CRUISE REPORT

EXPORT PATHWAYS FROM THE SUBPOLAR NORTH ATLANTIC OCEAN

R/V *Oceanus* Cruise OC 395-2

July 9-23, 2003

1. Introduction and Objectives

The importance of the pathways of the ocean's meridional overturning circulation has become increasingly apparent as the ocean's role in the global climate has been elucidated. As the strength of high latitude ocean convection changes in response to interannual and interdecadal climate variability, or in response to a long-term global warming trend, our understanding of how the ocean will respond depends on our knowledge of how and how quickly newly-ventilated waters spread from the subpolar North Atlantic to the subtropics and beyond. The conventional view, shaped mainly by tracer and hydrographic studies, is that the Deep Western Boundary Current (DWBC), which flows equatorward long the western boundary of the North Atlantic, is a direct and relatively rapid route for recently convected waters to reach subtropical and tropical latitudes. Trajectories of profiling floats recently deployed at mid-depth in the Labrador Sea seem to contradict this paradigm: All of the profiling floats that drifted southward along the western boundary of the Labrador Sea turned eastward along the subpolar-subtropical gyre boundary in the vicinity of Flemish Cap, rather than continuing southward along the DWBC path. As part of this project, we will collect new field observations and conduct hydrographic data analyses aimed at resolving this apparent contradiction. We hypothesize that the contradiction arises due to the profiling float sampling scheme (e.g., periodic surfacing in a narrow boundary current regime) and/or temporal variability or intermittency in the LSW export pathways. To test these ideas, we will sequentially release acoustically-tracked RAFOS floats at the LSW level in the DWBC along the western boundary of the Labrador Sea on a seasonal basis for three years, and track them as they transit through the junction in pathways near Flemish Cap. Analysis of the new float observations, in conjunction with satellite altimetry and historical and contemporaneous hydrographic data, will result in an improved description of the pathways of waters exiting the subpolar region, their temporal variability and the dynamics that affect them. Such an understanding is crucial since the extent to which the deep ocean is ventilated, and the time scale of that ventilation, determine the effectiveness of the ocean as a climate reservoir. The purpose of the cruise described below was to a) deploy the sound source moorings that will be used for tracking the RAFOS floats over the next five years, b) occupy a high-resolution CTD section across the DWBC near 50°N, and c) release the first set of six RAFOS floats in the DWBC.

2. Cruise Dates and Personnel

R/V *Oceanus* OC 395-2

The cruise was carried out aboard the R/V *Oceanus* from July 9-23, 2003. The cruise originated from and ended in St. John's, Newfoundland. The cruise track is shown in Figure 1.

Cruise Participants:

1.	Amy Bower	WHOI	Chief Scientist
2.	Susan Lozier	Duke University	Scientist
3.	Paula Perez-Brunius	WHOI	Research Associate
4.	Rochelle Reardon	WHOI	Technician
5.	Brian Guest	WHOI	Technician
6.	Brian Hogue	WHOI	Technician
7.	Jaime Palter	Duke University	Graduate Student
8.	Ana Rappold	Duke University	Graduate Student

3. Scientific Activities

3.1 CTD Stations

A total of 28 hydrographic (CTD; conductivity / temperature / depth) stations were occupied on the cruise. Appendix 1 contains the station locations, times and depths, and the stations are plotted in Figure 2. At each station, profiles of temperature and salinity (conductivity) were collected to within 10 m of the sea floor, which ranged in depth from 500-4300 m, using a Sea-Bird SBE-911+ CTD system. Water samples for calibration of the salinity profiles were collected at all of the stations.

3.2 Mooring Deployments

Four RAFOS float sound source moorings were deployed during the cruise at the locations indicated in Table 1 (see also Figure 1). These sources are used to track the locations of the RAFOS floats as they drift through the area.

Table 1: Sound Source Moorings

Station	Sound Source	Launch Date	Time (GMT)	Latitude N Deg	min	Longitude Deg	min	Water Depth (m)	Activation Date Time (GMT)	Pong Time (GMT)
A	69	18-July-2003	0321	56	45.53	48	1.03	3631	15-July-2003 1340	0130
B	77	16-July-2003	1201	53	29.74	37	0.2	2880	13-July-2003 1545	0100
C	49	14-July-2003	1040	45	0.57	35	59.50	4233	12-July-2003 1250	0300
D	16	12-July-2003	1104	37	59.95	41	59.34	4645	10-July-2003 1100	0200

A new system was used to monitor the operation of the sound sources immediately after deployment. Subsurface hydrophones (sonobuoys) were deployed at various distances from the sound sources, and the signal received was analyzed on a PC using several MATLAB routines. Two of the sound sources were positively identified as operational using this technique (B and C), while A was possibly heard. Sound source D was never heard, but this could be due to a combination of our distance away from the source and low source power during the 15-day ramp-up time. Table 2 contains the results of the sonobuoy tests.

Table 2: Sonobuoy Test Results

Date (mmddyy)	Position (lat/lon)	SS	Dist. (km)	ETOA (GMT)	Power Level	Signal?	Comments
071303	39 49.1N 40 31.4W	D	239	02:02:39	20%	No	Mic and rec at 1/2
071403	43 51.1N 37 01.4W	D	773	02:08:35	27%	No	Mic 80%, Rec 25%
071503	48 0.1N 36 20.0W	C	330	03:03:42	100%	Yes	same
071603	52 14.1N 36 50.3W	D	1633	02:18:08	40%	No	same
071603	52 22.0N 36 51.3W	C	821	03:09:07	100%	Yes	Mic 80&; Rec 20% Not as far from hydro.
071703	54 33.5N 40 29.4W	B	256	01:02:51	27%	Yes	
071703	54 39.8N 40 50.0W	D	1854	02:20:36	47%	No	
071703	54 43.1N 41 01.1W	C	1138	03:12:38	100%	Yes	
071803	56 47.0N 47 58.0W	B	786	01:08:44	33%	No	

071903	53 34.1N 47 22.6W	A G	353 191	01:33:56 01:32:08	27% 100%	No Yes	Heard German source K37, ~100 s earlier than A
072003	50 56.8N 45 50.7W	A	660	01:37:20	33%	No	On CTD station; hydrophone close to ship
072103	50 33.3N 47 14.8W	A	690	01:37:40	40%	Yes (barely)	Hardly visible above the noise.

3.3 RAFOS Float Deployments

Six acoustically tracked subsurface RAFOS floats were deployed at the locations listed in Table 3. The RAFOS floats were ballasted to drift at nominal depths of 700 and 1500 m, which correspond to different components of Labrador Sea Water. The floats were programmed to drift for a period of two years and then surface to relay their data by satellite.

Table 3: RAFOS Float Launch Information

Float No.	Launch Position	Launch Time (GMT)	Ballast Depth (dbar)	CTD Station
437	50 19.81N 47 55.65W	1230	1500	14
436	50 09.21N 48 26.91W	2127	1500	18
434	50 09.21N 48 26.91W	2127	700	18
435	50 00.58N 48 58.47W	0541	1500	22
433	50 00.55N 48 58.48W	0541	700	22
432	49 50.14N 49 30.47W	1247	700	26

3.4 Underway Measurements

Meteorological Data

Meteorological measurements were continuously recorded by sensors aboard the R/V *Oceanus*, including wind speed and direction, barometric pressure and relative humidity.

Thermosalinograph

Values of surface temperature and salinity were continuously measured and logged on the ship's computer using a Sea-Bird temperature-conductivity recorder installed in the ship's seawater intake line.

Shipboard Acoustic Doppler Current Profiler

Upper ocean currents were continuously measured with a 150 kHz narrow-band Acoustic Doppler Current Profiler mounted in the ship's transducer well. The depth range of good velocity data typically extended to 200-400 m below the vessel, depending on sea state conditions. An example of the data is shown in Fig. 3.

4. Highlights of Preliminary Scientific Findings

Though the RAFOS floats will not surface until the summer of 2005, we have been able to make a preliminary assessment of the CTD and ADCP data collected during the cruise. The Acoustic Doppler Current Profiler data, collected along the entire cruise track, reveals rich structure in the upper ocean velocity field (Figure 3). This is particularly so to the east of the Tail of the Grand Banks, where we crossed the North Atlantic Current. A signature of the Mann Eddy is revealed in the velocity data, as well as a branch of the current that may be associated with the Azores Current. Relatively weak currents were observed in the interior of the Labrador Sea, yet we were able to discern a sizeable southward Labrador Current as we crossed the continental slope. Our CTD transect, from the offshore side of Orphan Knoll to the 600 m isobath on the continental slope, revealed three strong salinity and temperature fronts in the upper ocean, Figure 4a. Additionally, the deep measurements have detailed the hydrographic signature of the deep overflow waters on the offshore side of Orphan Knoll, with isopycnals banked up against the slope, Figure 4b. Our early analysis of the CTD data suggests that the floats, at 700 m and 1500m, were indeed placed in a southward-flowing boundary current.

5. Release of Project Data

In accordance with the provisions specified in the cruise prospectus and application for foreign clearances, the full data results from this experiment will be provided to all clearance countries according to the following schedule:

Hydrographic Station Data, Mooring Data, and Underway Shipboard Measurements

All shipboard measurements, including underway data records and hydrographic station data, will be provided within 12 months of the termination of the cruise (July 23, 2004).

Subsurface Floats

Time series data and trajectories from the subsurface RAFOS floats will be provided within 18 months from the time when the last floats surface and complete their data transmissions. This is expected to occur in July 2005. Therefore we anticipate delivery of the final float data by January 2007.

6. Acknowledgements

The support and able assistance provided by the Captain and crew of the R/V *Oceanus* is gratefully acknowledged. Financial support for this research was provided by the U.S. National Science Foundation under grants to the Woods Hole Oceanographic Institution and to Duke University. We wish to thank the government of Canada for their cooperation on this project and for granting permission to carry out research in their Exclusive Economic Zone.

Appendix 1

CTD STATIONS OC395-2

Station	Month	Day	Year	Time(gmt)	Latitude	N/S	Longitude	E/W	Maxdb	#btls
001	Jul	19	2003	18:57:24	51.032000	N	45.649833	W	4318.0	12
002	Jul	19	2003	23:05:59	50.964167	N	45.864333	W	4309.0	12
003	Jul	20	2003	02:26:04	50.944000	N	45.961333	W	4299.0	18
004	Jul	20	2003	05:51:32	50.921833	N	46.054500	W	2836.0	15
005	Jul	20	2003	08:46:51	50.901000	N	46.145833	W	2624.0	14
006	Jul	20	2003	11:16:39	50.858500	N	46.283833	W	2958.0	14
007	Jul	20	2003	13:56:04	50.817167	N	46.416333	W	2917.0	14
008	Jul	20	2003	16:48:32	50.732333	N	46.657000	W	2156.0	14
009	Jul	20	2003	19:26:12	50.645667	N	46.899000	W	2925.0	14
010	Jul	20	2003	22:48:28	50.568667	N	47.158500	W	3050.0	14
011	Jul	21	2003	02:26:15	50.489667	N	47.421167	W	2960.0	14
012	Jul	21	2003	05:21:34	50.408833	N	47.684333	W	2868.0	14
013	Jul	21	2003	08:05:48	50.369833	N	47.814167	W	2821.0	14
014	Jul	21	2003	10:40:44	50.331167	N	47.945167	W	2789.0	14
015	Jul	21	2003	13:13:37	50.288500	N	48.075500	W	2755.0	14
016	Jul	21	2003	15:34:00	50.247667	N	48.207833	W	2687.0	14
017	Jul	21	2003	17:45:51	50.207167	N	48.338667	W	2627.0	14
018	Jul	21	2003	20:00:23	50.164667	N	48.469333	W	2508.0	14
019	Jul	21	2003	22:10:55	50.123667	N	48.602500	W	2320.0	14
020	Jul	22	2003	00:13:01	50.083167	N	48.735167	W	2193.0	12
021	Jul	22	2003	02:17:31	50.041333	N	48.868167	W	2066.0	12
022	Jul	22	2003	04:15:07	49.999333	N	49.000333	W	1919.0	11
023	Jul	22	2003	06:34:49	49.961500	N	49.122167	W	1784.0	10
024	Jul	22	2003	08:25:20	49.922167	N	49.248167	W	1678.0	9
025	Jul	22	2003	10:08:16	49.884167	N	49.373667	W	1540.0	9
026	Jul	22	2003	11:49:48	49.848000	N	49.501167	W	1397.0	9
027	Jul	22	2003	13:35:25	49.806500	N	49.631000	W	1206.0	8
028	Jul	22	2003	15:05:19	49.779500	N	49.711333	W	1089.0	8
029	Jul	22	2003	17:20:14	49.680667	N	50.017500	W	618.0	8
100	Jul	18	2003	11:33:46	55.494333	N	47.747667	W	107.0	22
101	Jul	18	2003	12:38:01	55.477333	N	47.728333	W	106.0	1
102	Jul	18	2003	13:09:33	55.470667	N	47.716333	W	523.0	22

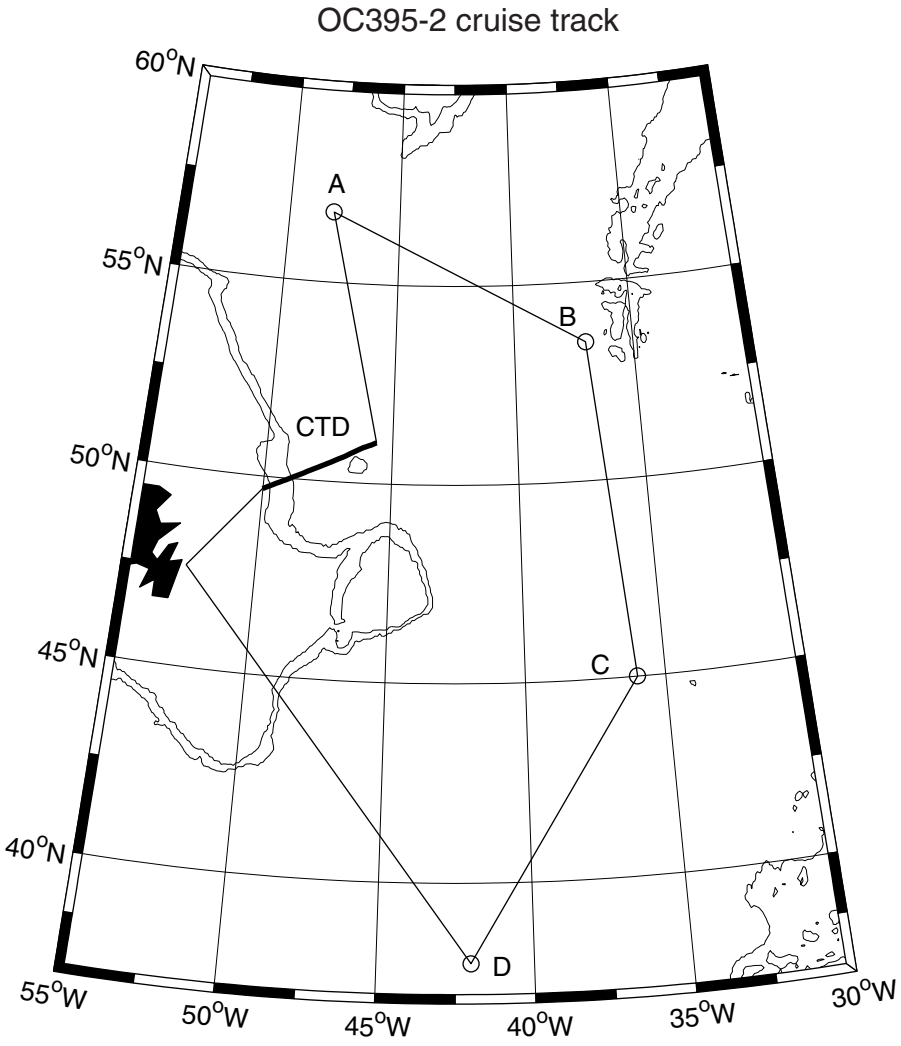

Figure 1. Cruise track. Circles denote final position of sound source moorings. Bold line represents the CTD transect.

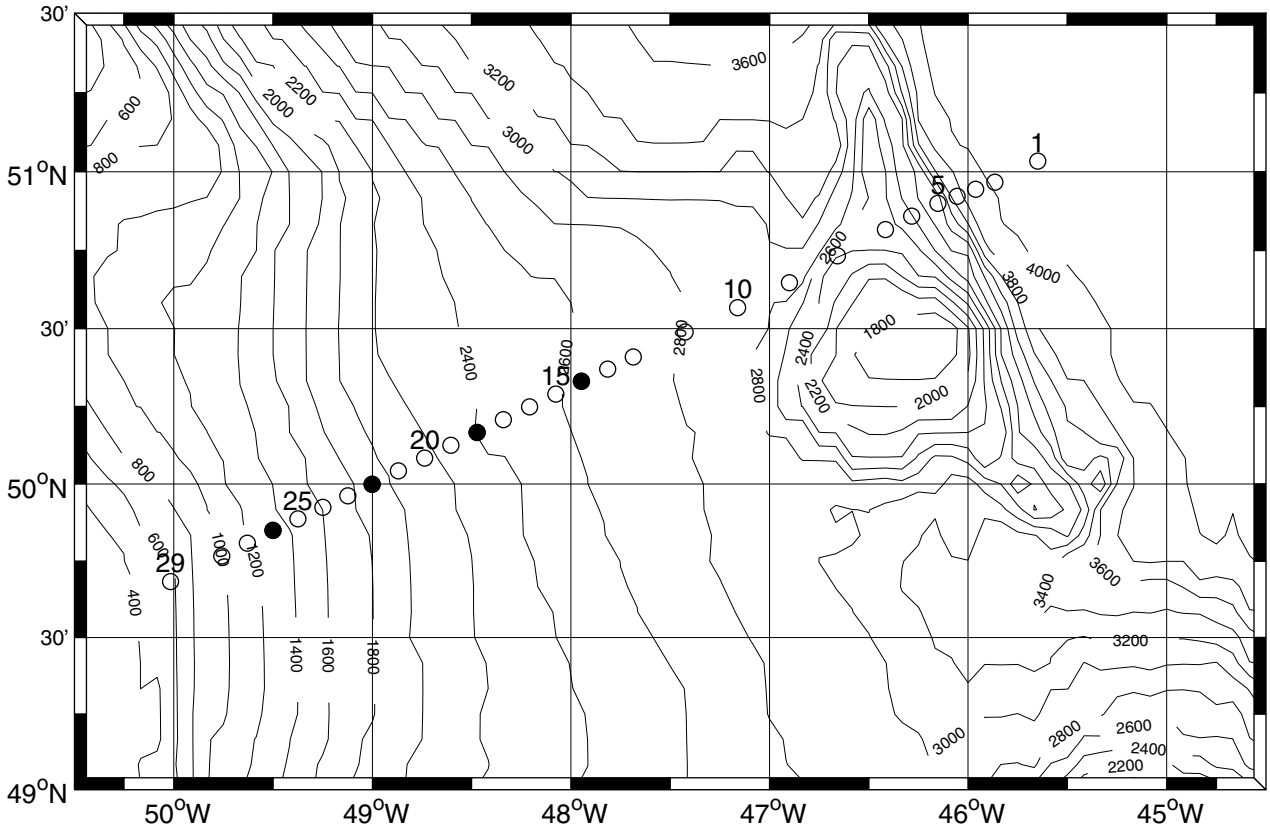

Figure 2. CTD section. Circles represent CTD stations. Filled circles show stations where floats were deloyed.

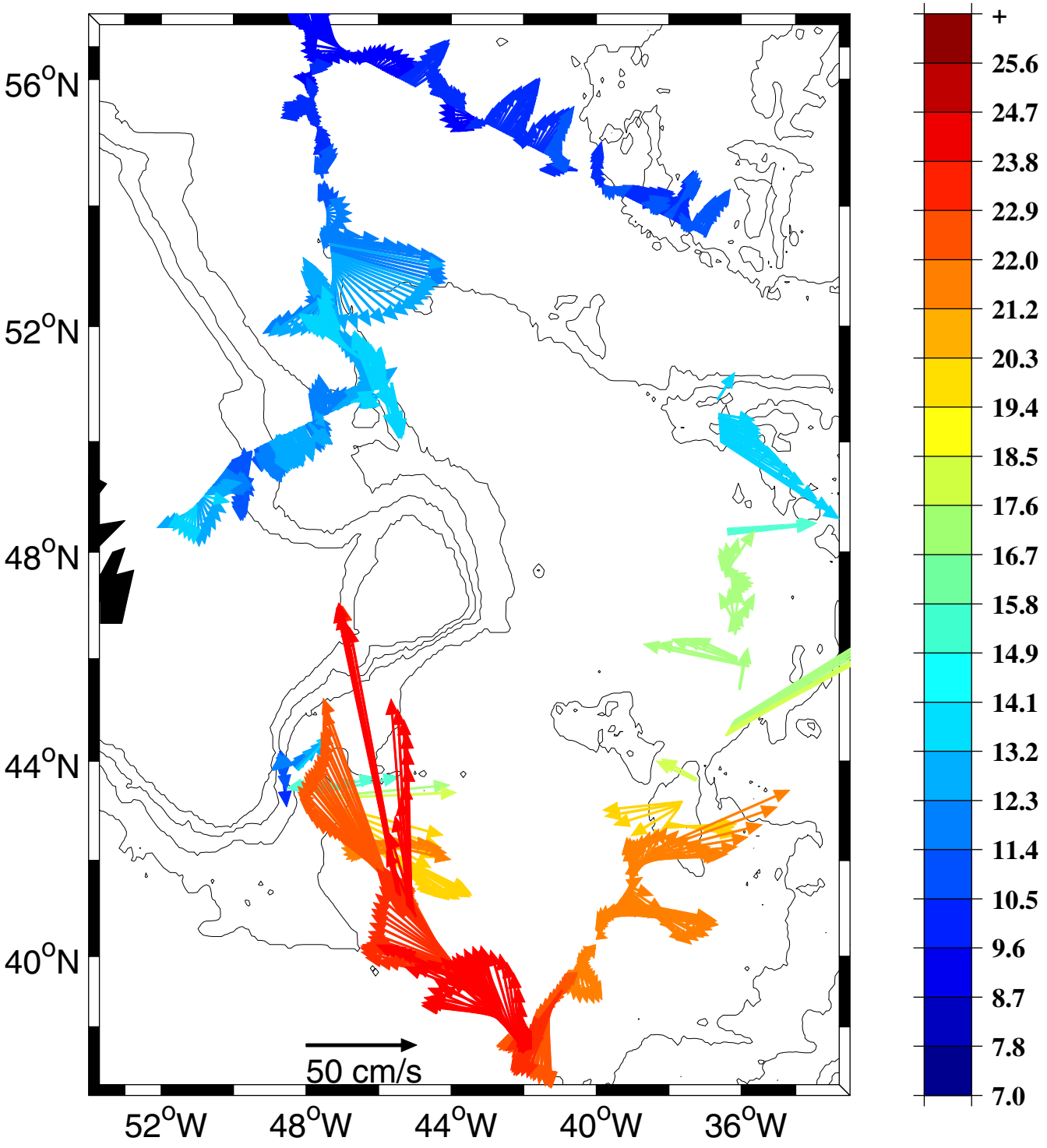

Figure 3. ADCP velocity at 60m, color coded by surface temperature.

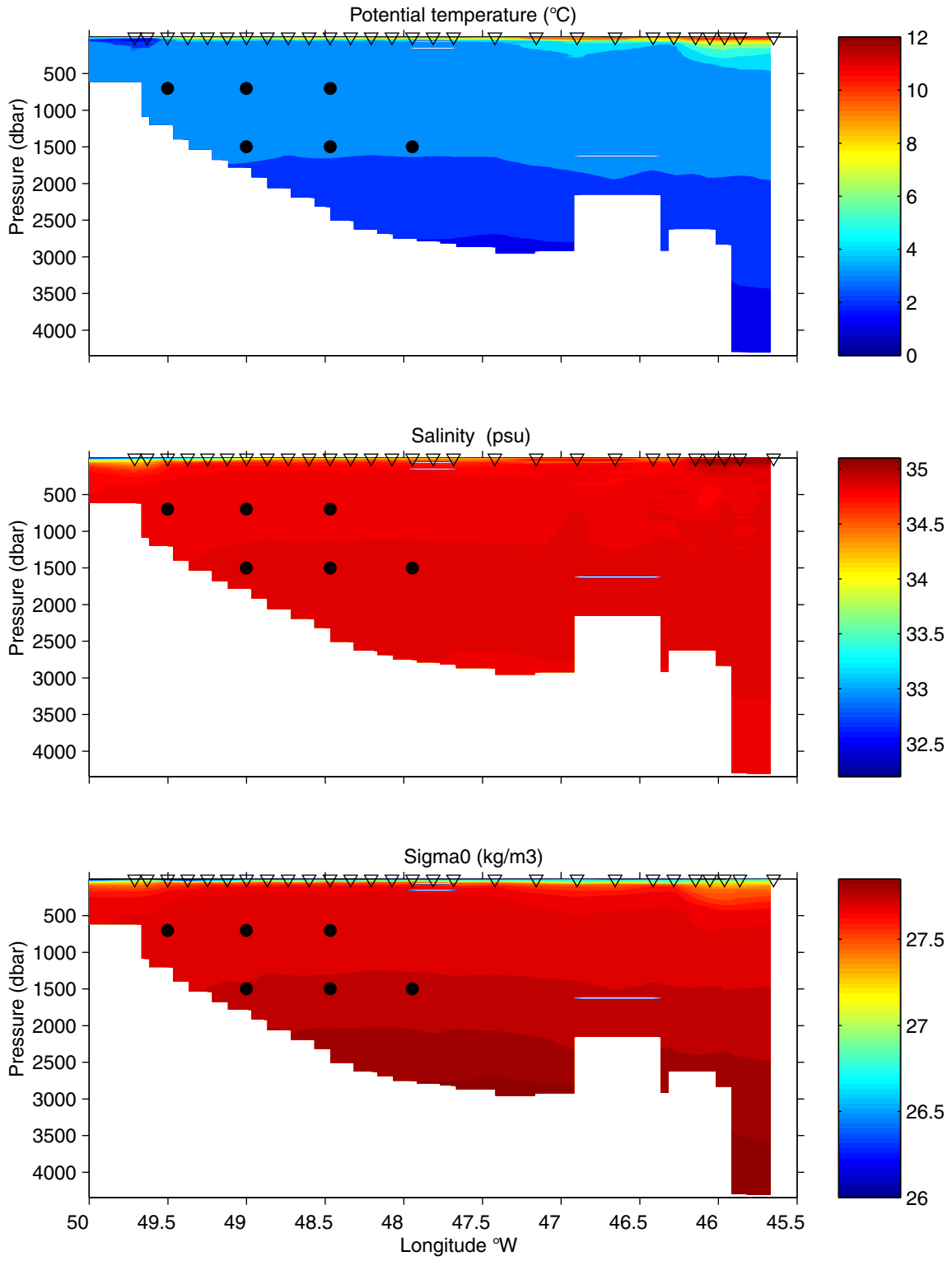

Figure 4a. CTD section along the Bonavista line (Figure 2). Inverted triangles show the position of the CTD casts. The black dots indicate the target depth and release sites of the RAFOS floats deployed during the cruise. Orphan Knoll is located between 47° and 46° W .

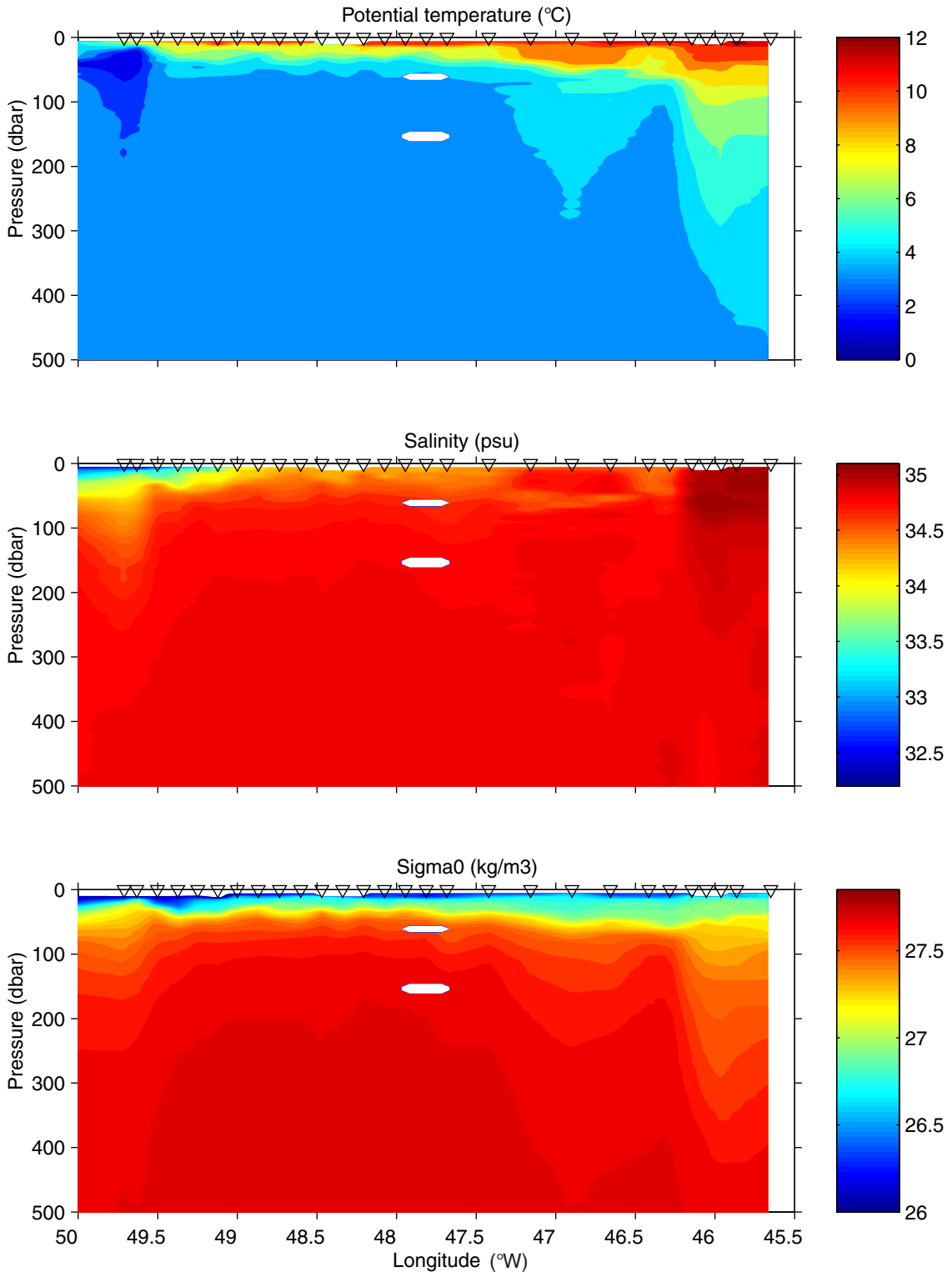

Figure 4b. Same as Figure 4a, but only showing the top 500 dbars.