 0-250m.

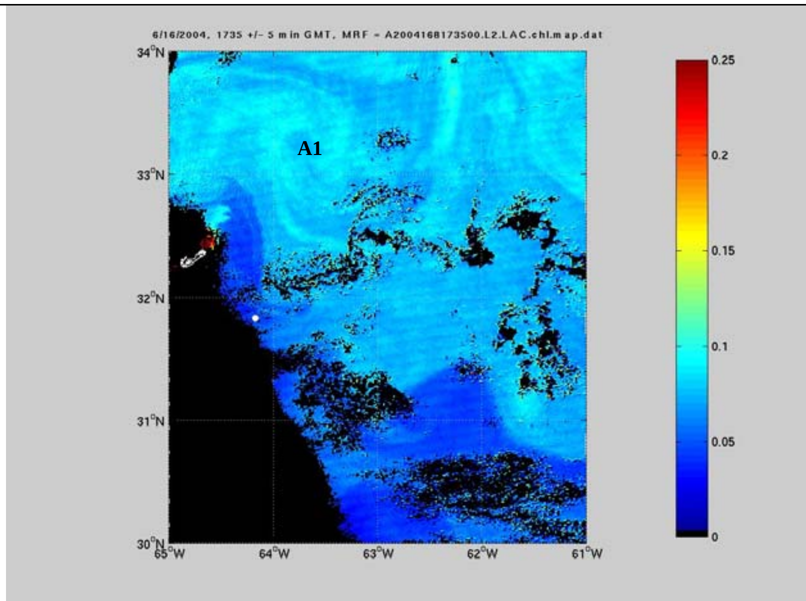

Figure 9. MODIS ocean color image for June 16, 2004. Center of anticyclone A1 indicated.

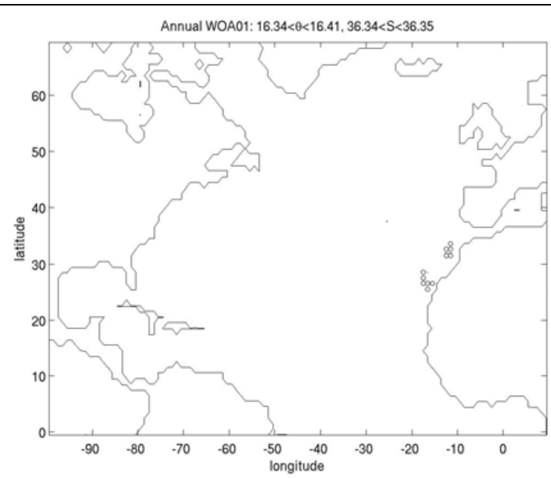

Figure 10. Circles note locations of water in World Ocean Atlas 2001 with potential temperature 16.34-16.41 C and salinity 36.34-36.35 per mille.

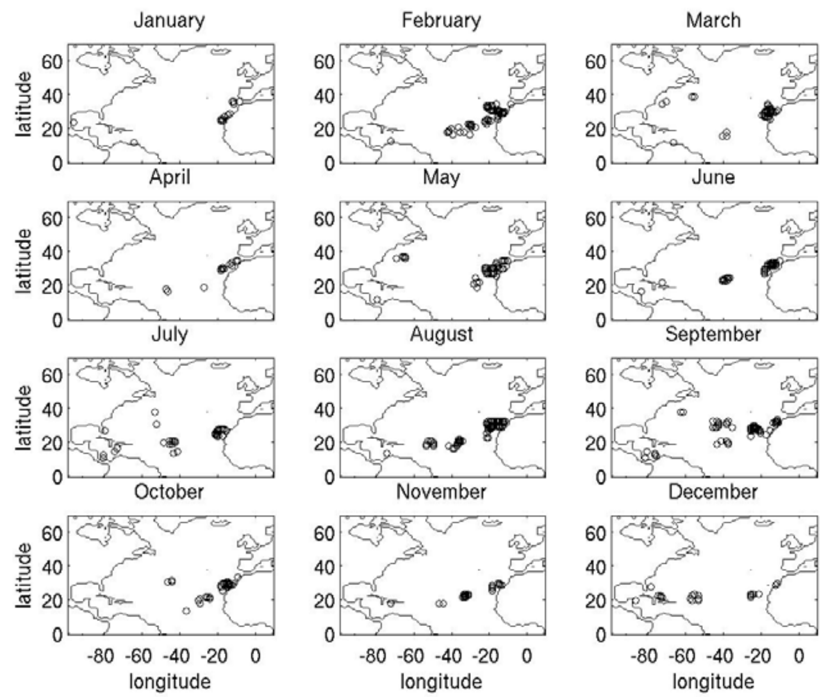

Figure 11. Circles note locations of water in World Ocean Atlas 2001 with potential temperature 16.34-16.41 C and salinity 36.34-36.35 per mille.

The XBT survey of cyclone C2 (centered at ca. 31 15.0, 59 36.8) revealed a clear upward perturbation of the main thermocline (Figure 12). Temperature at 700m is 10.7 degrees at eddy center, comparable to the perturbation associated with C1 measured earlier with BATS spatials plus CTDs from P. Sedwick's recent cruise on the R/V *Weatherbird II* (Figure 13). Although the signature of C2 is clear in the main thermocline, its near-surface expression is somewhat muted. Whereas the temperature at 100m mimics that of the deeper layers, 50m temperature is quite patchy and the sense of the temperature at 5m is nearly opposite to those of the deeper layers. The signature of C2 in the upper ocean velocity field is unambiguous (Figure 14).

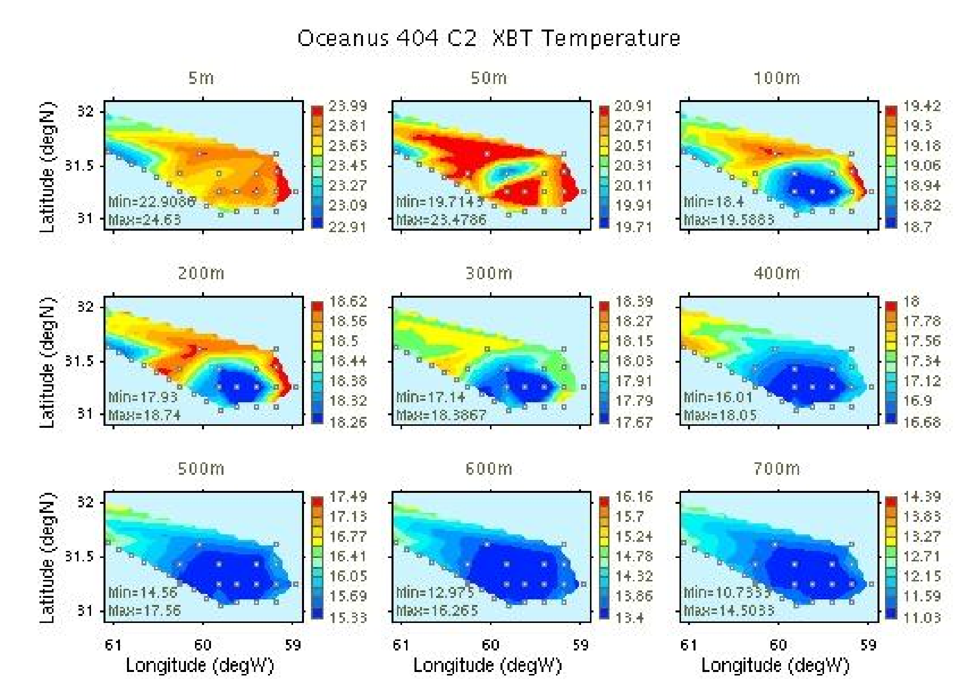

Figure 12. Temperature distribution in C2 based on XBT survey.

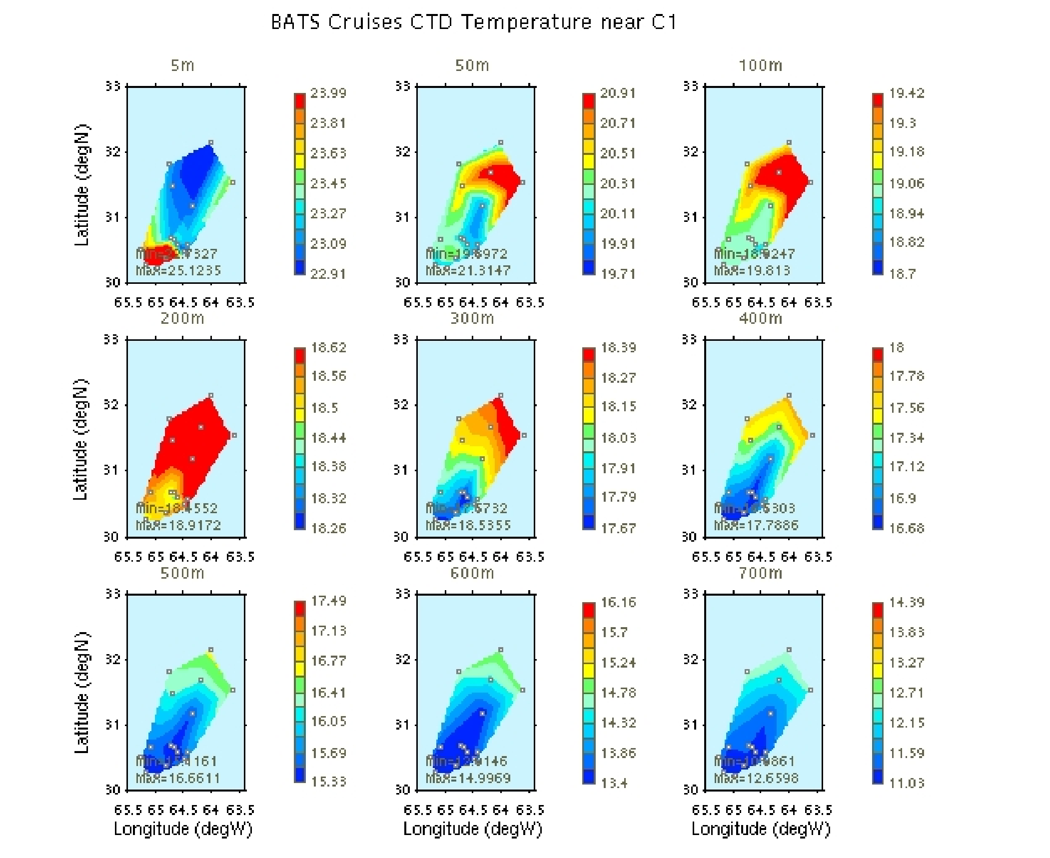

Figure 13. Temperature distribution in the NE quadrant of C1 measured by CTD on BATS spatial stations and profiles taken following a sediment trap deployed by Peter Sedwick on a subsequent cruise.

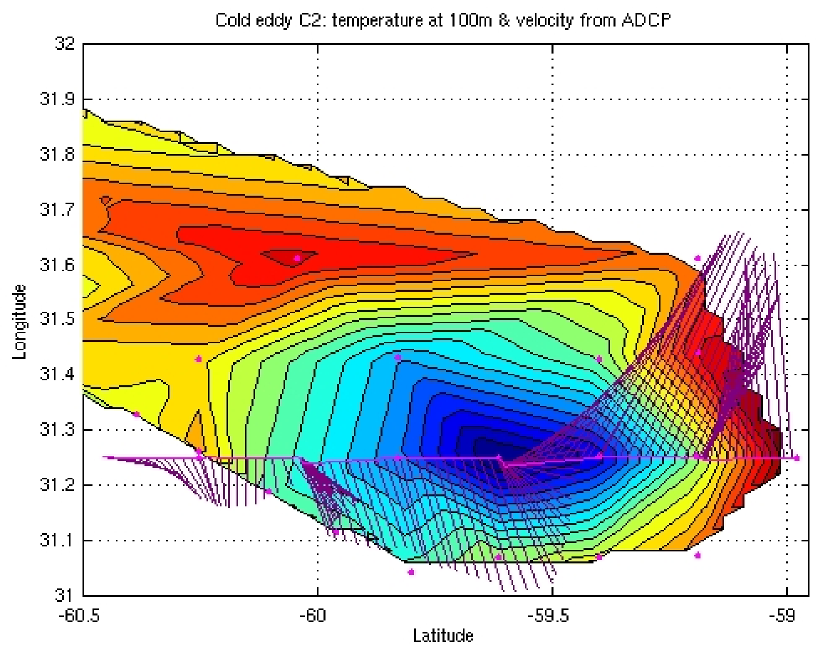

Figure 14: ADCP velocity vectors (0-100m average) overlayed on temperature at 100m from XBT data (station positions indicated by dots).

A recent MODIS image shows a chlorophyll anomaly associated with C2 (Figure 15). FRRF group reports that C2 has less chlorophyll, but higher variable fluorescence, than A1; contrast across eddy C2 is not as pronounced as in A1. However, further examination of the hydrography (Figure 16) and ADCP data suggest that the outermost stations of the CTD section were near the edge of the eddy rather than truly outside the feature. Microscopic analysis and FRRF on size fractionated C2 samples indicate a preponderance of small phytoplankton 1-2 microns in diameter, in contrast to those from A1 in which diatoms and dinoflagellates were found. VPR group reports finding much fewer colonial diatoms in C2 than in A1. Zooplankton assemblage in C2 comprised of copepods. MOCNESS tow at eddy center captured a lot of large migrators. Surface plankton tows showed little contrast across the eddy, but this may be a result of the sampling issue described above.

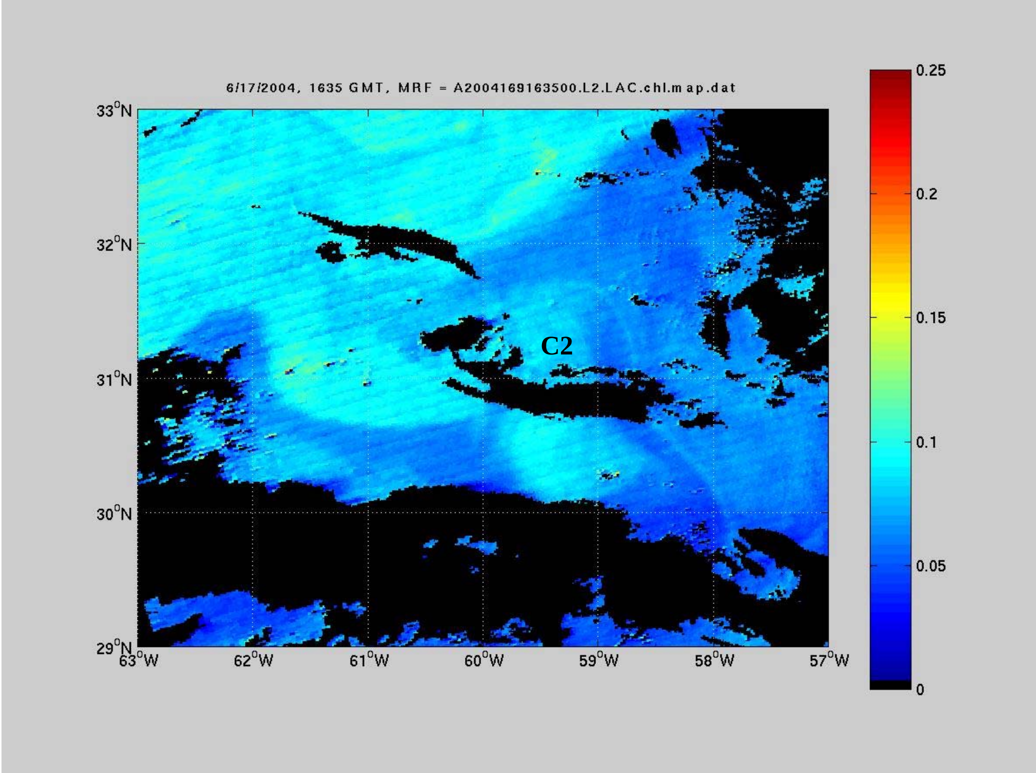

Figure 15. MODIS ocean color image for June 17, 2004. Center of anticyclone C2 indicated.

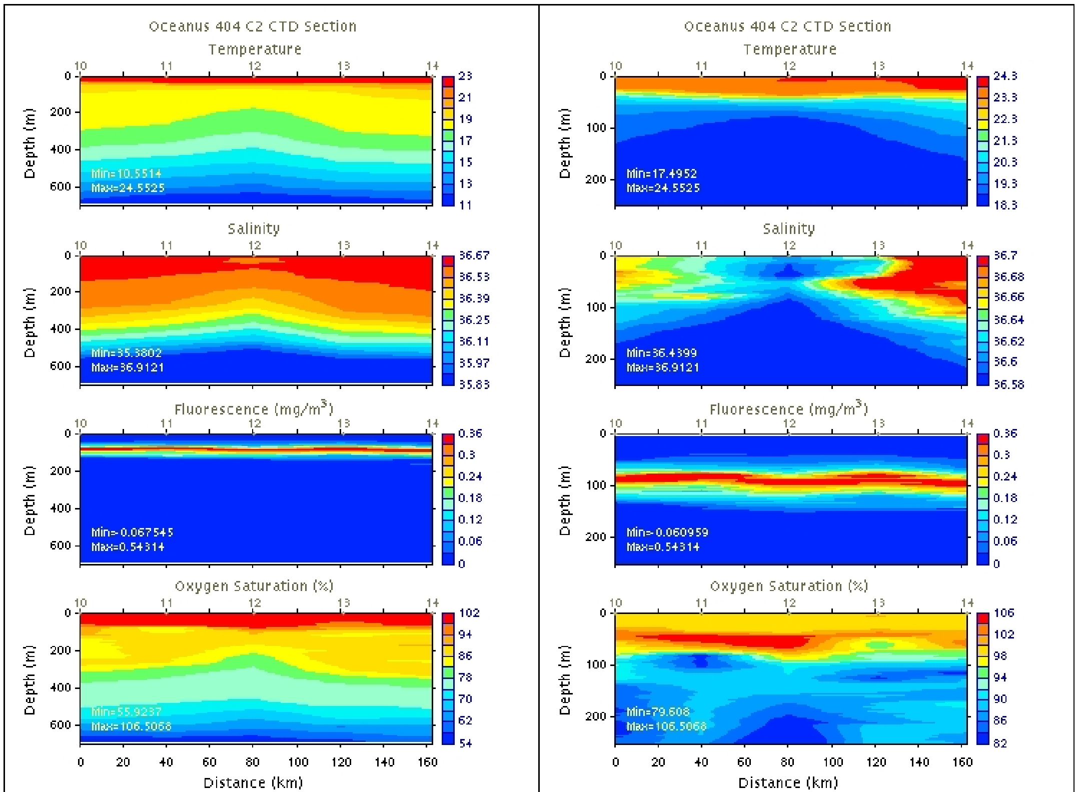

Figure 16. Temperature, salinity, fluorescence, and oxygen saturation across C2. Left: 0-700m; right: 0-250m.

Center of cyclone C1 located with XBT survey (Figure 17). Vertical sections reveal its impact on the main thermocline as well as upper ocean properties (Figure 18). Note the accumulation of oxygen in the euphotic zone in the eddy interior.

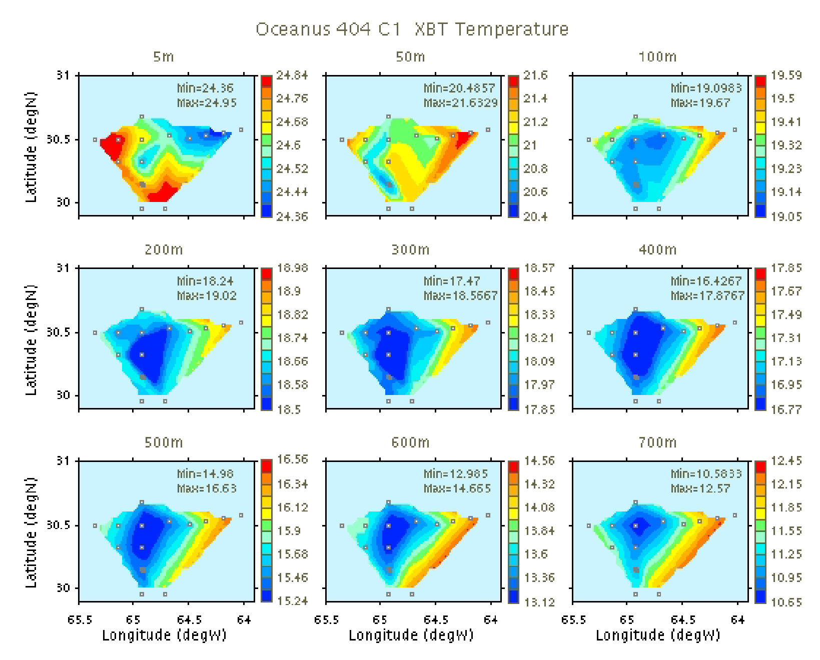

Figure 17. Temperature distribution in C1 based on XBT survey.

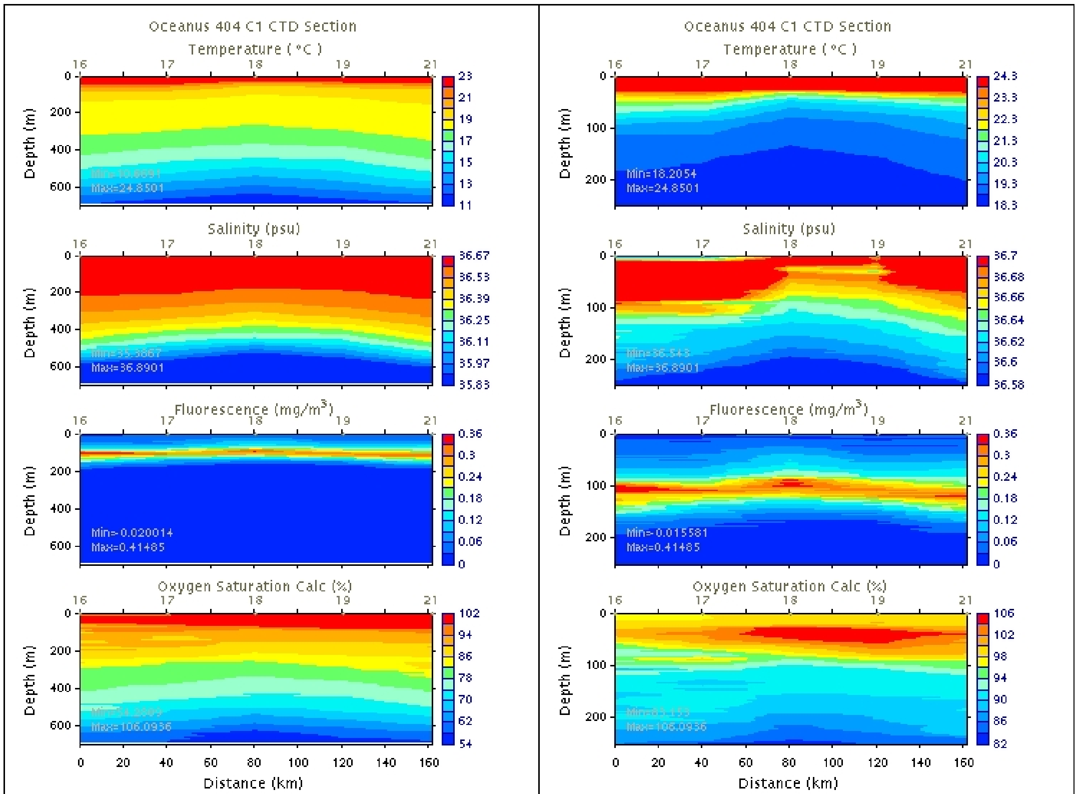

Figure 18. Temperature, salinity, fluorescence, and oxygen saturation across C1. Left: 0-700m; right: 0-250m.

4. Selection of the target feature

Salient characteristics of each of the five eddies sampled are summarized in the table below. Eddy A3 is a regular anticyclone and is therefore not considered a viable candidate. A1 is a Madeira Mode Water Eddy (bolus of 16 degree water) with strong and distinct biological and chemical characteristics. To our knowledge such features are rare in this region of the Sargasso Sea. Thus, there is concern that targeting an uncommon eddy type could potentially jeopardize the generality of the conclusions that could be drawn from our study. A2 is a Mode Water Eddy, but its perturbation to the seasonal thermocline is very weak. The subsurface fluorescence maximum descended to depths greater than 100m in the interior of the feature. Thus two viable candidates remain: C1 and C2. Both have strong points and weak points with respect to their impact on upper ocean biology and biogeochemistry; there is no clear winner from that point of view. However, based on the VPR transect and MODIS imagery, it appears that C2 is interacting with a filament of low-salinity, high-chlorophyll water to the west. There was concern that this streamer could potentially complicate interpretation of our measurements. Therefore we decided to target C1 on the grounds that it is a more isolated feature that will provide a more unambiguous context in which to study eddy-driven biogeochemical dynamics.

	Physics	Nutrients and Oxygen	FRRF	VPR	MOCNESS	Surface tows
A3	Regular anticyclone					Many tricho tufts
A1	Madiera Mode Water Eddy	Nitricline shoaled to 40m; NO_3 = 50 nM at 50m. High O_2 anomaly (ca. 106% sat at 40m) on northern flank; lower on southern flank (ca. 100% sat).	High Chl; subsurface max elevated to 60m with high Fv/Fm; diatoms and dinoflagellates evident in microscopic analysis	High Fluor at SE edge. Radiolaria and some diatoms at center. More diatoms and marine snow at edge.	Good migrator biomass	Most biomass at northern edge (St. 8); dominated by colonial rads with some shrimp and large amphipods
C2	Cyclone; perhaps in the process of intensifying?	Large O_2 anomaly (106 % sat) at 50m; stronger on the western flank, slightly weaker on the eastern flank.	Less chl than A1; size fractionated FRRF and microscope suggest preponderance of 1-2 micron cells. Vertically averaged chlorophyll (F_0) 6 % larger than C1	Fewer colonial diatoms in C2 than A1; zooplankton assemblage consists of copepods and cladocera. Highest fluor in this eddy.	Very high migratory biomass, with man juvenile euphausiids, amphipods, and gelatinous zooplankton	Biomass similar across eddy (daytime stations); more cladocerans at eddy center. Large diatoms on western side (St. 10,11,12).
C1	Cyclone; intensified in May	Nitracline shoaled to 80m at eddy center; transect values: 100,90,70,90,90 Large O_2 anomaly (106 % sat at 50m) with centroid slightly east of eddy center	Max chl values less than C2, but broader subsurface peak; more pronounced shoaling of subsurface chl max at eddy center. Consistently higher Fv/Fm than C2, with broad high values at eddy center. 80-90% of the phytoplankton assemblage comprised of small cells. One cast (CTD 19) had 25% of the cells greater than 5μ; collocated with maximum in $\%O_2$ saturation.	High fluor in 2 locations and local doming. Diatoms, copepods, and lots of radiolarian. Overall less plankton than C2 (# of images), but mean size is larger (size frequency dist'n of images).	Very low migrator biomass and biomass throughout the water column	High tricho tuft abundance at 2 westernmost stations. Community structure shifts occurred across the eddy and biomass was highest on the eastern edge (St. 21). Overall amount of material collected similar in C1 and C2.
A2	Mode water eddy; very weak perturbation to the seasonal thermocline					

4. Detailed sampling of the target feature C1

The target feature C1 was sampled intensively with a survey grid (Figure 19, top panel) and a final re-occupation of the centerline transect (Figure 19, lower panel). Section-by-section results are presented in Figures 20-24; horizontal maps are shown in Figures 25-28.

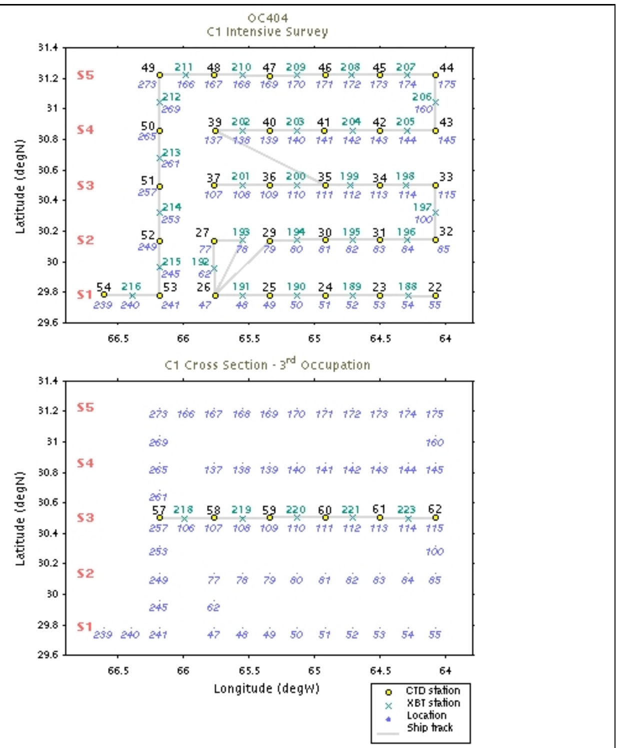

Figure 19. Station locations for C1 intensive survey (top) and final reoccupation of centerline transect (bottom). Transect identifiers S1 through S5 are indicated on the left.

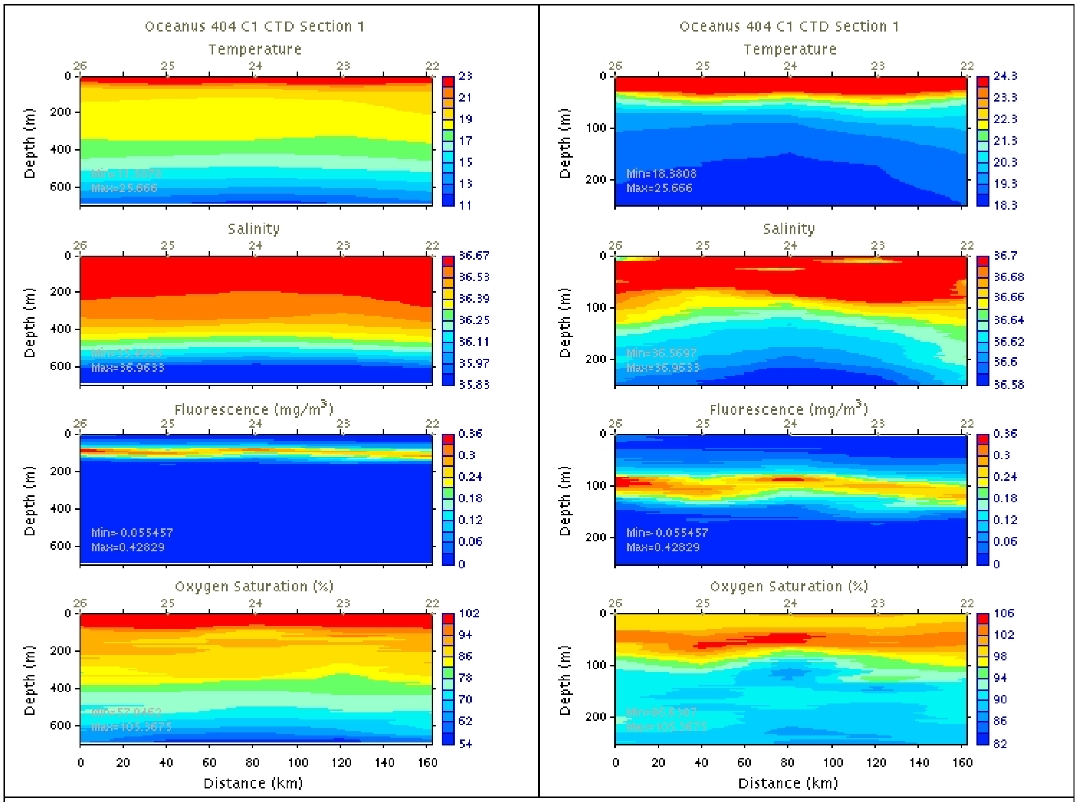

Figure 20: Temperature, salinity, fluorescence, and oxygen saturation for section 1 of the C1 survey grid. Left: 0-700m; right: 0-250m.

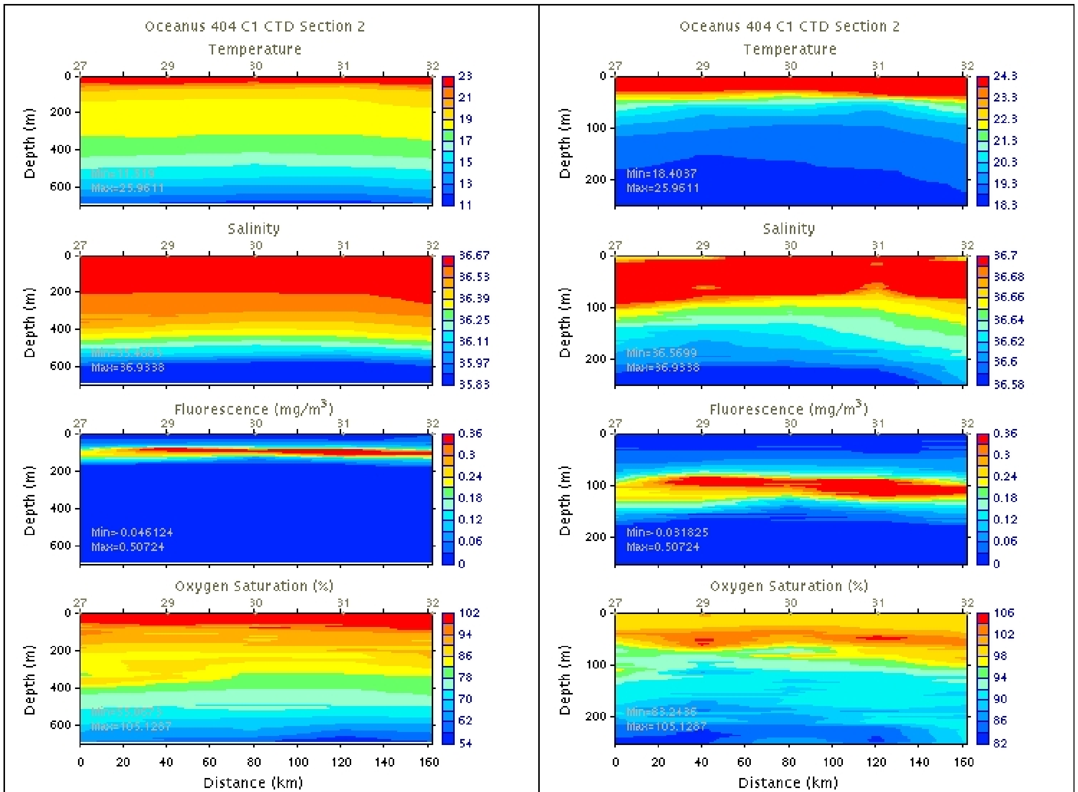

Figure 21: Temperature, salinity, fluorescence, and oxygen saturation for section 2 of the C1 survey grid. Left: 0-700m; right: 0-250m.

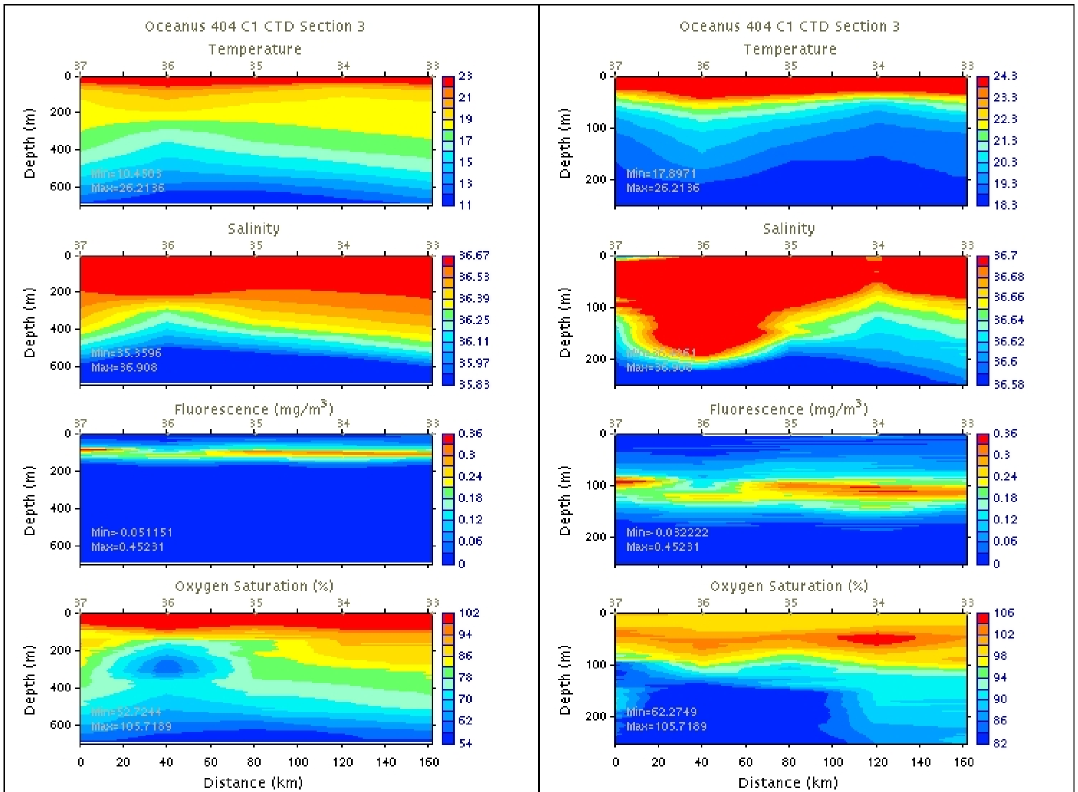

Figure 22: Temperature, salinity, fluorescence, and oxygen saturation for section 3 of the C1 survey grid. Left: 0-700m; right: 0-250m.

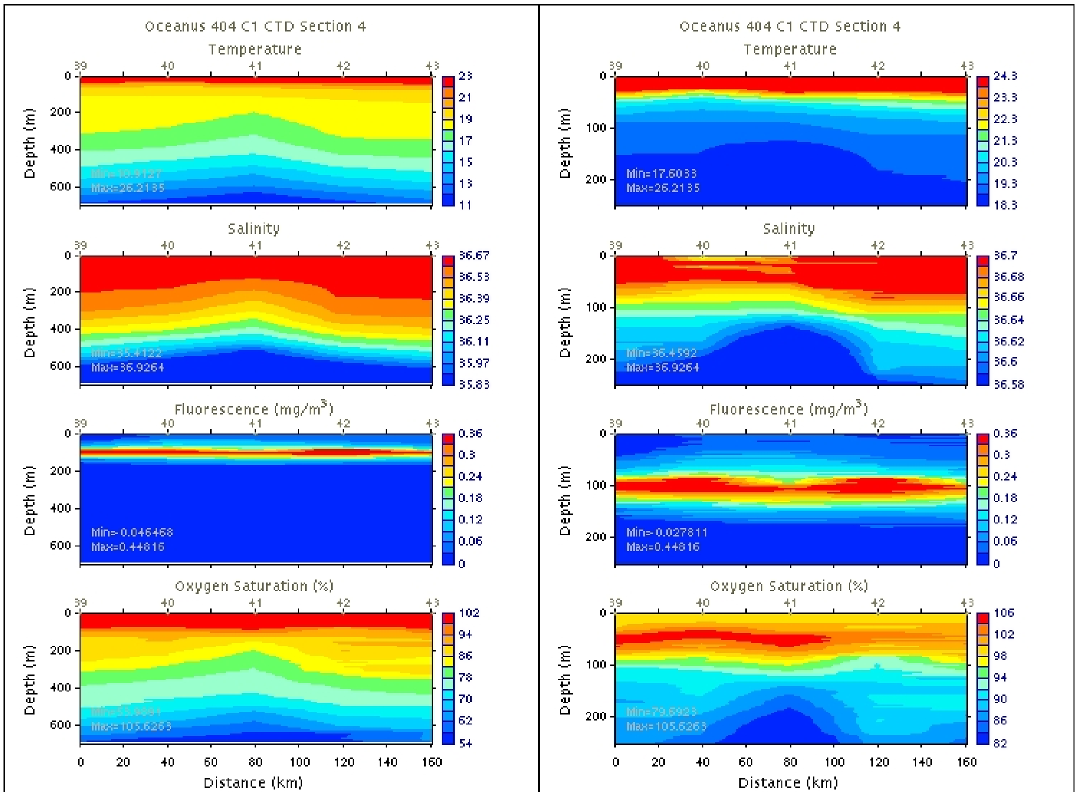

Figure 23: Temperature, salinity, fluorescence, and oxygen saturation for section 4 of the C1 survey grid. Left: 0-700m; right: 0-250m.

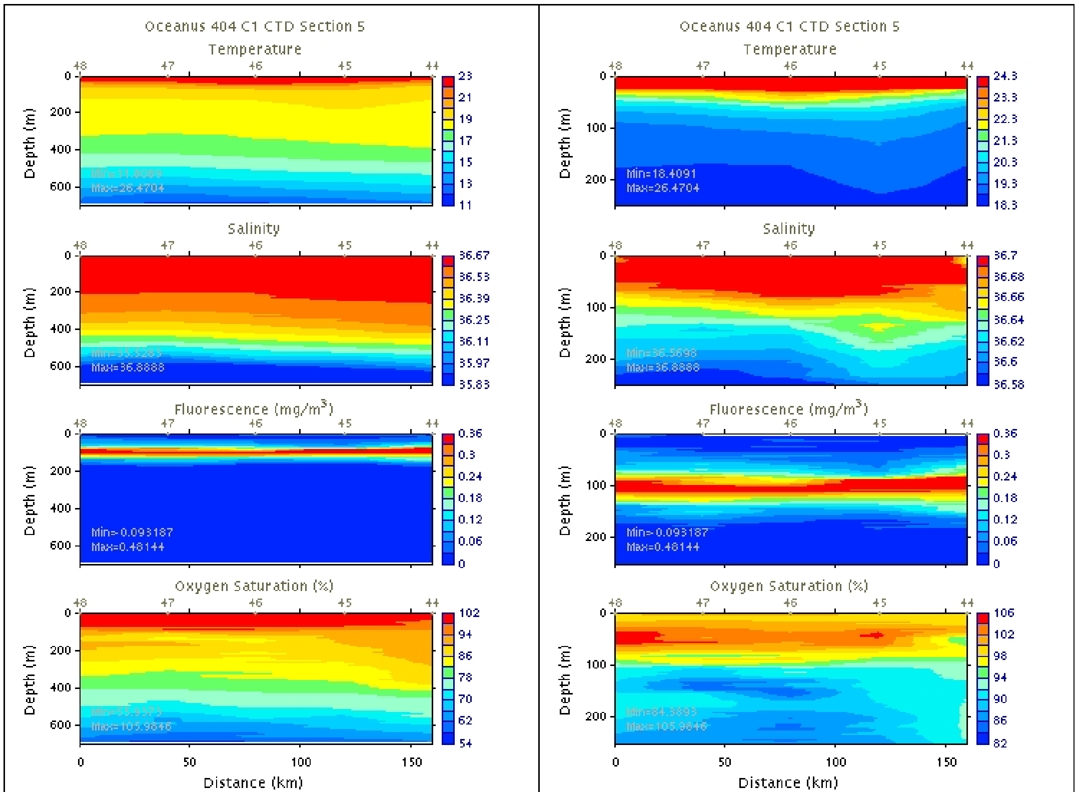

Figure 24: Temperature, salinity, fluorescence, and oxygen saturation for section 5 of the C1 survey grid. Left: 0-700m; right: 0-250m.

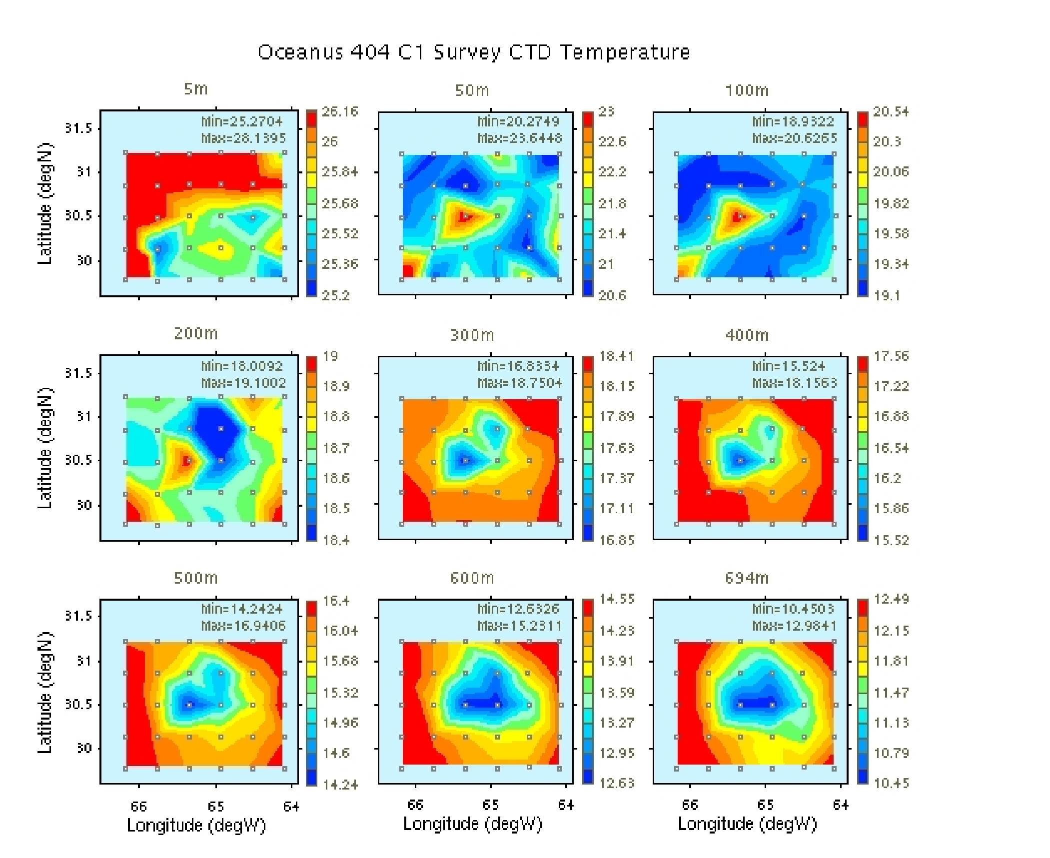

Figure 25. Horizontal maps of temperature at selected depths for the intensive survey of target feature C1.

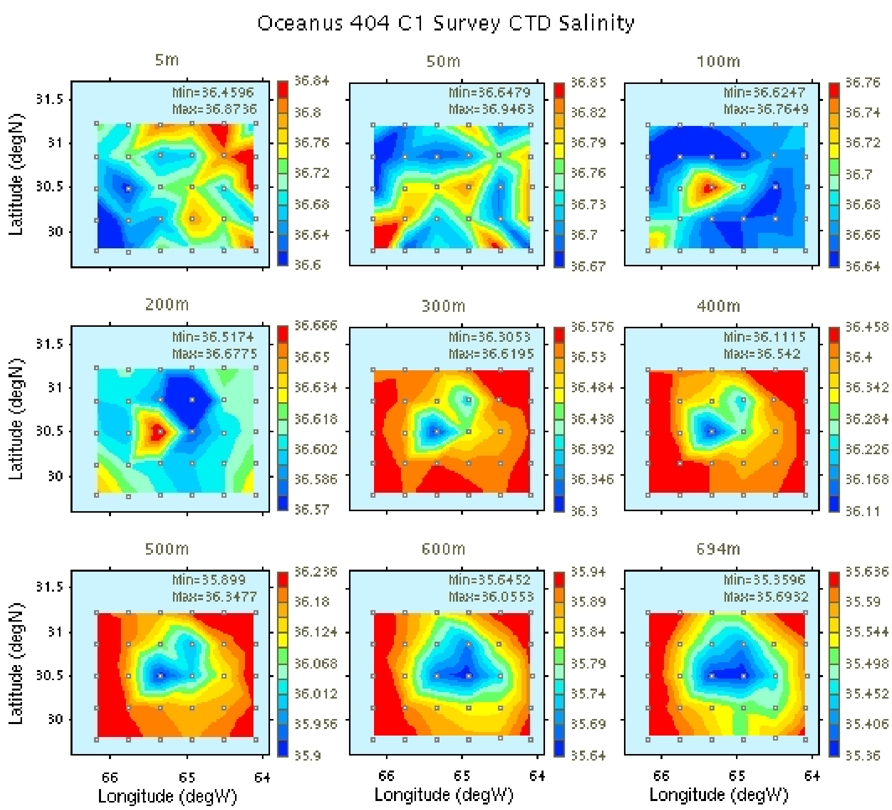

Figure 26. Horizontal maps of salinity at selected depths for the intensive survey of target feature C1.

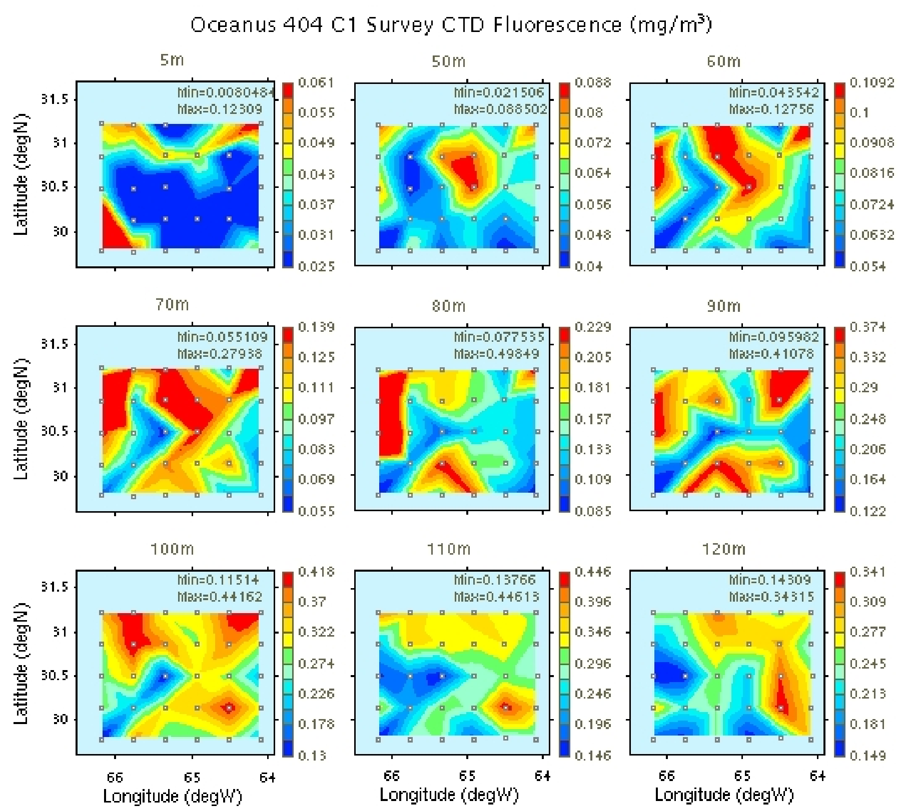

Figure 27. Horizontal maps of fluorescence at selected depths for the intensive survey of target feature C1.

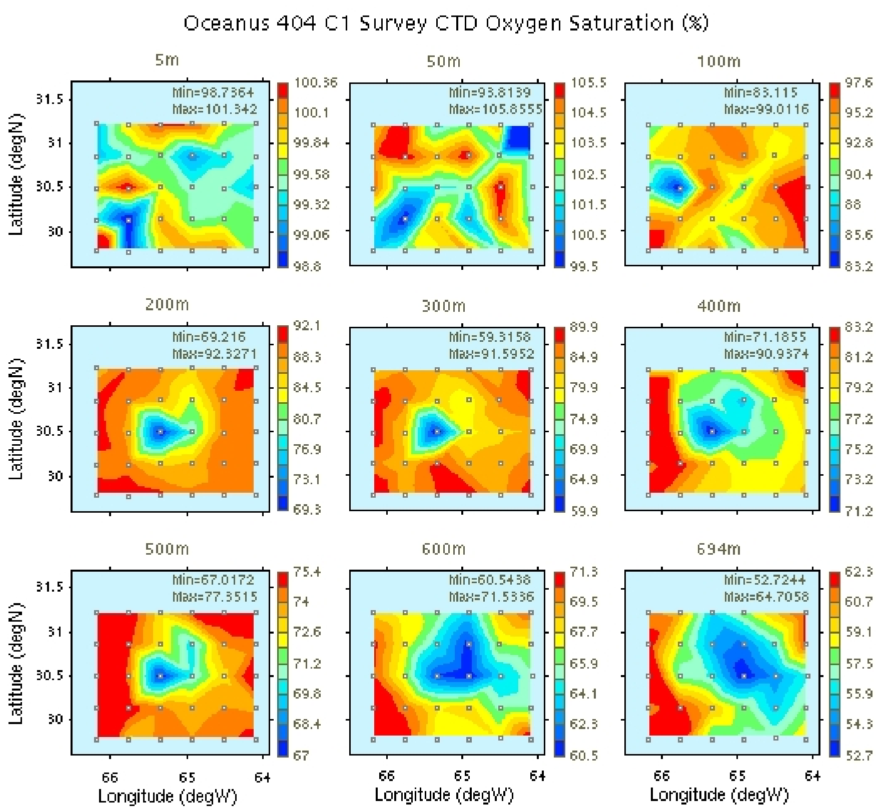

Figure 28. Horizontal maps of oxygen saturation at selected depths for the intensive survey of target feature C1.

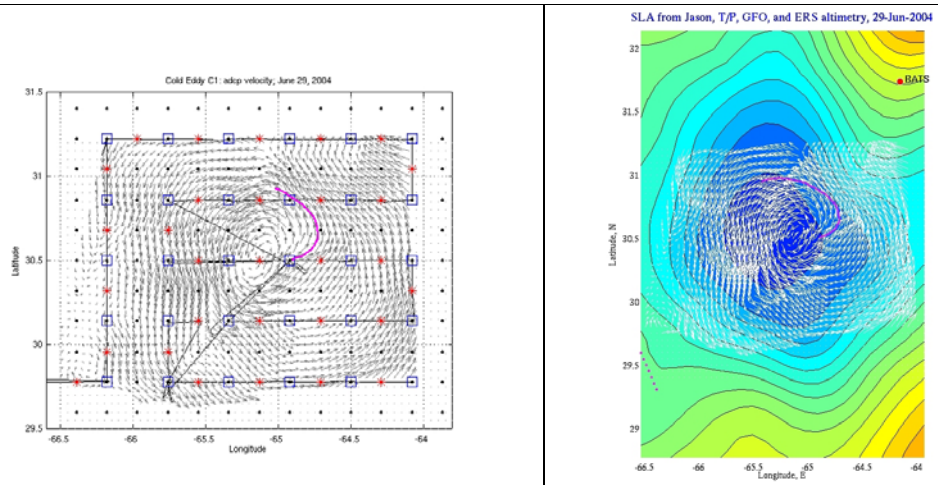

Figure 29. ADCP velocities (0-100m average) from the C1 grid survey. Left panel: interpolated velocity field and station positions (CTDs – blue squares; XBTs – red asterisks; cruise track - thin black line; drifter track – magenta line). Right panel: same velocity field overlayed on SLA map for June 29.

Shipboard ADCP measurements reveal the signature of C1 in the upper ocean velocity field (Figure 29). Trajectory of the UCSB bio-optical drifter follows the velocity field quite closely.

6. Temporal evolution of the target cyclone C1

Dramatic changes appear to have taken place along the central E-W section through eddy center (Figure 30). When this section was first occupied (C1 initial transect; stations 16-21; June 21-22), eddy center was characterized by (1) fairly uniform doming of temperature and salinity surfaces, (2) enhancement and shoaling of the subsurface chlorophyll maximum, and (3) enhancement of the subsurface oxygen maximum at 50m. The second occupation of this transect (C1 Survey grid; stations 33-37 and 51; June 25 and June 28) revealed thinning of the 18-degree water mass: this was associated with shoaling of the main thermocline/halocline and deepening of the seasonal thermocline and upper ocean halocline. Chlorophyll at eddy center decreased, with the minimum chlorophyll located one station west of eddy center (station 36). The subsurface maximum in dissolved oxygen at ca. 50m weakened between the first and second occupations. Moreover, the second transect revealed a large subsurface minimum in dissolved oxygen at ca. 300m. Rod Johnson reports that titrations aboard the R/V *Weatherbird II* indicate eddy center oxygen concentrations of 140 micromoles per kg at 300m and 160 micromoles per kg at 700m. This constitutes a major anomaly in the oxygen profile, in that the subsurface oxygen minimum is typically found at ca. 800m at BATS.

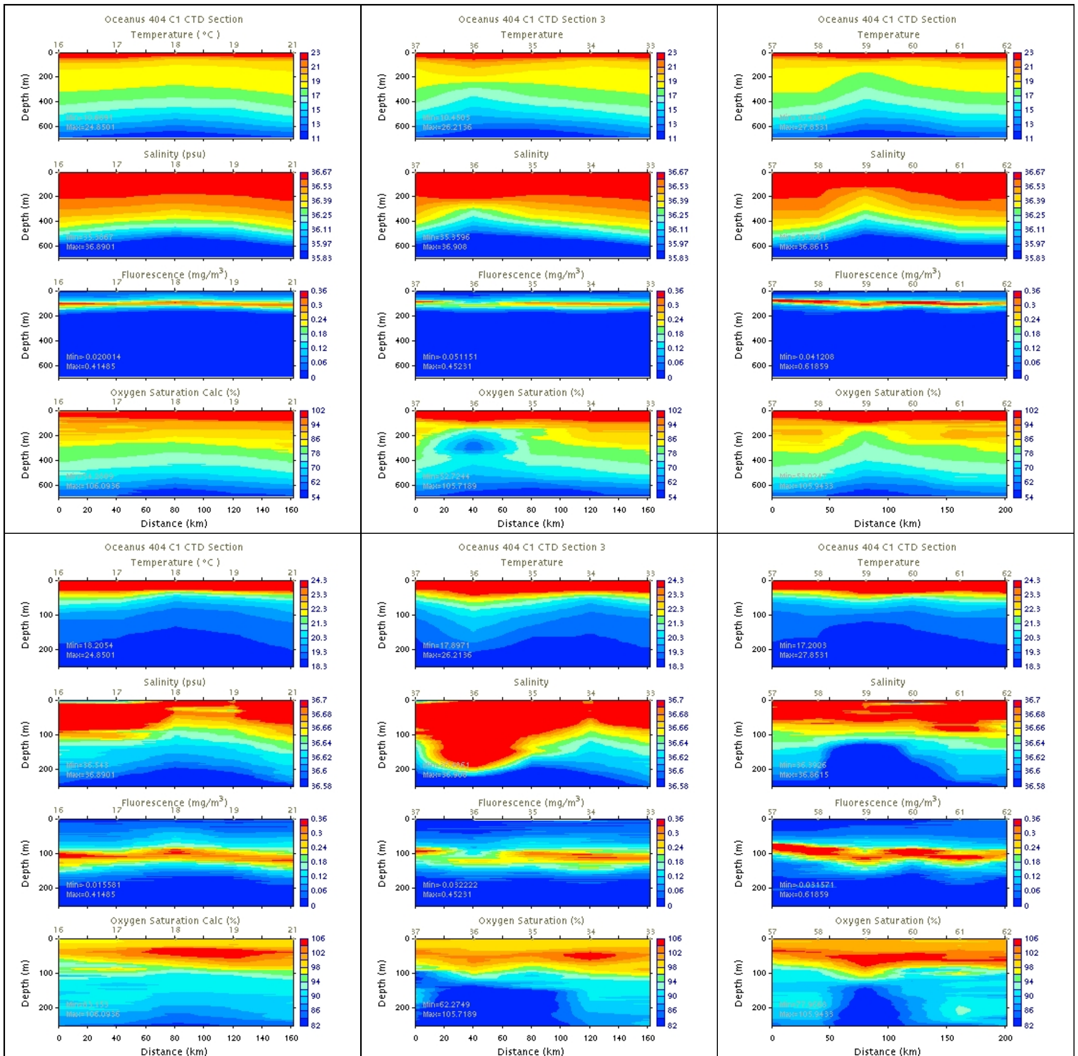

Figure 30: Temperature, salinity, fluorescence, and oxygen saturation from three E-W transects across eddy center (top: 0-700m; bottom 0-250m). Left: stations 16-21, occupied June 21-22; middle: stations 33-37 and 51, occupied June 25 and June 28; right: stations 57-62, occupied June 30-July 1.

Given these dramatic changes, we were inclined to reoccupy the central section one final time (stations 57-62; June 30-July 1). Between the second and third occupations, the upward doming of the main thermocline and halocline persisted. However, the deepening of the seasonal thermocline and upper ocean halocline is not evident in the third occupation as it was in the second. Once again a minimum in chlorophyll was associated with the maximal doming of the main thermocline and halocline. Curiously, the subsurface oxygen maximum at ca 50m increased in magnitude, such that it appears more similar to the first occupation than the second (except for the deepening of the maximum one station to the west of eddy center [station 59]). The low oxygen anomaly persisted at depth in the third occupation, but its amplitude was not sufficient to produce a detached local minimum in the 200-300m depth interval.

Examination of the remainder of the vertical sections from the survey reveals that the low oxygen anomaly was detected at one additional station of the survey grid: station 41, just north of eddy center. The low oxygen anomaly clearly has horizontal structure that corresponds closely to other hydrographic properties. For example, consider the oxygen saturation map at 200m. As indicated in the vertical sections, the largest amplitude anomaly occurs one station to the west of eddy center, station 36 at location #109. However, the anomaly is contiguous with other large amplitude perturbations at stations 35 and 41 (locations #111 and #141). Consecutively larger isopleths of oxygen saturation have self-similar structure, suggesting that the low oxygen anomaly is embedded in an eddy-scale feature.

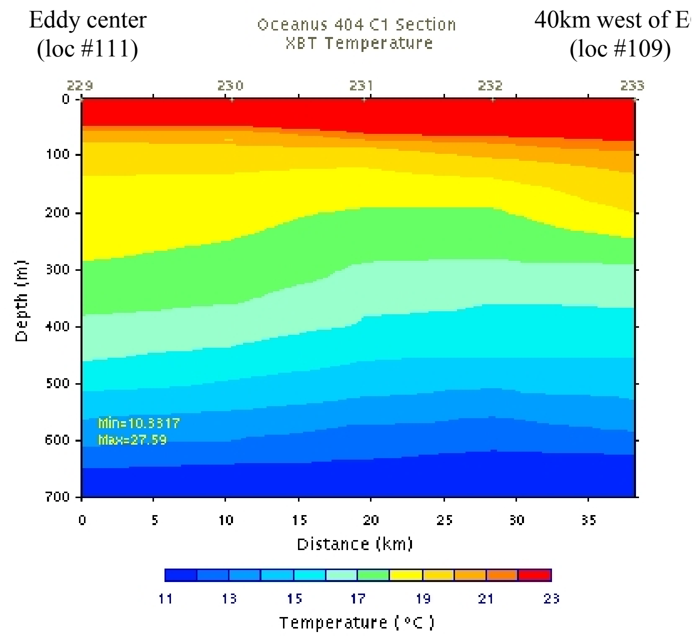

Figure 31: High resolution XBT section between Eddy Center (location #111) and one CTD station to the west (location #109).

Nevertheless, dramatic hydrographic changes clearly take place over relatively short distances. A high resolution XBT line in between Eddy center (location #111) and the adjacent CTD station to the west reveals thinning of the 18 degree water layer by more than 100m over 40km (Figure 31). Whereas the layer of 18 degree water is 150m in vertical extent at Eddy center (location #111), it is only 40m thick at location #109.

Water mass analysis indicates a discernible temperature-salinity signature of the anomalous feature (Figure 32, left panel). Interestingly, it is the oxygen anomaly that really sets this water mass apart (Figure 32, right panel). It is curious how far apart stations 36 and 55 are set apart from the rest in terms of their oxygen content in temperature and salinity space. This suggests that the peak in the anomalous subsurface oxygen minimum is very small in horizontal extent. Merging of these data with the R/V *Weatherbird II* survey data will be of great use in defining the spatial scale of this anomalous feature.

Key questions:

(1) Was this feature locally generated or is it of distant origin?

(2) Can mixing and/or heating account for the T-S anomaly?

(3) Was this feature present in the 1st occupation and we just missed it because of its small scale?

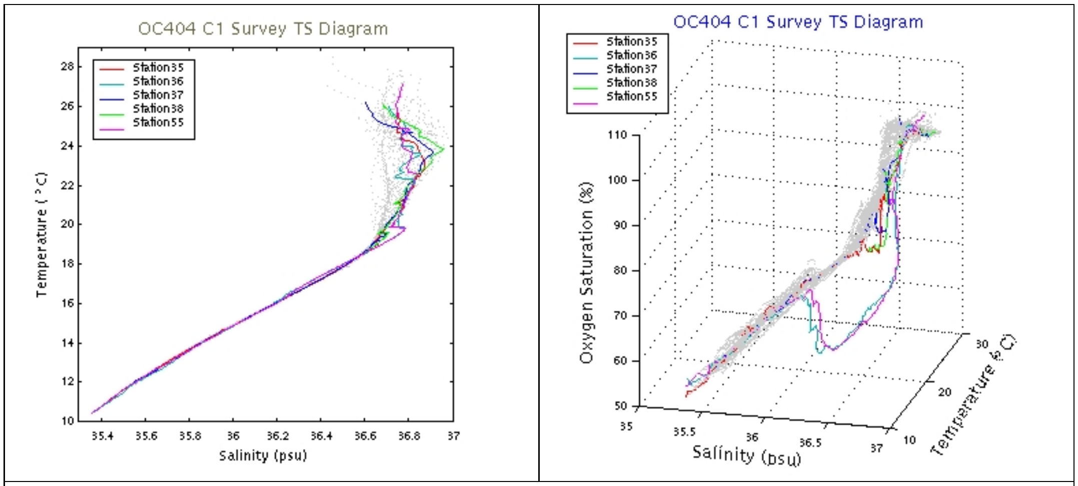

Figure 32. Water mass characteristics of all stations in the intensive survey of C1. Selected stations are indicated in color (see legend); all others plotted in gray. Left panel: temperature versus salinity. Right panel: temperature versus salinity and oxygen.

7. Cruise narrative

June 11, 2004 – Off the dock at 1600. Set waypoint 34 30, 66 30: center of AC3; ETA noon Sunday.

June 12, 2004 – Test cast at 1330 in slope water.

June 13, 2004 – Commenced XBT operations at 0240 well in advance of arrival at AC3.

Waypoint for AC1 set using map with last overpass of that feature (June 3).

AC3 is definitely not a Mode-water eddy; onward to AC1.

Updated plan: Sunday 13 June

XBT transect to AC1.

If AC1 is a Mode-water eddy,

1) find eddy center with an XBT search pattern
2) CTD transect (ca. 5 stations)
3) midnight MOCNESS tow at eddy center
4) VPR transect

If AC1 is not a Mode-water eddy, proceed to C2

June 14, 2004

ISUS sensitivity changed from 0-100 to 0-10 micromolar.

Configuration files:

OC404-1_ISUS_0_100_wrong.con (originally used for casts 1 and 2)
OC404-1_ISUS_0_100_right.con (casts 1+2 need to be reprocessed with this)
OC404-1_ISUS_0_10.con (starting with cast 3)

AC1 appears to be a MWE. Search pattern begun in clockwise manner to benefit from swirl velocity. Eddy center clearly delimited to the north upon completion of the loop; worked back to the S-SW to delimit southern boundary. After delimiting boundary of eddy core, moved back up 1 station to commence MOCNESS at midnight on Monday.

Southward displacement of Eddy center consistent with Jenifer Clark's analysis, which indicates that the CE/AC/MWE complex moved south.

Sampling Plan for Mode Water Eddy A1:

1055 Transit to eddy center

1200 MOCNESS

5-station CTD transect

June 15, 2004

Finished southern edge of transect with CTDs 4 and 5. CTD 4 showed raised fluorescence maximum: 60m instead of 100m in the background. CTD4 also showed a secondary maximum between 120 and 140m. Incubation water to be collected on our way back north in transit to finish the transect.

Feature A3 has anomalous water mass properties--- warm and salty at depth. Clearly not a MWE, the depression of the main thermocline occurs below the 18 degree water. We will take a 1500m cast at eddy center to further elucidate the feature.

1500m cast requires removal of the ISUS and PAR sensors. A new configuration file _deep was generated to go with this cast.

June 16, 2004

Underway XBT operations commenced south of the Gulf Stream, in transit toward a large anticyclone A3 at (34 30.0N, 66 30.0W). XBT data revealed this feature is a regular anticyclone, not a mode water eddy. Feature A3 is therefore not a contender for future study, but a single hydrocast (CTD 2) was deployed at eddy center for comparison purposes.

Transited to anticyclone A1 at (33 22.2N, 62 42.0W). Initially the feature appeared to be a mode water eddy. After locating its center, a cross section of 5 CTD stations was occupied, including a midnight MOCNESS tow at eddy center. Significant biological perturbations were evident in the southern flank of A1. The fluorescence maximum, typically at 100m in the background waters, was raised to ca. 60m, with a secondary peak at 120-140m. FRRF measurements indicated high variable fluorescence in the uplifted fluorescence maximum at 60m (Bibby, Koblizek, Wyman). Low-level nutrient measurements indicate nutrient enhancement at 60m, with measurable nitrate as shallow as 40m (Li). Water was collected from this feature for growout experiments (Bibby) and oxygen incubations (Mourino). Further hydrographic analysis of the eddy cross-section revealed thinning of the 18 degree water at eddy center, with a bolus of 16 degree water below containing a distinctive salinity anomaly. These aspects were barely discernible from the 0-700m data being collected. Therefore, a 1500m CTD (including nutrient, oxygen, and helium samples) was occupied at eddy center to obtain more information about the vertical structure and water mass characteristics of the anomalous feature. Clearly A1 is not a mode water eddy and is therefore no longer a candidate for future study.

At 0500 we are underway toward Cyclone C2 (31 15.0N, 60.0 15W) towing the VPR with hourly XBT drops. ETA is 0400 EDT Thursday. Upon arrival we will continue with a detailed search for eddy center. At that point the VPR will come out and water sampling operations will recommence. Upon completion of water sampling we will transit to cyclone C1 (30 30.0N, 64 30.0W), as time will not allow for inspection of anticyclone A2 (ca. 29N, 62W).

June 16, 2004

Towing VPR toward C2. Difficulties with the XBT wire fouling on the VPR cable. Solution: slow to 7 knots, fly the VPR to port, slow turn of the ship to port, launch XBT off starboard quarter.

June 17, 2004

Search for C2 center. Temperature at 700m is 11 degrees at eddy center, comparable to the perturbation associated with C1 (based on BATS spatials plus Sedwick CTDs).

June 18, 2004

VPR recovered at 0200 after 45 hours of flawless towing. CTD section across C2 begins, and is complete by 1800. Steamed back to eddy center for a MOCNESS tow and a 0-200 CTD for collecting water for incubations. VPR deployed and then recovered to fix a trim problem. VPR then redeployed and we begin towing toward C1 at 0400.

Note #1: ISUS reconfigured to 0-100 micromolar setting at CTD 12. Configuration file updated accordingly.

Note #2: Original plan for Niskin bottle samples called for 3 bottles to be fired at the surface. We found that the 3rd bottle was rarely used and we were running short on the single bottles in the high resolution part of the profile (40-100m). It was therefore decided to move one surface bottle to that portion of the profile, so we added a second bottle to the 70m target depth. Unfortunately, this change was not propagated to the CTD operator and therefore bottles continued to be fired at the original depths during CTDs 10 and 11. The cast sheets for CTDs 10 and 11 were reconciled with what actually happened on the CTD, and the CTD operator began firing bottles in the new configuration starting at CTD 12.

June 19, 2004

Towing the VPR toward C1. ETA 0730 Sunday the 20th. Tentative schedule:

Sunday 0730 arrive at C1 waypoint

Search for eddy center

5-station CTD transect

MOCNESS tow at eddy center

CTD cast at eddy center for incubations

June 20, 2004

0930-0945 Fluorometer offline for cleaning.

Sampling of cyclone C2 (31 15.0, 59 36.8) is complete. Recent altimeter data shows it has intensified. Comparing our XBT and CTD traces from C2 to those from the BATS/Sedwick cruises in and near C1 in early June, it appears that the cold temperature anomalies are similar in the two features. A recent MODIS image shows a chlorophyll anomaly associated with C2; no good images over C1 yet. FRRF group reports that C2 has less chlorophyll, but higher variable fluorescence, than A1; contrast across eddy C2 is not as pronounced as in A1. However, further examination of the hydrography and ADCP data suggest that the outermost stations of the CTD section were near the edge of the eddy rather than truly outside the feature. Microscopic analysis and FRRF on size fractionated C2 samples indicate a preponderance of small phytoplankton 1-2 microns in diameter, in contrast to those from A1 in which diatoms and dinoflagellates were found. VPR group reports finding much fewer colonial diatoms in C2 than in A1. Zooplankton assemblage in C2 comprised of copepods. MOCNESS tow at eddy center captured a lot of large migrators. Surface plankton tows showed little contrast across the eddy, but this may be a result of the sampling issue described above.

Upon completion of sampling in C2, the VPR was redeployed and a transect toward C1 was begun. ETA is 0930 EST Sunday, at which time a detailed search for eddy center will begin. Water sampling operations will recommence no later than Monday morning, to be completed by Tuesday morning. Preliminary analysis of C1 findings to be completed by Tuesday night so a decision can be made on the target feature in advance of the Weatherbird II's departure Wednesday morning.

Analysis of the anomalous hydrographic characteristics of A1 continues. Based on the T,S, and oxygen anomalies, it appears that the bolus of 16 degree water in A1 came from near the Azores... perhaps "Madeira mode water"...

June 21, 2004

VPR/XBT survey completed. CTD section across C1 begins.

ADCP crashes, has to be rebooted, and files are re-arranged. ADCP normally writes to April. When April went down, ADCP started writing to a local disk. After writing 3 files, it ran into a read-only file in that same directory, so the machine crashed. Files re-ordered by Patrick.

June 22, 2004

Midnight MOCNESS tow at eddy center, then last station of C1 transect occupied. VPR/XBT transect to center of A2 begins at 0700.

A2 is a mode water eddy with a weak near-surface expression.

A science meeting was convened to gather input from all parties with respect to choice of the target eddy feature. Salient characteristics of each of the five eddies sampled are summarized in the table below. Eddy A3 is a regular anticyclone and is therefore not considered a viable candidate. A1 is a Madeira Mode Water Eddy (bolus of 16 degree water) with strong and distinct biological and chemical characteristics. To our knowledge such features are rare in this region of the Sargasso Sea. Thus, there is concern that targeting an uncommon eddy type could potentially jeopardize the generality of the conclusions that could be drawn from our study. A2 is a Mode Water Eddy, but its perturbation to the seasonal thermocline is very weak. The subsurface fluorescence maximum descended to depths greater than 100m in the interior of the feature. Thus two viable candidates remain: C1 and C2. Both have strong points and weak points with respect to their impact on upper ocean biology and biogeochemistry; there is no clear winner from that point of view. However, based on the VPR transect and MODIS imagery, it appears that C2 is interacting with a filament of low-salinity, high-chlorophyll water to the west. There was concern that this streamer could potentially complicate interpretation of our measurements. Therefore we decided to target C1 on the grounds that it is a more isolated feature that will provide a more unambiguous context in which to study eddy-driven biogeochemical dynamics.

June 23, 2004

Detailed survey of C1 begins.

News of the certification issue breaks.

MOCNESS tow at midnight in SW corner of grid.

June 24, 2004

Continuation of C1 grid. Return to SW corner of grid for noontime MOCNESS tow and collection of water for growout incubation (Bibby).

June 25, 2004

C1 grid continues. Deployment of UCSB bio-optical spar at eddy center. Completion of 3rd line of CTD grid; time to give the hydro team a break. Steam back to eddy center for a CTD cast for incubation water and midnight MOCNESS tow. VPR deployment for ca 10 hours, followed by noontime MOCNESS tow at eddy center.

June 26, 2004

Bottle #22 has been leaking slightly upon opening of spigot with vent closed. Bottle changed out with spare.

June 27, 2004

Continuation of CTD grid. Midnight MOCNESS on NW corner of grid. Not clear that eddy edges have been delimited; plan is to add two lines of stations to the west.

June 28, 2004

After completion of the 1st additional line to the west, it appears the eddy edge has been delimited. Began a VPR tow back toward the east, with plans for eddy center. VPR recovered and hung from the crane for optics adjustment. Images are now clearer and fewer.

June 29, 2004

VPR tow concluded at eddy center. Intercalibration CTD station with Weatherbird II at eddy center. Passed over 1 bottle of ethanol and 15 liters of Millipore water to the Weatherbird II. MOCNESS tow at noon ran into trouble, with the pressure sensor reading –69m shortly after it entered the water. Troubleshooting begins with Erich Horgan and URI. Meanwhile, the VPR tow across the eddy from SW to NE continues.

WBII completes work at eddy center. Rod states three objectives remain: (1) additional PP array in an area of high fluorescence; (2) outside control station; (3) additional transect work.

Comms at 2100:
(1) Based on recently occupied VPR transect from SW corner to eddy center, we recommend PP array at location #63, 29 57.6 65 33.1.
(2) Based on extended CTD grid, a good control site outside the eddy is location #241, 29 46.8 66 10.9.
(3) Suggest S-N transect work through eddy center to complement our W to E transect; two crossing transects will provide one last snapshot of the eddy feature and the anomalous water mass now at eddy center.

June 30, 2004

Comms with WBII at 0900

Fluorescence they observe at location of PP array deployment is the highest they have seen during the cruise.

Characteristics of anomalous water mass:
Thinning of 18 degree water
Positive (negative) salinity anomaly in seasonal (main) thermocline
Oxygen at 300m: 140 micromoles per kg (WBII wet oxygens)
Oxygen at 800m: 160 micromoles per kg
According to Rod, the oxygen minimum typically resides at 800m; the oxygen minimum at 300m in this feature is the lowest he has seen at BATS.

Recovery of UCSB bio-optical spar.

Headed for location # 257 to begin W to E transect.

July 1, 2004

Completed W to E transect. Headed south to SE corner to begin VPR transect from SE to NW.

Adjusted WBII S-N section.

Oblique tow with hoop net at 139, CTD to collect water for incubations.

Finish VPR tow to NW corner.

July 2, 2004

Steam back to 139 for oblique tow, then back to 111 for oblique tow, facilitating two day/night comparisons.

Plans emerge to re-occupy the oxygen anomaly west of eddy center for further helium sampling. Comms with WBII indicate anomalous oxygen feature observed at location 95 and 140, but not at 110. Therefore we will try loc 109, where the feature was observed on the prior 2 transects.

Station 109 reoccupied with pronounced subsurface minimum at 300 and maximum at 70-80. Core cast taken, with both features resampled for helium (2 bottles).

CTD and SOCNESS at BATS in transit back to BDA.

July 3, 2004

Arrival in BDA.

8. Cruise participants

Dr. Dennis Joseph McGillicuddy, Jr., Chief Scientist, Woods Hole Oceanographic Institution
Dr. William John Jenkins, Woods Hole Oceanographic Institution
Dr. Valery Kosnyrev, Woods Hole Oceanographic Institution
Ms. Olga Kosnyreva, Woods Hole Oceanographic Institution
Dr. Beatriz Mourino Carballido, Woods Hole Oceanographic Institution
Dr. Cabell Seal Davis III, Woods Hole Oceanographic Institution
Mr. Andrew Girard, Woods Hole Oceanographic Institution
Mr. Patrick Rowe, Woods Hole Oceanographic Institution
Dr. Laurence Anthony Anderson, Woods Hole Oceanographic Institution
Mr. Paul James Lethaby, Bermuda Biological Station for Research
Mr. Nathanial Jackson Buck, Bermuda Biological Station for Research
Mr. Qian Li, University of Miami
Dr. Thomas Spencer Bibby, Rutgers University
Mr. Michal Koblizek, Institute of Microbiology, Czech Republic
Mr. Kevin Duane Wyman, Rutgers University
Mr. David W. Menzies, University of California Santa Barbara
Dr. Sarah Anne Stone, Virginia Institute of Marine Science
Ms. Grace Kathleen Henderson, Virginia Institute of Marine Science