DEL-SG-07-90

Oceanographic Data Report Number 8: Density Profiles from the Delaware Estuary

October 1986 - September 1988

$2.00

University of Delaware

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By

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October 1990

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Newark, Delaware 19716

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CONTENTS

A. INTRODUCTION

This report presents analysis of physical oceanographic data collected on the SCENIC cruise series in the Delaware Estuary between October 1986 and September 1988. Detailed biological, chemical, and physical data from discrete samples are published in a separate report (see section on data collection). The data used in this report were collected by a computer controlled conductivity, temperature, and depth sensor system (CTD). Due to missing or incomplete CTD records, results from only 17 of the 24 SCENIC cruises were used for this report.

The SCENIC cruise series was supported primarily by a grant from the National Science Foundation (OCE68-01616). Partial support for the cruises was provided by a grant from NOAA Office of Sea Grant, Department of Commerce (NA86AA-D-SG040). Support for publication of this report came from NOAA Office of Sea Grant, Department of Commerce.

The University of Delaware Sea Grant College Program is supported cooperatively by the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and by the State of Delaware.

We thank the crew of the R/V Cape Henlopen and numerous volunteer members of the scientific staff for their aid during the cruises on which the CTD data were collected. We thank Timothy F. Pfeiffer, Timothy W. Deering, and Walter M. Dabell for aid in transferring CTD data from the tape records to the VAX and PC computer systems and for advice in development of software for the analysis.

B. DATA COLLECTION

Data from the following cruises are used in this report:

SCENIC-3	28-30 October 1986
SCENIC-4	3-4 December 1986
SCENIC-5	11-12 January 1987
SCENIC-6	18-19 February 1987
SCENIC-8	21-23 March 1987
SCENIC-10	27-30 April 1987
SCENIC-11	26-28 May 1987
SCENIC-12	24-26 June 1987
SCENIC-13	26-30 July 1987
SCENIC-15	29 September - 1 October 1987
SCENIC-16	4-6 November 1987
SCENIC-17	5-7 December 1987
SCENIC-18	5-7 January 1988
SCENIC-20	22-24 March 1988
SCENIC-21	11-14 April 1988
SCENIC-23	26-29 July 1988
SCENIC-24	6-8 September 1988

Figure B1 shows the Delaware Estuary with average station locations for the SCENIC cruises. Exact location of the stations sampled on each cruise and biological, chemical, and physical data for discrete samples are given elsewhere (Lebo et al. 1990). For this report, data is only presented for the salinity gradient of the estuary (stations 14-26). Distances are measured upstream from the mouth of Delaware Bay based upon a standard steam mileage system (DRBC 1988).

The routine sampling stations were in the main shipping channel of the estuary with bottom depths of 10-20 meters. Data collected at approximately 13 stations were used to prepare this report. The salinity at station 14 was essentially zero parts per thousand (ppt); chloride concentrations at that station ranged from 400-6000 μM (salinity = 0.01-02 ppt) during the study period. At the most seaward station (number 26), salinity was about 27-30 ppt.

Data acquisition was made with a Neil Brown CTD system on a General Oceanics rosette sampler aboard the R/V Cape Henlopen. Discrete samples were taken in Niskin bottles. Originally, the data were processed through a Tektronix computer, and stored on 9-track tapes. On later cruises, the Tektronix system was replaced with an IBM AT computer. With the conversion to the IBM system, data was stored on floppy disks.

At each station, the CTD was lowered through the water column to the bottom. Temperature and salinity were measured as a function of depth as the

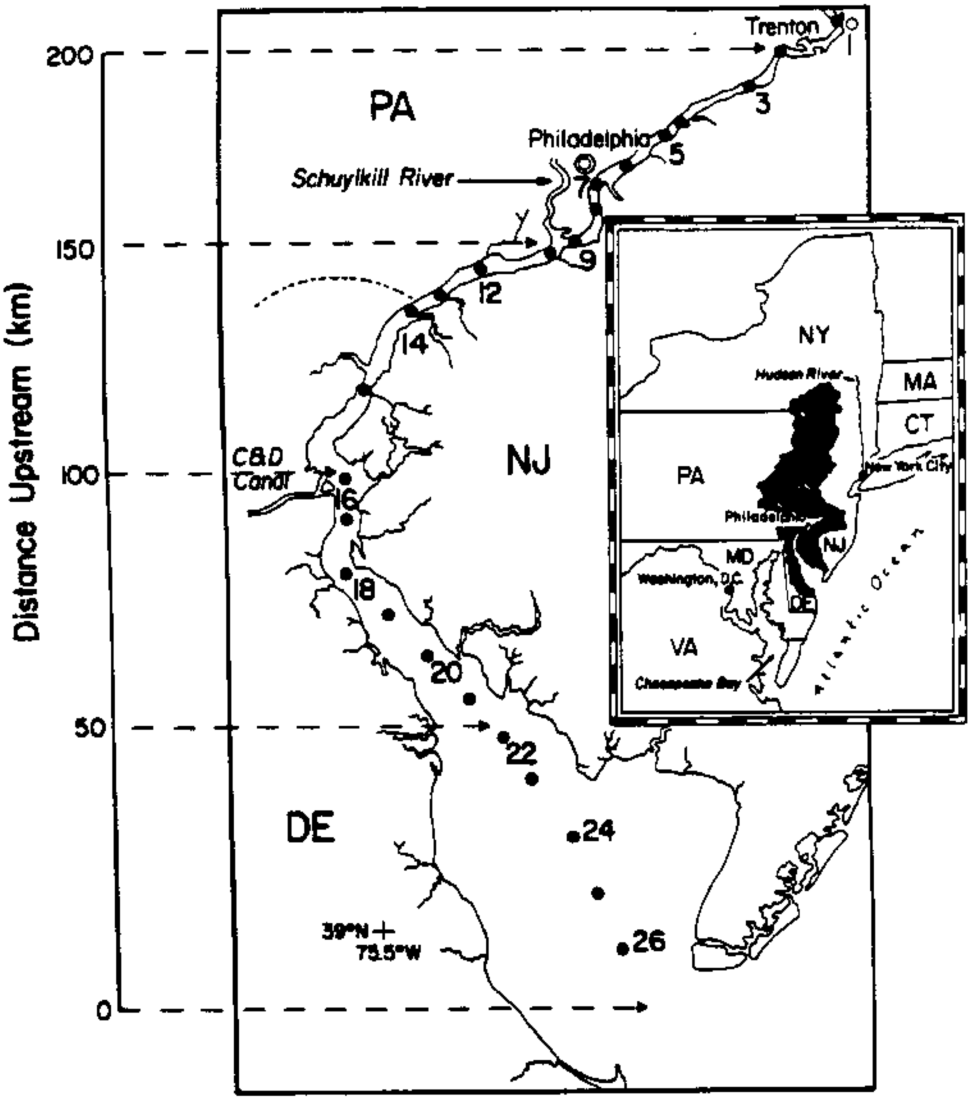

Figure B1. Station locations for SCENIC cruise series. The salinity gradient of the estuary begins at near station 14 (130 km), and salinity increases to around 30 parts per thousand at the mouth of Delaware Bay.

sampling array was being lowered; discrete water samples were collected as the CTD was being raised to the surface. The CTD sensors collected data at a frequency of 15 Hz as the unit was lowered through the water column at a maximum speed of 1 m s^{-1}. Data used for profiles was averaged in 1 m increments (1 db) representing a minimum of 15 data points.

References

Delaware River Basin Commission. 1988. The Delaware River Basin steam mileage system. Delaware River Basin Commission Report No. 105, W. Trenton, NJ. 111 p.

Lebo, M.E. et al. 1990. Data from the Delaware Estuary SCENIC Cruises. April 1986 - September 1988. University of Delaware Oceanographic Data Report No. 7, Newark, DE.

C. THE TREATMENT OF DATA

Construction of profiles

Profiles were constructed by using depth-interpolated data for each of the 13 stations on an individual cruise; data was linearly interpolated to produce values for temperature, salinity, and sigma-t at depth intervals of 1 db. Data for each cruise was setup in ASCII files, and transferred to Surfer software. The contour intervals for the different parameters are indicated at the front of each section. Temperature and salinity data were used directly. Values for sigma-t, the deviation of sigma-t from the annual average, Brunt Väisälä frequency, and the horizontal gradient of sigma-t were calculated as noted below.

Cruise season designations

SPRING	SUMMER	FALL	WINTER
Scenic-8	Scenic-12	Scenic-3	Scenic-4
Scenic-10	Scenic-13	Scenic-15	Scenic-5
Scenic-11	Scenic-23	Scenic-16	Scenic-6
Scenic-20	Scenic-24		Scenic-17
Scenic-21			Scenic-18

Calculation of sigma-t

Sigma-t was calculated using the International Equation of State (EOS80). Although salinity used in this study is not based on the Practical Salinity Scale (PSS78), it is treated as the practical salinity since the difference between the new and old scale is not significant.

Sigma-t weighted annual average

The annual average for sigma-t was calculated by taking the average of four seasonal values. Seasonal averages were calculated to lessen the influence of uneven seasonal sampling (e.g. spring and winter have five cruises, while summer has four and fall has only three). The 17 cruises are classified into four seasons as designated above. The average for each season was calculated first, and then the annual average was calculated as the "weighted average" of the four seasonal averages.

Calculation of Brunt-Väisälä frequency

The Brunt-Väisälä frequency is defined as follows:

$$N = [- \frac{g}{\rho} \cdot \frac{\partial \rho}{\partial z}]^{\frac{1}{2}} \tag{1}$$

If the hydrostatic approximation is assumed ($\partial p = \rho g \partial z$), then the expression for the Brunt-Väisälä frequency simplifies to:

$$N = g \cdot [- \frac{\partial \rho}{\partial p}]^{\frac{1}{2}} \tag{2}$$

where g is the gravitational constant (9.7976 $m \cdot s^{-2}$), ρ is density ($Kg \cdot m^{-3}$), and p is pressure (db, 10^4 $Kg \cdot m^{-1} \cdot s^{-2}$). In this study, sigma-t is used instead of density; the use of sigma-t instead of density does not change the result. Stability is defined as N^2.

Calculation of sigma-t horizontal gradient

The horizontal gradient of sigma-t was calculated by taking the difference of sigma-t between two neighboring points at the same depth as follows:

$$\text{Horizontal Gradient of } \sigma_t = \frac{\partial \sigma_t}{\partial x} \tag{3}$$

where σ_t is sigma-t ($Kg \cdot m^{-3}$) and x is distance between two points (km).

D. TEMPERATURE PROFILES

Profiles of temperature were constructed for the Delaware Estuary as a function of distance upstream from the mouth of Delaware Bay and depth below the surface. Depths are expressed in decibars pressure where 1 decibar (db) is equivalent to 1 meter depth below the surface. Temperatures are shown in isotherms (°C). Figures D1-D17 show temperature profiles for individual cruises. Except for cruises 12, 13, 23, and 24, isotherms are shown at intervals of 0.1°C; for those four summer cruises, the intervals are at 0.5°C.

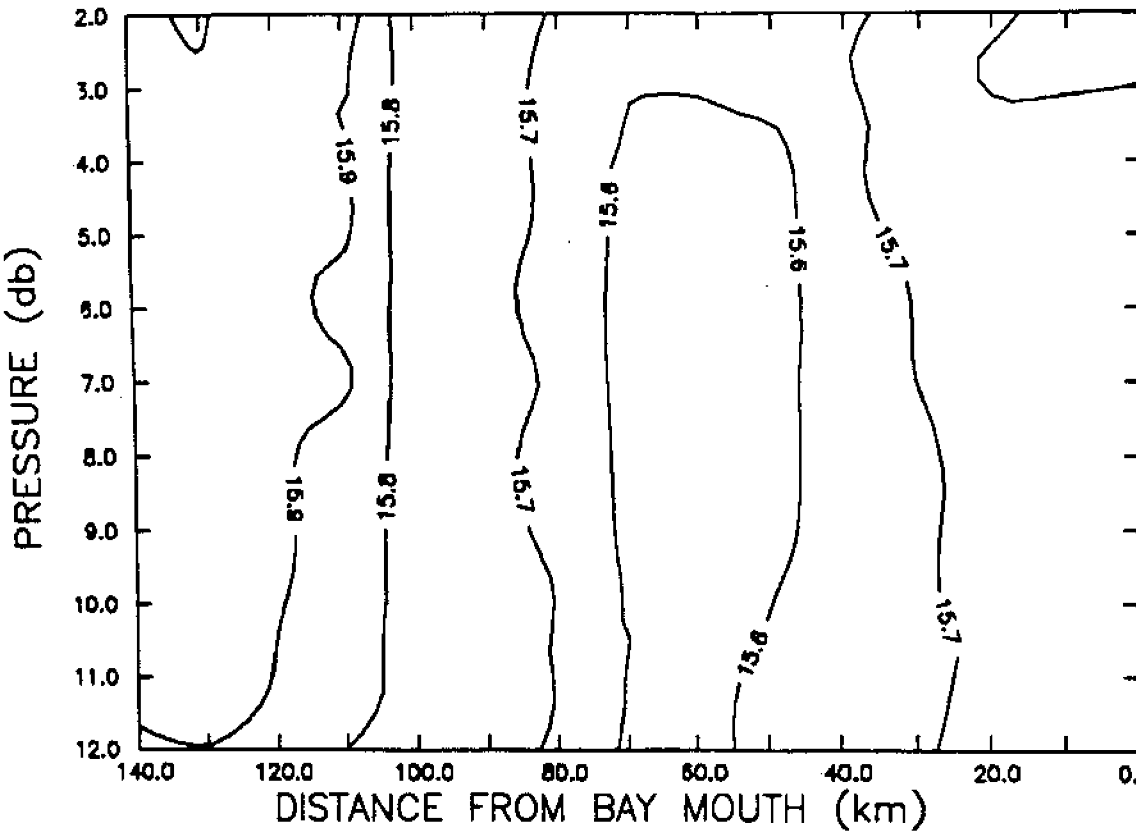

Figure D1. Profile of temperature for Scenic-3 (28-30 October 1986). Isotherms are in degrees Celsius.

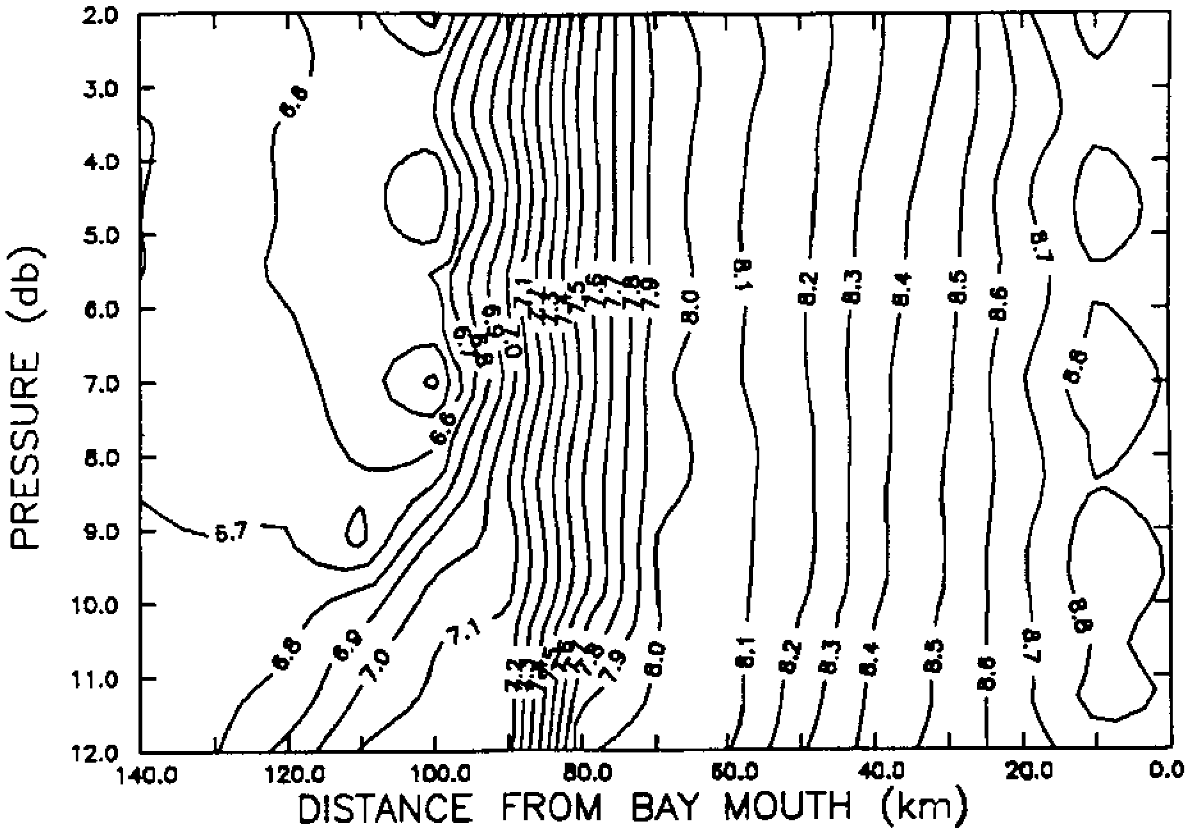

Figure D2. Profile of temperature for Scenic-4 (3-4 December 1986). Isotherms are in degrees Celsius.

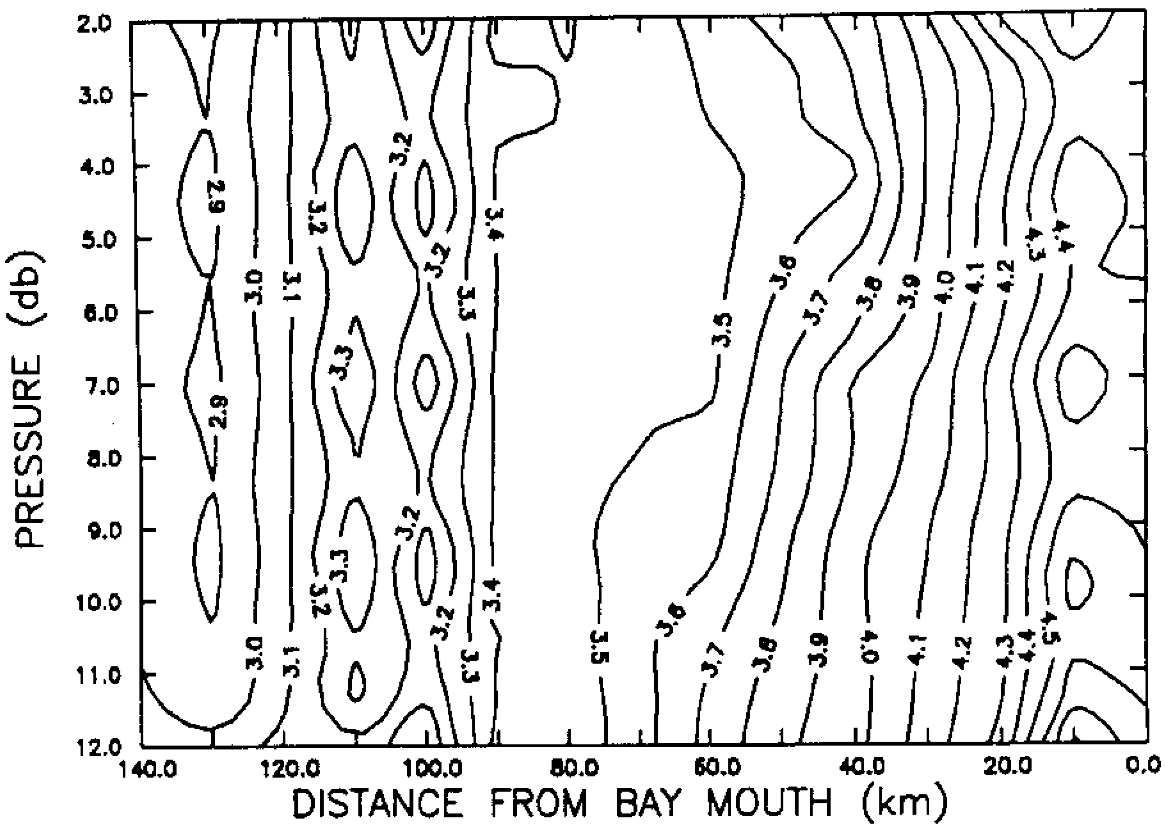

Figure D3. Profile of temperature for Scenic-5 (11-12 January 1987). Isotherms are in degress Celsius.

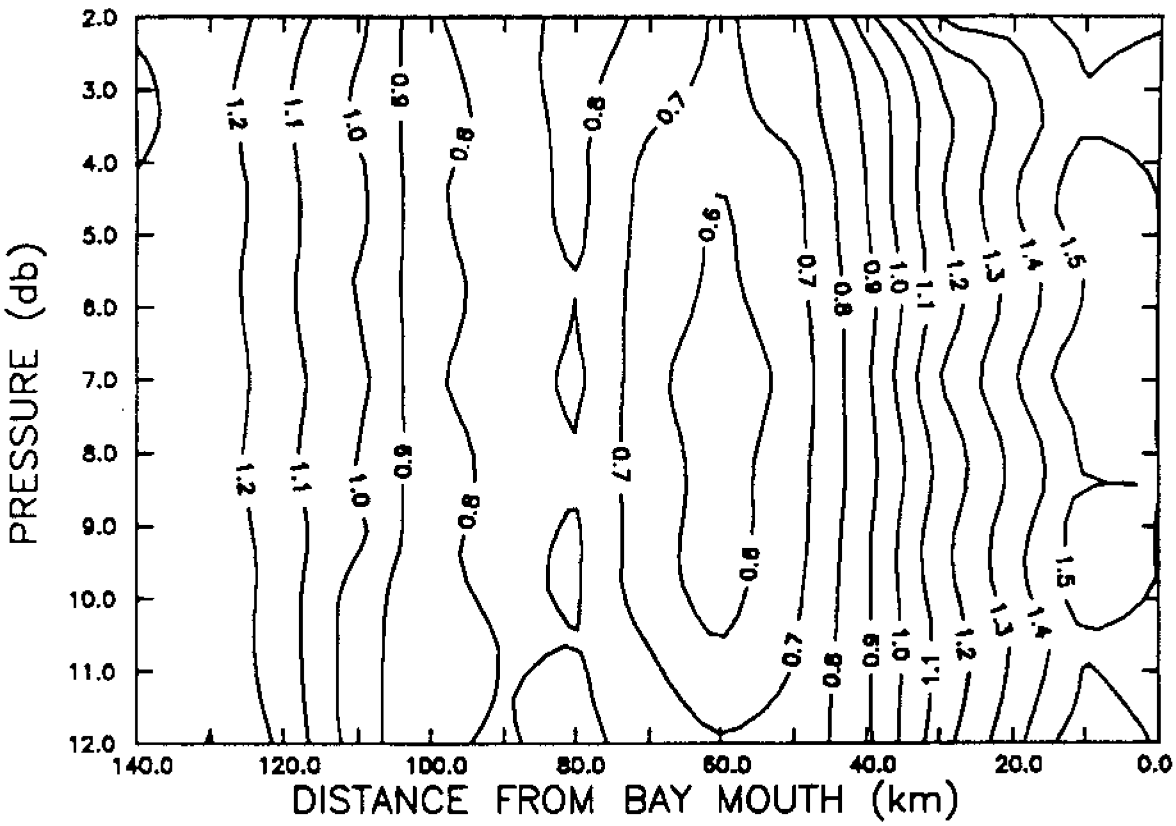

Figure D4. Profile of temperature for Scenic-6 (18-19 February 1987). Isotherms are in degrees Celsius.

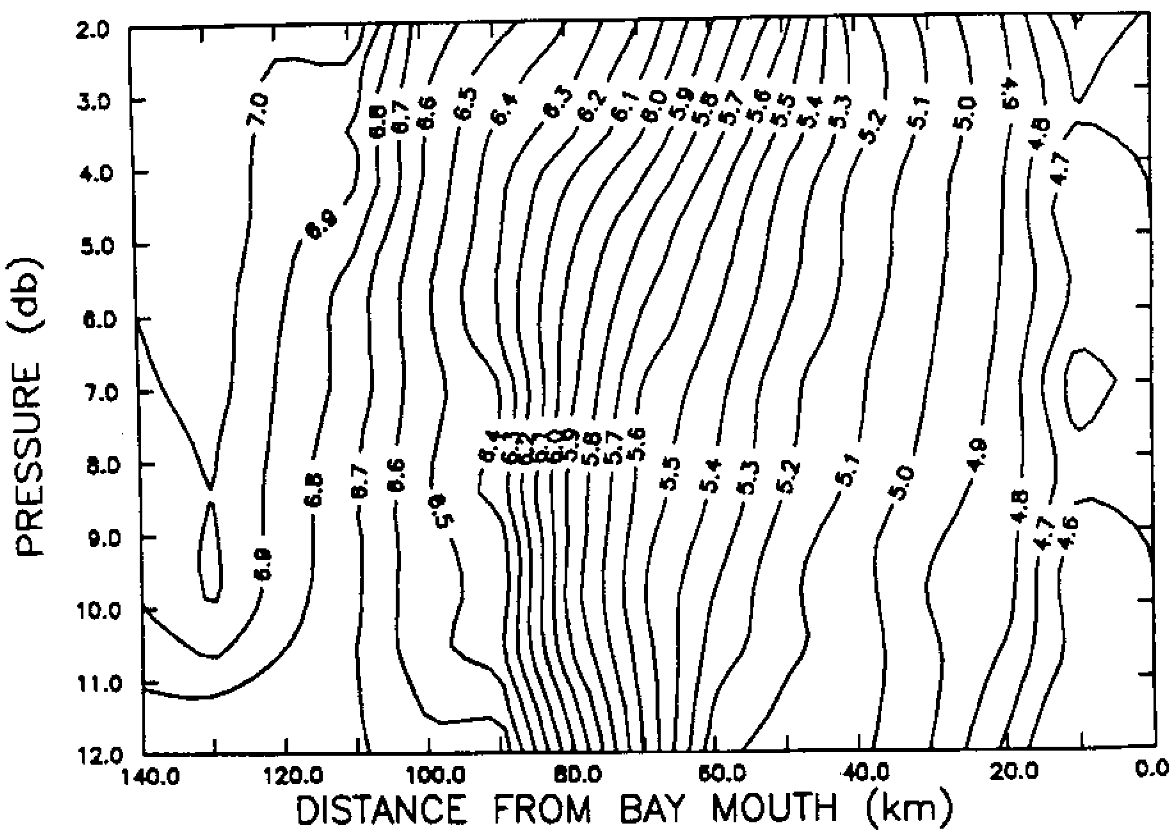

Figure D5. Profile of temperature for Scenic-8 (21-23 March 1987). Isotherms are in degrees Celsius.

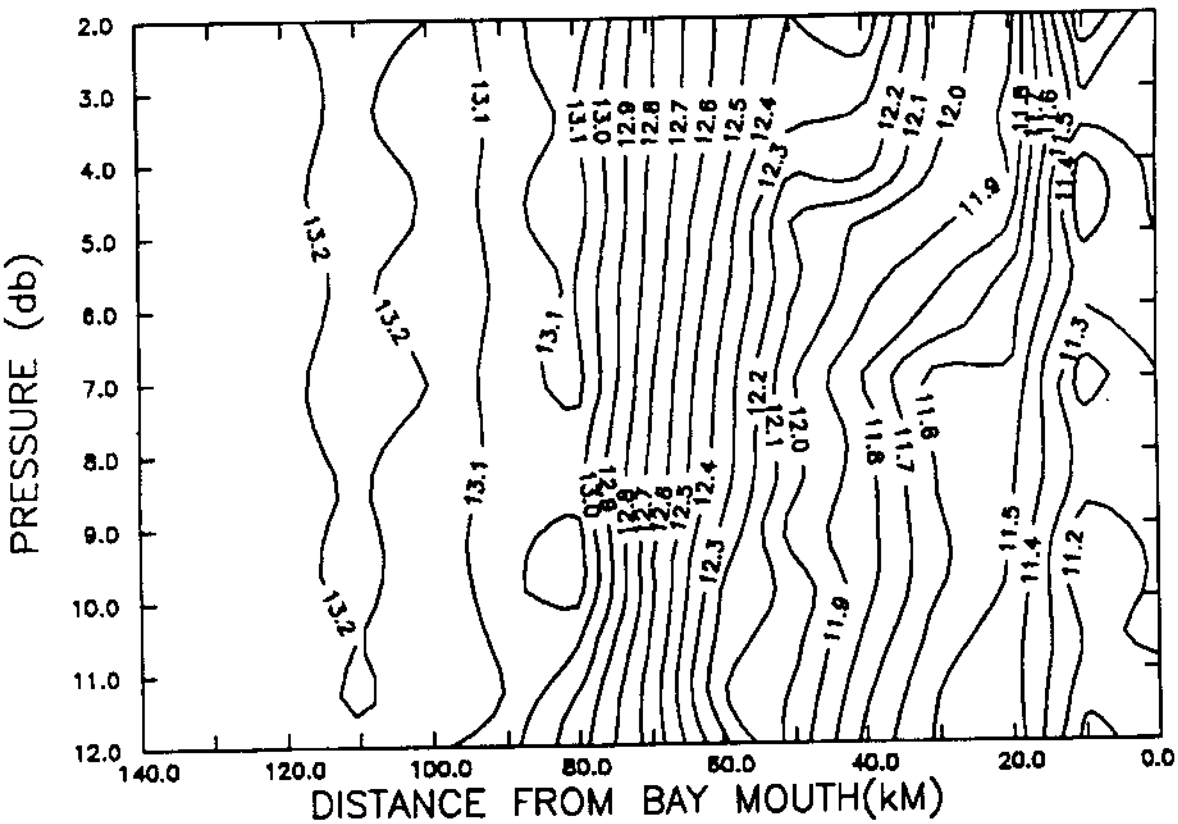

Figure D6. Profile of temperature for Scenic-10 (27-30 April 1987). Isotherms are in degrees Celsius.

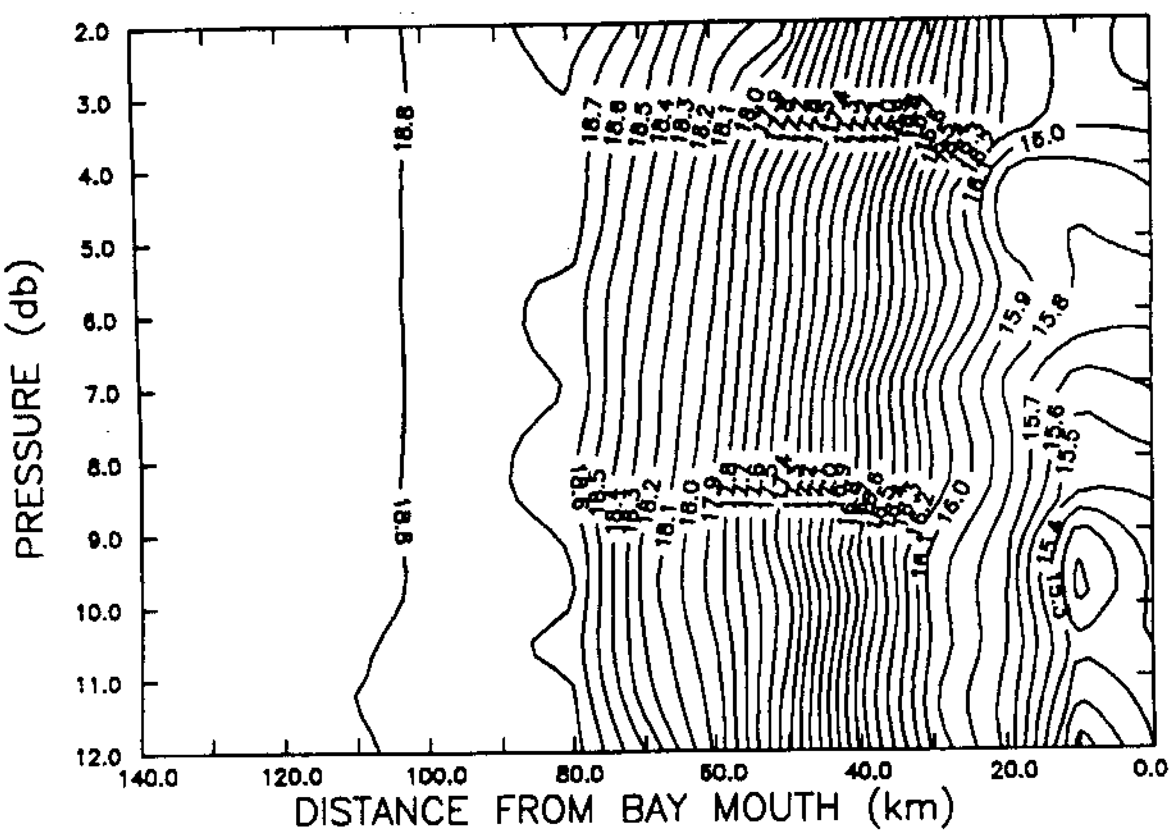

Figure D7. Profile of temperature for Scenic-11 (26-28 May 1987). Isotherms are in degrees Celsius.

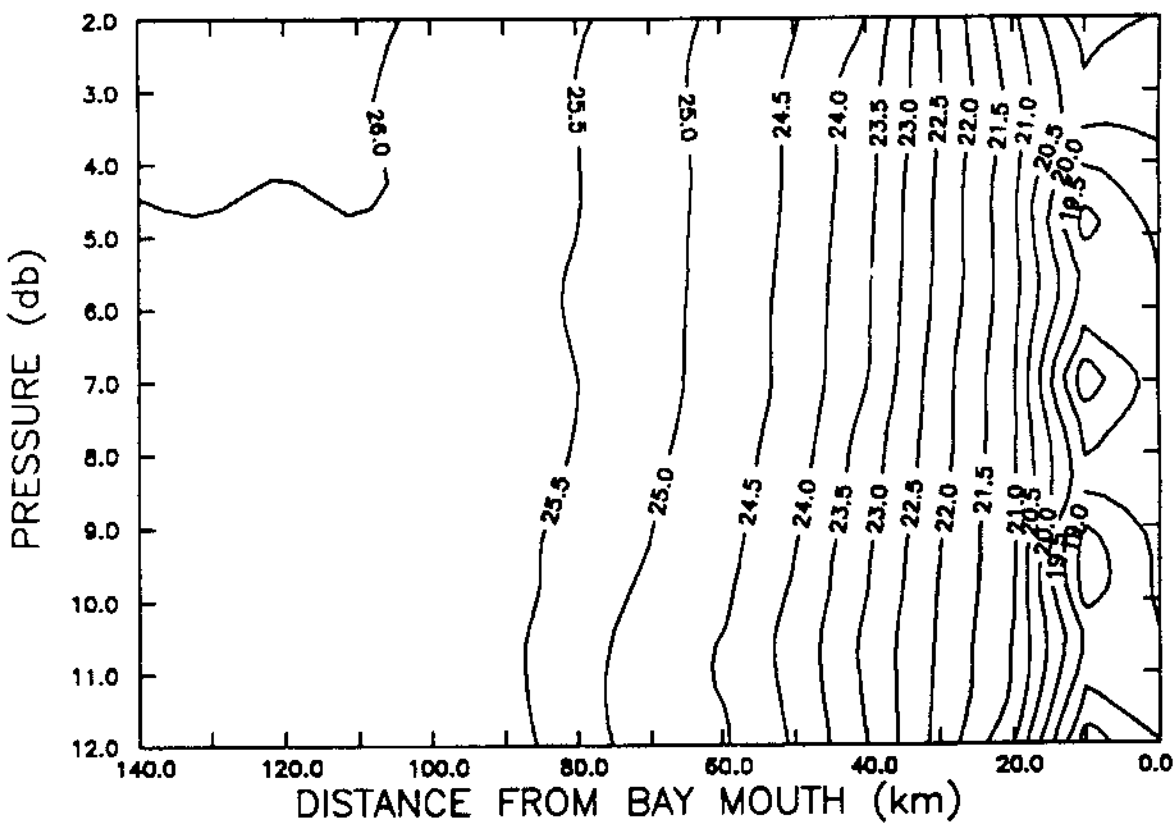

Figure D8. Profile of temperature for Scenic-12 (24-26 June 1987). Isotherms are in degrees Celsius.

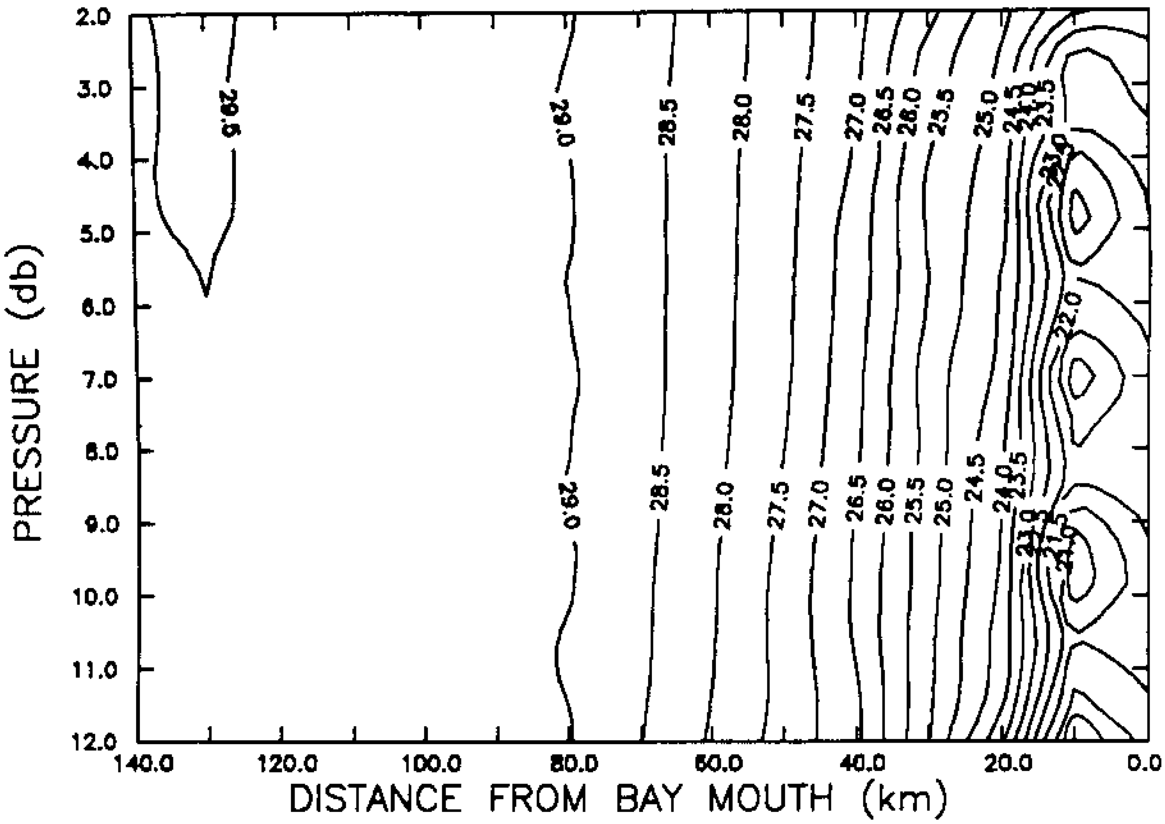

Figure D9. Profile of temperature for Scenic-13 (26-30 July 1987). Isotherms are in degrees Celsius.

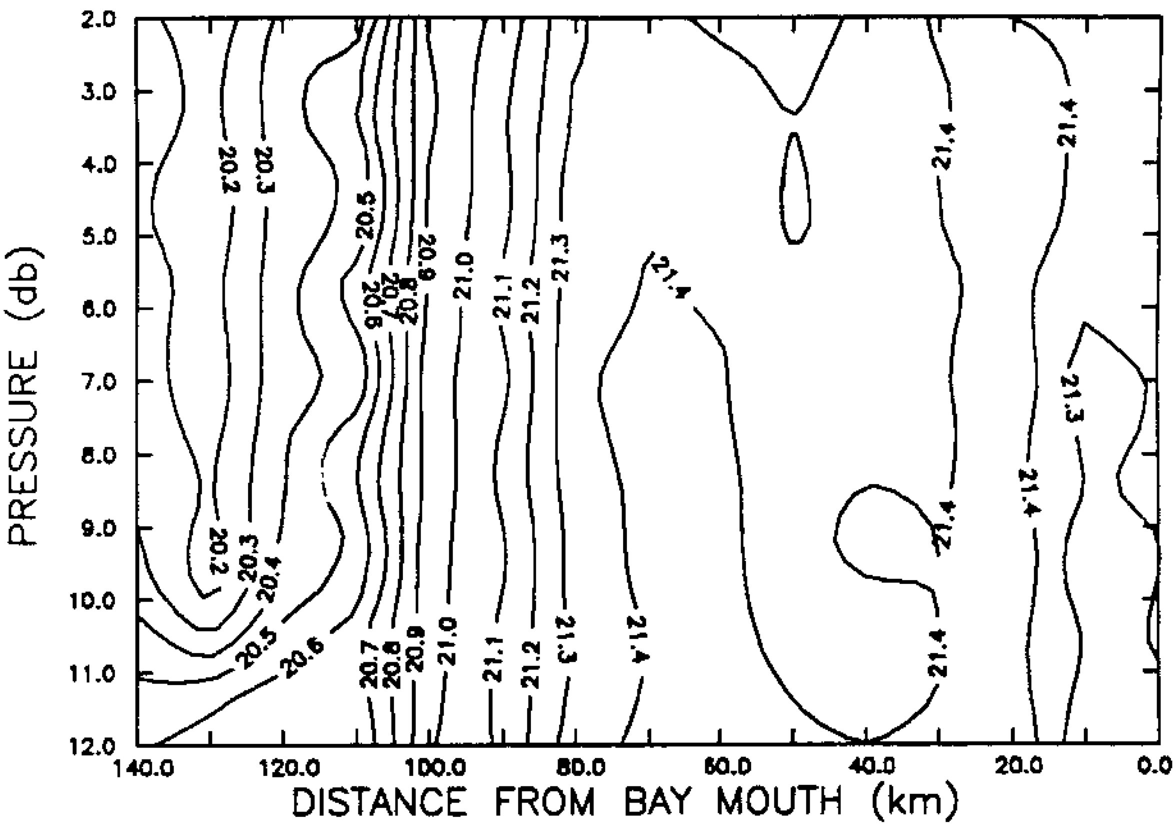

Figure D10. Profile of temperature for Scenic-15 (29 September - 1 October 1987). Isotherms are in degrees Celsius.

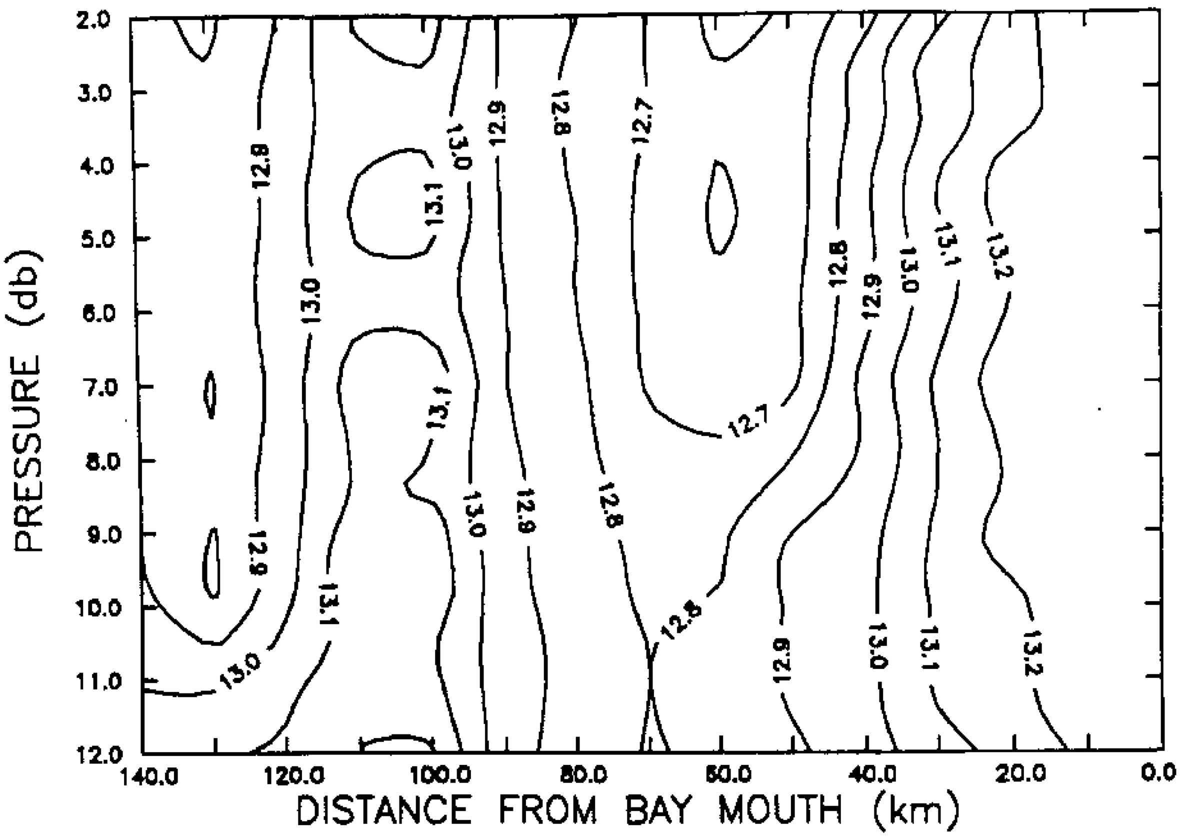

Figure D11. Profile of temperature for Scenic-16 (4-6 November 1987). Isotherms are in degrees Celsius.

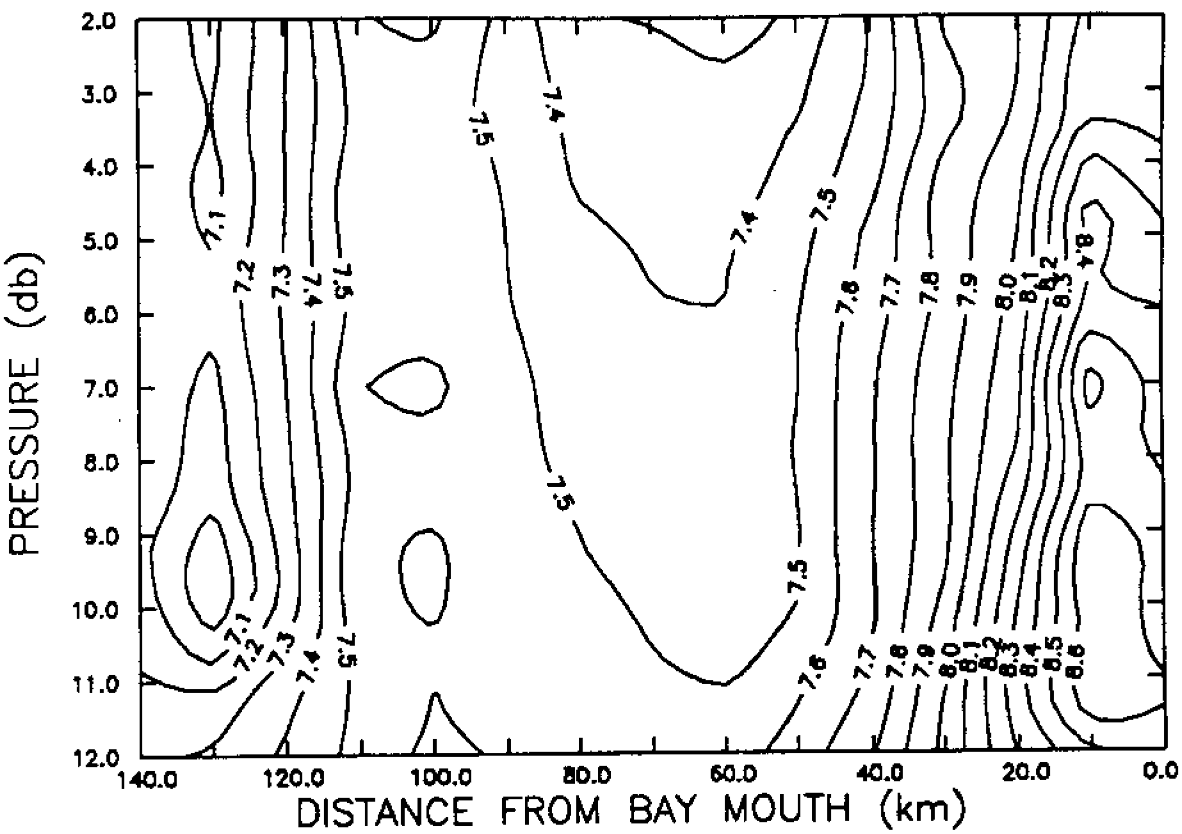

Figure D12. Profile of temperature for Scenic-17 (5-7 December 1987). Isotherms are in degrees Celsius.

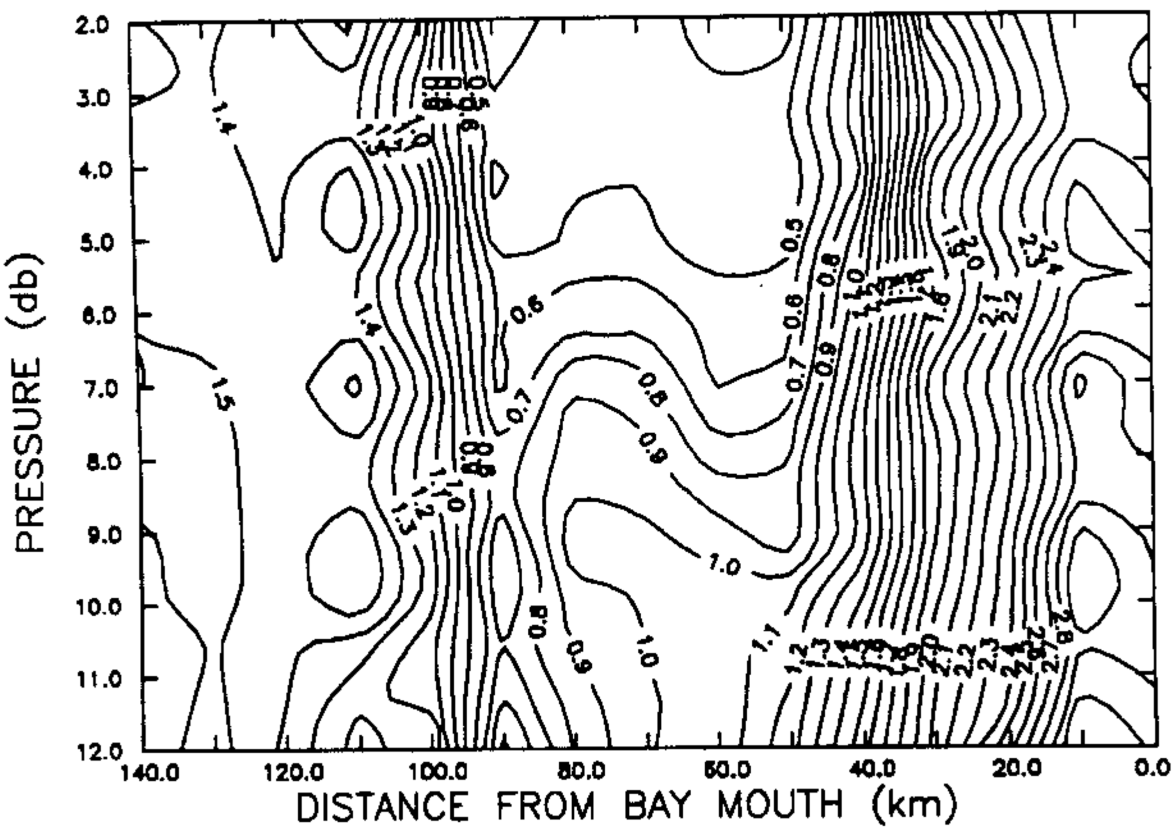

Figure D13. Profile of temperature for Scenic-18 (5-7 January 1988). Isotherms are in degrees Celsius.

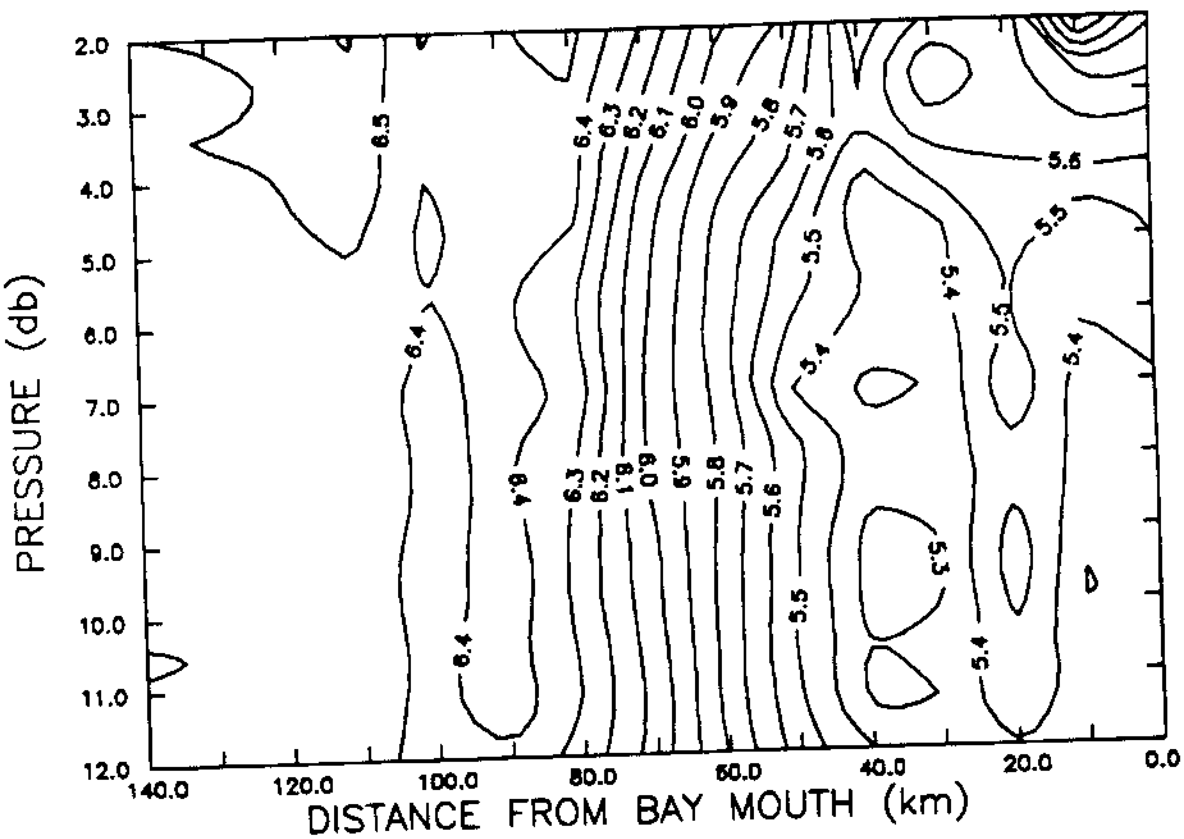

Figure D14. Profile of temperature for Scenic-20 (22-24 March 1988). Isotherms are in degrees Celsius.

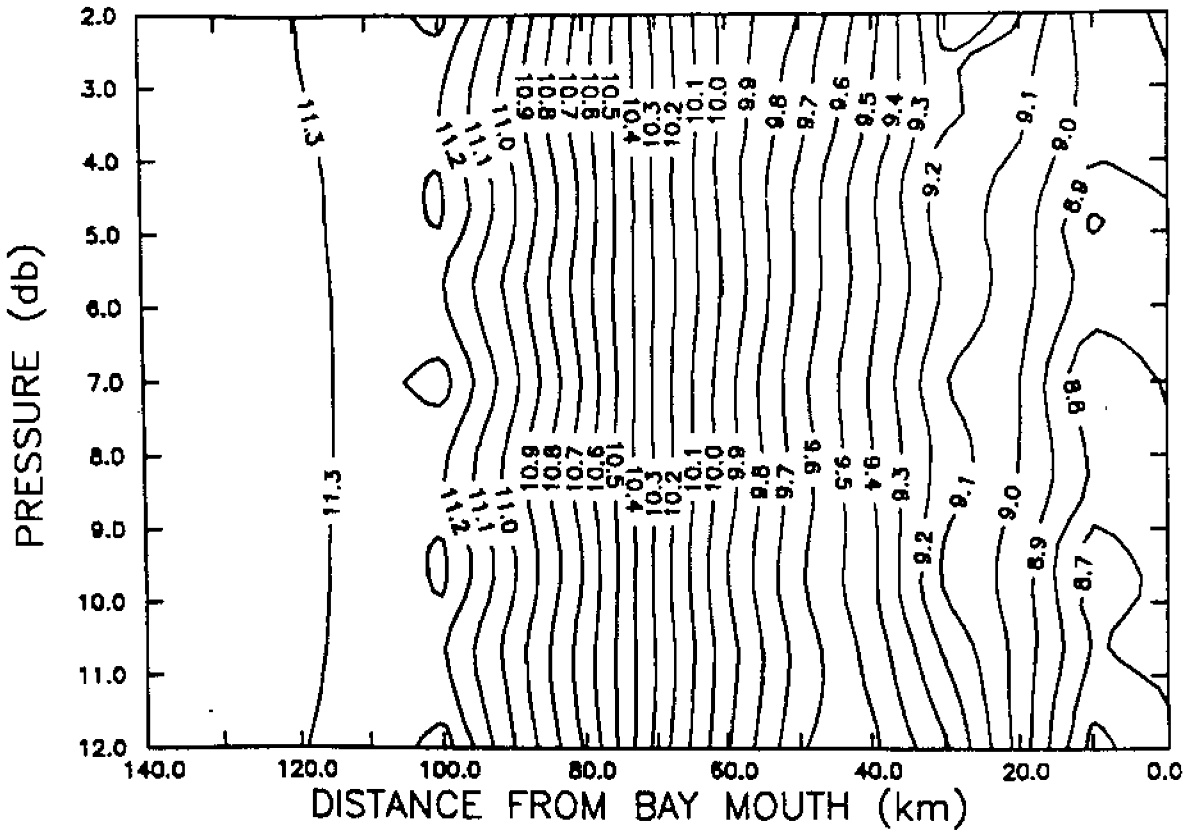

Figure D15. Profile of temperature for Scenic-21 (11-14 April 1988). Isotherms are in degrees Celsius.

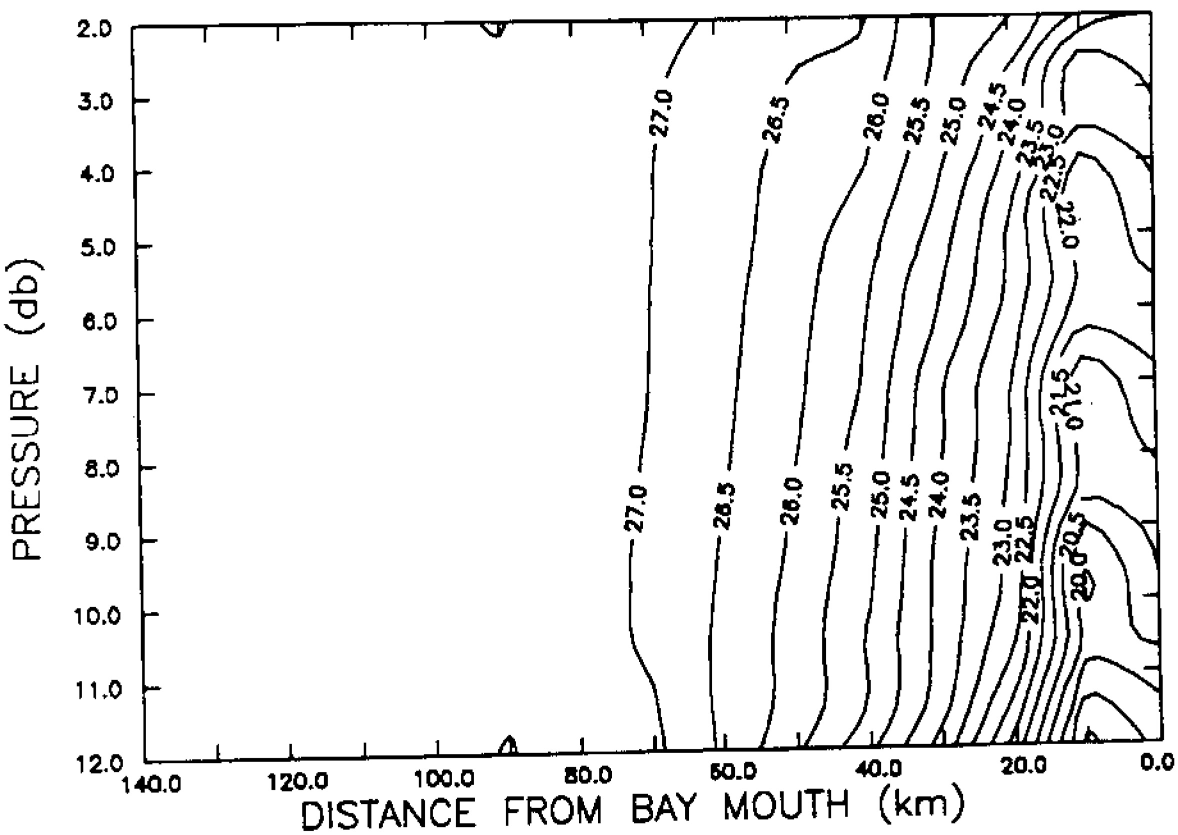

Figure D16. Profile of temperature for Scenic-23 (26-29 July 1988). Isotherms are in degrees Celsius.

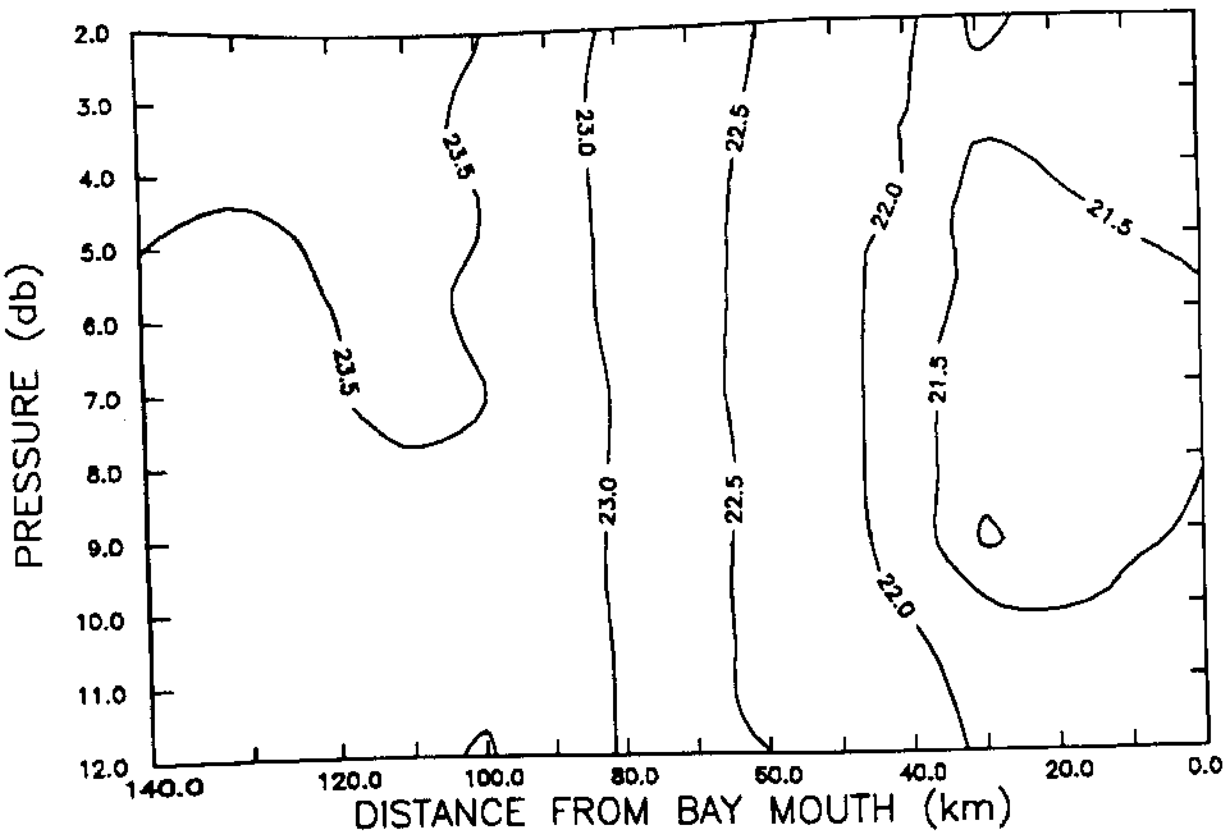

Figure D17. **Profile** of temperature for Scenic-24 (6-8 September 1988). Isotherms are in degrees Celsius.

E. SALINITY PROFILES

Profiles of salinity were constructed for the Delaware Estuary as a function of distance upstream from the mouth of Delaware Bay and depth below the surface. Depths are expressed in decibars pressure where 1 decibar (db) is equivalent to 1 meter of depth below the surface. Salinity is shown as isopleths in parts per thousand (ppt). Figures E1-E17 show salinity profiles for individual cruises. Isopleths are in intervals of 2 ppt.

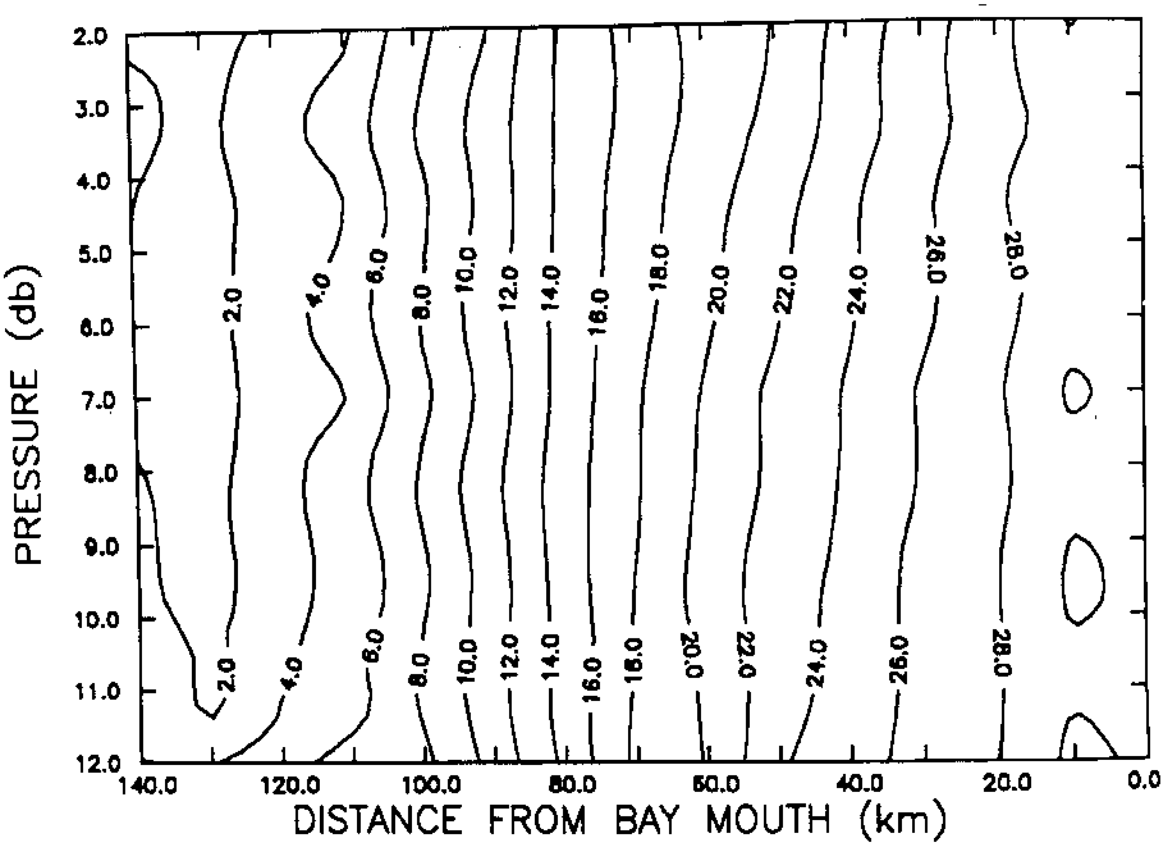

Figure E1. Profile of salinity for Scenic-3 (28-30 October 1986). Isopleths are in parts per thousand.

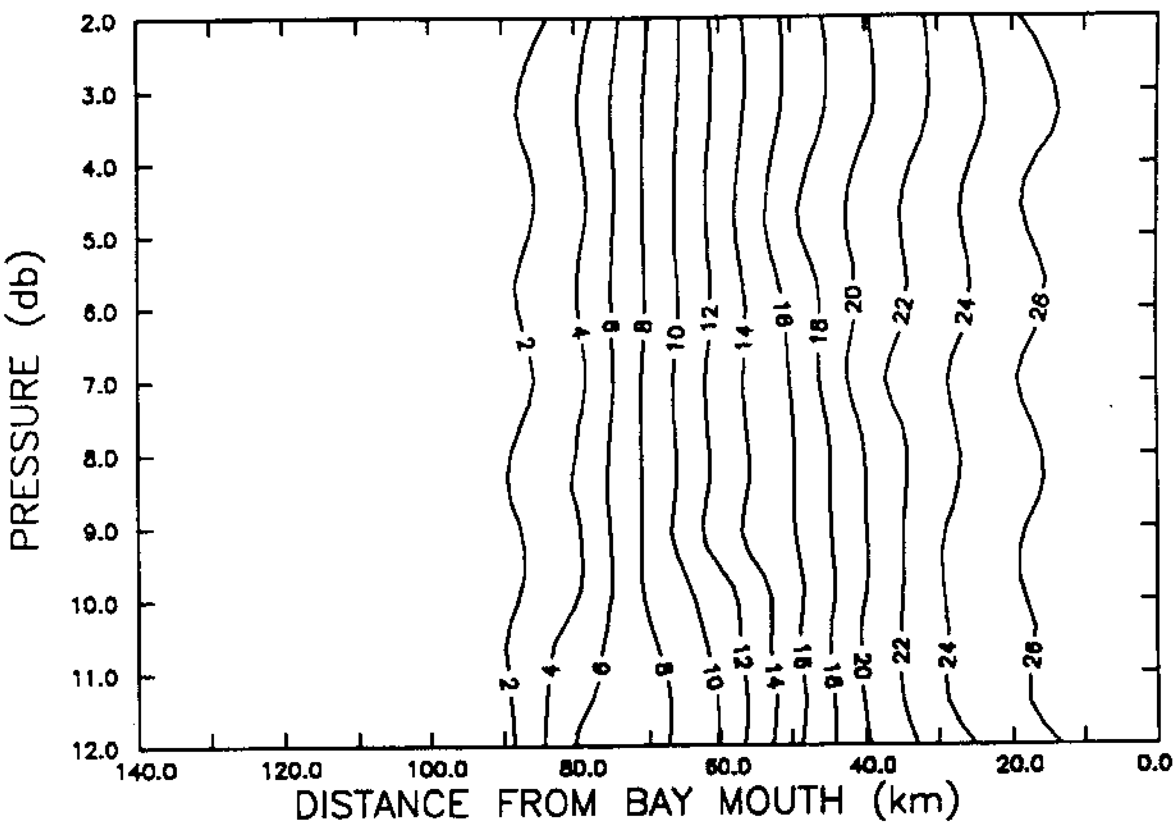

Figure E2. Profile of salinity for Scenic-4 (3-4 December 1986). Isopleths are in parts per thousand.

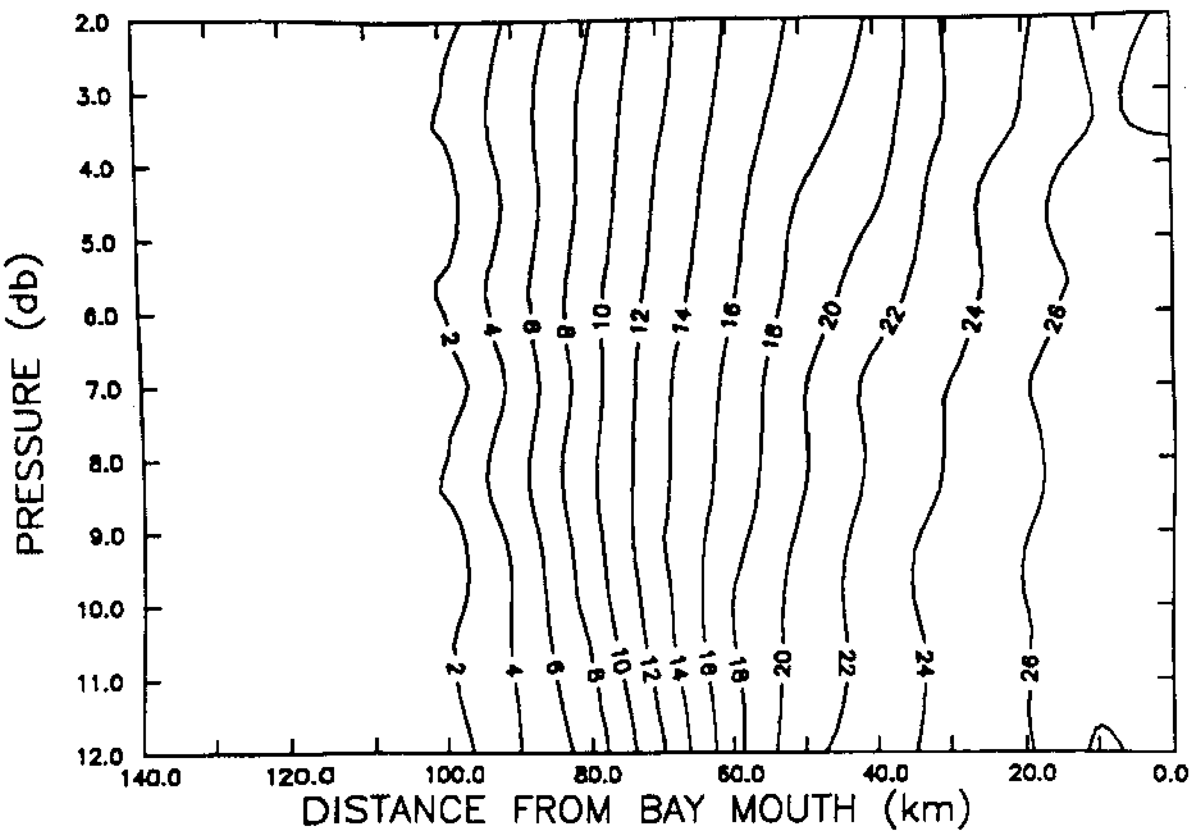

Figure E3. Profile of salinity for Scenic-5 (11-12 January 1987). Isopleths are in parts per thousand.

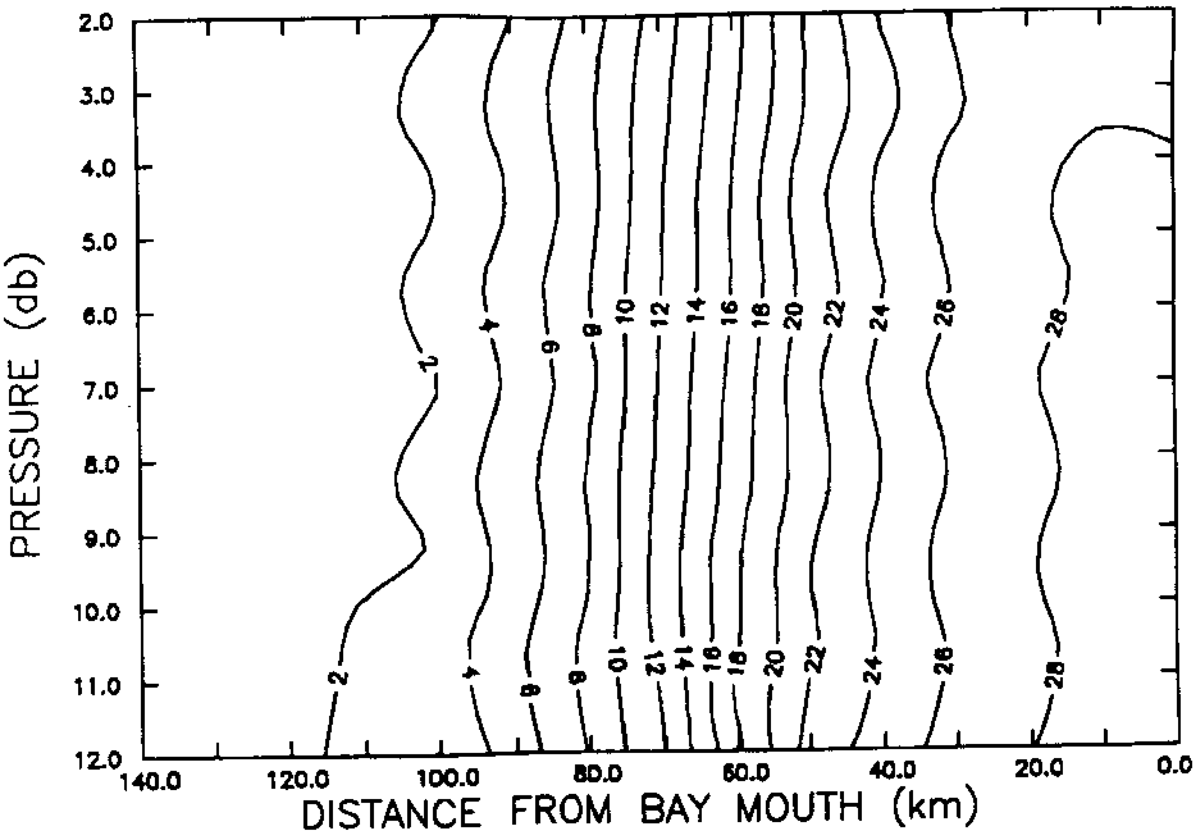

Figure E4. Profile of salinity for Scenic-6 (18-19 February 1987). Isopleths are in parts per thousand.

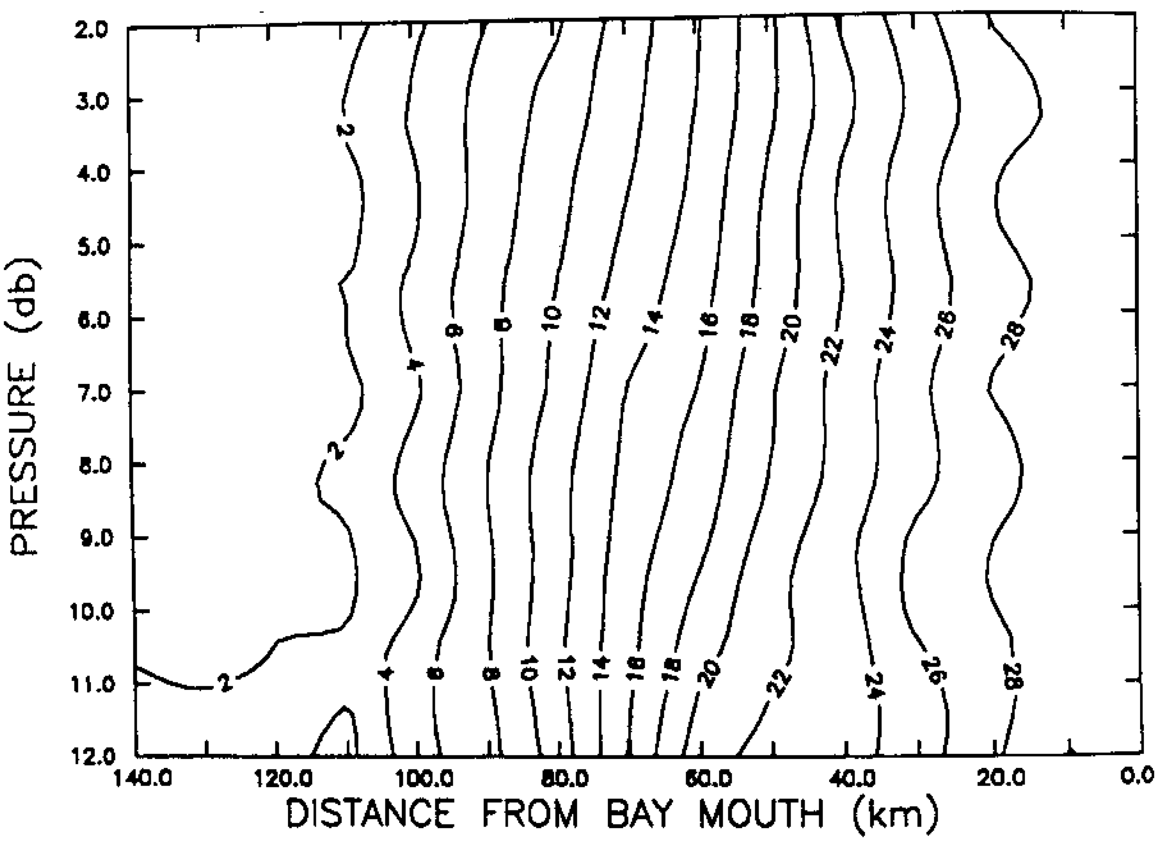

Figure E5. Profile of salinity for Scenic-8 (21-23 March 1987). Isopleths are in parts per thousand.

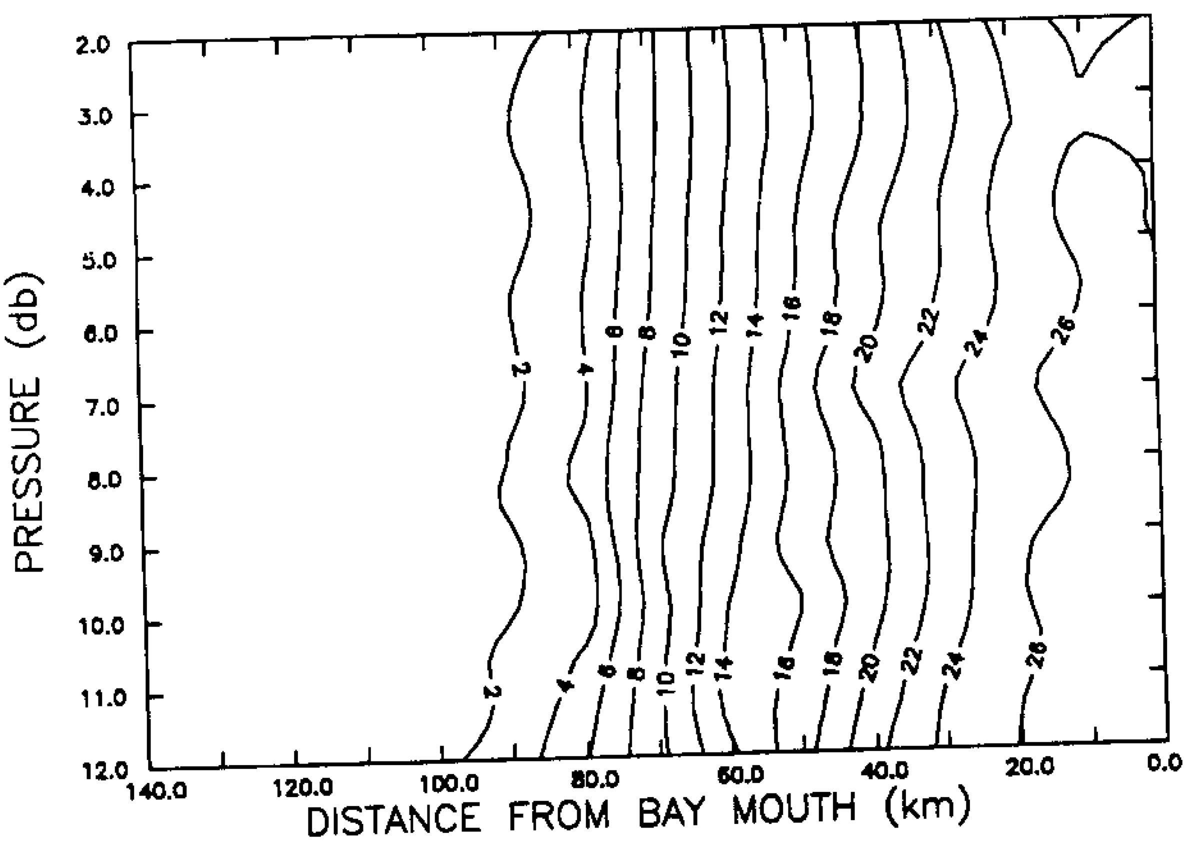

Figure E6. Profile of salinity for Scenic-10 (27-30 April 1987). Isopleths are in parts per thousand.

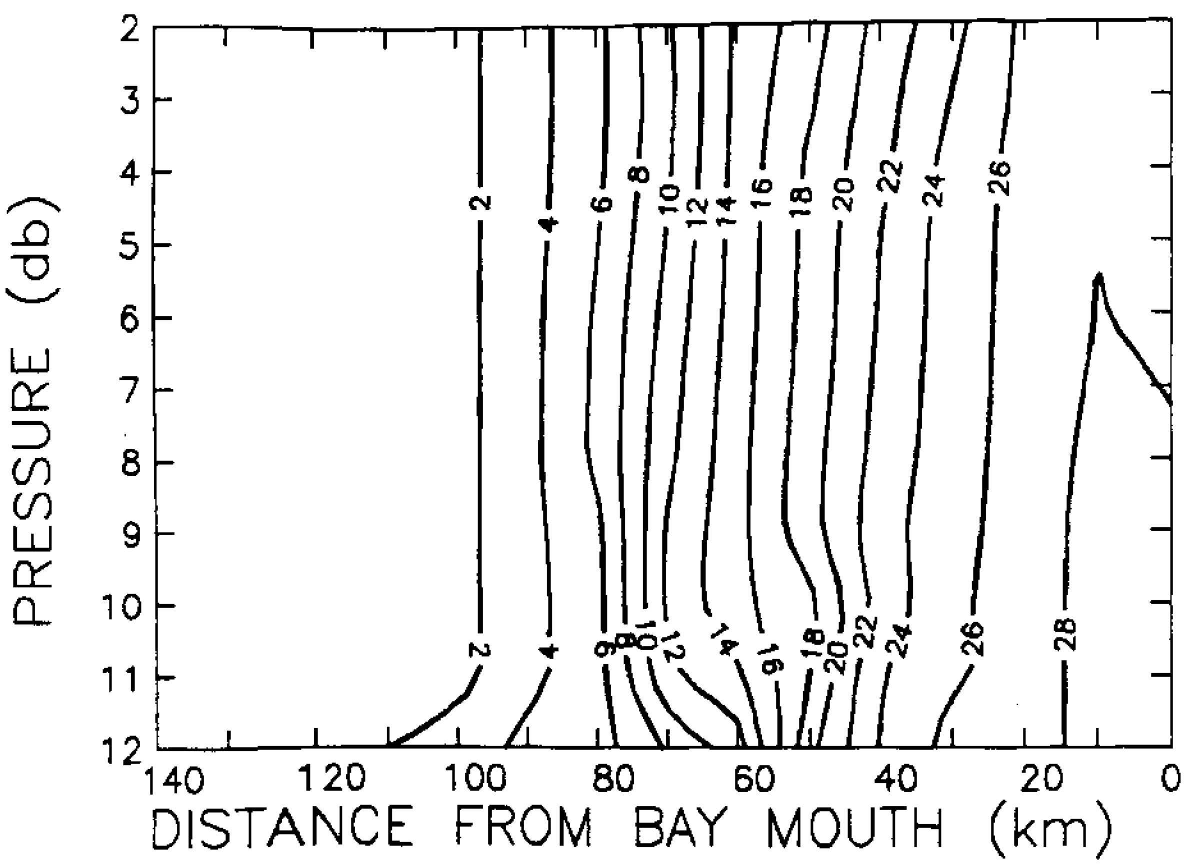

Figure E7. Profile of salinity for Scenic-11 (26-28 May 1987). Isopleths are in parts per thousand.

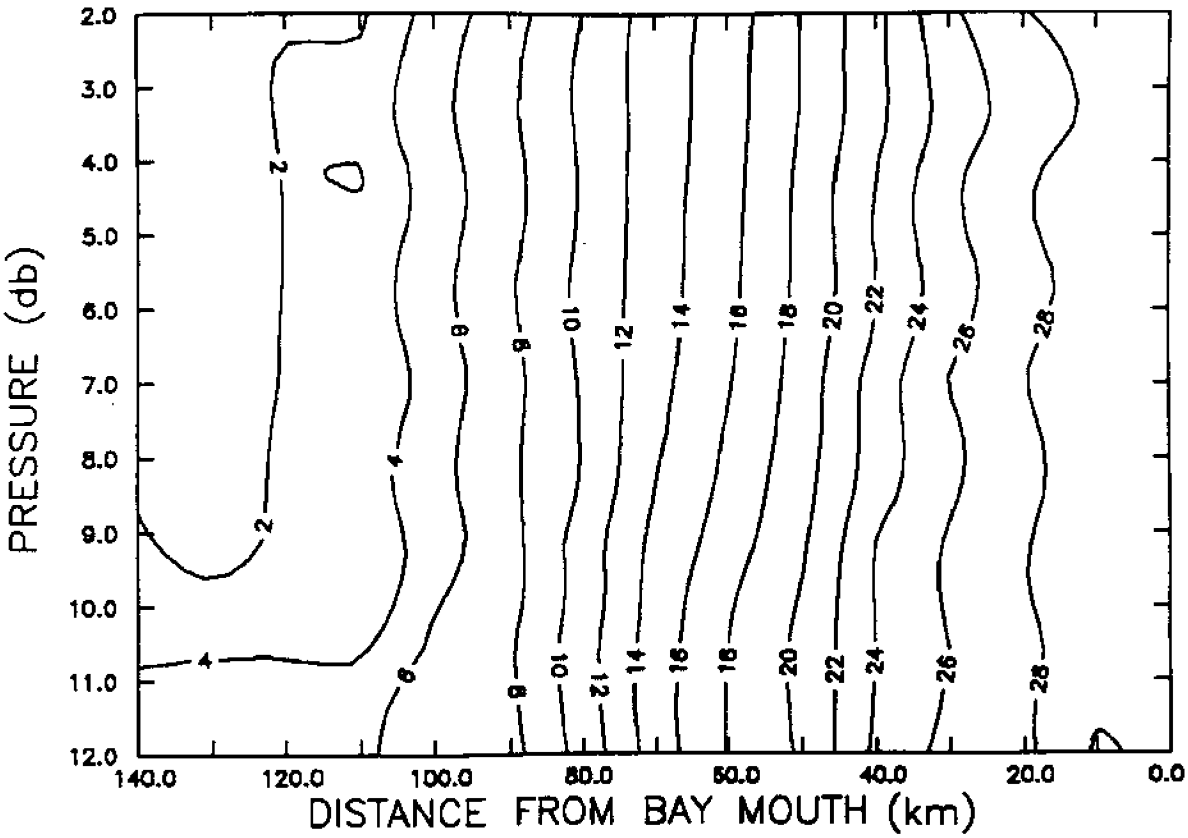

Figure E8. Profile of salinity for Scenic-12 (24-26 June 1987). Isopleths are in parts per thousand.

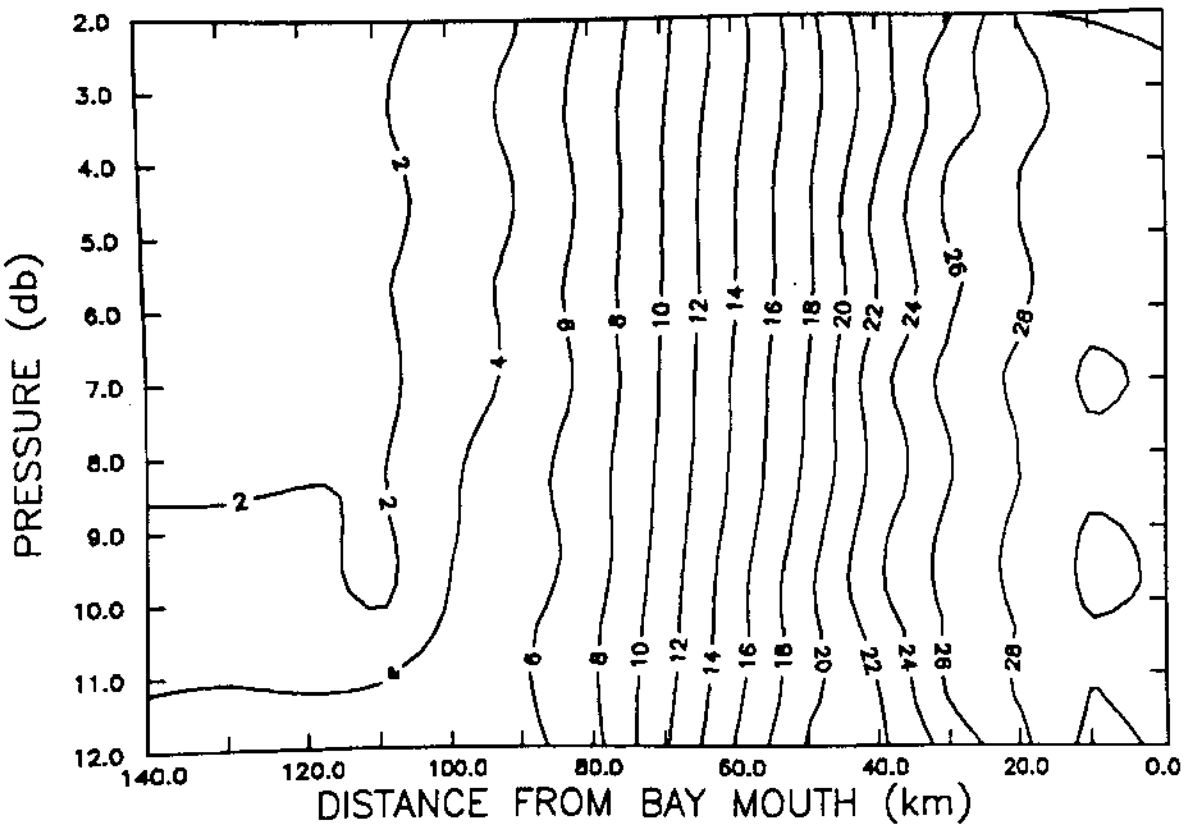

Figure E9. **Profile** of salinity for Scenic-13 (26-30 July 1987). Isopleths are in parts per thousand.

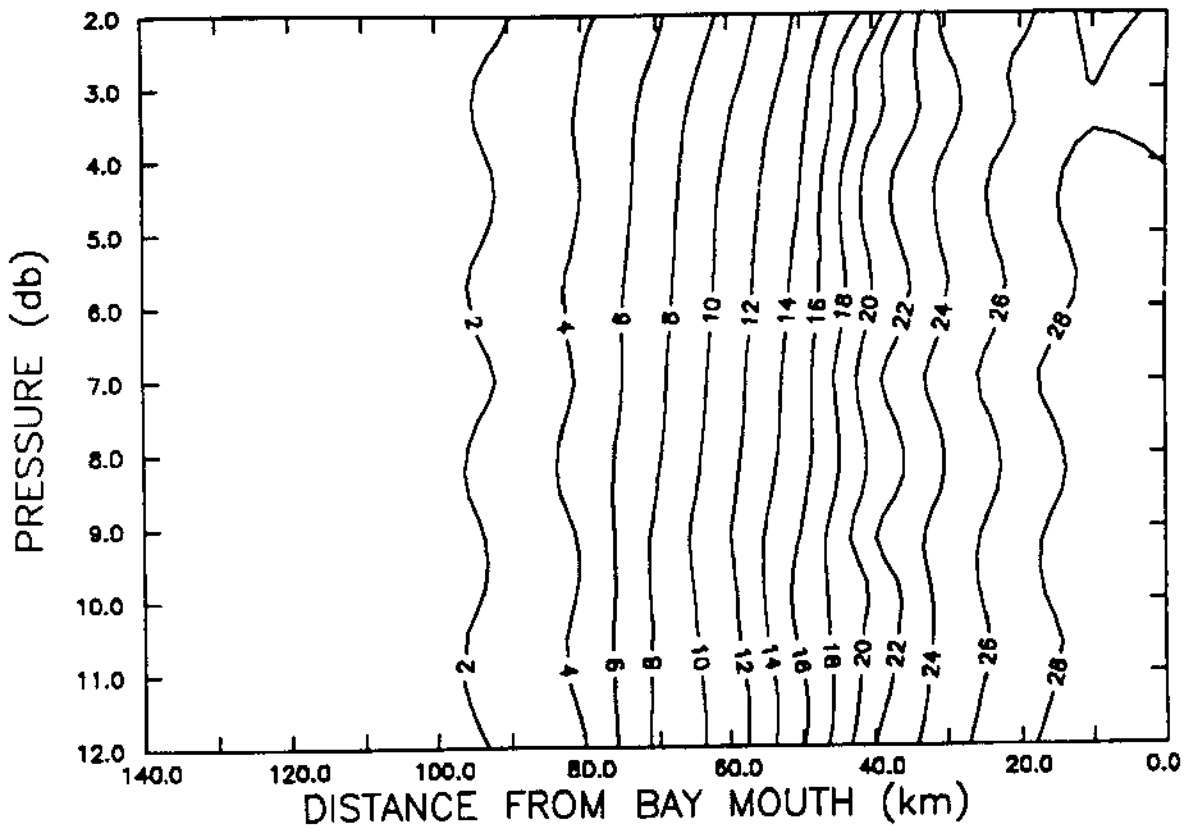

Figure E10. Profile of salinity for Scenic-15 (29 September - 1 October 1987). Isopleths are in parts per thousand.

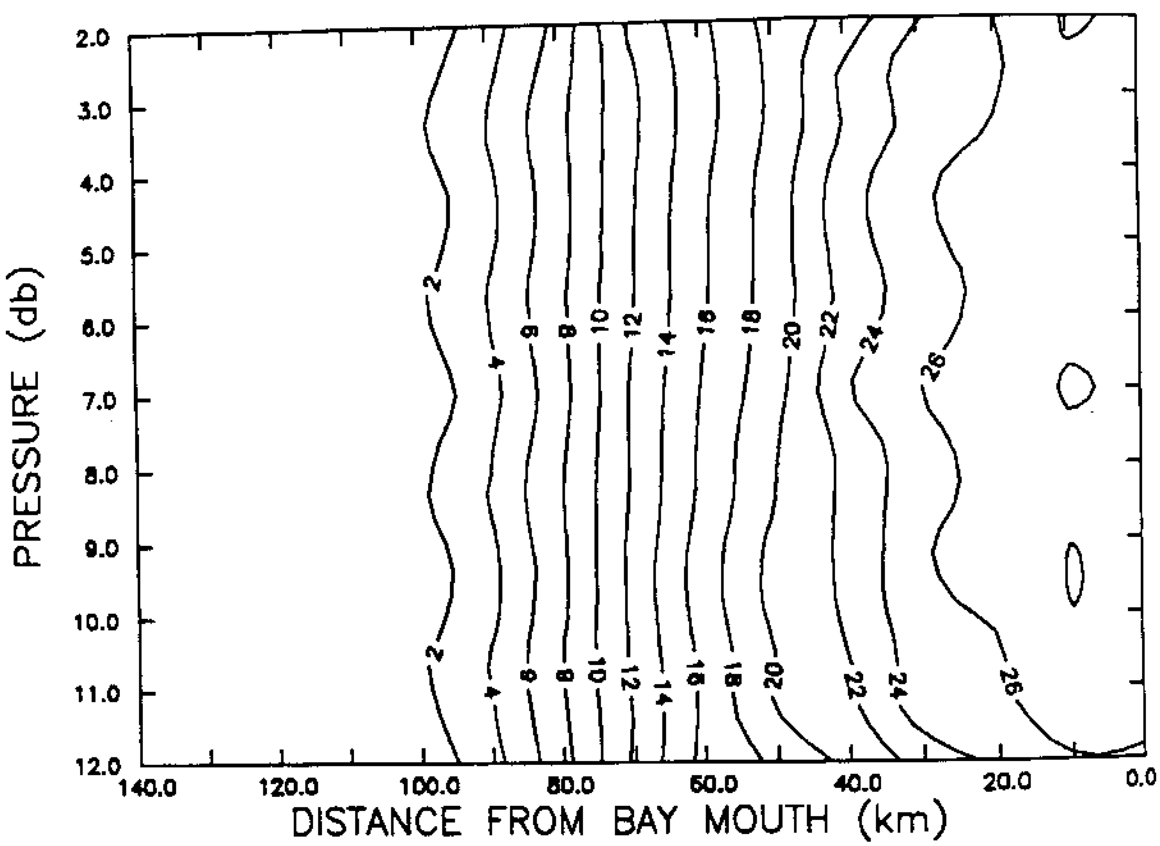

Figure E11. Profile of salinity for Scenic-16 (4-6 November 1987). Isopleths are in parts per thousand.

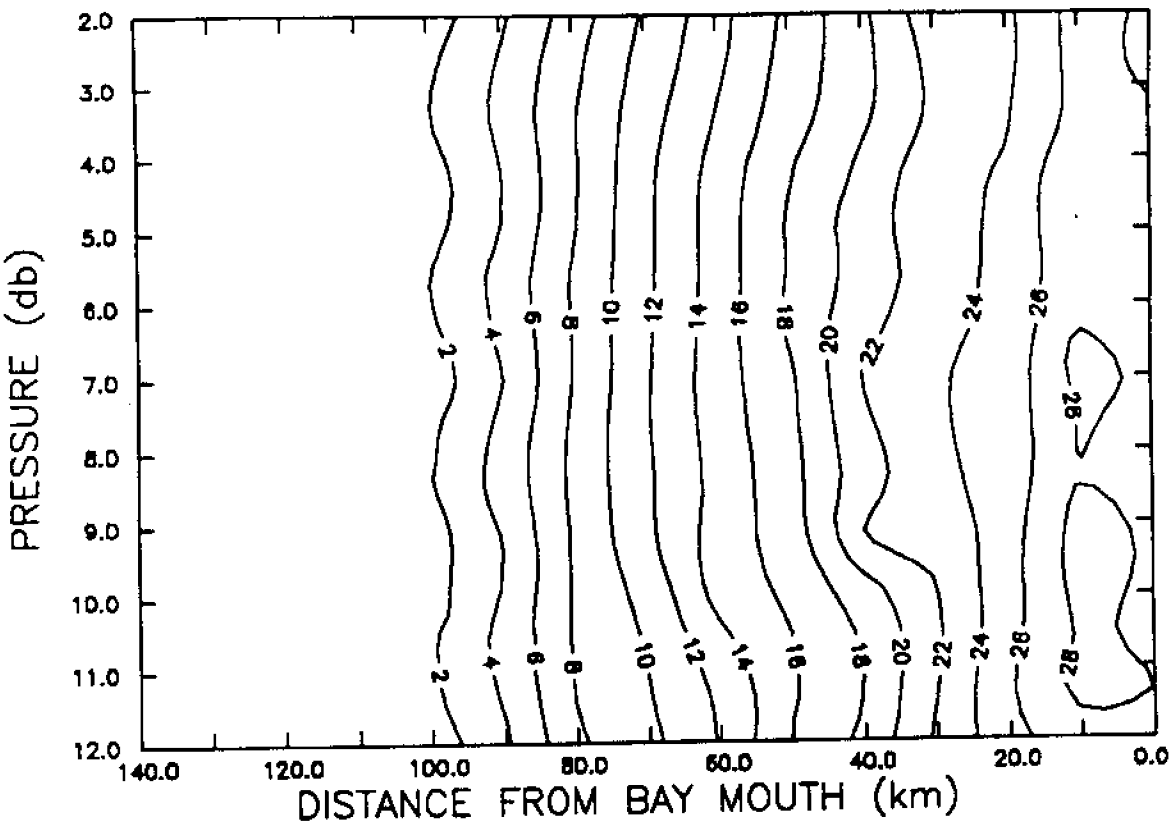

Figure E12. Profile of salinity for Scenic-17 (5-7 December 1987). Isopleths are in parts per thousand.

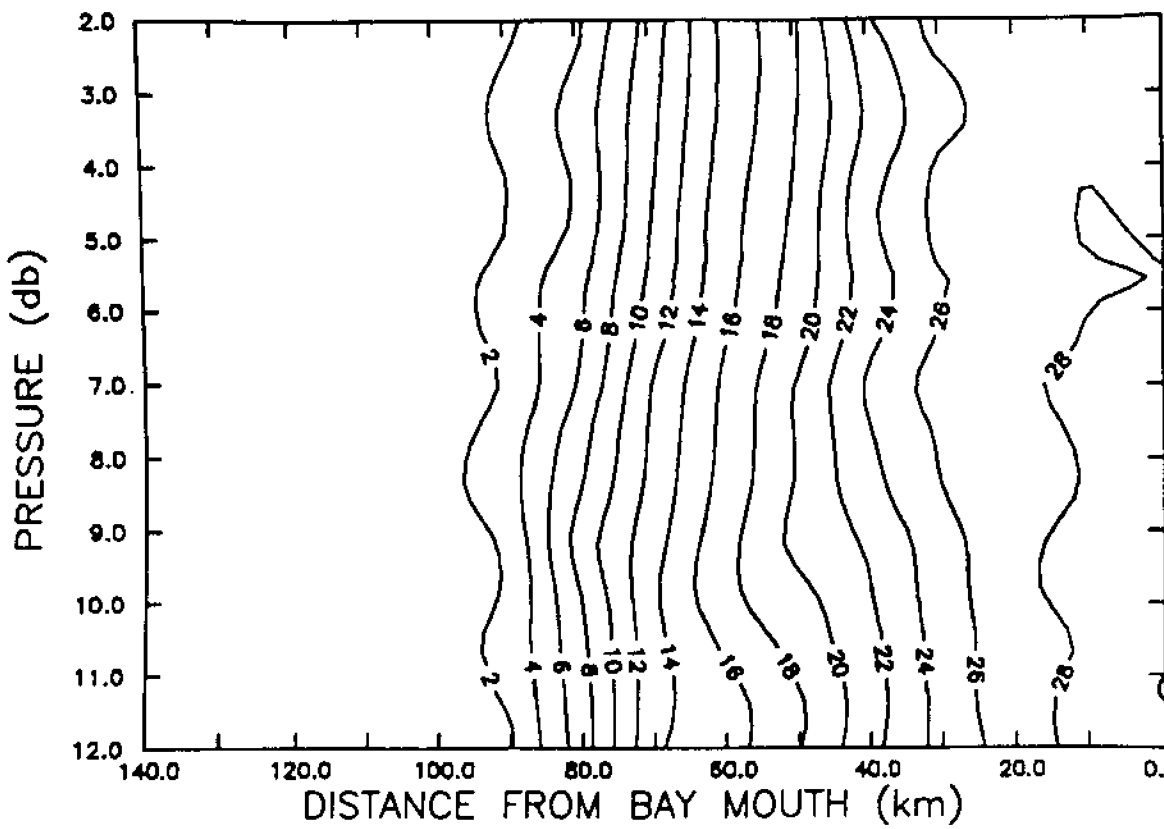

Figure E13. Profile of salinity for Scenic-18 (5-7 January 1988). Isopleths are in parts per thousand.

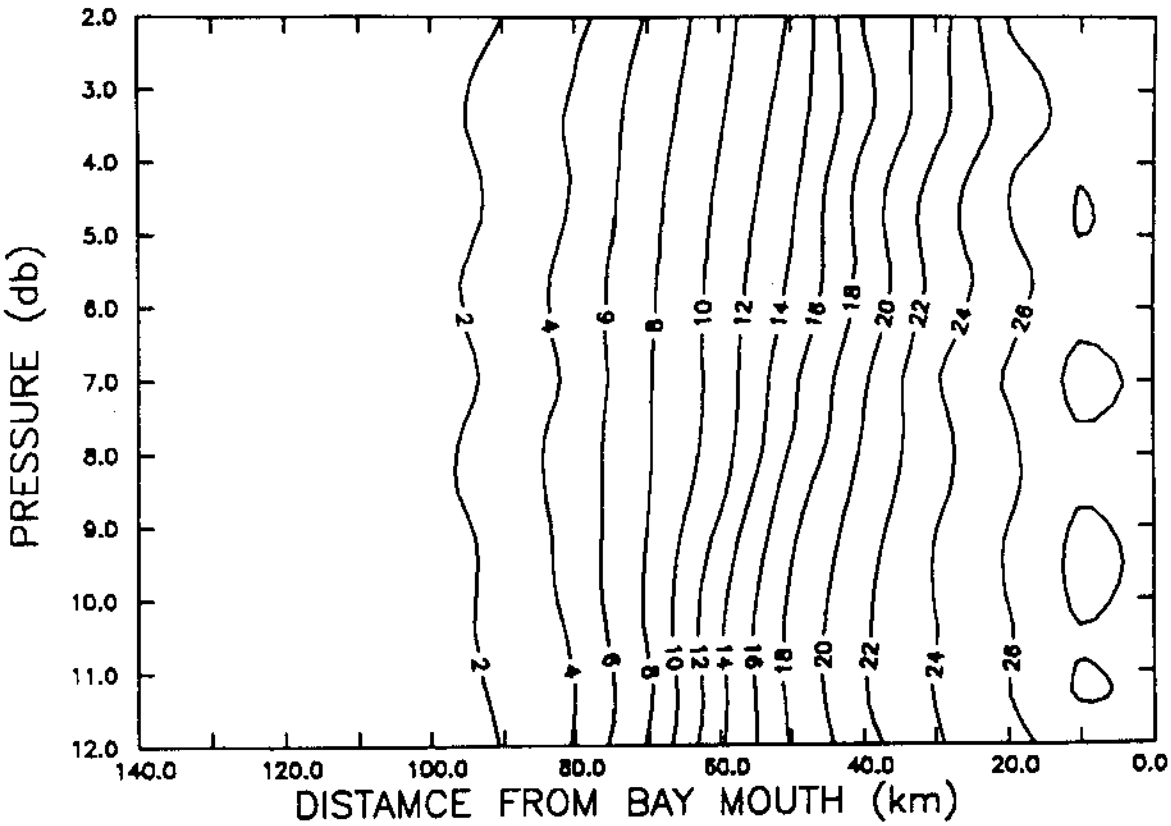

Figure E14. Profile of salinity for Scenic-20 (22-24 March 1988). Isopleths are in parts per thousand.

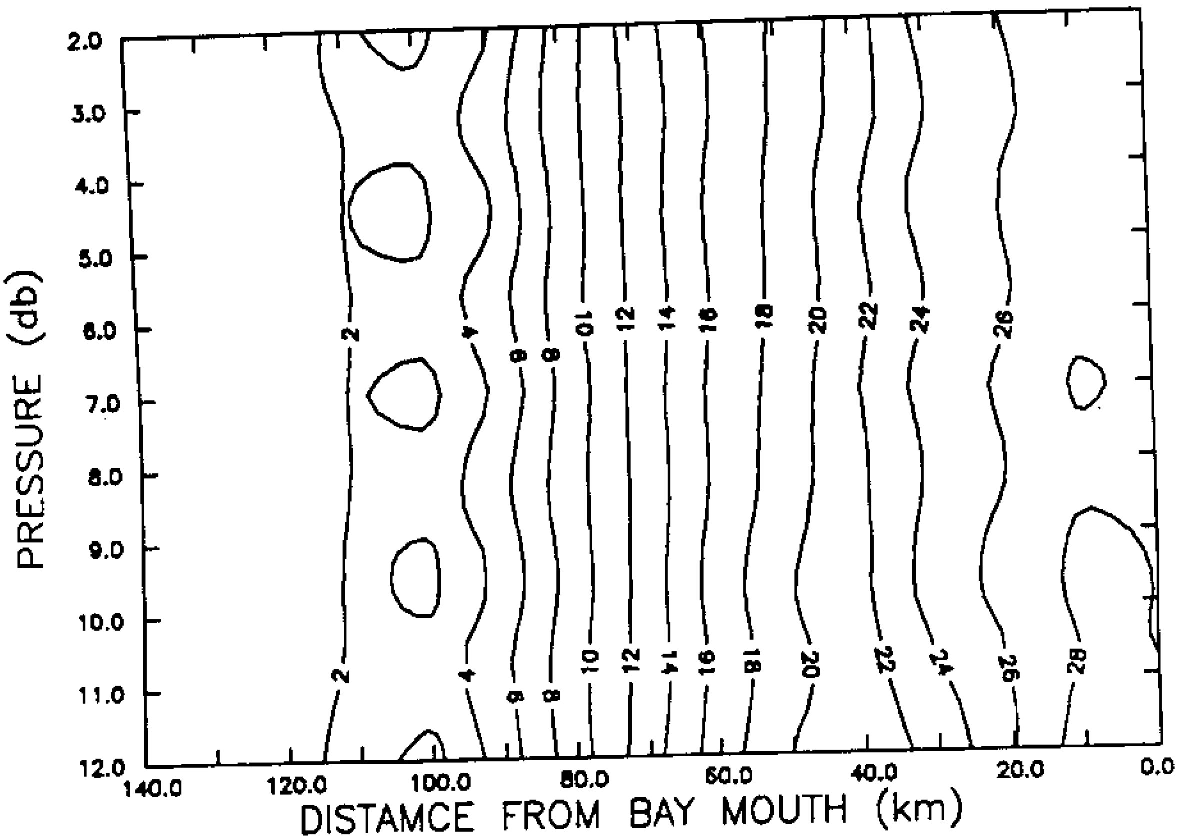

Figure E15. Profile of salinity for Scenic-21 (11-14 April 1988). Isopleths are in parts per thousand.

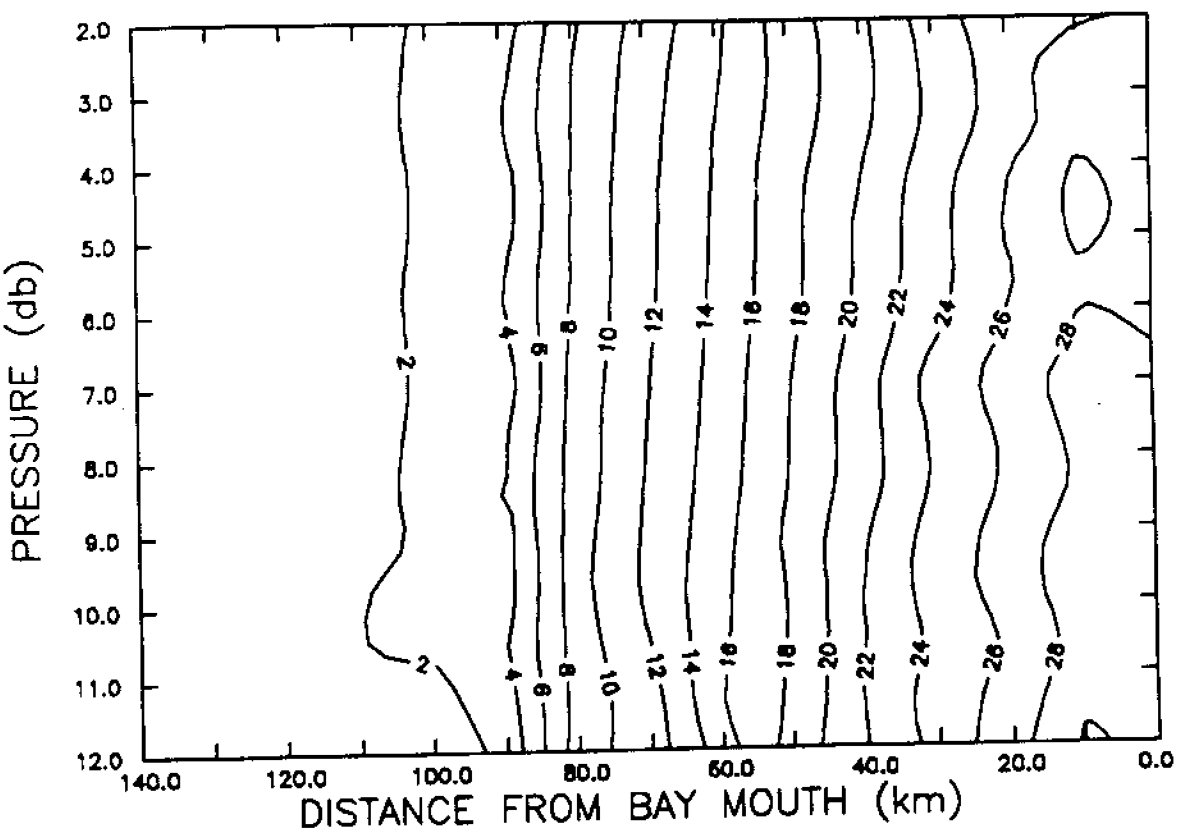

Figure E16. Profile of salinity for Scenic-23 (26-29 July 1988). Isopleths are in parts per thousand.

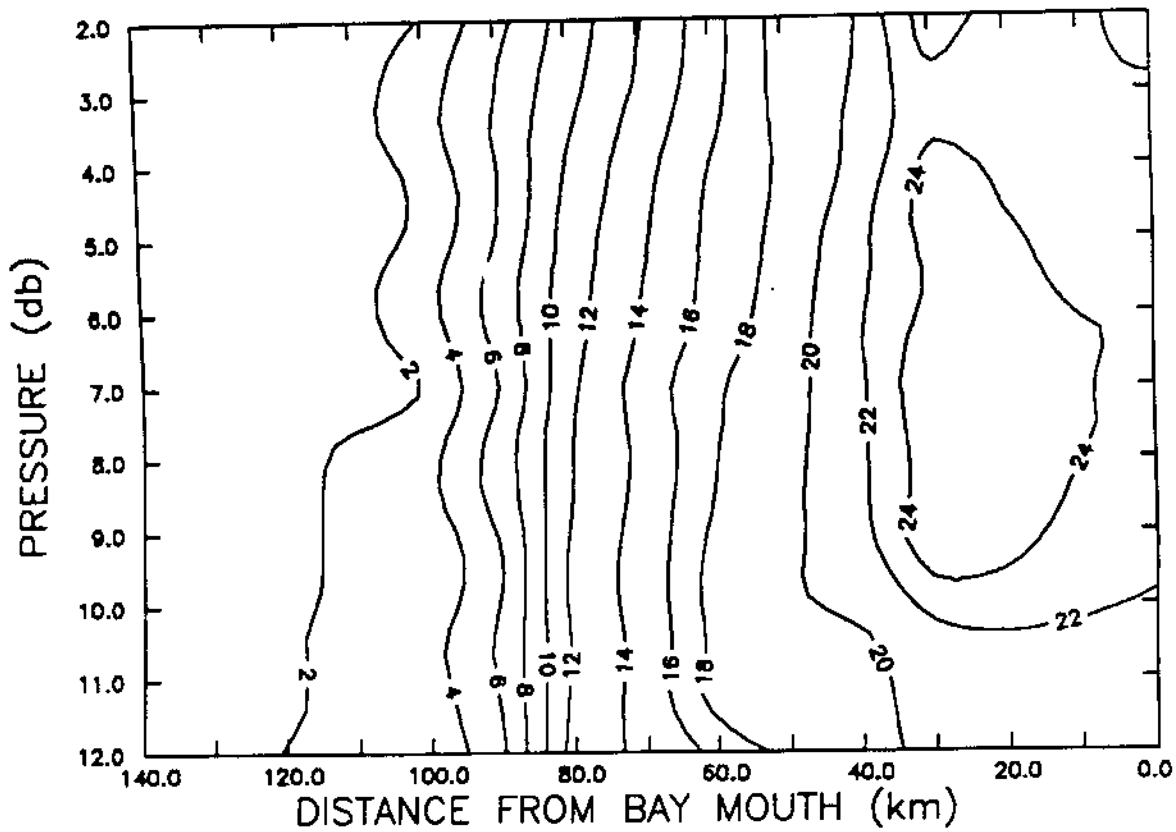

Figure E17. Profile of salinity for Scenic-24 (6-8 September 1988). Isopleths are in parts per thousand.

F. DENSITY PROFILES

Profiles of density were constructed for the Delaware Estuary as a function of distance upstream from the mouth of Delaware Bay and depth below the surface. Depths are expressed in decibars pressure where 1 decibar (db) is equivalent to 1 meter of depth below the surface. Density is expressed as sigma-t (σ_t = density in $Kg \cdot m^{-3}$ minus 1000). Profiles of σ_t for individual cruises are shown in Figures F1-F17. Isopleths are in increments of 2 $Kg \cdot m^{-3}$.

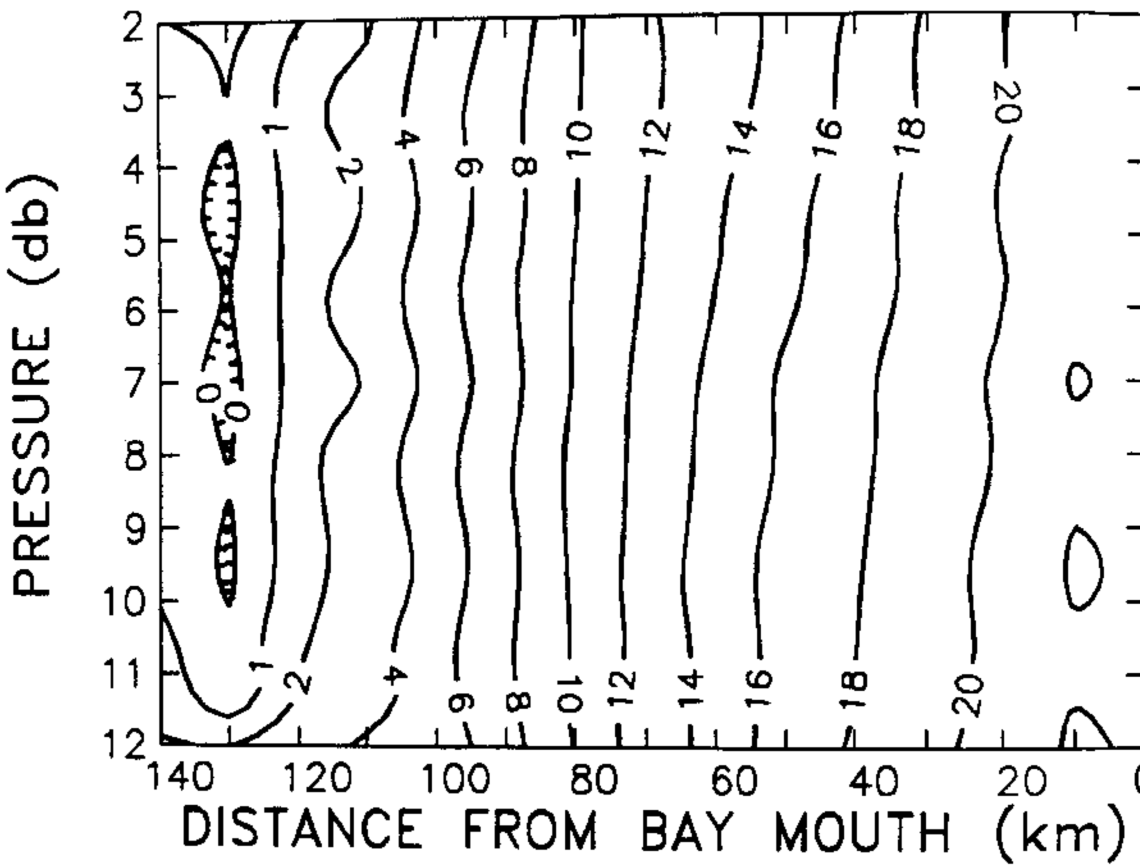

Figure F1. Profile of sigma-t for Scenic-3 (28-30 October 1986). Isopycnals are in $Kg \cdot m^{-3}$.

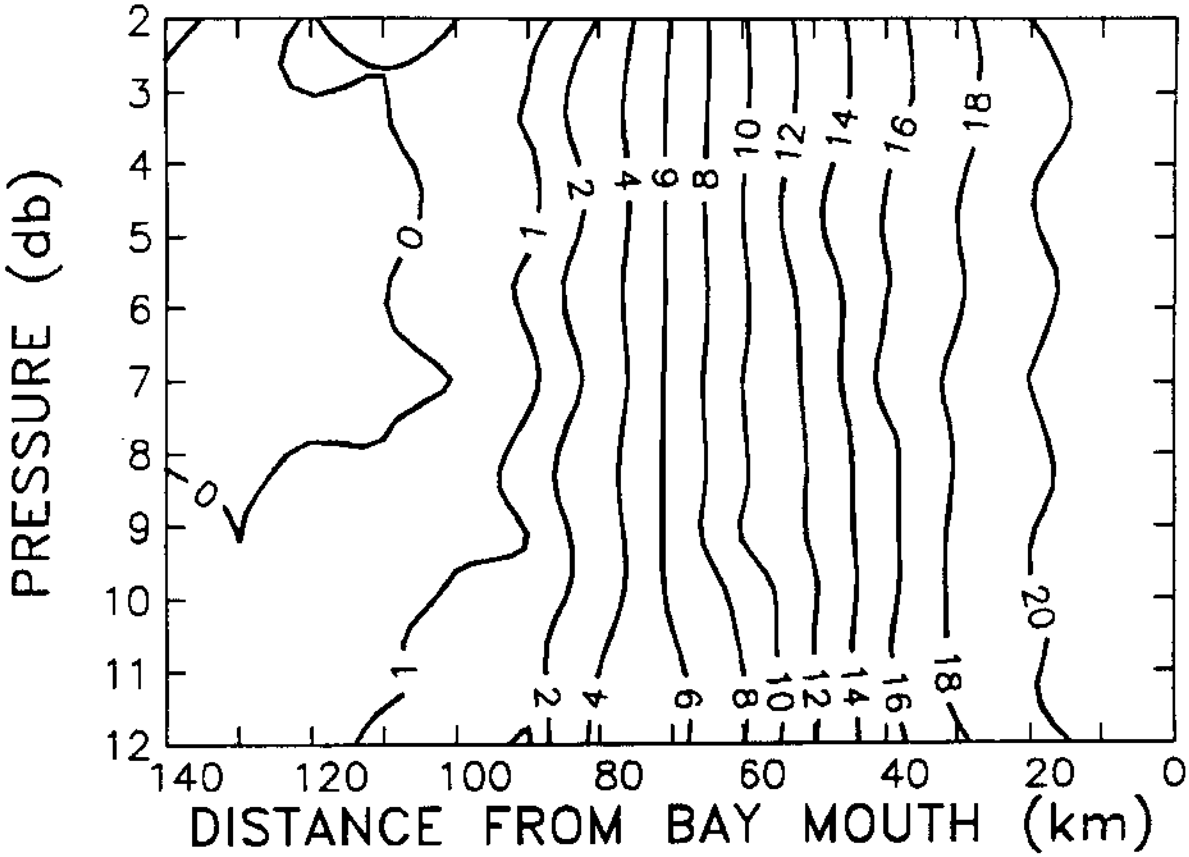

Figure F2. Profile of sigma-t for Scenic-4 (3-4 December 1986). Isopycnals are in $Kg \cdot m^{-3}$.

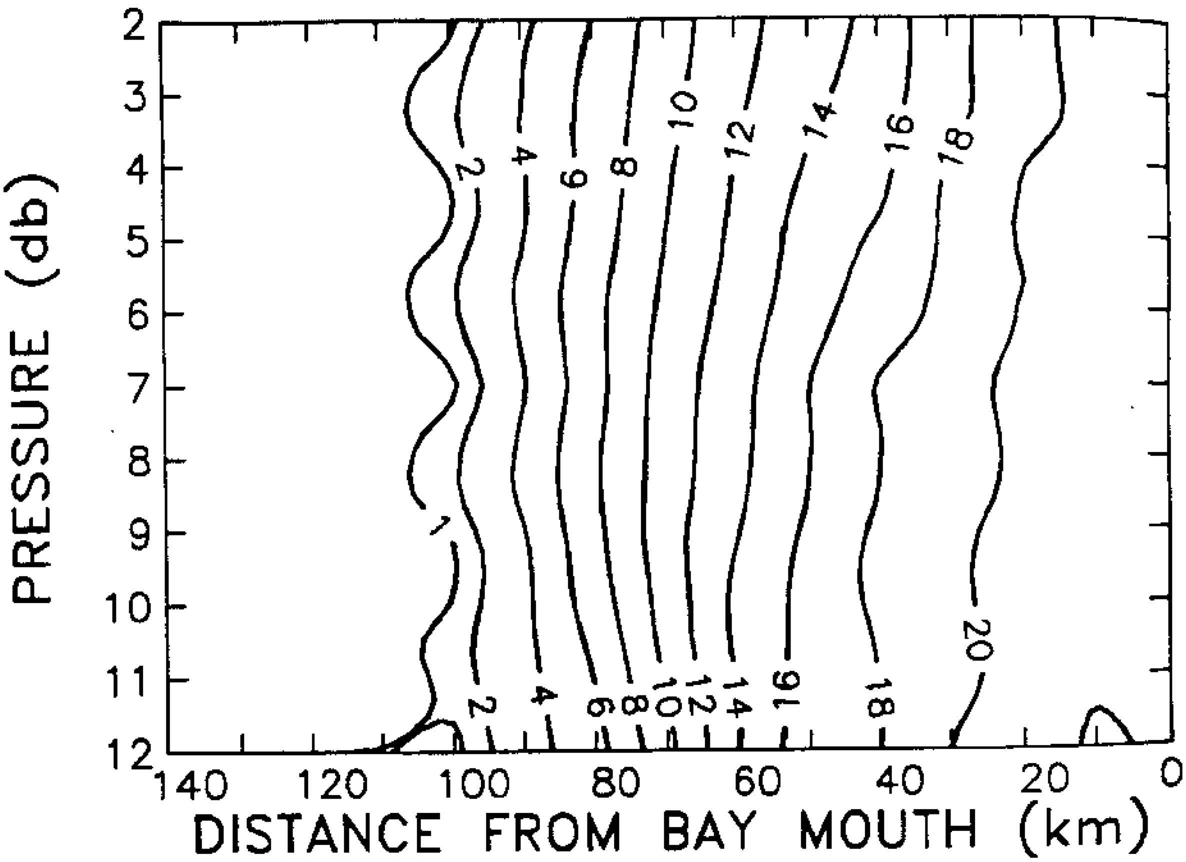

Figure F3. Profile of sigma-t for Scenic-5 (11-12 January 1987). Isopycnals are in $Kg \cdot m^{-3}$.

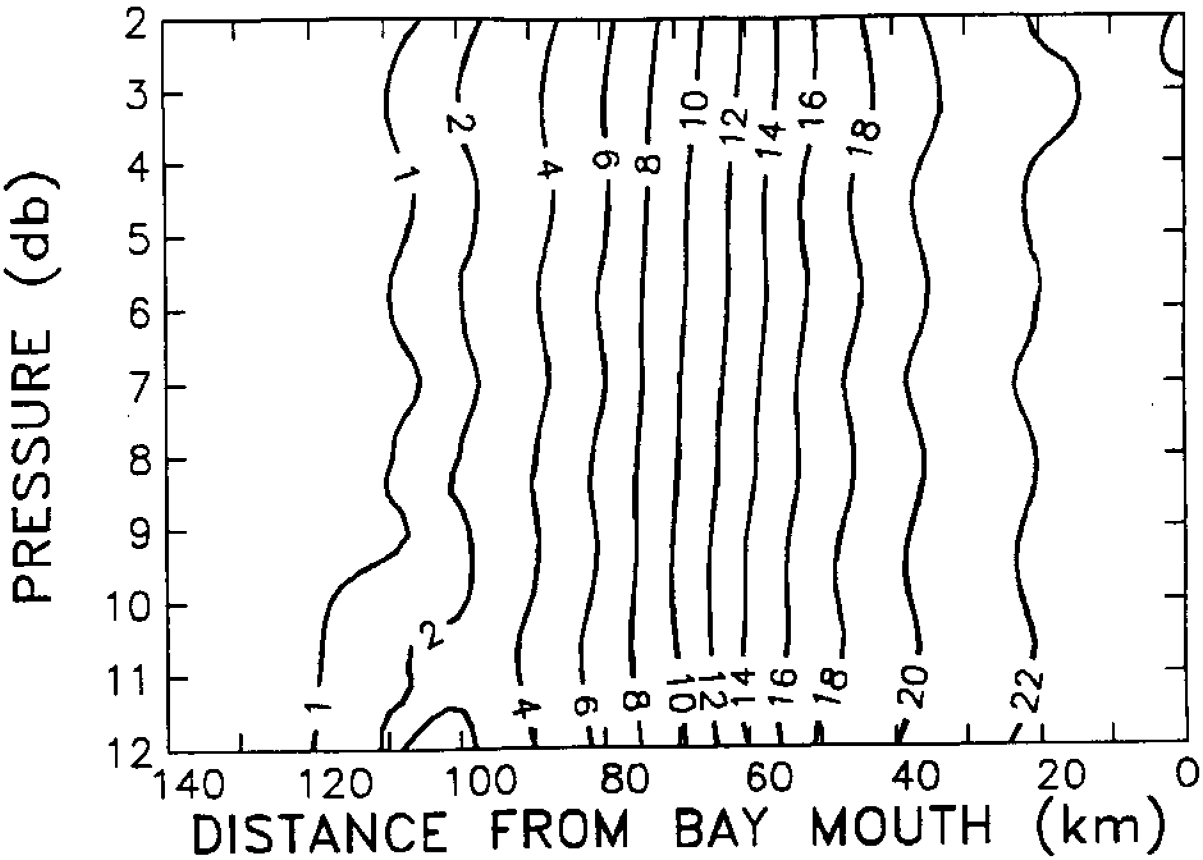

Figure F4. Profile of sigma-t for Scenic-6 (18-19 February 1987). Isopycnals are in $Kg \cdot m^{-3}$.

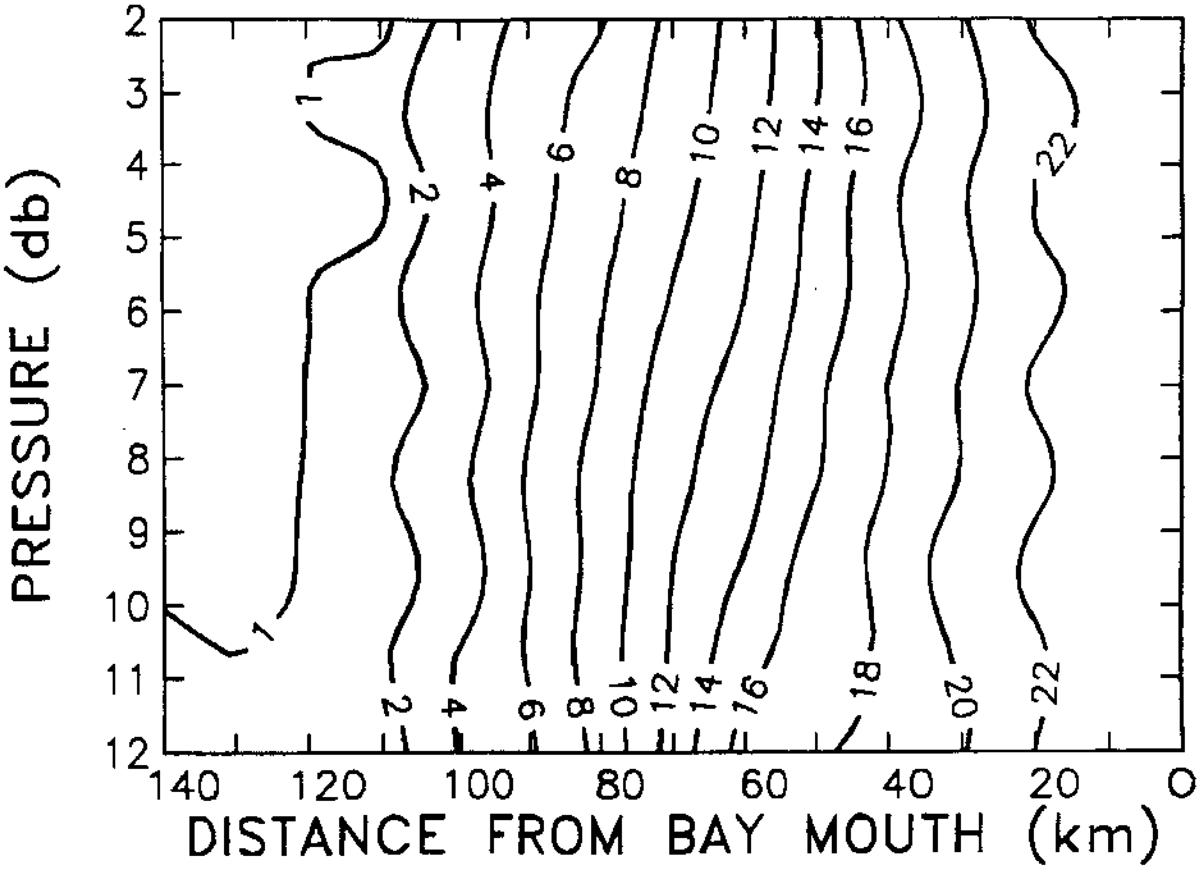

Figure F5. Profile of sigma-t for Scenic-8 (21-23 March 1987). Isopycnals are in Kg·m^{-3}.

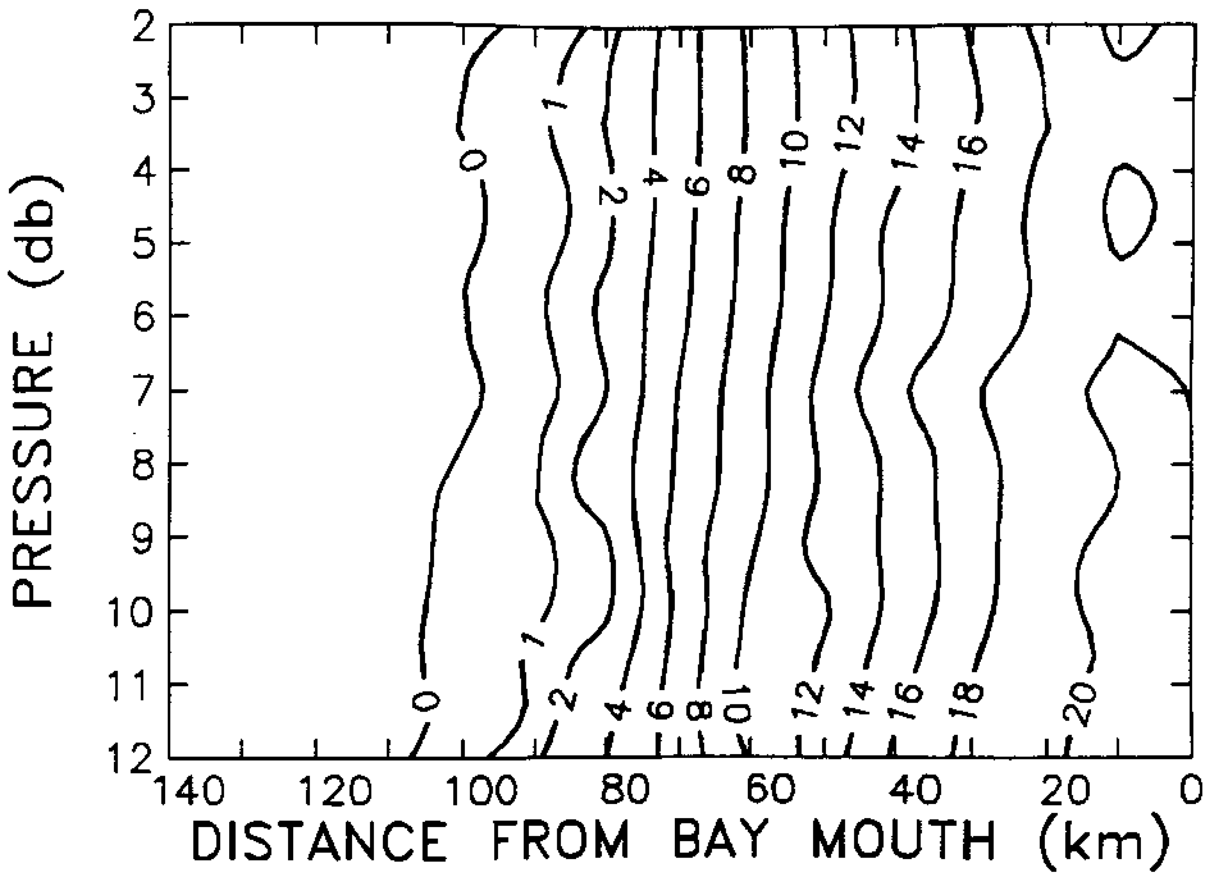

Figure F6. Profile of sigma-t for Scenic-10 (27-30 April 1987). Isopycnals are in $Kg \cdot m^{-3}$.

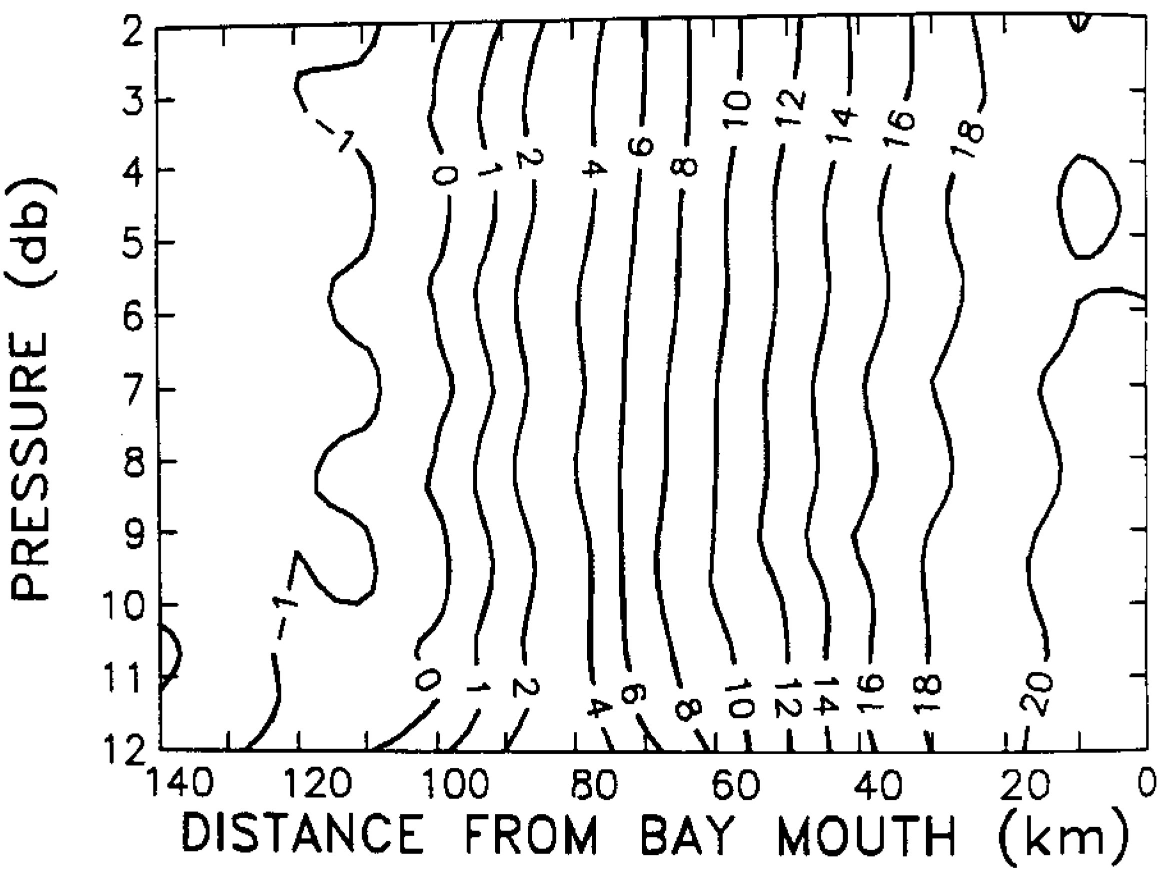

Figure F7. Profile of sigma-t for Scenic-11 (26-28 May 1987). Isopycnals are in $Kg \cdot m^{-3}$.

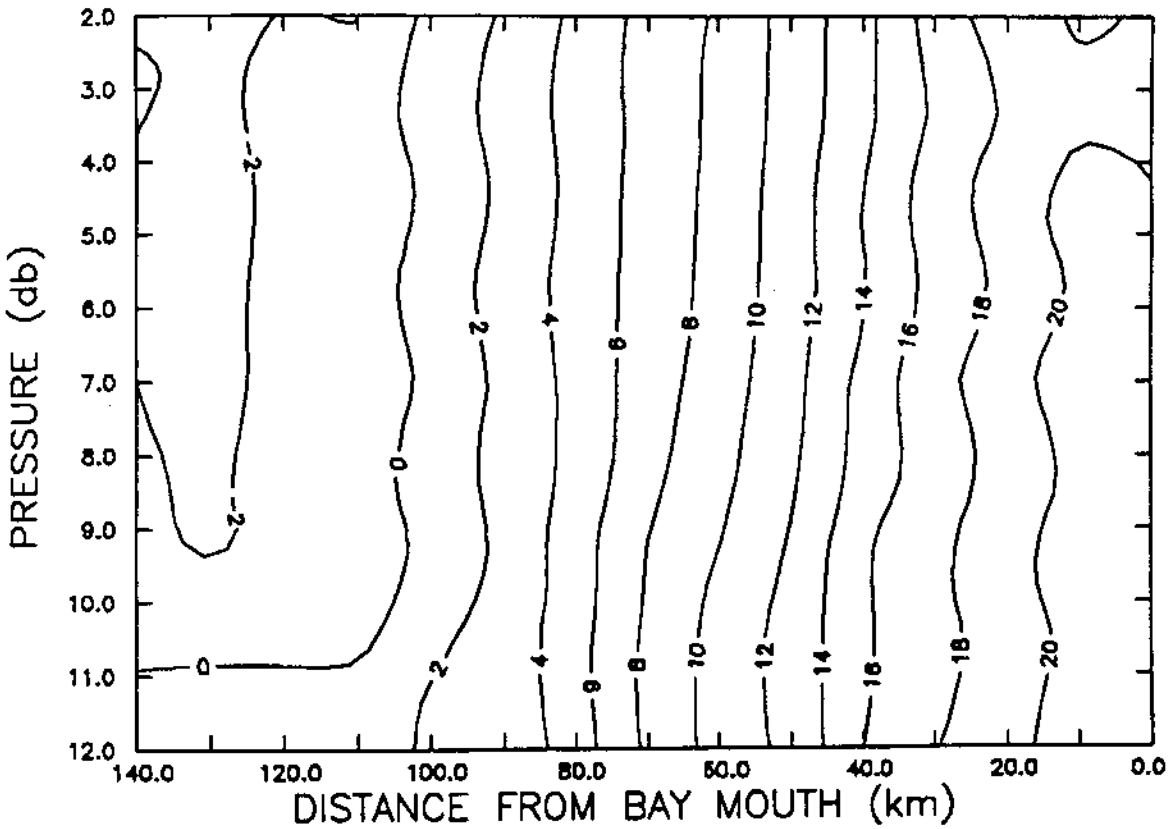

Figure F8. Profile of sigma-t for Scenic-12 (24-26 June 1987). Isopycnals are in $Kg \cdot m^{-3}$.

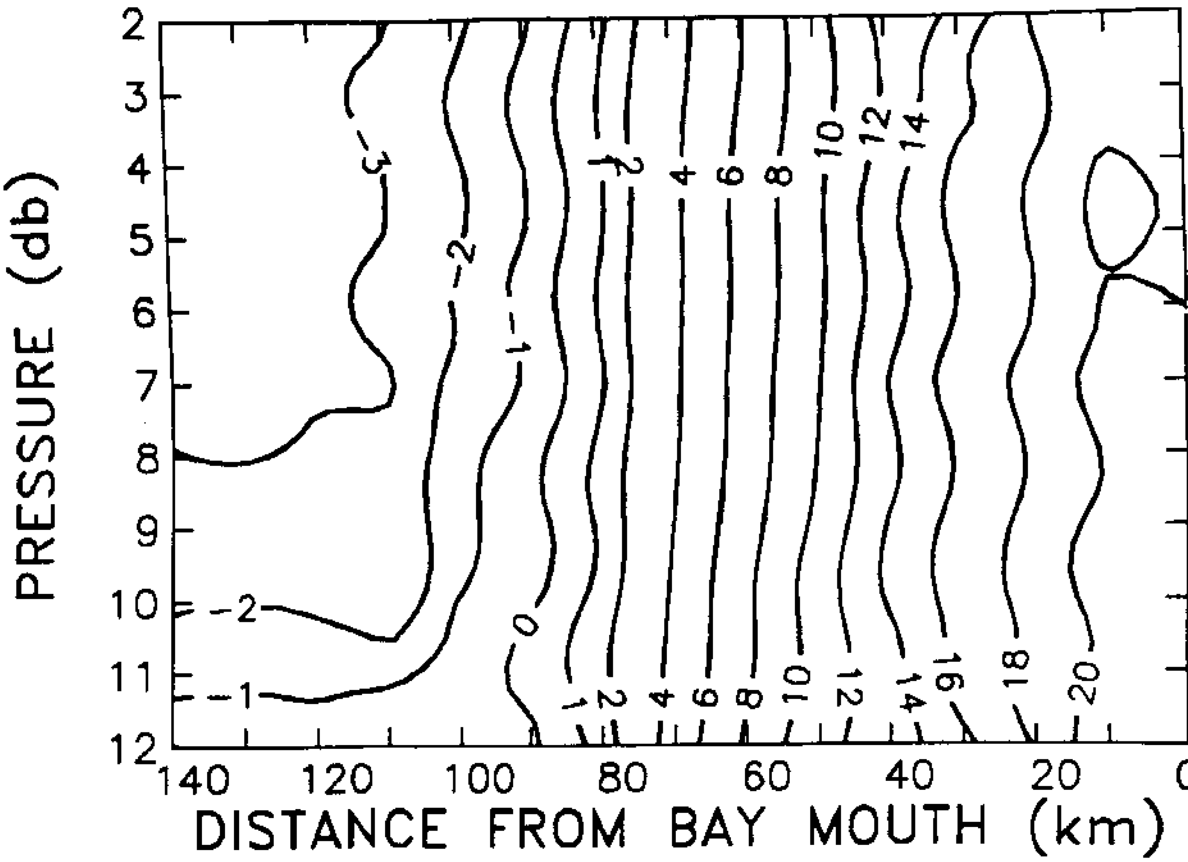

Figure F9. Profile of sigma-t for Scenic-13 (26-30 July 1987). Isopycnals are in $Kg \cdot m^{-3}$.

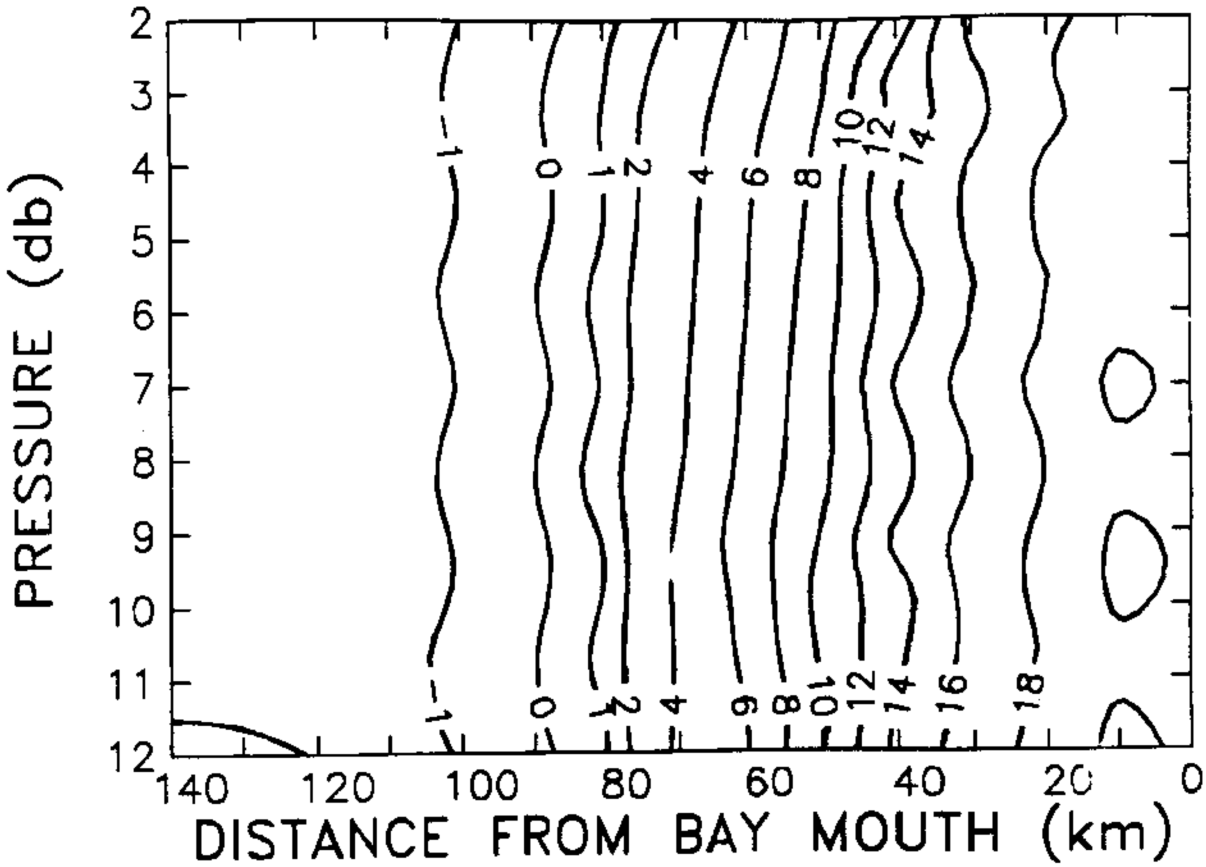

Figure F10. Profile of sigma-t for Scenic-15 (29 September - 1 October 1987). Isopycnals are in $Kg \cdot m^{-3}$.

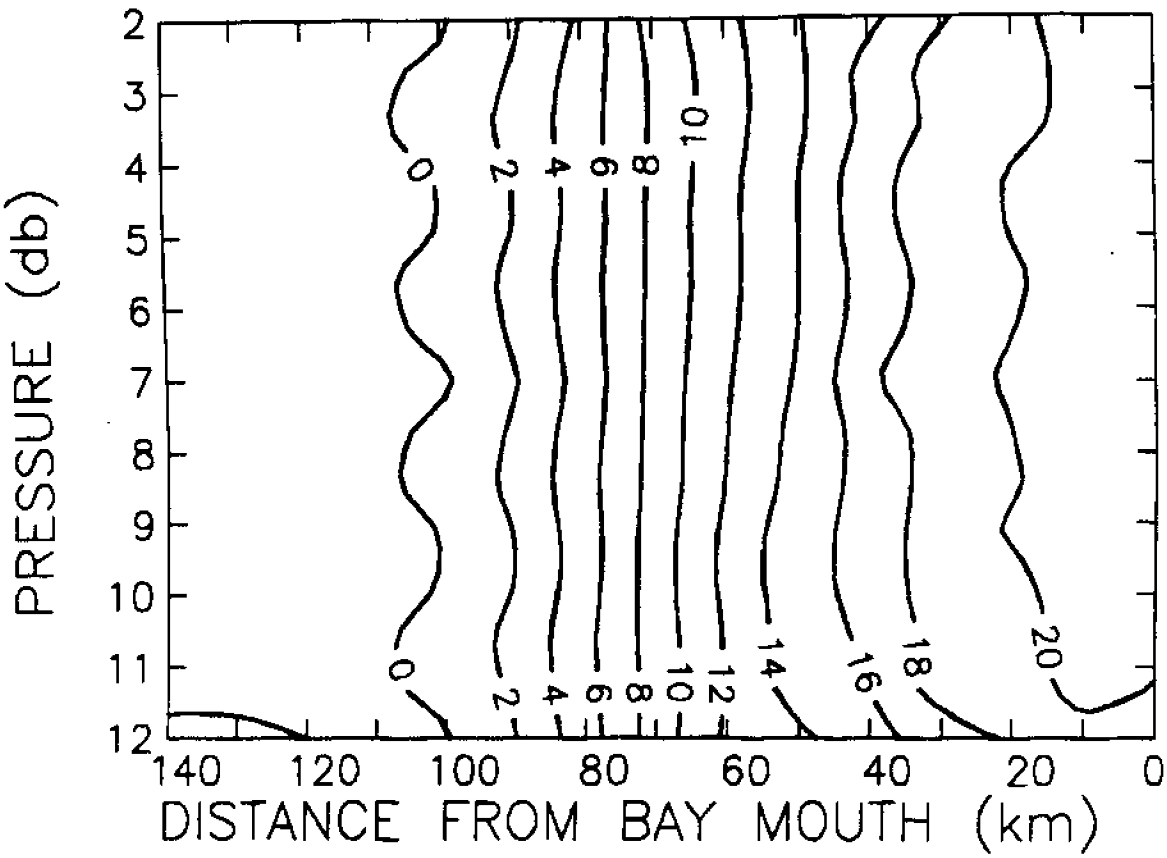

Figure F11. Profile of sigma-t for Scenic-16 (4-6 November 1987). Isopycnals are in $Kg \cdot m^{-3}$.

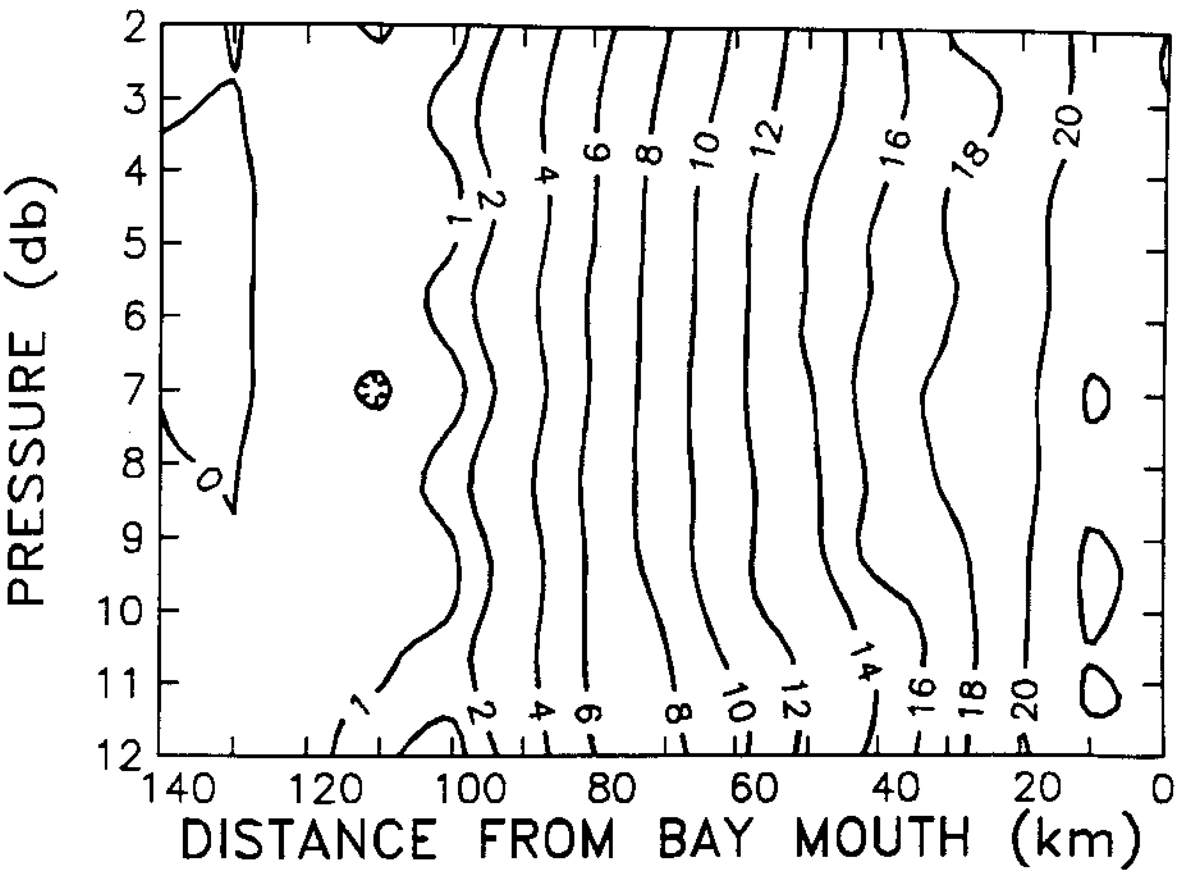

Figure F12. Profile of sigma-t for Scenic-17 (5-7 December 1987). Isopycnals are in $Kg \cdot m^{-3}$.

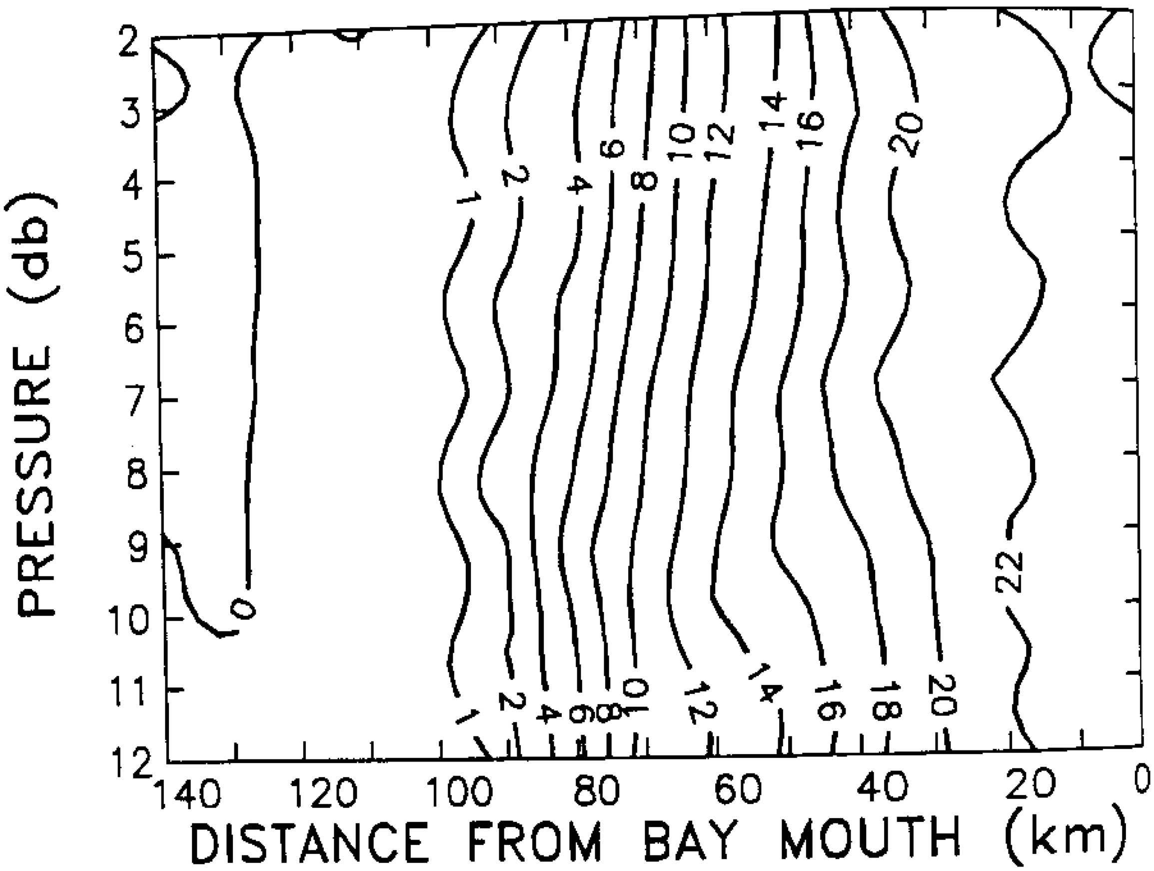

Figure F13. Profile of sigma-t for Scenic-18 (5-7 January 1988). Isopycnals are in Kg·m^{-3}.

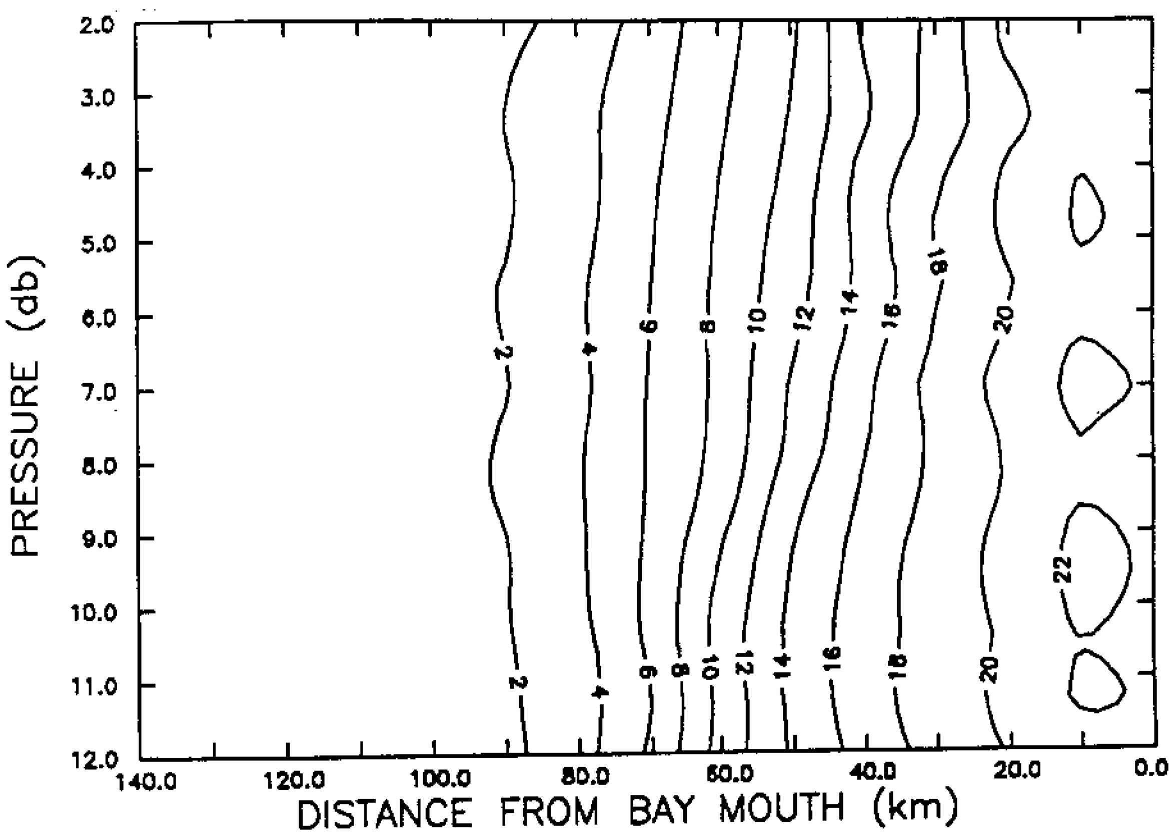

Figure F14. Profile of sigma-t for Scenic-20 (22-24 March 1988). Isopycnals are in $Kg \cdot m^{-3}$.

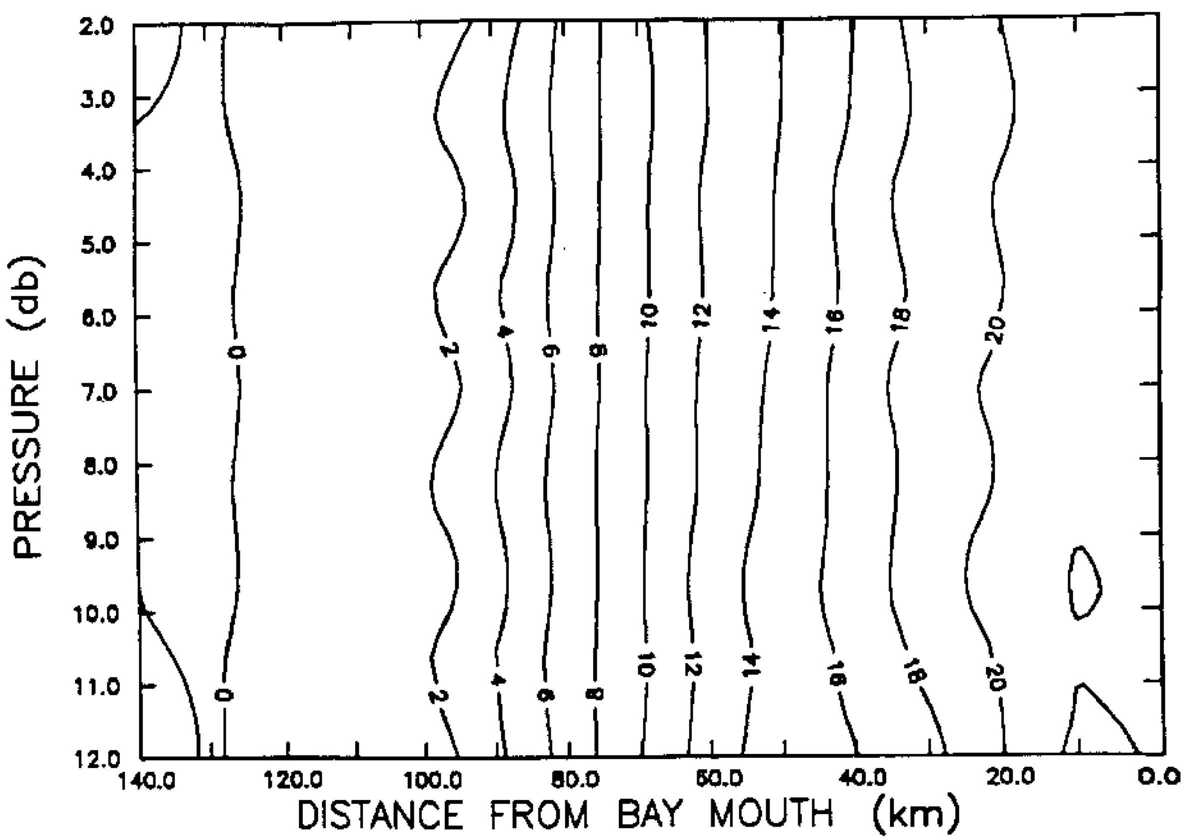

Figure F15. Profile of sigma-t for Scenic-21 (11-14 April 1988). Isopycnals are in $Kg \cdot m^{-3}$.

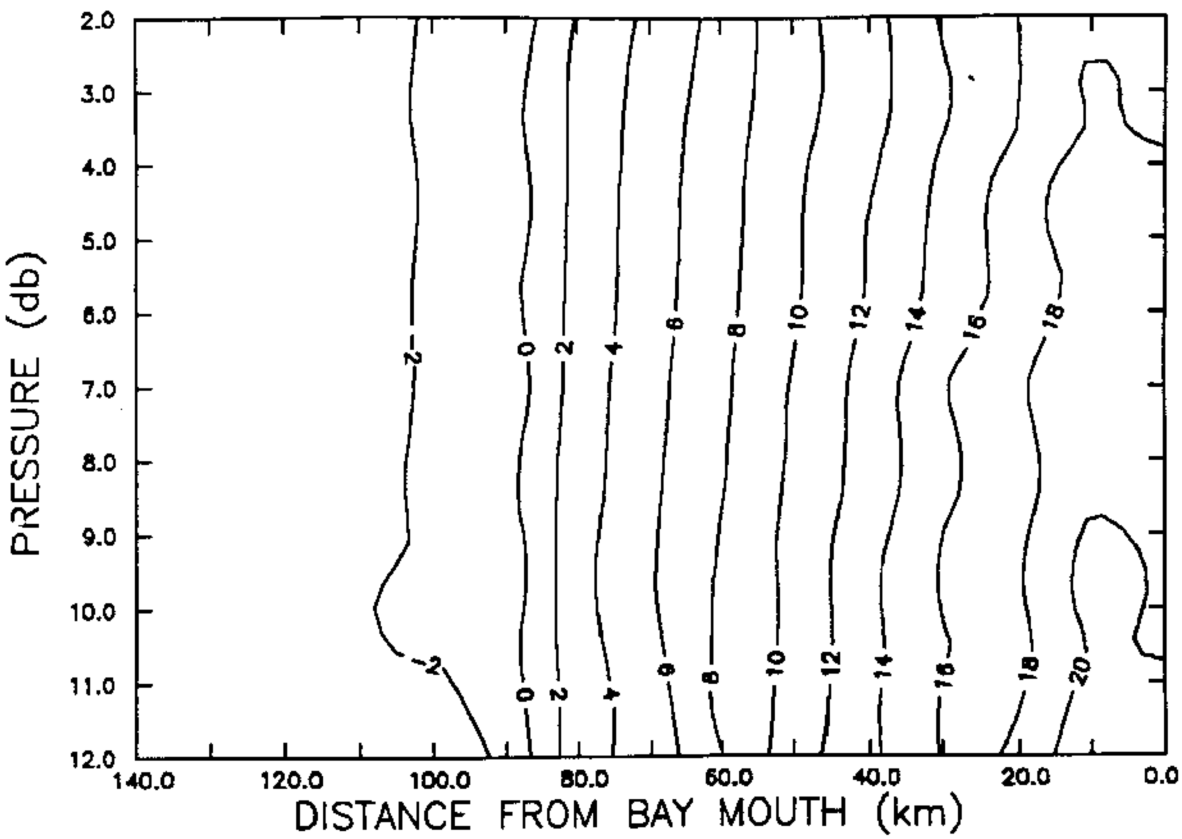

Figure F16. Profile of sigma-t for Scenic-23 (26-29 July 1988). Isopycnals are in $Kg \cdot m^{-3}$.

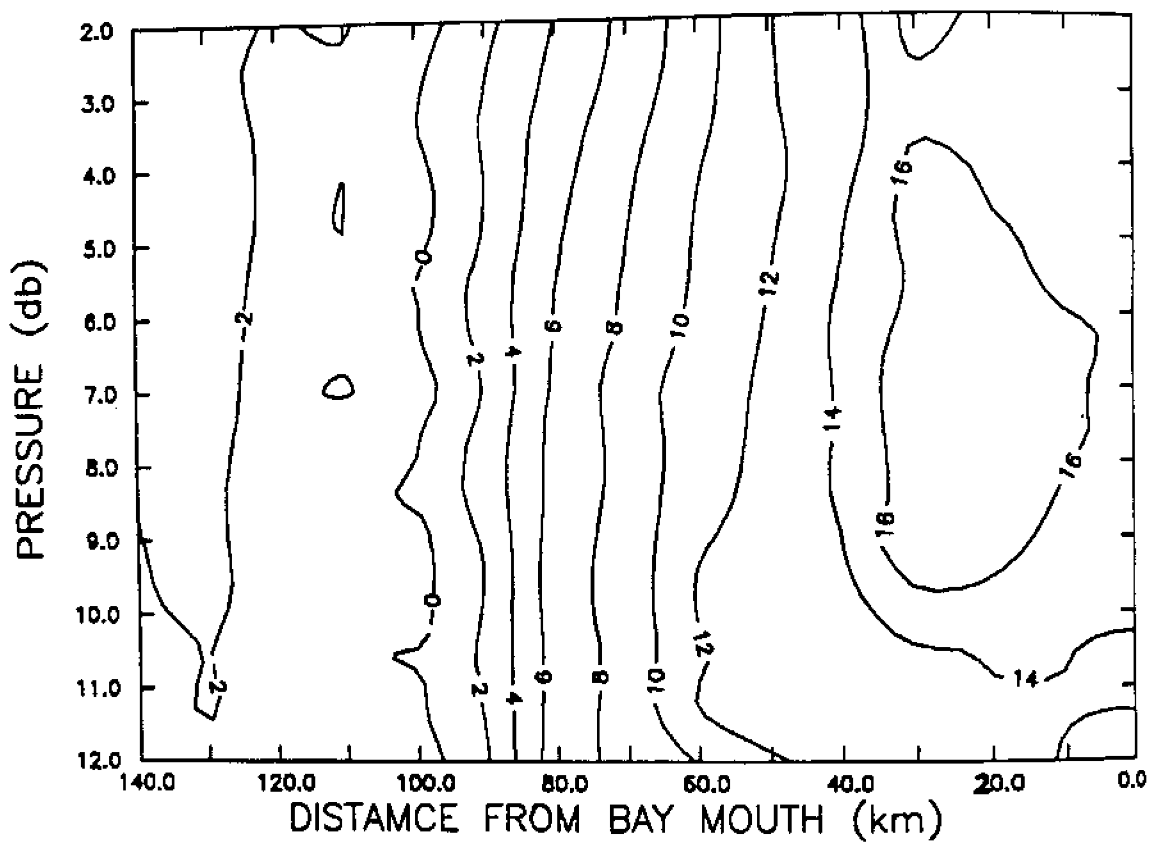

Figure F17. Profile of sigma-t for Scenic-24 (6-8 September 1988). Isopycnals are in Kg$\cdot$m^{-3}.

G. BRUNT VÄISÄLÄ FREQUENCY

Profiles of Brunt-Väisälä frequency were constructed for the Delaware Estuary as a function of distance upstream from the mouth of Delaware Bay and depth below the surface. Depths are expressed in decibars pressure where 1 decibar (db) is equivalent to 1 meter of depth below the surface. Brunt-Väisälä frequency (N) is shown as isopleths in intervals of $0.4 \times 10^{-2}\ s^{-1}$ for individual cruises in Figures G1-G17.

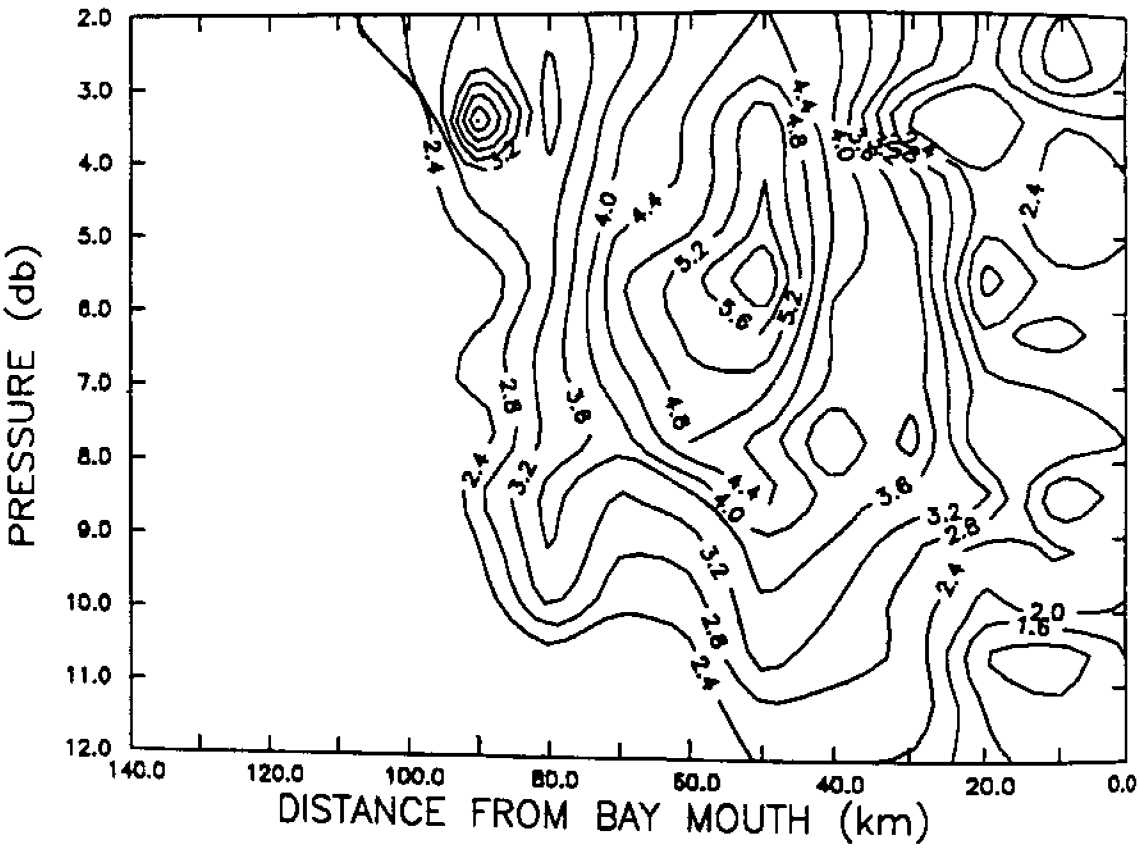

Figure G1. Profile of Brunt-Väisälä frequency for Scenic-3 (28-30 October 1986). Isopleths are in 10^{-2} s^{-1}.

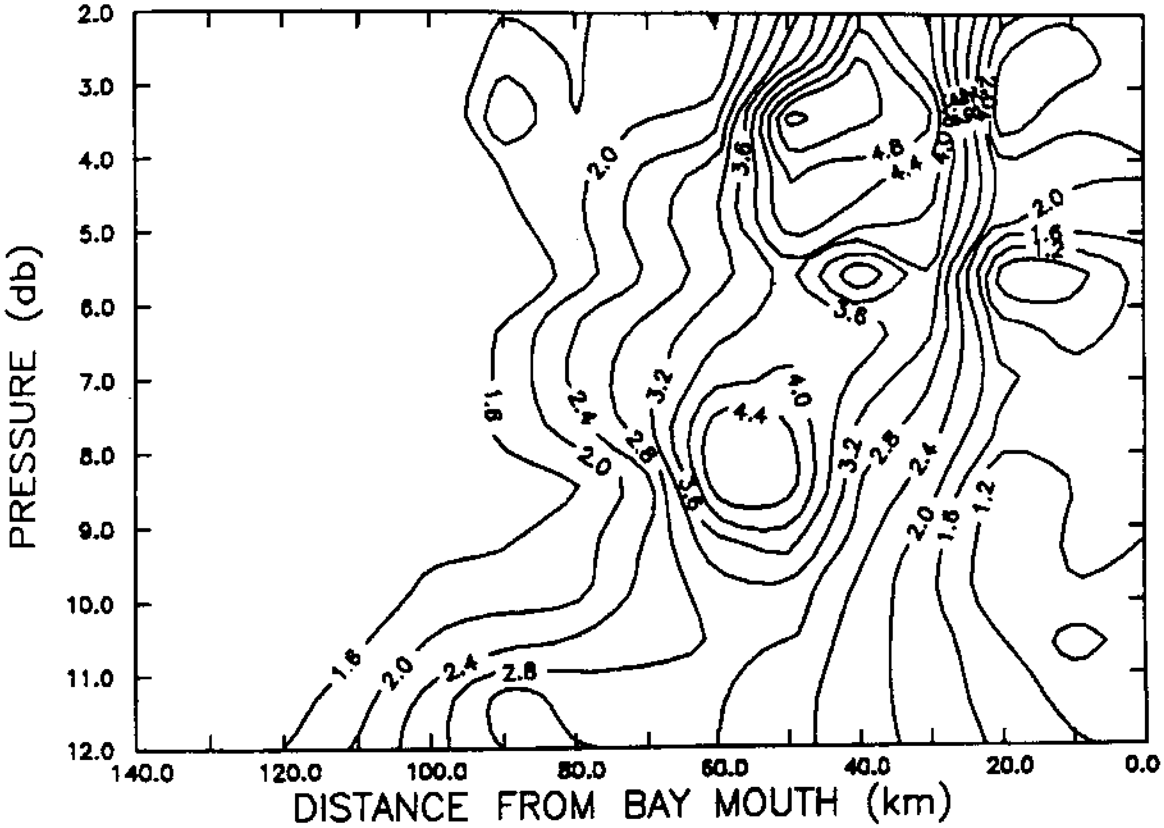

Figure G2. Profile of Brunt-Väisälä frequency for Scenic-4 (3-4 December 1986). Isopleths are in $10^{-2}\ s^{-1}$.

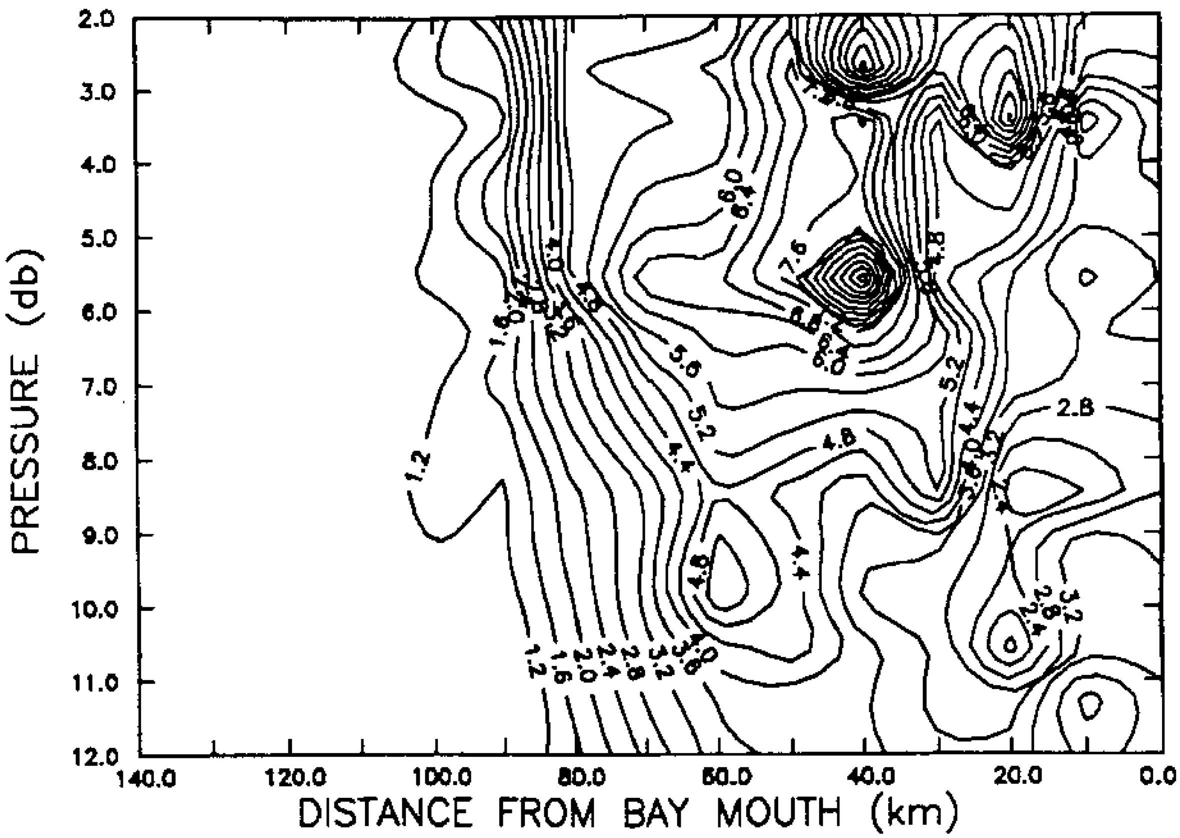

Figure G3. Profile of Brunt-Väisälä frequency for Scenic-5 (11-12 January 1987). Isopleths are in 10^{-2} s^{-1}.

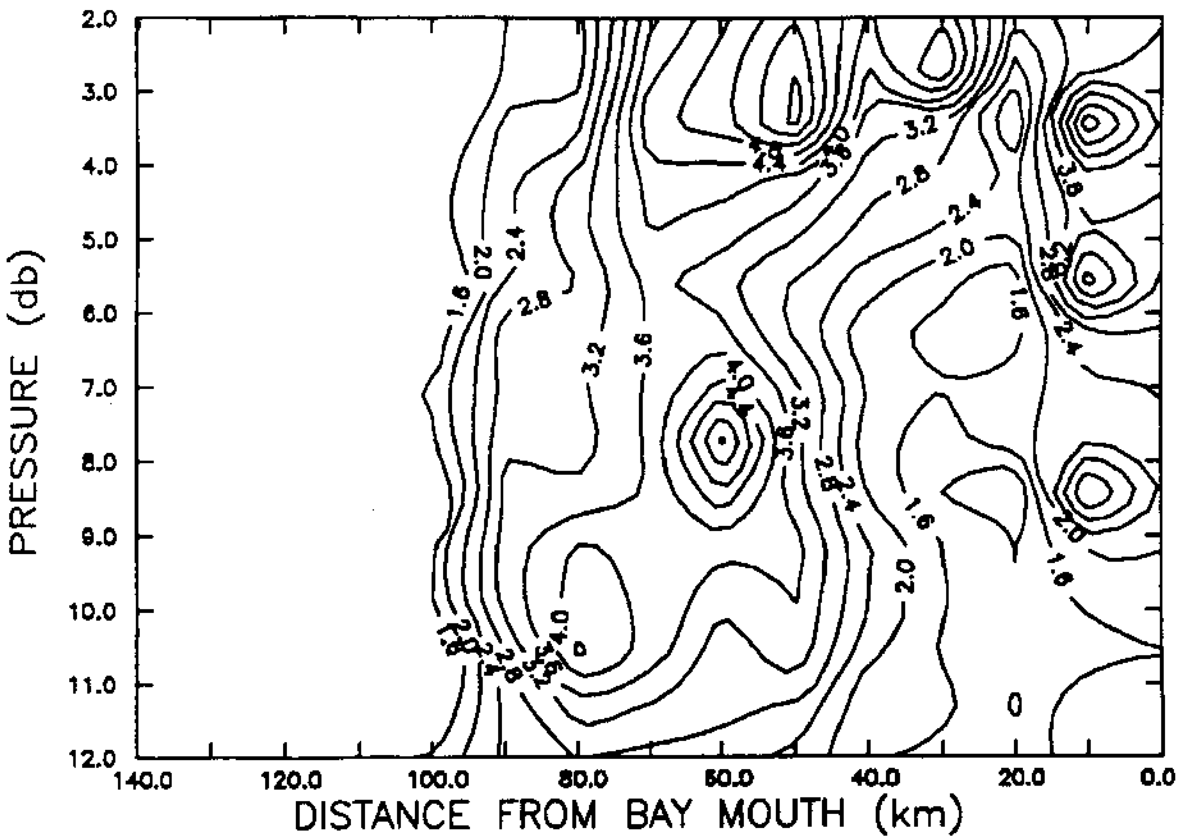

Figure G4. Profile of Brunt-Väisälä frequency for Scenic-6 (18-19 February 1987). Isopleths are in 10^{-2} s^{-1}.

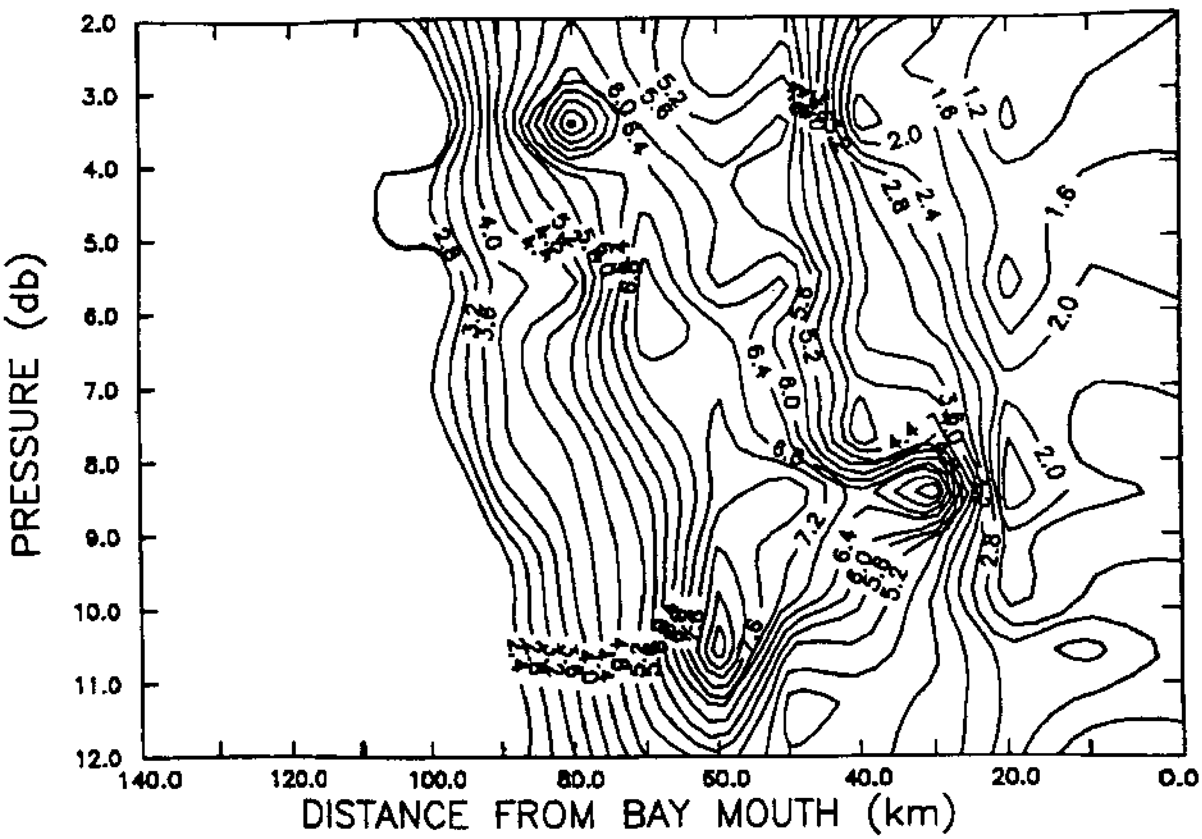

Figure G5. Profile of Brunt-Väisälä frequency for Scenic-8 (21-23 March 1987). Isopleths are in 10^{-2} s^{-1}.

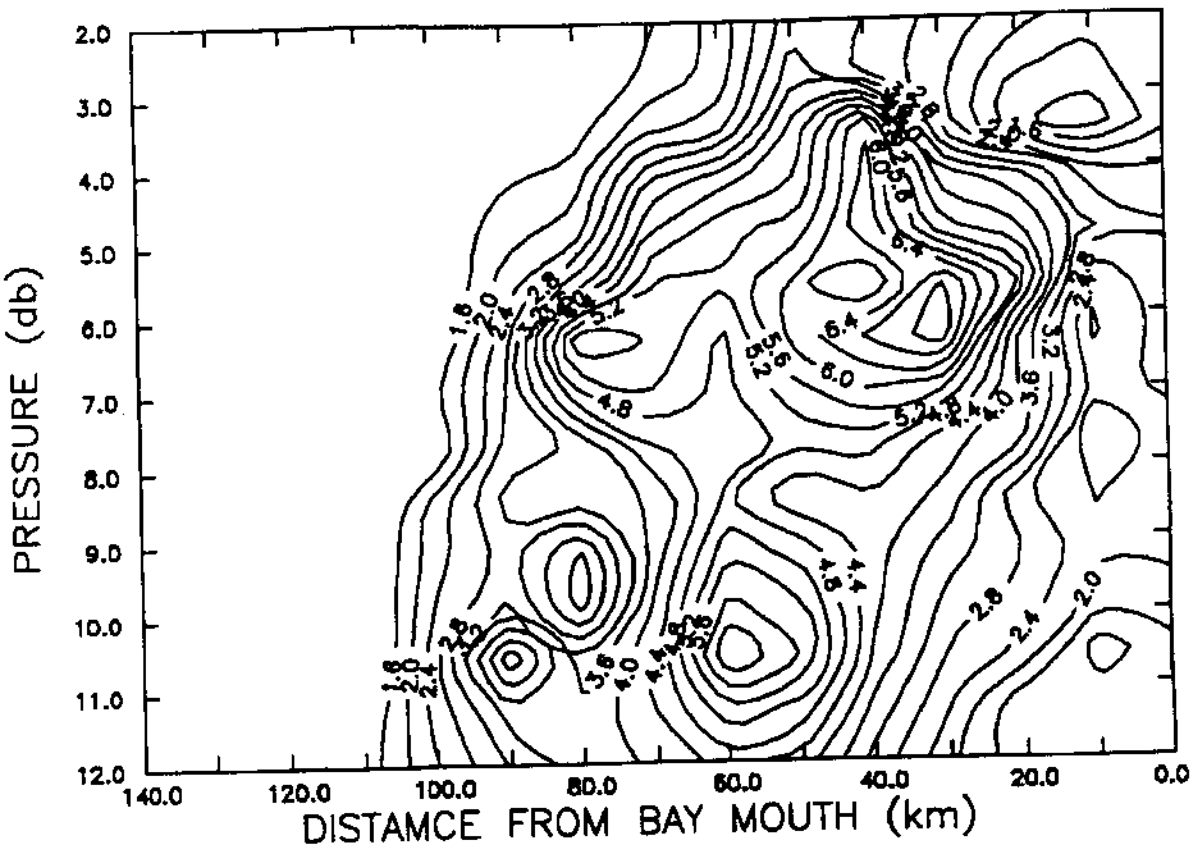

Figure G6. Profile of Brunt-Väisälä frequency for Scenic-10 (27-30 April 1987). Isopleths are in 10^{-2} s^{-1}.

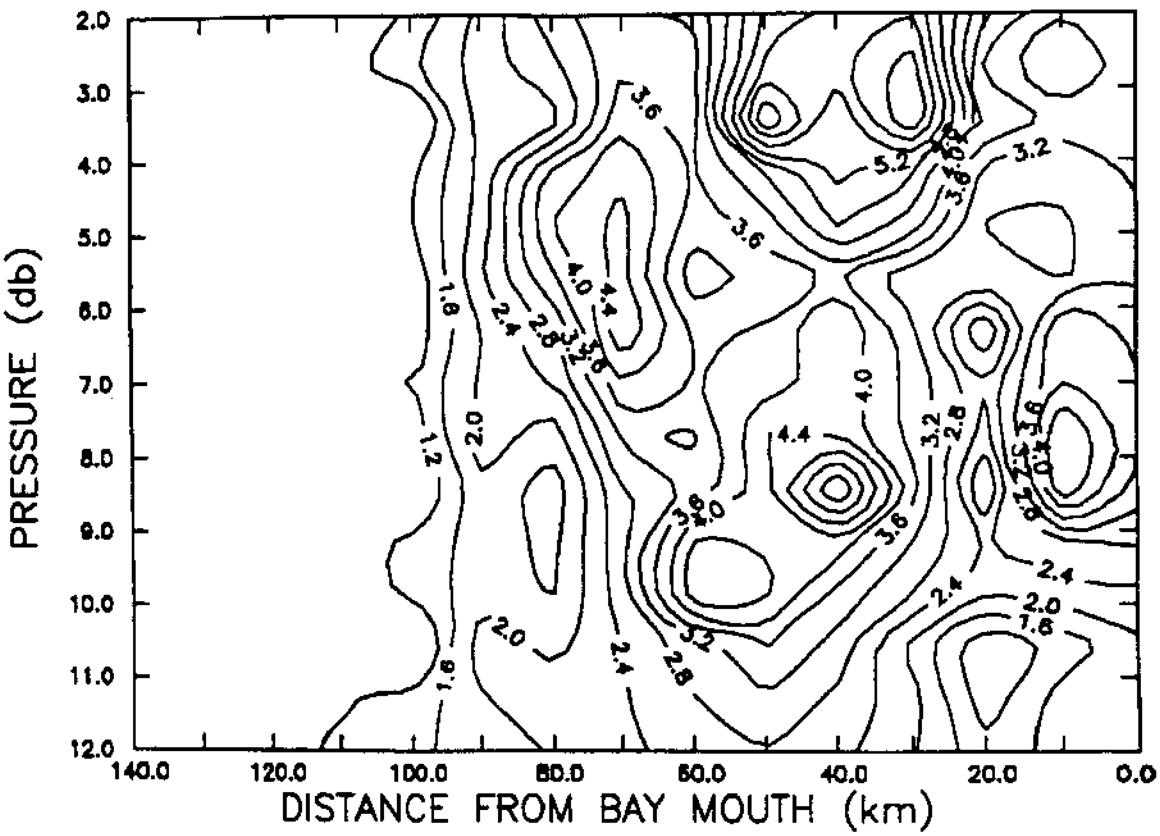

Figure G7. Profile of Brunt-Väisälä frequency for Scenic-11 (26-28 May 1987). Isopleths are in 10^{-2} s^{-1}.

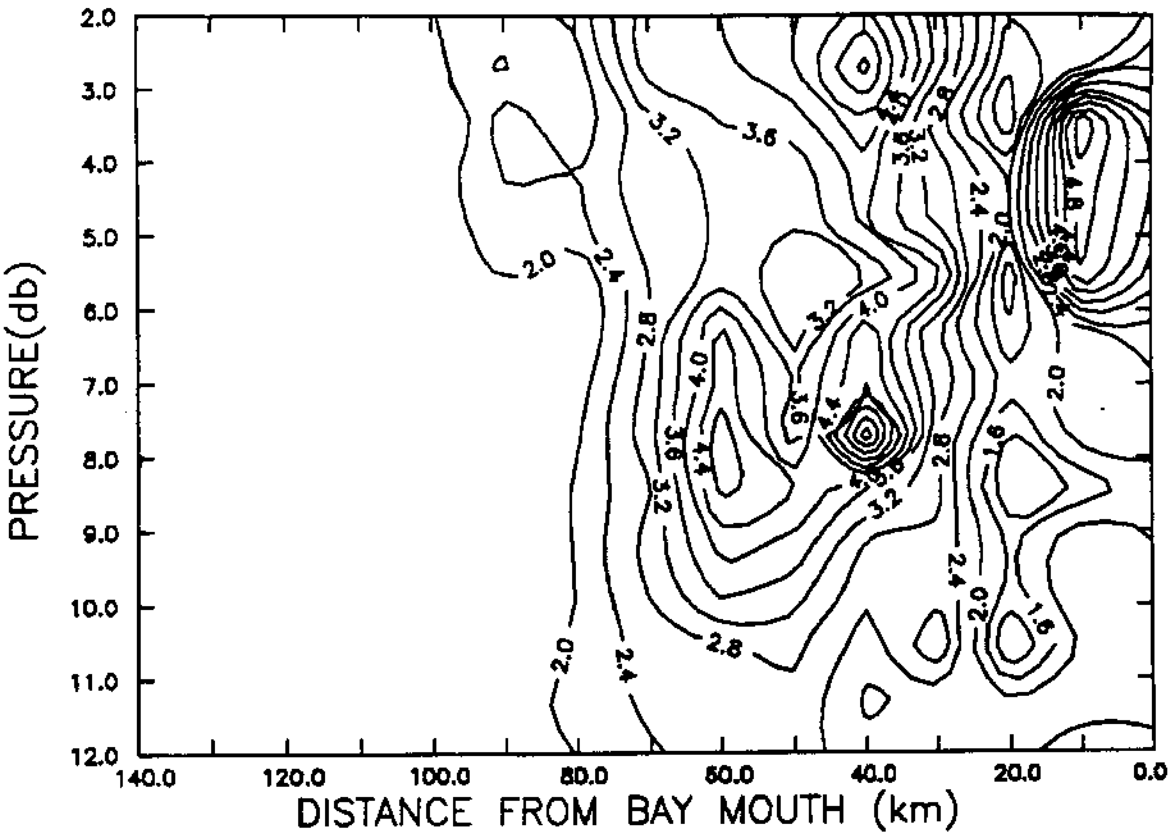

Figure G8. Profile of Brunt-Väisälä frequency for Scenic-12 (24-26 June 1987). Isopleths are in 10^{-2} s^{-1}.

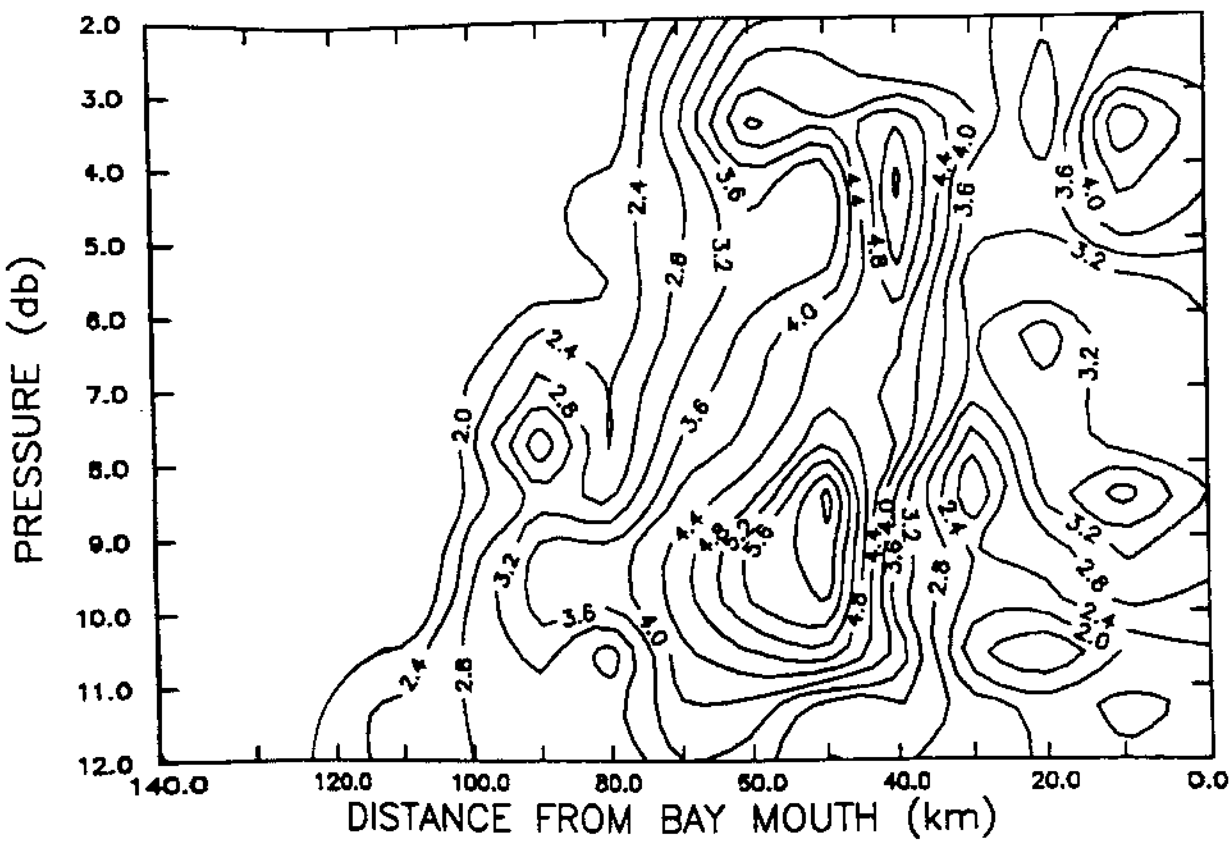

Figure G9. **Profile** of Brunt-Väisälä frequency for Scenic-13 (26-30 July 1987). Isopleths are in 10^{-2} s^{-1}.

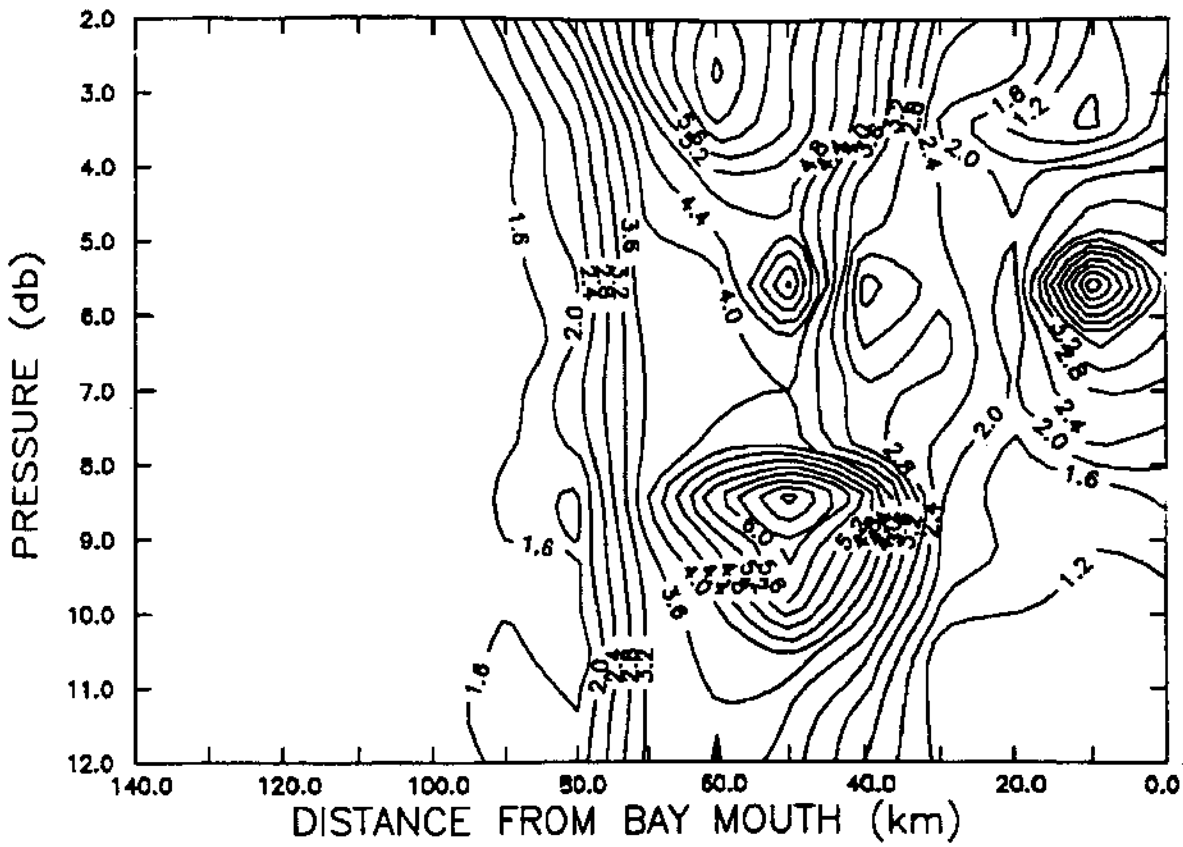

Figure G10. Profile of Brunt-Väisälä frequency for Scenic-15 (29 September - 1 October 1987). Isopleths are in 10^{-2} s^{-1}.

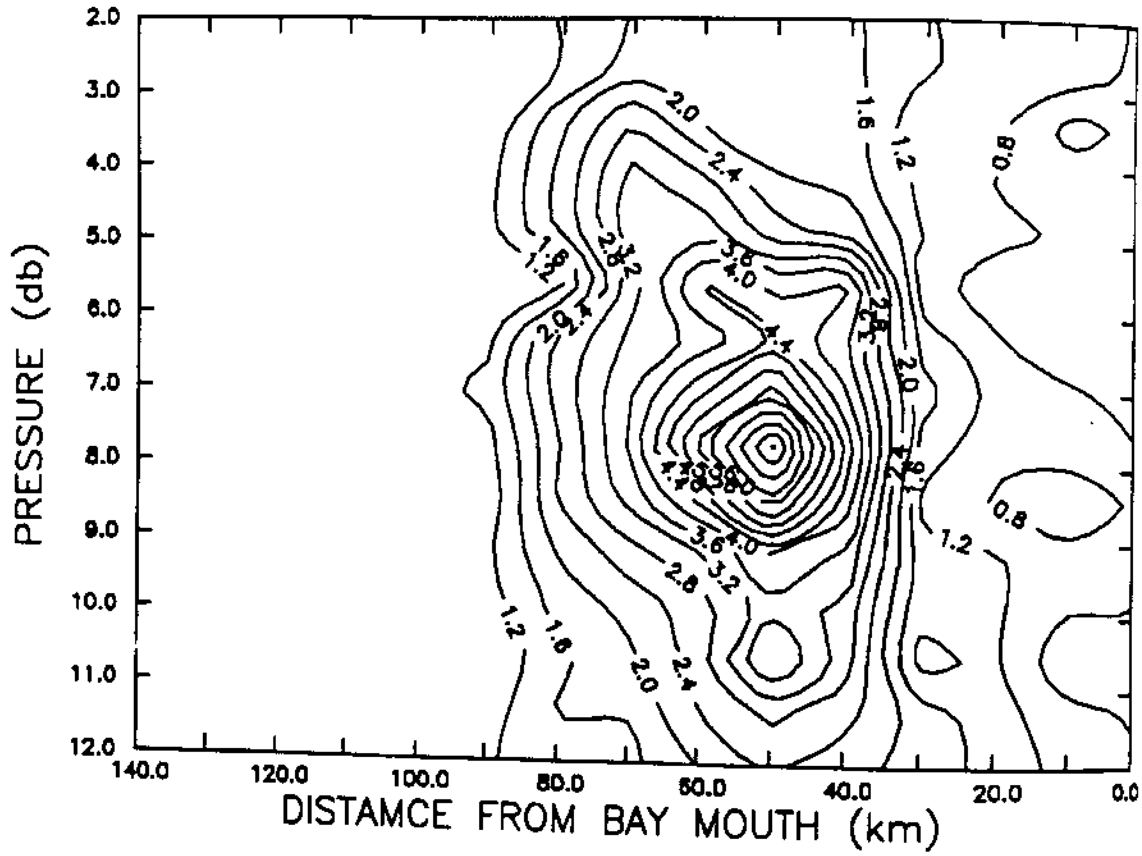

Figure G11. Profile of Brunt-Väisälä frequency for Scenic-16 (4-6 November 1987). Isopleths are in 10^{-2} s^{-1}.

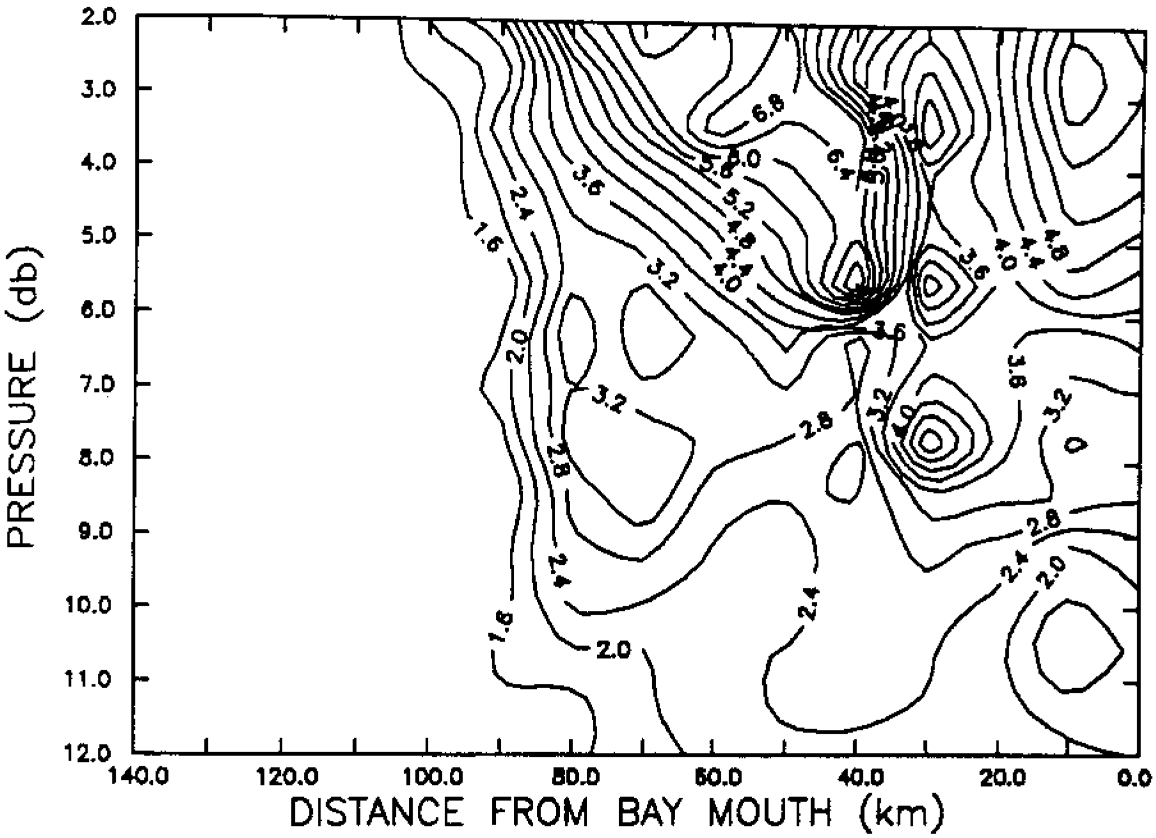

Figure G12. Profile of Brunt-Väisälä frequency for Scenic-17 (5-7 December 1987). Isopleths are in 10^{-2} s^{-1}.

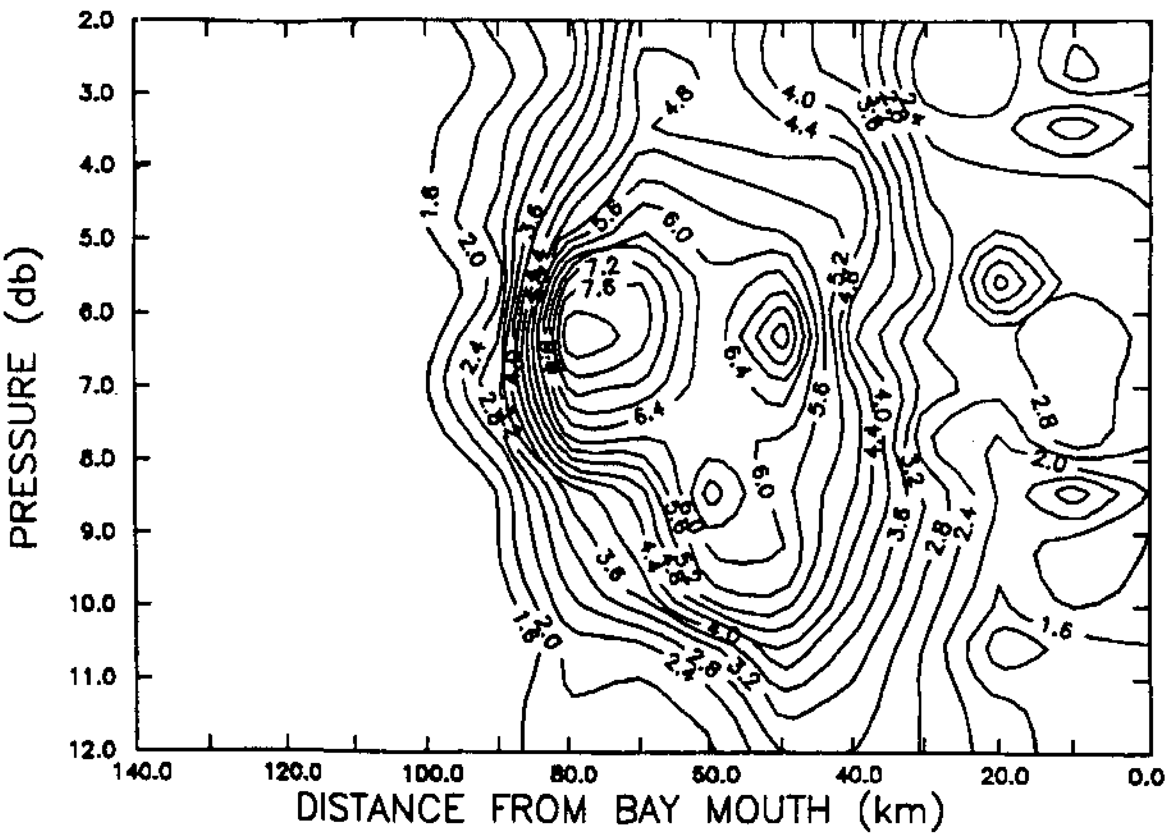

Figure G13. **Profile** of Brunt-Väisälä frequency for Scenic-18 (5-7 January 1988). Isopleths are in 10^{-2} s^{-1}.

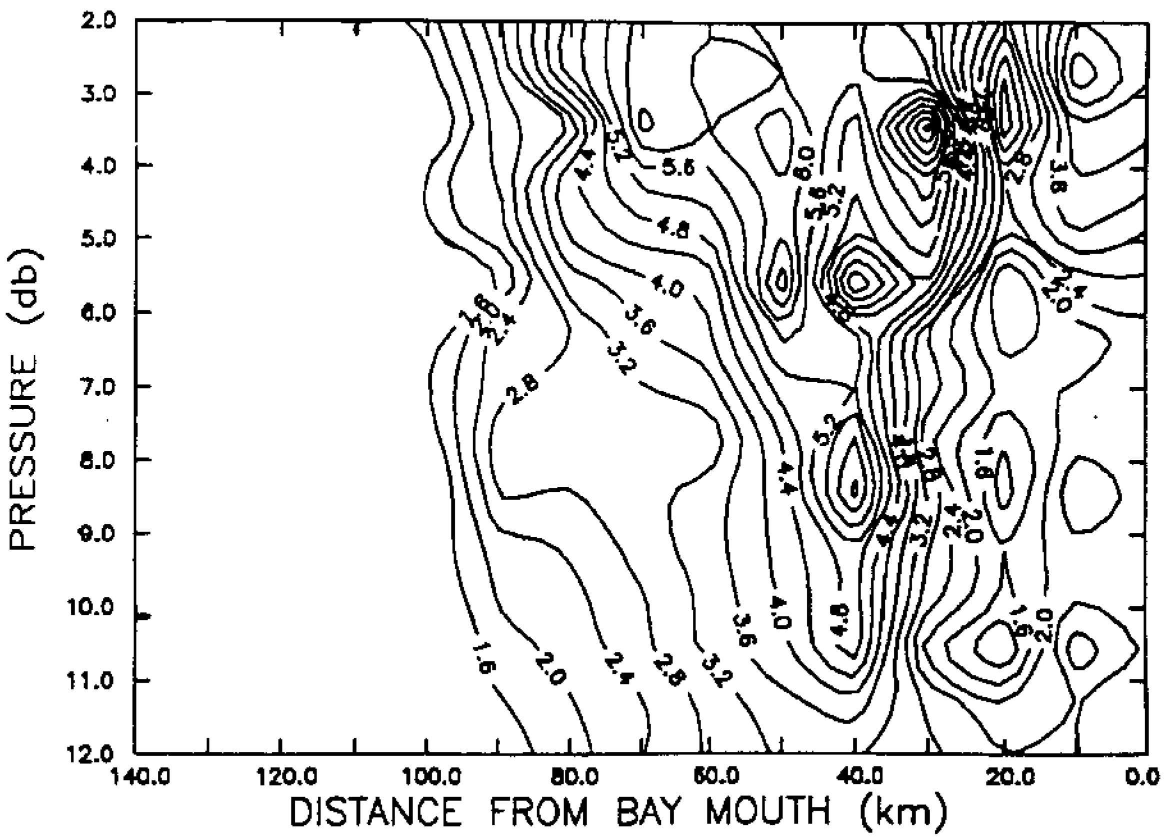

Figure G14. Profile of Brunt-Väisälä frequency for Scenic-20 (22-24 March 1988). Isopleths are in 10^{-2} s^{-1}.

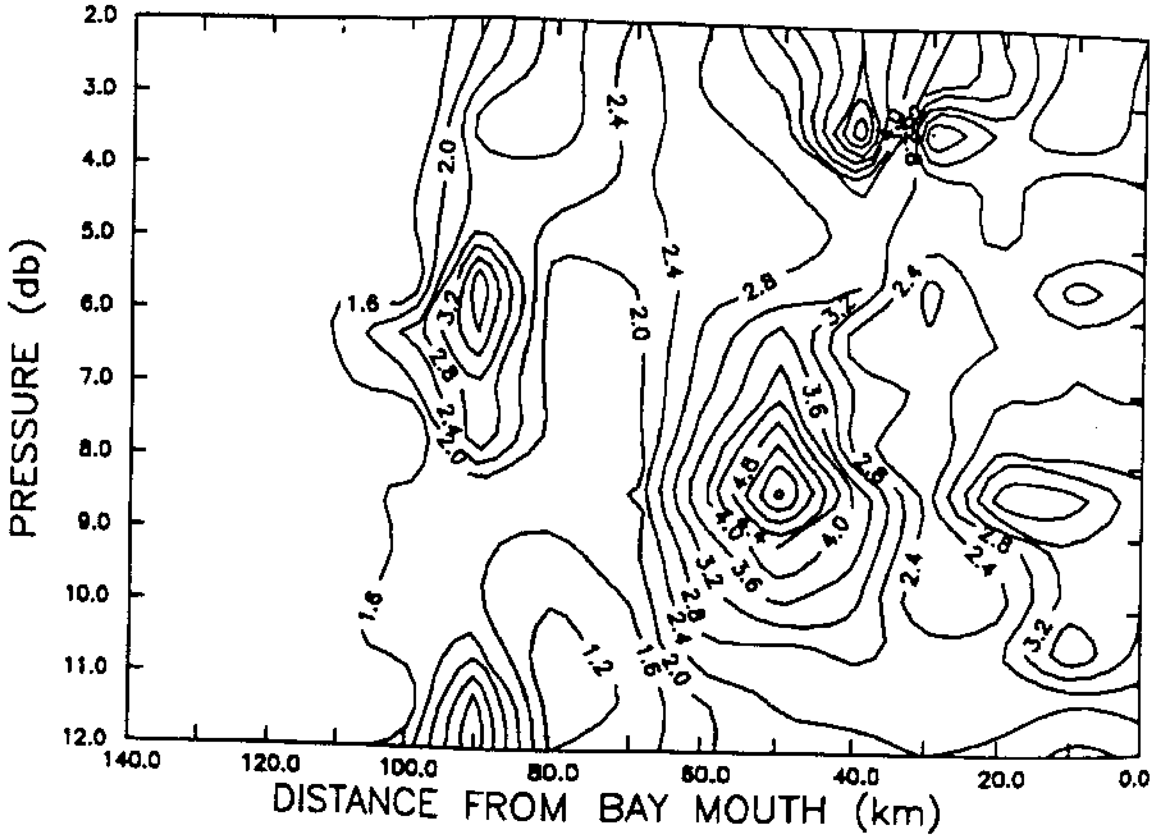

Figure G15. Profile of Brunt-Väisälä frequency for Scenic-21 (11-14 April 1988). Isopleths are in 10^{-2} s^{-1}.

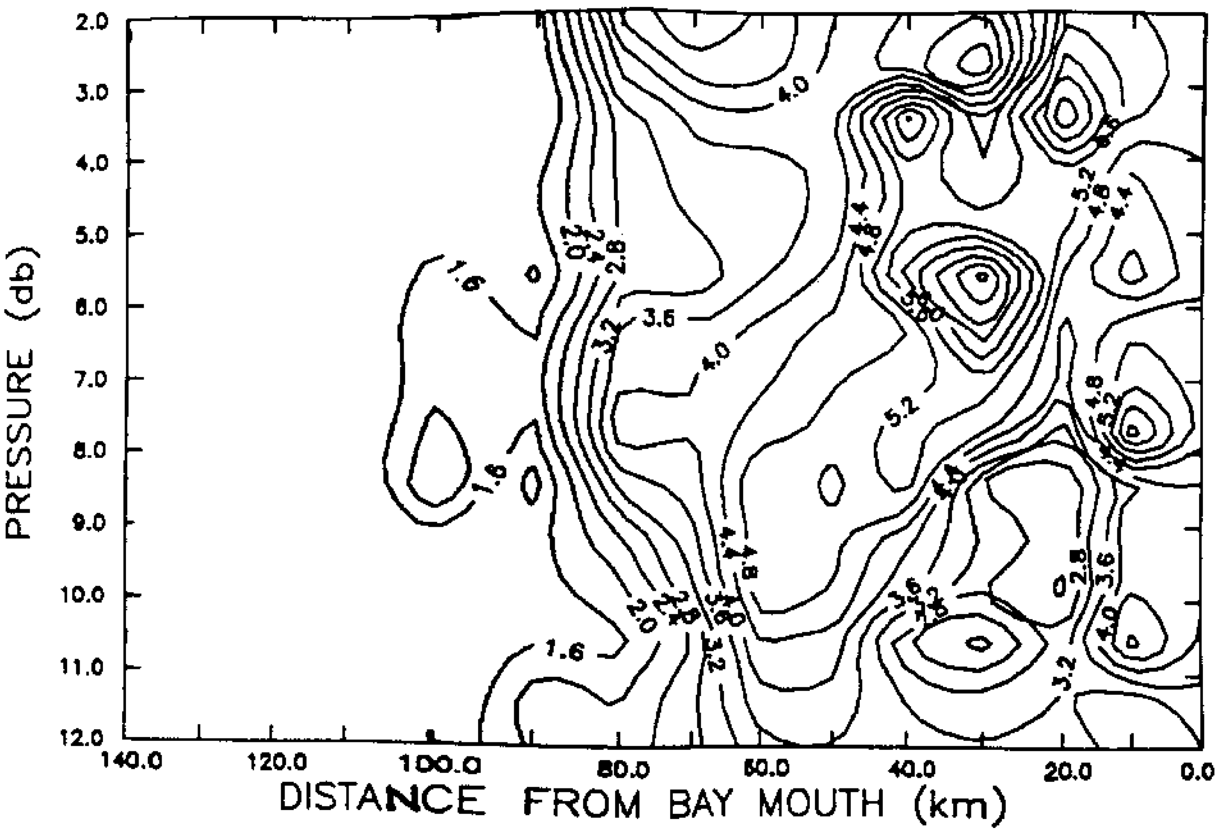

Figure G16. Profile of Brunt-Väisälä frequency for Scenic-23 (26-29 July 1988). Isopleths are in 10^{-2} s^{-1}.

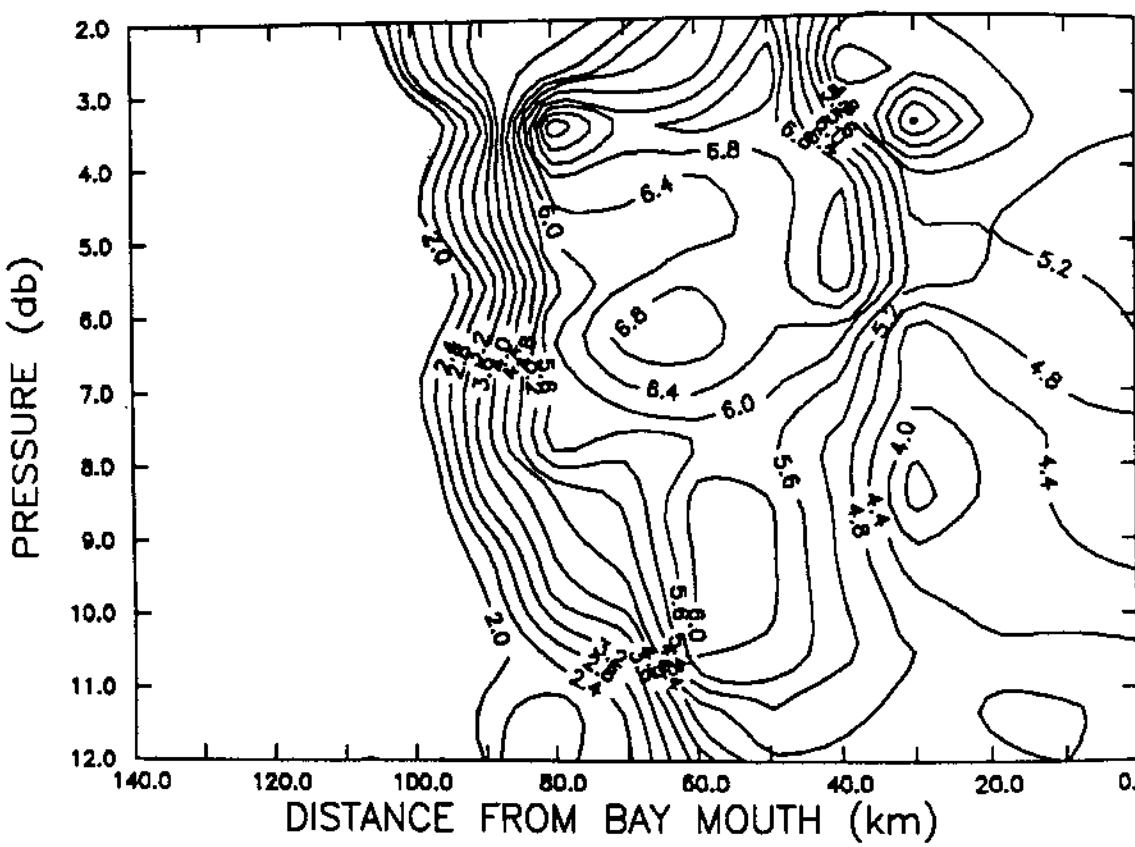

Figure G17. Profile of Brunt-Väisälä frequency for Scenic-24 (6-8 September 1988). Isopleths are in 10^{-2} s^{-1}.

H. AVERAGES AND STATISTICS

Profiles of average values and standard deviation of average values of temperature, salinity, sigma-t, horizontal sigma-t gradient, Brunt-Väisälä frequency, and stability are shown in Figures H1-H5 and H7-H11. These averages and standard deviations are based upon the 17 individual cruise data sets, not weighted. Seasonally averaged sigma-t, weighted by season, is shown in Figure H6.

The average profile of sigma-t showed a strong horizontal density gradient along the Delaware Estuary (Fig. H1). This horizontal gradient was due to changes in both salinity and temperature; average salinity increased and temperature decreased downstream toward the mouth of the bay (0 km, Figs. H2, H3). The majority of the gradient was due to the horizontal salinity gradient. Average salinity increased from <2 to 28 ppt (Fig. H3) while average temperature only decreased from 13.8 to 11.2°C (Fig. H2). Temperature, although contributing to the density gradient, was highly variable. The standard deviation of temperature was 6.4-9.0°C (Fig. H4) for average temperatures of 11.2-13.8°C (Fig. H2). Salinity was more constant with the standard deviation of salinity ranging from <1 to 3 ppt (Fig. H5).

The profile of average sigma-t also suggests partial vertical stratification in the middle of the estuary (Fig. H1); average isopycnals were slanted in surface waters toward the mouth of the bay indicating a vertical density gradient. The similarity between seasonally averaged sigma-t (Fig. H6) and the non-weighted average sigma-t (Fig. H1) suggests that the plots are a good representation of the average vertical density distribution. Partial vertical stratification of the water column in the middle of the estuary is supported by average profiles of Brunt-Väisälä frequency and stability. When average Brunt-Väisälä frequency and stability are examined (Fig. H7-H8), the highest values occurred in the middle of the estuary (40-70 km) supporting partial vertical stratification in this region.

The middle of the estuary also is a region of active mixing. When the standard deviation of average sigma-t is examined (Fig. H9), density was most variable between 40 and 80 km suggesting fresh and salt water actively mix in this region. Mixing in this region is supported by the average horizontal sigma-t gradient which also was highest in this region (Fig. H10-H11). This implies the existence of a front in this region between fresh and salt waters, and supports the speculation about mixing. The horizontal gradient in sigma-t decreases toward the mouth of the bay indicating more constant conditions in coastal waters.

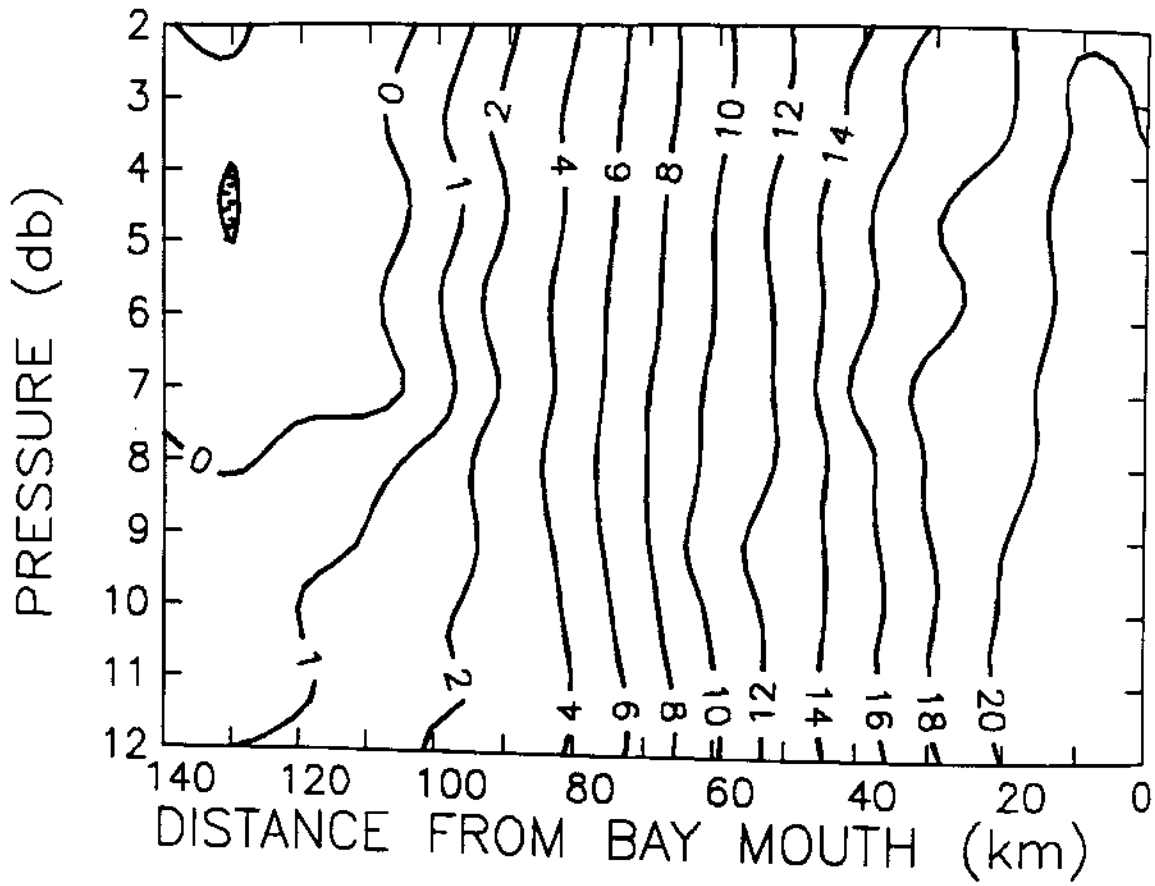

Figure H1. Profile of average sigma-t for the 17 individual cruises. Isopycnals are in $Kg \cdot m^{-3}$.

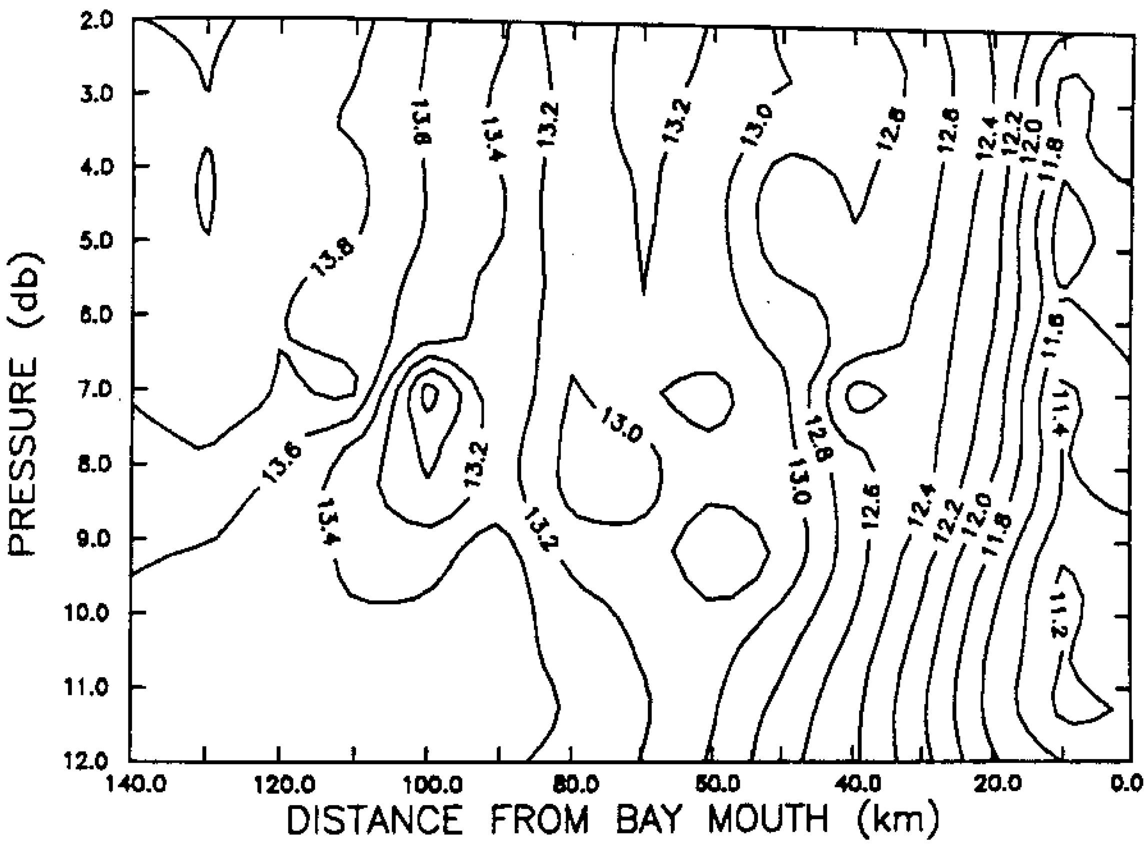

Figure H2. Profile of average temperature for the 17 individual cruises. Isotherms are in degrees Celsius.

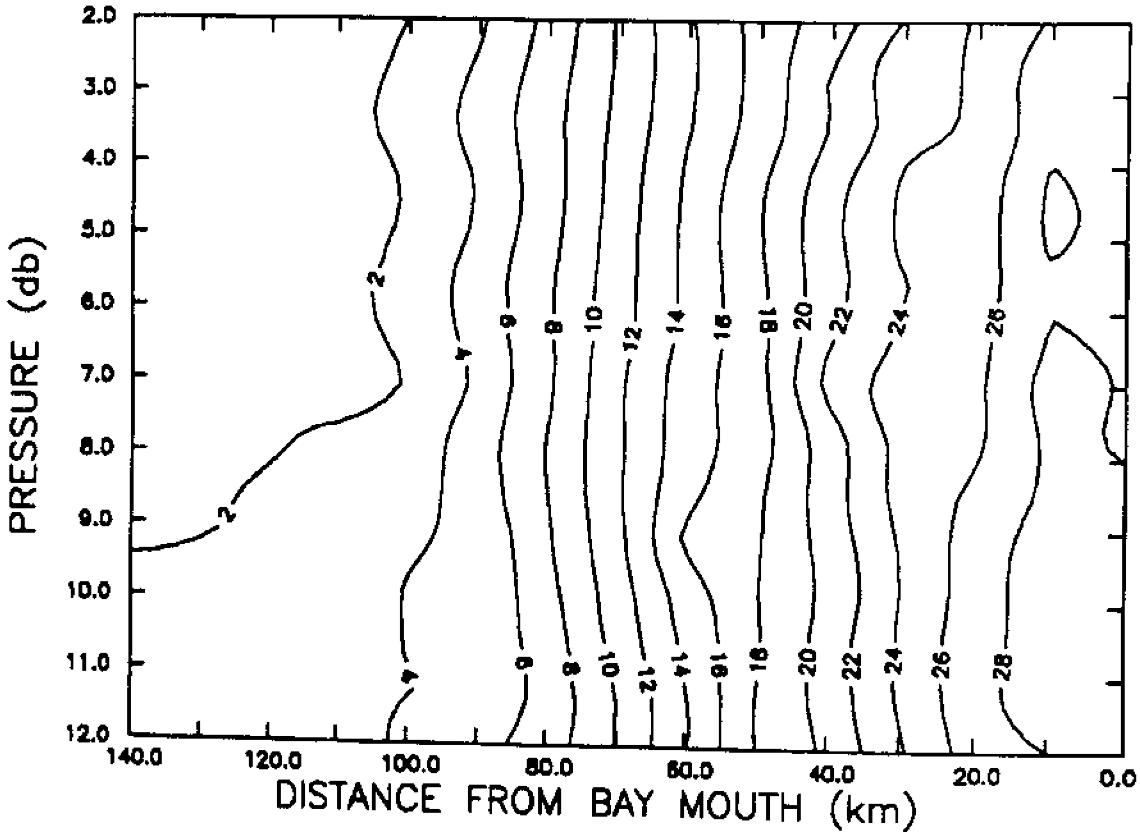

Figure H3. Profile of average salinity for the 17 individual cruises. Isopleths are in parts per thousand.

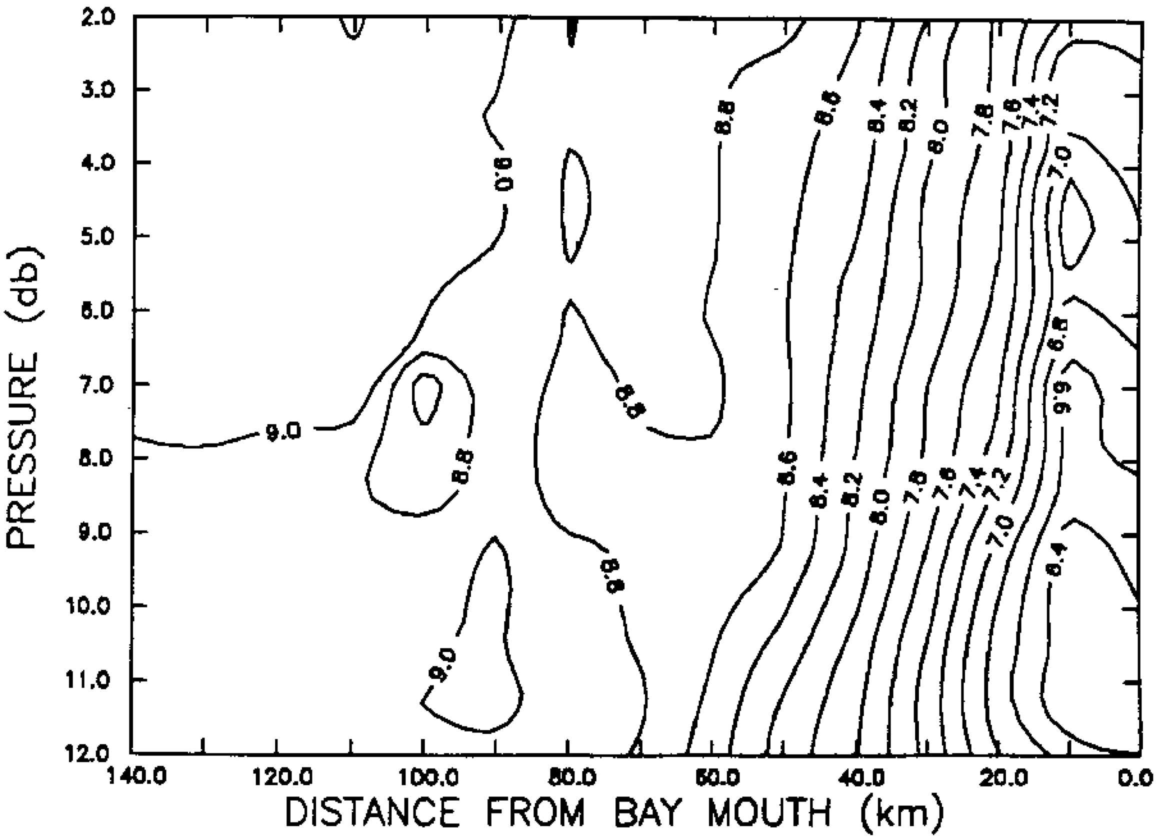

Figure H4. Profile of standard deviation of temperature for the 17 individual cruises. Isopleths are in grees Celsius.

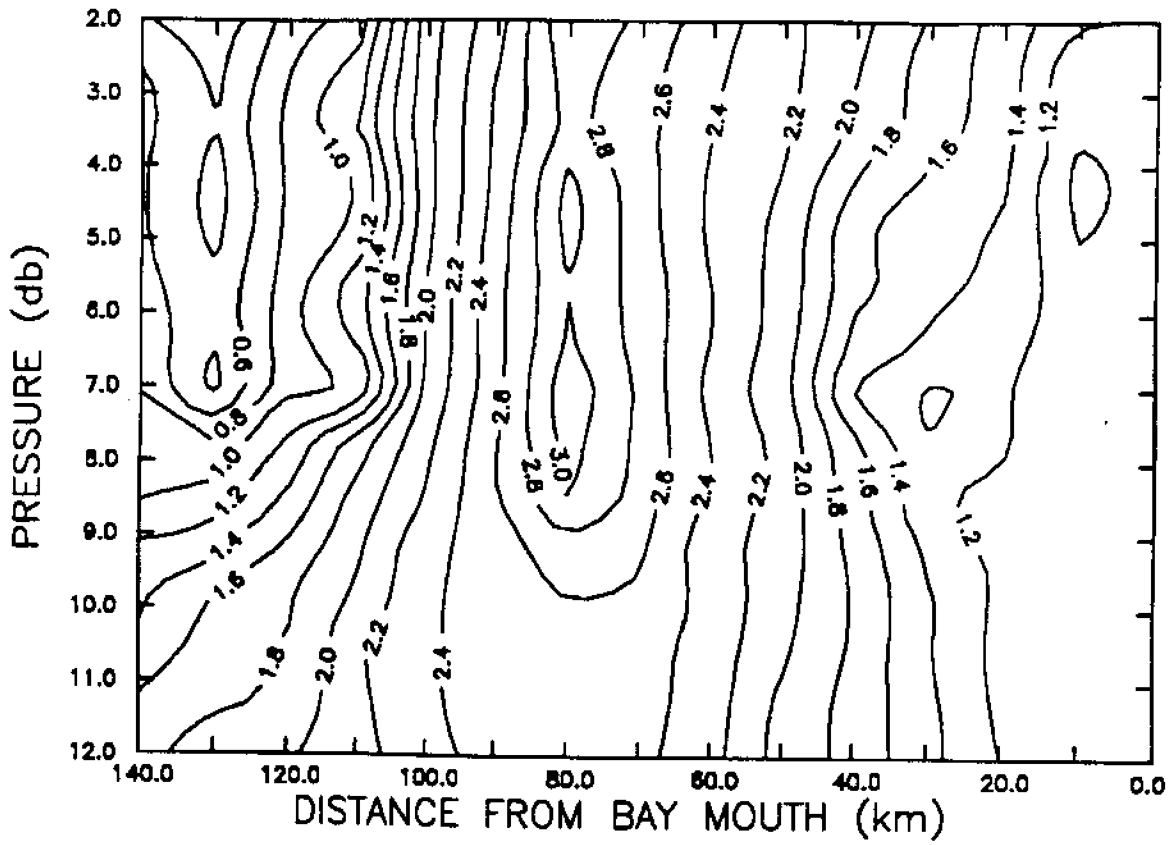

Figure H5. Profile of standard deviation of salinity for the 17 individual cruises. Isopleths are in parts per thousand.

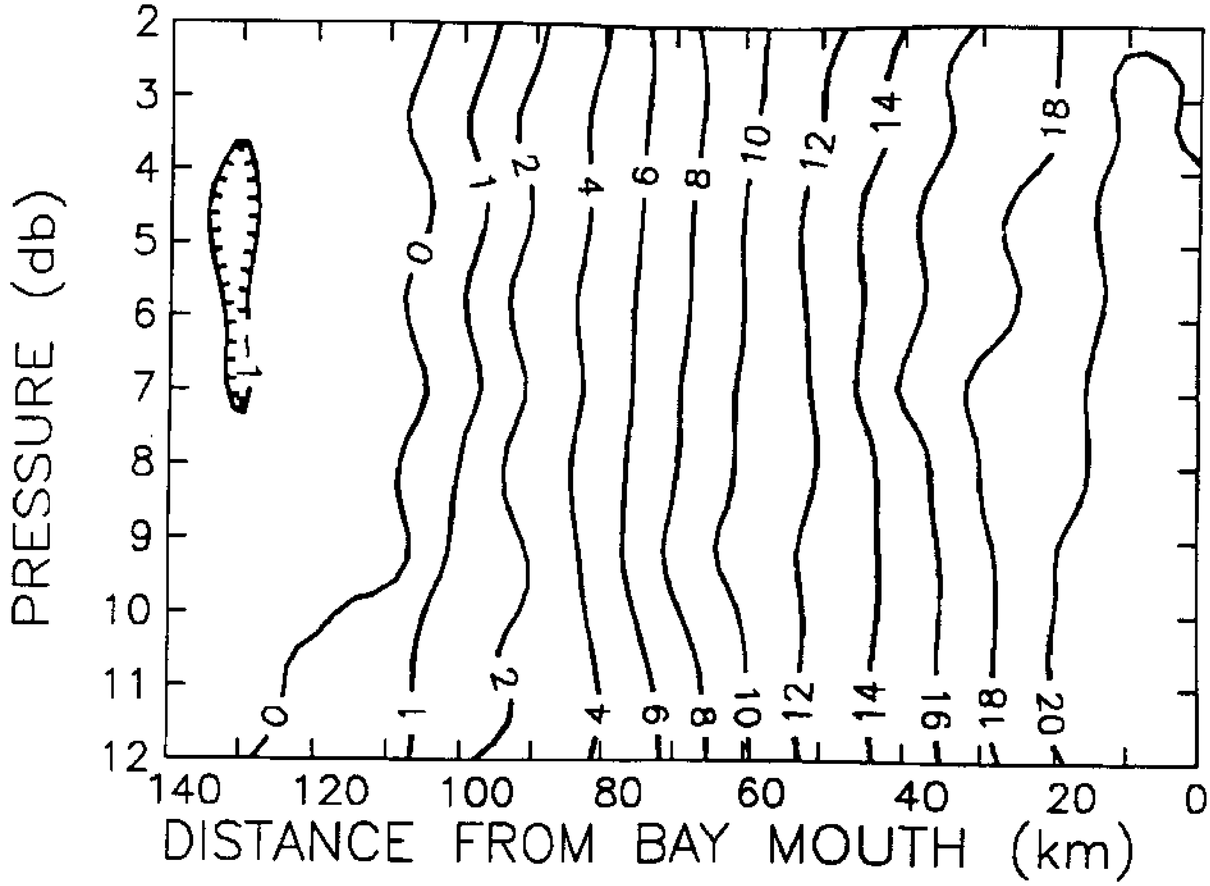

Figure H6. Profile of average sigma-t weighted by season. Isopycnals are in $Kg \cdot m^{-3}$.

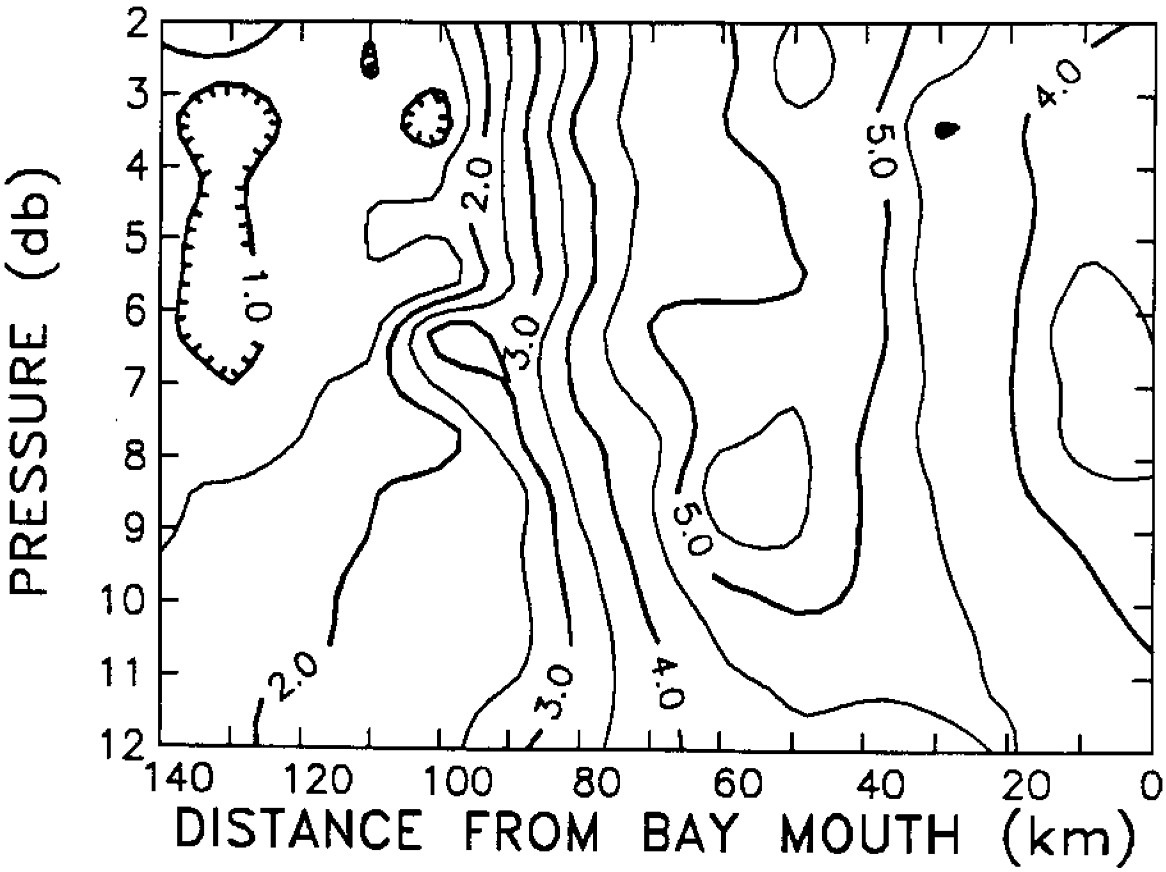

Figure H7. Profile of average Brunt-Väisälä frequency for the 17 individual cruises. Isopleths are in 10^{-2} s^{-1}.

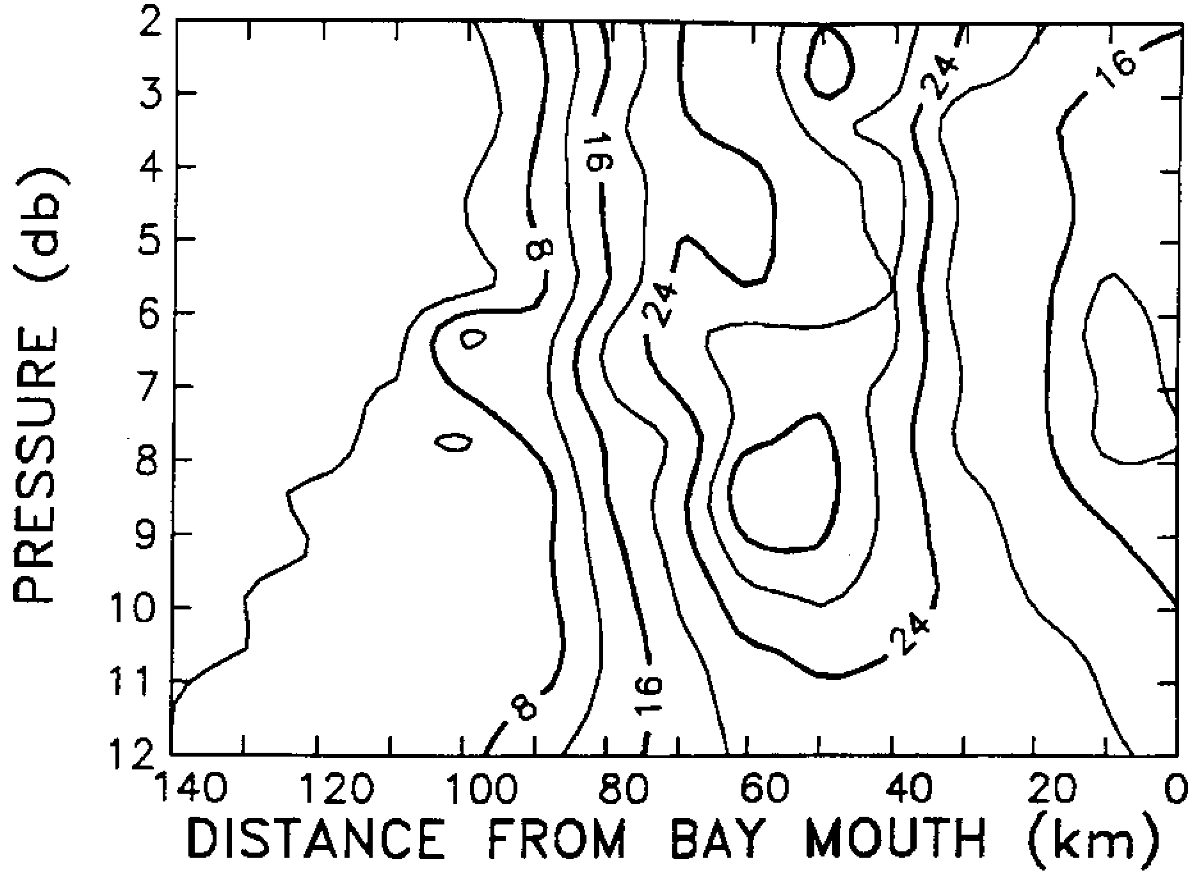

Figure H8. Profile of average stability for the 17 individual cruises. Isopleths are in $10^{-4}\ s^{-2}$.

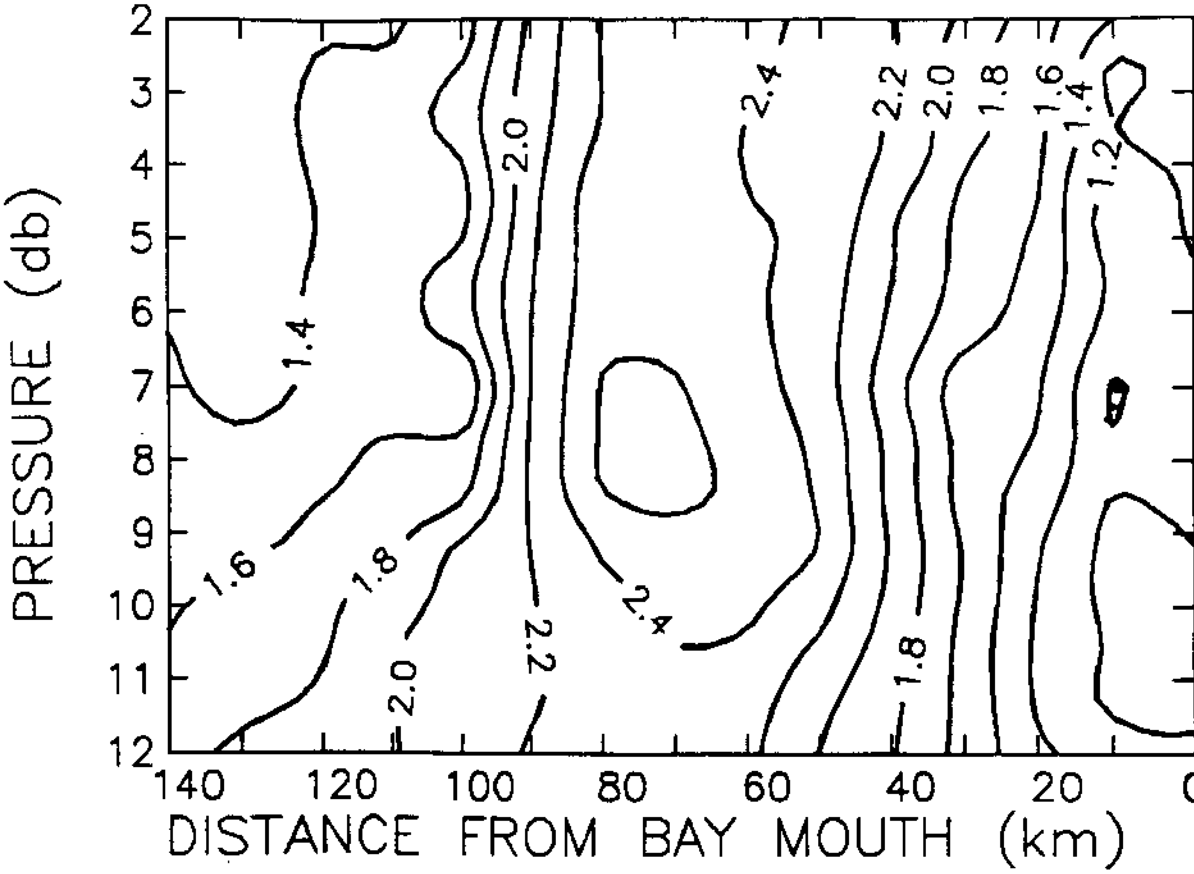

Figure H9. Profile of standard deviation of sigma-t for the 17 individual cruises. Isopleths are in $Kg \cdot m^{-3}$.

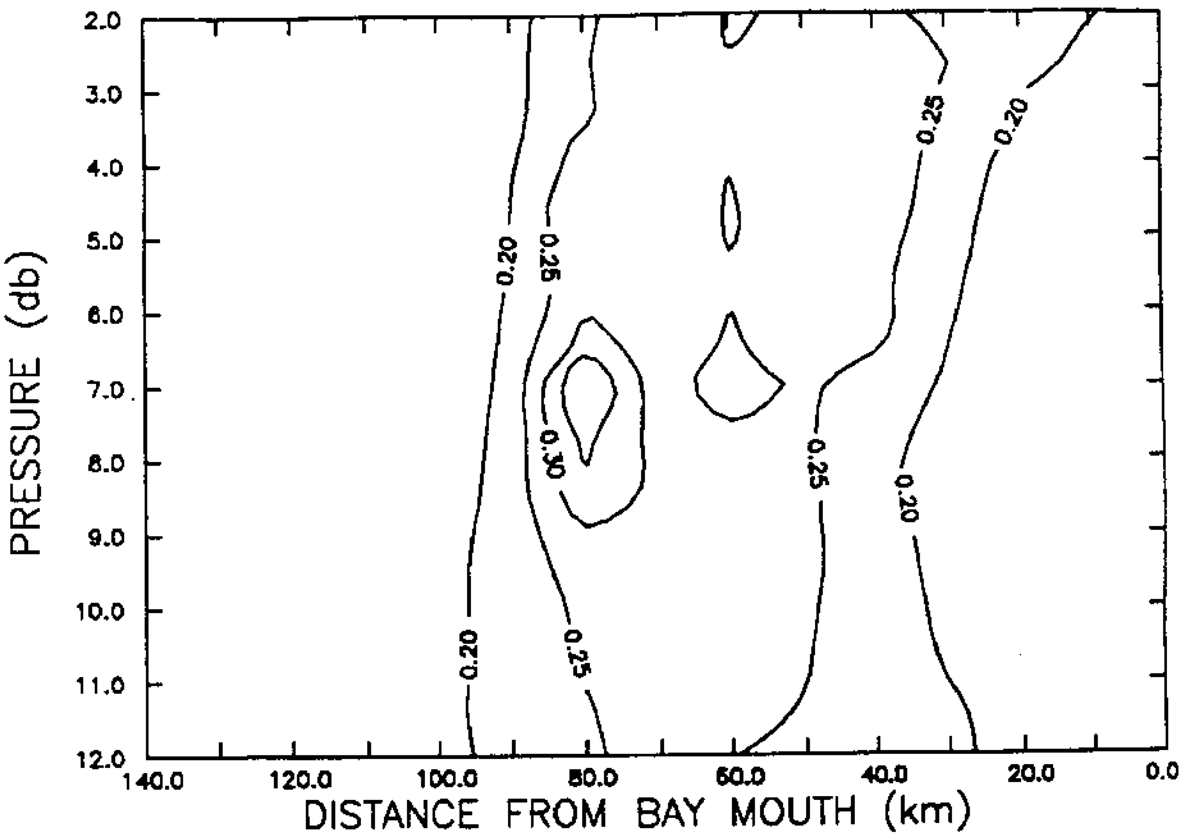

Figure H10. Profile of average sigma-t horizontal gradient for the 17 individual cruises. Isopleths are in 10^{-3} $Kg \cdot m^{-3} \cdot km^{-1}$.

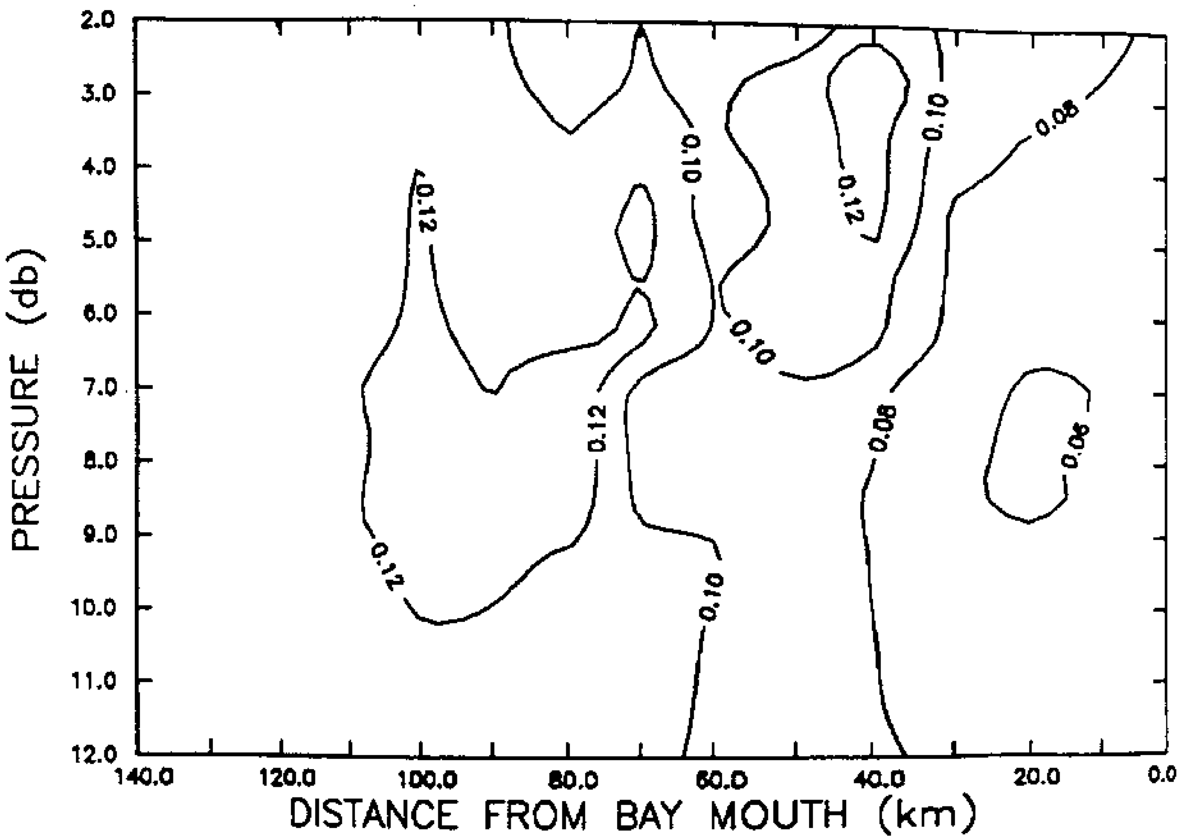

Figure H11. Profile of standard deviation of the horizontal gradient of sigma-t for the 17 individual cruises. Isopleths are in 10^{-3} $Kg \cdot m^{-3} \cdot km^{-1}$.

I. SEASONAL VARIATIONS

Profiles are shown for temperature, salinity, sigma-t, horizontal sigma-t gradient, and stability averaged by season in Figures I1-I20. The classification of cruises into four seasons is given in Section C.

Seasonal average temperatures are shown in Figures I1-I4. During all seasons, there was a horizontal gradient in average temperature. The direction of the gradient, however, reversed during the spring and fall. During the spring and summer (Fig. I1, I2), average temperature was warmer in fresh waters than near the mouth of the bay. In the fall, the gradient reversed, and temperatures were warmer in coastal waters (Fig. I3). This trend continued through the winter (Fig. I4) until water temperatures increased again in the spring.

Seasonal average salinity profiles, in contrast to temperature, were all very similar (Figs. I5-I8). In all seasons, there was a strong horizontal salinity gradient which began around 120-140 km upstream from the mouth of Delaware Bay, and salinity increased to approximately 28 ppt at the mouth.

Figures I9-I12 present profiles of average sigma-t by season. Although all averages showed well-developed horizontal stratification, as was seen in the average profile of all individual cruises (Fig. H1), there were some subtle differences between the seasons. In summer (Fig. I10), the water was least dense due to high water temperatures (Fig. I2), while seasonal averages for fall-spring were all similar (Fig. I9, I11-I12). However, isopycnals during the winter were more compressed in the middle of the estuary (40-80 km) than those of spring and fall. This can be more clearly seen in the seasonal horizontal sigma-t gradient profiles (Figs. I13-I16). In the winter, the horizontal sigma-t gradient was $>0.30 \times 10^{-3}$ $Kg \cdot m^{-3} \cdot km^{-1}$ throughout this region. During other seasons, the horizontal sigma-t gradient only exceeded 0.30×10^{-3} $Kg \cdot m^{-3} \cdot km^{-1}$ for isolated pockets.

Stability profiles (Figs. I17-I20) show a more diverse image by season than sigma-t. The most prominant feature in the profiles was high stability of deeper waters in the middle of the estuary (40-80 km). The degree of stability changed, but a maximum occurred at a depth of 7-10 db for all seasons. Stability in this region was lowest during the summer and increased during fall-winter to maximal values in the spring. Another feature common to all season was low stability in the upper estuary (100-140 km) In all seasons, stability was $<8 \times 10^{-4}$ s^{-2} in this region, with stability $<4 \times 10^{-4}$ s^{-2} during the fall-spring.

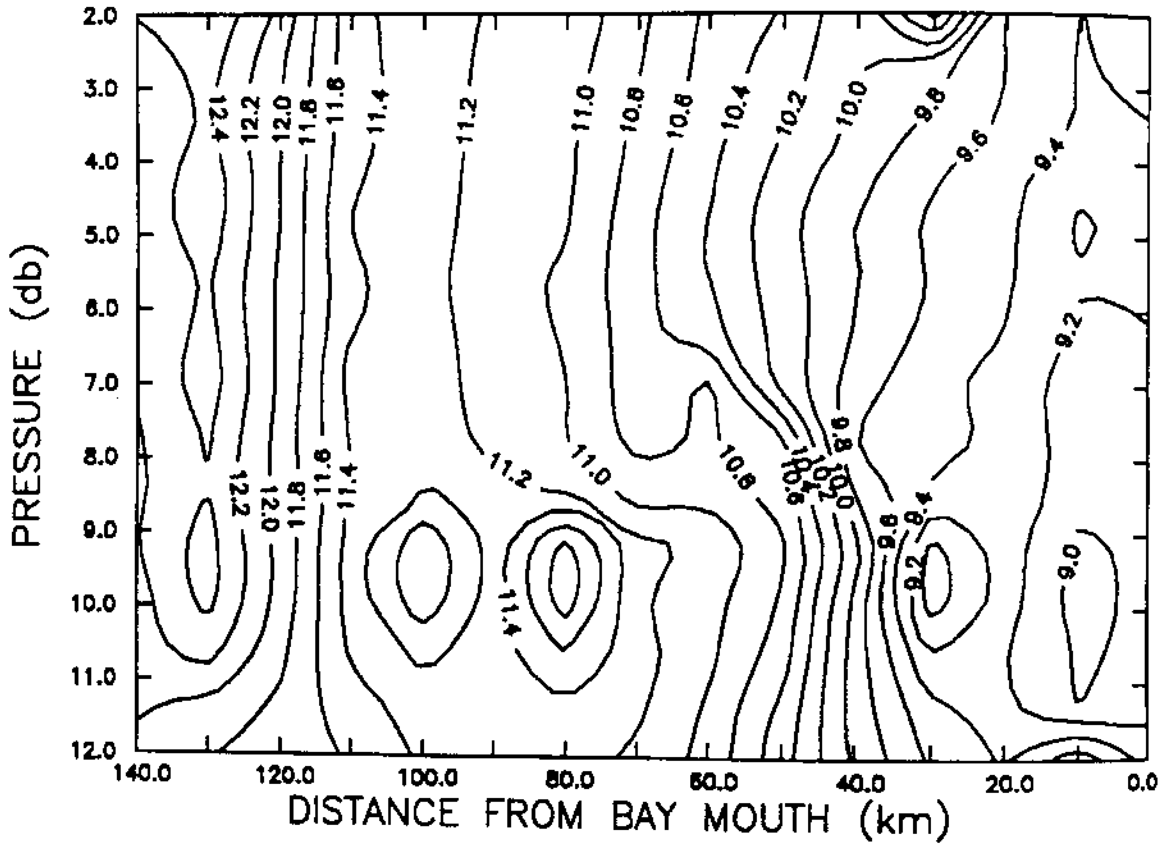

Figure I1. Profile of average temperature for spring cruises. Isotherms are in degrees Celsius. See section C for cruise designations.

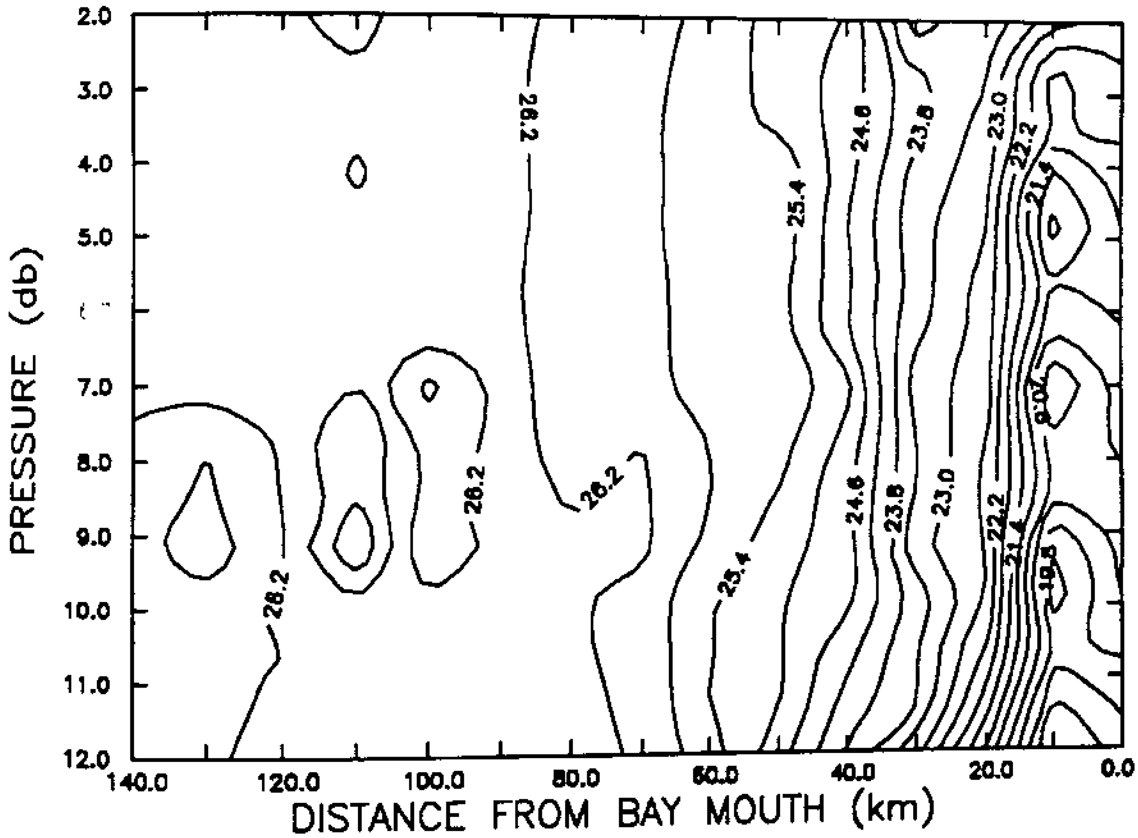

Figure I2. Profile of average temperature for summer cruises. Isotherms are in degrees Celsius. See section C for cruise designations.

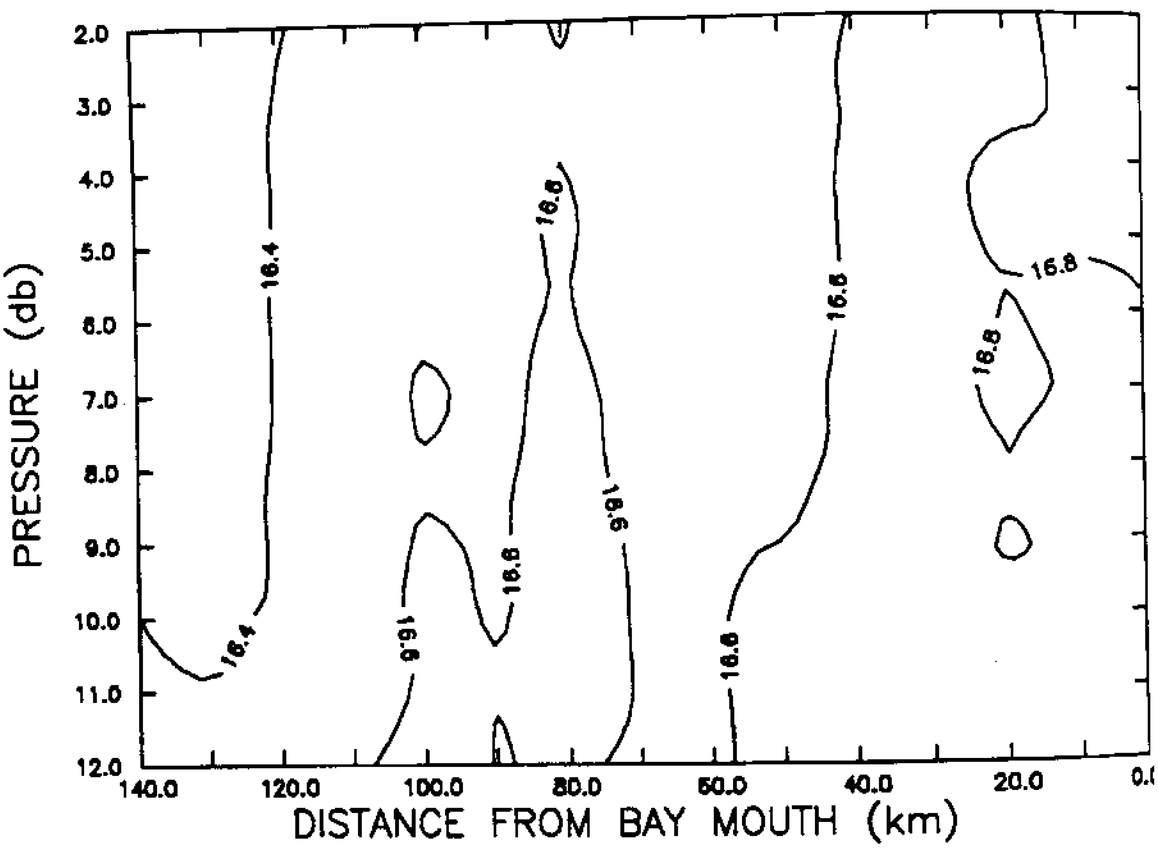

Figure I3. Profile of average temperature for fall cruises. Isotherms are in degrees Celsius. See section C for cruise designations.

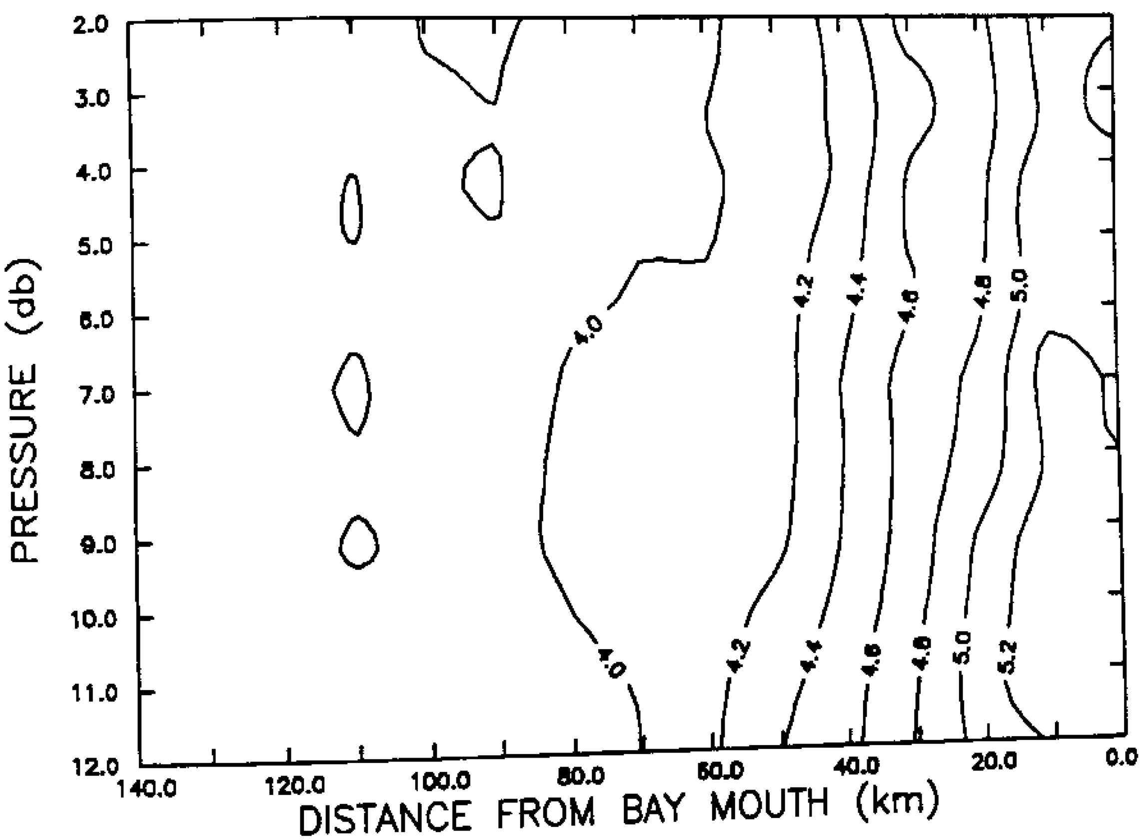

Figure I4. Profile of average temperature for winter cruises. Isotherms are in degrees Celsius. See section C for cruise designations.

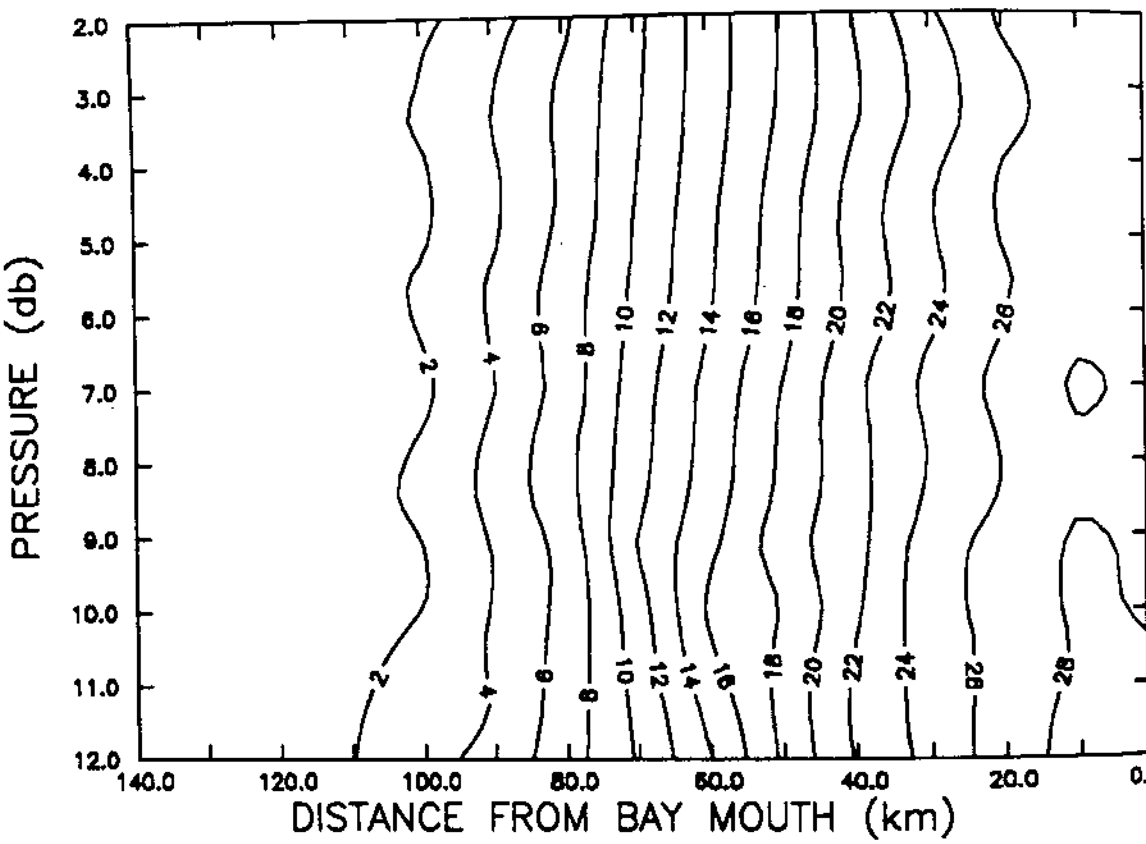

Figure 15. Profile of average salinity for spring cruises. Isopleths are in parts per thousand. See section C for cruise designations.

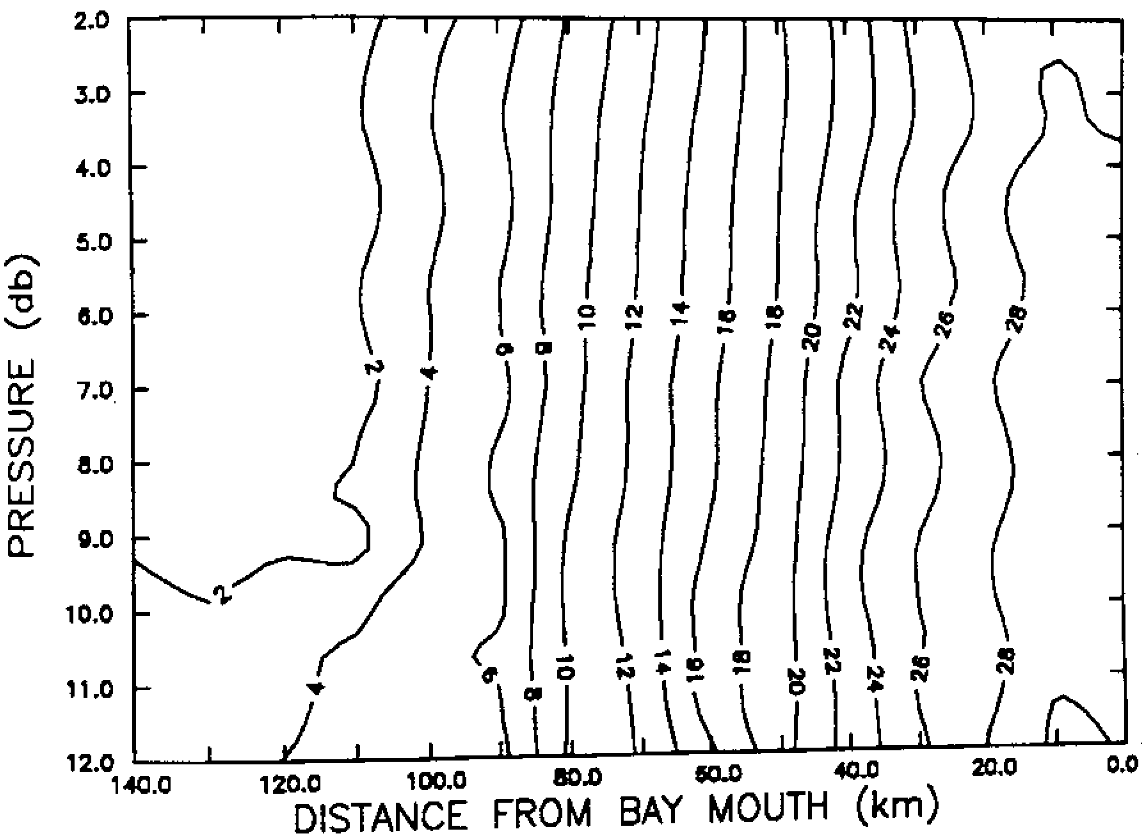

Figure I6. Profile of average salinity for summer cruises. Isopleths are in parts per thousand. See section C for cruise designations.

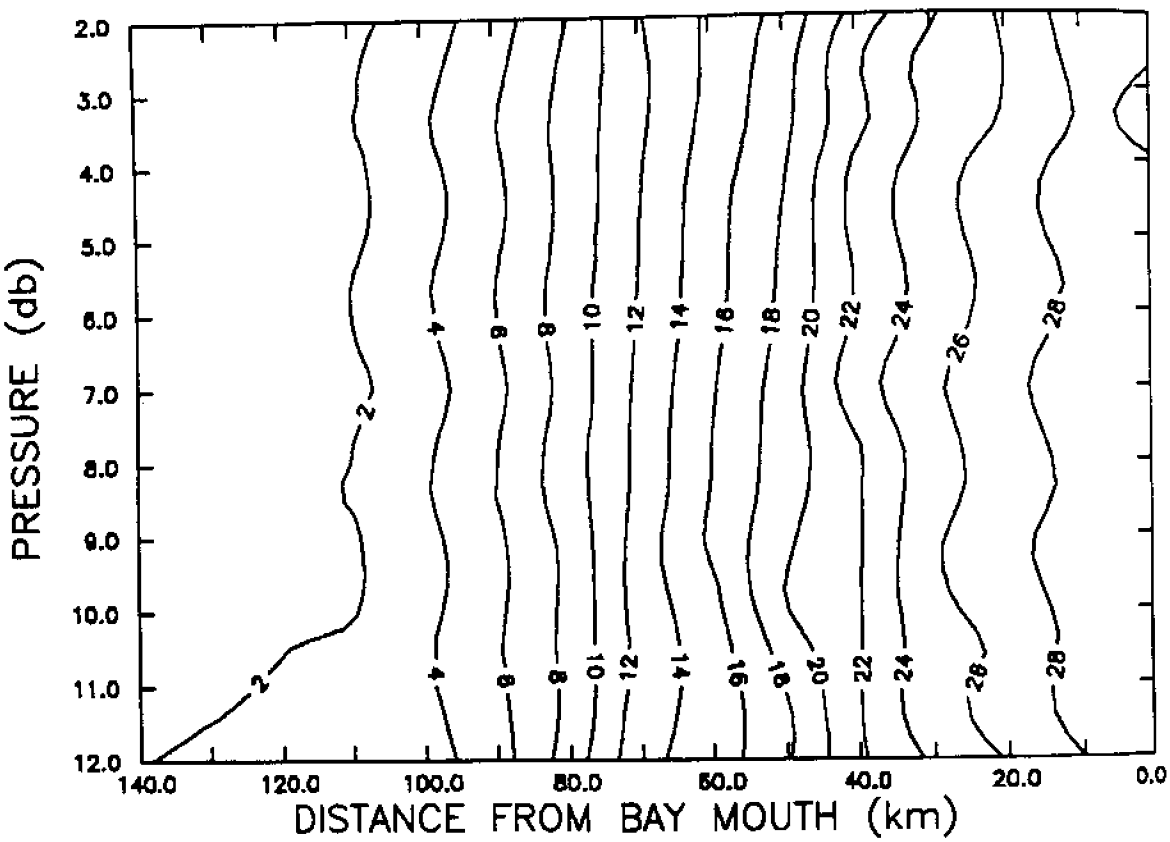

Figure I7. Profile of average salinity for fall cruises. Isopleths are in parts per thousand. See section C for cruise designations.

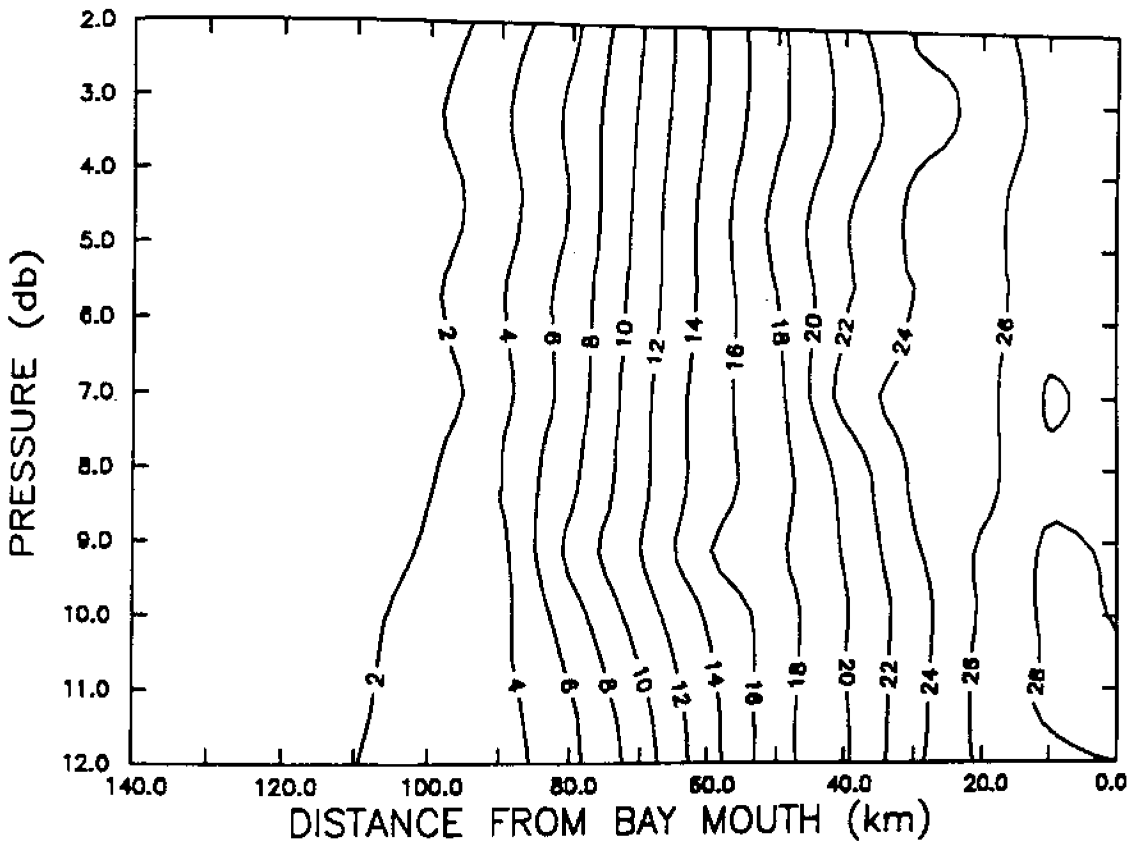

Figure I8. Profile of average salinity for winter cruises. Isopleths are in parts per thousand. See section C for cruise designations.

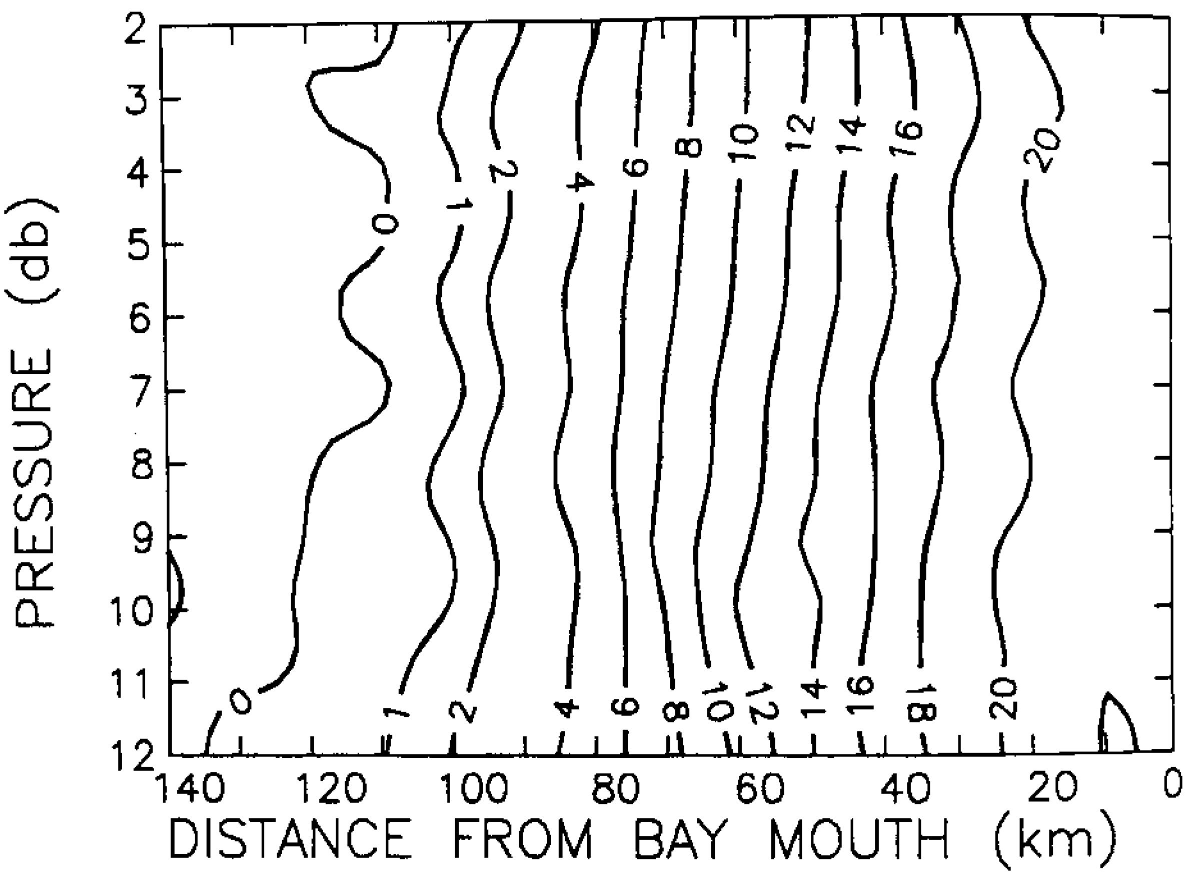

Figure I9. Profile of average sigma-t for spring cruises. Isopycnals are in $Kg \cdot m^{-3}$. See section C for cruise designations.

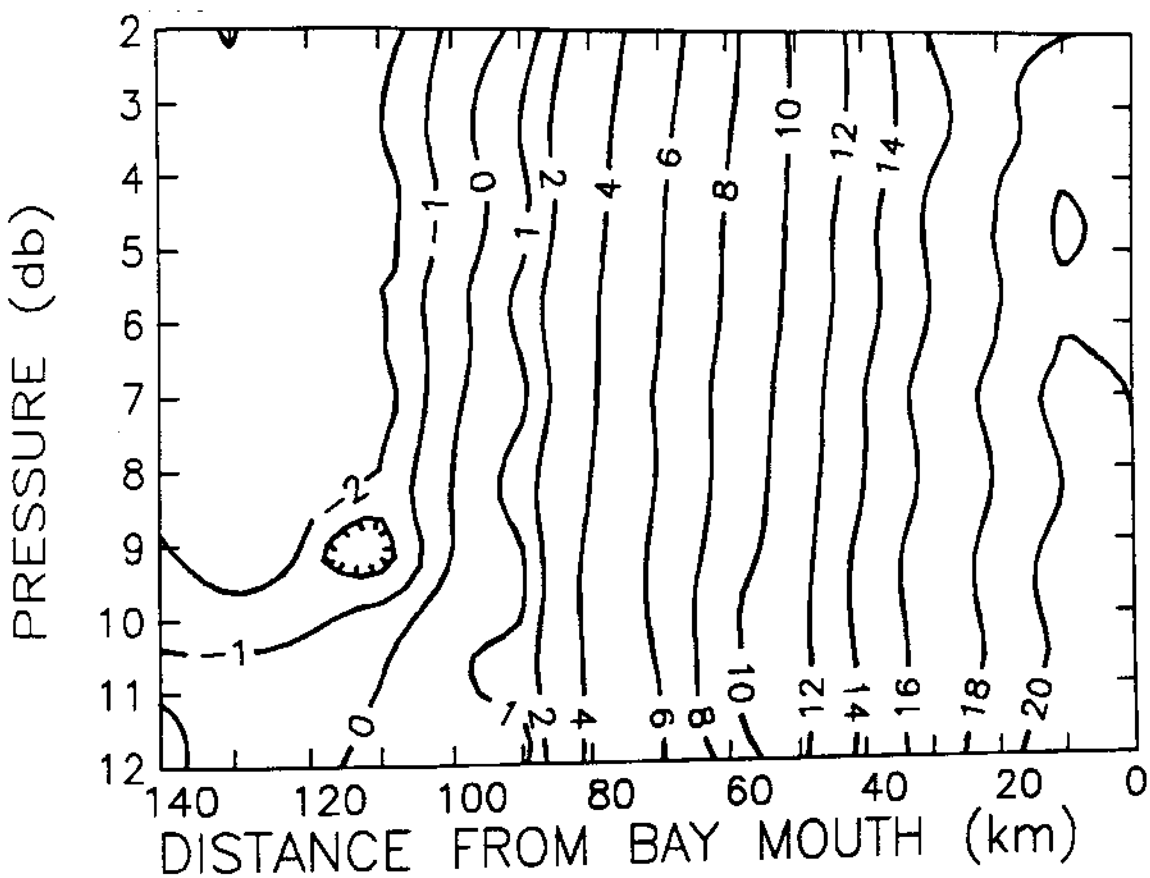

Figure I10. Profile of average sigma-t for summer cruises. Isopycnals are in $Kg \cdot m^{-3}$. See section C for cruise designations.

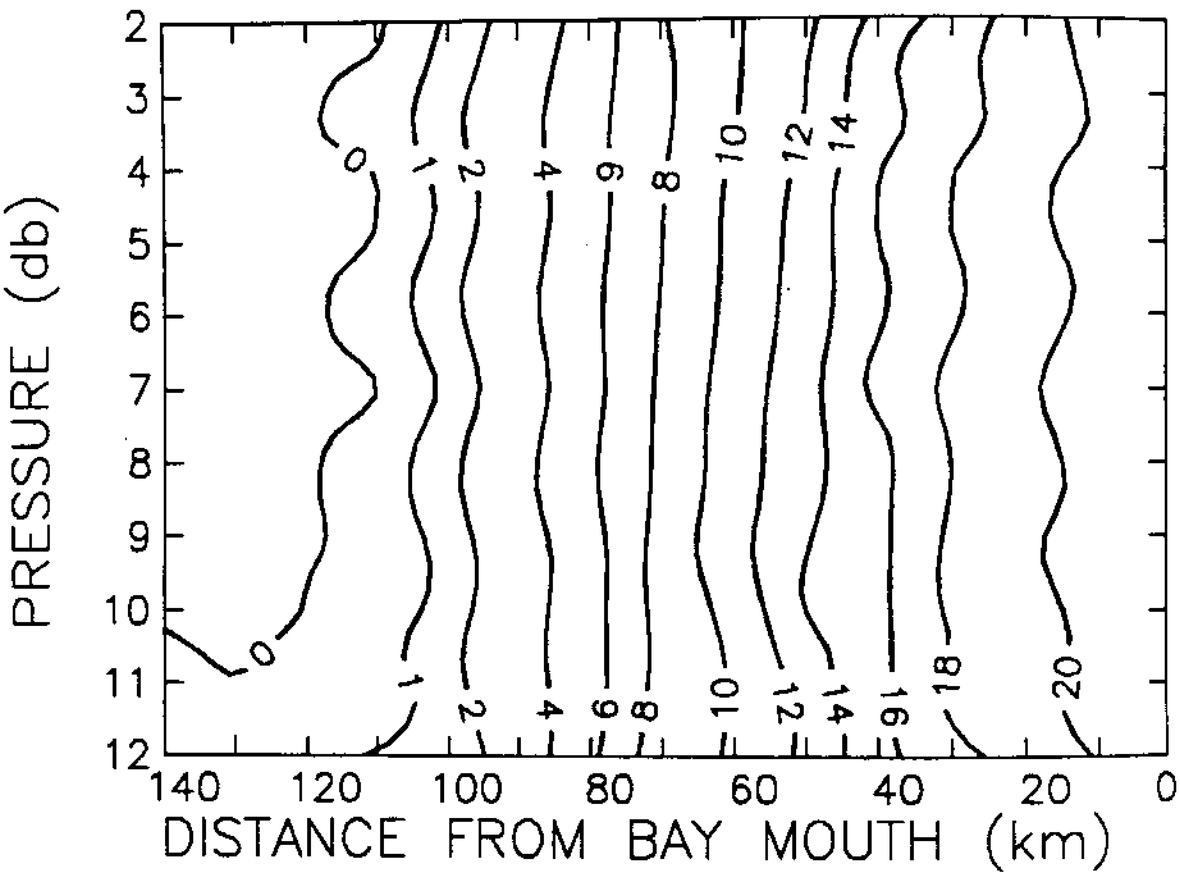

Figure I11. Profile of average sigma-t for fall cruises. Isopycnals are in $Kg \cdot m^{-3}$. See section C for cruise designations.

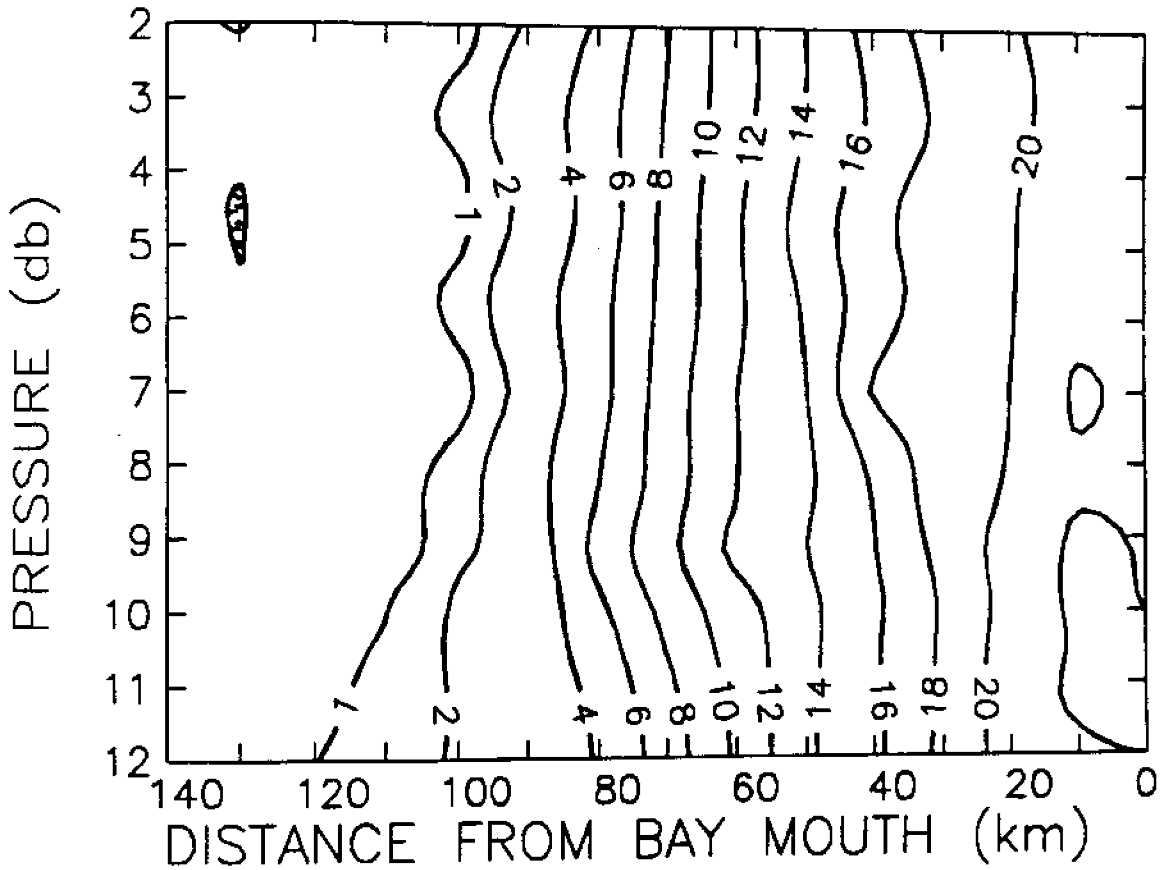

Figure I12. Profile of average sigma-t for winter cruises. Isopycnals are in $Kg \cdot m^{-3}$. See section C for cruise designations.

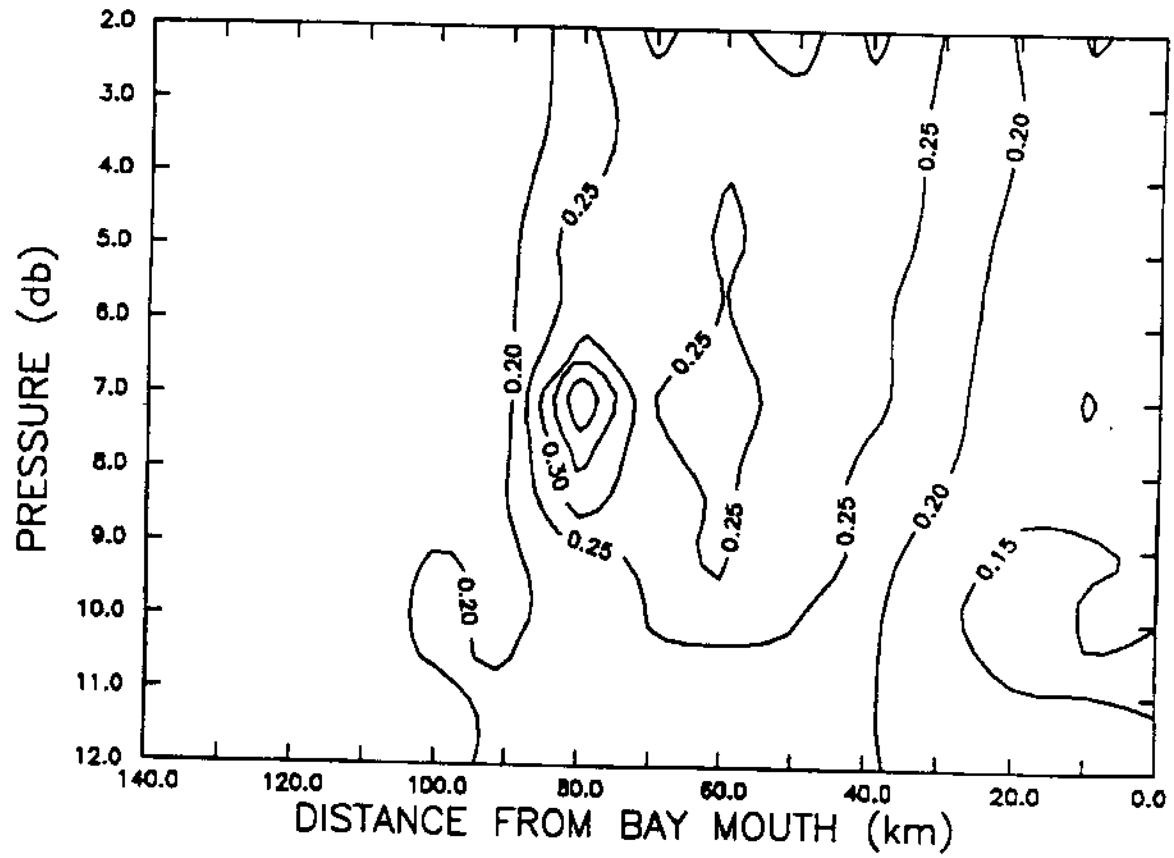

Figure I13. Profile of average horizontal gradient of sigma-t for spring cruises. Isopleths are in $Kg \cdot m^{-3} \cdot km^{-1}$. See section C for cruise designations.

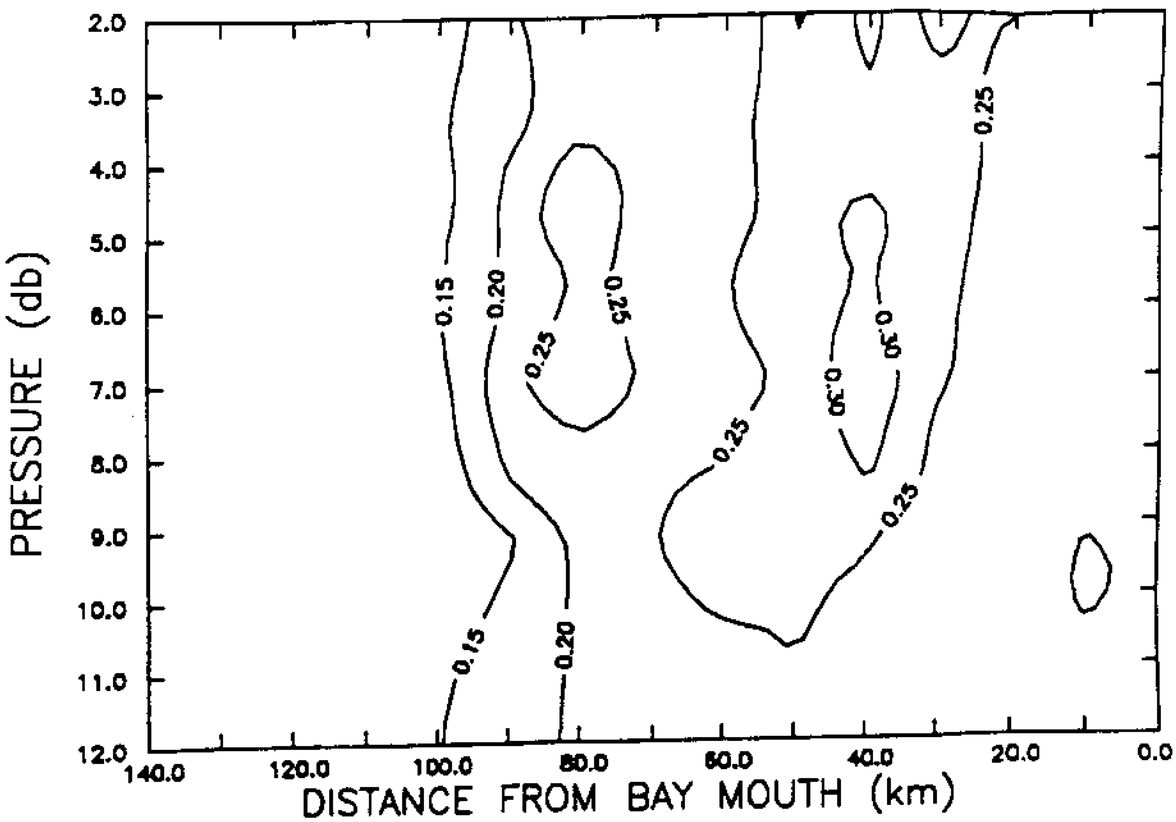

Figure I14. Profile of average horizontal gradient of sigma-t for summer cruises. Isopleths are in $Kg \cdot m^{-3} \cdot km^{-1}$. See section C for cruise designations.

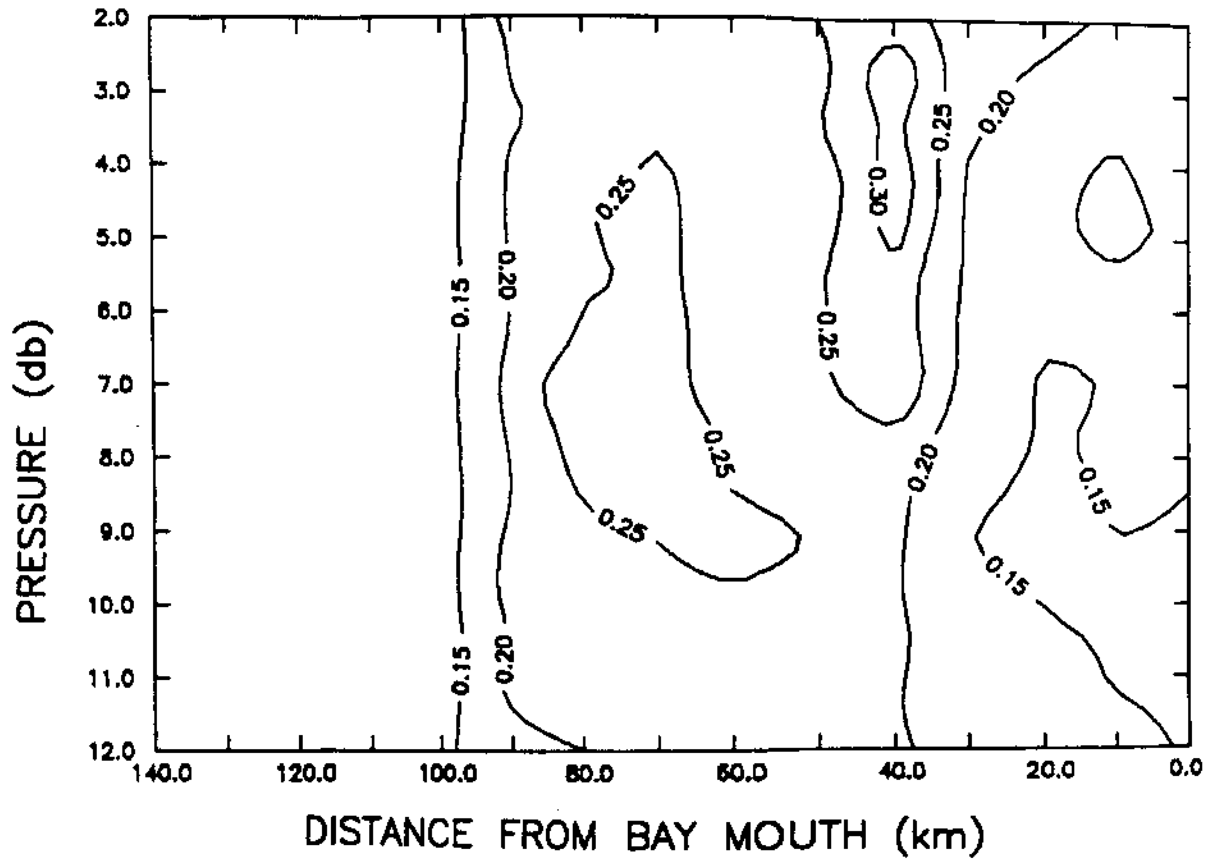

Figure I15. Profile of average horizontal gradient of sigma-t for fall cruises. Isopleths are in $Kg \cdot m^{-3} \cdot km^{-1}$. See section C for cruise designations.

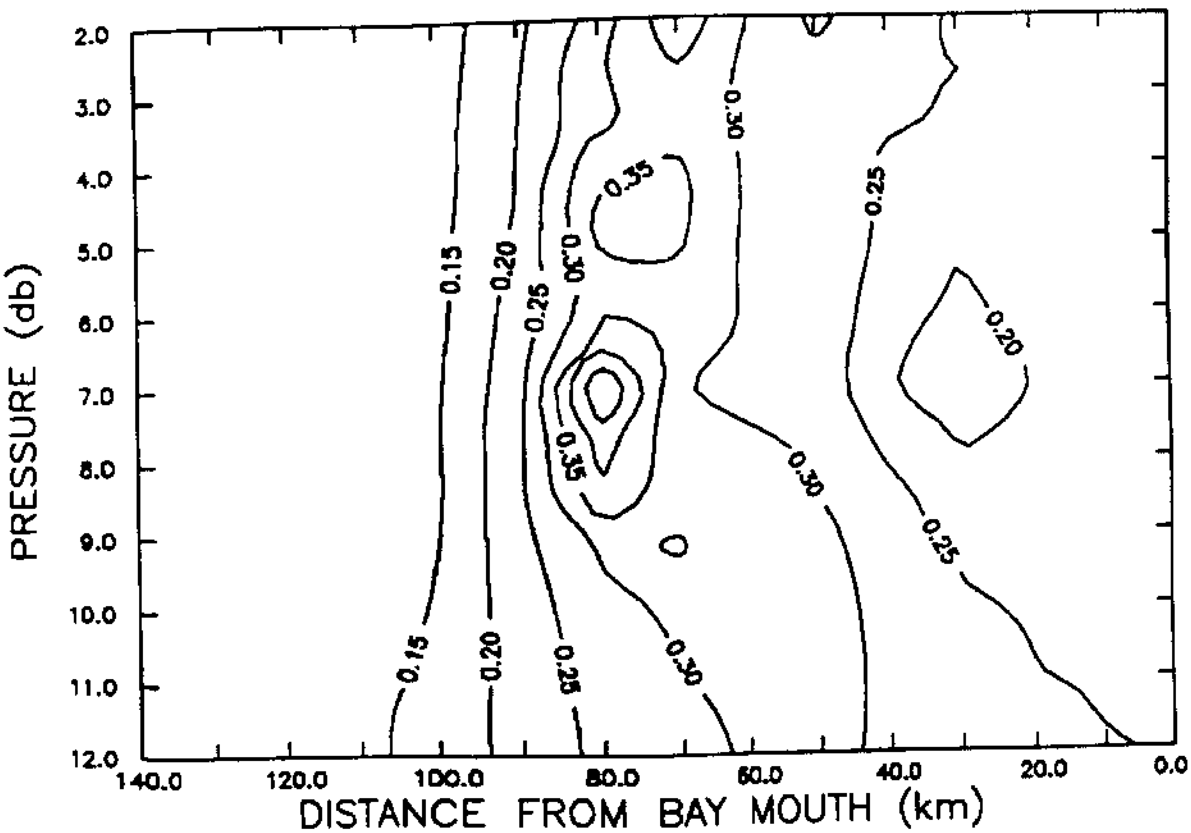

Figure I16. Profile of average horizontal gradient of sigma-t for winter cruises. Isopleths are in $Kg \cdot m^{-3} \cdot km^{-1}$. See section C for cruise designations.

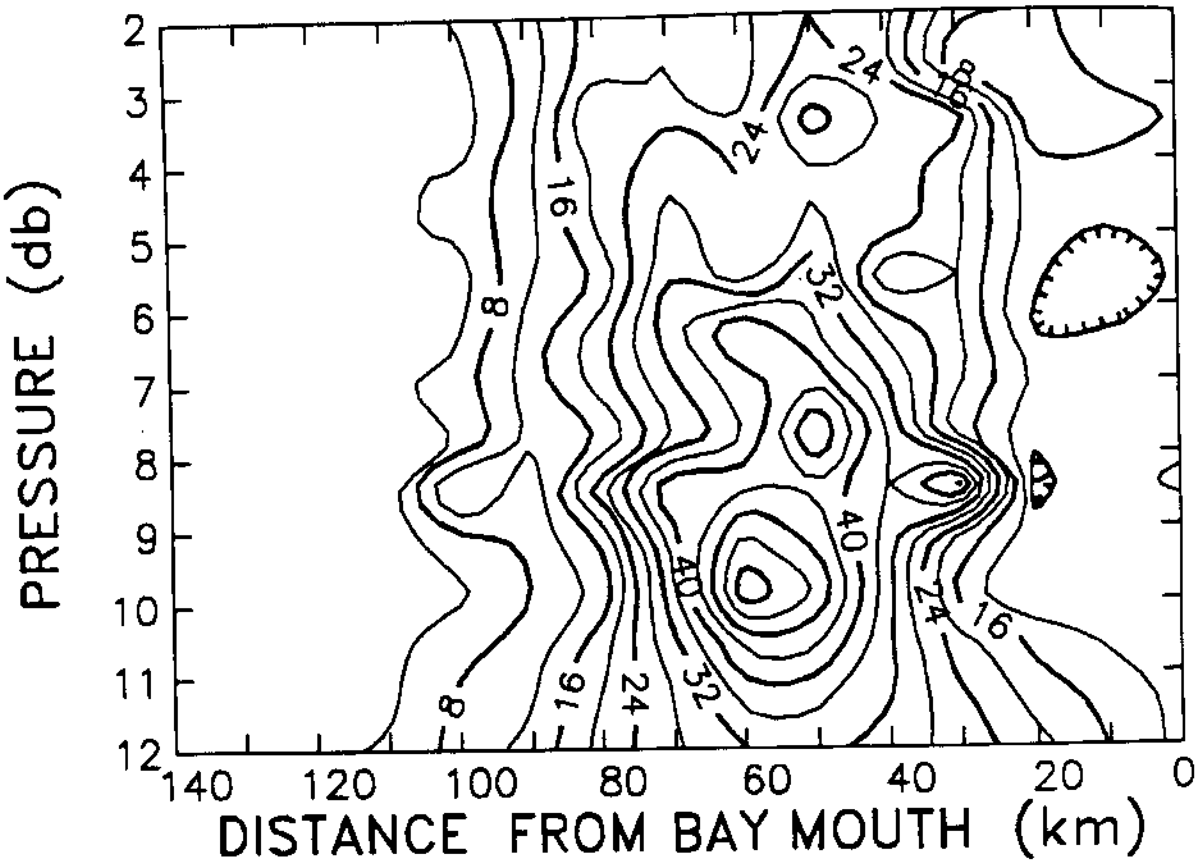

Figure I17. Profile of average stability (N^2) for spring cruises. Isopleths are in 10^{-4} s^{-2}. See section C for cruise designations.

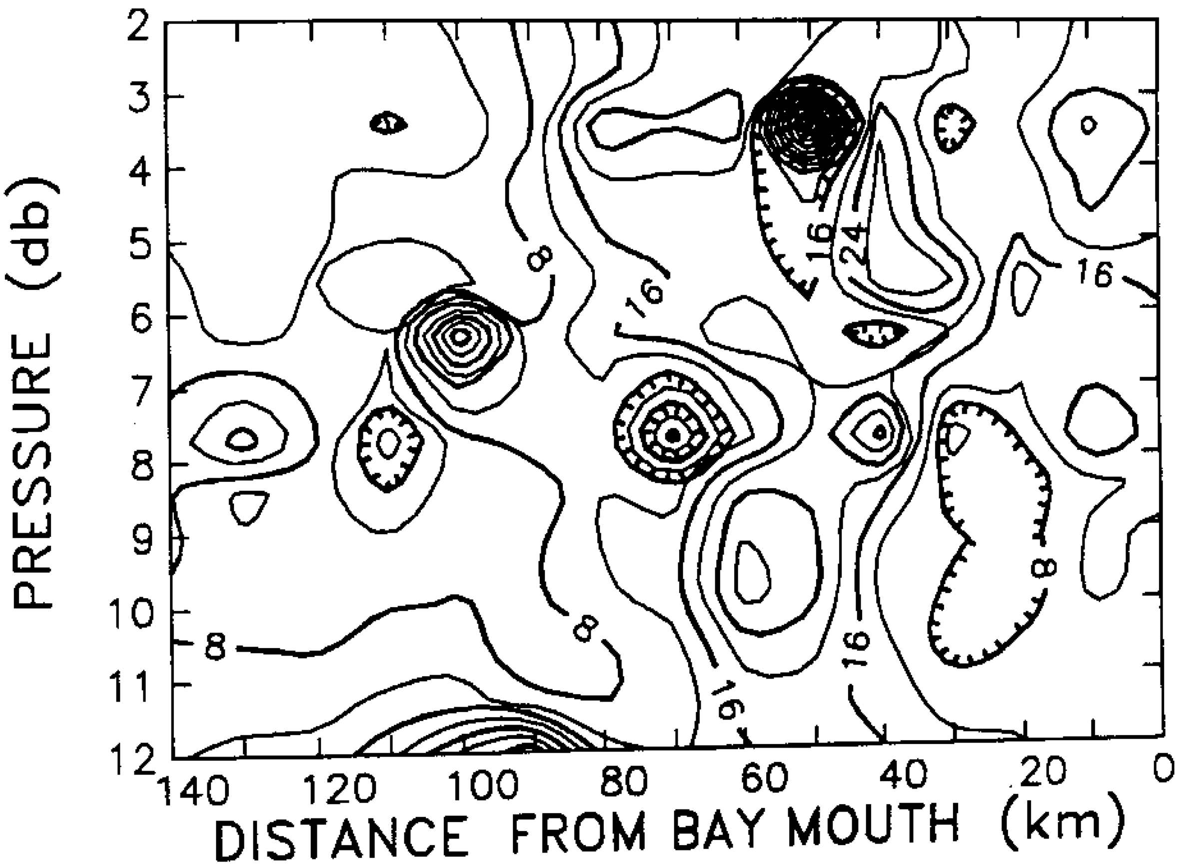

Figure I18. Profile of average stability (N^2) for summer cruises. Isopleths are in $10^{-4}\ s^{-2}$. See section C for cruise designations.

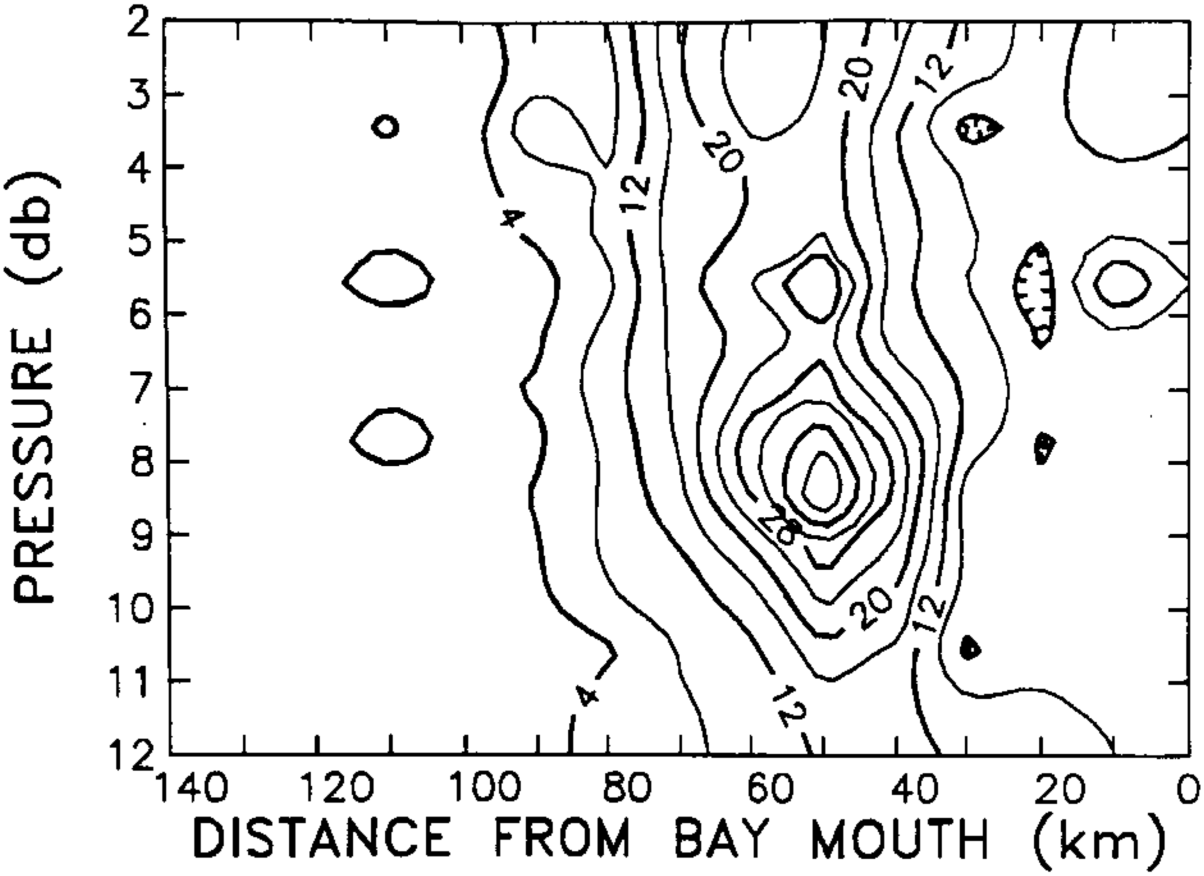

Figure I19. Profile of average stability (N^2) for fall cruises. Isopleths are in 10^{-4} s^{-2}. See section C for cruise designations.

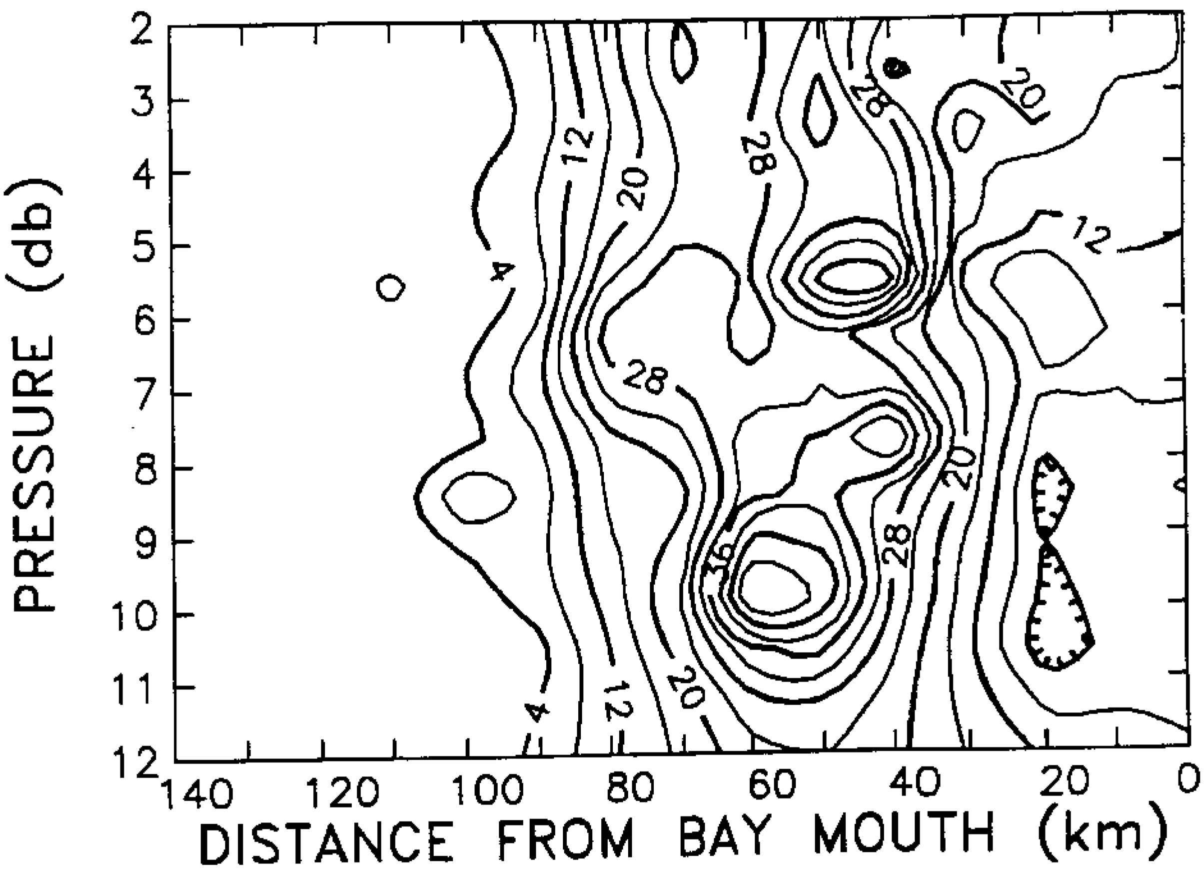

Figure I20. Profile of average stability (N^2) for winter cruises. Isopleths are in 10^{-4} s^{-2}. See section C for cruise designations.