To: Dennis McGillicuddy
From: Larry Anderson
Date: July 7, 2006

EDDIES Report #11:
Deep Oxygen Minimum

Q: Did the size and intensity of the deep (880 db) oxygen minimum in Eddy A4 change in size and intensity from Leg 1 to Leg 3?

During Leg 1, the $O_2$ anomaly was only found at Weatherbird Station 29, and was bounded to the North, East, South and West by stations 30, 31, 38 and 39 respectively, which were all 10 km away, and separated in time from station 29 by 3, 5, 48 and 50 hours respectively (Figs. 1-2). The low $O_2$ water is associated with a T-S anomaly (Fig. 1b). The low $O_2$ water is about 10 km south of Eddy Center (EC has cold T at 100 db and warm T at 650 db in Fig. 3). (At the time of station 29, the Valery's estimate of EC is 12 km away, directly north of station 40; Fig. 2.) Stations 30 and 31 are at background $O_2$ concentrations, suggesting an e-folding scale of 6.7 km, while stations 38 and 39, which have mid-range $O_2$, suggest 9 km (Fig. 3).

An interesting occurance is that Leg 1 station 32 found mid-range $O_2$ (cyan), but that station 33, only 3.1-hours later at the same site, did not. (Nor did station 36, 12.5 hours later than 32.) Another interesting place is station 8, where mid-range $O_2$ was found, when Eddy Center was around that location. But station 13, at the same site as station 8 but 38 hours later, found only the normal $O_2$ background. This suggests rapid movement of the feature, probably associated with rotation around and translation with Eddy Center.

During Leg 3, the $O_2$ minimum was found at many Oceanus and Weatherbird stations (Fig. 4-6). Although the data is not synoptic (though all are between yeardays 229.8-236.7), the station pairs OC 43 and 44 (as well as OC 66 and 67) are 3 hours apart and 30 km apart, indicating the $O_2$ anomaly to be over 30 km in diameter or length.

This would appear to suggest that the $O_2$ anomaly grew in size and intensity from Leg 1 to Leg 3.

However, the $O_2$ anomaly is associated with a T-S anomaly which also grew in size and intensity from Leg 1 to Leg 3 (Fig. 4b). Thus it seems the size of the feature was undersampled during Leg 1. In particular, as stations 38 and 39 were 48 and 50 hours later than station 29, and the Eddy completes one rotation in 5-6 days, the limits of the feature to the South and West during Leg 1 are not well constrained.

During Leg 3, at the time of OC 43-44, the low $O_2$ "red line" is SW of EC; but at the time of OC 66-67, the low $O_2$ "magenta line" is NE of EC. Thus the apparent stationarity of the low $O_2$ patch in Leg 3 may be a case of it rotating clockwise as the Eddy moves SW.

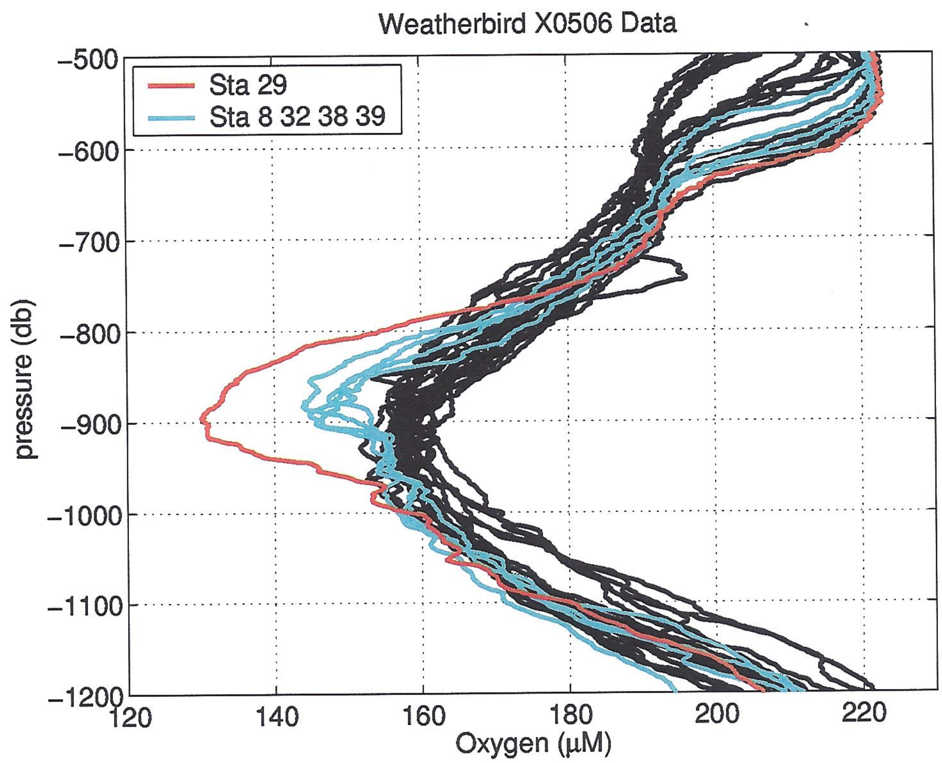
The close association of the $O_2$ anomaly with the T-S anomaly indicates advection rather than remineralization as the source. Other instances of entrainment and mixing may be suggested by the temporal evolution of the submesoscale variability (e.g. in isopycnal depth) in C1 and A4 at 100 db, and the T-S anomaly at 200 db in C1. Thus entrainment of outside water at discrete levels appears to occur in typical eddies. The entrainment at discrete levels is curious, but may be associated with the fact that the eddy is composed of discrete slabs of winter water at various depths, only one of which is the driver of the circulation; and/or that horizontal convergence may be occurring at certain depths, as driven by variation in verical velocity.

In all plots, the low $O_2$ profiles/stations are in red; mid-range oxygen in cyan; background oxygen in black. All plots are scaled so distance in km is the same length along both axes.

- Calibrate OC and WB salinity. Jim Ledwell (email 16 May 2006) suggests the following Oceanus calibrations:Leg 1, CTD-Autosal=-0.021; Leg 2, -0.0011; Leg 3, -0.012; Leg 4, -0.0014.

- Try mapping T, S, $O_2$ and pressure along isopycnals (e.g. $\sigma_{880}$, $\sigma_{650}$). But need to calibrate salinity first.

Leg 4 data are shown in Figs. 7-10. The latest calibrations are used (see Report #12). Stations [8 10 11 15 21] differ significantly from the others (Fig. 7), presumably because these are far from Eddy Center (Figs. 8 and 10). Aside from these, only station 16 has background $O_2$ at 880 db (Fig. 7). Stations [8 10 11] have strangely low $O_2$ between 100-400 db (Fig. 7), though perhaps it is real because T-S is also off the main trend (Fig. 9b). The T-S relationship near 880 db is similar to Leg 3, though perhaps showing mixing at T=9.5, S=35.22 (Fig. 9a). The $O_2$ minimum was not boxed in (Fig. 10). Stations 19 and 20, 16 km and 3.6 hours apart, were both within the $O_2$ minimum, so the extent was at least 16 km, and west of Eddy Center (Fig. 10).


Weatherbird X0506 Data
Sta 29
Sta 8 32 38 39
pressure (db)
Oxygen (μM)
-500
-600
-700
-800
-900
-1000
-1100
-1200
120
140
160
180
200
220

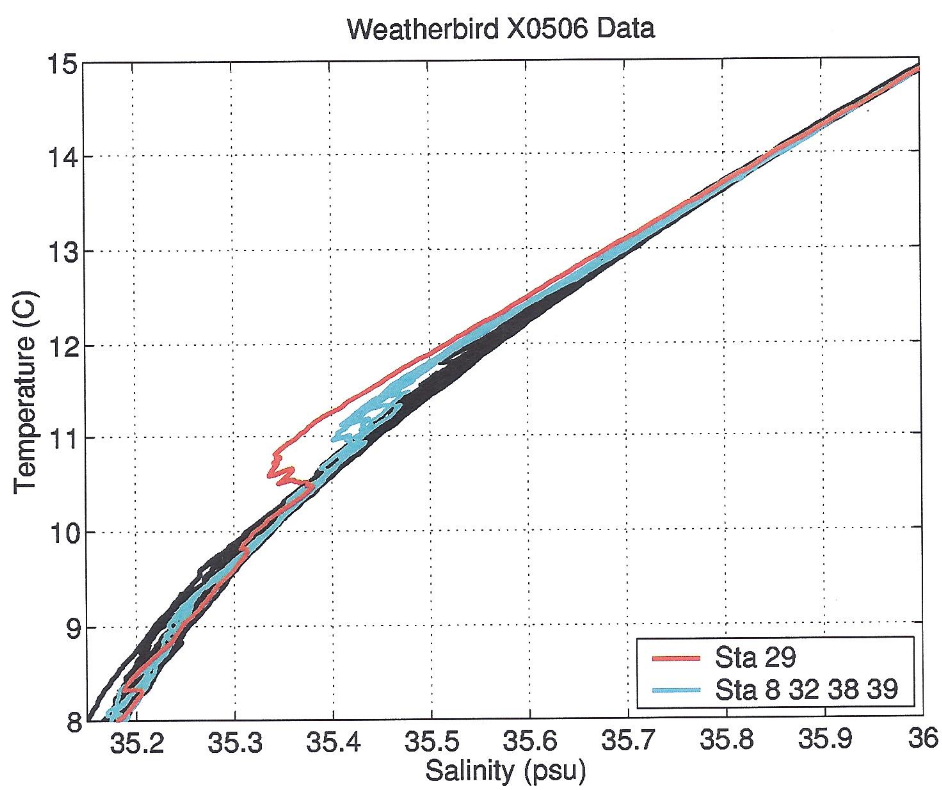

Weatherbird X0506 Data
Sta 29
Sta 8 32 38 39
Temperature (C)
Salinity (psu)
15
14
13
12
11
10
9
8
35.2
35.3
35.4
35.5
35.6
35.7
35.8
35.9
36

Fig. 1.

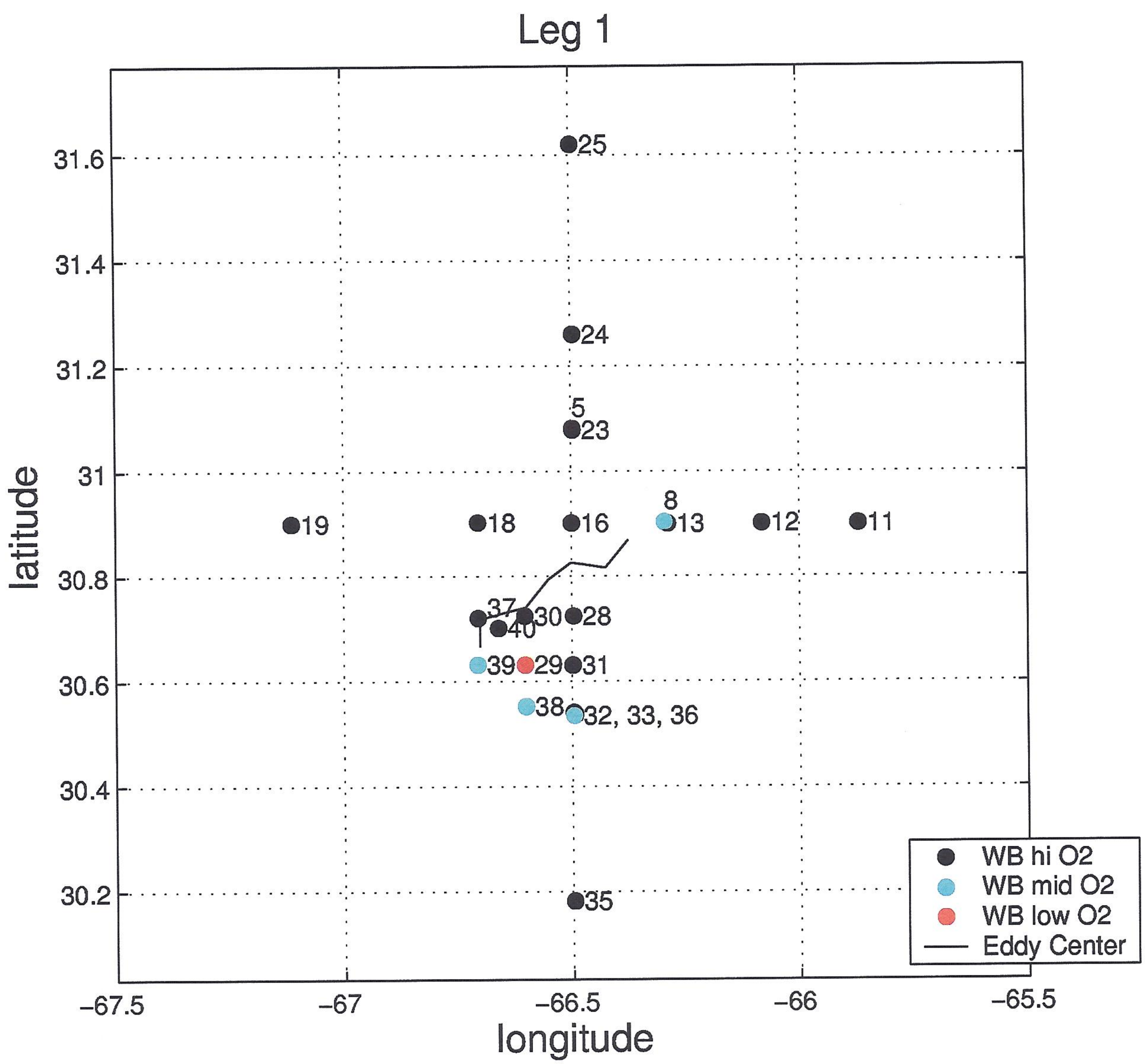
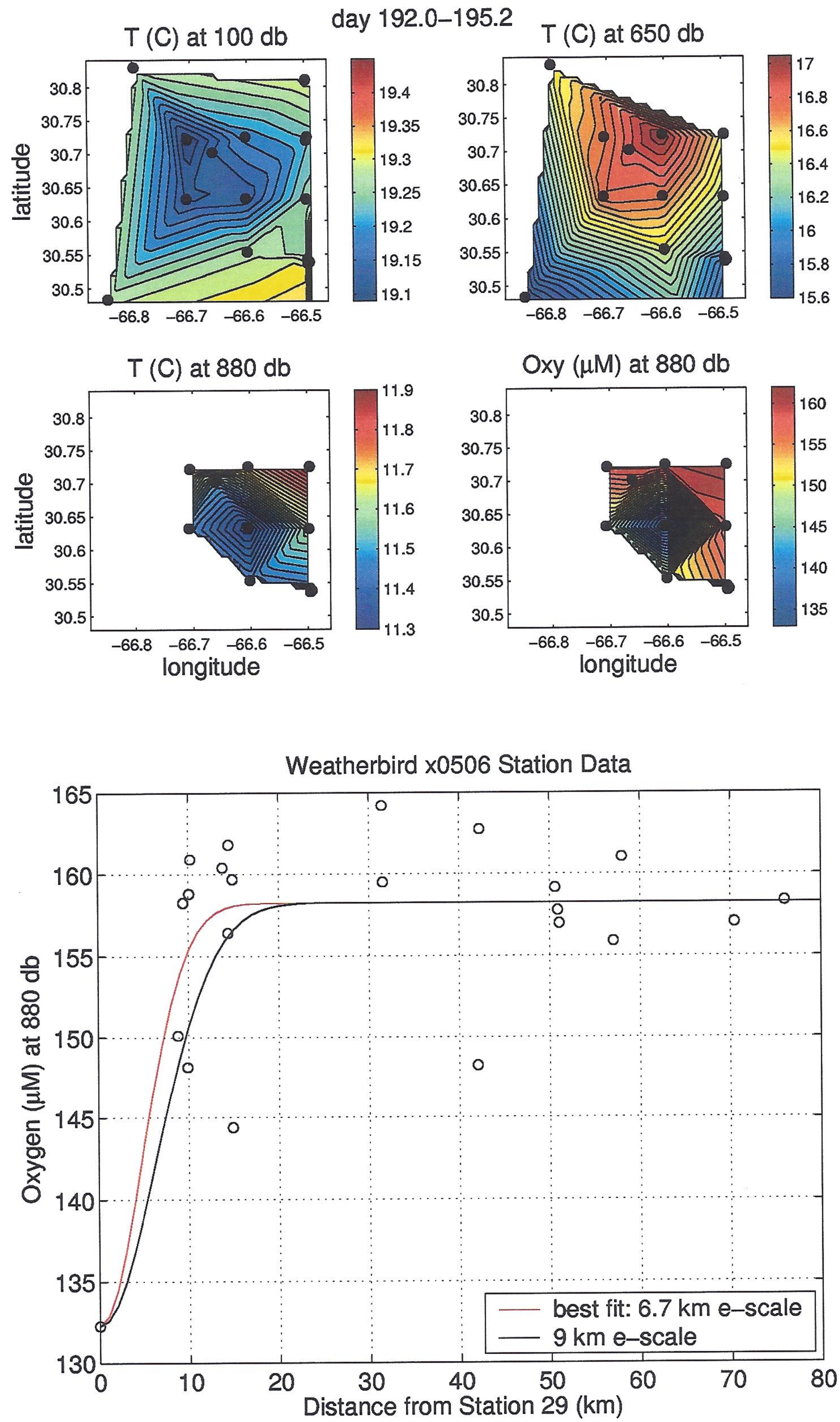

Leg 1
latitude
longitude
31.6
31.4
31.2
31
30.8
30.6
30.4
30.2
-67.5
-67
-66.5
-66
-65.5
25
24
5
23
19
18
16
8
13
12
11
37
30
28
40
39
29
31
38
32, 33, 36
35
WB hi O2
WB mid O2
WB low O2
Eddy Center

Fig. 2.



day 192.0–195.2
T (C) at 100 db
T (C) at 650 db
T (C) at 880 db
Oxy (μM) at 880 db
latitude
longitude
Weatherbird x0506 Station Data
Oxygen (μM) at 880 db
Distance from Station 29 (km)
best fit: 6.7 km e–scale
9 km e–scale


Fig. 3.

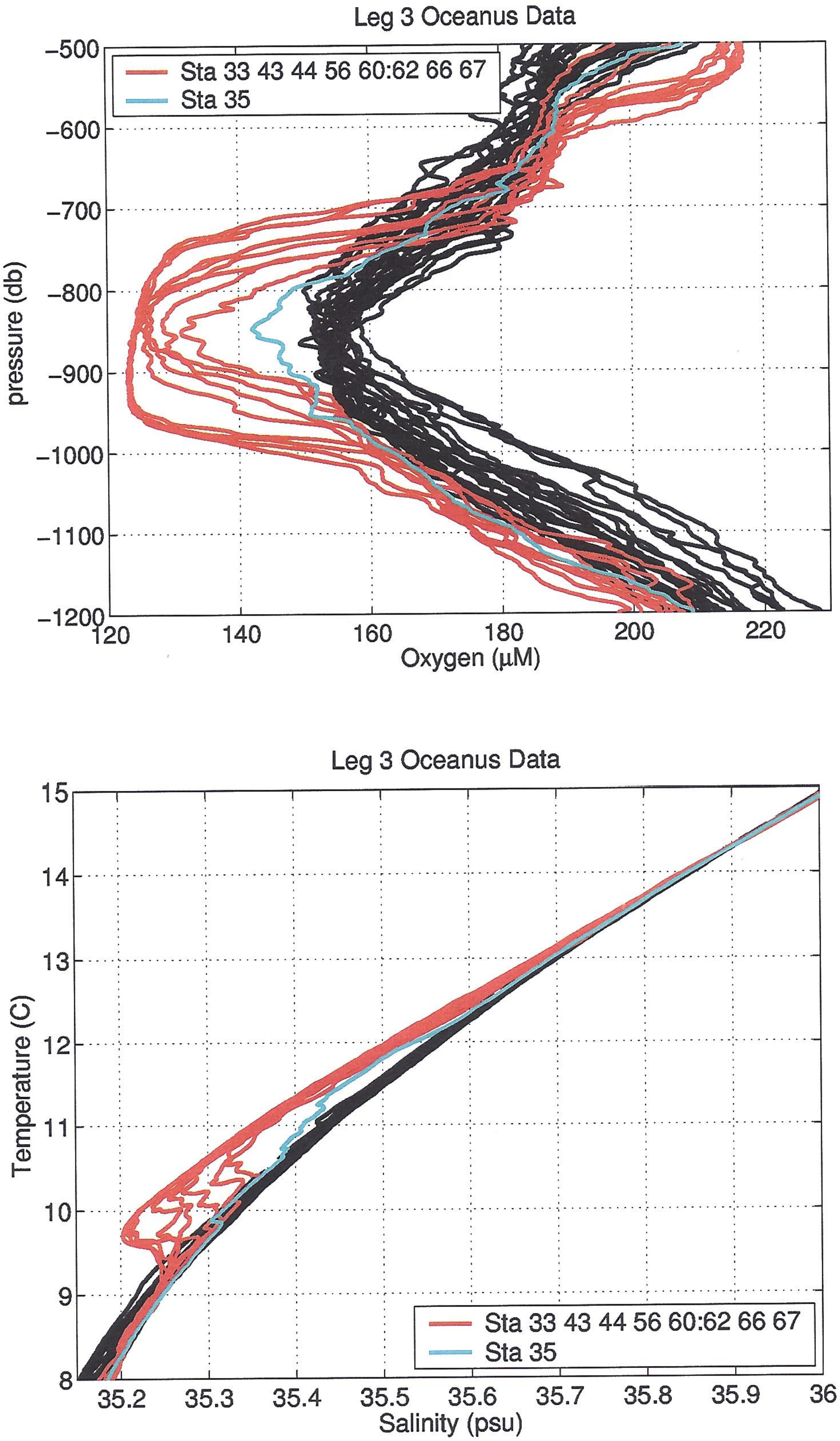
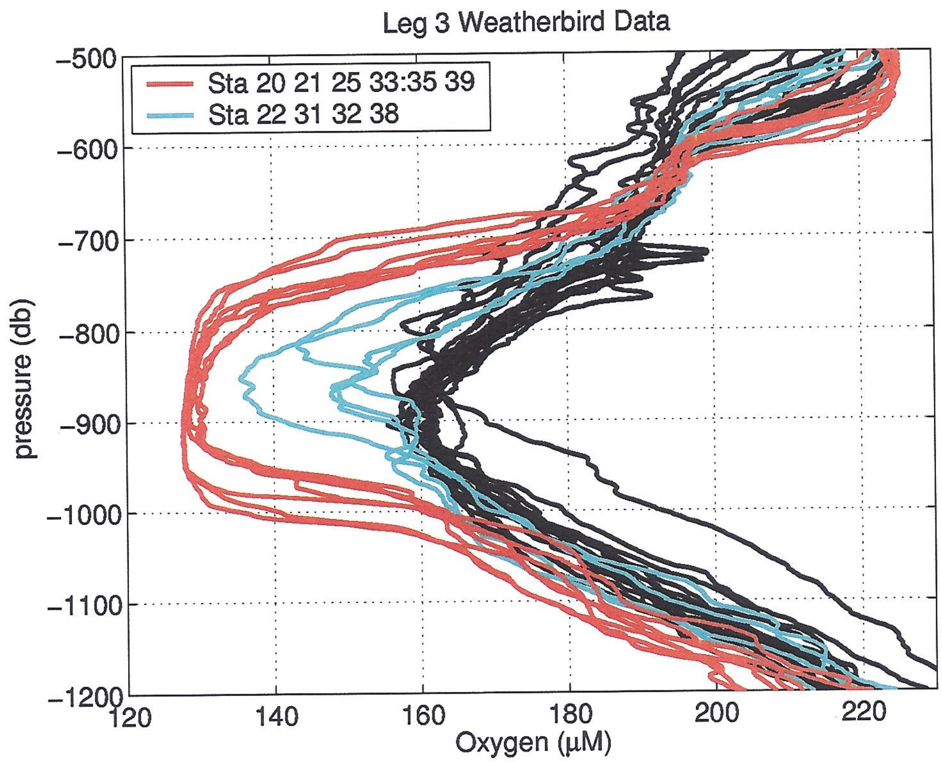

Leg 3 Oceanus Data
Sta 33 43 44 56 60:62 66 67
Sta 35
pressure (db)
-500
-600
-700
-800
-900
-1000
-1100
-1200
120
140
160
180
200
220
Oxygen (μM)
Leg 3 Oceanus Data
Temperature (C)
15
14
13
12
11
10
9
8
35.2
35.3
35.4
35.5
35.6
35.7
35.8
35.9
36
Salinity (psu)
Sta 33 43 44 56 60:62 66 67
Sta 35

Fig. 4.


Leg 3 Weatherbird Data
Sta 20 21 25 33:35 39
Sta 22 31 32 38
pressure (db)
-500
-600
-700
-800
-900
-1000
-1100
-1200
120
140
160
180
200
220
Oxygen (μM)

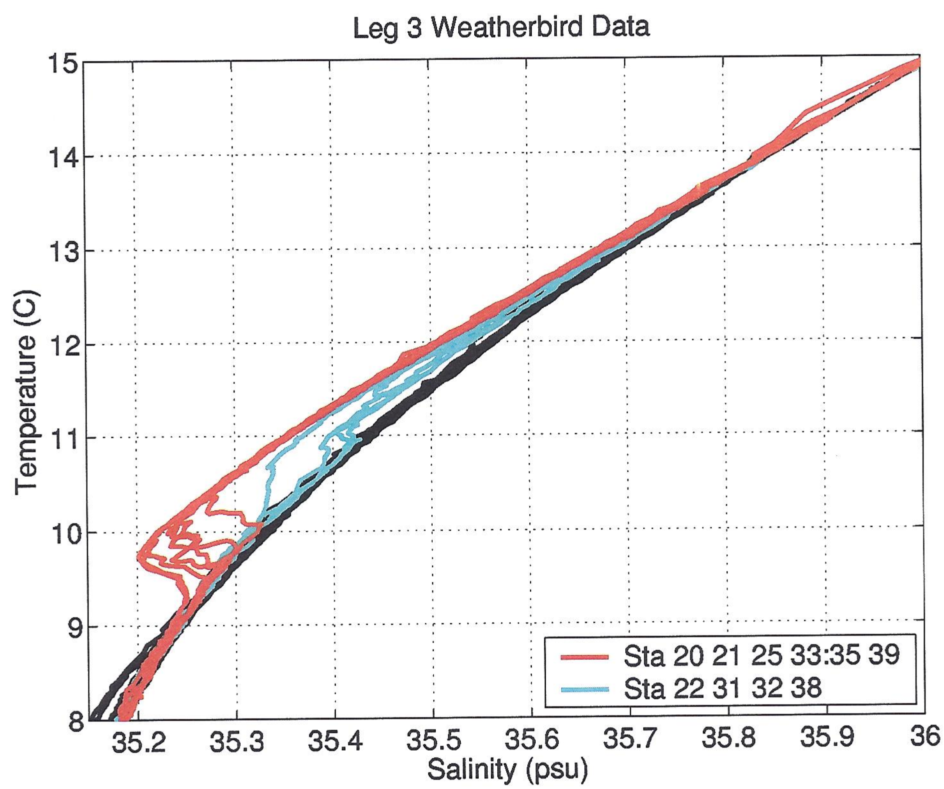

Leg 3 Weatherbird Data
Temperature (C)
15
14
13
12
11
10
9
8
Sta 20 21 25 33:35 39
Sta 22 31 32 38
35.2
35.3
35.4
35.5
35.6
35.7
35.8
35.9
36
Salinity (psu)

Fig. 5.

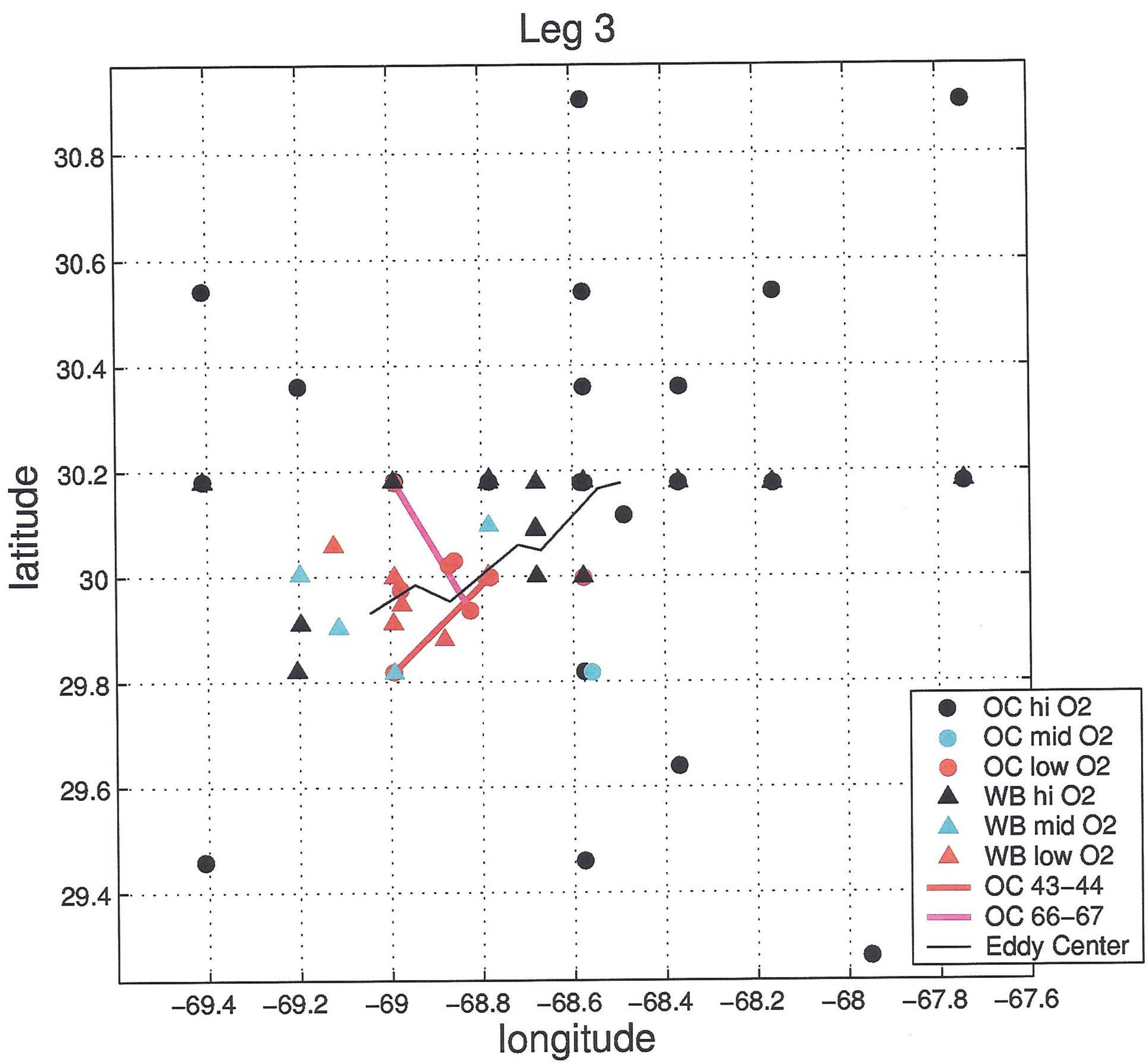

Leg 3
30.8
30.6
30.4
30.2
30
29.8
29.6
29.4
latitude
−69.4
−69.2
−69
−68.8
−68.6
−68.4
−68.2
−68
−67.8
−67.6
longitude
OC hi O2
OC mid O2
OC low O2
WB hi O2
WB mid O2
WB low O2
OC 43–44
OC 66–67
Eddy Center

Fig. 6.

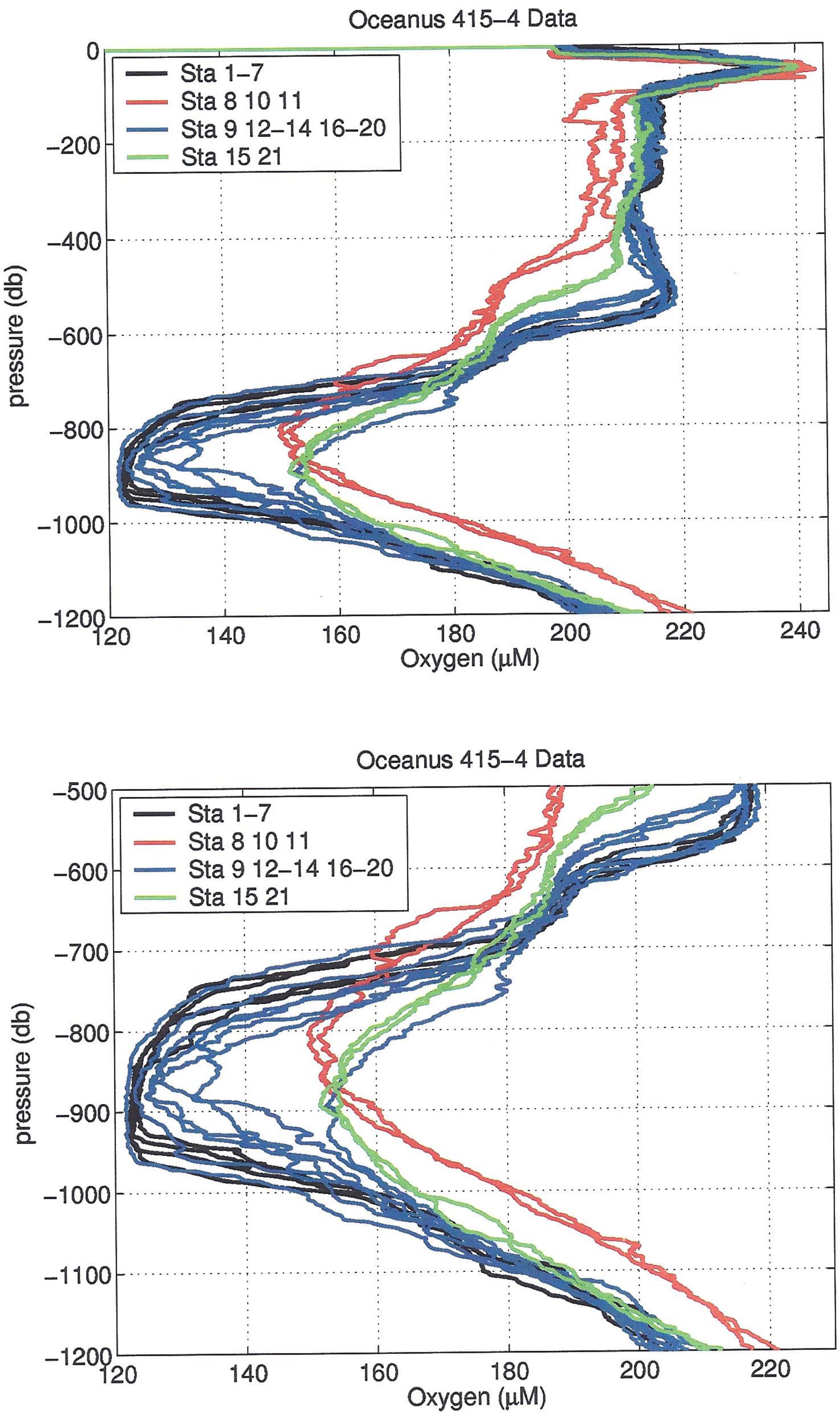

Oceanus 415–4 Data
Sta 1–7
Sta 8 10 11
Sta 9 12–14 16–20
Sta 15 21
pressure (db)
Oxygen (μM)
0
−200
−400
−600
−800
−1000
−1200
120
140
160
180
200
220
240
Oceanus 415–4 Data
Sta 1–7
Sta 8 10 11
Sta 9 12–14 16–20
Sta 15 21
pressure (db)
Oxygen (μM)
−500
−600
−700
−800
−900
−1000
−1100
−1200
120
140
160
180
200
220

Fig. 7.

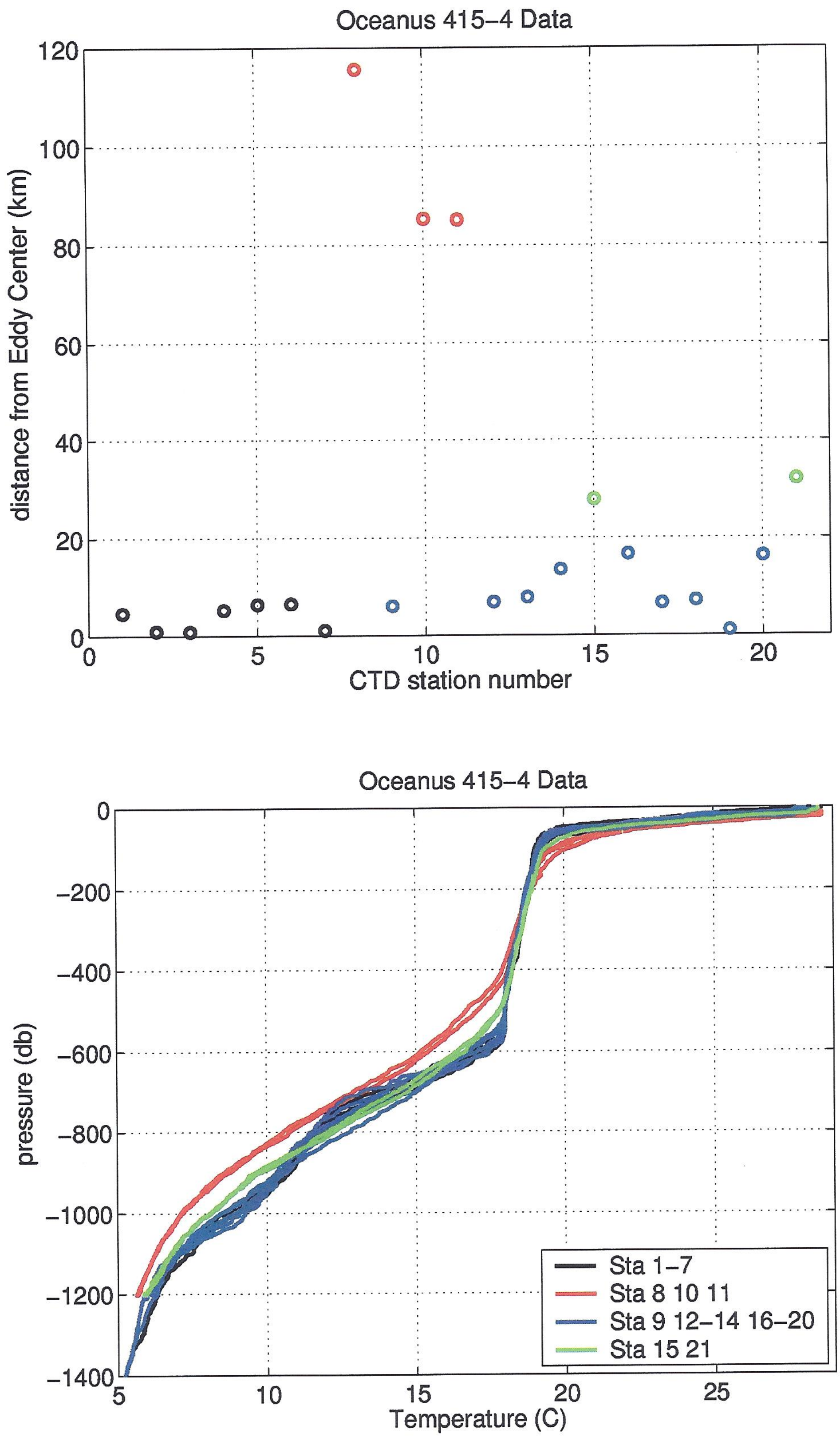
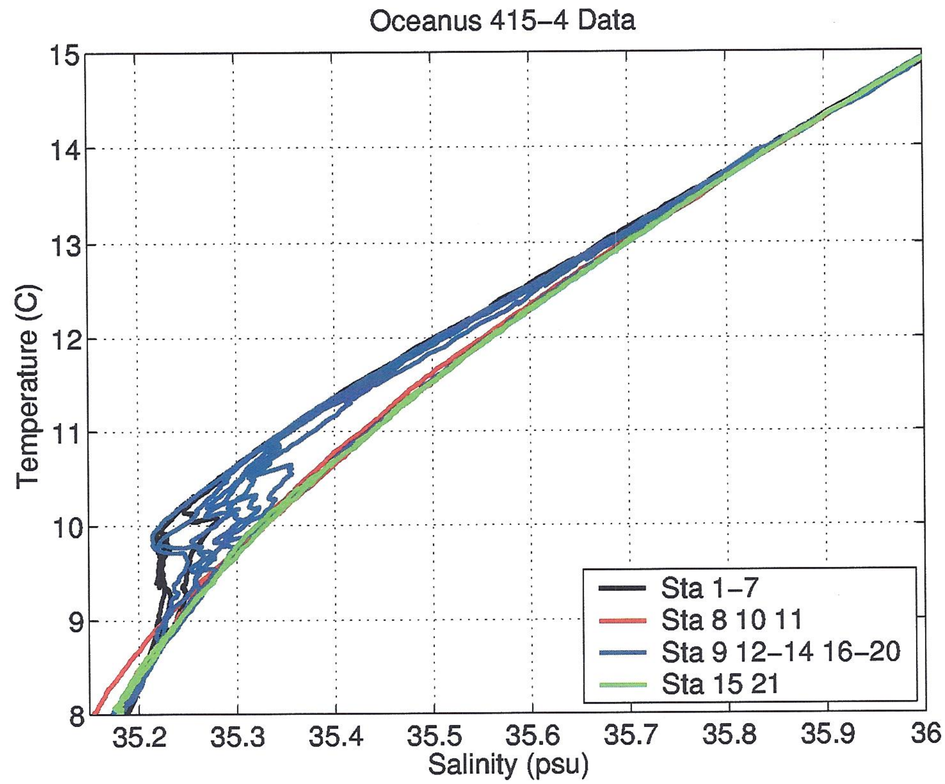

Oceanus 415–4 Data
distance from Eddy Center (km)
CTD station number
Oceanus 415–4 Data
pressure (db)
Temperature (C)
Sta 1–7
Sta 8 10 11
Sta 9 12–14 16–20
Sta 15 21

Fig. 8.


Oceanus 415–4 Data
Temperature (C)
Salinity (psu)
15
14
13
12
11
10
9
8
35.2
35.3
35.4
35.5
35.6
35.7
35.8
35.9
36
Sta 1–7
Sta 8 10 11
Sta 9 12–14 16–20
Sta 15 21

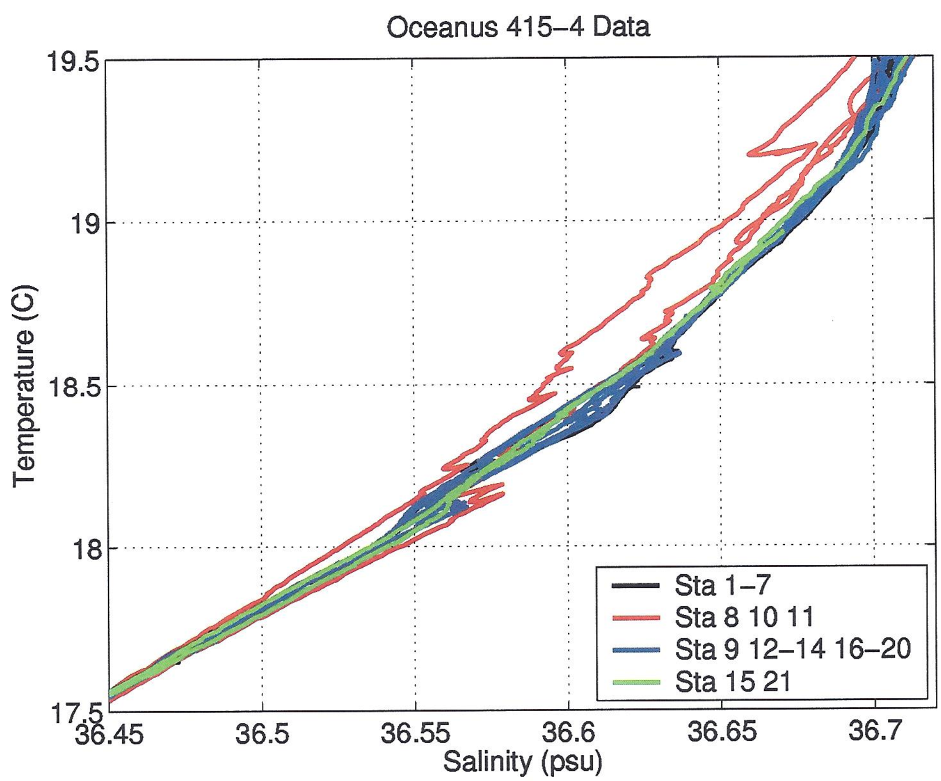
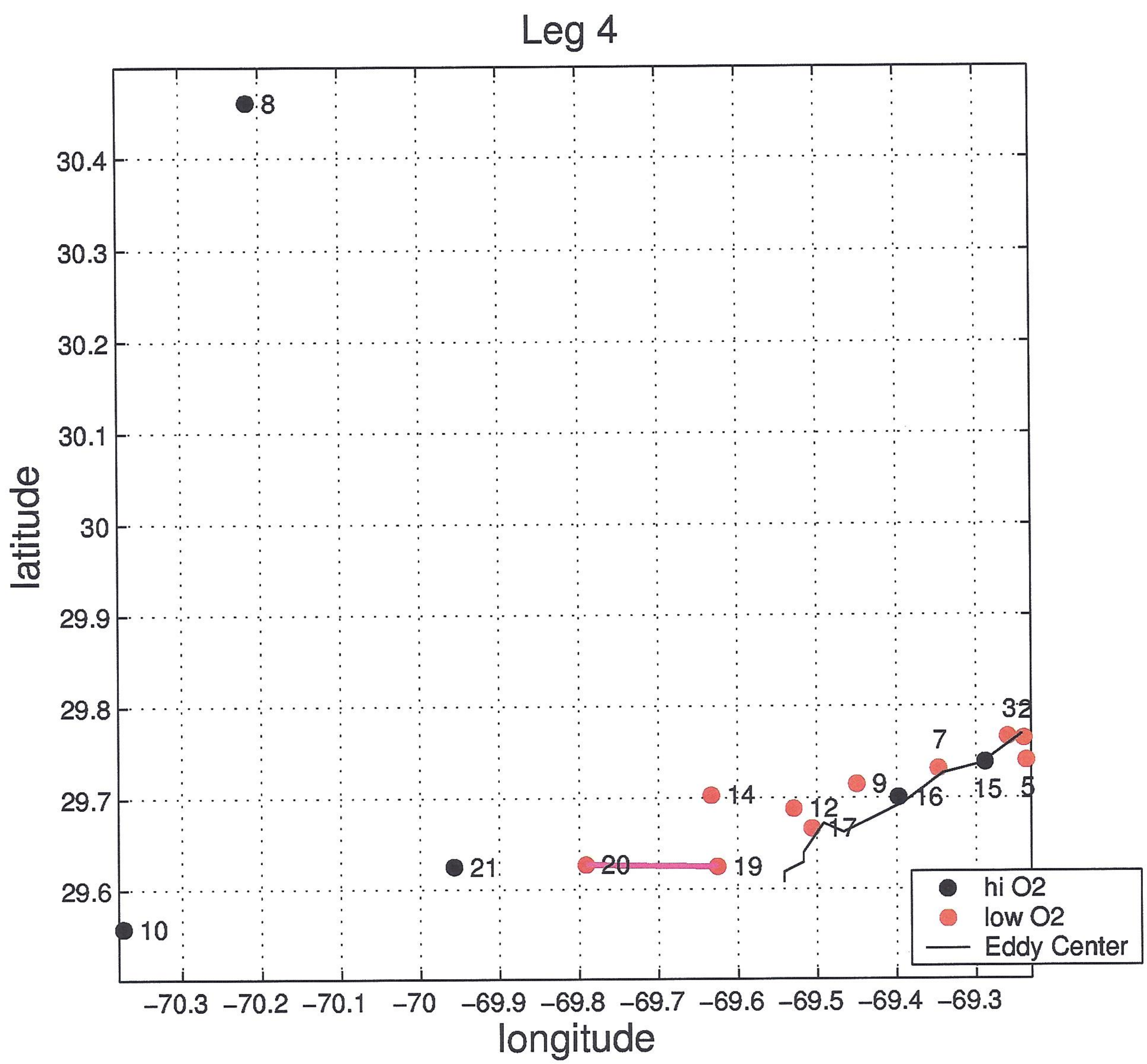

Oceanus 415–4 Data
Temperature (C)
Salinity (psu)
19.5
19
18.5
18
17.5
36.45
36.5
36.55
36.6
36.65
36.7
Sta 1–7
Sta 8 10 11
Sta 9 12–14 16–20
Sta 15 21

Fig. 9.



Leg 4
latitude
longitude
30.4
30.3
30.2
30.1
30
29.9
29.8
29.7
29.6
-70.3
-70.2
-70.1
-70
-69.9
-69.8
-69.7
-69.6
-69.5
-69.4
-69.3
8
10
21
20
19
14
12
17
9
16
7
15
3
2
5
hi O2
low O2
Eddy Center


Fig. 10.