Cruise Report
R/V F. G. Walton Smith Cruise 0813
7 - 11 September 2008

Development Cruise for Dye Experiments with Airborne LIDAR

DRAFT

Summary

The purpose of the Walton Smith Cruise 0813 was to develop techniques for performing dye release experiments in the upper ocean in concert with an airborne LIDAR operation, and to determine the sensitivity of the LIDAR, as currently configure to dye in the water.

Cruise participants

Science Party

James R. Ledwell, Senior Scientist, WHOI
Miles Sundermeyer, Associate Professor, UMass Dartmouth
Eugene E. Terray, Research Specialist, WHOI
Leah Houghton, Research Associate, WHOI
Deborah Schwartz, Graduate Student, UMass Dartmouth

Ship's Crew

Shawn Lake, Captain
Andrew Exumna, Engineer
Stewart Bell, Mate
Jimmy Bovina, Cook
William Smith, ABS
Dennis Ilias, Marine Technician, RSMAS

Site

Operations were carried out within a few nautical miles of 33.8 N, 74.5 W, which was southeast of Cape Hatteras off shore of the Gulf Stream (Fig. 1), in oligotrophic waters (Fig. 2). The site was determined by criteria of optical clarity of the water but also proximity to an airport for the LIDAR system. The aircraft was based at Richmond, Virginia, but had the possibility of refueling in Manteo, North Carolina.

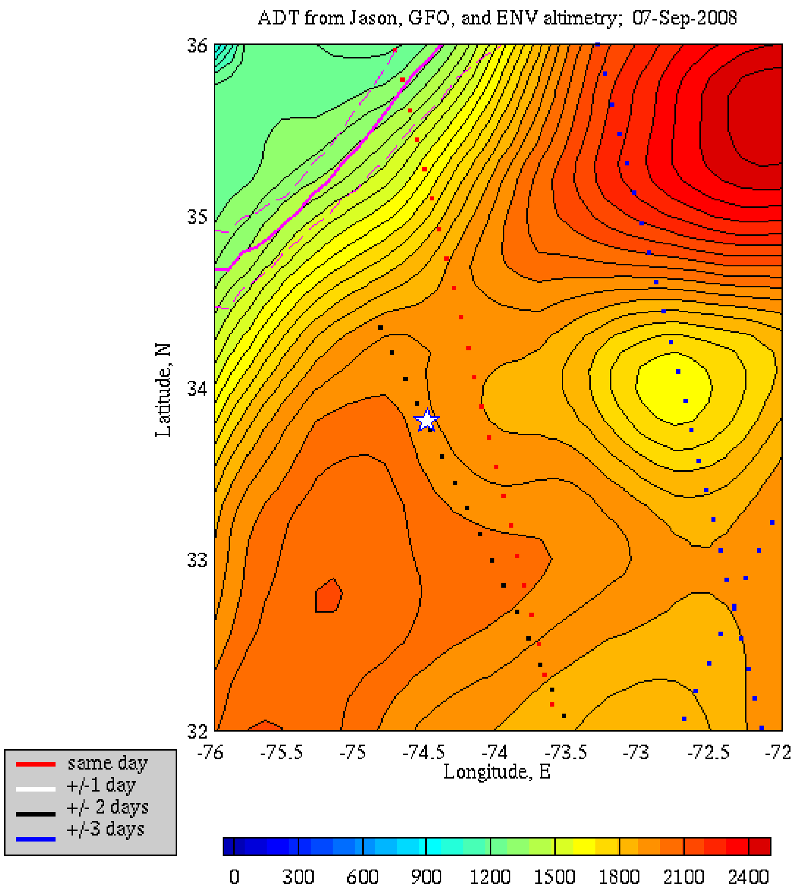


Fig. 1. Sea Surface Height from various satellites for 7 September 2008. The star marks the center of operations for the cruise. Though the flow here is suggested to be to the SE, the observed flow was approximately 0.5 m/s to the SW during the cruise.

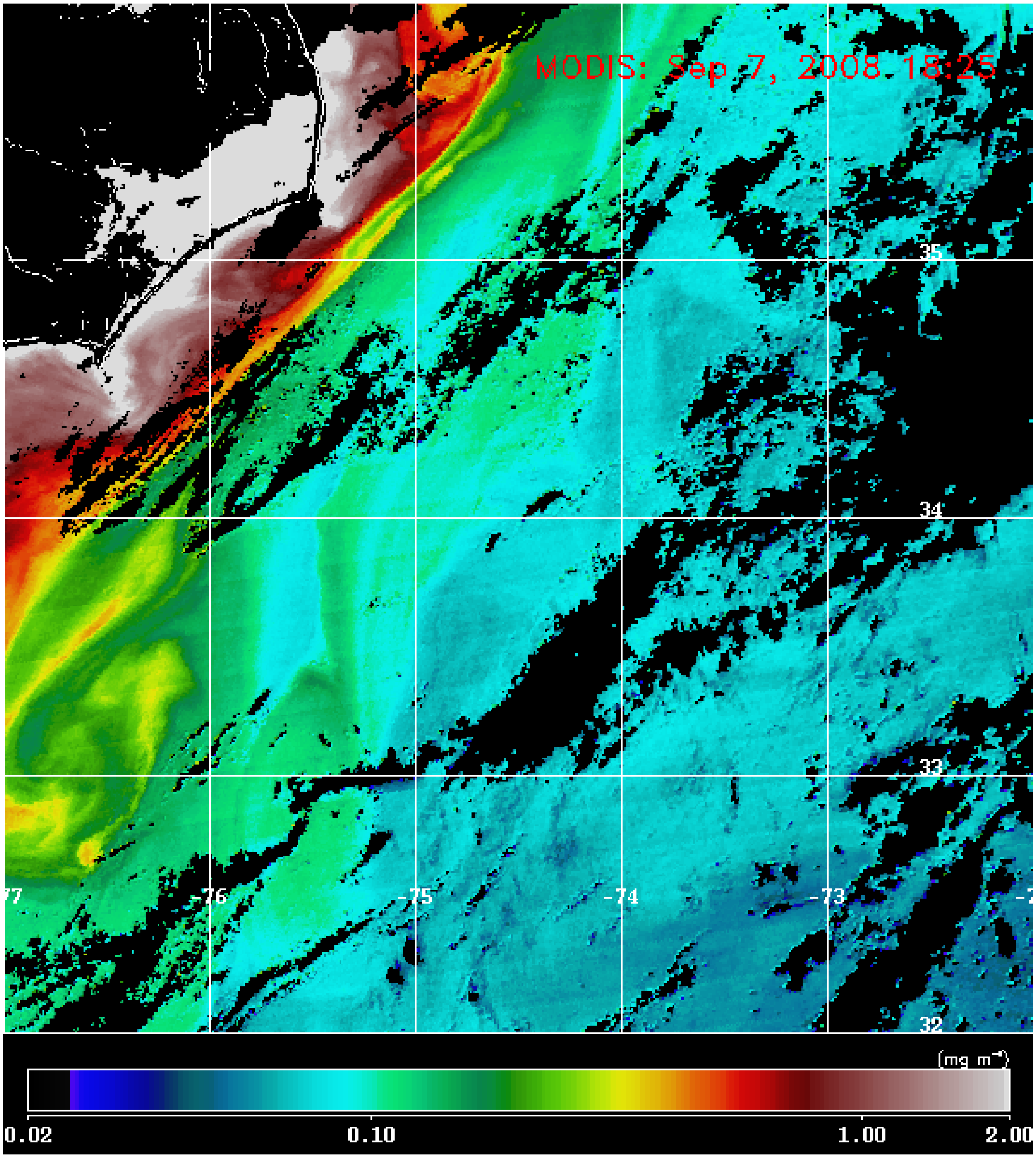


Fig. 2. Chlorophyll estimated from the MODIS Satellite on 7 September 2008. Clhorophyll levels near the site at 33.8 N, 74.5 W are approximately 0.08 mg/m^3 in this image. Cape Hatteras is visible in the NW corner.

Instruments

SeaBird SBE911 CTD for hydrography, dye release and dye sampling

Satlantic SPMR 7-wavelength radiometer system (profiler and reference), to measure Apparent Optical Properties (AOP), especially the diffuse attenuation coefficient near the excitation (490 nm) and emission (515 nm) wavelengths of fluorescein dye

WETLabs AC-9 Absorption-Attenuation Meter to measure inherent optical properties (IOP)

SeaBird SBE19 CTD to accompany the AC-9

(4) Drogues with "high flier" floats, staffs and lights, and 7-meter holy-sock drogues

(2) Pails with 40 lbs each of fluorescein dye (42.5%) mixed with alcohol and water to give a specific gravity of 1.00, by Abbey Color, Inc.

Hydrography

The CTD pumps were not coming on during this cruise. It was decided to remove the ducts between the thermistors and the conductivity cells and the tubes to the pumps to open the cells to the flow, for Cast 3 on. Also, the secondary thermistor was completely exposed to the flow, while the protective duct was left on the primary thermistor for CTD Cast 3. Fig. 3 shows profiles of temperature, salinity and potential density anomaly for this cast. The difference between the two temperatures was so small that the protective duct was put back on the secondary thermistor. The inversions in density and the disagreement between the two salinities were small, suggesting that this method of sampling was adequate for our purposes.

Table 1. Hydrography at 30 m depth

Variable	Units	Cast 3
P	dbar	30.0
S	psu	36.211
T	^{o}C	27.379
σ_θ	kg/m^3	23.558
dS/dz	10^{-3} m^{-1}	-3.13
dT/dz	10^{-2} $^{o}C/m$	3.20
$d\sigma_\theta$ /dz	10^{-2} kg/m^4	1.26
α	10^{-4} $^{o}C^{-1}$	3.16
β	10^{-4} psu^{-1}	7.36
Γ	10^{-4} $^{o}C/m$	2.33
R_ρ		-4.4
N^2	10^{-4} s^{-2}	1.21
N	10^{-2} s^{-1}	1.10
N	cph	6.30

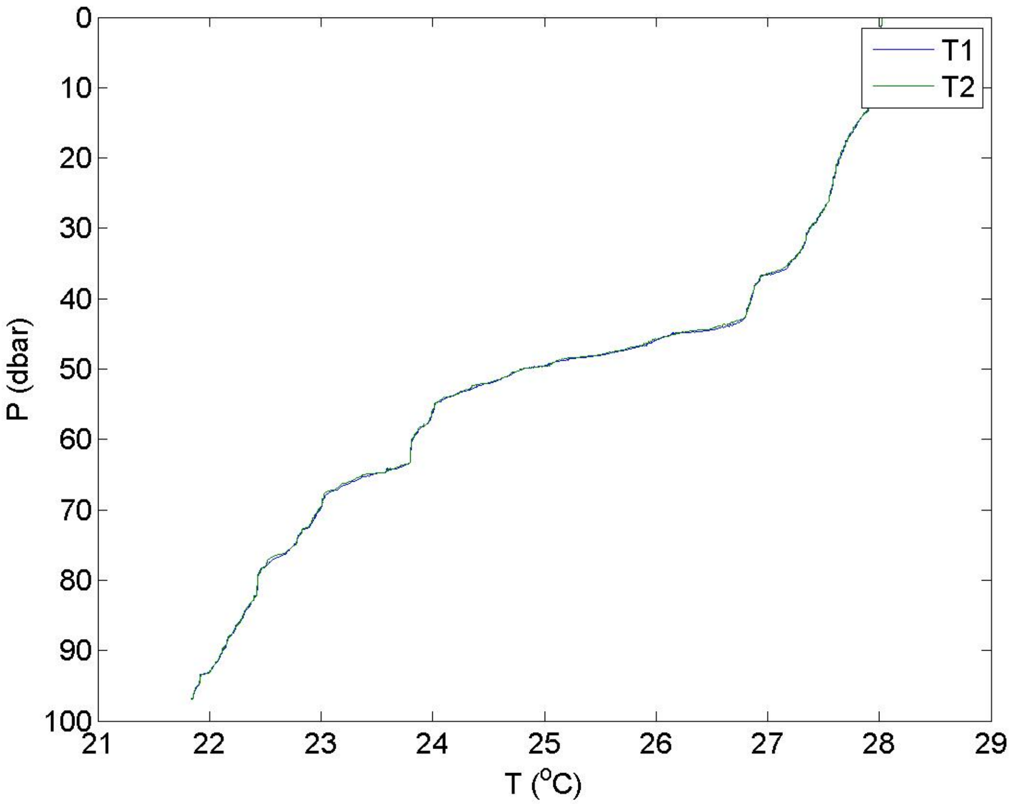


Fig. 3a. Temperature profiles from Cast 3.

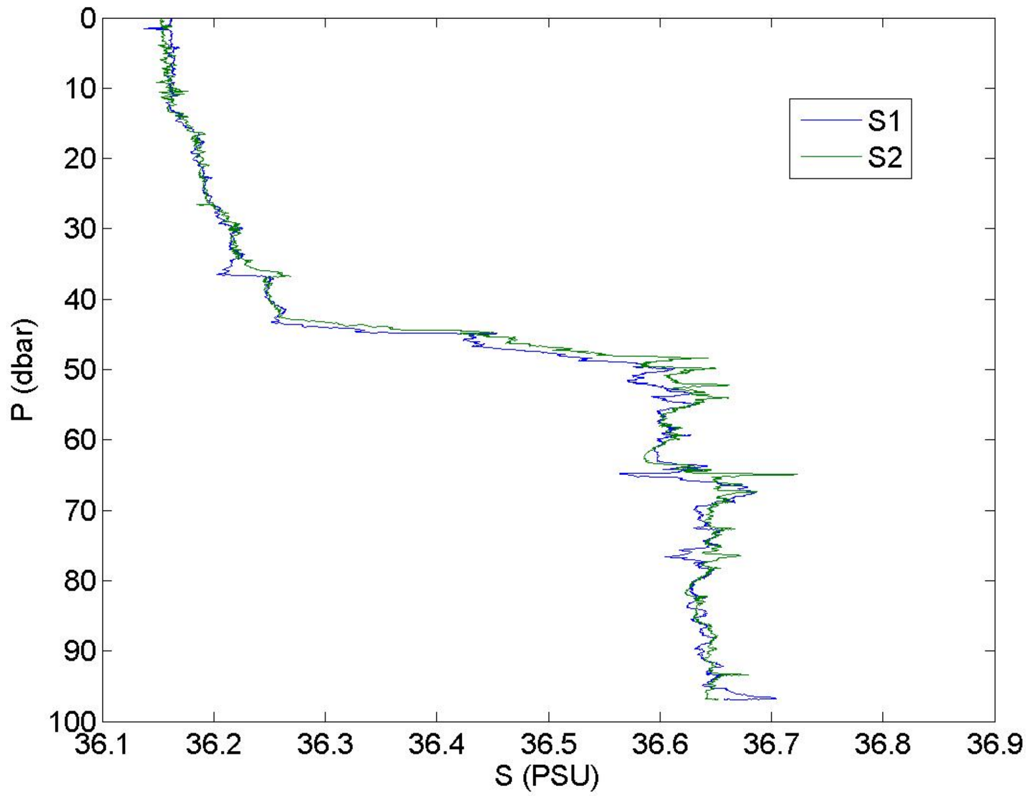


Fig. 3b. Salinity profiles from Cast 3.

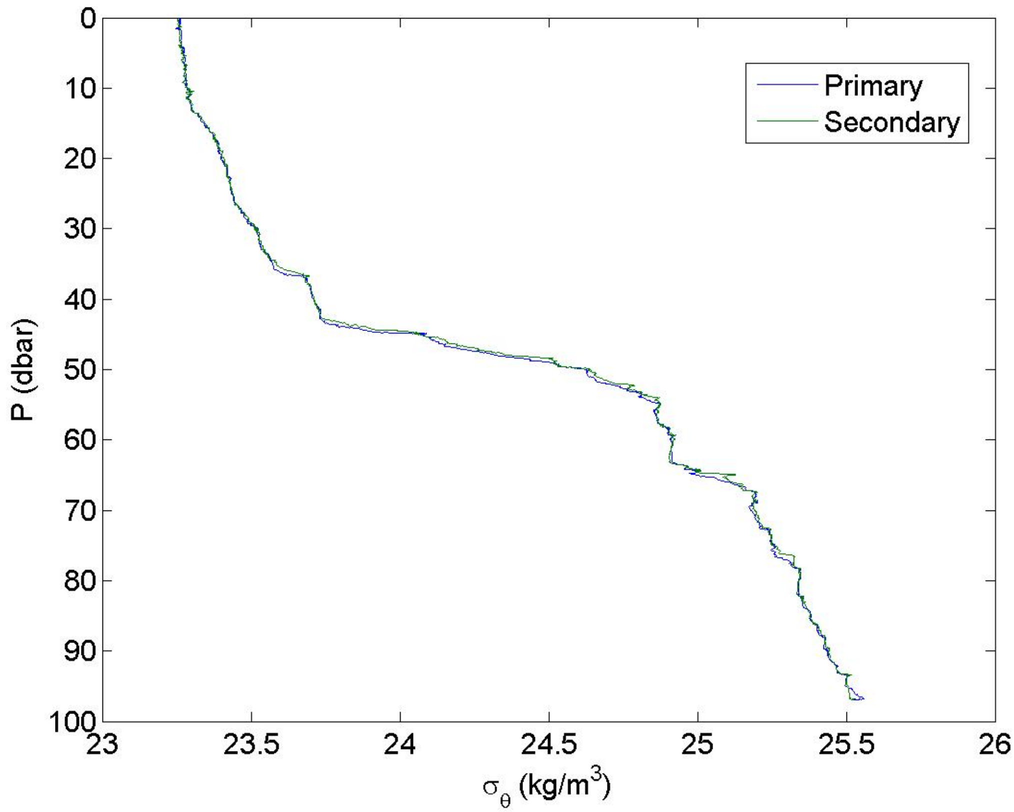


Fig. 3c. Potential density profiles form Cast 3.

Apparent Optical Properties

The Satlantic SPMR Radiation Profiler used was S/N 011, borrowed from Heidi Sosik, and set up with advice from Sam Laney. It measures downwelling irradiance (ED) at 411, 442, 490, 509, 554, 665, and 684 nm, and upwelling radiance (LU) at nominally the same wavelengths. A reference radiometer was mounted on the roof of the winch house on the boat to read the incident downwelling irradiance at the surface (ES). The profiling radiometer was deployed 9 and 10 September a little after noon in partly cloudy conditions.

Table 2. SPMR Profile Data

Parameter	Units	Profile 1	Profile 2
Date		9/9/08	9/10/08
Time (Local)		1230	1230
Drop speed	m/s	0.92	0.70
Starting P*	dbar	4.8	4.8
Maximum P	dbar	76	137

* as read by the instrument - the sensors started at the surface, so there is a pressure offset.

Figure 4 shows the results from Profile 2, take on 9/9/09, in semilog coordinates for the three frequencies of most interest. 442 and 490 bracket the frequency of the LIDAR, which is at 470 nm. 509 nm is near the wavelength of the fluorescein emission of 515 to 520 nm.

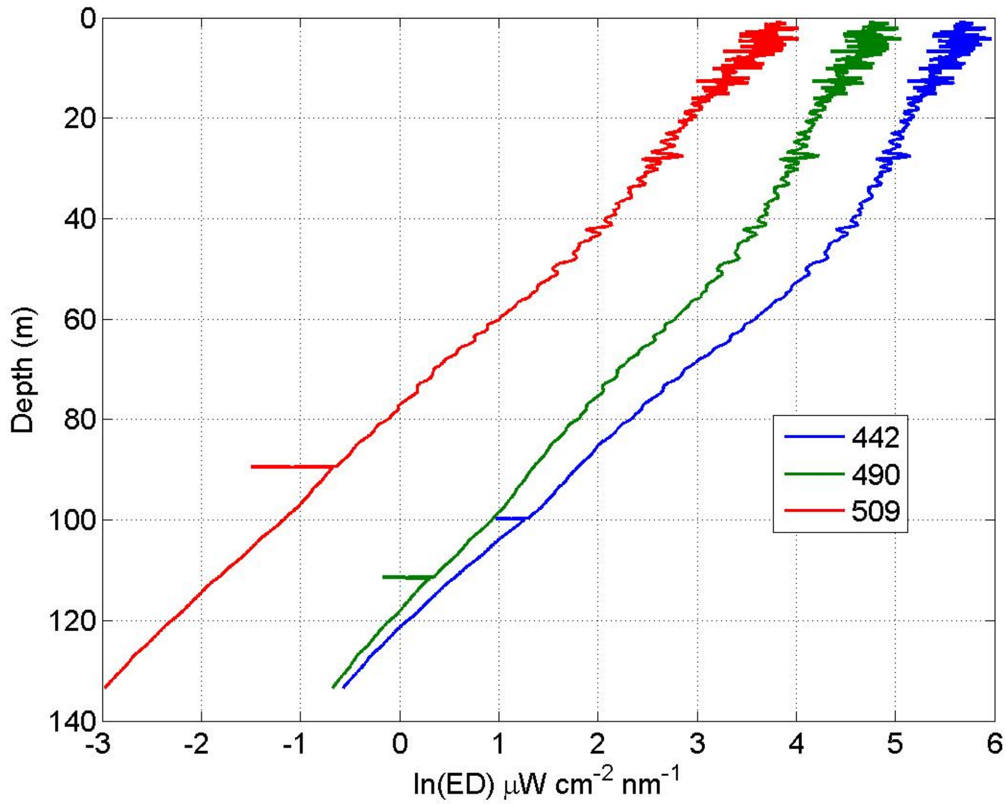


Fig. 4. Downwelling radiation profiles from the SPMR, Profile 2, 9/9/08. The 442 nm profile has been offset by 1 unit to the right; the 509 nm profile one unit to the left for clarity. Optical depths for diffuse radiation can be estimated roughly from the depth over which the natural log of the radiation decreases by 1 unit.

Dye Injection

A 40-lb pail of 42.5% fluorescein dye from Abbey Color, Inc., was mixed with surface seawater in a 55-gallon drum, to bring the level to approximately 185 liters. The specific gravity of the material from Abbey Color was 1.00, so the density of the mixture was close to that of seawater. Approximately 7.5 kg of fluorescein were injected by pumping at a rate F_{inj} of about 2.5 L/min through a garden hose coupled to the CTD cable. The hose was terminated on the CTD cage in a short PVC 'T' with small holes to diffuse the dye before entry into the water.

Prior to the release, four drogues with "Hi Fliers", with radar reflectors and flashing lights were deployed at the corners of a square 600 meters on a side. The drogues were centered at 30 meters depth, the target depth for the dye release. The dye release system was towed at a speed U of about 0.5 m/s in a square about 500 meters on a side within the square defined by the drogues as they drifted with the current. The dye square was completed before the dye was exhausted, and so the eastern side of the box was dyed twice. The plume of the dye could be seen from the deck of the ship, faintly, even at the depth of 30 meters.

The concentration (mixing ratio by weight) of the dye in the drum was about $C_{\text{drum}} = 4\%$. One can expect the thickness H of the plume of the dye left in the wake of the towed system, say 20 minutes after injection ($5/N$) to be around 2 meters and the width W to be about 10 meters (aspect ratio of 5). The concentration in this initial plume would then be:

$$C_{\text{plume}} = C_{\text{drum}}\, F_{\text{inj}}/(UWH)$$

i.e., about 170 ppb (parts per billion by weight).

It seems that in the upper ocean such plumes of dye spread at a rate on the order of 1 cm/s by processes that are not well understood (hence our research interest). So an hour after injection the width of the plume might be on the order of 100 m, giving a further dilution of a factor of 10, to 17 ppb. After about 3 hours, we might expect our square, or an equivalent area with shape transformed by horizontal shear and strain, to be fairly well filled in. If a 500-m square were to be completely filled in, and if the height of the dye layer were increased by vertical mixing to 5 m, then the average concentration in this area would be 6 ppb. Peak concentrations would be several times this value.

The optical thickness of such a patch of dye can be calculated from the absorption coefficient of fluorescein, some pertinent values of which are listed in Table 3.

Table 3. Absorption Coefficient of Fluorescein

Wavelength (nm)	Absorption Coef ($\text{ppb}^{-1}\ \text{m}^{-1}$)
470	0.0314
480	0.0503
490	0.0675

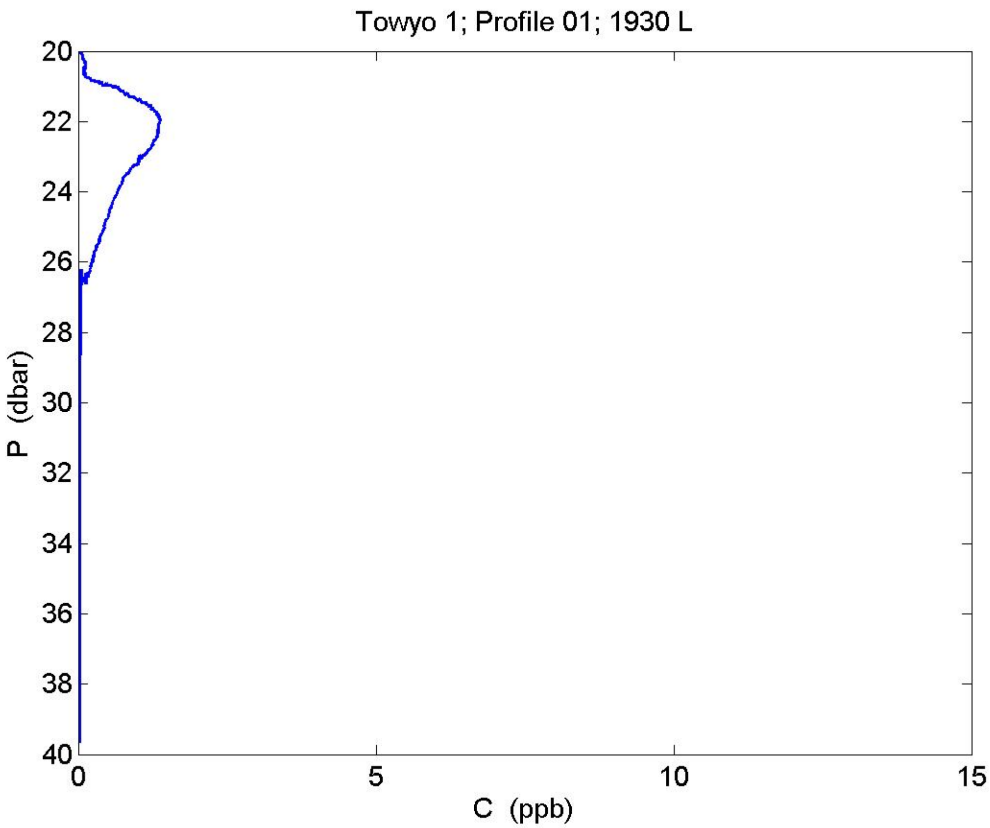
So at 470 nm the optical depth of a 5-m thick layer of dye at average concentration of 6 ppb would be about unity: $(0.0314\ \text{ppb}^{-1}\ \text{m}^{-1})(5\ \text{m})(6\text{ppb}) = 0.94$. This estimate guided the choice of injection parameters. The physical thickness of the patch does not affect this number, only the area occupied by the dye, because the average concentration varies inversely with the thickness.

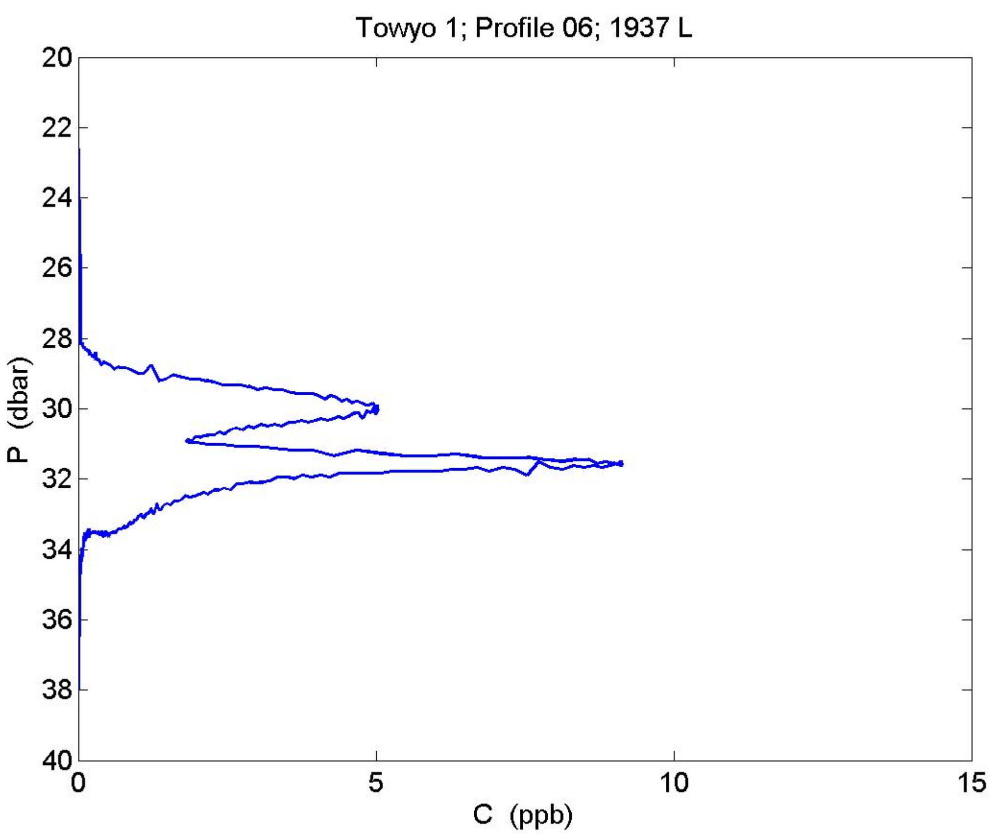
The dye was released between 1740 and 1900 (Local Time). Preflight sampling from the ship occurred from 1915 to 2046, i.e., between 0.25 and 3 hours after injection (see Table 4 for these times). The aircraft was sampling from about 2115 to 2300, i.e., between 3 and 5 hours after injection, roughly, and so we would expect the dye layer to attenuate the direct LIDAR light at 470 nm typically by factor of 1/e.

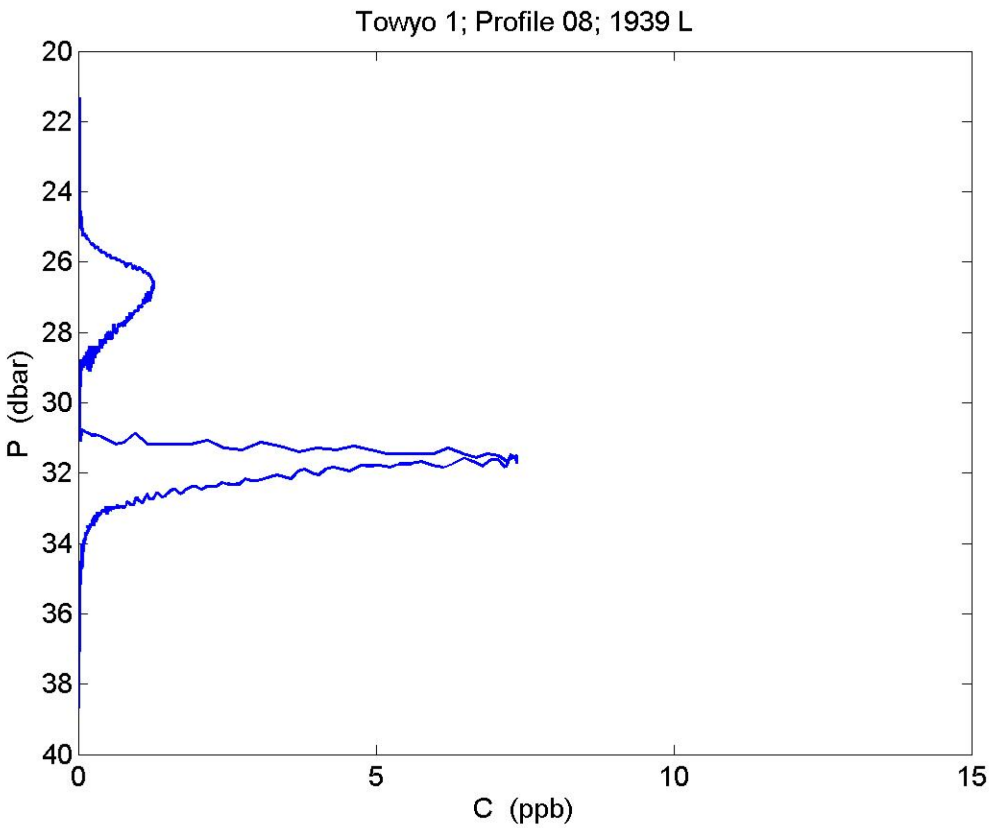
Table 4. Timing of Injection and Sampling of the Dye Patch (Local Time,

Event	Start Time	End time	Middle time	Time since mid-injection (min)
Injection	1742	1900	1821	-39 - 39
Towyo 1	1915	1947	1931	54 - 86
Towyo 2	2022	2046	2034	121 - 145
LIDAR	2115	2300	2208	174 - 219
Towyo 3	0004	0145	0058	339 - 456

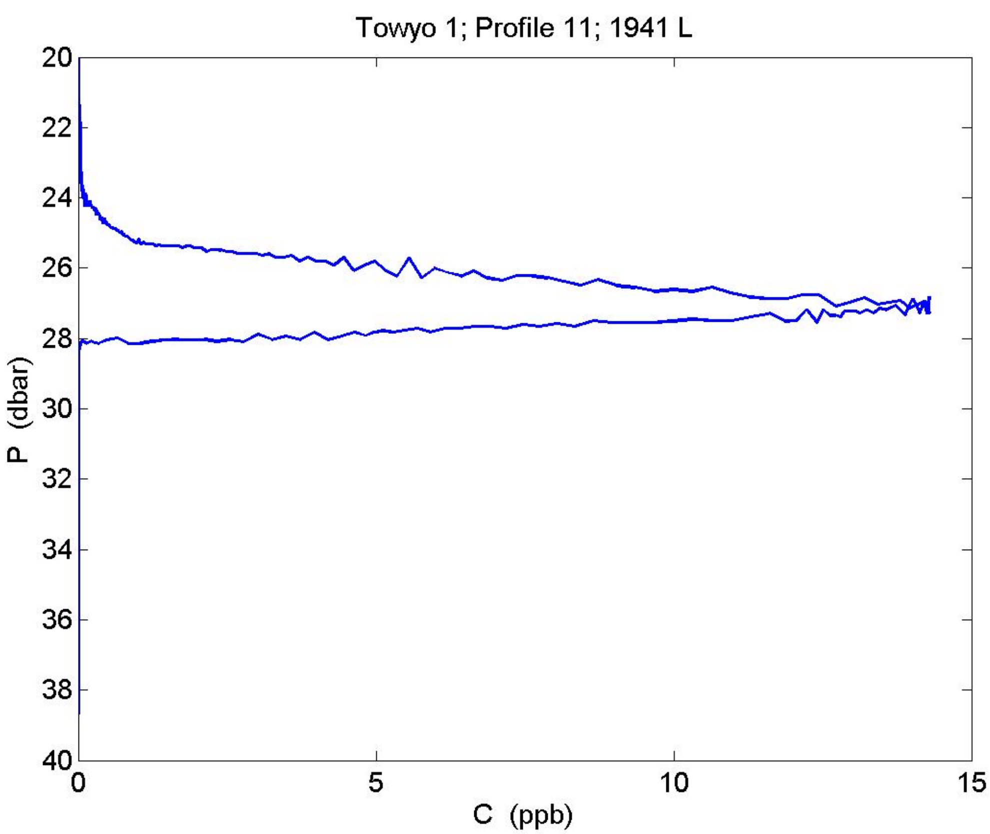
Representative examples of profiles obtained during the towyos are shown in the following figures. The time given in the title is the local time. Note the change of ranges of the axes from one towyo to the next. Note the variation in shapes, widths and amplitudes of the profiles. Also note that none of these profiles are as rich in dye as expected of the average from the considerations above at the time they were obtained. Hence, we most likely never samples the core of the patch, but were always around the edges, especially during towyo 3 for which the dye concentrations are 10 times less than expected of the average within the patch.


Towyo 1; Profile 01; 1930 L
P (dbar)
C (ppb)
20
22
24
26
28
30
32
34
36
38
40
0
5
10
15

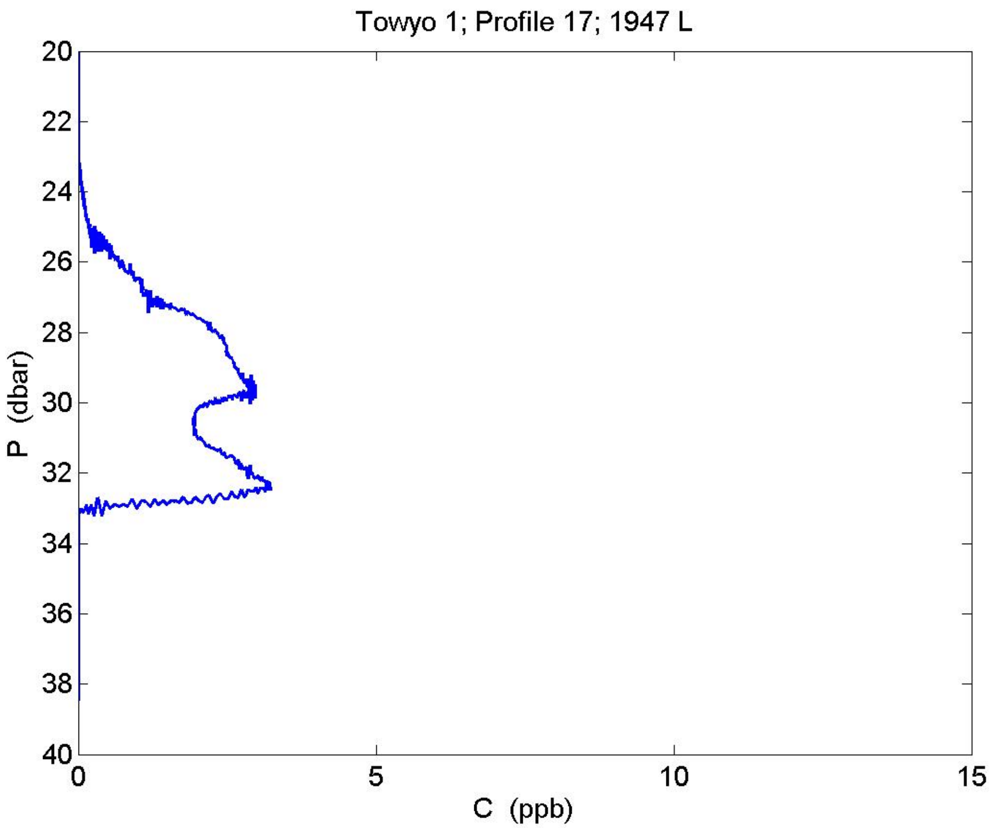

Towyo 1; Profile 06; 1937 L
P (dbar)
C (ppb)
20
22
24
26
28
30
32
34
36
38
40
0
5
10
15



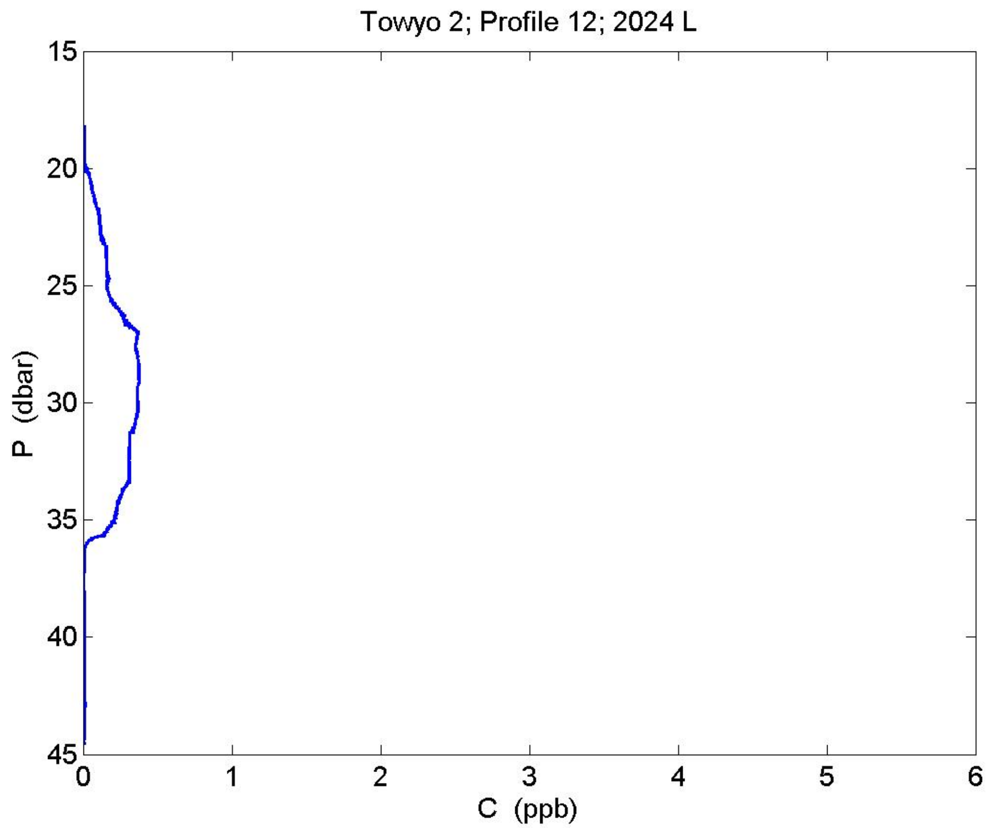
Towyo 1; Profile 08; 1939 L
P (dbar)
C (ppb)
20
22
24
26
28
30
32
34
36
38
40
0
5
10
15



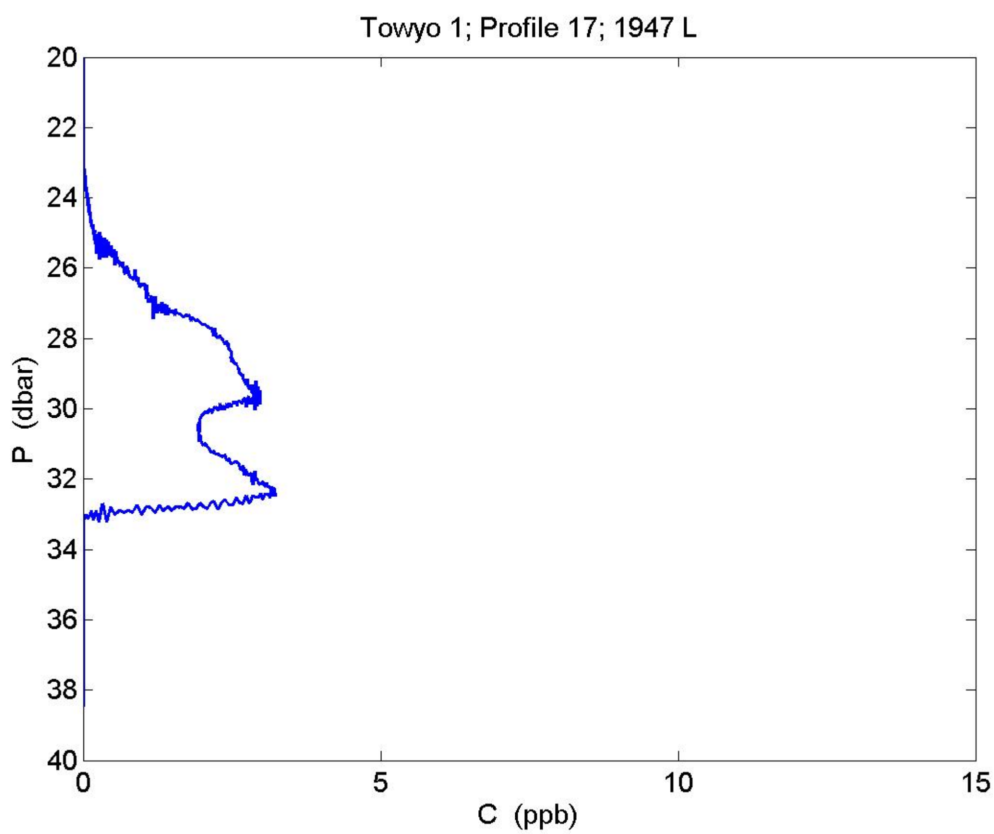
Towyo 1; Profile 11; 1941 L
P (dbar)
C (ppb)
20
22
24
26
28
30
32
34
36
38
40
0
5
10
15



Towyo 1; Profile 17; 1947 L
P (dbar)
C (ppb)
20
22
24
26
28
30
32
34
36
38
40
0
5
10
15

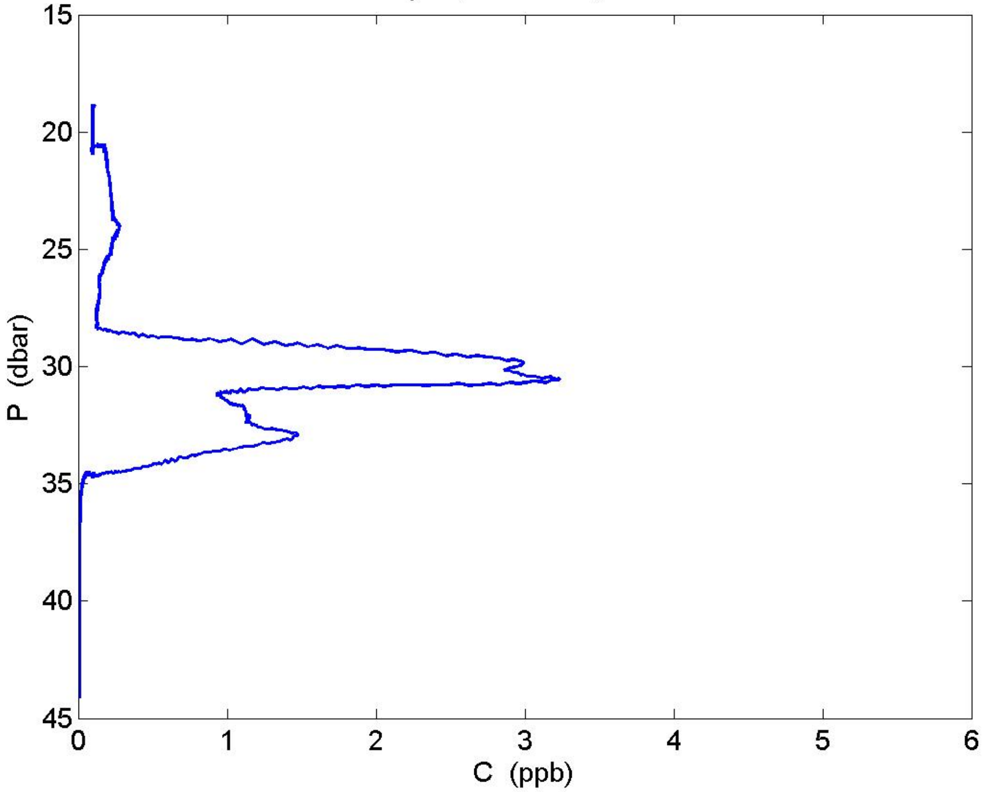


Towyo 2; Profile 12; 2024 L
P (dbar)
15
20
25
30
35
40
45
0
1
2
3
4
5
6
C (ppb)

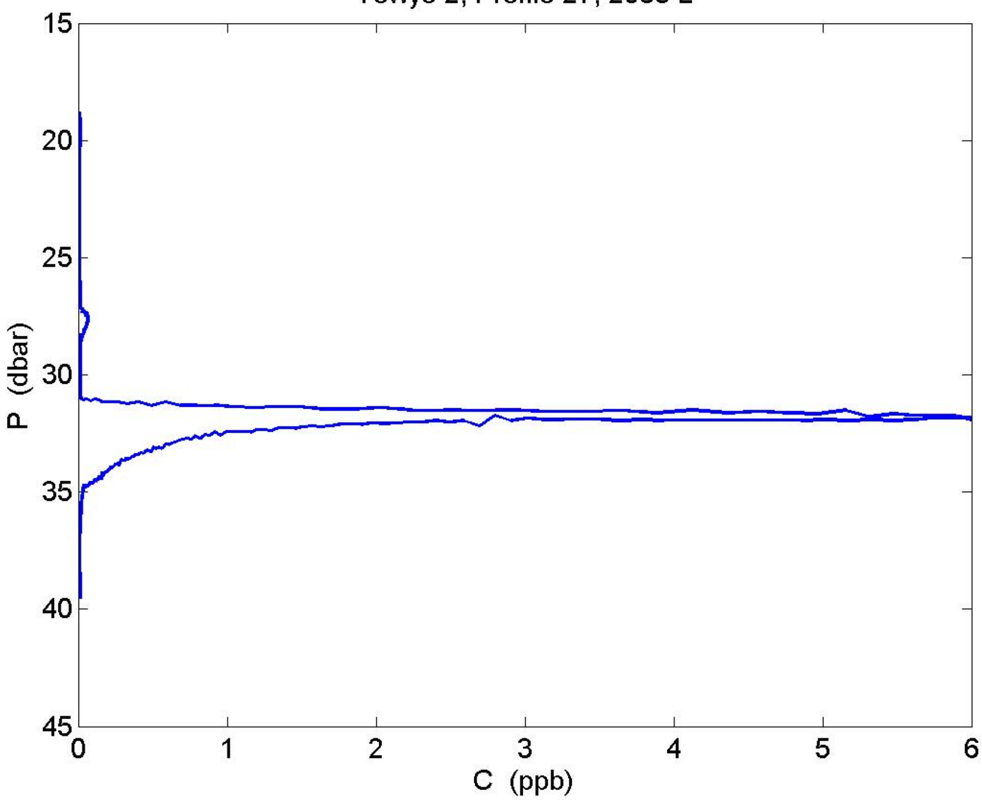


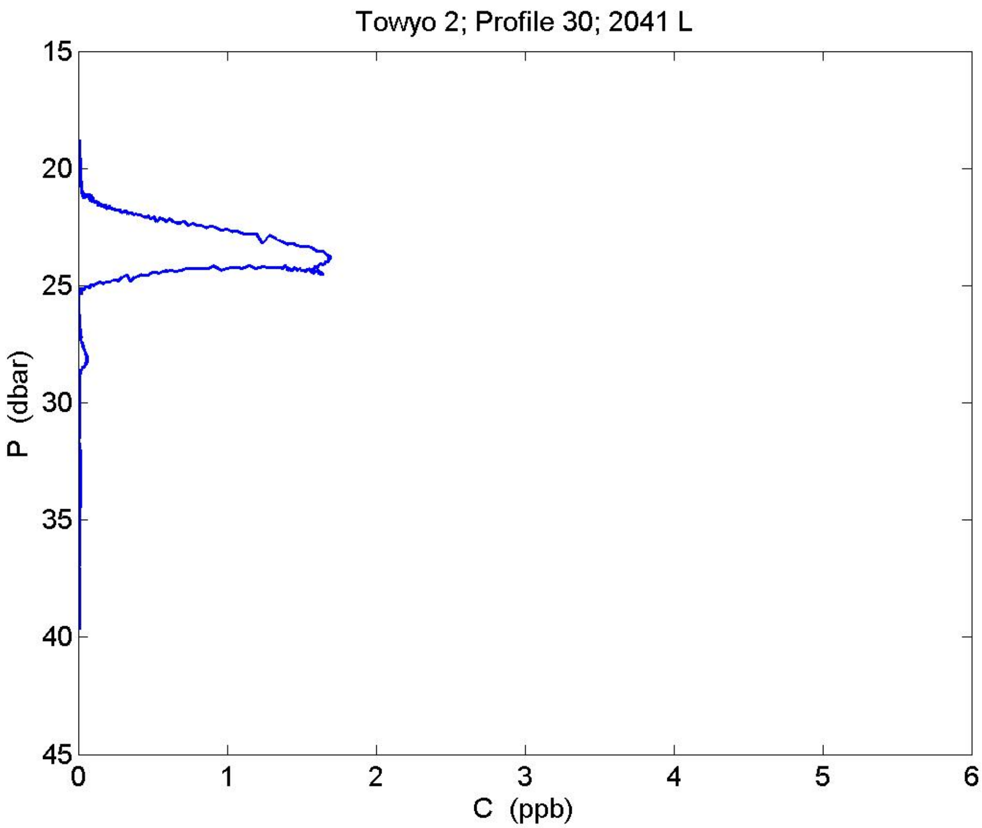
Towyo 1; Profile 17; 1947 L
P (dbar)
20
22
24
26
28
30
32
34
36
38
40
0
5
10
15
C (ppb)

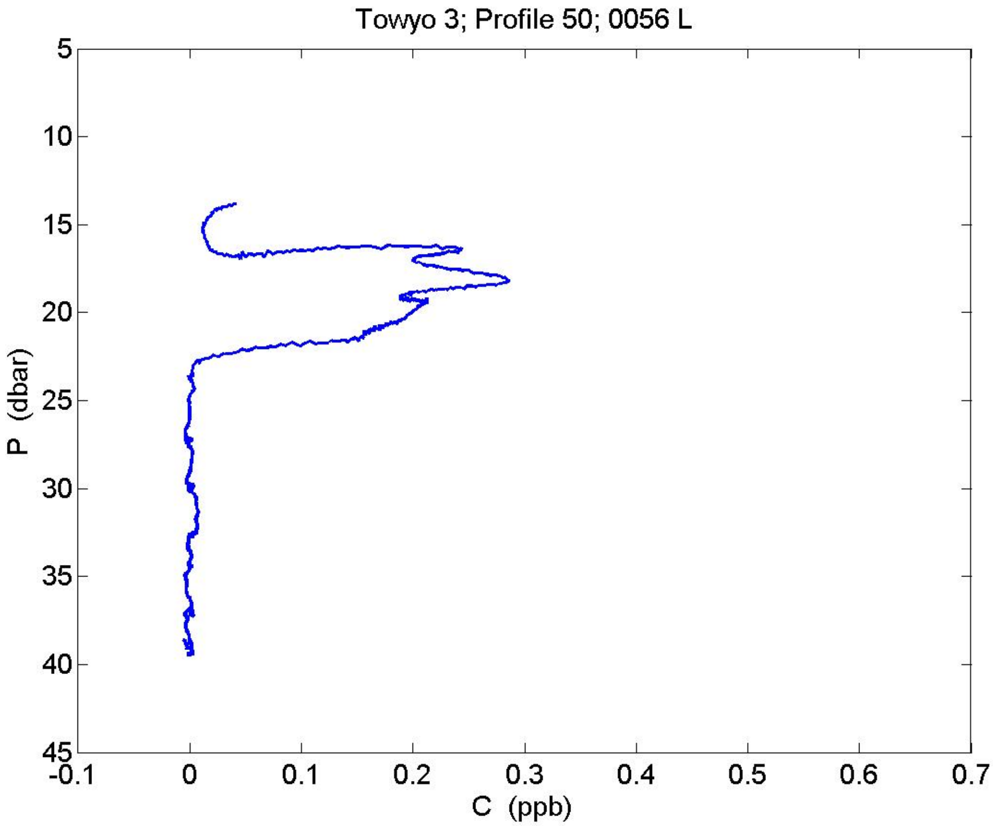
Towyo 2; Profile 19; 2031 L



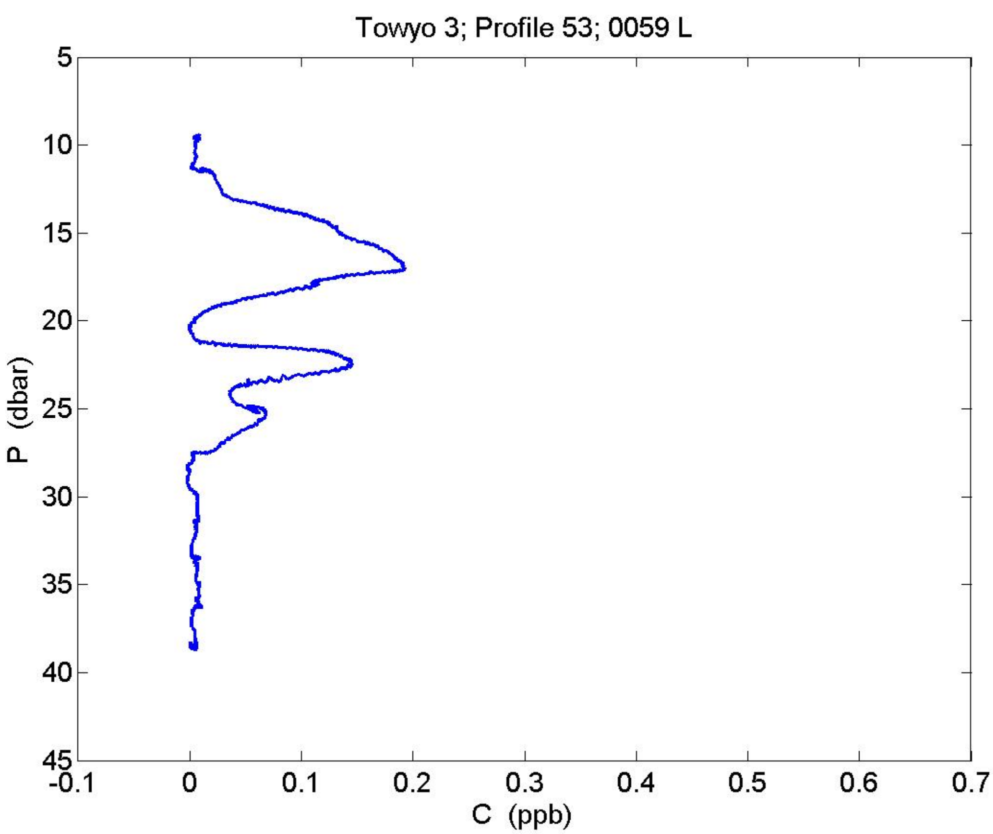
Towyo 2; Profile 27; 2038 L



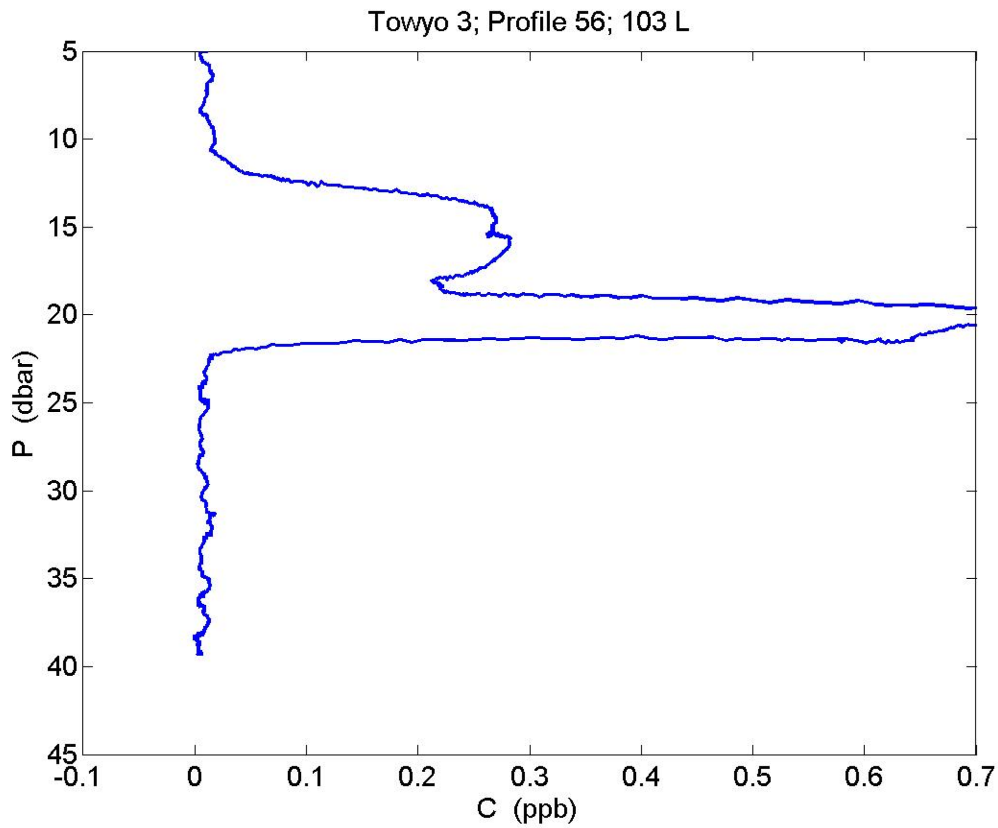

Towyo 2; Profile 30; 2041 L
15
20
25
30
35
40
45
P (dbar)
0
1
2
3
4
5
6
C (ppb)

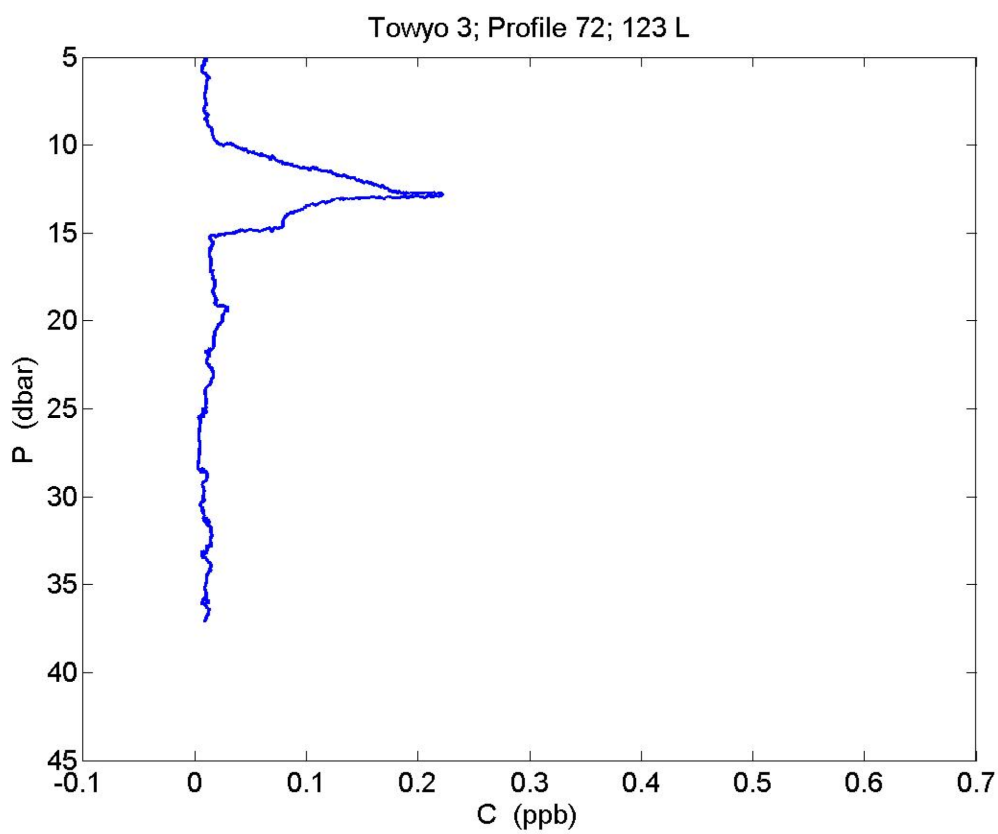


Towyo 3; Profile 50; 0056 L
P (dbar)
C (ppb)
5
10
15
20
25
30
35
40
45
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7



Towyo 3; Profile 53; 0059 L
P (dbar)
C (ppb)
5
10
15
20
25
30
35
40
45
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7


Towyo 3; Profile 56; 103 L
P (dbar)
C (ppb)
5
10
15
20
25
30
35
40
45
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7


Towyo 3; Profile 72; 123 L
P (dbar)
C (ppb)
5
10
15
20
25
30
35
40
45
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7