**OC404-4 Cruise Report**
**Draft – August 19, 2004**

## Contents



## 1. Objectives

Voyage 404-4 of R/V *Oceanus* was the second 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]. A summary of the findings from voyage 404-1 of R/V *Oceanus* ("Survey 1") is available at the same URL.

The specific objectives of this cruise "Survey 2" were to:

1. Conduct detailed grid survey of target feature cyclone C1
(XBT, ADCP, CTD/Rosette, MOCNESS, VPR, Light probe)

2. Coordinate with R/V *Weatherbird II* in joint sampling operations of target feature C1

3. Resample other candidate eddy features A1 and C2 as time allows.

## 2. Cruise Narrative

*July 25, 2004*

Depart St. Georges ca. 1100. Begin XBT, ADCP survey to determine EC. Waypoint chosen on the basis of the most recent altimetry and drifter tracks from the R/V *Seward Johnson* provided by Paty Matrai.

*July 26, 2004*

ADCP track reveals velocity structure of C1 (Figure 1). First southward pass cut through the feature just east of eddy center. Turned to the west, then north, then east, and again south to box in the feature. Alongtrack temperature section reveals doming of the main thermocline,

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

depression of the seasonal thermocline, and associated thinning of 18-degree water (Figure 2). Temperature maps derived from XBT observations illustrate the opposite sense of the temperature anomalies in the near surface and main thermocline strata (Figure 3).

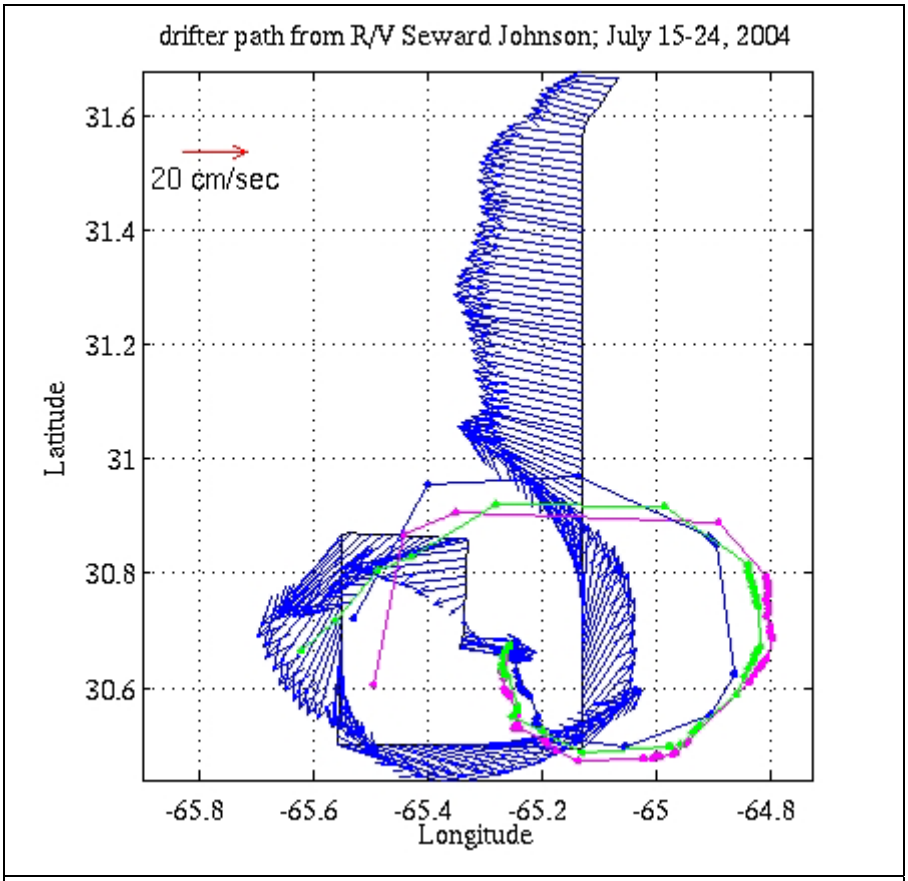


Figure 1. ADCP velocity observations from initial search for C1 eddy center. Blue, green, and magenta lines indicate drifter paths from Paty Matrai aboard the R/V Seward Johnson.

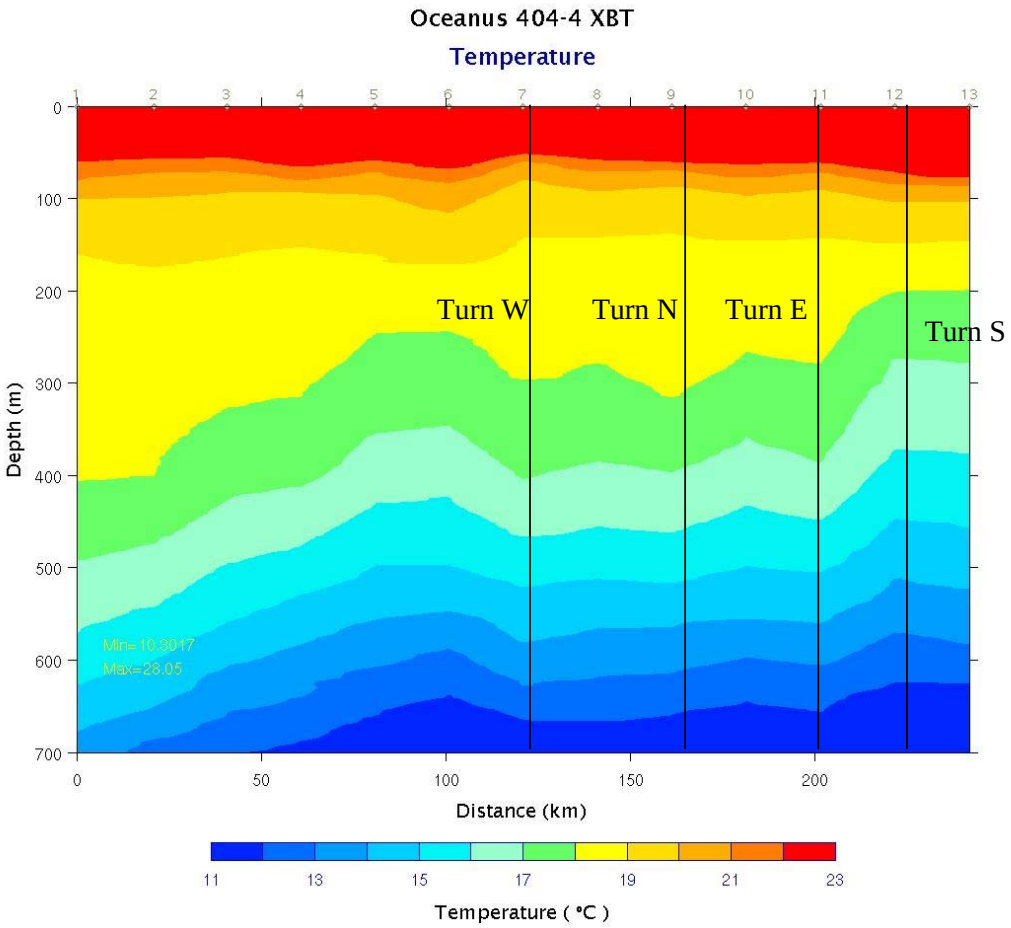


Figure 2. Alongtrack XBT section. Vertical bars indicate turning points in the cruise track (Figure 1).

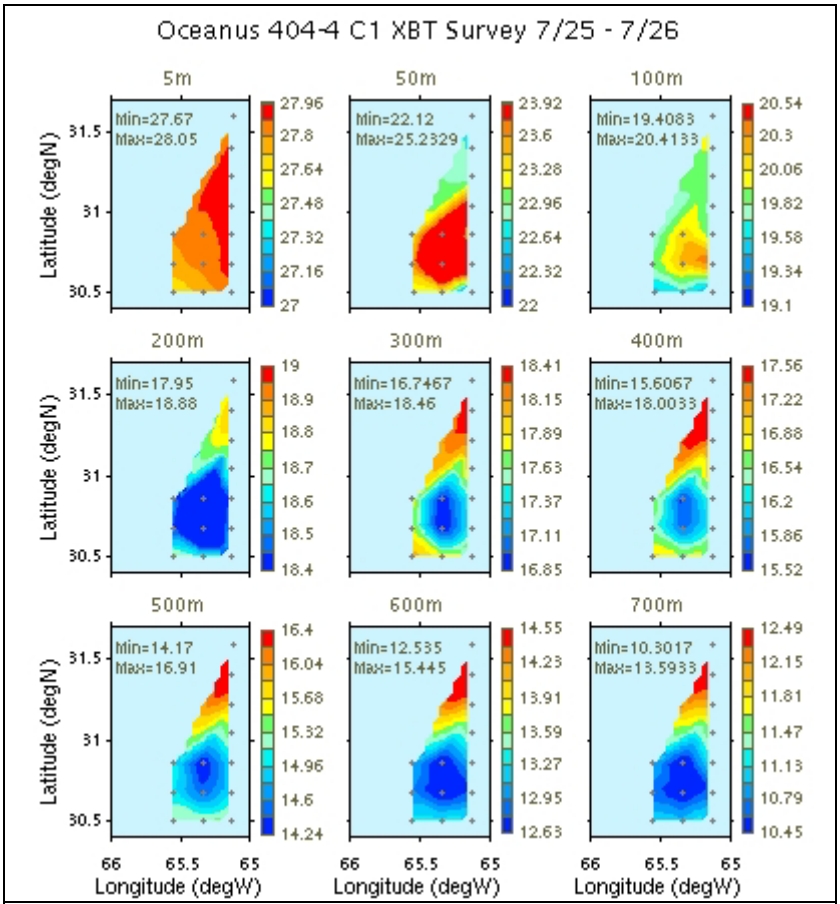


Figure 3. Temperature maps based on XBT observations from the initial search for C1 eddy center.

UCSB bio-optical drifter deployed at eddy center (#241). CTD survey begins; starting with high resolution stations at eddy center.

Configuration file oc404-4.con overwritten with new PAR coefficients.

Rendezvous with Seward Johnson to drop off parts. Paty Matrai reports lowest $^{14}C$ productivities she has ever measured.

Noon and midnight MOCNESS tows at eddy center (#241).

*July 27, 2004*

CTD survey continues.

*July 28, 2004*

Although the results from the survey grid are still unfolding, several things are apparent:

(1) The anomalous oxygen deficit is still present at eddy center. It has shoaled somewhat and become less intense (minimum concentration has increased from 140 to 160 micromoles per kg). Nevertheless, its signature is unmistakable at eddy center and in the station 20km to the north (we increased the resolution of our stations to 20km in the eddy core).

(2) At eddy center, the euphotic zone oxygen maximum has descended from 60m to 80m, and increased in concentration from ca. 220 to 230 micromoles per kg.

(3) At eddy center, the deep fluorescence maximum is reduced in magnitude and deep. There is a band around eddy center in which the fluorescence maximum is higher in magnitude and shallower than in surrounding waters.

(4) The depression of the upper seasonal thermocline and haloclines present at eddy center during Survey 1 appears to have relaxed somewhat.

*July 29, 2004*

Grid survey continues. Midnight and noon MOCNESS tows at the NW corner of the grid (location # 337).

*July 30, 2004*

Northernmost leg of grid completed, ending at NE corner. Steamed ca. 20 miles to BATS for a 200m incubation cast. Deployed VPR and began NE to SW transect through the eddy. Data dropouts began in late afternoon, VPR recovered ca. ¾ through the transect. Steamed down to SW corner (location #137) to begin southernmost line of stations. Upon completion of CTD at #137, a MOCNESS tow was initiated. The cable jumped the sheave on deployment. MOCNESS recovered, sheave replaced, and wire reterminated. Initial VPR repairs were completed (cleaning and reseating of connectors in J-box), so VPR was redeployed for testing during the CTD/MOCNESS down time. VPR data dropout problems persisted, so the southern line of stations was recommenced.

*July 31, 2004*

Southern line of stations completed. Objectives for the weekend are:

1. Locate eddy center in preparation for joint ops with WBII.

2. Occupy E-W line of CTD stations along N boundary of the grid to delimit high chlorophyll strip in that area.

3. MOCNESS tows

XBT line toward eddy center began at 1430. VPR tested but intermittent data losses continue. MOCNESS fails during midnight tow; stops communicating after descending 30m. Upon recovery, the electrical splice at the termination appears to have leaked. Splice repaired. XBT/ADCP survey of eddy center completed (Figures 4-6). ADCP velocities indicate eddy center is bounded by location #s 265, 264, 239, and 240 (Figure 4). Based on the temperature anomalies (Figure 5 and 6), we now refer to location # 240 as eddy center. These temperature anomalies suggest slight weakening of the eddy: the minimum temperature at 700m has increased from 10.3 in the first survey to 10.5 in the second.

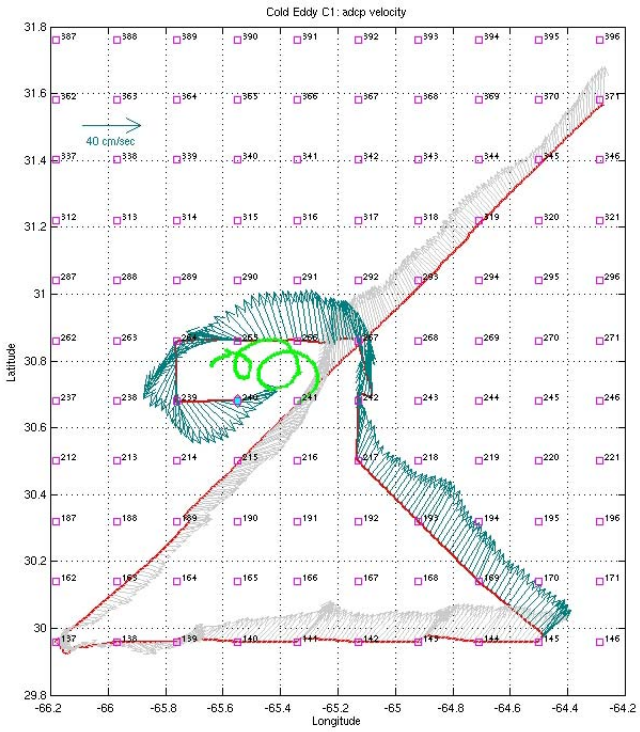


Figure 4. ADCP velocity observations from search for C1 eddy center, July 31, 2004. Green line indicates trajectory of the UCSB bio-optical drifter.

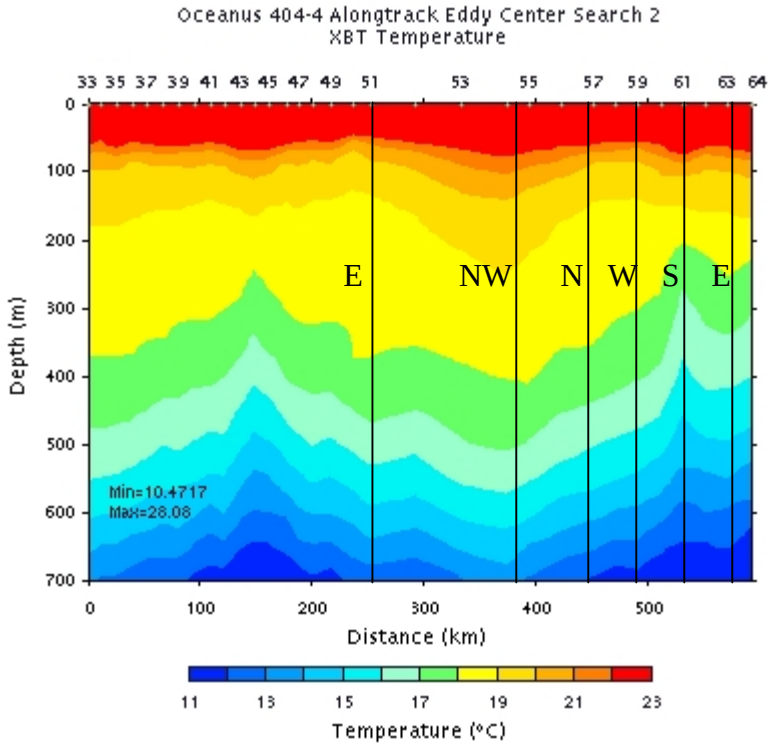


Figure 5. Alongtrack XBT section from search for eddy center July 31, 2004. Vertical bars indicate turning points in the cruise track (Figure 4).

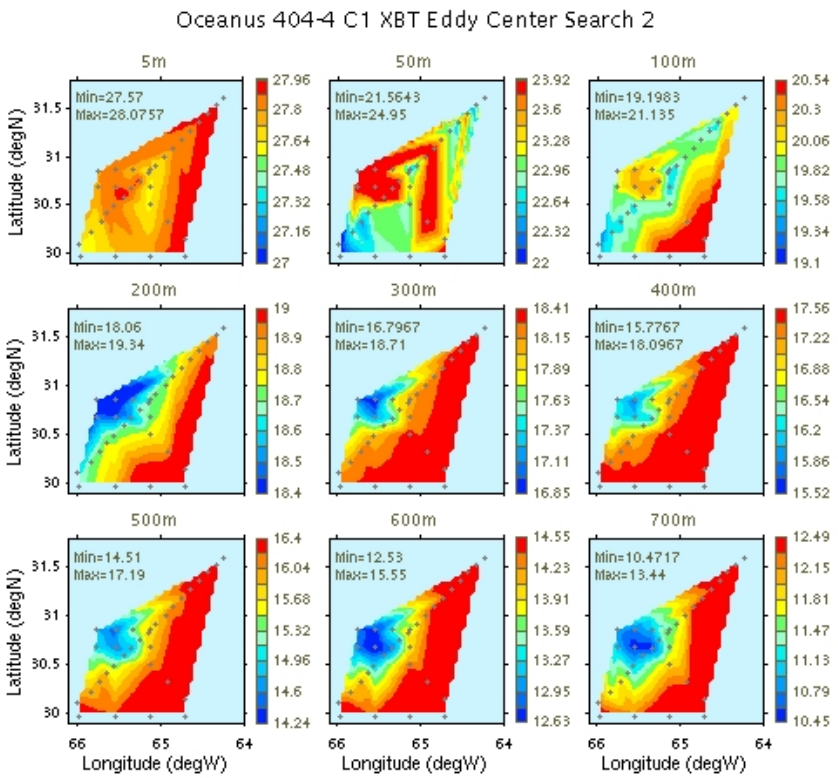


Figure 6. Temperature maps based on XBT observations from the second search for C1 eddy center.

*August 1, 2004*

Began east to west section along northern periphery. Electrical fault on CTD at station 34 (location 393). Again the splice appears to have leaked. Splice repaired and instrument redeployed. Fluorometer changed character during station 35. Midnight MOCNESS tow at location #389.

*August 2, 2004*

VPR test run 0700-0900. Return to #389 for daytime pair of MOCNESS tow previous midnight. Analysis of northern section reveals an anomalous feature at station 34 (location #393): elevation of the main thermocline, depression of the seasonal thermocline, and thinning of the 18 degree water. Oxygen in the euphotic zone is high (ca. 235 micromoles per kg) and an anomalous oxygen deficit is present at ca. 200m (oxygen concentration ca. 180 micromoles per kg). Qualitatively this feature is similar in many ways to C1. ADCP velocity observations suggest cyclonic rotation in this area, so we diverted back to station 34 to execute a 20km box around the anomalous feature (Figure 7). The lateral extent of the oxygen deficit is ca. 20 km in the east—

west direction (Figure 8, top panels). The north-south extent is smaller, in the oxygen deficit is not detected in stations 20 km to the north and south (Figure 8, lower panels).

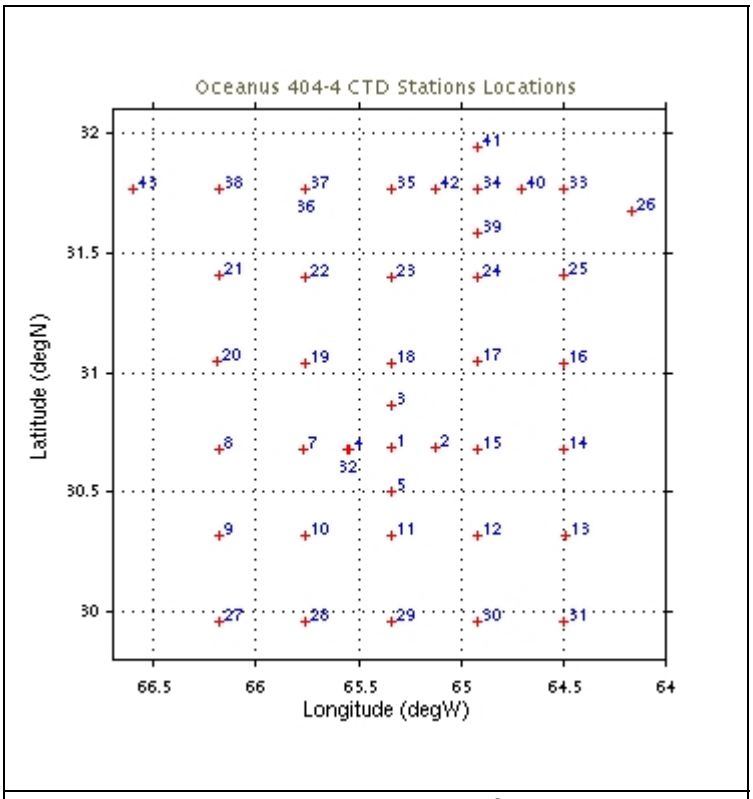


Figure 7. CTD station locations as of August 3, 2004.

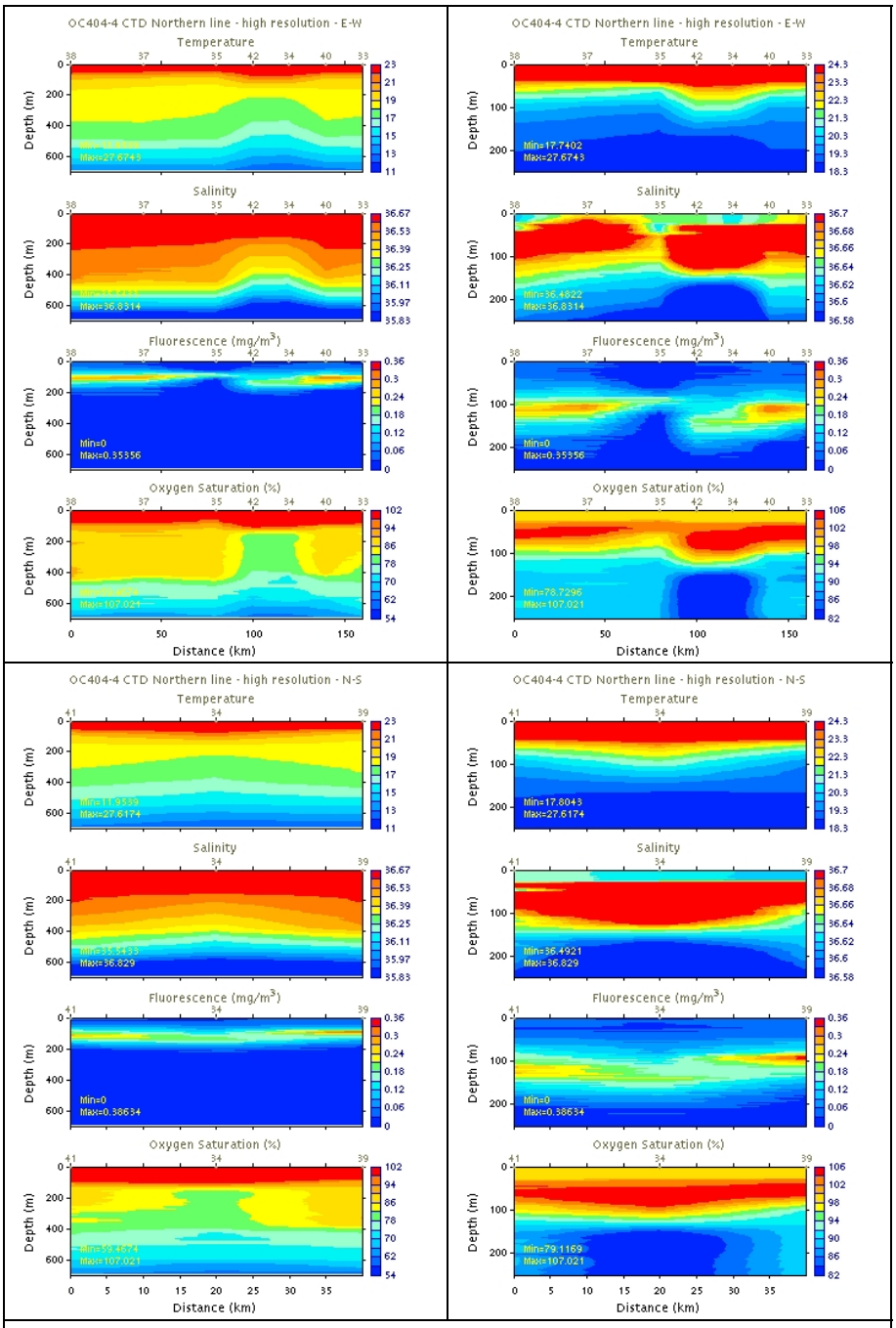


Figure 8. West to east (top panels) and north to south (lower panels) transects through anomalous cyclonic feature in NE portion of the survey grid.

*August 3, 2004*

Occupied N-S transect on western side of the grid, completing the survey of C1 (Figures 9-20). Midnight MOCNESS tow at SW corner.

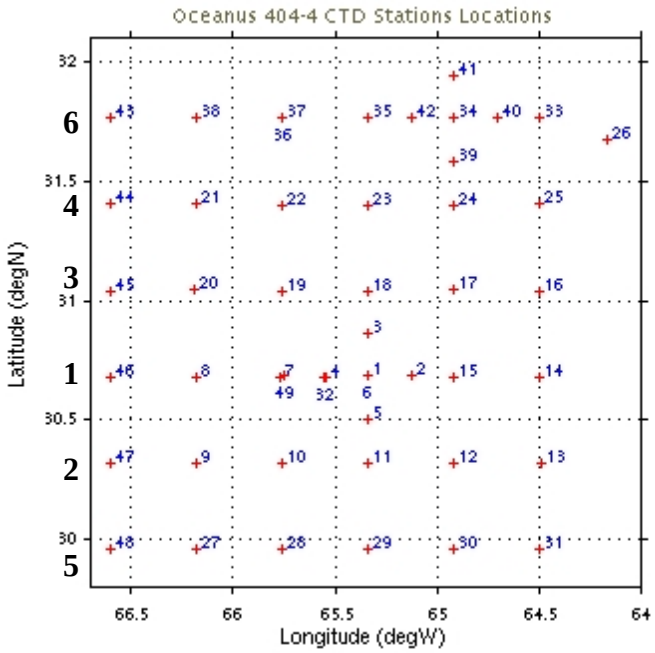


Figure 9. Station locations for C1 survey. Section identifiers indicated at left in bold numerals.

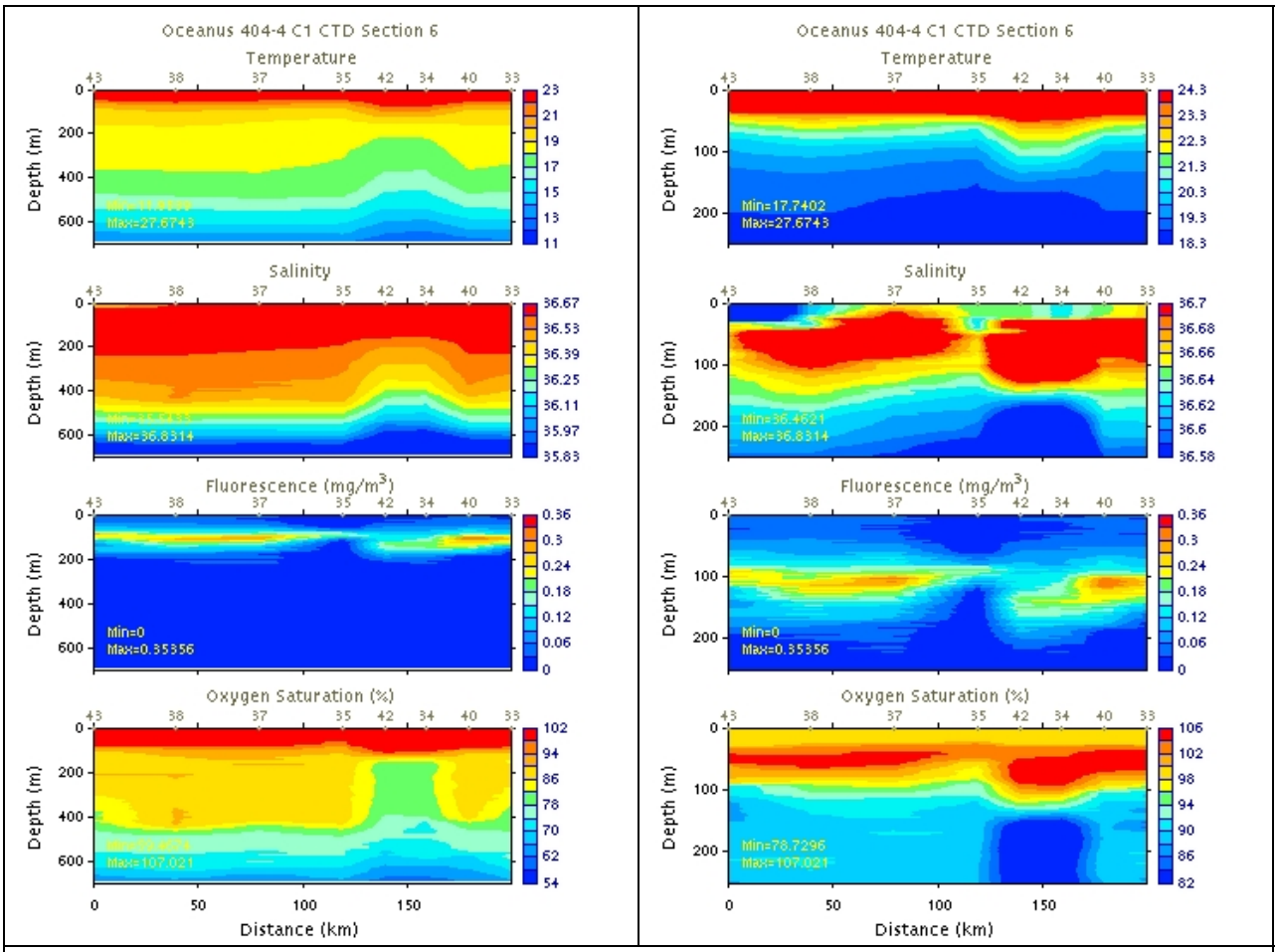


Figure 10: Temperature, salinity, fluorescence, and oxygen saturation for 31 45.7N section (# 6) of the C1 survey grid. Left: 0-700m; right: 0-250m.

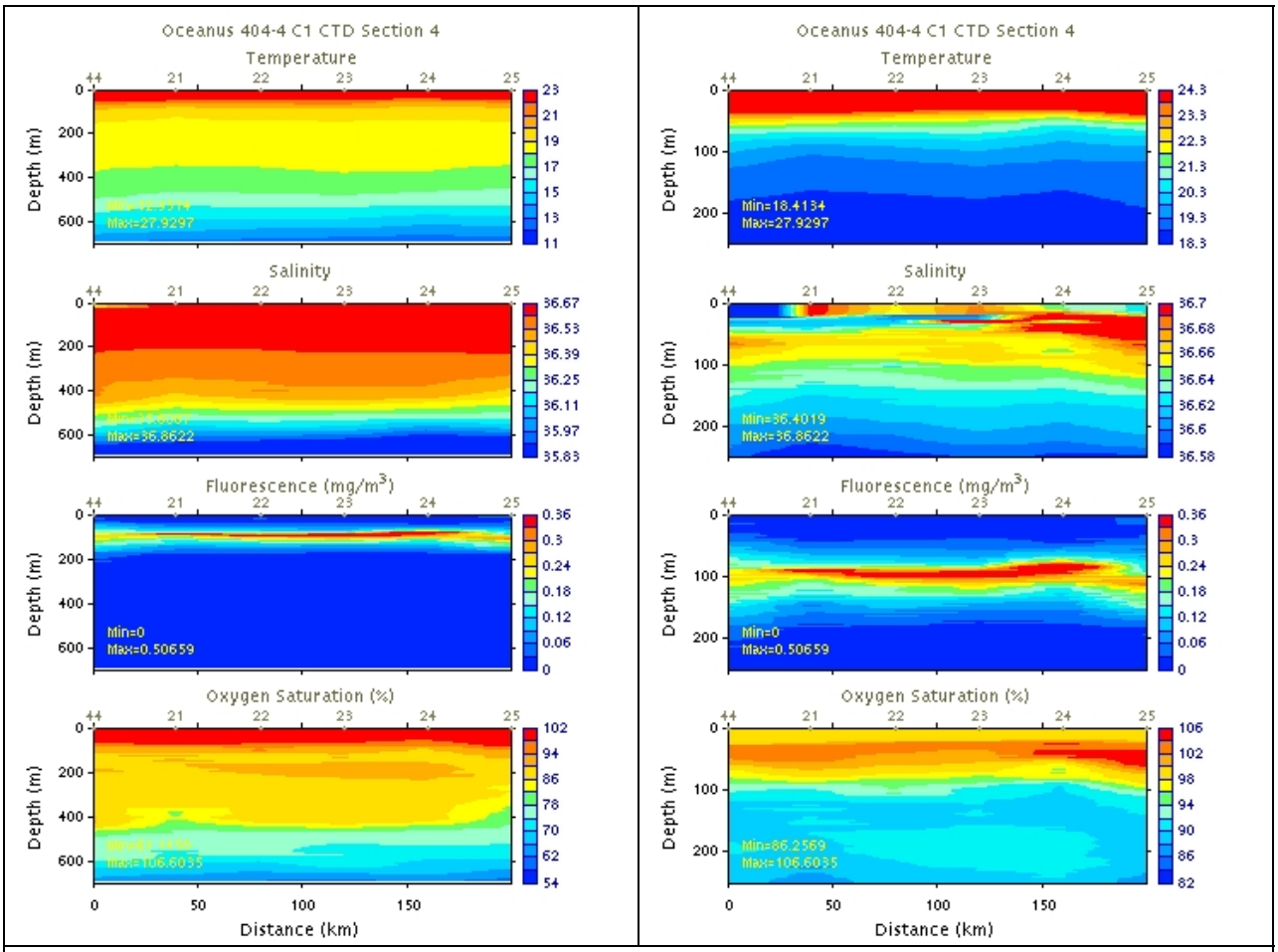


Figure 11: Temperature, salinity, fluorescence, and oxygen saturation for 31 24.1N section (# 4) of the C1 survey grid. Left: 0-700m; right: 0-250m.

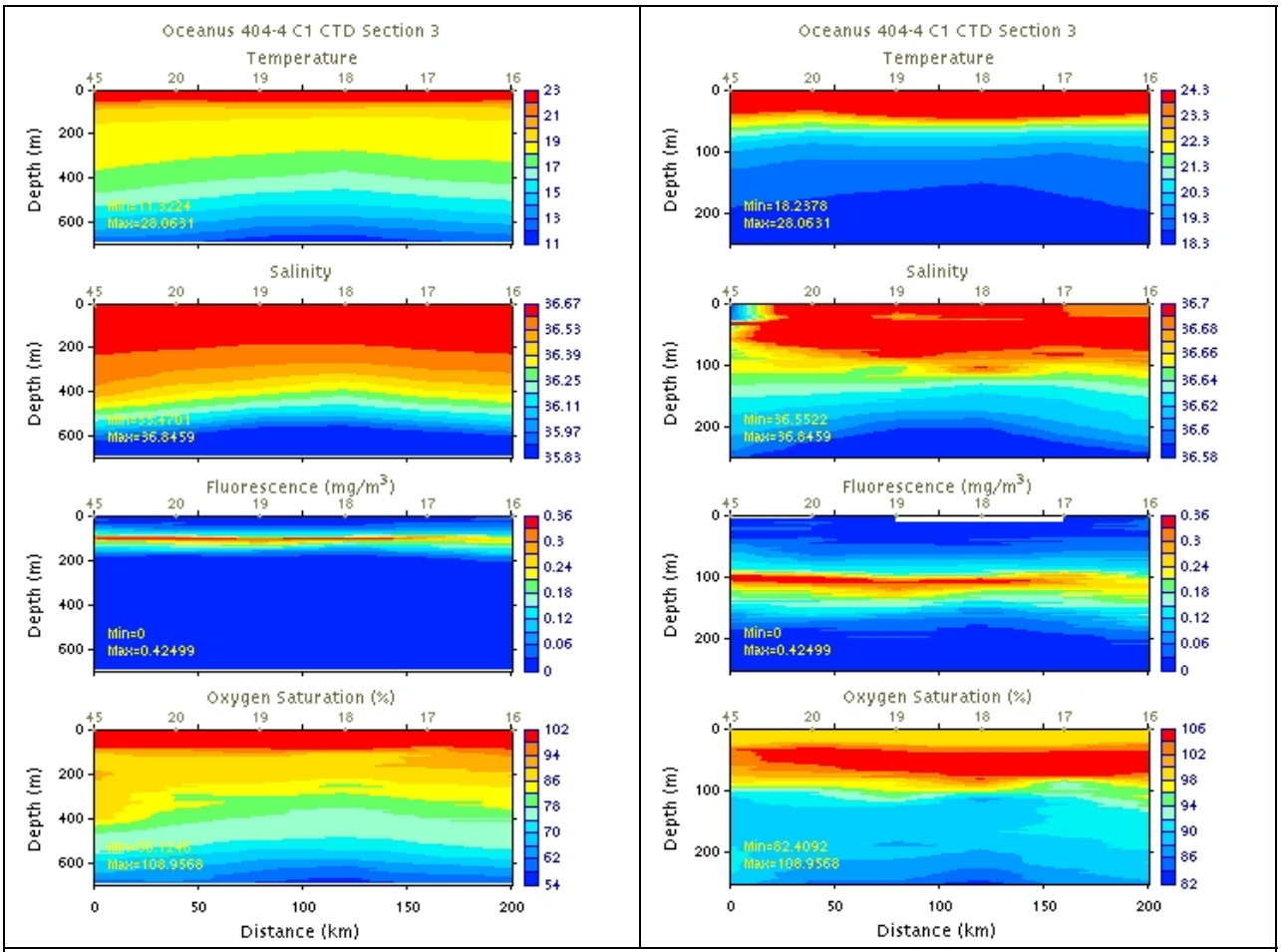


Figure 12: Temperature, salinity, fluorescence, and oxygen saturation for 31 02.4N section (# 3) of the C1 survey grid. Left: 0-700m; right: 0-250m.

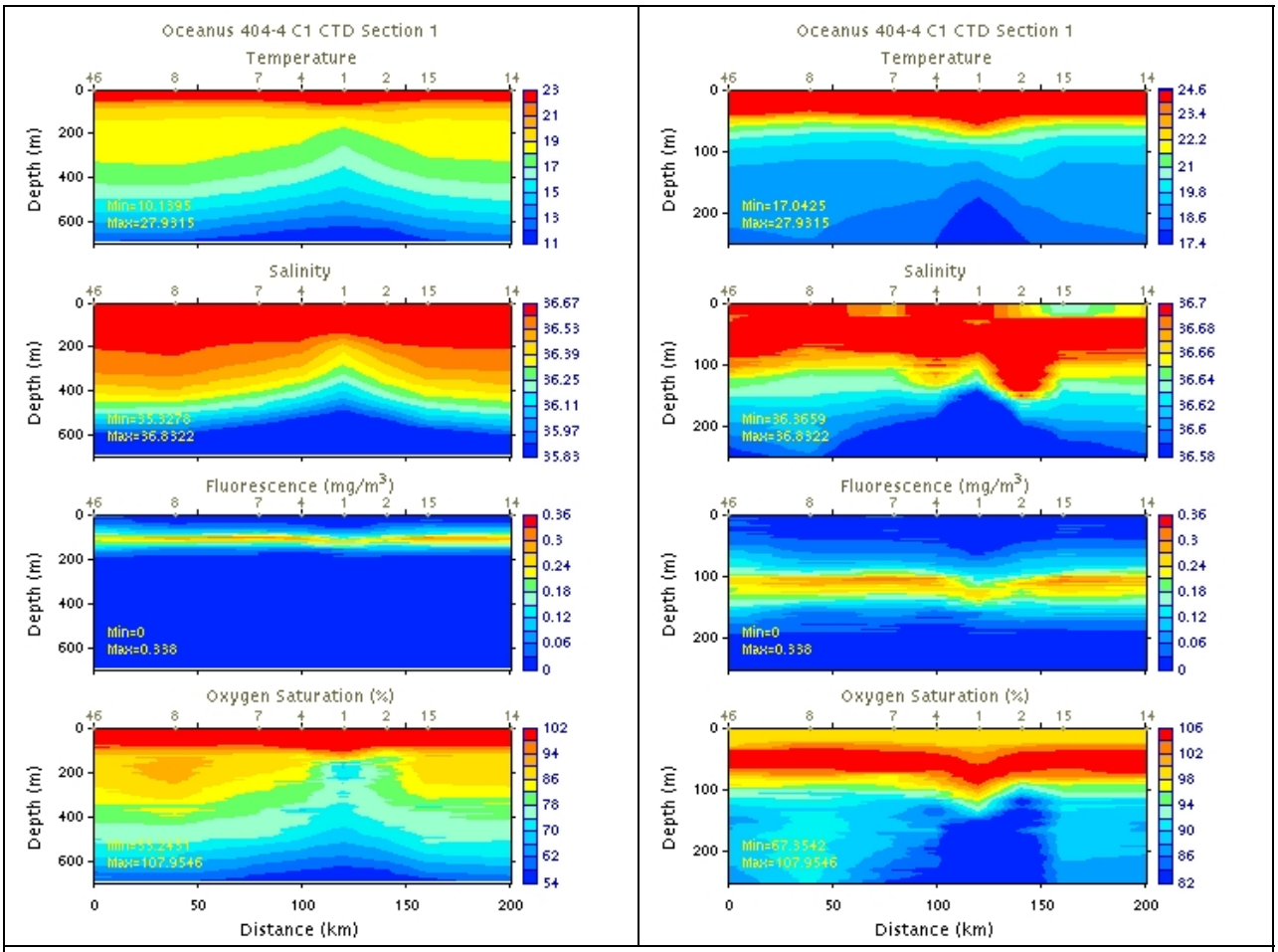


Figure 13: Temperature, salinity, fluorescence, and oxygen saturation for 30 40.8N section (# 1) of the C1 survey grid. Left: 0-700m; right: 0-250m.

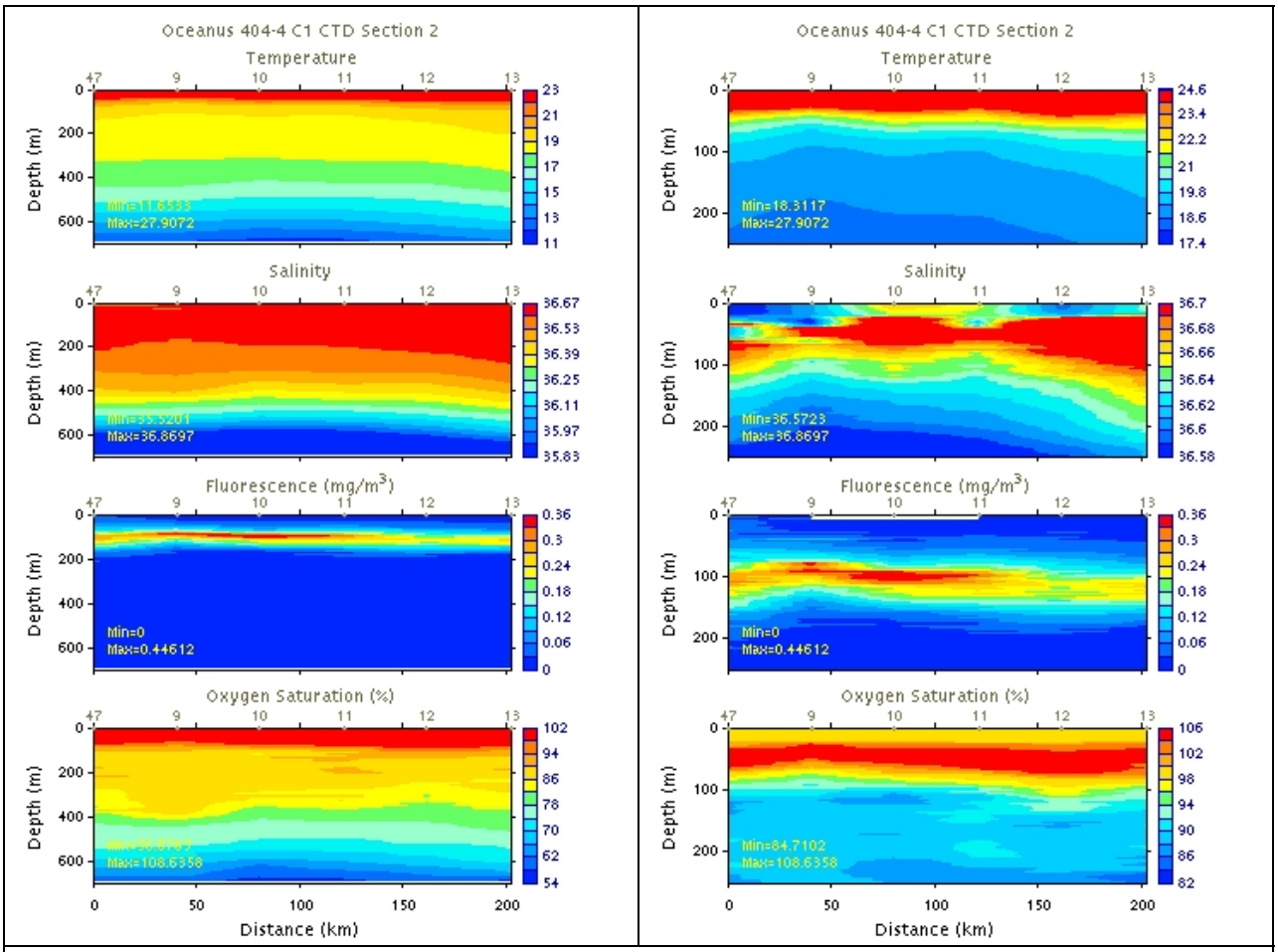


Figure 14: Temperature, salinity, fluorescence, and oxygen saturation for 30 19.2N section (# 2) of the C1 survey grid. Left: 0-700m; right: 0-250m.

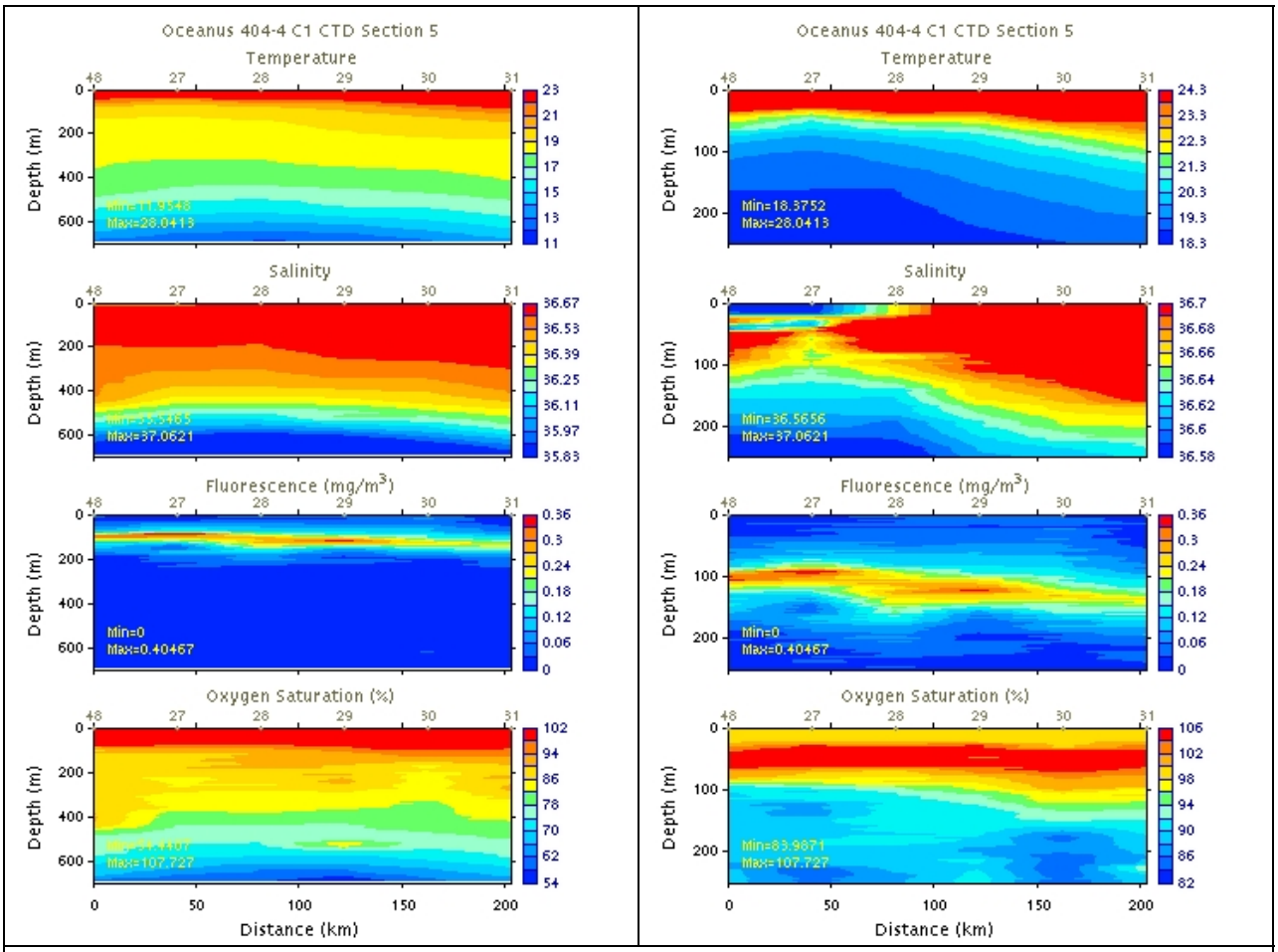


Figure 15: Temperature, salinity, fluorescence, and oxygen saturation for 29 57.6N section (# 5) of the C1 survey grid. Left: 0-700m; right: 0-250m.

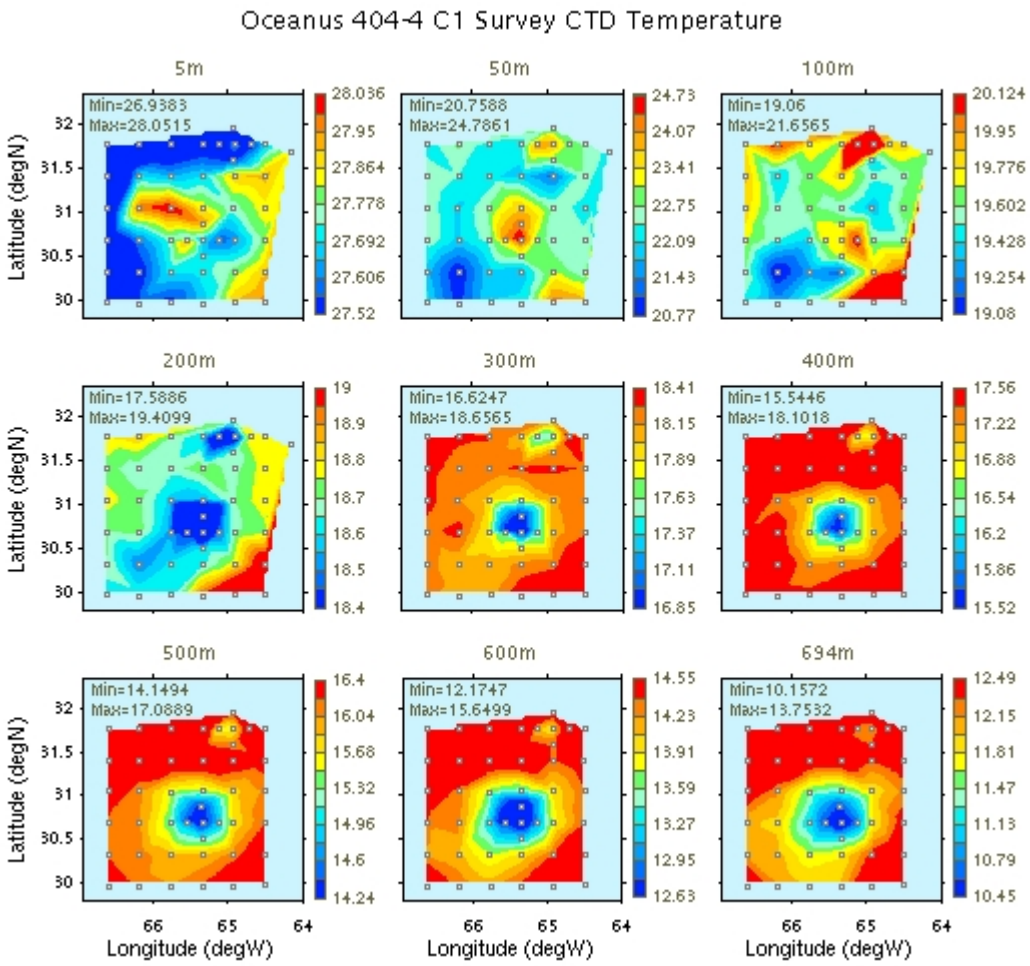


Figure 16. Horizontal maps of temperature at selected depths for C1 survey grid.

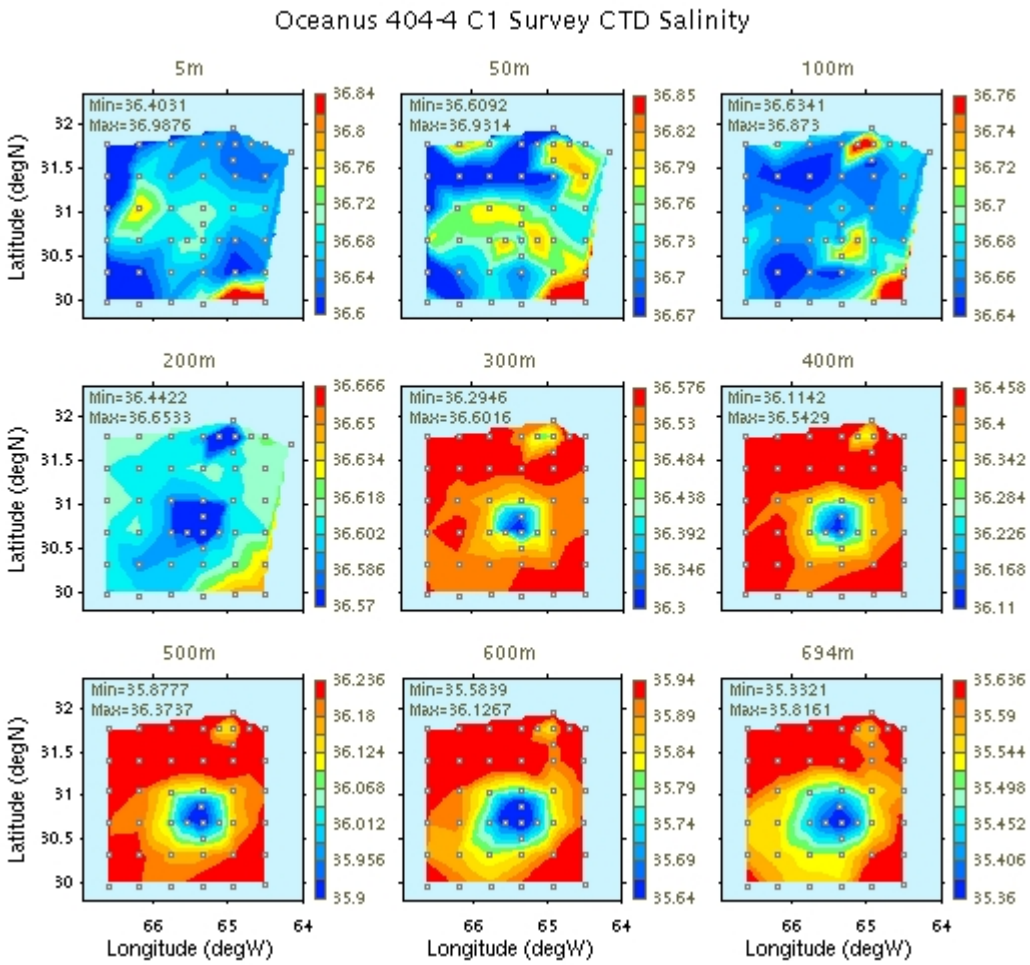


Figure 17. Horizontal maps of salinity at selected depths for C1 survey grid.

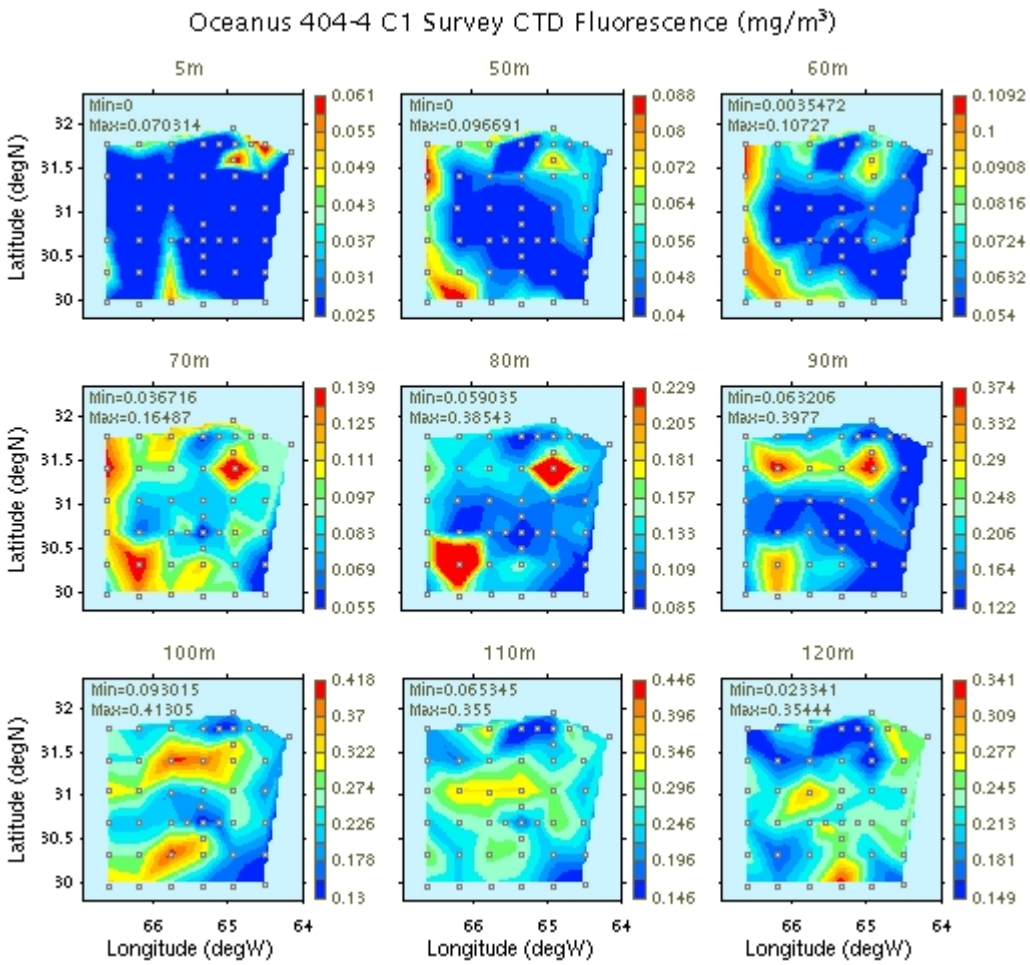


Figure 18. Horizontal maps of fluorescence at selected depths for C1 survey grid.

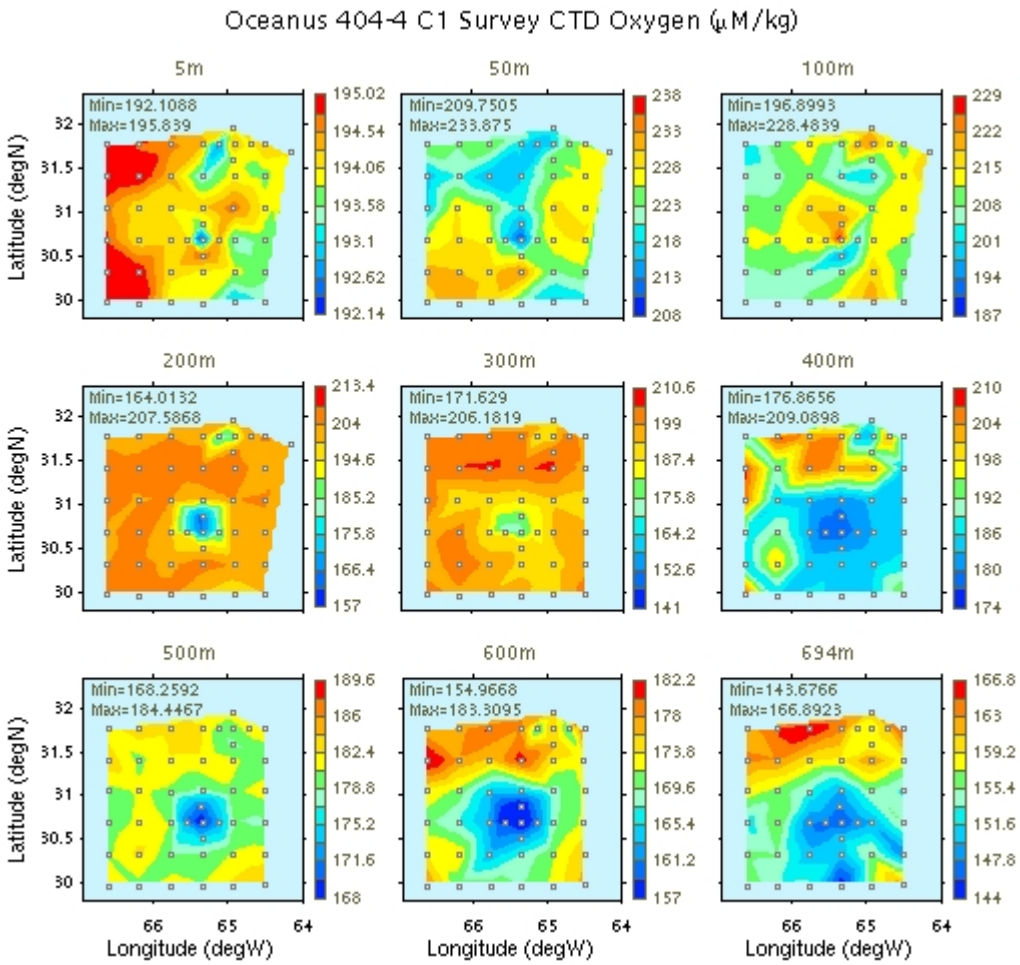


Figure 19. Horizontal maps of oxygen at selected depths for C1 survey grid.

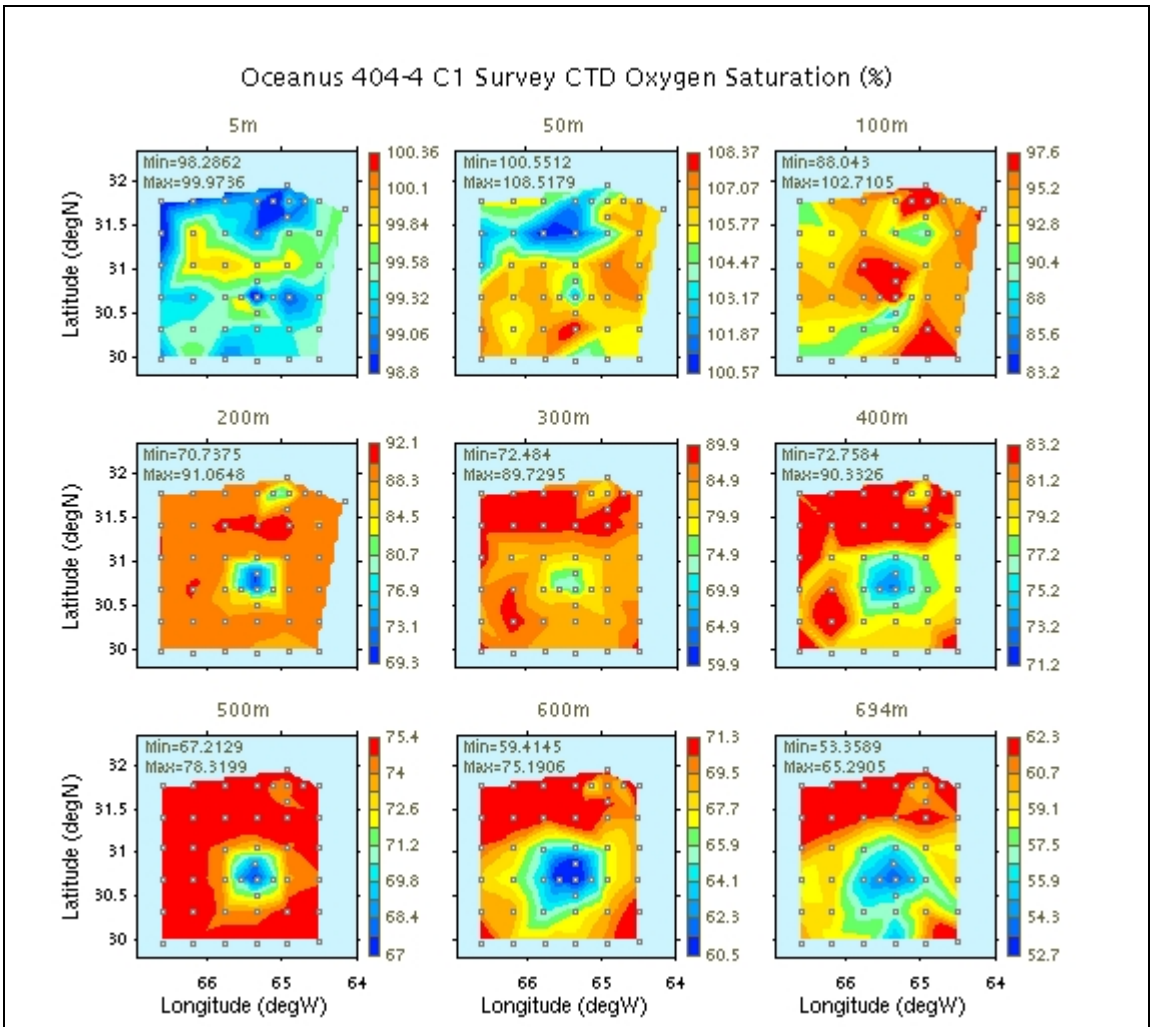


Figure 20. Horizontal maps of oxygen saturation at selected depths for C1 survey grid.

*August 4, 2004*

Steaming toward eddy center for rendezvous with Weatherbird II. XBTs dropped along the way. Comms with WBII at 0800 indicate thick mode water at locations 240 and 241; XBT at 239 dropped during comms, revealing thin mode water and eddy center. Joint CTD scheduled for 1045 at location 239. Time allowed us to drop an XBT one station to the west at 238, where mode water thickens again (Figure 21).

Intercalibration station executed with Weatherbird II at location #239. Noontime MOCNESS tow. Recovered UCSB bio-optical spar. Midnight MOCNESS tow. Collected water for incubations. Deployed VPR.

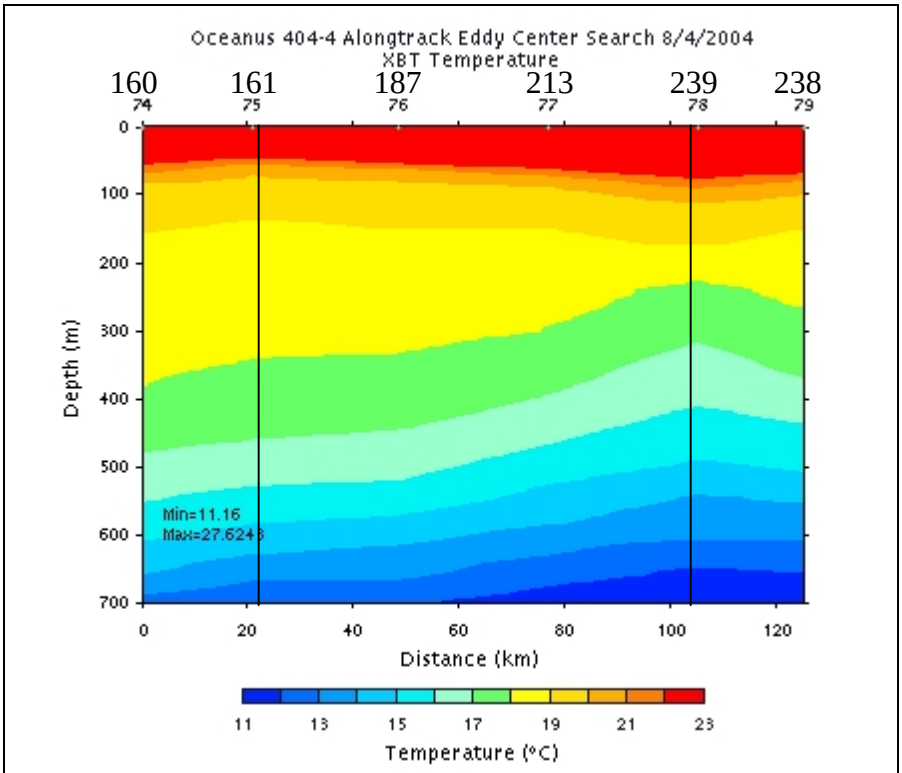


Figure 21. Alongtrack XBT section from SW portion of survey grid toward eddy center on August 4, 2004. Vertical bars indicate turning points in the cruise track, and location identifiers are shown above XBT drop numbers.

*August 5, 2004*

VPR survey continues.

*August 6, 2004*

VPR pulled out for a CTD cast in an area of elevated fluorescence (CTD 51, just south of location # 339). Fluorescence peak is shoaled to 80m; Bibby reports high variable fluorescence in the peak; Qian reports measurable nutrients at 80m. VPR survey continues.

Dramatic changes in oxygen inventories have taken place in the core of C1 (Figure 22, left panel). In the first occupation of eddy center (Survey 1, cast 17), the oxygen profile exhibited vertical structure typical of this region at this time of year (compare with climatology). The second occupation (Survey 1, cast 36) revealed the existence of a dramatic oxygen minimum centered at ca. 300m. This was accompanied by an increase in nitrate (Figure 22, right panel) over a similar depth interval (perhaps a little deeper; note profile is constrained at 200, 300, and 500m). The changes in 100-400m oxygen and nitrate inventories amount to 1.4 mol N $m^{-2}$ and 10.4 mol $O_2$ $m^{-2}$, equivalent to approximately three times the annual new production. The

relative changes in oxygen and nitrate inventories are within about 10 percent of that expected from photosynthetic stoichiometry of 138 $O_2$ : 106 C : 16 N : 1 P.

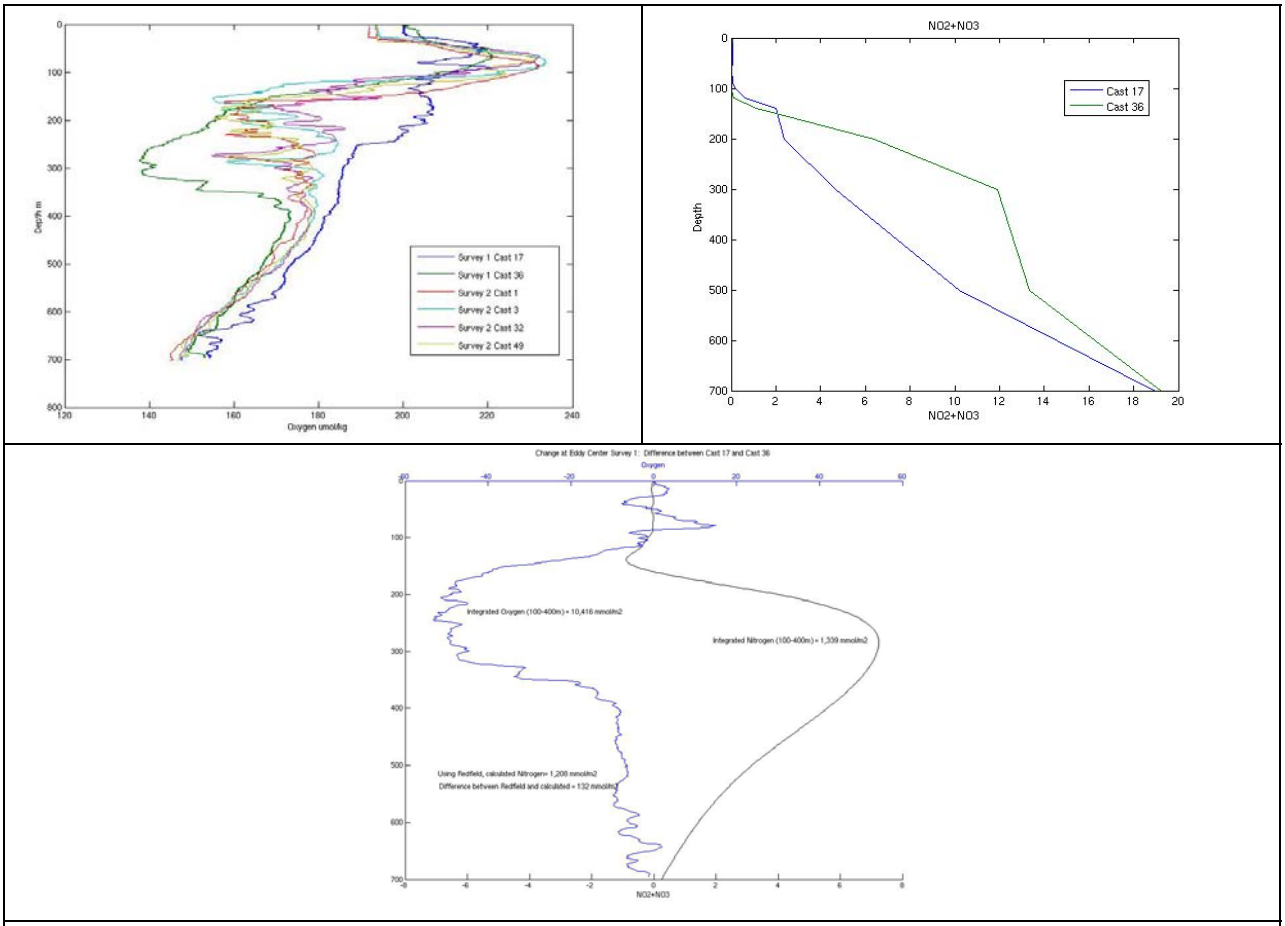


Figure 22. Oxygen and nitrate plus nitrite profiles from C1 eddy center (top), and changes in oxygen and nitrate inventories between casts 17 and 36 during Survey 1 (bottom).

*August 7, 2004*

VPR/XBT/ADCP survey continues in heavy weather. An unusually strong (for this time of year) cold front slowly passed through the region, bringing wind gusts over 50 knots. Conditions became too rough to recover the VPR safely, so we continued the survey beyond C1 to obtain another time point within one of the eddy features sampled during Survey 1.

Our first target was the anticyclone north of BATS, whose positive sea level anomaly appears contiguous with the central core of A1 (the Madeira mode water eddy) now located north-northwest of BATS (Figure 23). From the satellite data it was not clear whether the smaller anticyclone to the north of BATS was a new feature or some derivative of A1. The VPR/XBT/ADCP survey of this feature (Figure 24) revealed it is a regular anticyclone, with

downward displacement of both the main and seasonal thermoclines (Figures 25), and clockwise circulation (Figure 26). Curiously, fluorescence recorded by the VPR appears to be somewhat elevated inside the feature.

Next we continued to the adjacent cyclone to the east. Again, the available satellite data were not definitive with respect to the origin of that feature: it is quasi-contiguous with a cyclone further to the south and east, which appears to be a remnant of C2. Investigation of this "new" cyclone revealed large thermocline displacements and very high velocities, approaching 1 m $s^{-1}$. VPR data indicate anomalously low salinities inside the feature. A single CTD profile in its center confirmed its water mass anomalies (Figure 27). The observed characteristics match those of cold core rings originating from the Gulf Stream and slope waters (e.g. Vastano et al., 1980). Interestingly, this cold core ring escaped detection by ring-tracking experts with whom we have been in contact this summer. Indeed, it is unusual to observe cold rings so far south. Perhaps this will be the first (?) to be sampled at the BATS site, through which it will pass in the next couple of months if it continues on its current trajectory.

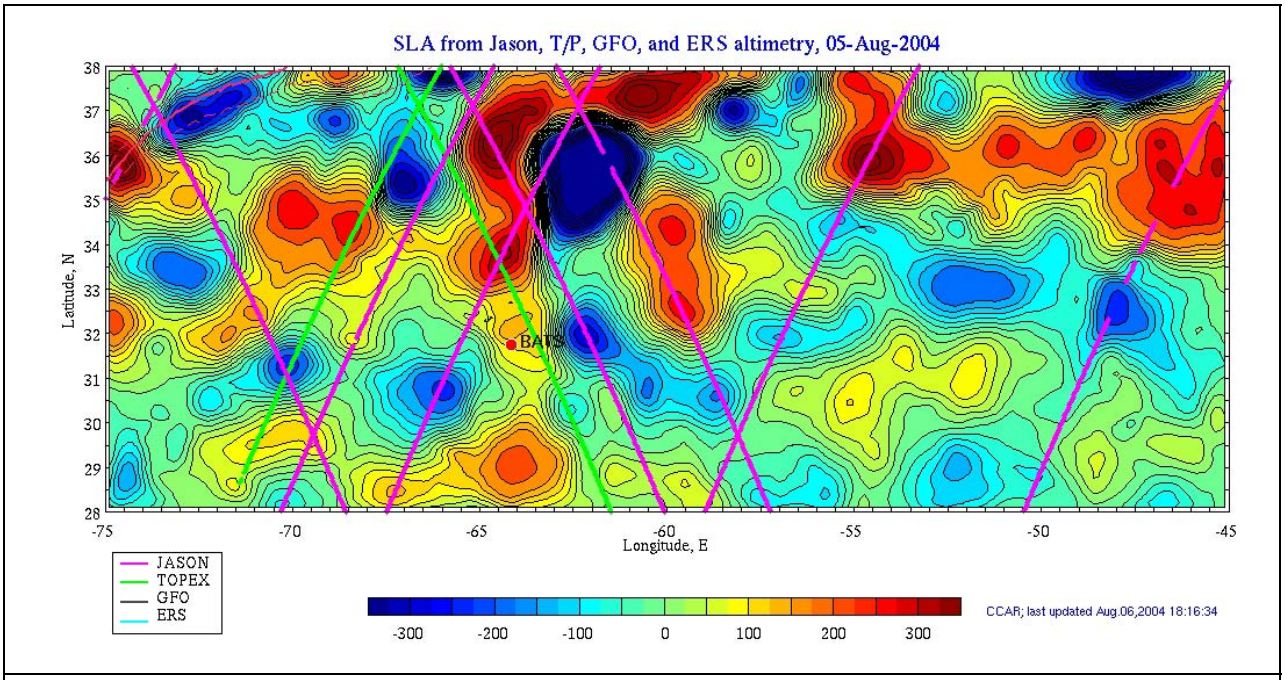


Figure 23. Objective analysis of sea level anomaly (mm) for August 5, 2004.

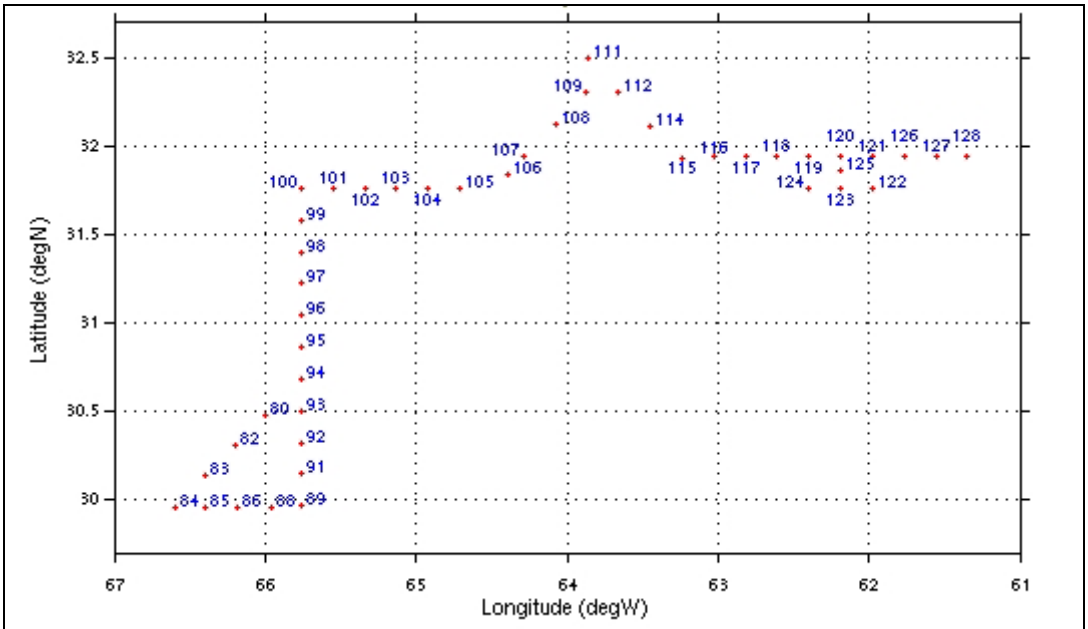


Figure 24. XBT drop locations for the VPR/XBT/ADCP survey August 5-8.

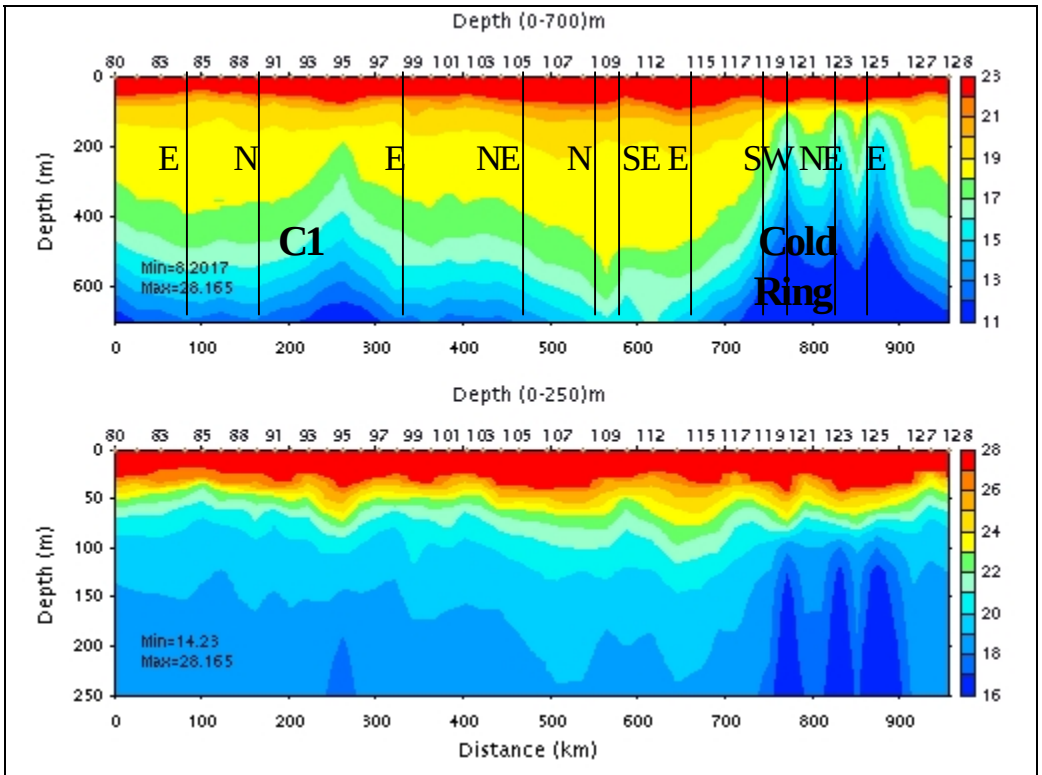


Figure 25. Alongtrack XBT section from the VPR/XBT/ADCP survey August 5-8. Vertical bars indicate turning points in the cruise track (Figure 24). Three hydrographic features are labeled: cyclone C1, anticyclone north of BATS (AC), and Cold Ring.

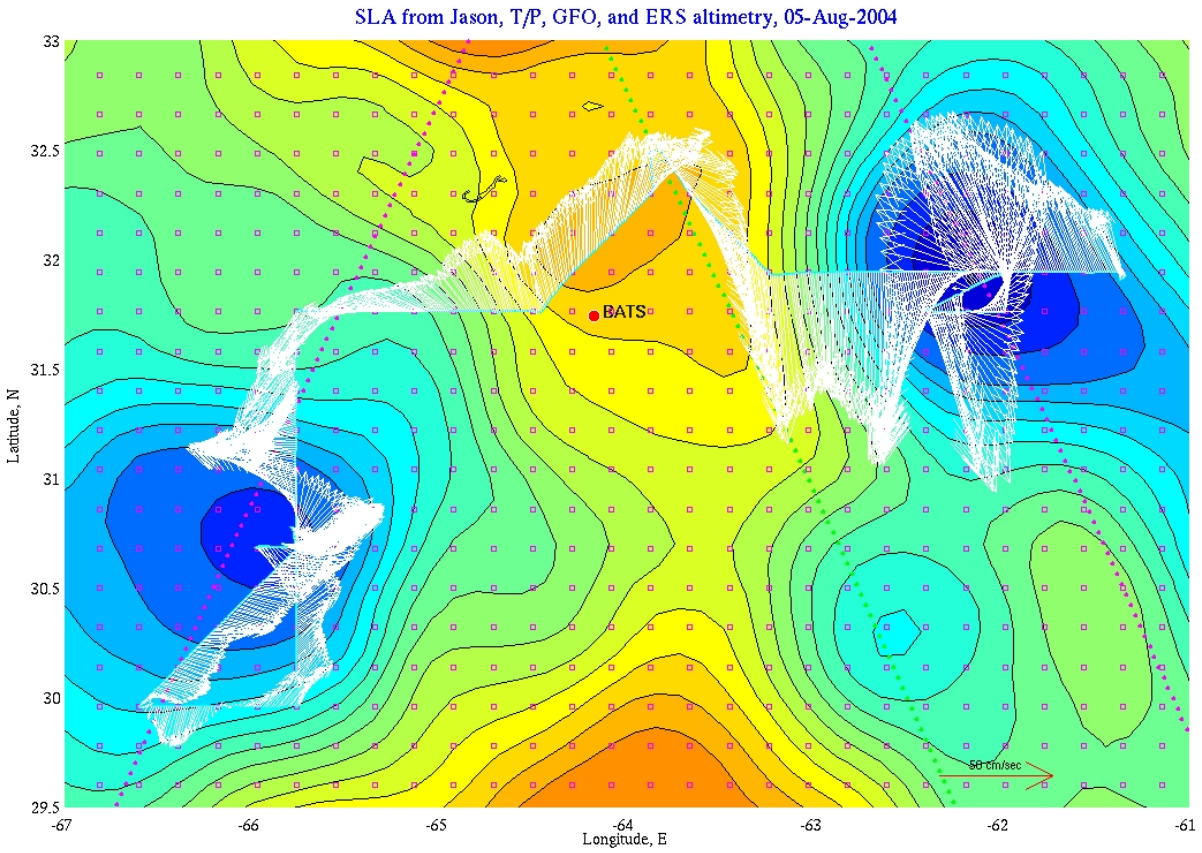


Figure 26. Vertically averaged ADCP velocity measurements along VPR/XBT survey track (Figure ) overlayed on objectively analyzed sea level anomaly from August 5. Dotted lines indicate altimetric ground tracks, and magenta squares are the location grid for station planning.

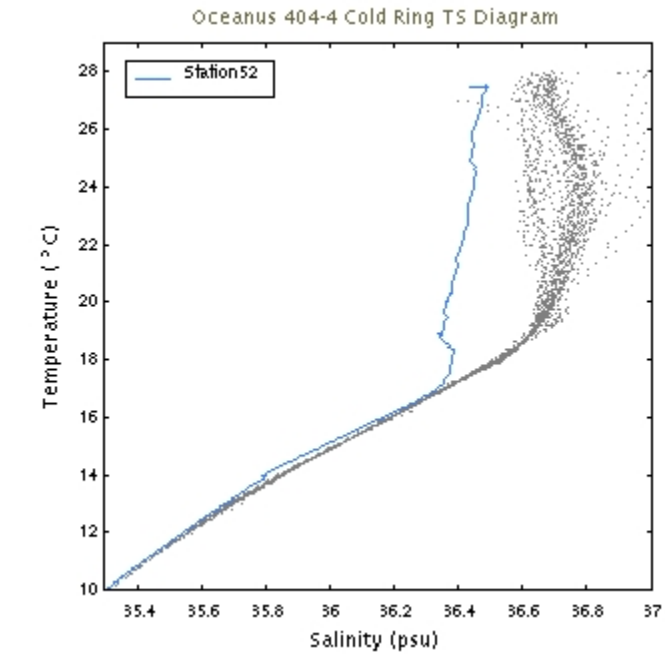


Figure 27. Temperature versus salinity for CTD casts 1-51 (gray dots) and cast 52 (blue line).

*August 8, 2004*

After a single CTD cast in the cold ring, we departed for the last known position of cyclone C2. Eddy center was located with an XBT/ADCP survey (Figures 28-31). Based on the 700m temperature anomaly, C2 has weakened slightly since Survey 1 (minimum temperature increased from 10.73 to 10.96).

Midnight MOCNESS tow conducted at eddy center.

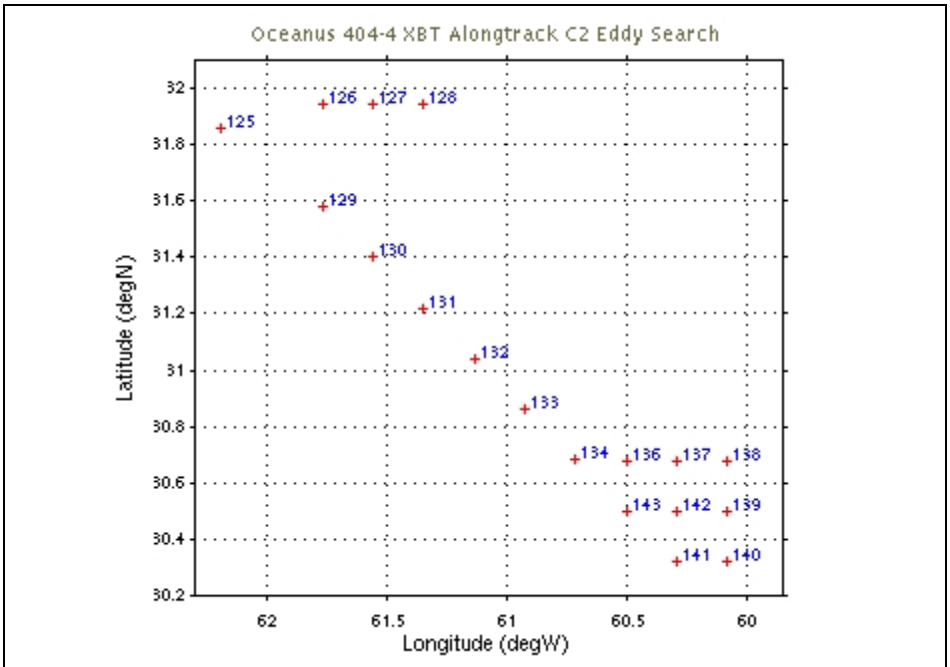


Figure 28. XBT drop locations for the XBT/ADCP survey August 7-8.

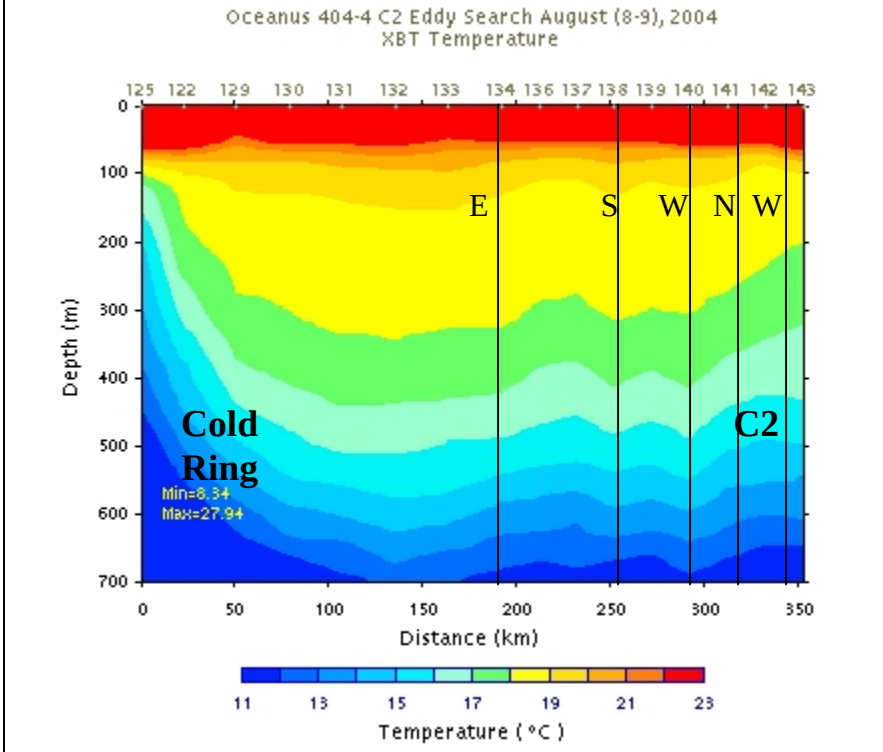


Figure 29. Alongtrack XBT section from the XBT/ADCP survey August 5-8. Vertical bars indicate turning points in the cruise track (Figure 28). Two hydrographic features are labeled: Cold Ring and cyclone C2.

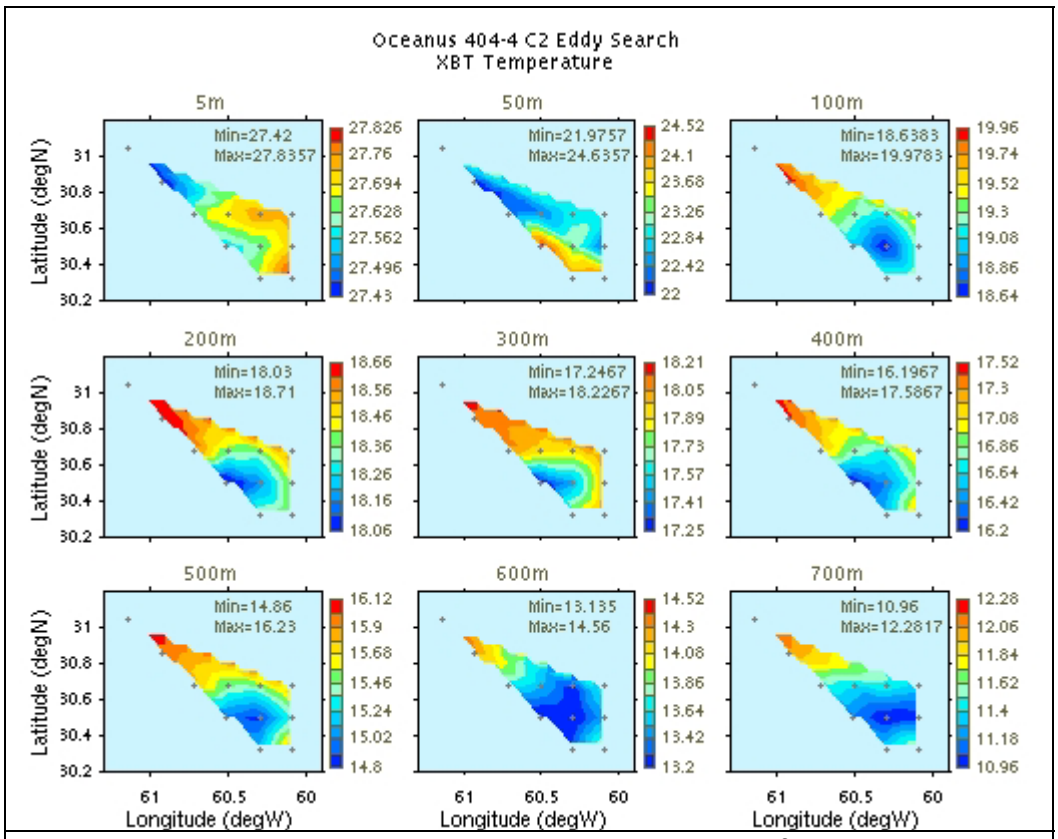


Figure 30. Temperature maps based on XBT observations from the search for C2 eddy center.

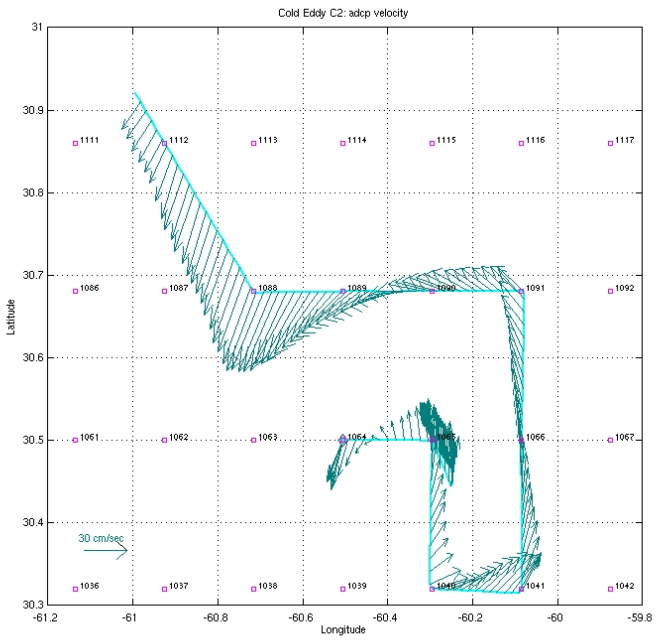


Figure 31. Vertically averaged ADCP velocity measurements along VPR/XBT survey track (Figure ). Magenta squares are the location grid for station planning.

*August 9, 2004*

CTD survey of C2 begins. Daytime MOCNESS tow at eddy center to complete day/night pair. Midnight MOCNESS tow at # 1069; clearly an outside station according to the ADCP data (Figure).

*August 10, 2004*

CTD survey of C2 continues.

XBT 149 simultaneous with CTD 64 at # 1063.
XBT 151 simultaneous with CTD 65 at # 1013.

Midnight MOCNESS tow at eddy periphery (location # 1017).

Temporal evolution of the oxygen profile at the center of C2 shows some commonality with that observed in C1 (Figure 32). The euphotic zone oxygen minimum deepened and strengthened. Also, the 200-400m oxygen deficit tended to relax back to the background profile (Survey 1, cast 14; Survey 2, cast 61). The change in 100-400m oxygen inventory at eddy center between Survey 1 and Survey 2 is 3.09 mol $O_2$ $m^{-2}$ (or 0.4 mol N $m^{-2}$ using Redfield), approximately equivalent to the annual new production.

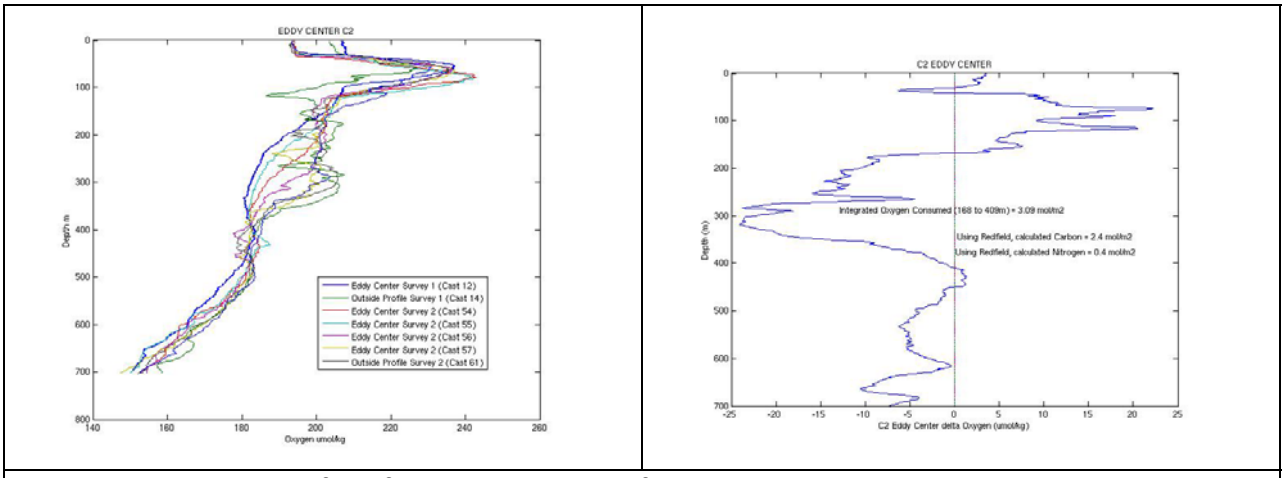


Figure 32. Oxygen profiles from cyclone C2 (left). Survey 1: eddy center [12], outside [14]; Survey 2: eddy center [54], 10 km N [61], S [56], E [57], and W [55] of eddy center, and outside [61]. Right panel: changes in oxygen inventory between Survey 1 cast 12 and Survey 2 cast 54.

*August 11, 2004*

Finished all but westernmost station of CTD grid. Steamed to the eastern end of the section (location # 1069) and deployed VPR for E-W transect through C2 (Figure 33). Recovered VPR at location # 1061, and completed final CTD of E-W transect (cast 68, location # 1061). Results of the C2 survey are presented in Figures 34-39.

XBT 164 simultaneous with CTD 68 at # 1061. Science operations completed, began steaming for Bermuda.

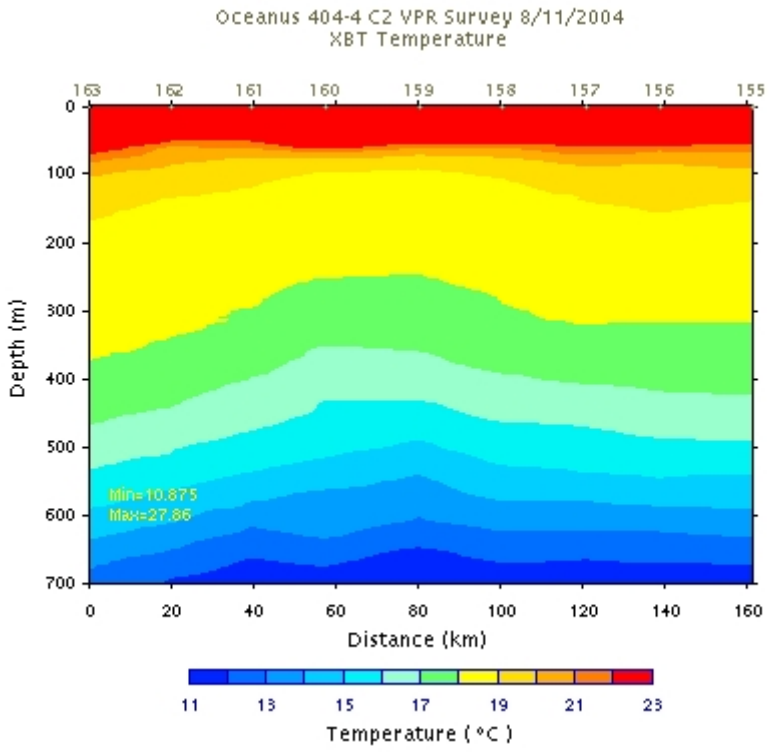


Figure 33. Alongtrack XBT section from the VPR survey through C2 on August 11.

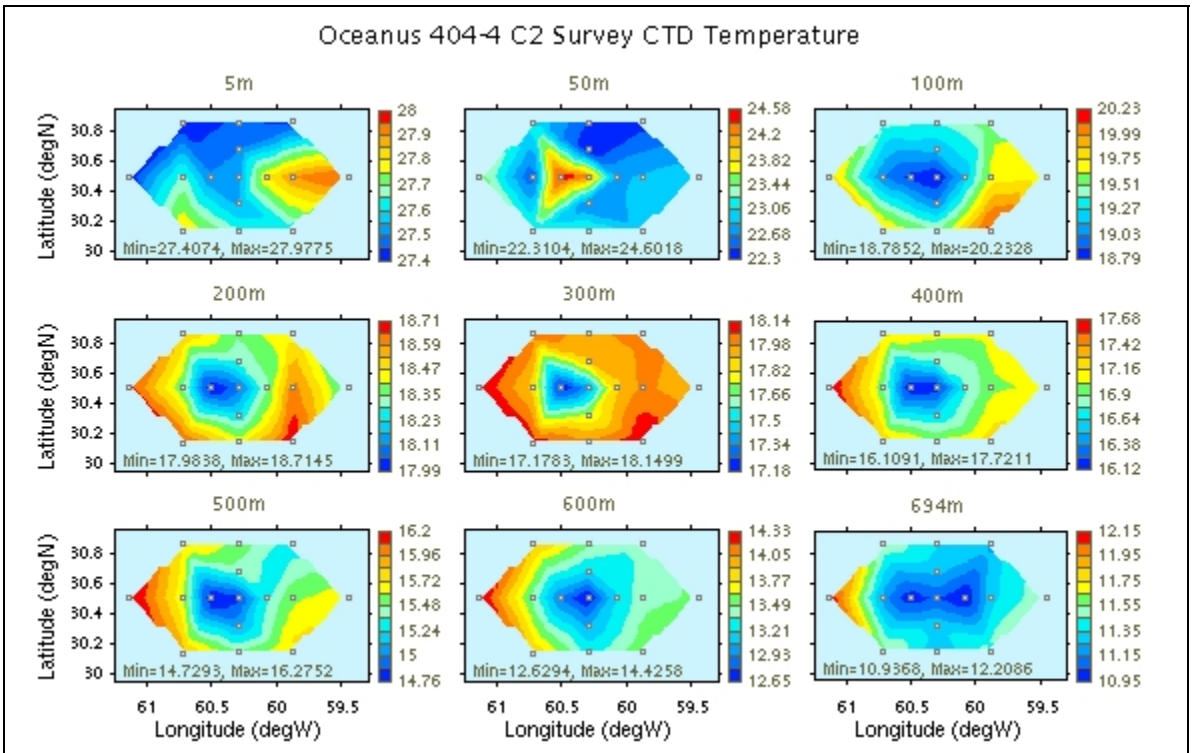


Figure 34. Horizontal maps of temperature at selected depths for C1 survey grid.

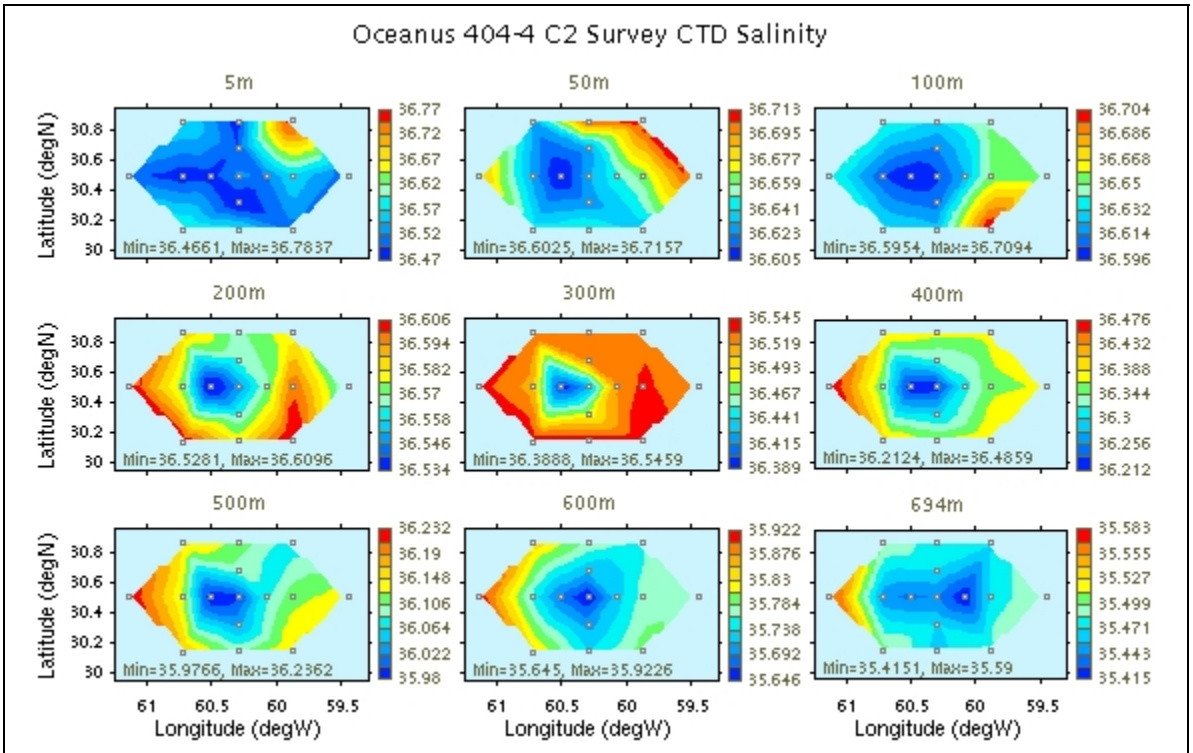


Figure 35. Horizontal maps of salinity at selected depths for C1 survey grid.

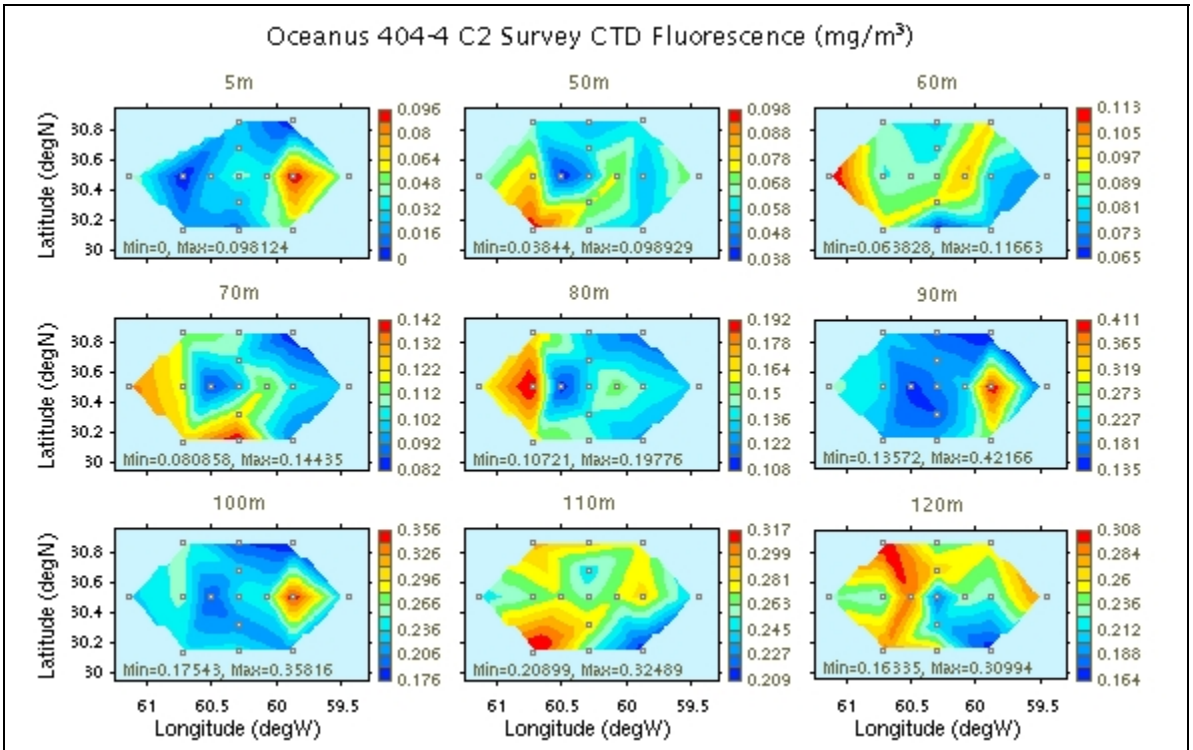


Figure 36. Horizontal maps of fluorescence at selected depths for C1 survey grid.

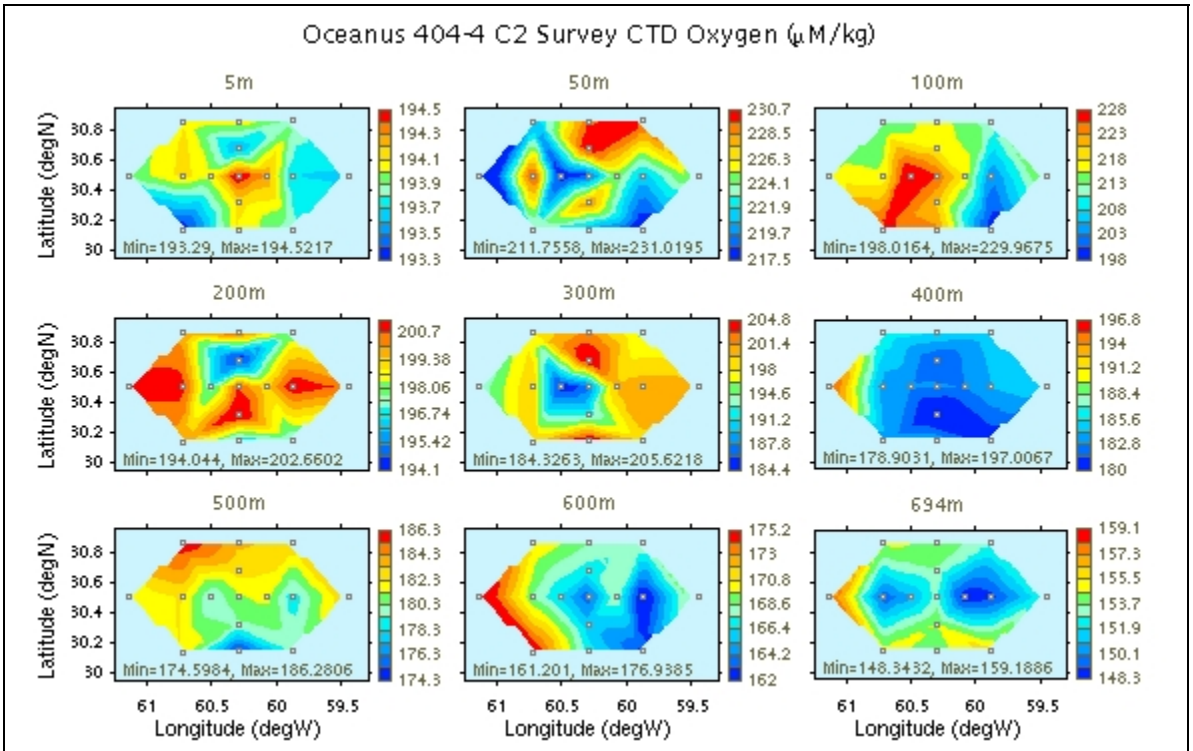


Figure 37. Horizontal maps of oxygen at selected depths for C1 survey grid.

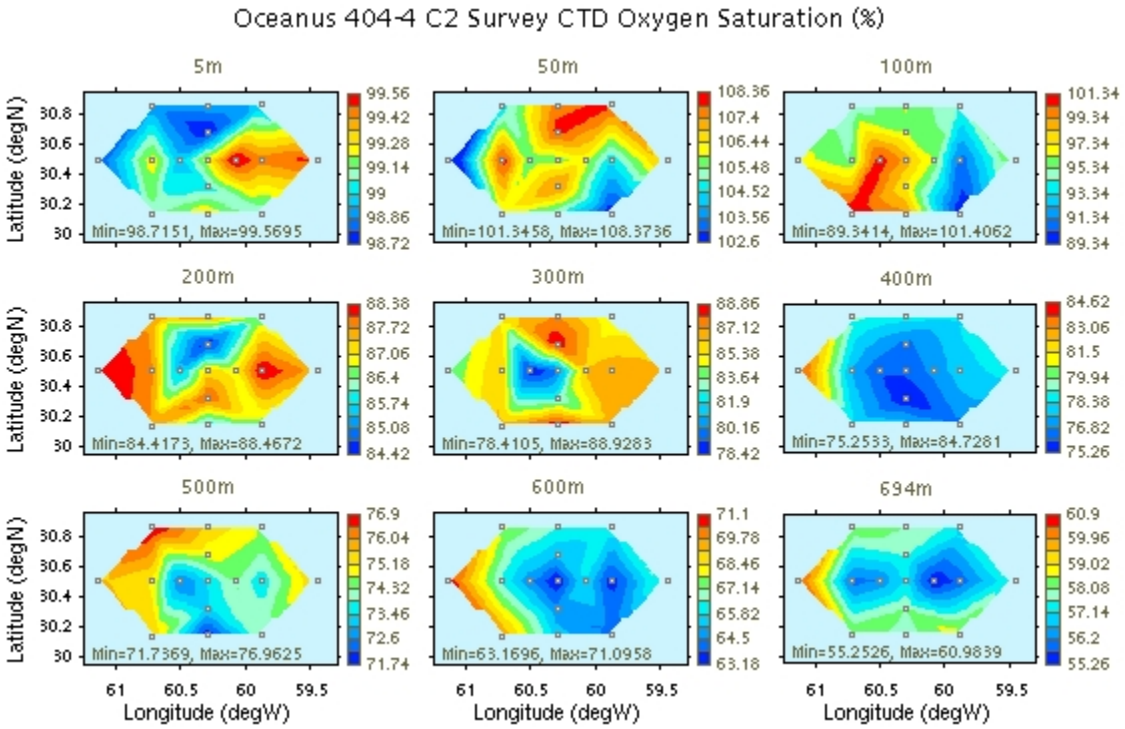


Figure 38. Horizontal maps of oxygen saturation at selected depths for C1 survey grid.

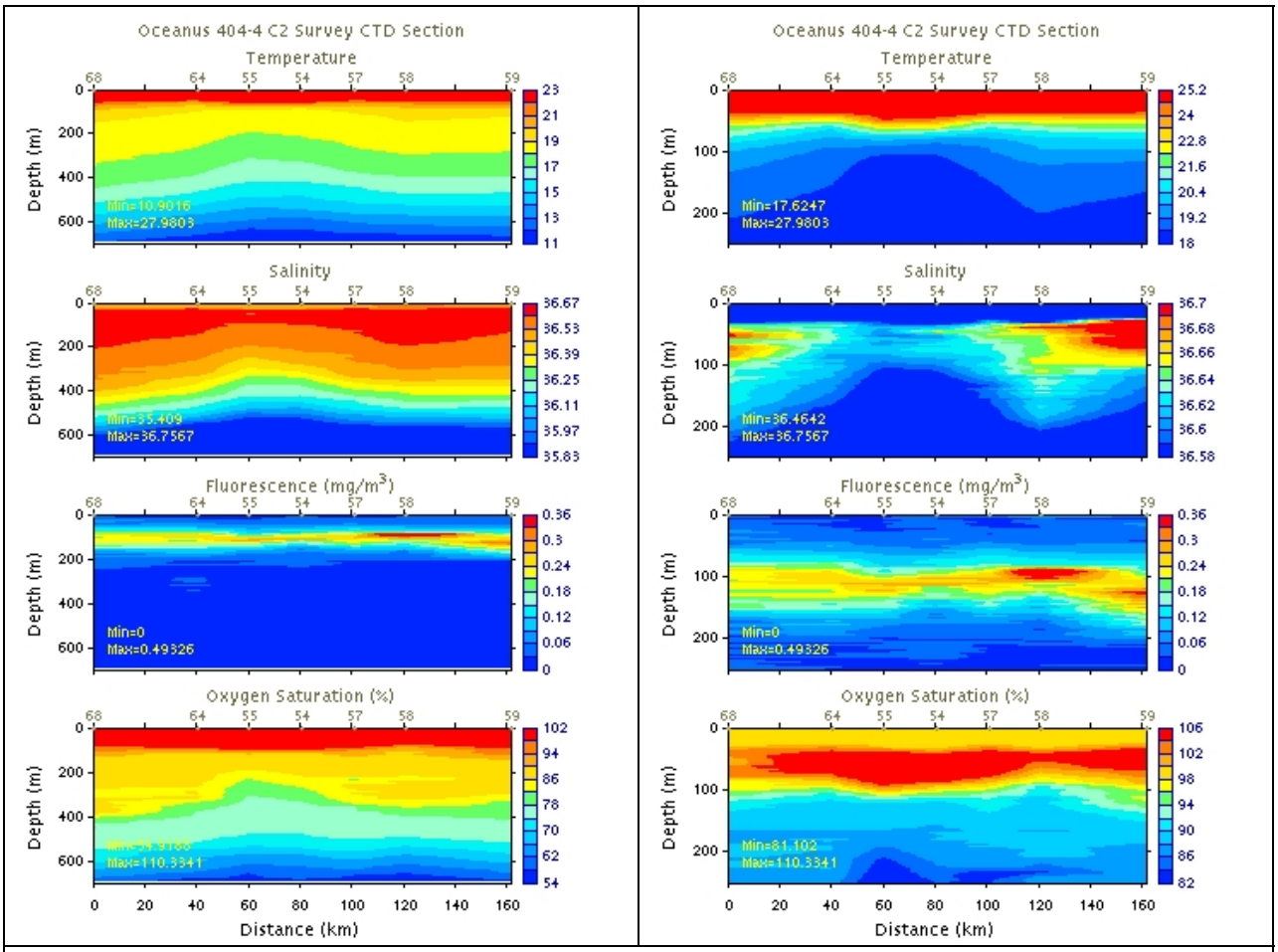


Figure 39: Temperature, salinity, fluorescence, and oxygen saturation for central transect through C2. Left: 0-700m; right: 0-250m.

*August 12, 2004*

Made port in Bermuda at 1600 hours local time.

**3. Summary of MOCNESS Tows**

July 26-27 Day/night pair at eddy center (#241)
July 29 Day/night pair at NW corner (# 337)
July 30 Midnight tow at SW corner (# 137) aborted – cable jumped sheave
July 31 Midnight tow aborted – cable problem
August 1-2 Day/night pair at # 389
August 3 Midnight tow @ # 135
August 4-5 Day/night pair @ # 239
August 8/9 Day/night pair @ #1065 – C2 eddy center
August 9 Night tow @ # 1069 – C2 outside
August 10 Night tow @ # 1017 – C2 periphery

## 4. Comparison of CTD oxygen sensor with Winkler titrations

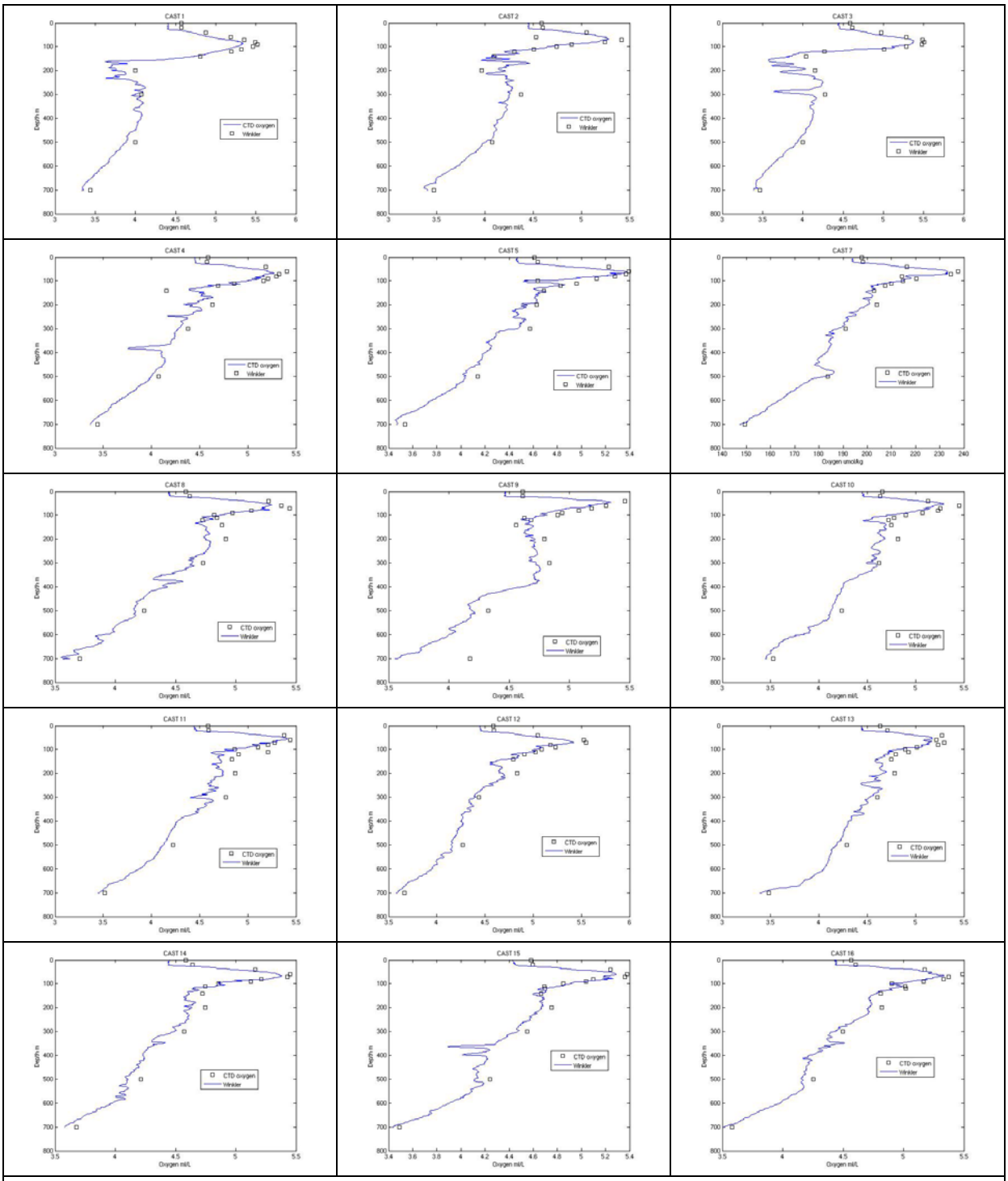


Figure 40: Comparison between CTD oxygen sensor and Winkler titrations of Niskin samples.

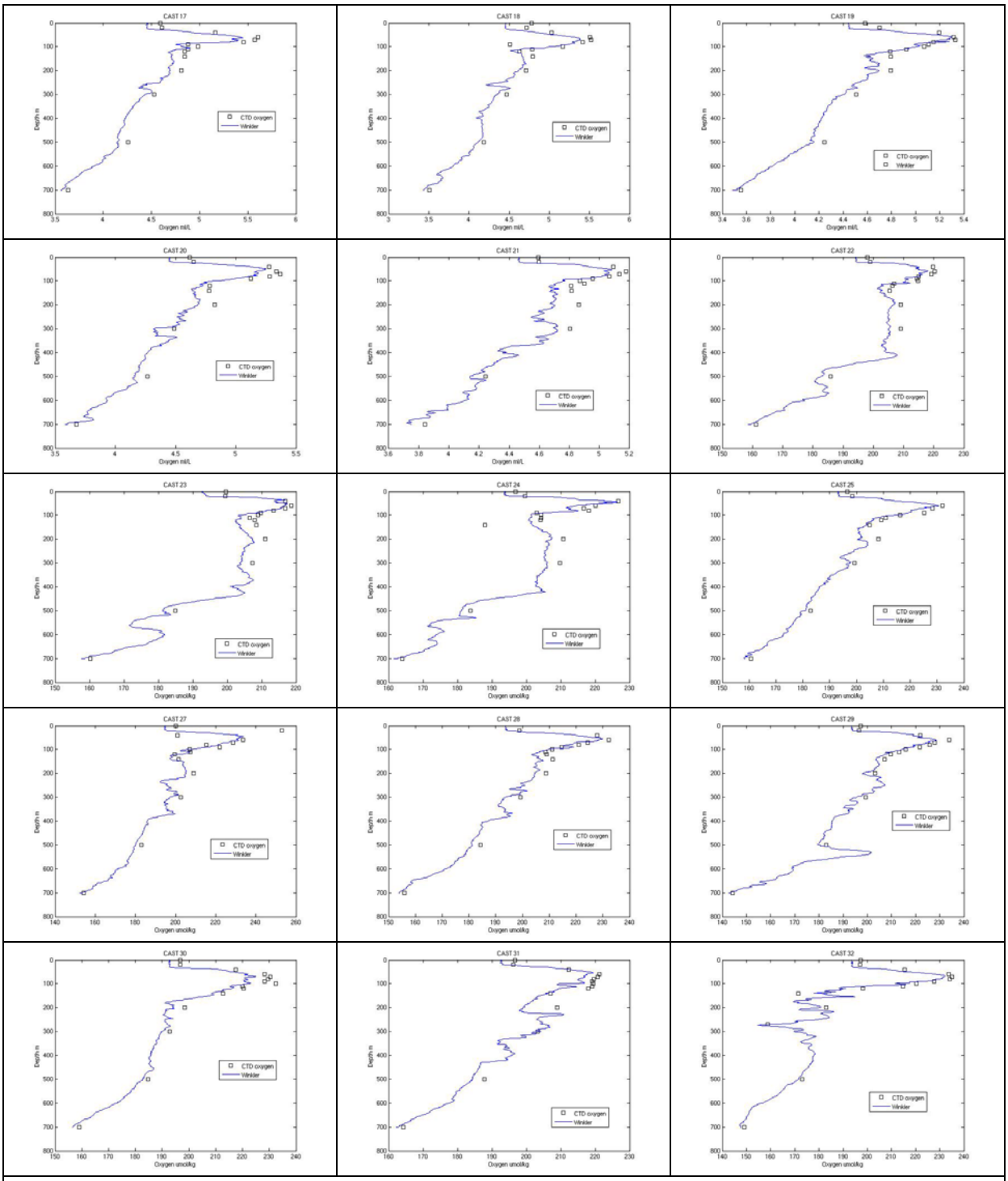


Figure 41: Comparison between CTD oxygen sensor and Winkler titrations of Niskin samples.

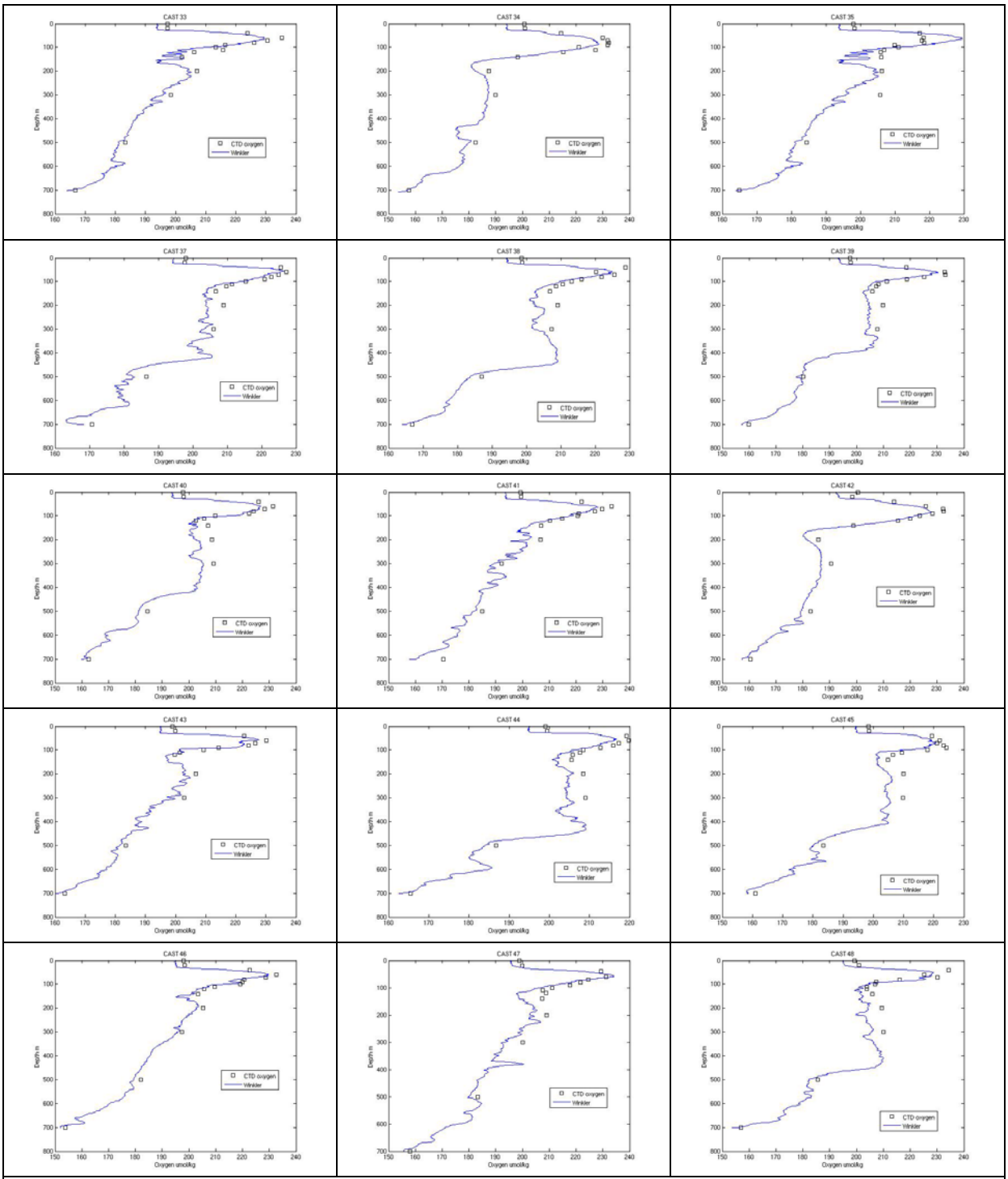


Figure 42: Comparison between CTD oxygen sensor and Winkler titrations of Niskin samples.

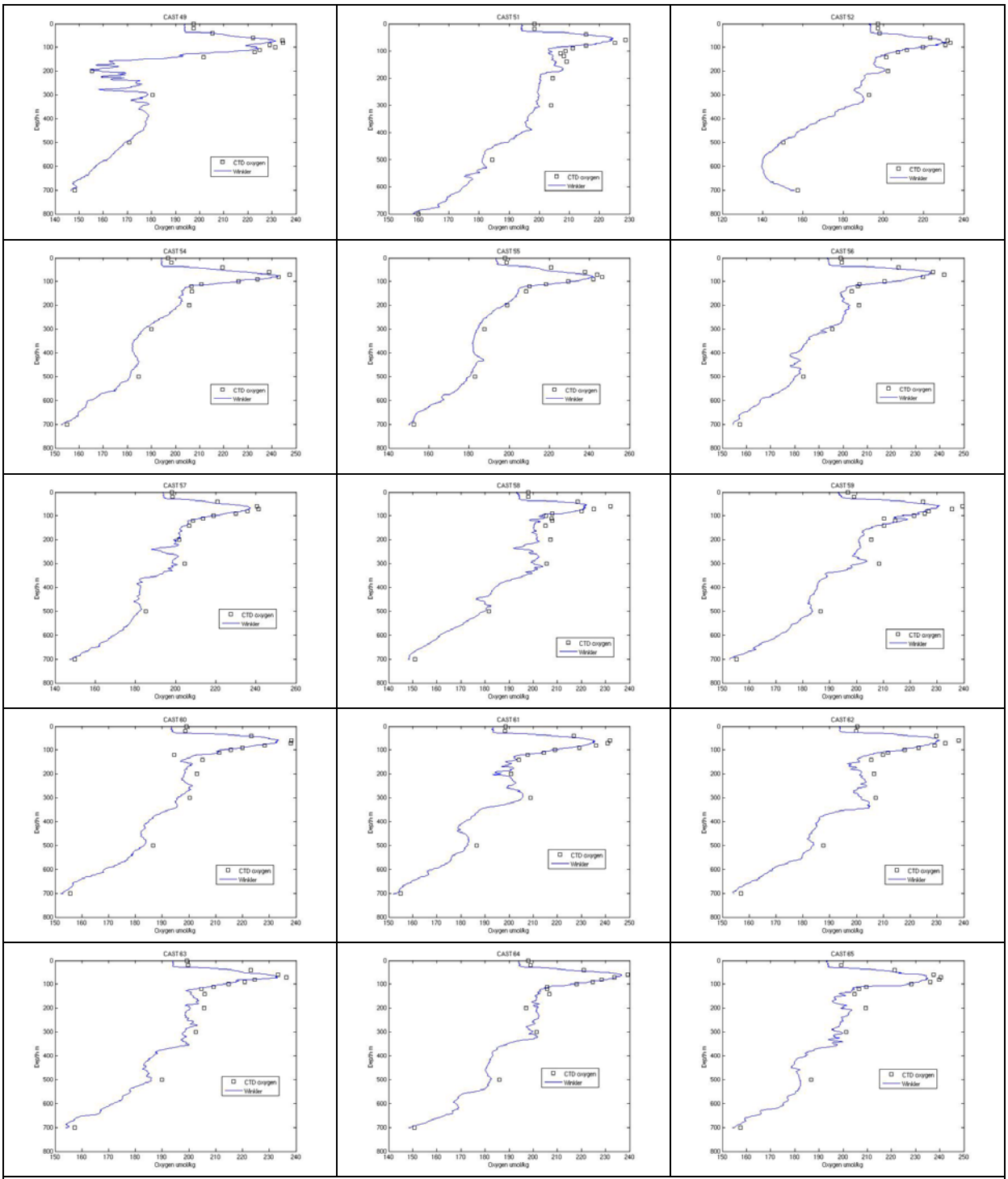


Figure 43: Comparison between CTD oxygen sensor and Winkler titrations of Niskin samples.

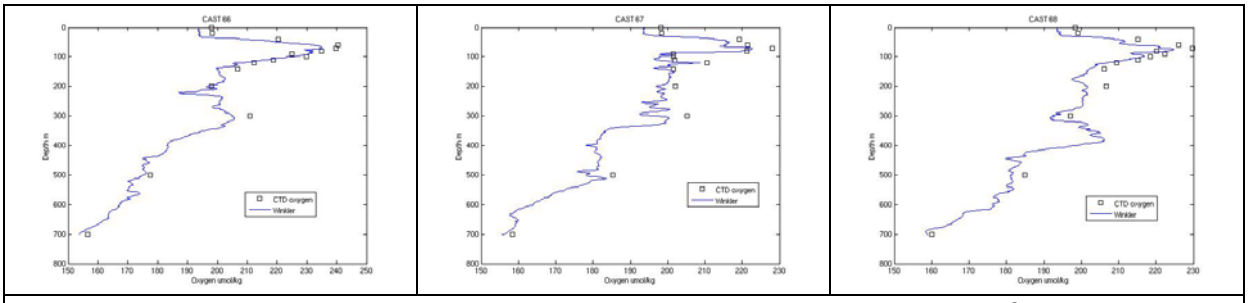


Figure 44: Comparison between CTD oxygen sensor and Winkler titrations of Niskin samples.

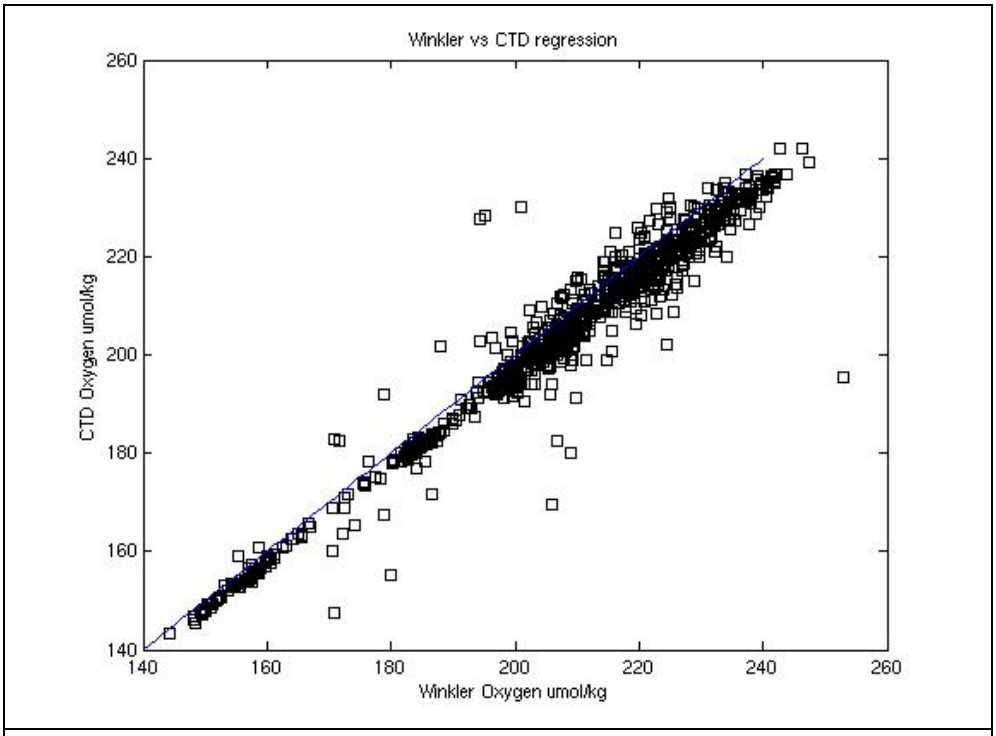


Figure 45: Winkler titrations versus CTD oxygen probe (primary).

## 5. Fluorometric chlorophyll and phaeopigment profiles

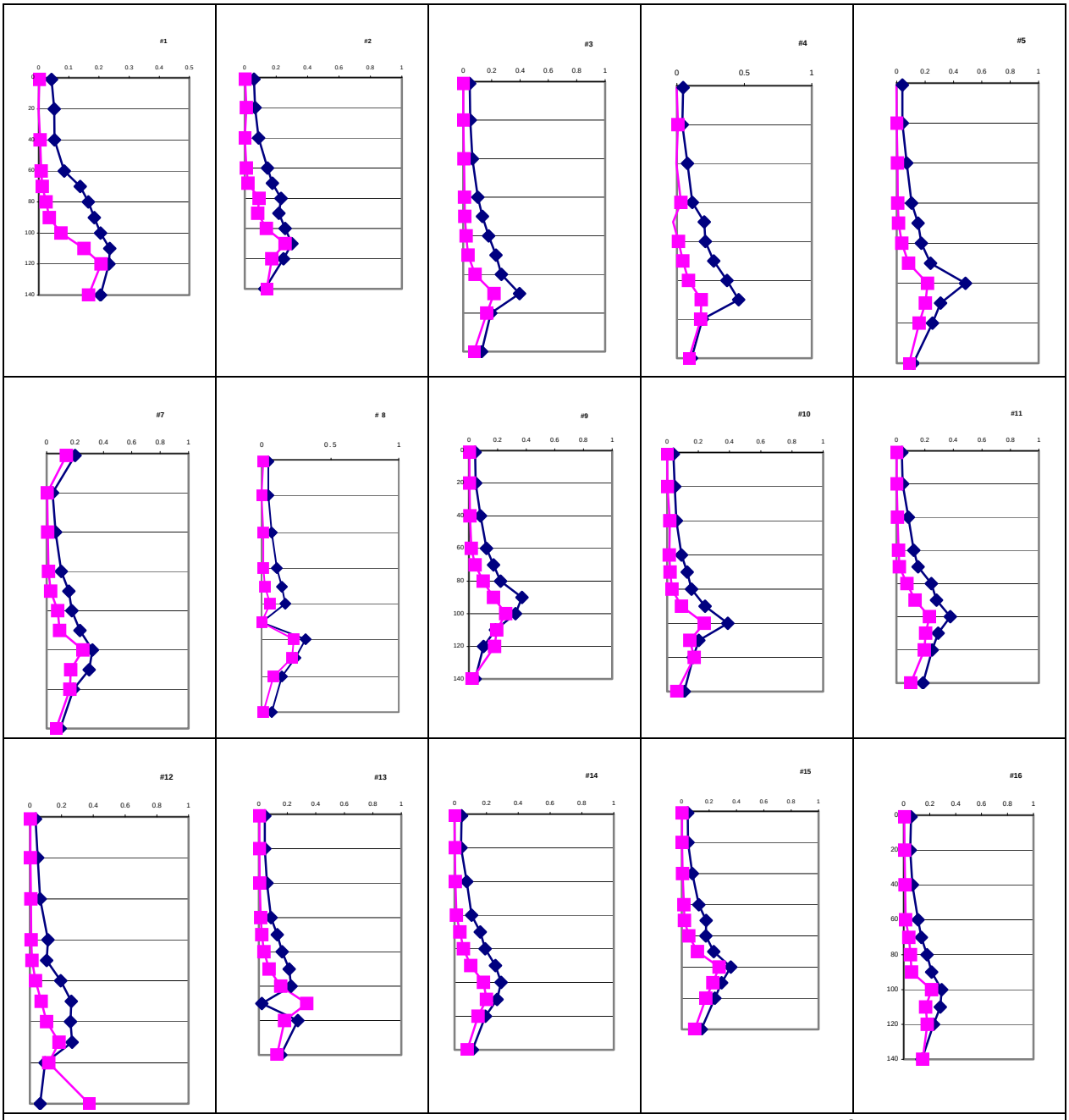


Figure 46: Fluorometric chlorophyll (blue) and phaeopigment (magenta) profiles.

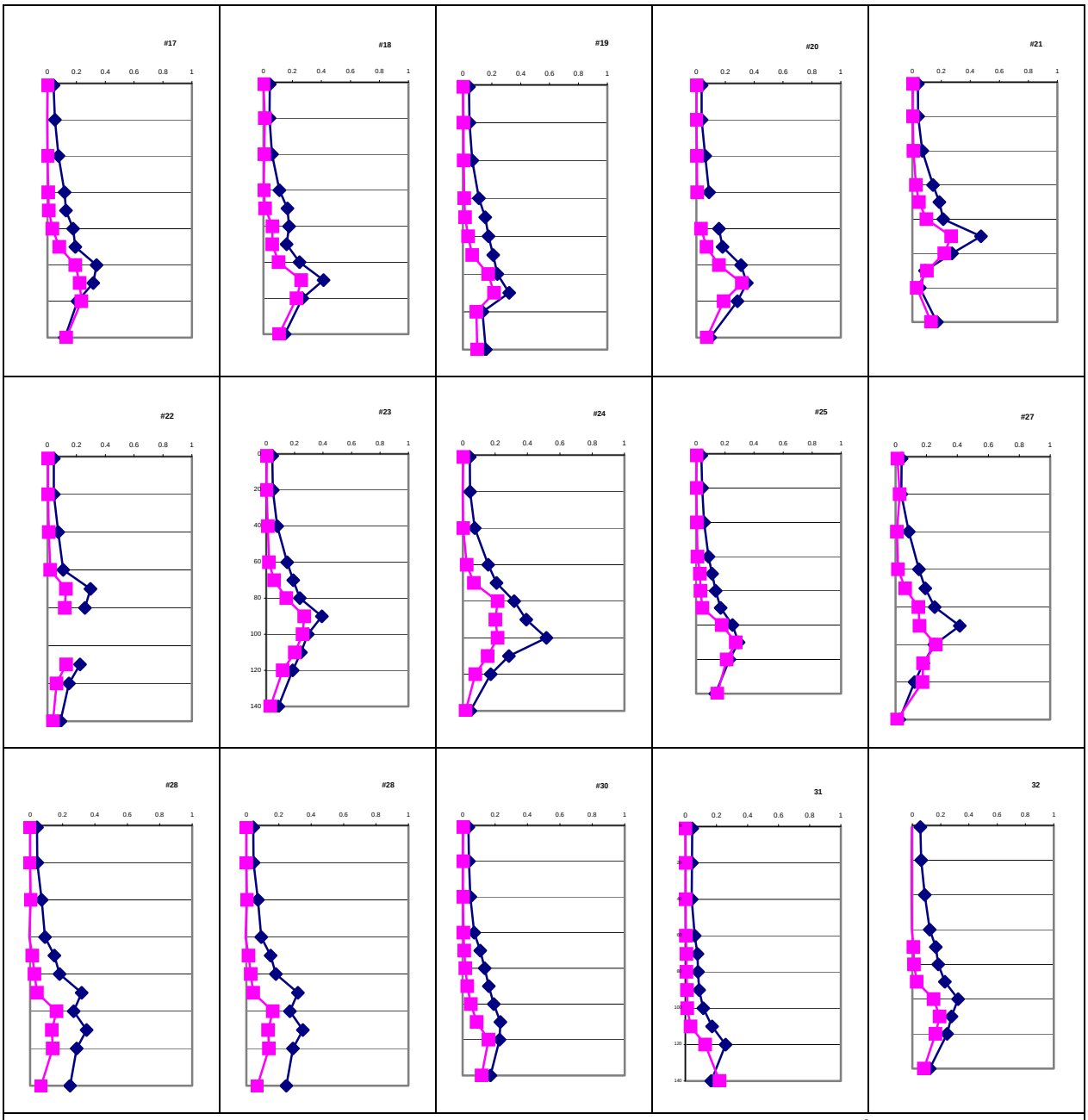


Figure 47: Fluorometric chlorophyll (blue) and phaeopigment (magenta) profiles.

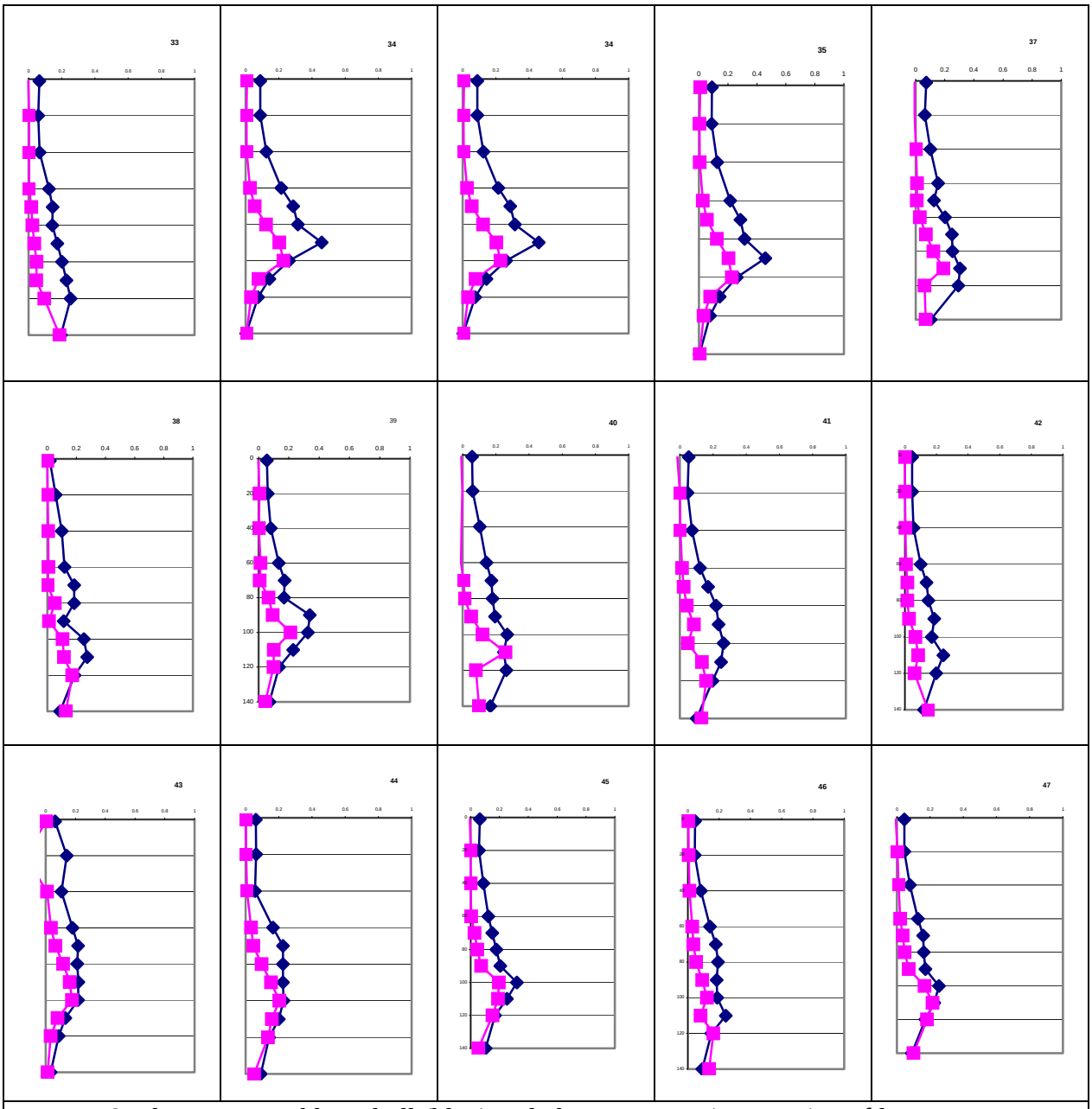


Figure 48: Fluorometric chlorophyll (blue) and phaeopigment (magenta) profiles.

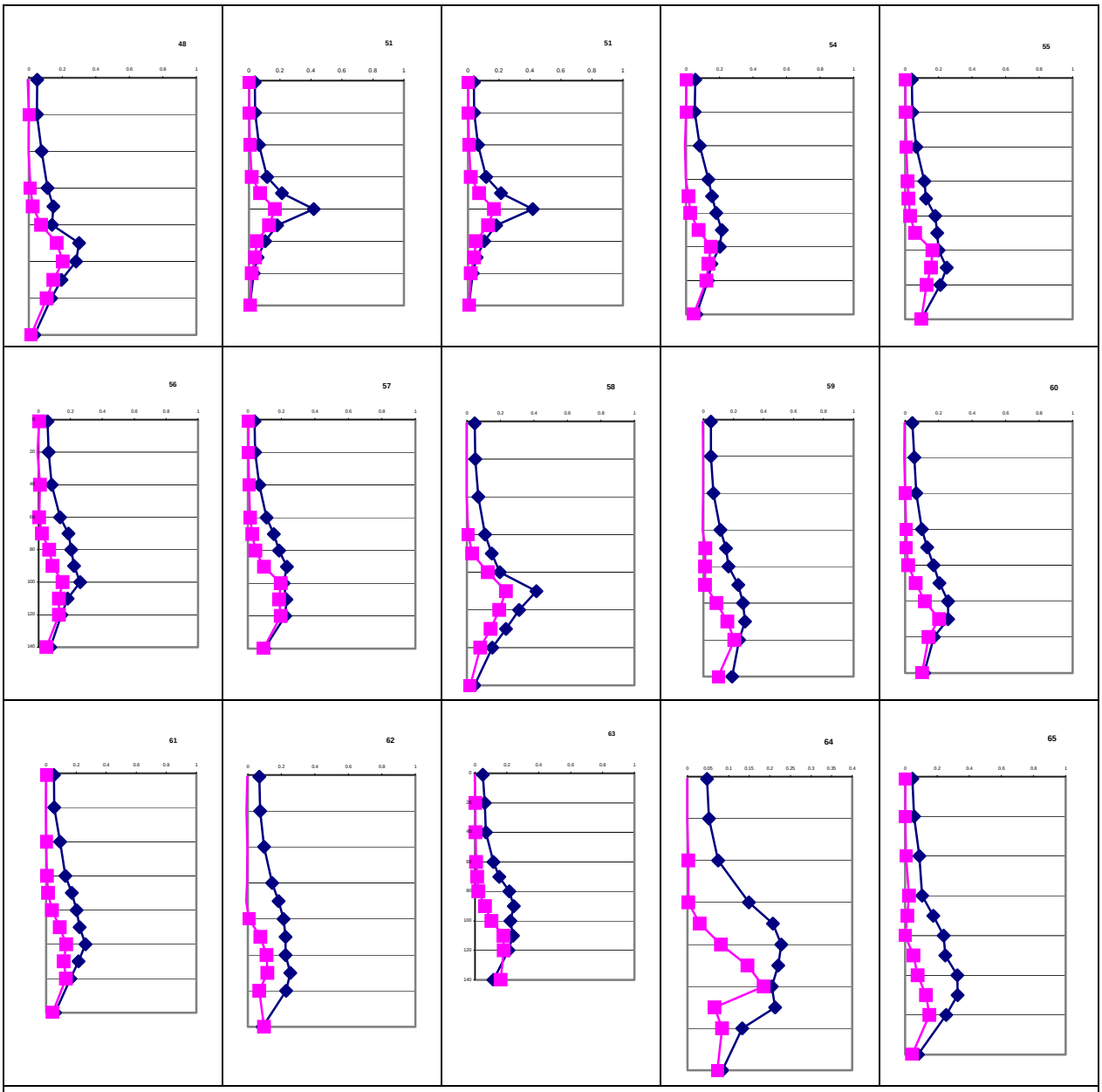


Figure 49: Fluorometric chlorophyll (blue) and phaeopigment (magenta) profiles.

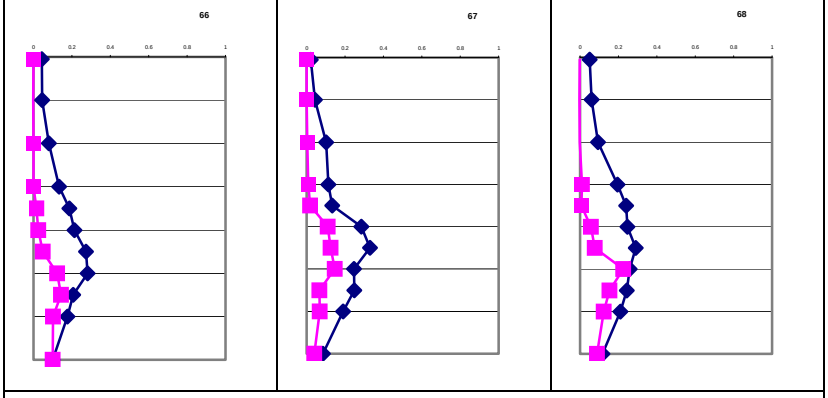


Figure 50: Fluorometric chlorophyll (blue) and phaeopigment (magenta) profiles.

## 6. Cruise Participants

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