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Oceanographic Conditions of Georges Bank Spawning Grounds, 1992-1994

by

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Abstract

Oceanographic surveys were conducted on the southern flank of Georges Bank in the month of May for three consecutive years (1992, 1993, and 1994) to investigate the physical environment of recently hatched cod and haddock larvae. Observations including a) anomalous wind events, b) advective water mass intrusions, c) highly resolved tidal fronts, and d) small-scale patchiness of acoustic backscatter and fluorescence are discussed. Attempts to follow larval patches around the tidal ellipse and to map the distribution of organisms relative to the moving water are described.

INTRODUCTION

In late spring of 1992, 1993, and 1994 oceanographic surveys of Georges Bank spawning grounds were conducted to examine stratification variability and its effect on larval fish survival. The first two years were funded by NOAA Climate and Global Change, Marine Ecosystem Response Program and the later year was funded by the US GLOBEC Program (Global Ecosystem Dynamics).

The objectives of these cruises were to test and intercalibrate a variety of sampling systems for determining the distribution and abundance of larval fish and their planktonic prey in relation to hydrographic conditions. An additional objective was to test and evaluate different sampling strategies that could be used in future field operations.

The purpose of this manuscript is to provide a progress report and summary of data collected by the Woods Hole NMFS scientists. Many other scientists (approximately 100) and institutions are involved. This report is intended for scientists outside the GLOBEC project as a brief overview of work in progress. Much of the text and figures are extracted from Manning et al., 1994 and Taylor et al., (in prep). The sampling systems are described and the data is summarized primarily in the form of contoured distributions. The discussion section is limited to brief notes on the significant unplanned observations of a) a wind event, b) the appearance of Scotian Shelf Water on Georges Bank, c) highly resolved tidal fronts, and d) small structure of the fluorescence signal.

SAMPLING SYSTEMS

ShipBoard

The primary shipboard sampling systems used during this cruise to accomplish the above objectives were:

MOCNESS: Multiple Opening/Closing Net and Environmental Sensing Systems with 1 m² (0.333-mm mesh nets) and 1/4 m² (0.064-mm mesh nets) mouth openings and each equipped with 9 nets and conductivity/temperature/depth measuring packages (identified as MOC1 and MOC1/4, respectively).

Seabird Electronics Seacat Model 19 CTD (Profiler): a conductivity, temperature, and depth measuring instrument with a sampling rate of 2 observations/second. During a bongo haul, the Profiler was attached above the bongo frame and towed double-obliquely through the water.

MKS CTD: a Conductivity/Temperature/Depth measuring system equipped with a fluorometer and rosette water sampler.

Near real time satellite: Satellite derived SST was sent to the ship via radio transmission at 300 baud.

Mooring

A physical oceanographic mooring with instruments to measure the temperature, salinity and current in the upper 50 m of the water column was deployed to monitor the vertical structure in the water column during the 1992 and 1993 cruise periods.

VACM: Vector Averaging Current Meters were attached at 15m and 45m to record current velocity and temperature 16 times per hour.

RBR Temperature Loggers (TPODS): Single channel temperature loggers (model series XL-105) used in fixed mode of operation as part of the moored array. Temperature observations were recorded every 2 minutes of their deployment. Instruments were attached at 5, 25, and 35 meters.

Seabird Electronics Seacat Model 16: Internally recording temperature / conductivity instruments intended for fixed mooring operations. Instruments were attached at 1, 10, 20, 30, 40, and 50 meters and recording every 2 minutes.

Drifting

Loran-C Buoy Marker Buoy: These instruments, manufactured by Seimac Limited and loaned to us by Art Allen of USCG Research and Development Lab, received Loran radio signals at a user defined setting (we used 30 minutes) and transmitted the time delays via VHF radio to the ship in both 1992 and 1993.

GPS/VHF/ARGOS drifters: These instruments, manufactured by Brightwaters Instrument Systems, received both GPS and ARGOS positions and relayed the fixes via VHF in 1994.

METHODS

Sampling Operations

During the first three days of cruise AL9204, AL9205, AL9306, and AL9403, a survey was conducted to locate cod and haddock larvae on the southern flank of Georges Bank and to provide an initial indication of the hydrographic conditions in the region. A bongo-net (61-cm dia., 0.333-mm & 0.505-mm nets) equipped with a Seabird CTD profiler was used on approximated 30 stations (5-10 mile spacing) between the 50 and 100 m isobaths.

From the survey information a site was chosen for deployment of the physical oceanographic mooring, the BIOSPAR mooring¹, and the drifters (Figure 1 and Figure 2). This site (approximately 80m bottom depth) was selected to be in the region of the bank which characteristically has a stratified water column. It is identified as the stratified site (S). A second site (approximately 50m depth) was selected in the characteristically well-mixed, shallow portion of the bank nearest to the site S. This site is referred to as the mixed site (M).

After deployment of the moorings, drifters were deployed near the site S. The drifters consisted of the surface canister with electronics tethered to a 6m long holey sock drogue at 10m depth. The vessel had a VHF receiving unit to track the buoy's position. The drifters formed a third site, the Drifting site (D) which was expected to drift southwest away from the site S during the course of the study.

At the three sites two different sampling schemes were conducted. The first was called a "site transect" which extended from 2 miles south to two miles north of the site (essentially across isobath). A MOC1 tow was made starting at the southern end and towed toward the site.

¹The BIOSPAR (Bioacoustic Sensing Platform and Relay) is a dual-beam biological echo sounder and satellite and radio communications system mounted on a spar buoy. This instrument was deployed by WHOI personnel.

After it was completed the vessel returned to the southern end of the transect and a CTD Tow-Yo was made along the 4 miles section at 2.5 knots with profiles every 5 minutes (approximately 0.2 mile spacing). The Greene Bomber (a dual beam acoustic system operated by WHOI personnel) was towed during both MOC1 and Tow-Yo. On some occasions a MOC1/4 tow was made at the completion of the Tow-Yo. In some cases the transects were conducted jointly with R/V ENDEAVOR (1992) and both R/V DELAWARE II and R/V COLUMBUS ISELIN (1994) for intercomparison of systems on the two vessels and for a more complete sampling of the water column by the full suite of available instrument systems.

The second sampling operation conducted in 1992 was the fine scale "grids". These are attempts to survey a square mile of ocean in a Lagrangian sense. In other words, our objective was to map the physical and biological variables relative to the moving water mass assuming a slab like advection over a 3-4 hours of the tidal cycle. The sampling was conducted on nominally 6 transects that were one mile long and 0.2 miles apart. In some cases, R/V ENDEAVOR simultaneously ran grid lines offset by 0.1 miles for the ALBATROSS IV grid so that the combined effort sampled the square mile of water with a transect spacing of 0.1 miles. The movement of the water during the sampling had to be taken into account in order to sample the intended parcel of water. The tidal currents are often greater than 50 cm sec⁻¹ and, over the 4 hours required to conduct the sampling, would displace the parcel of water a distance three to four times greater than the size of the square. To compensate for movement during the sampling, a drifting buoy (with drogue at 10 meters) was used as a reference marker and all grid lines were positioned relative to the drifter at the time the lines were run. The Greene Bomber was deployed on all grid lines. A MOC1 tow was conducted on the first and last lines. A CTD Tow-Yo was conducted on the second through fifth lines with profiles every 3 minutes (for an approximate along-track spacing of 200m). Four grids were completed by ALBATROSS, three of which were conducted with Endeavor.

In order to reference the position of samples relative to the moving parcel of water the following procedure, as suggested by Captain Dean Smehil, was used on Grid #'s 4 & 5. The proposed one mile grid pattern was drawn on the ALBATROSS IV radar screen with a grease pen. The ship was simply steered such that the signal from the drifters radar reflector traced out the pattern on the screen.

The approximate location of the three sites and a summary of the operations conducted at each site in the first year, 1992, is shown in Figure 1.

Some "longer transects" of observations also were occupied. These included two Tow-Yo transects with the Greene Bomber between the site S and M, with CTD profiles every kilometer. An along isobath transect of CTD stations every 5 miles was occupied from 25 miles northeast to 20 miles southeast of the site S. In some cases transects also were occupied near the western end of Georges Bank and across the eastern side of Great South Channel. These transects included sampling by MOC1, Greene Bomber and the MK5 CTD.

Processing Operations

MOCNESS and most bongo samples for most cruises have been sorted and identified for fish larvae, eggs, and zooplankton. Fish larvae were measured to the nearest tenth millimeter and all lengths were converted to live lengths using Bolz and Lough (1983) algorithm. All data includes lengths of larval fish specimens taken for biochemical analysis. Copepods and fish eggs from selected MOCNESS hauls have been staged according to life history traits. Depth distributions have been plotted using total numbers, however, means and standard deviations have been calculated for each haul. Weighted mean depth was calculated for fish eggs and larvae using the following formula:

$$wmd = \Sigma \text{product} / \Sigma \text{density}$$

where $\Sigma \text{product}$ = midpoint of depth interval * density of specimens. When more than one depth profile was performed during a haul, each depth profile was considered be either an up or down haul. Separate sets of analysis were performed for each type of haul (i.e. up or down). Day and night distributions have been calculated for selected MOCNESS hauls at stratified, drifter, and mixed sites. Density distributions of fish eggs and larvae have been calculated using MOCNESS volume data.

The Seabird PROFILER (CTD) records were bin-averaged to 1m using Seabird "BINAVG" software. Corrections were applied after calibration with Niskin bottle samples. Seabird PROFILER data was contoured at sea using Golden Software's SURFER routines.

The Neal Brown MarkV CTD was deployed a total of 470 times over the three years. The

General Oceanics software "CTDPOST" was used to generate 1 meter bin averages. Corrections were applied after calibration with Niskin bottle samples. In order to merge position, water depth, and other "header" information with the pressure, temperature, salinity, and fluorometry, several processing steps were developed.

The Lagrangian coordinates for the grid paths were calculated differently for different grids depending on whether we a) were near the mooring, b) were near the drifter, and c) used the "grease pen" technique. This "XY" current position file (where x and y are in kms relative to the start of the operation) along with that of the ship position file became input to a FORTRAN routine "LAGRD.EXE" to obtain the back calculated Lagrangian positions.

A data acquisition system called the Scientific Computing System (SCS) developed by engineers at Atlantic Marine Center (AMC) was in its first year of operation on the AL9204. It provides the scientists with continuous records of position, ship speed/direction, wind speed/direction, air temperature, and several other variables.

Satellite SST records as transmitted from shore were run through a ADD_POSN.For routine that merged temperatures with geographic grid points and then contoured with SURFER at sea.

RESULTS

Physical Oceanography:

The physical oceanographic program consisted of 1) deploying a mooring to measure the water column structure during the course of the study, 2) deploying drifters to track for repeated sampling of the same water parcel, and 3) CTD profiles to measure the water column structure in connection with the other sampling programs on the cruise. Results are presented in that order.

1) Mooring

The physical oceanographic mooring shown in Figure 2b was deployed in 1992 and 1993. It contained 2 VACM current meters, 6 SEACAT conductivity/temperature recorders and 3 Branker temperature recorders. The deployment and recovery of the mooring were accomplished successfully except for the loss of one SEACAT recorder in 1992.

The hourly averaged time series from 1992 of detided velocity from the two VACM records and the shipmounted anemometer are presented in Figure 3. The temporal evolution of the water column structure as measured by the mooring is contoured in Figure 4 including resultant wind speed in the top panel. Similar contouring of the 1993 mooring was not possible due to the episodic impingement of slope water into the mooring area.

2) Drifters

As depicted in Figure 5, the quality of the Loran-C Buoy fixes in 1992 was variable but sufficient for general tracking. The buoy drifted about 100 km to the WSW in 7 days (15 cm s^{-1}), essentially along the isobaths. In 1994, the drogued drifter was deployed on three occasions, twice in the stratified area and once in the well-mixed water (Figure 6). The ship and drifter positions, displayed on a laptop screen, were used to guide the ships track during MOCNESS hauls. The results were satisfactory as most of the MOCNESS hauls intersected the drifter track at about their mid-point. Two of the drifter tracks at Stratified Site I and Mixed Site performed as expected in the bank's circulation having a 10 km semidiurnal tidal excursion and a southwestward mean drift along isobaths of about 12 cm/s (10 km/day). However, on Stratified Site II, May 22-23, the expected tidal excursion was observed but there was little mean drift. The difference is most likely due to changes in the wind pattern during the cruise.

3) CTD

The temperature, salinity and fluorescence data collected by the CTD systems showed considerable structure in both the along isobath and cross isobath directions and significant interannual variability. The SEABIRD surface salinity for AL9204 is contoured in Figure 7. The SEABIRD bottom temperature for both bongo surveys AL9205 and AL9403-II are presented in Figure 8. The most significant oceanographic observations was the presence of a cold ($<3^\circ\text{C}$), fresh ($<32\text{ PSU}$) water in 1992 (see discussion below) and a warm ($>13^\circ\text{C}$), salty ($>34\text{ PSU}$) water impinging on the bank in the southwestern corner of the survey in 1994 (Figure 8)

Two TOW-YO sections conducted in 1993 demonstrate the difference in water column structure as a function of tidal phase (Figure 9). Two tow-yo sections were also conducted during an off-bank phase of the tide in the early hours of May 24, 1994. In Figure 10, the most notable feature is the relatively high values of fluorescence near the tidal front and distributed throughout the water column.

Grid study figures begin with a summary of cruise tracks (Figure 11) followed by detailed tracks of grid#1 in Figure 12.

Biology

1) Bongo Surveys

During the initial Bongo surveys, few month-old cod were collected in shoal waters on the Southeast Part; however, a broad area of haddock and cod larvae was located on the Southwest Part from the shoals to the 90 m isobath, centered near 68 00' Lg. The abundance of larvae was relatively low, less than 6 larvae per Bongo-net haul was typical (Figure 13). Larval haddock were about four times as abundant as cod. Most larvae were recently hatched, 4-5 mm SL. Both cod and haddock were a few weeks older, 5-8 mm, and more abundant in the shoal water < 60 m depth. In 1992, the patch of larvae was located farther to the southwest (40-70 miles) than expected from previous years surveys conducted in the last half of May. Perhaps the cold band of water observed in April that moved onto the southern edge of Georges Bank displaced eggs and larvae southwest and more onto the shoals. The cold water (<4 °C) also may have retarded development and induced high mortality of the eggs and larvae in the year.

In 1994, a patch of larval haddock was located from the BONGO-NET grid of 42 stations on the southern flank of Georges Bank. The larval patch, identified by haul catches greater than 4, was about 15 x 30 miles in extent, centered on the 70-m isobath. Highest catches were in the range of 10-20 per haul. A few (1-7) cod larvae were caught on most stations, but no identifiable patch. The size of cod and haddock larvae ranged from recently hatched to 14-19 mm; modal size appeared to be 7-8 mm.

2) MOCNESS hauls

A total of 103 MOCNESS hauls were made over the three years. In 1992 seven hauls were made at the drifter site (D), 8 at the stratified site (S), and 10 hauls at the mixed site. Few cod or haddock larvae were collected at the stratified-water sites; most larvae were collected at the mixed site in water < 50 m bottom depth. The MOCNESS vertical profiles indicated that cod and haddock larvae were distributed broadly through the water column, generally more abundant towards the bottom. Haddock larvae were collected in greater numbers at depths deeper than 20 m in several hauls. Zooplankton abundance generally appeared to be highest in the upper 40 m of the water column. The copepod *Calanus finmarchicus* dominated the zooplankton hauls in stratified waters.

Along the transect occupied at the western end of the survey region (68° 20' W) five MOC1 hauls were made simultaneously with the Greene Bomber. Haddock and cod larvae (7-8 mm mode) were collected at the shallowest stations; their abundance and vertical distribution was similar to the previous three site study. On the transect across the eastern side of the Great South Channel three MOC1 hauls were made from 50-80 m bottom depth. Older haddock and cod larvae (6-11 mm) were collected in all hauls. The general distribution pattern of larvae observed during the cruise is consistent with the recirculation of some fraction of larvae on the eastern side of the Great South Channel.

In 1992, a total of 182 cod and 189 haddock larvae were collected with the 1M MOCNESS and frozen for biochemical studies. All but 2 cod and 7 haddock came from the shoal or transect sites. Larvae were sampled from a total of 11 MOC1 hauls representing both day and night tows. Larvae were sampled from both integrated and discrete depth nets. The majority of gadid larvae were frozen on petri dishes in the ships freezer. Other samples were frozen in liquid nitrogen. These samples will be analyzed for RNA and DNA content using an automated fluorescence procedure. We will attempt to sample otoliths from these larvae. Standard length will either be measured directly or estimated from DNA content.

In 1994, thirty seven hauls were made on the stratified sites and 16 hauls on the mixed site. A single 10-m² MOCNESS haul was made at Stratified Site II and the Mixed Site, and since no pelagic juvenile cod or haddock were caught, this sampler was not used further. Most 1-m² MOCNESS hauls had replicate profiles so that one profile-set of samples could be used for picking larval fish for biochemical analysis. Yellow-tail flounder (*Hippoglossoides platessoides*) were much more abundant than haddock and cod larvae. A total of 2,512 larvae were frozen (1,072 haddock, 236 cod, 1,204 yellow-tail), and 1,803 larvae preserved in alcohol (219 haddock, 56 cod, 1,522 yellow-tail) for otolith analysis. Because of the variability observed in the vertical distribution of larval fish, it was difficult to generalize patterns until all the samples are fully processed.

DISCUSSION

While most of our cruise went as planned, we were also fortunate to encounter some

interesting phenomenon. A very brief description of these unplanned observations are presented in this discussion section. Detailed analysis of these anomalous oceanographic features and the biological consequences is expected in forthcoming papers.

Scotian Shelf Washover

The temperature and salinity data on a number of transects in 1992 indicate the presence of low temperature (<4 °C) and low salinity (<32.00 PSU) in small patches or layers in the water column. This is believed to be a remnant of a large influx of Scotian Shelf Water (SSW) onto eastern Georges Bank which was observed in satellite images from March through June 1992 and confirmed by shipboard observations on cruise ALB 92-04 in early May. NOAA buoy 44011 SST sensor also recorded unusually cold water from late March through the end of May. The cause of this feature, as reported by Rusham et al., 1994 and Bisagni et al., (in prep.), may be the unusually large St. Lawrence River runoff in the spring of 1991. The thickness of the lens as defined by the 32 ppt isohaline varies in both the cross and along-isobath directions (Figure 14). The influx and continued presence of SSW may have important implications for the plankton communities in the bank, both by the unusually cold temperatures and by a westward displacement of the water on the southern flank of the bank.

May 25 Wind Event

A slight warming period over a few days from May 22 through mid-May 24 resulted in a build up in stratification in the vicinity of the mooring site of approximately 4 degC temperature gradient in the top 20 meters of the water column (Figure 4). This was followed by a period of strong northeasterly winds on late May 24 Figure 3 contributing to mixing of the upper water column (Figure 4) as well as unusually fast westward drift of the surface waters (Figure 5). This observation supports the hypothesis that the onset of stratification on Georges Bank in late spring is not a steady seasonal process but rather an intermittent addition of the sun's heat interrupted by occasional 2-3 day wind events. Examination of the NOAA Buoy 44011 wind record for the entire month of May 1992 reveals at least three other events occurred with magnitudes similar to that observed on May 24th and 25th. Superimposed on these wind-driven cycles are the semi-diurnal advection of both the tidal front and the shelf-slope front. The former advection is clearly evident in the 1992 mooring record as seen by the oscillating isopycnals in the bottom panel of Figure 4 and, as will be demonstrated in the 1993 data report (Taylor, et al. in prep), the intrusion of slope water is possible in the lower portion of the southern flank water column.

Small Scale Fluorescence Structure

The structure of the fluorescence, assumed to be an indicator of chlorophyll-a abundance, showed a patchy distribution that in many instances was associated with similar structure in the temperature and salinity distributions. There is often a subsurface maximum, especially for the those cast in the stratified area (see, for example, Figure 15), but there are horizontal gradients as well. Much of the future analysis on this data set will be estimating the lengths scales of these patches. This requires remapping these parameters in a Lagrangian reference frame. One such study already in progress (Wiebe et al., 1994) relates the acoustic properties of these patches to other physical and biological parameters.

CONCLUSIONS

While these cruises were meant to be "pilot studies" and instrument "test", a large volume of data was collected to allow intercomparison of the net, towed-acoustic, CTD, and moored systems under a variety of conditions. The joint operations with three other vessels also should allow intercomparison with the video, acoustic and pumping systems. The ability to determine the three dimensional distribution of the organisms in relation to hydrographic conditions on relatively short space scales is believed to be very important to the objectives of the US GLOBEC field study. The observations made on these cruises potentially provide a significant contribution to our knowledge of the system. The ability to map a small parcel of water that is being advected by the strong tidal currents on Georges Bank is a significant challenge but we have made great progress in that effort. The "grid" studies in particular provide for the first time an opportunity to conduct a interdisciplinary investigation sub-mesoscale dynamics on the southern flank of Georges Bank.

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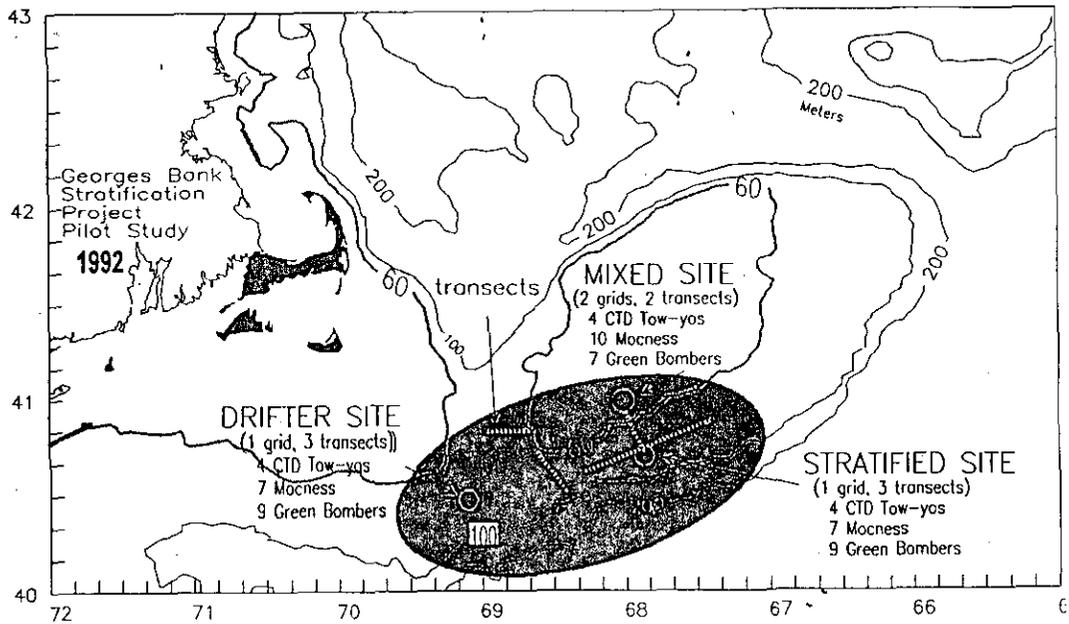


Figure 1a. Station map of operations on the main leg of the ALBATROSS cruises in the spring of 1992.

Georges Bank Stratification Project
May 1992 Pilot Study

Well Mixed
7 Moaness
2 CTD Tow-Yos
2 Grids
6 Green Bombers

DRIFTER
7 Moaness
4 CTD Tow-Yos
1 Grid
9 Green Bombers

Fixed Mooring
6 Moaness
3 CTD Tow-Yos
1 Grid
5 Green Bombers

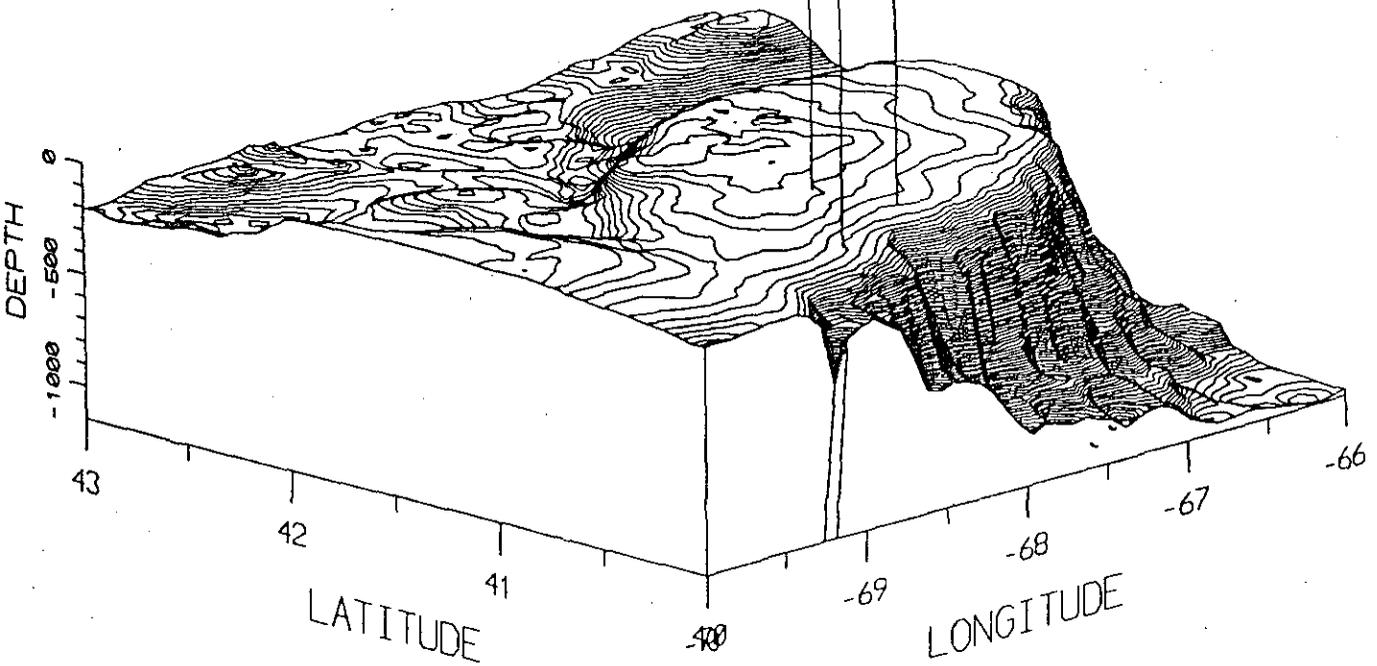


Figure 1b. A 3-d perspective of Figure 1a.

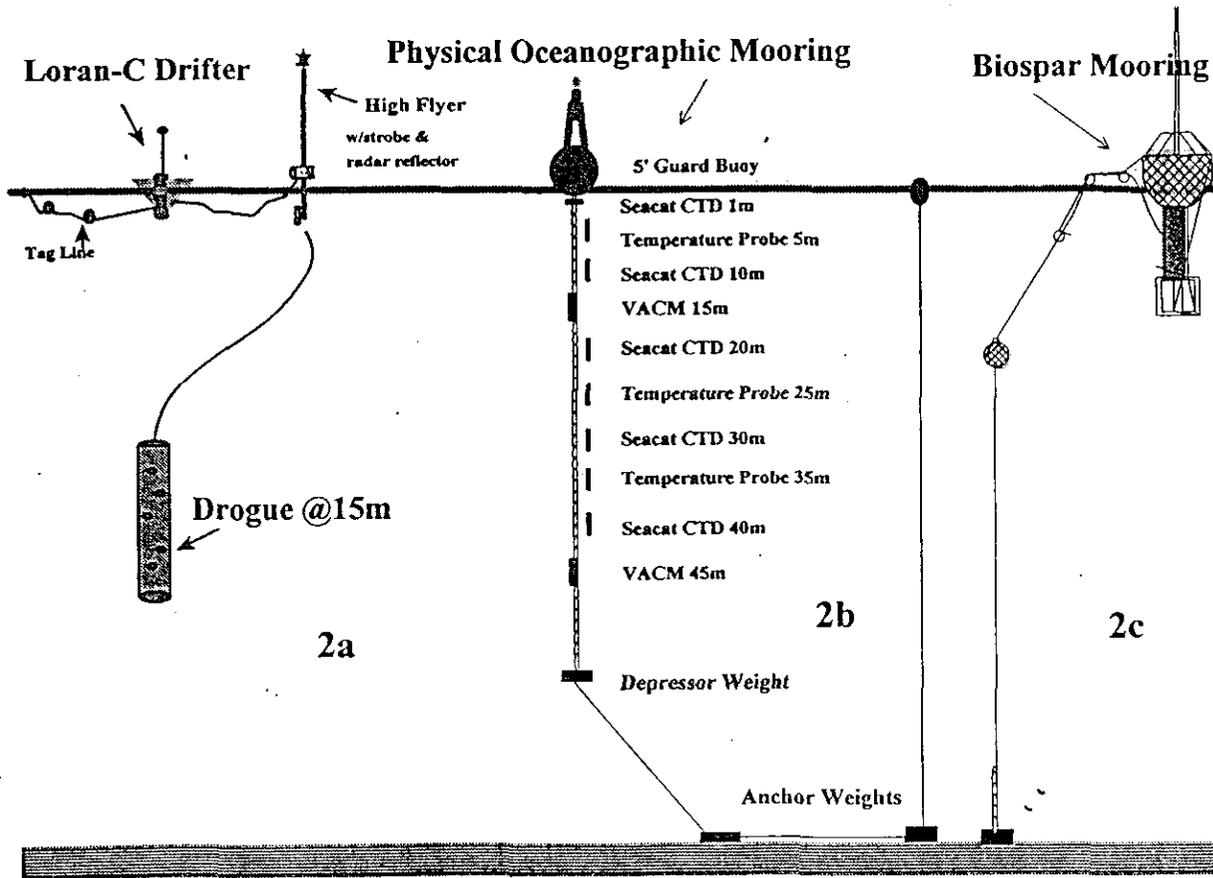


Figure 2. Loran-C Marker Buoy Drifter (a) and mooring (b and c) configuration in May 1992.

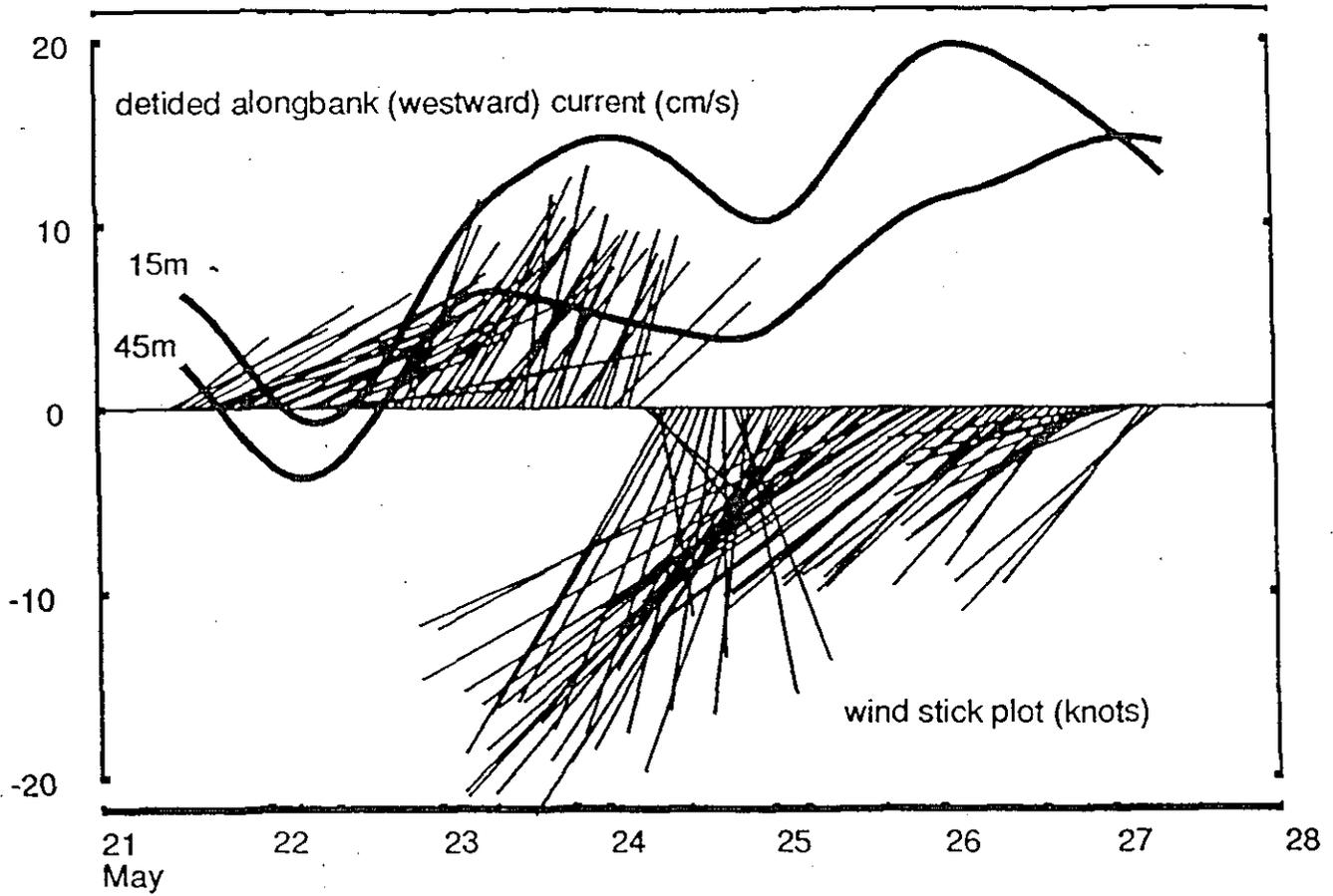
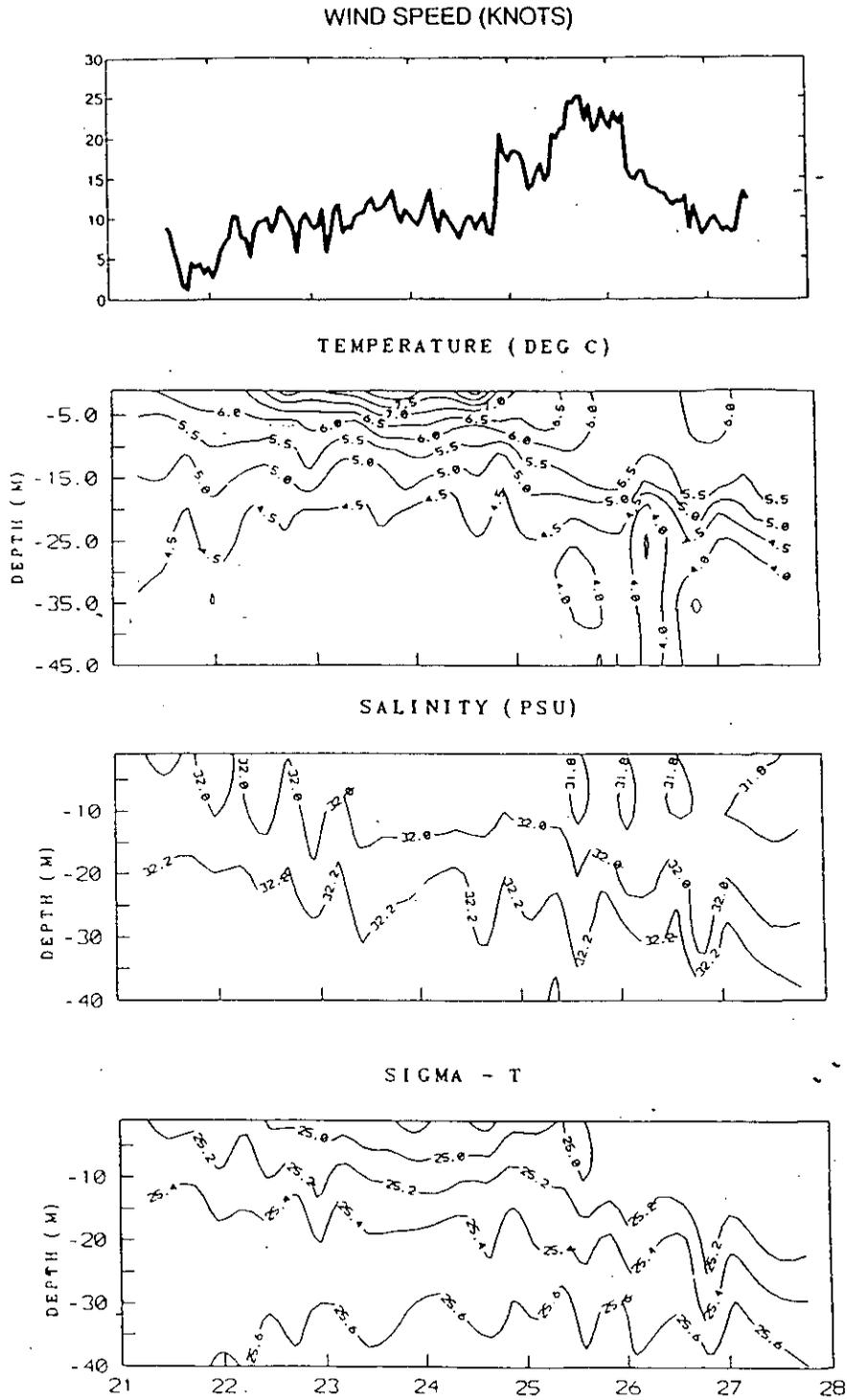


Figure 3. Time series of wind (shipboard anemometer) and current (VACMS).



MAY. 1992

Figure 4. Evolution of water column structure as measured by the mooring. Wind speed is depicted in the top panel above the contoured structure of temperature, salinity, and density in the lower 3 panels.

Drifter Track May 22-28, 1992

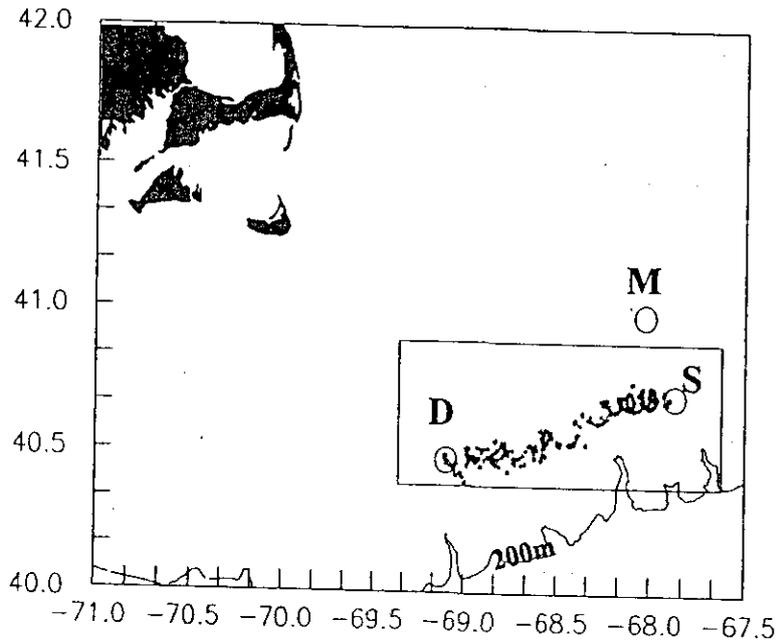


Figure 5. Drifter track (1992) including an blown-up version in lower panel.

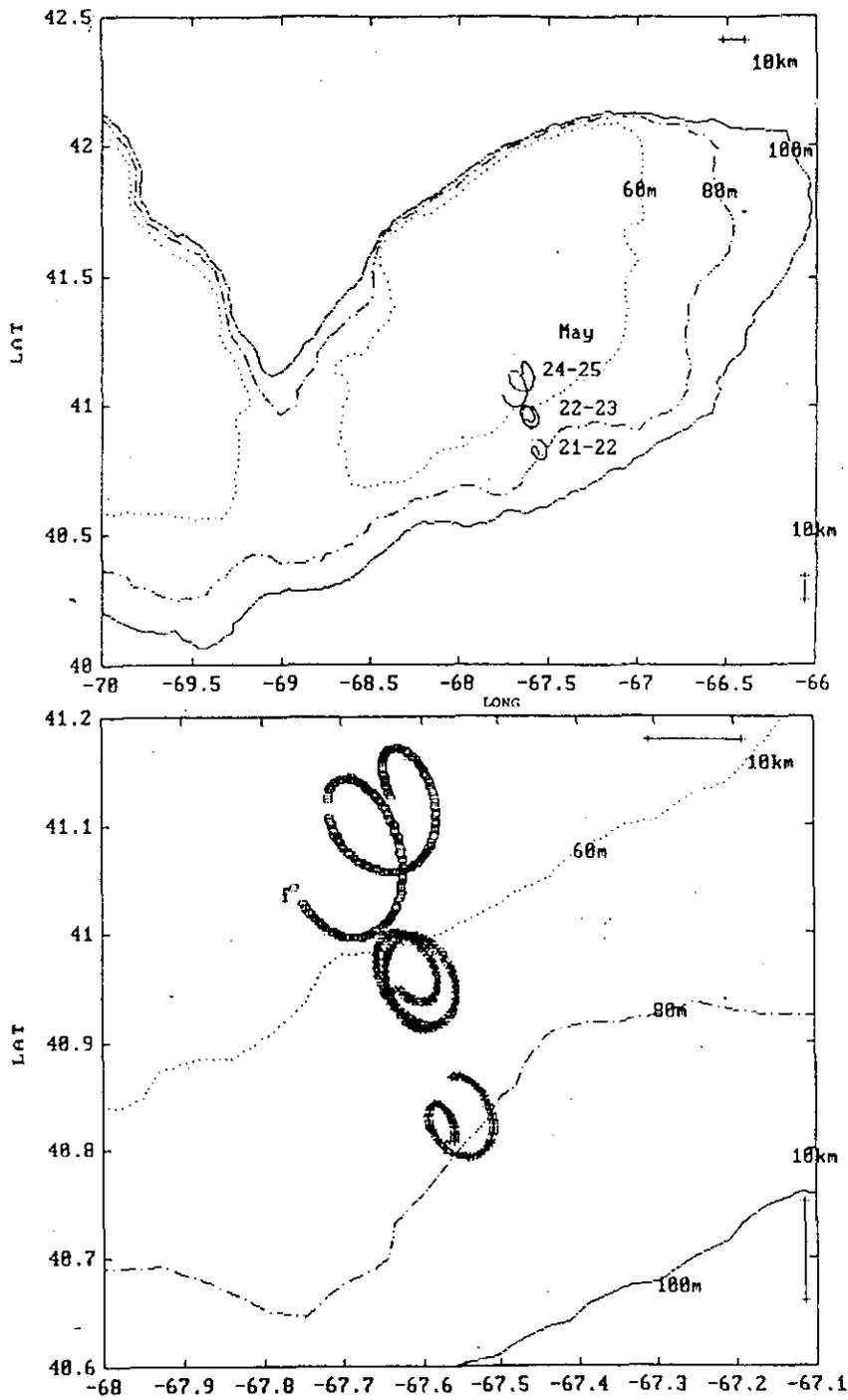


Figure 6. Drifter track (1994) including an blown-up version in lower panel.

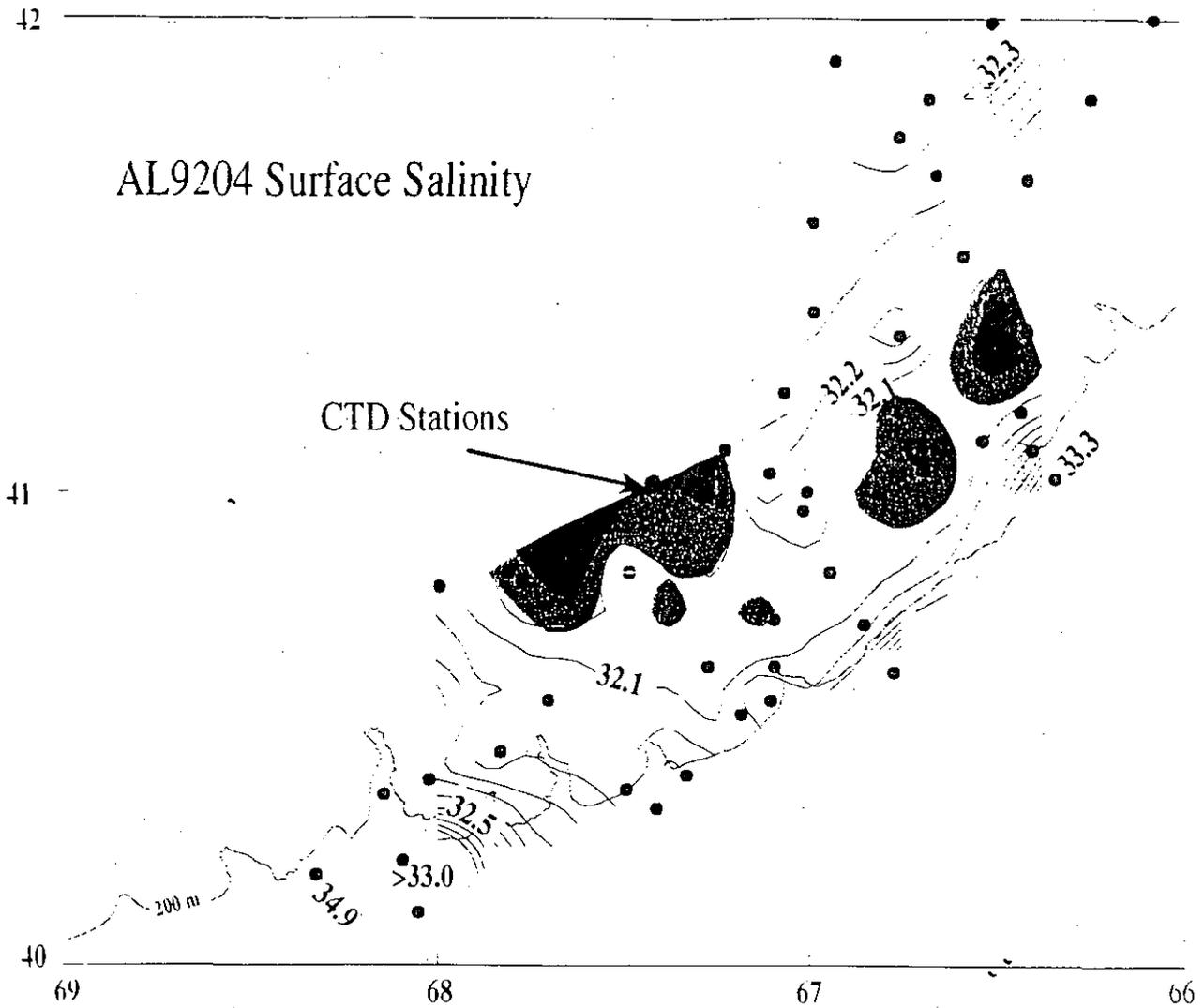
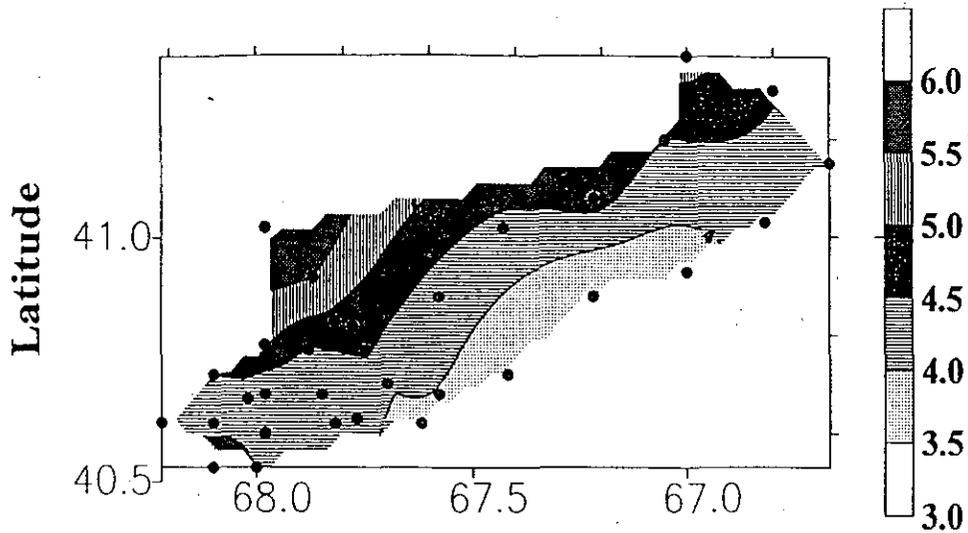


Figure 7. Surface salinity (5m) as measured by SEABIRD CTD stations (dots) indicating the band of Scotian Shelf Water along the shelf edge of Georges Bank (200m contour superimposed).

AL9205 Seabird Bottom Temperature



AL9403-II Seabird Bottom Temperature

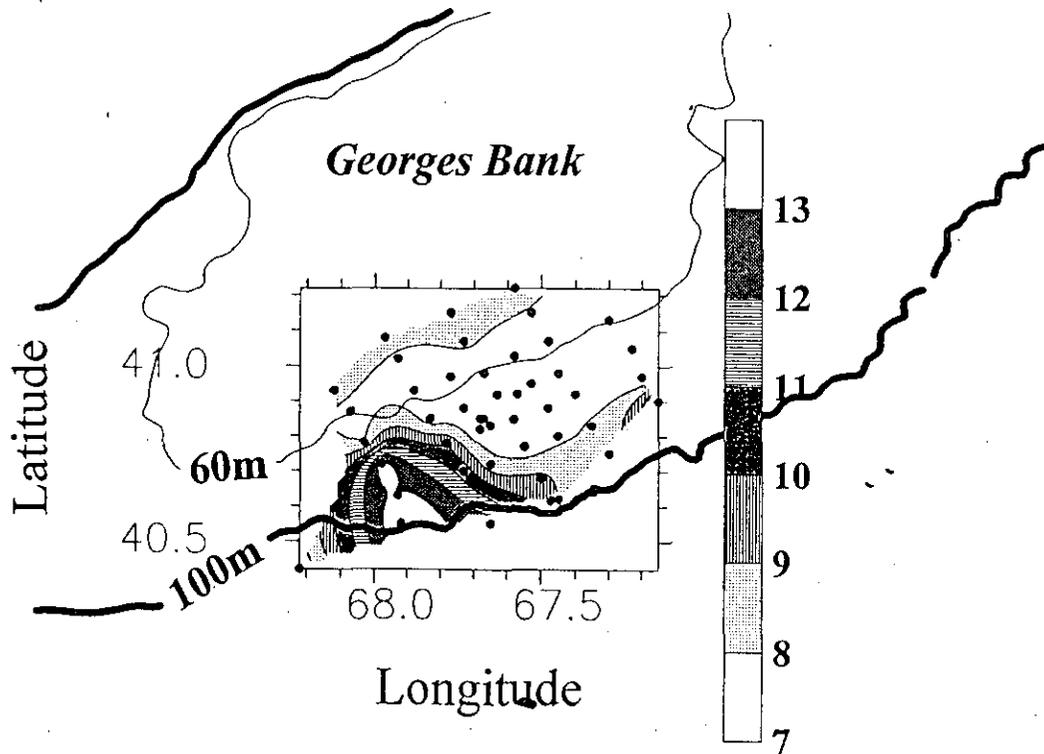


Figure 8. Bottom temperature measured with CTD stations in mid-May a) 1992 and b) 1994 in the same general area. Note the difference in temperature scale and the opposite cross-bank gradient.

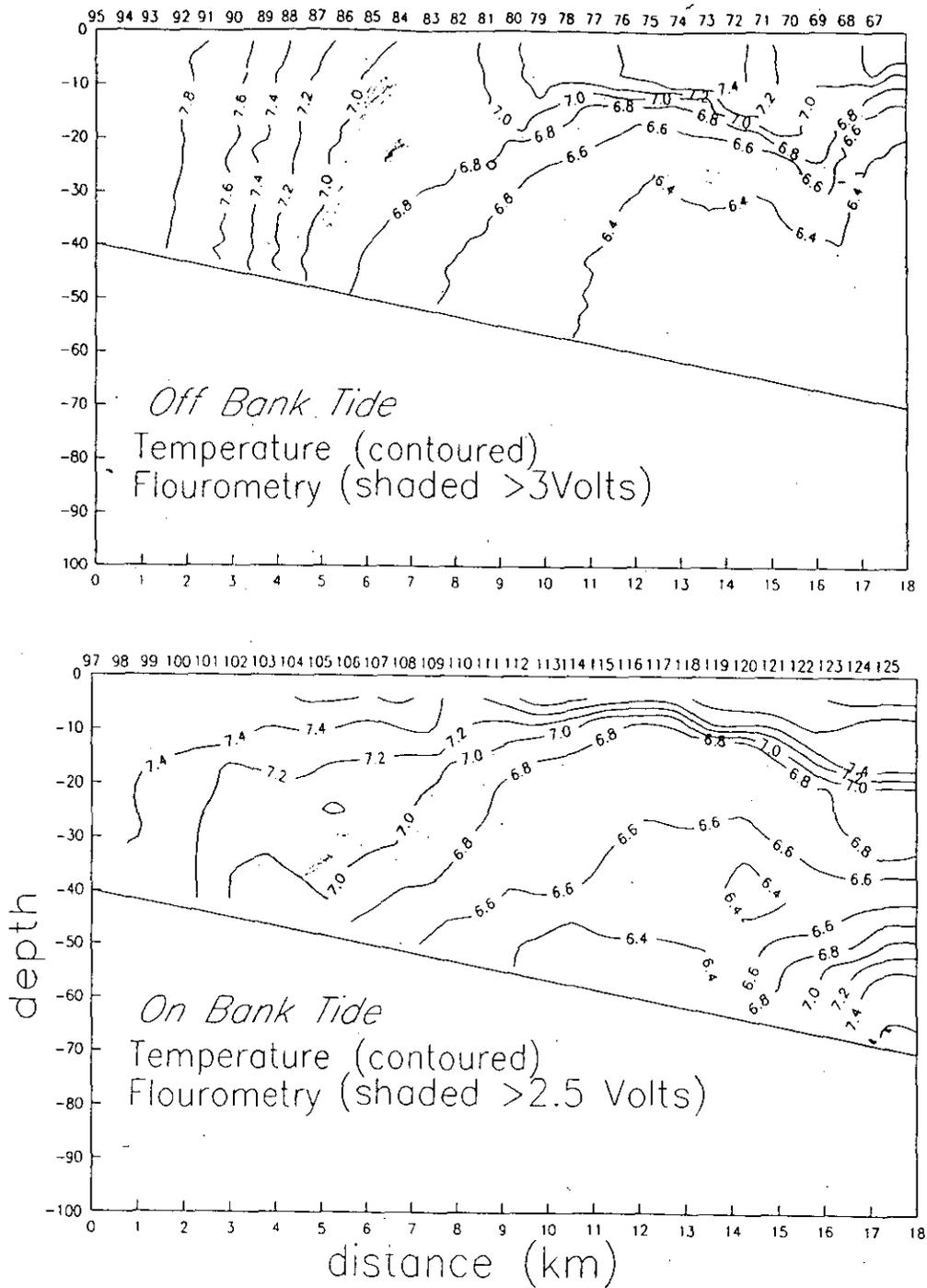


Figure 9. Two across-bank TOW-YO transects during two different phases of the tide in 1993 demonstrating the dispersal of the fluorescence front on the on-bank phase.

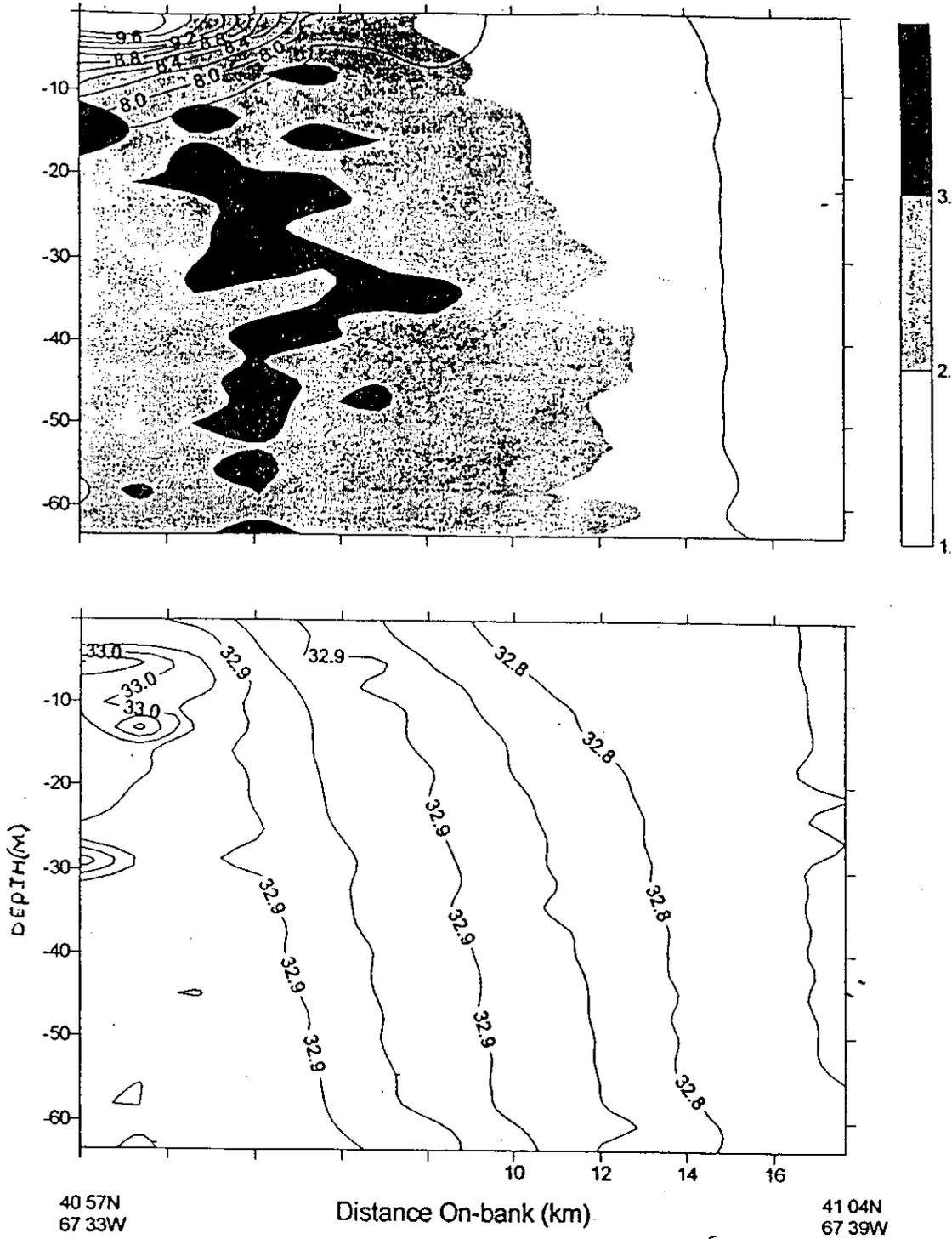


Figure 10. One across-bank TOW-YO transect in 1994 demonstrating the fluorescence front.

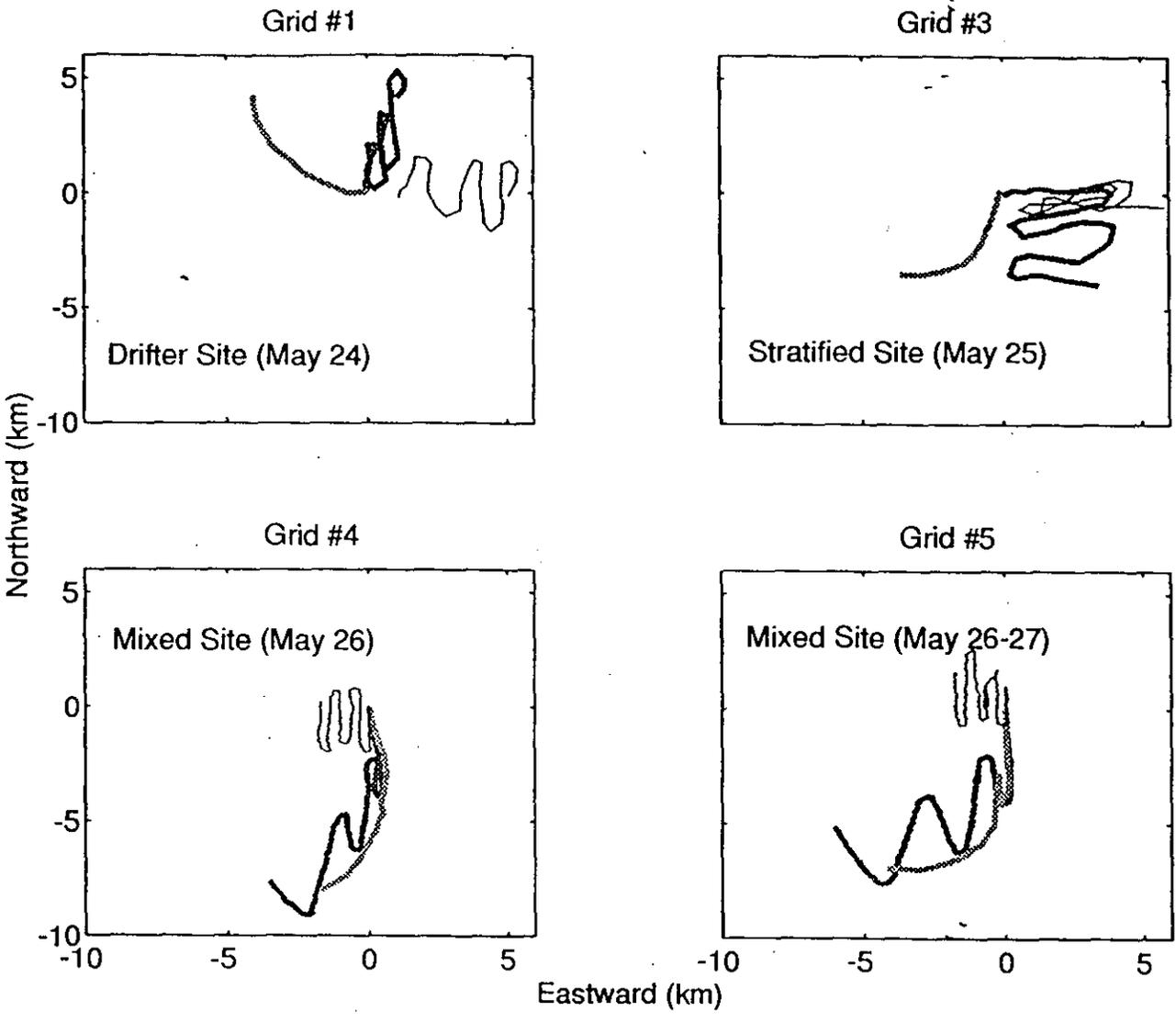


Figure 11. Summary of the grid operations including drifter track (gray line), ship track (thick black line), and the track relative to moving drifter (thin line).

Grid #1 Drifter Site May 24, 1992

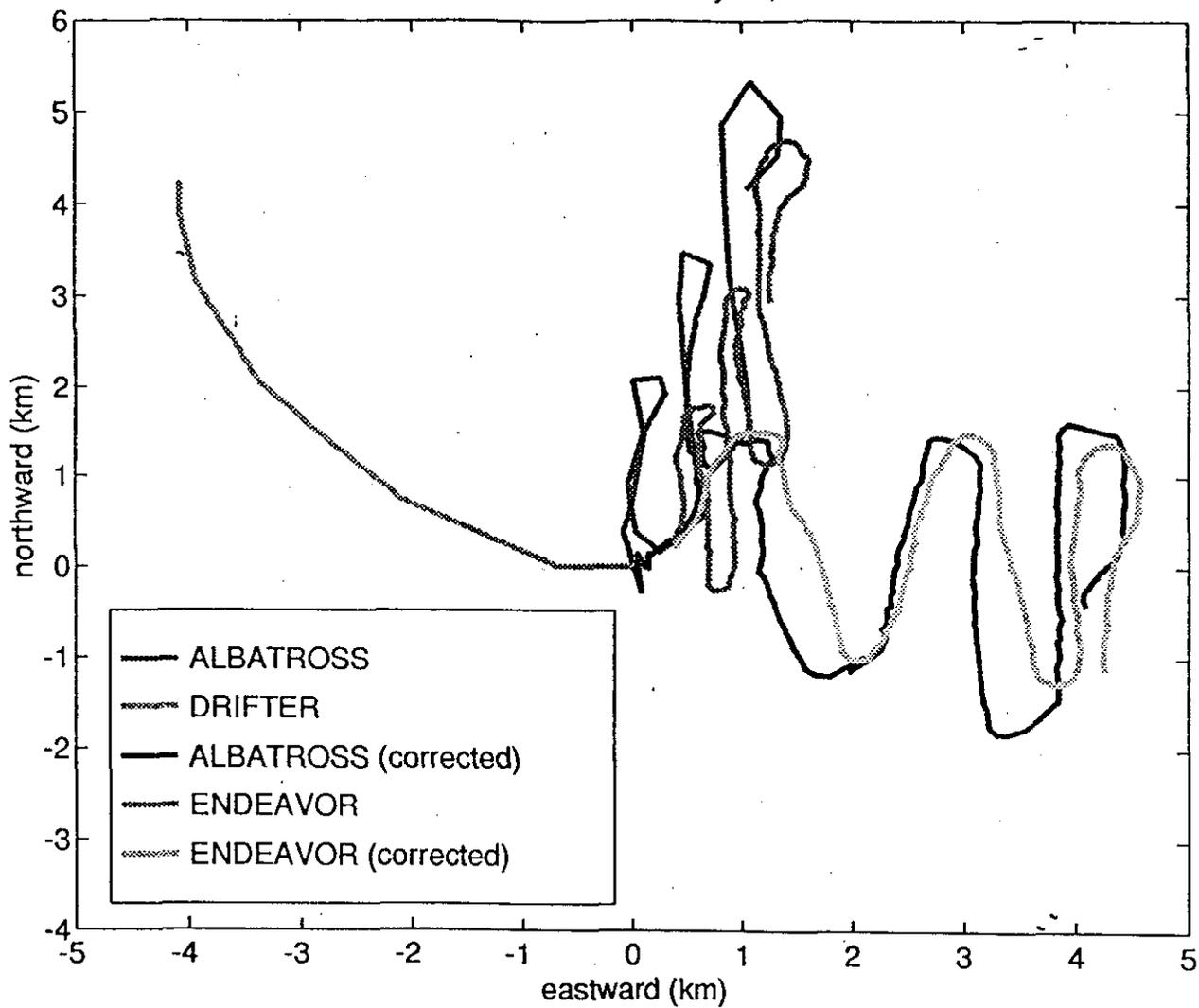


Figure 12. Grid paths in both geographic and Lagrangian coordinates.

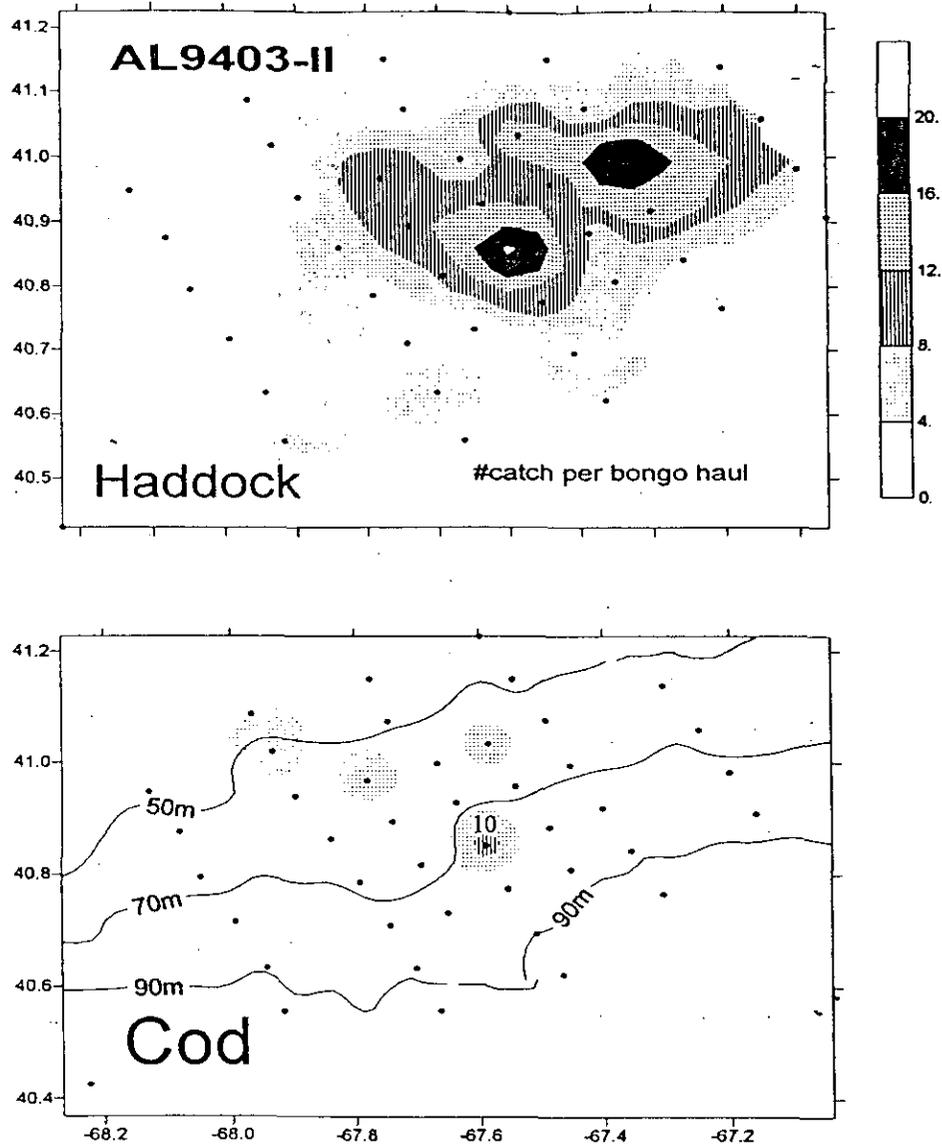


Figure 13. Catch per tow in bongo survey 1994 for haddock (top) and cod (bottom).

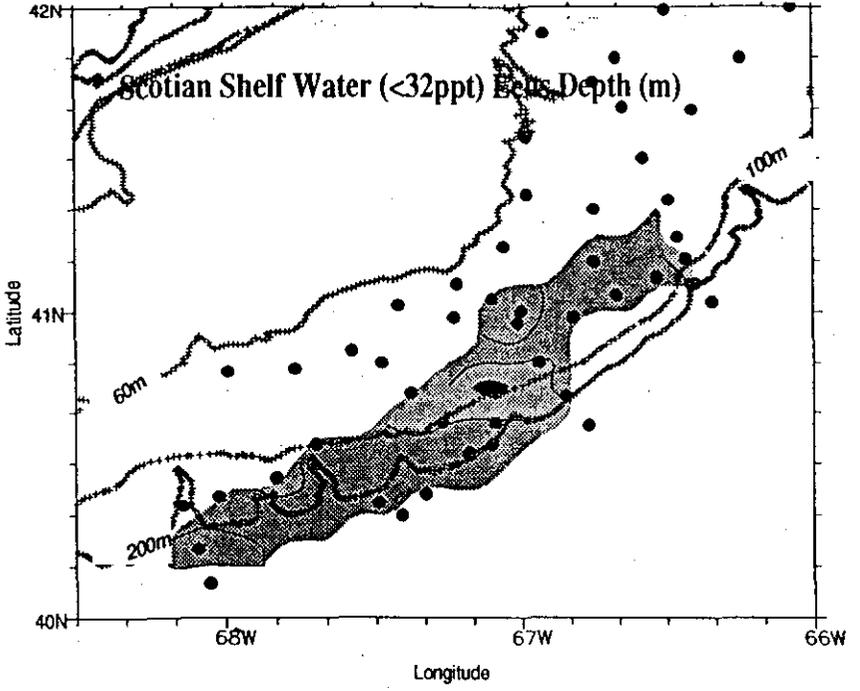


Figure 14.. Scotian Shelf Water lens thickness contour.

May 1992 Section#13 Fluorescence (volts)

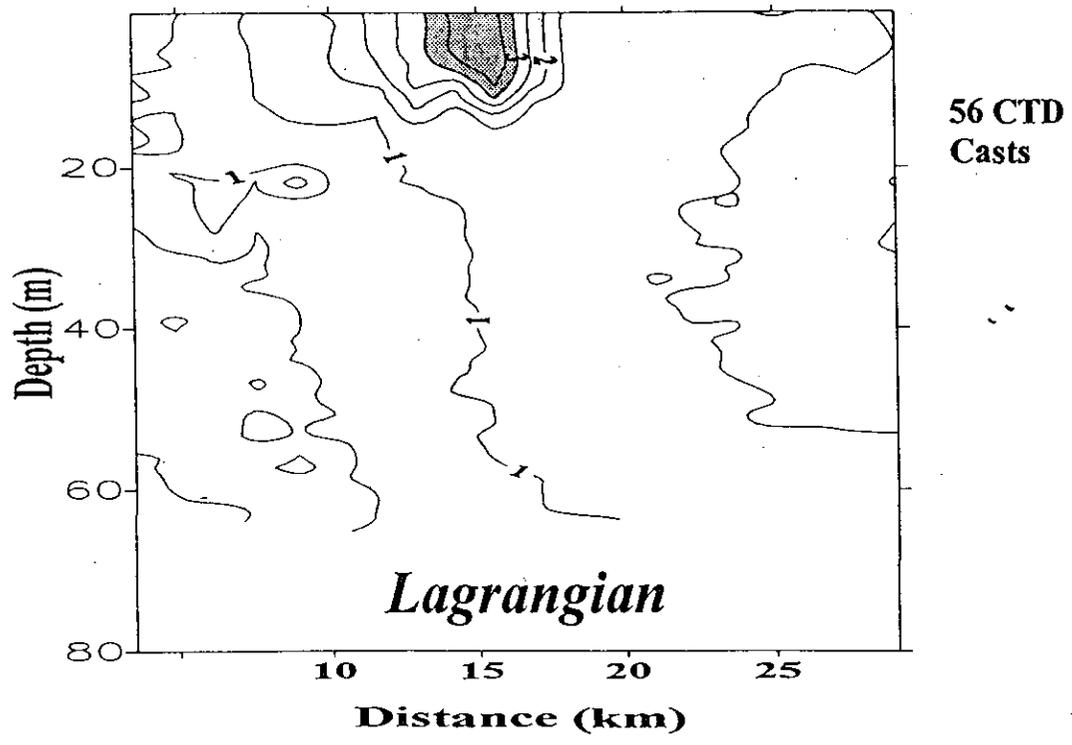
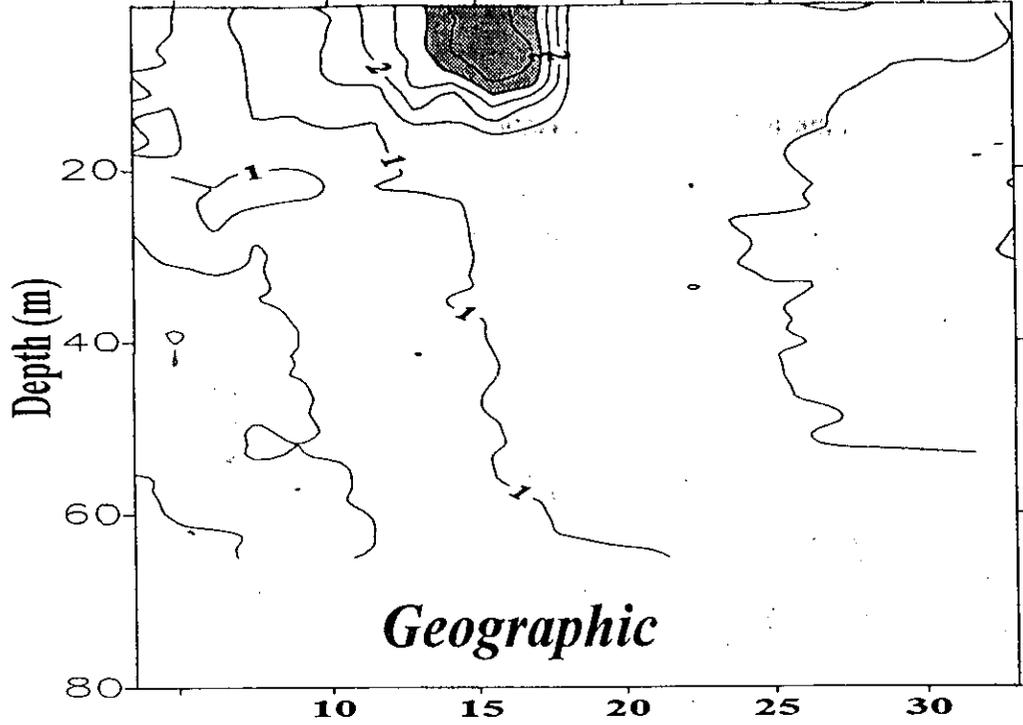


Figure 15. Difference in small scale fluorescence structure in geographic vs Lagrangian (relative to moving water) reference frame.

APPENDIX . Naming Conventions and archive access

DATA ARCHIVES at this time are in two forms: 1) Anonymous FTP and 2) JGOFS.

1) To get position files type:

```
ftp ftp.wh.who.edu
connect...
username: anonymous
          311 Guest login ok, send ident as password
password: (your email address)
          230 Guest login ok, access restrictions apply.
ftp>cd pub/gbs/shipposn
ftp>get <filename>
ftp>quit
```

2) To browse and access GLOBEC data in general use Georges Bank Information System under development. In MOSAIC open:
<http://lake.mit.edu/globec.html>