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J. Hamilton, S. Prinsenberg, and L. Malloch

Ocean Sciences Division
Maritimes Region
Fisheries and Oceans Canada

Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia
Canada B2Y 4A2

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by

J. Hamilton, S. Prinsenberg, and L. Malloch

Ocean Sciences Division,
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Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia
Canada, B2Y 4A2

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Abstract

Hamilton, J., S. Prinsenberg, and L. Malloch. 2002. Moored current meter and CTD observations from Barrow Strait, 1998-1999. Can. Data Rep. Hydrogr. Ocean Sci. 157 : v + 65 pp.

An array of 9 instrumented moorings deployed in the eastern end of Barrow Strait from August 1998 to August 1999 provides yearlong records of current, ice drift, temperature and salinity. Current data collected with Acoustic Doppler Current Profilers and specialised instrumentation for near-pole direction measurement, are presented as contour plots of both bihourly and low-pass filtered observations. Results of a tidal analysis of the current data are also presented. Temperatures, salinities and densities obtained from moored CTDs are displayed as time series plots for both bihourly and low-pass filtered data, and as power spectra. Statistical results include means, extrema and standard deviations of all measured parameters.

CTD sections across Barrow Strait and Wellington Channel derived from ship-based surveys in 1998 and 1999 are also presented.

Résumé

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On a ancré un ensemble de neuf batteries d'instruments dans la partie est du détroit de Barrows de août 1998 à août 1999, afin d'obtenir sur toute l'année des données au sujet des courants, de la dérive des glaces, de la température et de la salinité. Les données sur les courants recueillies avec des profileurs de courant à effet Doppler et des instruments spécialement conçus pour effectuer des mesures en direction quasi polaire sont présentées sous forme de tracés de contours d'observations réalisées toutes les deux heures et d'observations par filtrage passe-bas. On présente aussi les résultats d'une analyse tidale des données sur les courants. Les températures, salinités et densités enregistrées par les sondes CTD ancrées sont indiquées sous forme de graphiques chronologiques, cela tant pour les données d'observation aux deux heures que pour les données d'observation par filtrage passe-bas. Les statistiques obtenues comprennent les moyennes, les extrêmes et les écarts-types de tous les paramètres mesurés.

Des profils de conductivité, température et profondeurs dans le détroit de Barrows et le chenal Wellington, établis d'après des relevés par navire réalisés en 1998 et 1999, sont aussi présentés.

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Introduction

Three main passages through the Canadian Archipelago connect the Arctic Ocean with the Northwest Atlantic, allowing for exchange of mass, heat and salt that impact on the circulation and mixing patterns of both oceans. A net volume transport of 2×10^6 m^3s^{-1} into Baffin Bay is typical of the estimates reviewed in Prinsenberg and Bennett (1987). This transport results in a heat gain and salt loss for the Arctic Ocean.

Barrow Strait is the widest of the connecting passages through the Canadian Archipelago. Estimates based on through-ice CTDs and some limited current meter data, indicate that flow through Barrow Strait accounts for roughly 1/3 of the total transport through the Archipelago (Prinsenberg and Bennett, 1987). As such, it is an important pathway for any increased freshwater discharge from the Arctic Ocean that may result from a climate-warming trend. The data presented here are from the first year of a multiyear program to quantify and examine the inter-annual variability of the exchange through Barrow Strait, and more generally, to improve our understanding of the circulation within the Arctic Archipelago. This will lead to better projections of the response of Arctic waters and their ecosystems to climate change, new capabilities to predict ice distributions and movement for Arctic marine transportation, and improved contingency strategies for marine environmental emergencies.

Described here are the methods used to collect and process the yearlong records of current rate and direction, ice drift, temperature, salinity and density from Barrow Strait. The data are presented as unfiltered and low-pass filtered time series plots along with relevant statistical summaries for each season. CTD data are also presented as power spectra. Results of tidal analyses give tidal amplitudes, phase and ellipse orientation as a function of depth for each of the 5 main tidal constituents (K1, M2, O1, S2, P1). Separate tidal analyses have been done for the period when there is solid ice cover, and the 3 month period of open water.

Finally, hydrographic sections at the eastern and western ends of Barrow Strait, and across Wellington Channel are presented. These cross-sectional diagrams are created from a 35 station CTD survey conducted during each field study.

Mooring Locations and Description

A total of 9 moorings were deployed at the eastern end of Barrow Strait, with instrumentation concentrated around the 200 m contours on both the north and south sides of the Strait (See Figure 1). An illustration of the moorings deployed is shown in Figure 2. Acoustic Doppler Current Profilers (ADCPs) and precision heading references were mounted in streamlined buoyancy packages to provide current rate and direction information. A unique measurement strategy was required to obtain reliable direction measurements in this area because of the proximity of the site to the magnetic pole, and is described in detail by Hamilton [2001]. Two current measurement systems were moored about 1.2 km apart on both the north and south sides of the Strait to provide coverage over 160 m of the 200 m water column. (The range of the RDI Inc., 300 kHz WorkHorse Sentinels used in this experiment is typically 70 to 80 m in the clean Arctic waters, but occasionally drops to 60 m in winter.) Measurements of temperature, conductivity and pressure at 5 levels on both sides of the Strait were also made, using moored SeaBird MicroCat CTDs. Instrumentation was distributed over 4 moorings at each site as a risk management strategy to minimise the impact of potential losses to ice ridging and icebergs.

All instruments recorded bihourly data over the yearlong deployment. The upward looking ADCPs logged average speeds from 100 pings over a 5 minute on-period every 2 hours, and also provided a simultaneous ice drift speed. Concurrent direction measurements were logged separately with the precision heading reference system, and have been merged with the ADCP speed data for presentation here. CTDs recorded a single temperature, conductivity and pressure every 2 hours. Post-deployment calibration demonstrated remarkable stability from all 10 of the moored CTDs over the yearlong deployment.

A ninth mooring was deployed to measure the variation in magnetic declination, which is significant near the magnetic pole. Instrumentation consisted of a precision heading reference fixed to the non-magnetic mooring anchor. Although this mooring was recovered, the precision heading reference which is designed to be pulled off the anchor when the release is triggered, was lost due to a corrosion problem. With these measurements lost, data from the NRCAN Geomagnetic Observatory at Resolute has been used to correct the current direction data for the variation in magnetic declination. This procedure is described by Hamilton [2001].

The loss of the anchor-mounted compass was the only loss incurred. The 4 ADCP/compass systems and 10 CTDs were all successfully recovered. All of these instruments functioned properly for the full deployment period with the exception of the compass in the deep system on the south side. Direction data from the nearby upper ADCP/compass system has been used to construct a direction record for this deeper current record.

Data Processing

Current Speed and Direction Data

The ADCPs were mounted in streamlined buoyancy packages (A2 "SUBs" manufactured by Open Seas Inc.) and set up to measure current relative to the instrument axes, ignoring their own compass information. A depth cell size of 4 m was chosen. Typically, the highest useful depth cell in the data sets from the upper ADCP instruments was centered around 10 m. Current data above this level were rejected based on RDI's standard echo intensity quality criterion. The upper ADCPs also recorded ice drift speed.

Direction was provided using an independent compass package mounted in the A2 tail to give the orientation of the ADCP relative to magnetic north. Both the ADCP and compass were set up to sample every 2 hours, but because of concern about clock drift over the yearlong deployment, the compass was programmed to sample for 10 seconds, 15 minutes before the hour, on the hour, and 15 minutes after the hour. The ADCP clocks were found to lose about 8 minutes over the yearlong deployments, while the compass controllers lost about 20 minutes. When the current and direction data were merged, a time-weighted linear interpolation between direction samples was used to provide the most appropriate direction to merge with the rate information. Looking at the yearlong records, the measured direction change over 15 minutes was less than 25°, 93%

of the time (and less than 5°, 50% of the time), so any uncertainty introduced by this interpolation method is small.

The records were then corrected for the variation in magnetic declination using magnetic observatory data from the NRCAN observatory in Resolute.

The deep ADCP/Pole compass system on the South side of the Strait did not provide reliable direction data due to a memory corruption problem with the compass sensor. In this case, bi-hourly current directions from the lowest bin of the nearby ADCP/pole compass moored at ~80m depth, are ascribed to the corresponding depth bin (or the nearest bin for which there is reliable rate data) of the deep ADCP. A bi-hourly heading for the deep system is calculated based on this current direction, allowing for the calculation of current directions for all bins of the lower instrument.

The accuracy of this procedure depends on the directional shear in the middle of the water column. This shear is low. Looking at the relative direction difference between bins (which does not rely on any compass) for the lower instrument, the average difference and standard deviation on the difference between adjacent bins is 0.3°±7° for currents greater than 10 cm/s. About 45% of the time the range of the lower instrument is great enough that the direction transfer is being done at a depth where both ADCP instruments are providing reliable data. In periods of reduced range, current direction from the upper instrument has to be applied to the highest reliable bin of the deep instrument. 90% of the time the highest reliable bin of the deep instrument is within 5 depth bins (20m) of the upper instrument's lowest bin. Over 5 depth bins the average difference is 1.2°±19°.

Vertical excursions of the ADCPs caused by current drag forces acting on the mooring were small. For the 2 ADCP/pole compass systems moored at about 80 m depth, the standard deviation in the depth over the year was only 0.6 m, with a maximum observed depth excursion of 7 m. Nonetheless, depth corrections for mooring dip have been applied where necessary using depth information from the moored CTDs, so that reported current speeds are at the correct absolute depth.

The ADCPs also provide ice drift velocity when there is solid or near-solid ice cover.

Moored CTD Data

SeaBird MicroCat CTDs were set up to measure temperature, conductivity and pressure every 2 hours for the yearlong deployment. For the 2 shallowest CTDs (which are subjected to the greatest dip due to current drag forces acting on the mooring), the standard deviation in the depth is only 0.7 m. The maximum excursion occurred in a unique, short duration event, and is 10 m. Post-deployment calibrations of all 10 MicroCat CTDs revealed no perceptible change in sensor calibration when compared against a SBE25 ship-based CTD system.

Low-Pass Filtering

Some of the data series presented have been filtered to remove the semidiurnal and diurnal tides, using the technique described by Godin (1972). The technique uses three simple averaging filters applied in sequence. Godin, working with hourly observations, recommends two consecutive applications of a filter that averages over 24 samples, followed by one that averages over 25 samples. Here, where the sampling is bihourly, averages over 12 and 13 samples are applied instead.

Tidal Analysis

Harmonic tidal analysis of the current data using Foreman's (1978) method is applied separately to a 157 day period of solid ice cover, and a 73 day period of broken or no ice. The tidal ellipse axes amplitudes, orientations and phases for the main tidal constituents (K1, M2, O1, P1 and S2) are plotted as a function of depth.

The periodic vector function describing a particular constituent, traces an ellipse over a tidal cycle with major and minor amplitudes defined by the length of the semi-major and semi-minor axes. The major axis amplitude is always positive. The sign of the minor axis amplitude defines the rotation sense of the current ellipse. When positive the vector traces the ellipse in a counter-clockwise direction; when negative, the rotation sense is clockwise.

Ellipse orientation is the angle measured counter-clockwise from east to the semi-major axis.

The phase is a measure of the timing of high water referenced to astronomic positions over the Greenwich meridian. Phase is measured counter-clockwise from this chosen reference.

Ship-Based CTD Surveys

Three lines consisting of 35 CTD stations in total were attempted in August, 1998 and again in August, 1999 (Figure 1). The instrument used was a portable SeaBird SBE25 CTD configured to pump water through the conductivity cell but not past the temperature sensor. Data were stored at 1 Hz by averaging over 8 instrument samples. Standard SeaBird processing is used and data are binned to 2 m.

Data Presentation

Yearlong time series of bihourly temperature, salinity and density from the moored CTDs are shown in Figures 3 and 4. A warming and freshening of the near-surface occurs in mid-summer. While temperatures in this portion of the water column drop back to near-freezing values in early fall, it is not until early January that salinity increases to typical winter values. Warmer, saltier water measured by the lower instruments suggests the penetration of Atlantic water near the bottom.

Power spectra of the moored CTD measurements shown in Figures 5 and 6 demonstrate that energy in the diurnal band is typically greater than that in the semidiurnal band. For example, the variance in the diurnal band of the 170 m south side salinity measurements is 0.006 ppt^2 which is 4 times greater than the variance in the semidiurnal band. Since the inertial period for this location is 12.45 hours, internal waves is not the generating mechanism. This periodic vertical displacement is most likely caused by interaction between topography and the K1 tide, the strongest tidal constituent here.

Current data are shown as contour plots in Figures 7-10. Data from the deep and mid-water ADCPs (moored about 1.2 km apart) have been combined, for both the north and south sides. Data are presented in along-strait and cross-strait components, where positive values are defined as flow towards 105° true and 15° true, respectively. Figures 7 and 8 are one month samples of unsmoothed data, revealing both the tidal and lower frequency character of the flow.

In the yearlong records of smoothed data shown in Figures 9 and 10, where tides have been removed using the low-pass filter described above, a signal suggestive of meteorological forcing is apparent. Missing data near the surface from mid-winter through to late spring are caused by a decrease in the effective range of the ADCPs when the water is at its clearest, and contains a minimum of acoustic reflectors. (The manufacturer's suggested data quality acceptance criteria have been applied.) The smoothing method used has smeared the impact of missing raw data over the filter length.

Smoothed temperature, salinity and current data are shown for each moored CTD level in Figures 11-20. The extended periods of no current data in Figures 14 and 18 are again the result of the way the low-pass filter deals with missing raw data that occur at the outer range limit of the ADCP. Tables 1 through 12 provide a summary of the CTD data and ADCP data at the CTD depths, with statistics computed over each season, and for the entire year. Density has been included in these statistical summaries. Temperature in the upper water column reaches its peak in late summer, but it is not until the fall that the water is at its freshest in this upper layer.

Annual and seasonal mean flows are summarised in Figures 21-26. For clarity, only every fifth ADCP depth bin has been used to generate the graphs. Over the year, flow is predominantly eastward on the south side of the Strait, with a weaker westward flow on the north side. This signal is strongest in the summer. The consistent northward cross-strait velocity seen on the southern side suggests that the axis of the mean flow may not be precisely aligned with the along-strait direction.

The variance in the bihourly, and low-pass filtered current data for the yearlong ADCP records are shown in Figure 27. Some variance values for the smoothed data at the outer range limit of the ADCPs are not shown, as the smoothing filter acting on missing data from these outer bins has removed segments of data that make the calculation unreliable. Diurnal and semidiurnal tides account for over half of the total variance in the along-strait current speeds throughout the water column.

Results of a tidal analysis of the ADCP data are plotted as a function of depth for the 5 largest tidal constituents in Figures 28 - 37. The K1 constituent is the strongest tide followed closely in magnitude by the M2 constituent. Ellipse orientations are generally along-strait as expected. Some differences between ice and no-ice periods are evident near the surface on the south side. Tidal constants are summarised in Tables 13 - 17.

Ice velocities on the north and south sides of the Strait as measured by the upper ADCPs are shown in Figures 38 and 39. Since the ice drift measurement quality is degraded by the presence of open water, there are periods in the time series where no data are presented. The manufacturer's suggested data quality standards have been applied to the ice drift data. An additional criterion applied here is that where the magnitude of the "error velocity" for a particular ensemble is greater than 1 cm/s, the ice drift velocity estimate and the adjacent estimates are rejected.

Results of 1998 and 1999 ship-based, August CTD surveys along the 3 lines shown in Figure 1 are shown as contoured sections in Figures 40 - 46. Stations are shown as the downward pointing arrows at the surface. The surface layer of fresher, warmer water is a result of ice melt and solar heating. The sloping isopycnals are evidence of intensification of currents on the southern side of Barrow Strait and the western side of Wellington Channel.

Acknowledgements

We thank Brian Petrie for his valuable input and review of this report, and Larry Newitt (NRCAN) for his expertise, and for providing the Resolute Observatory magnetic declination data. We also thank Dave Greenberg for his review of the manuscript, and Francis Kelly for the map and mooring illustration he drafted.

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References

Foreman, M.G.G.,1978. *Manual for tidal currents analysis and prediction.* Pacific Marine Science Report 78-6. Institute of Ocean Sciences, Sidney, B.C., 70pp.

Godin, G, 1972. *The Analysis of Tides.* Liverpool: Liverpool University Press, 264pp.

Hamilton, J. M., 2001. Accurate Ocean Current Direction Measurements Near the Magnetic Poles, in *Proceedings of the Eleventh (2001) International Offshore and Polar Engineering Conference*, 656-660. ISOPE: Stavanger, Norway.

Prinsenberg, S.J. and E.B. Bennett, 1987. Mixing and transports in Barrow Strait, the central part of the Northwest Passage. *Continental Shelf Research*, 7(8), 913-935.

Figure 1. A map of the work area showing the location of the northern and southern mooring sites (the open boxes), and the hydrographic survey lines (the dashed lines).

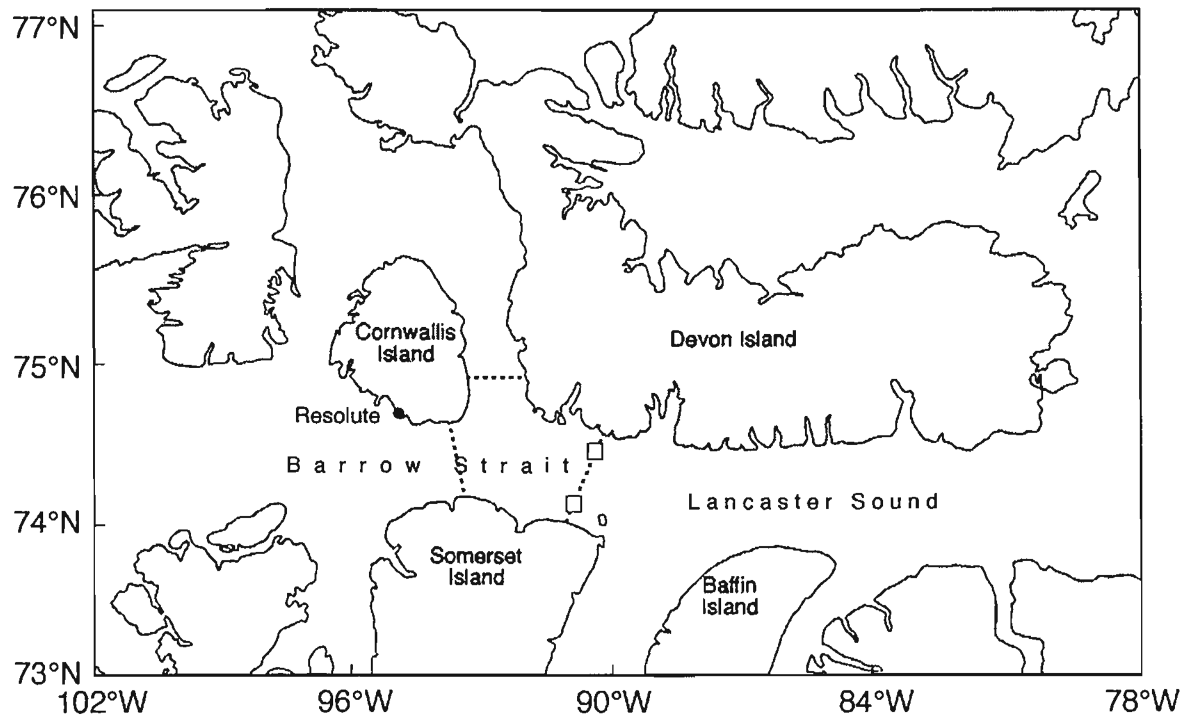


Figure 2. Illustration of the instrumented moorings deployed around the 200 m contour on both sides of Barrow Strait. A ninth mooring (not shown) was deployed to measure the variation in the position of the North magnetic pole.

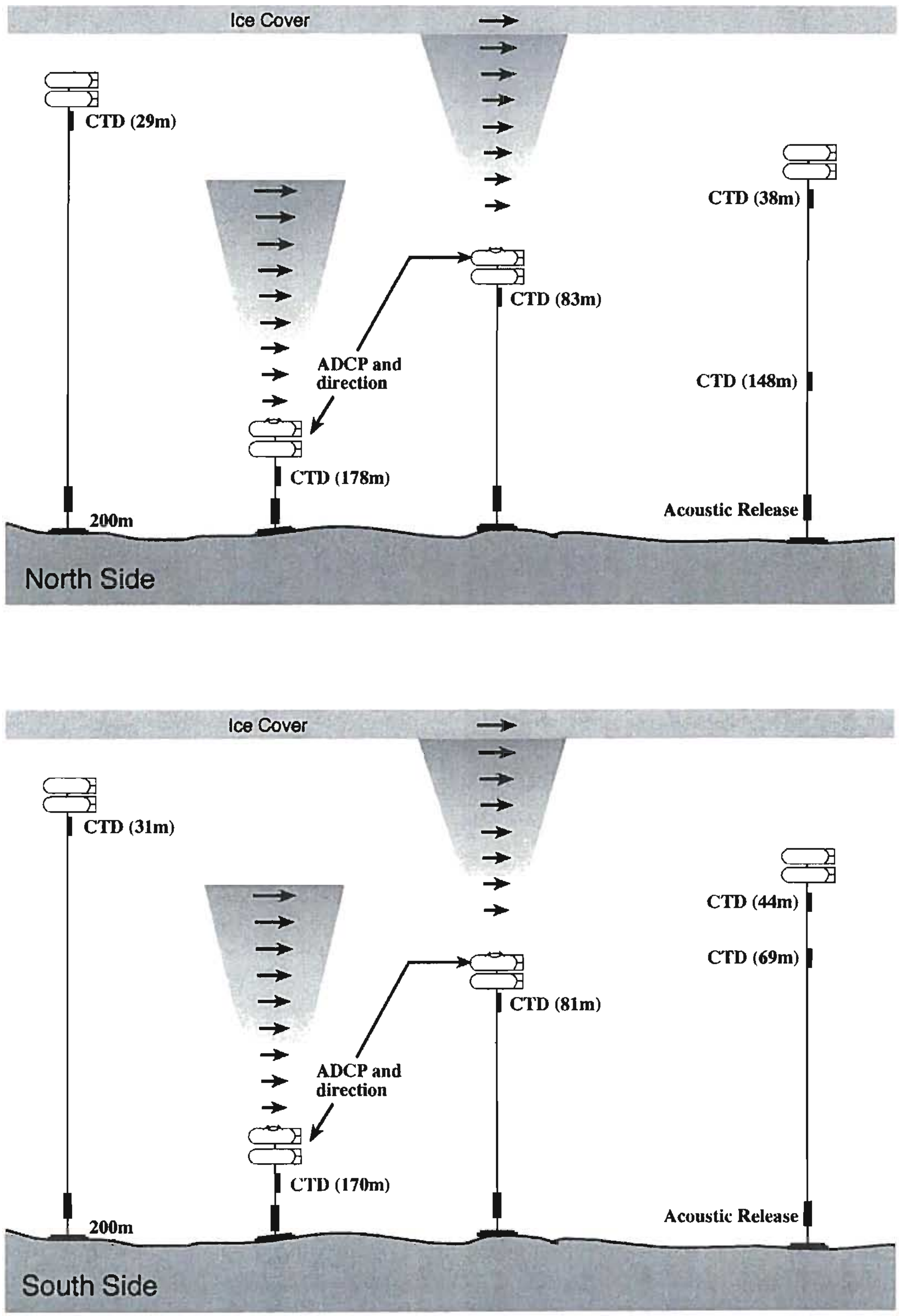


Figure 3 - Moored bihourly CTD data from South side of Barrow Strait: Aug 1998 - Aug 1999.

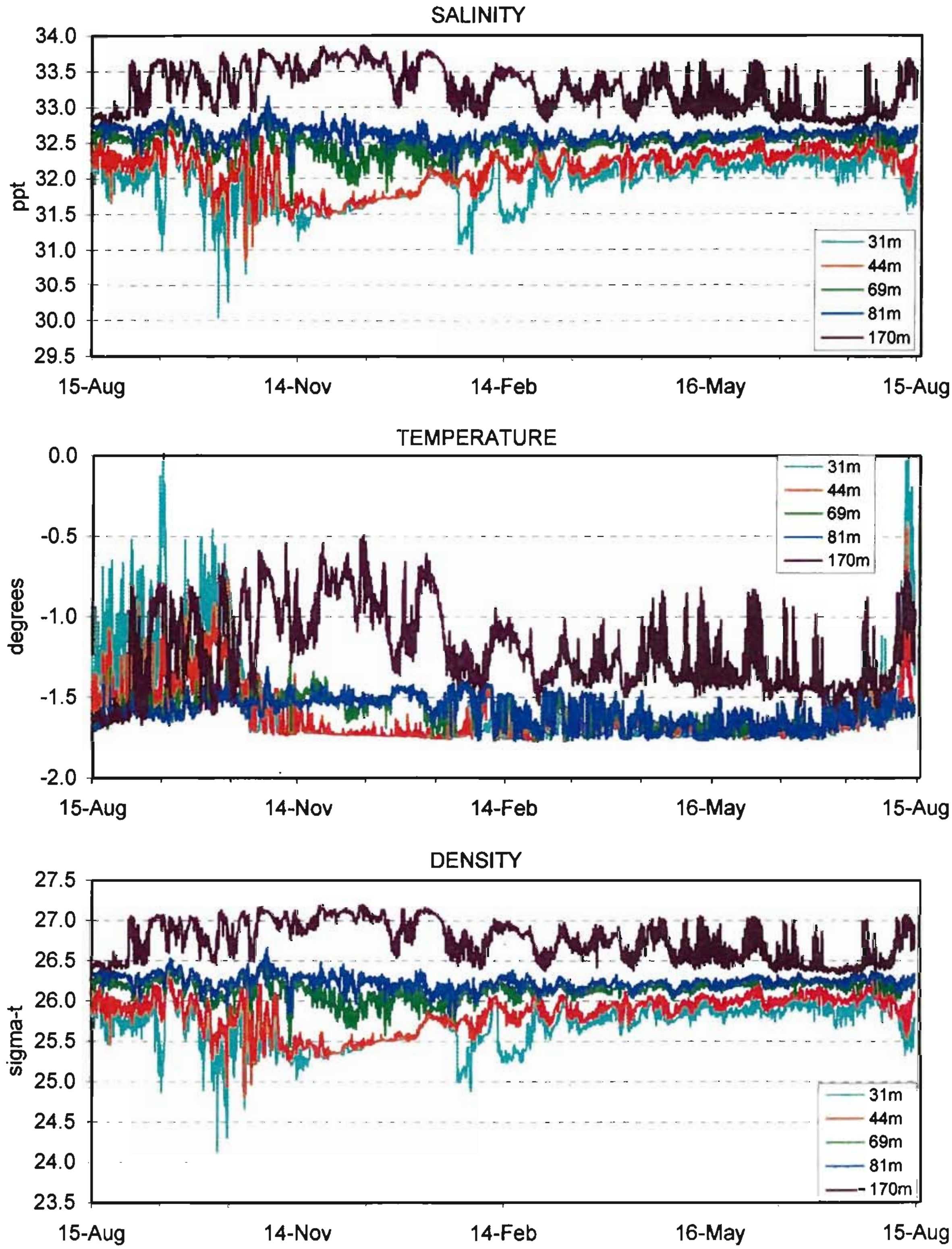


Figure 4 - Moored bihourly CTD data from North side of Barrow Strait: Aug 1998 - Aug 1999.

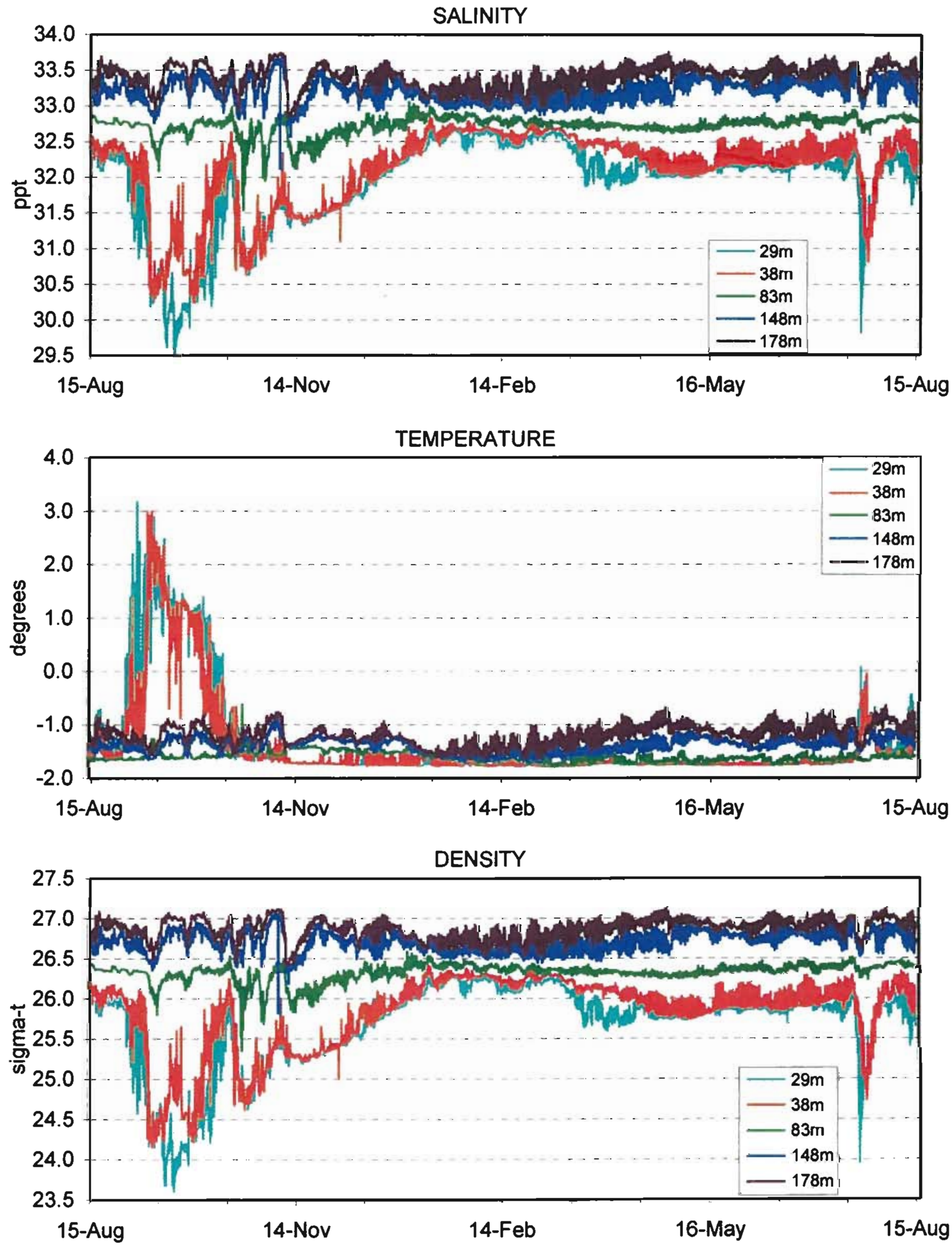


Figure 5 - Power Spectra of moored bihourly CTD data from South Side of Barrow Strait: Aug 1998 - Aug 1999.

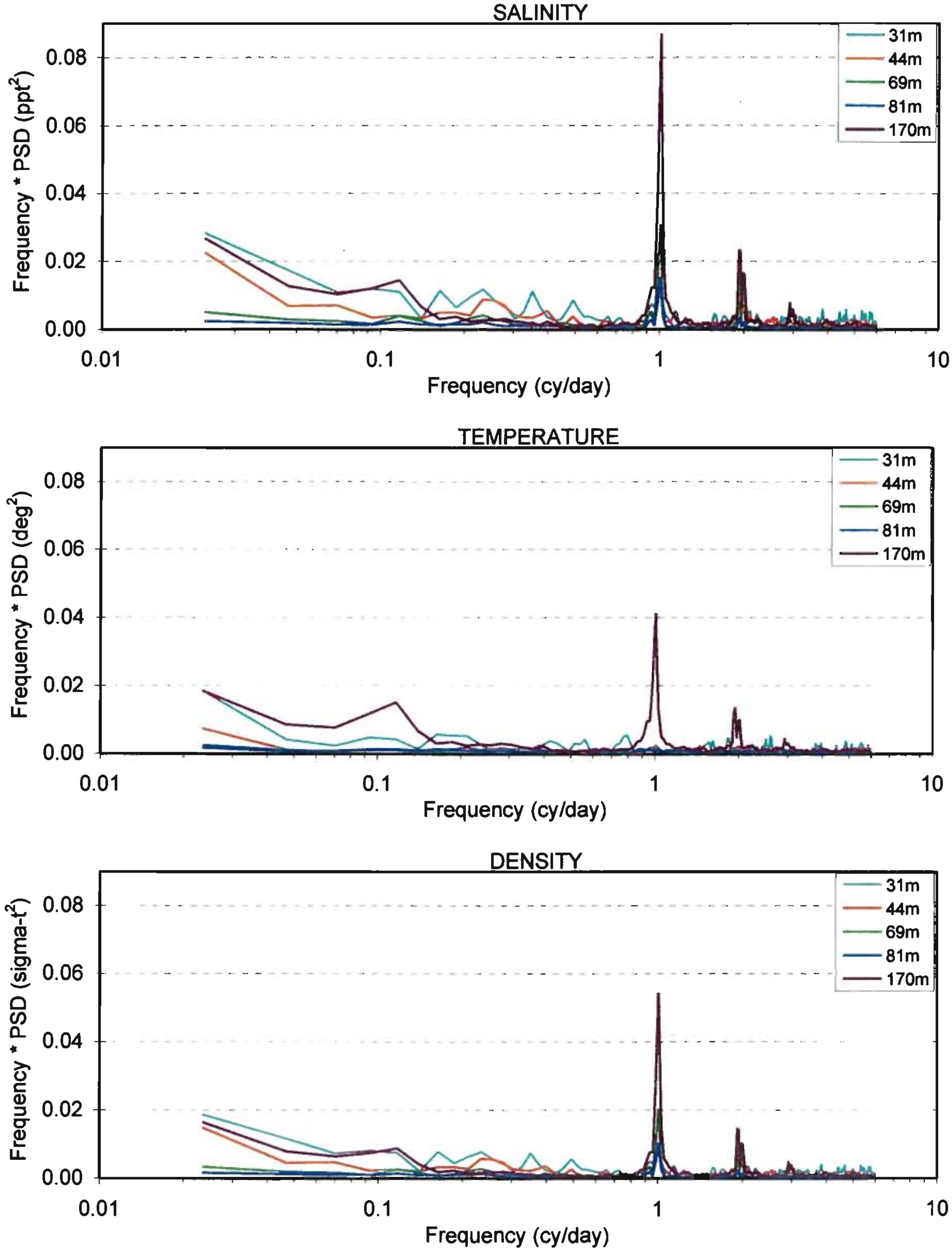


Figure 6 - Power Spectra of moored bihourly CTD data from North Side of Barrow Strait: Aug 1998 - Aug 1999.

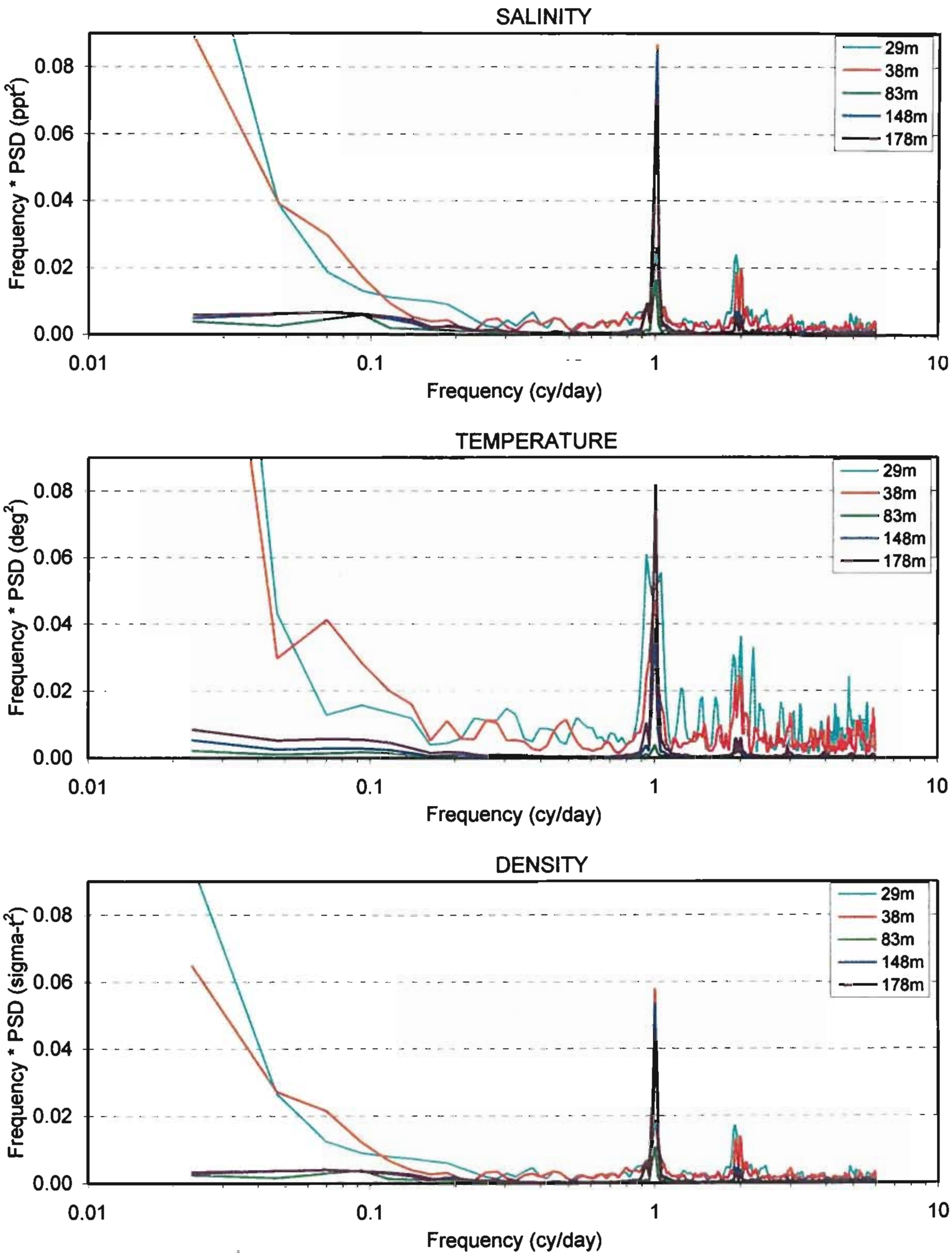


Figure 7 - Bihourly current data, South side of Barrow Strait : Sept 1, 1998 – Sept 29, 1998.

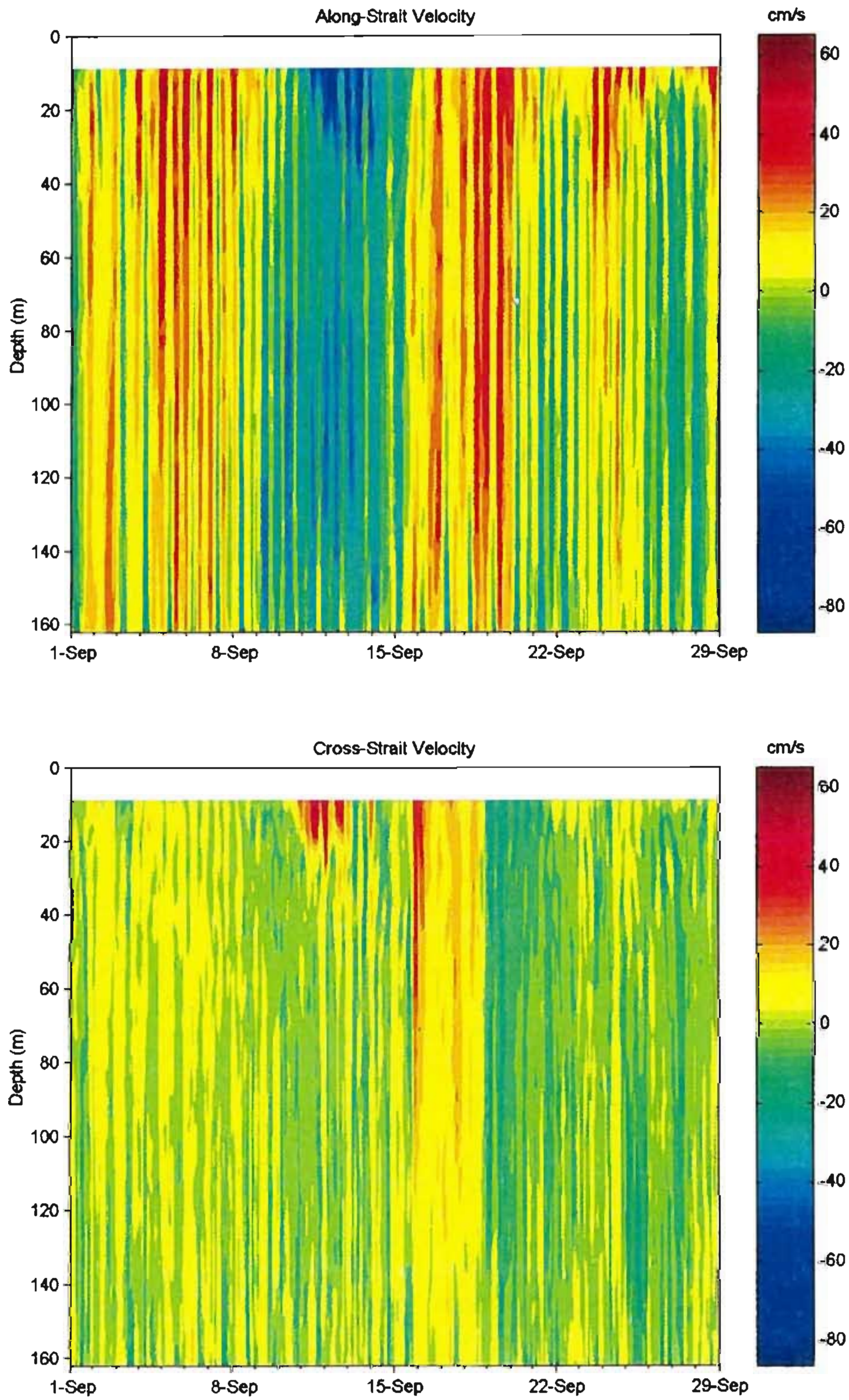


Figure 8 - Bihourly current data, North side of Barrow Strait: Sept 1, 1998 – Sept 29, 1998.

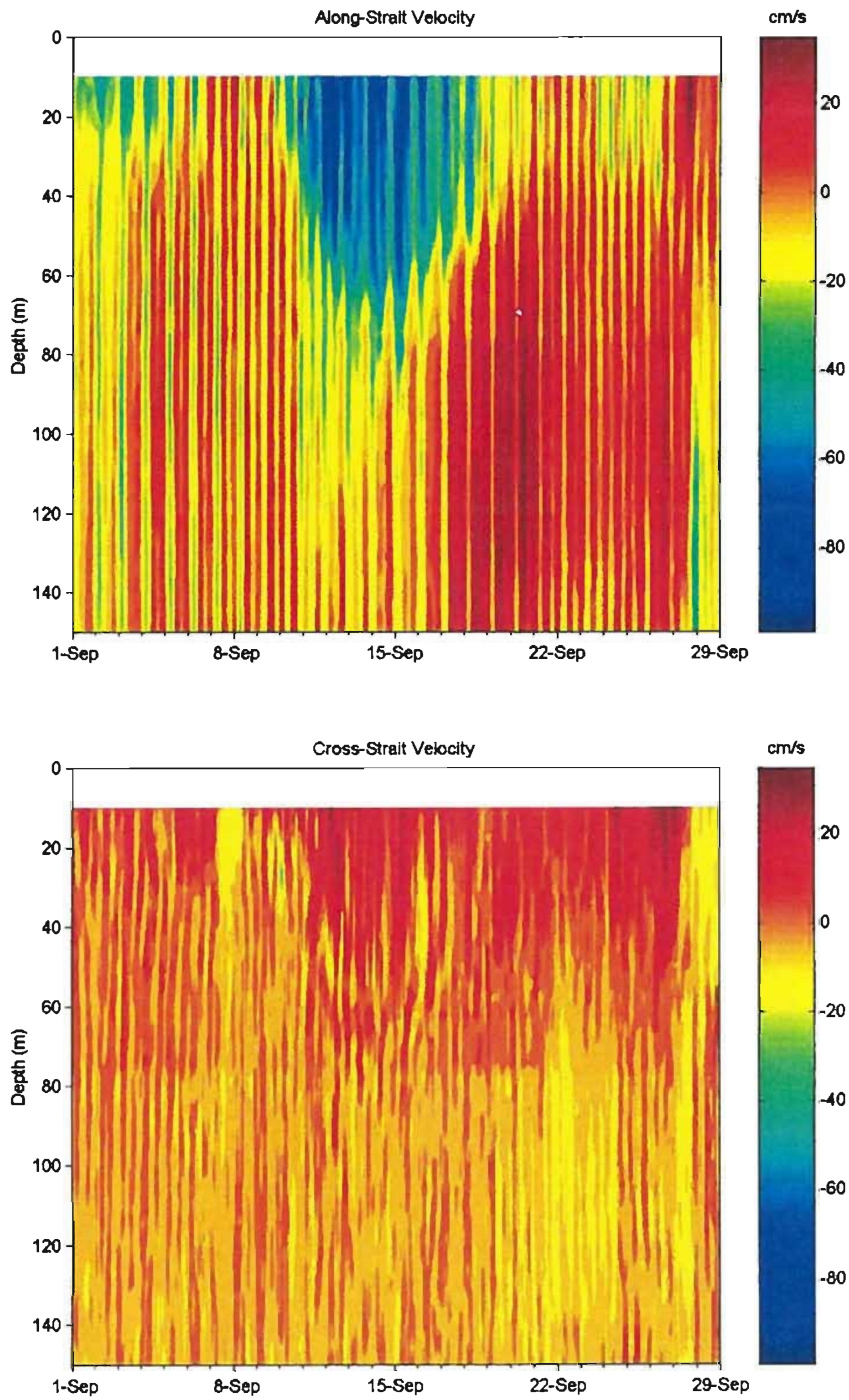
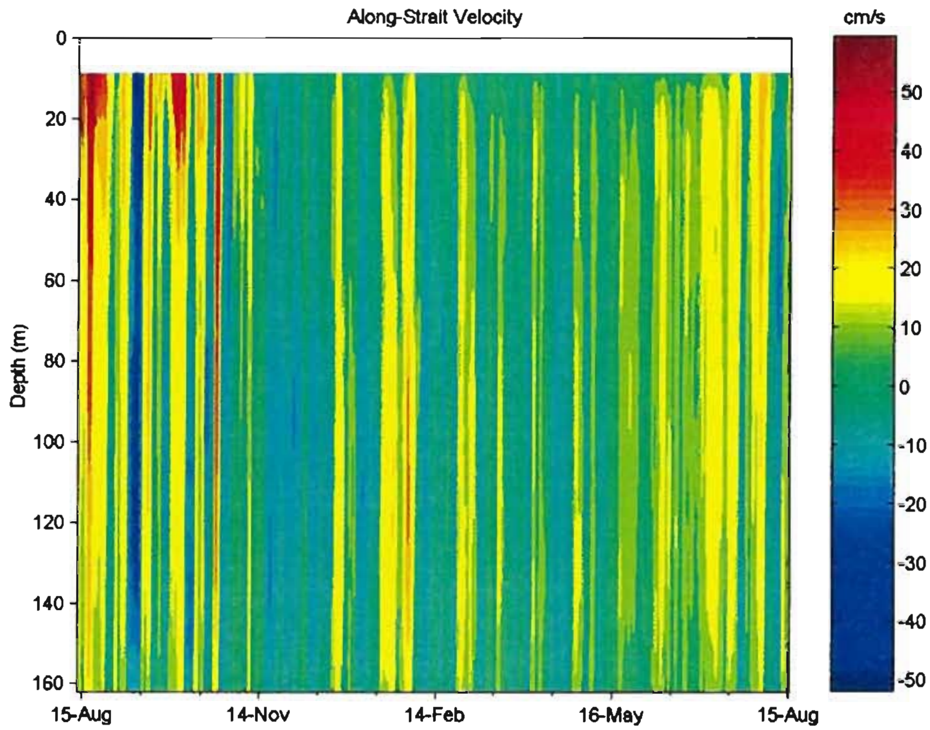


Figure 9 - Low-pass filtered currents, South side of Barrow Strait: Aug 1998 – Aug 1999.



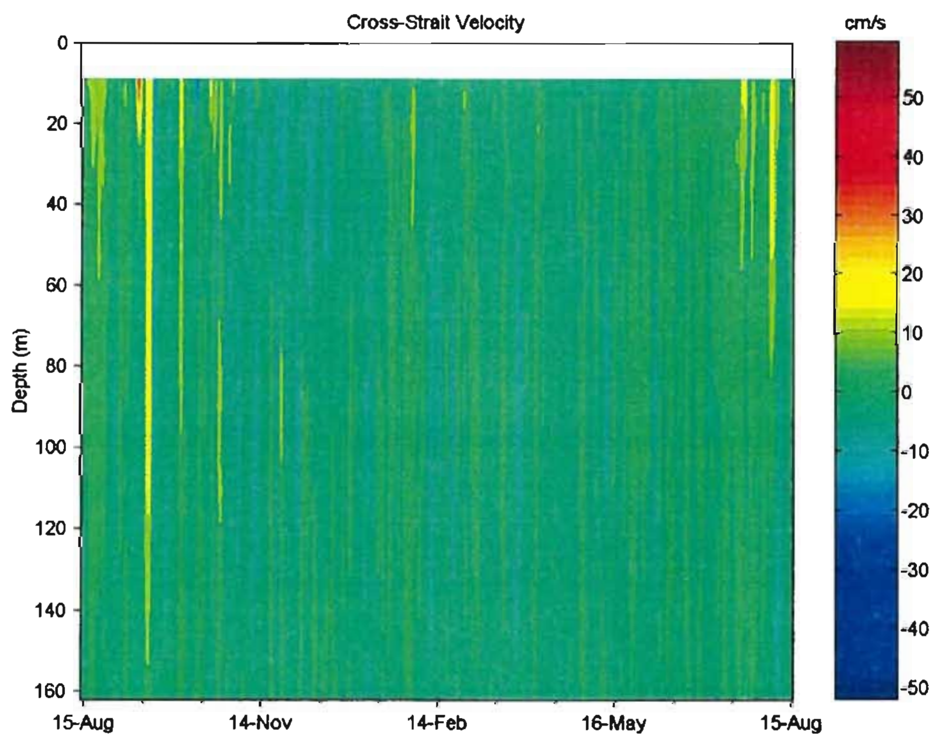
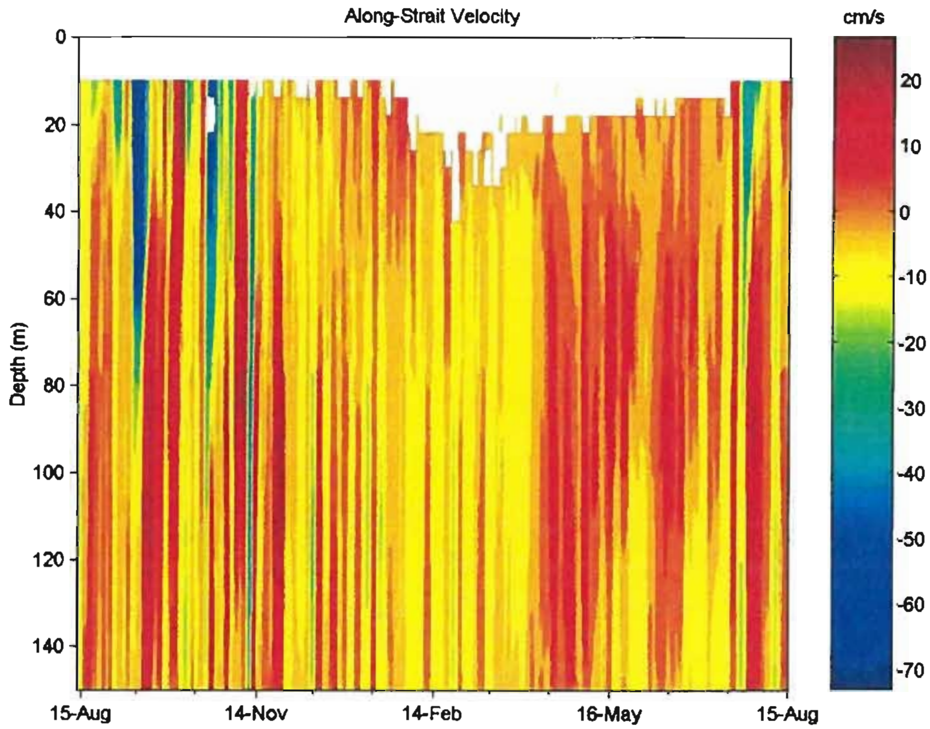


Figure 10 - Low-pass filtered currents, North side of Barrow Strait: Aug 1998 – Aug 1999.



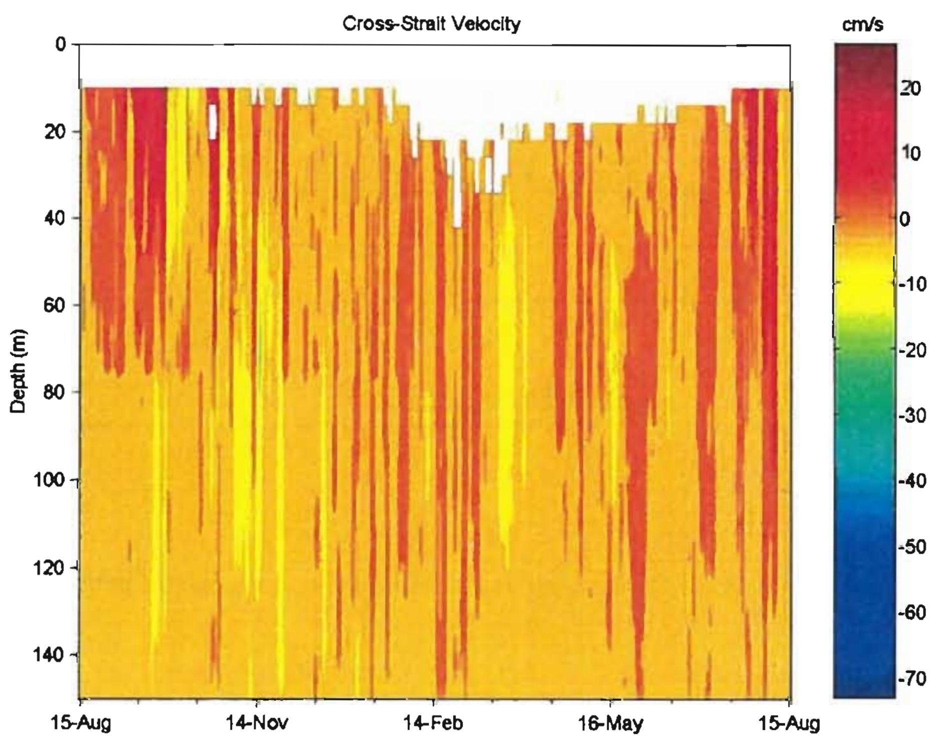


Figure 11 - Low-pass filtered T,S and current data from 31m depth, South side of Barrow Strait: Aug 1998 - Aug 1999.

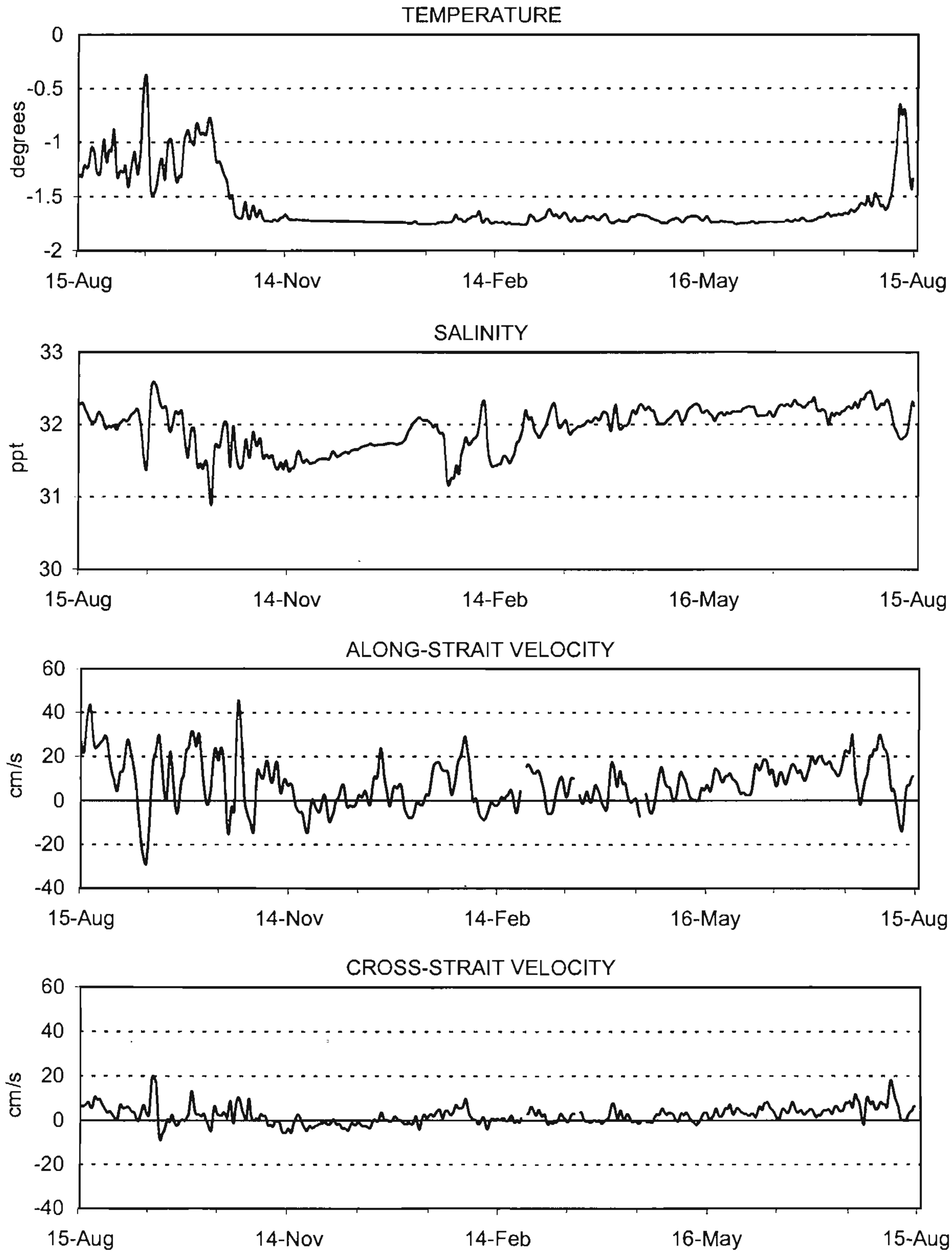


Figure 12 - **Low-pass filtered T,S and current data from 44m depth, South side of Barrow Strait: Aug 1998 - Aug 1999.**

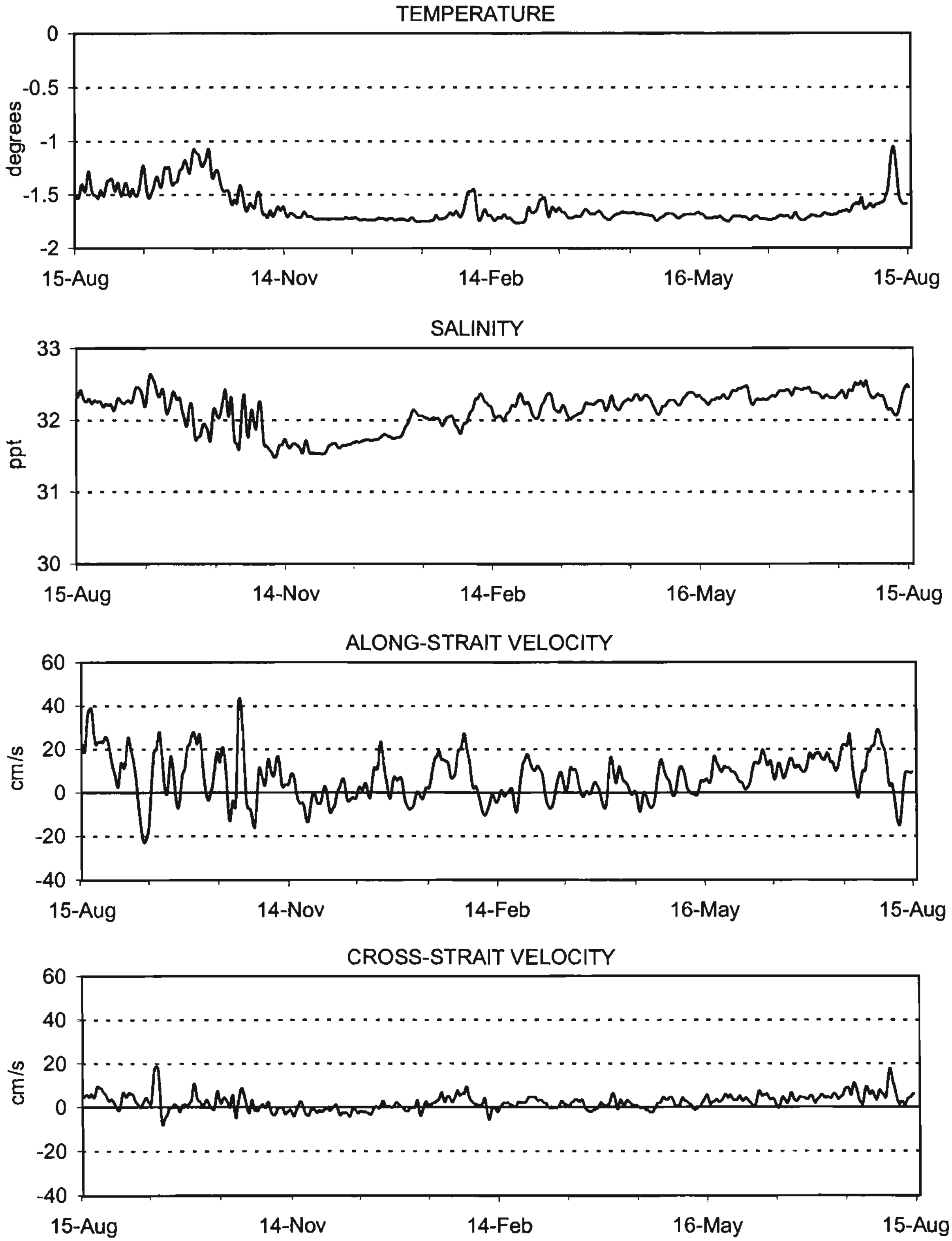


Figure 13 - **Low-pass filtered T,S and current data from 69m depth, South side of Barrow Strait: Aug 1998 - Aug 1999.**

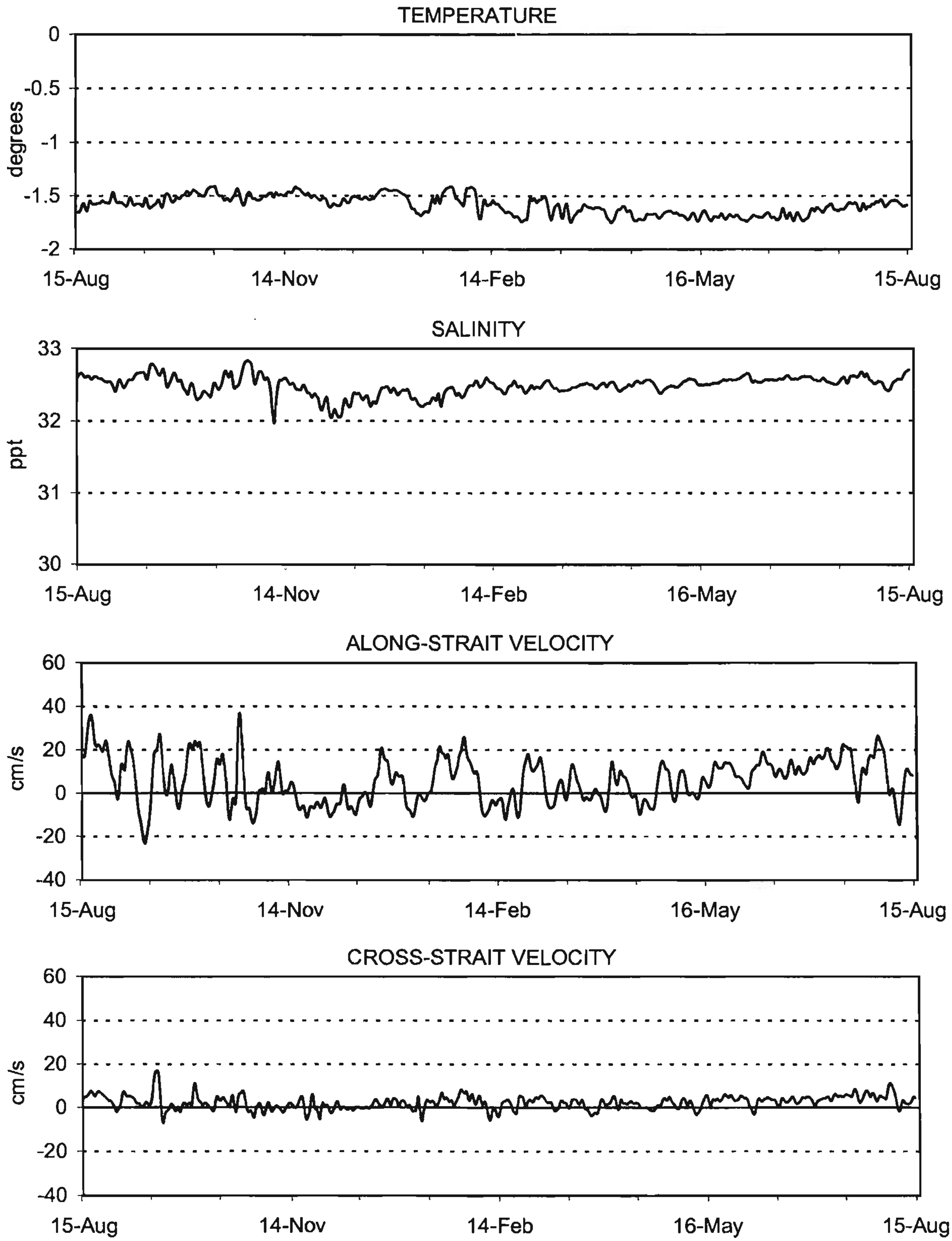


Figure 14 - Low-pass filtered T,S and current data from 81m depth, South side of Barrow Strait: Aug 1998 - Aug 1999.

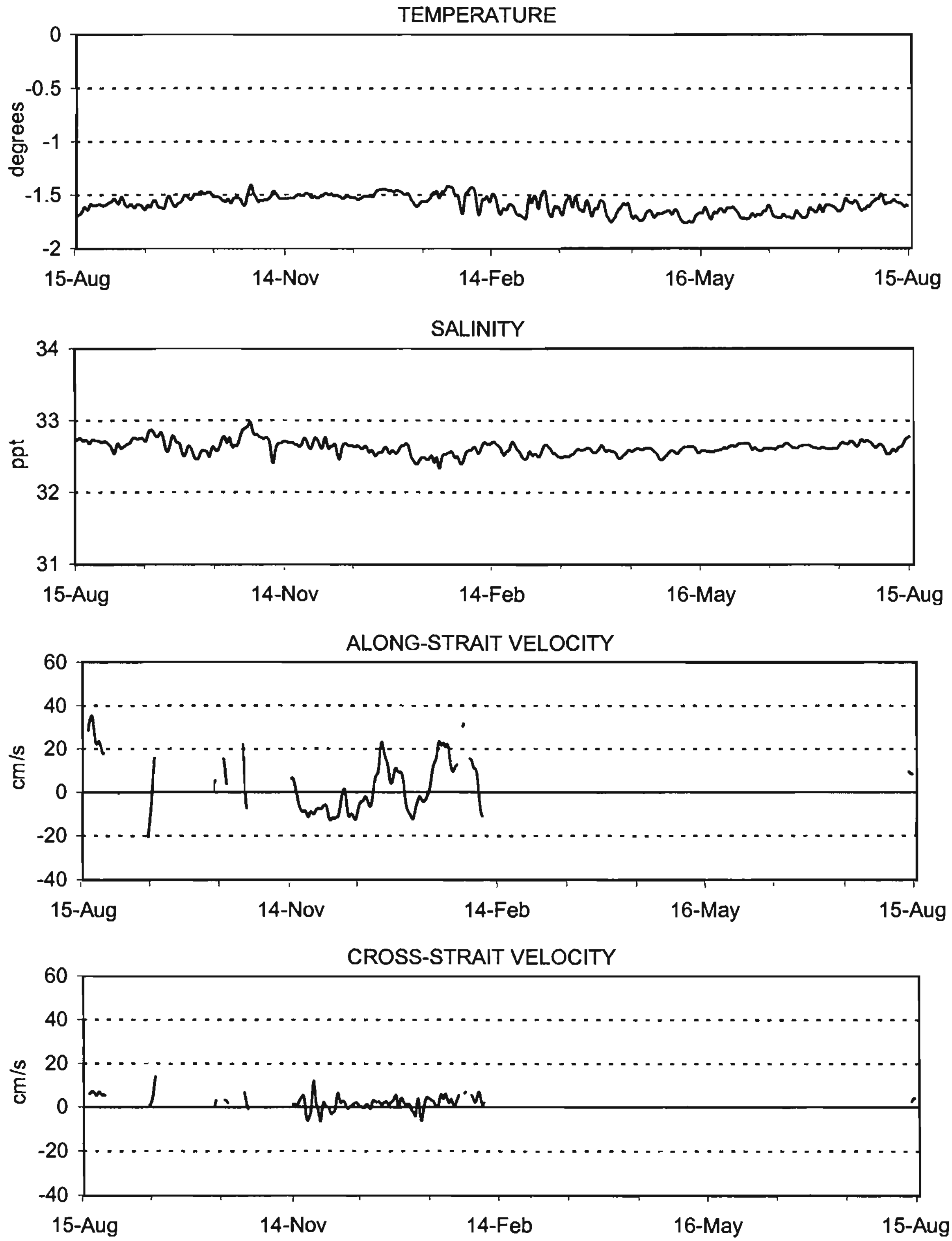


Figure 15 - Low-pass filtered T,S and current data from 170m depth, South side of Barrow Strait: Aug 1998 - Aug 1999.

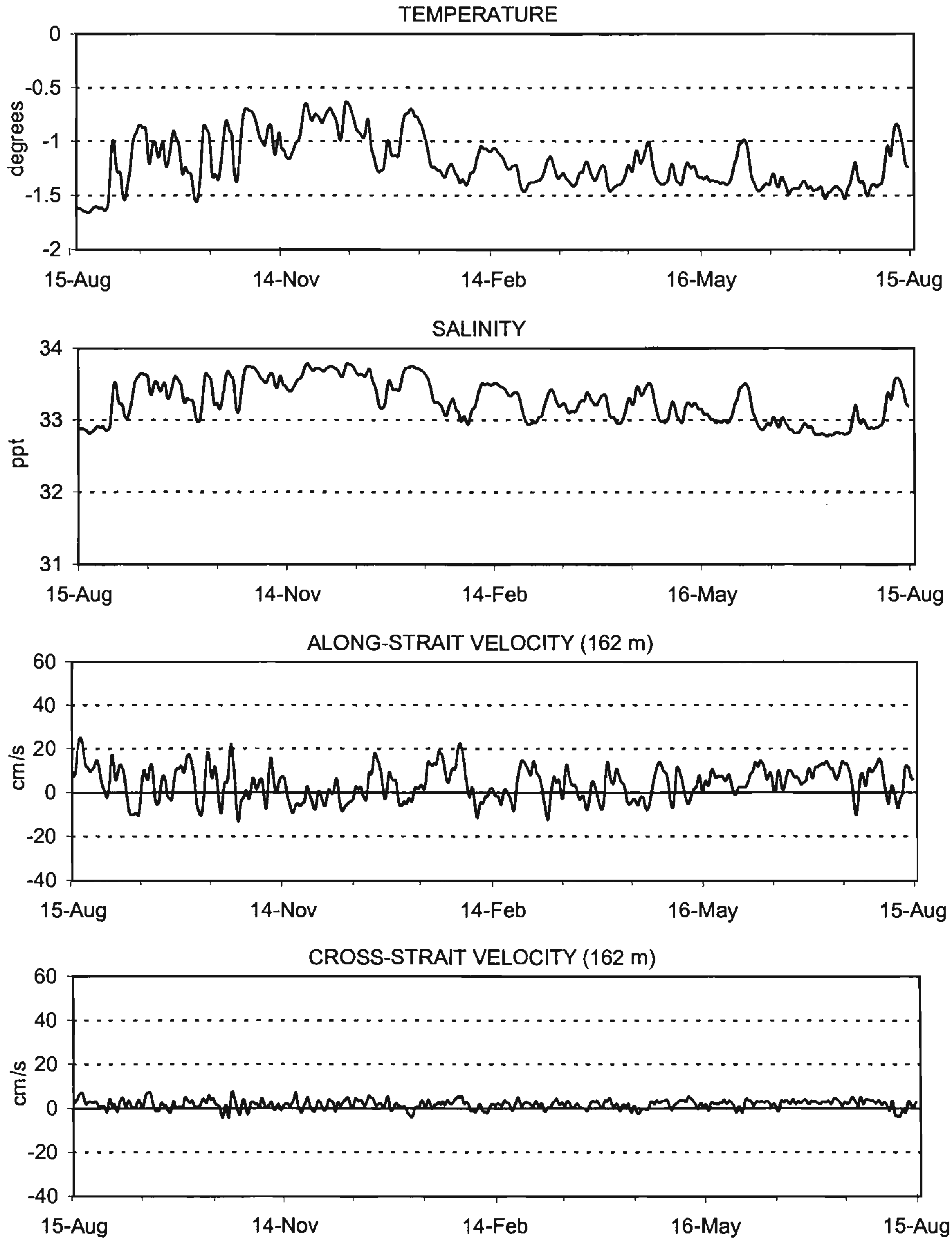


Figure 16 - Low-pass filtered T,S and current data from 29m depth, North side of Barrow Strait: Aug 1998 - Aug 1999.

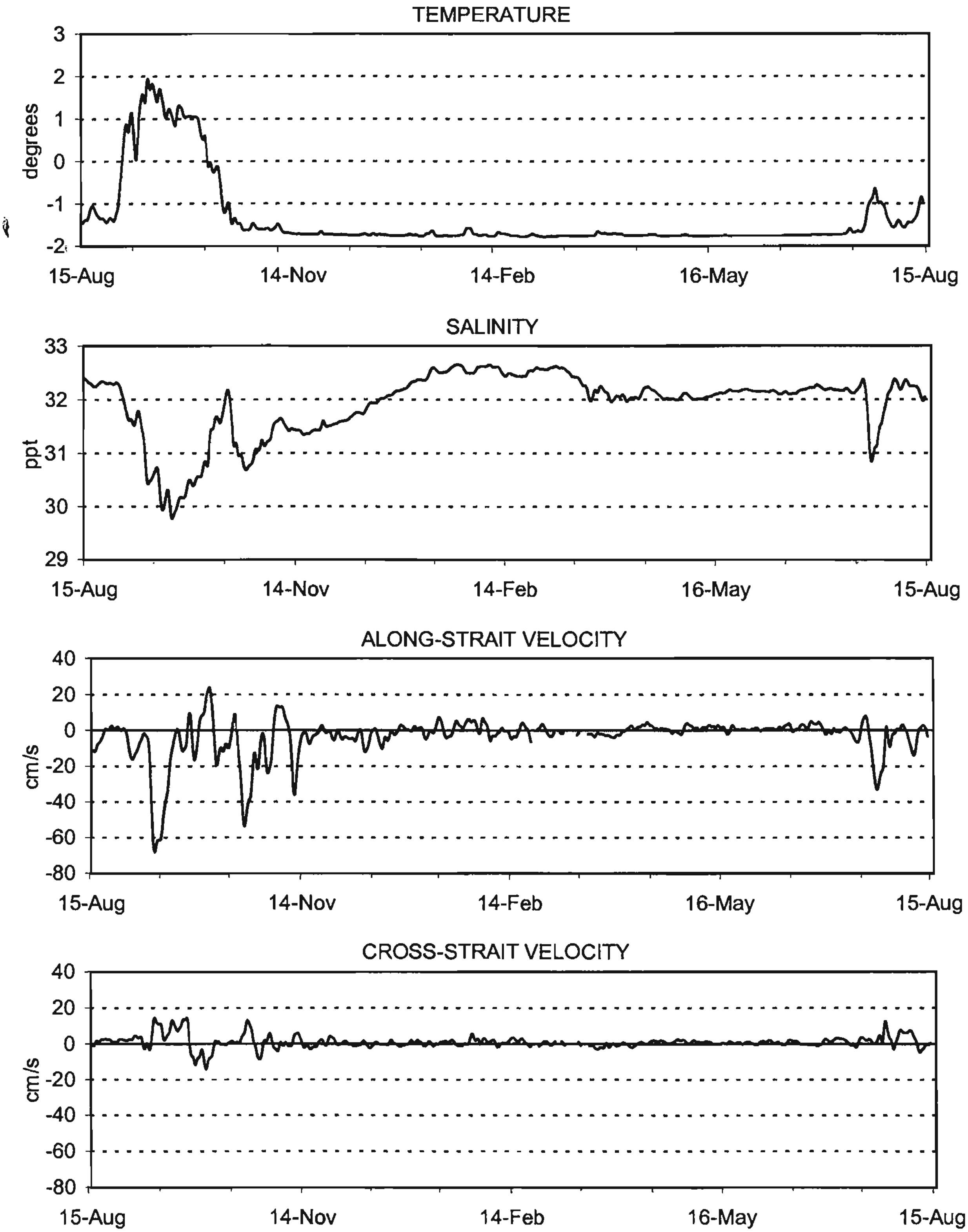
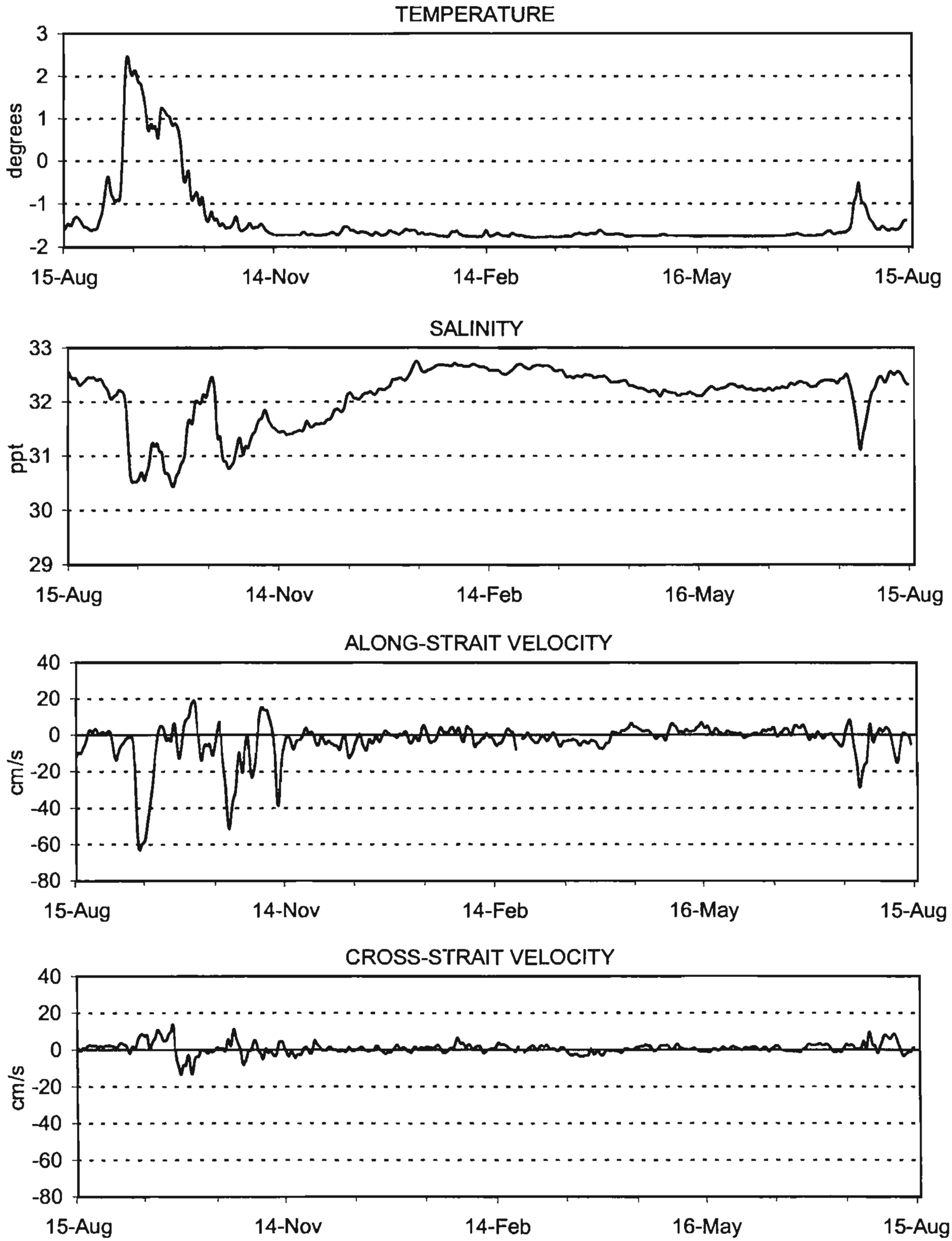


Figure 17 - **Low-pass filtered T,S and current data from 38m depth, North side of Barrow Strait: Aug 1998 - Aug 1999.**



<u>Figure 18</u> - Low-pass filtered T,S and current data from 83m depth, North side of Barrow Strait: Aug 1998 - Aug 1999.

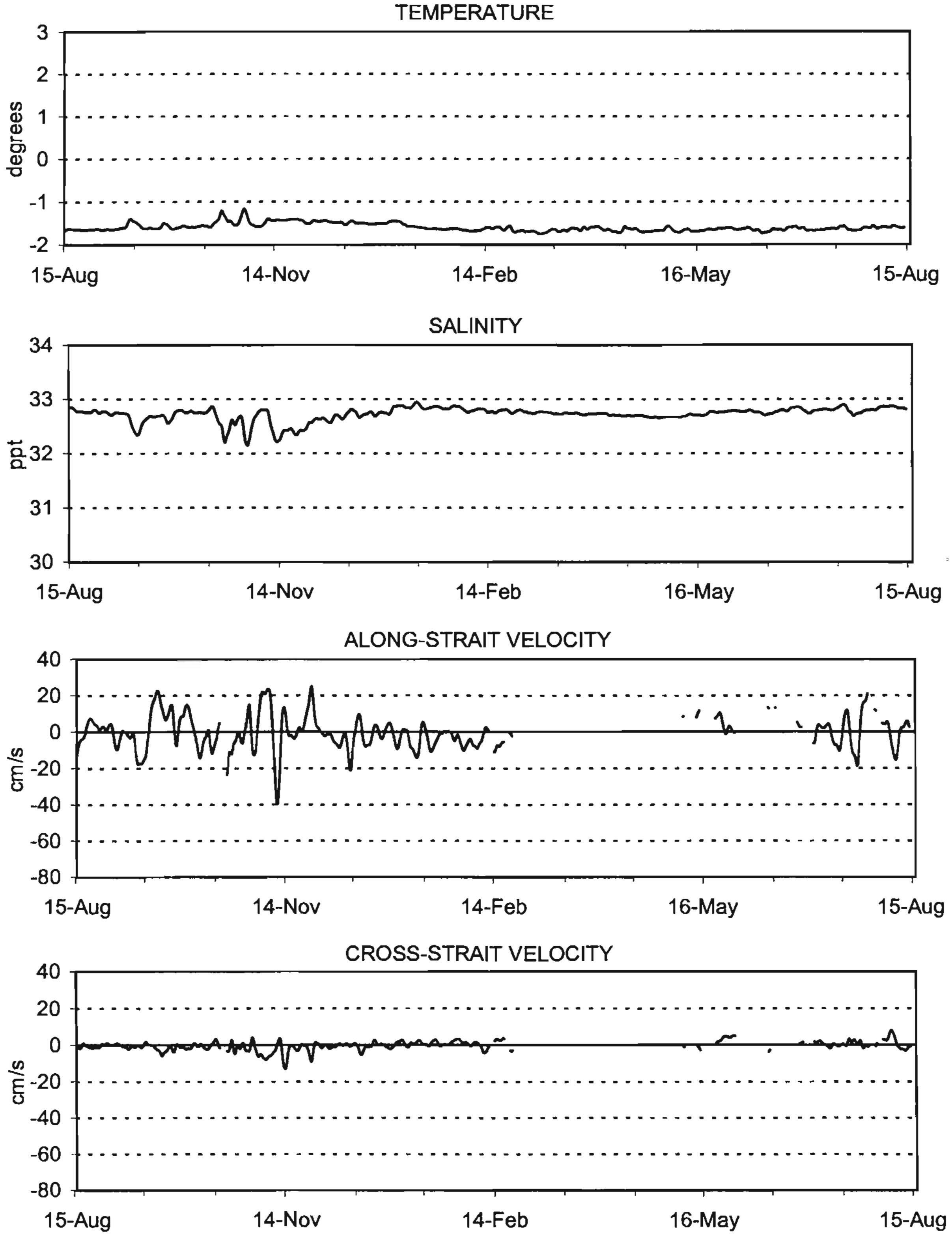


Figure 19 - Low-pass filtered T,S and current data from 148m depth, North side of Barrow Strait: Aug 1998 - Aug 1999.

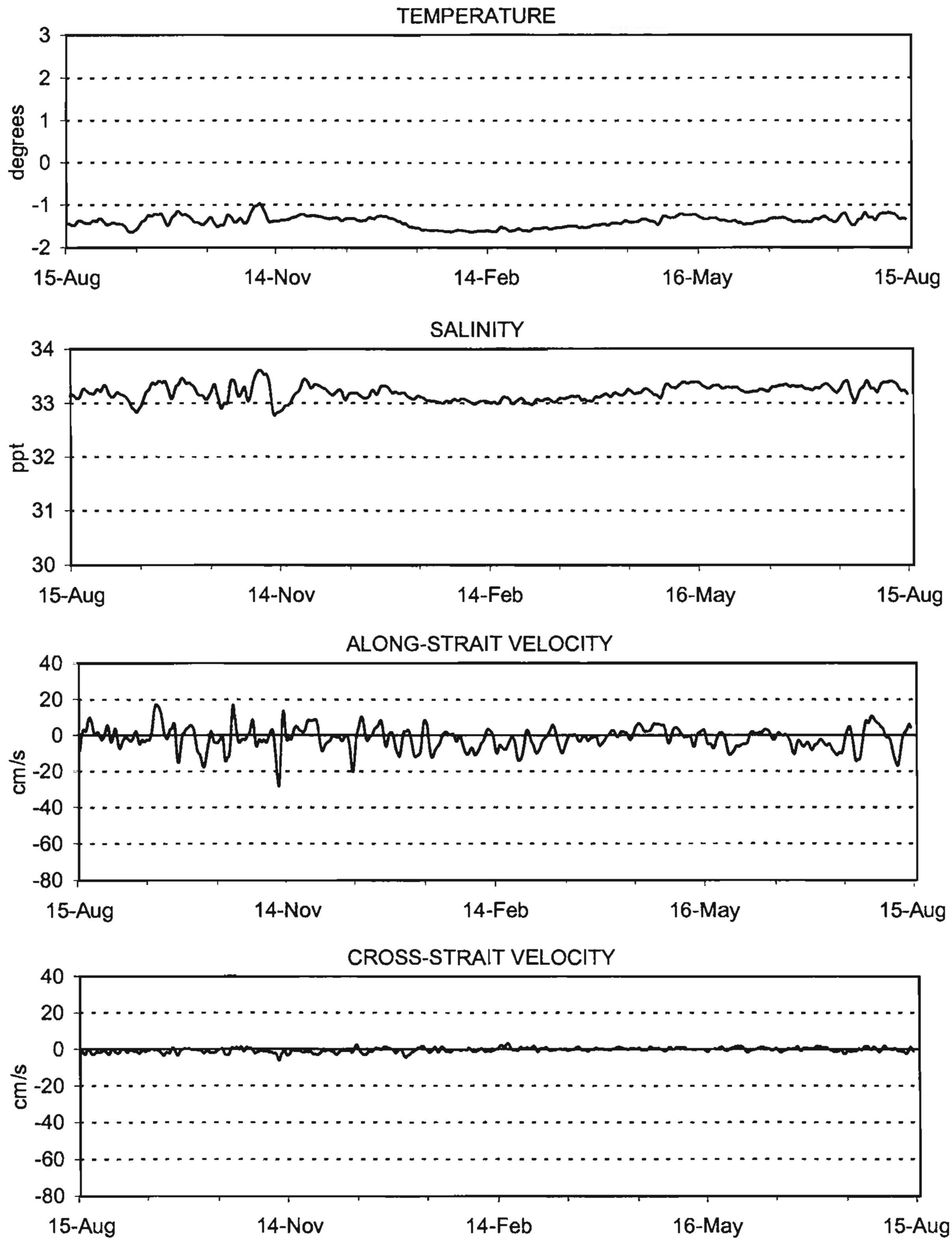


Figure 20 - **Low-pass filtered T and S data from 178m depth, North side of Barrow Strait: Aug 1998 - Aug 1999.**

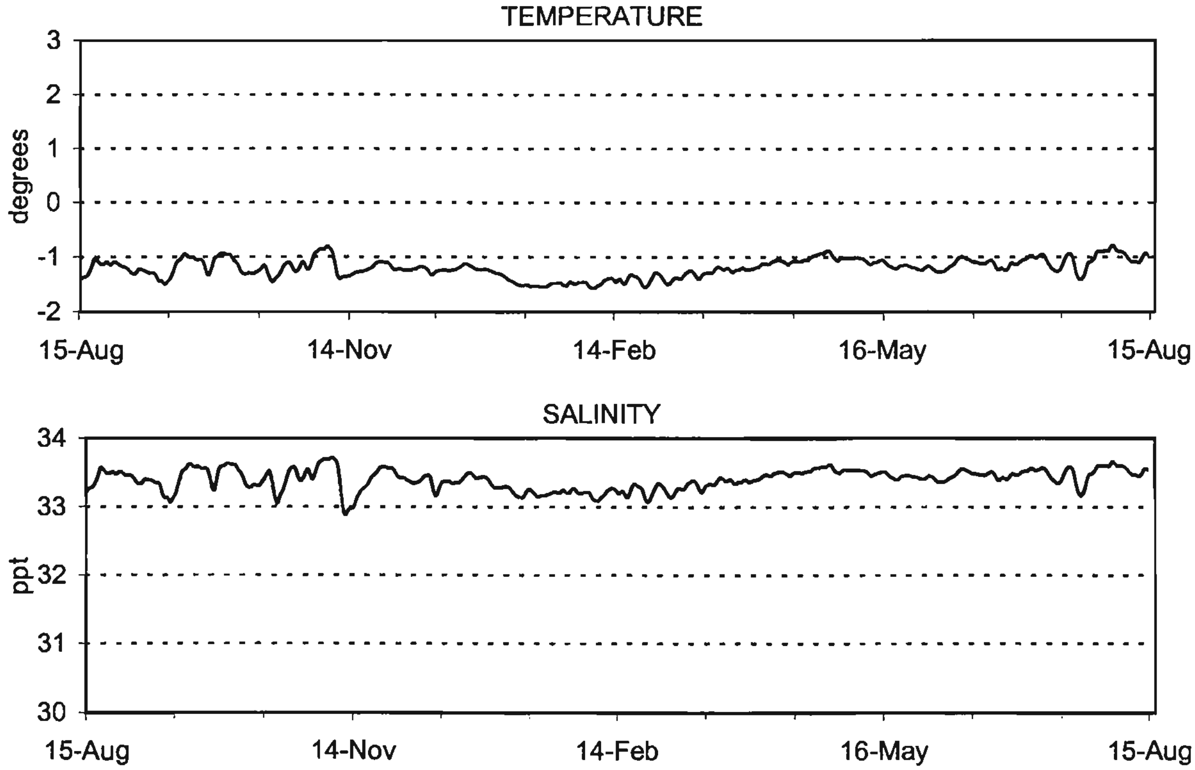
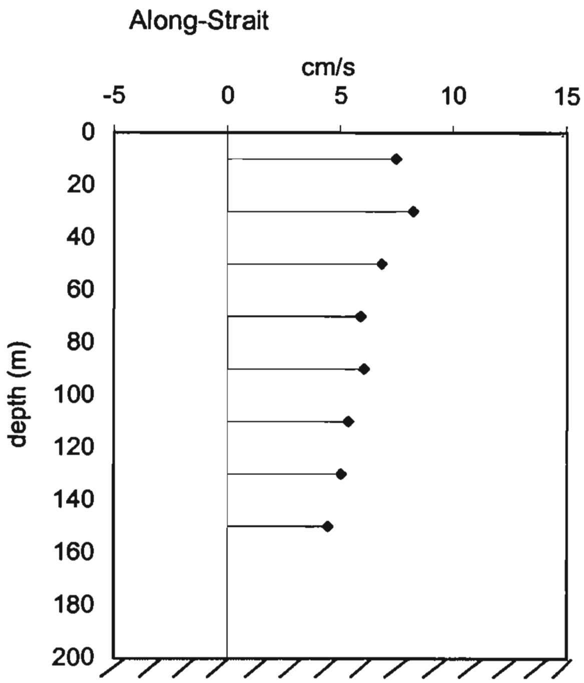
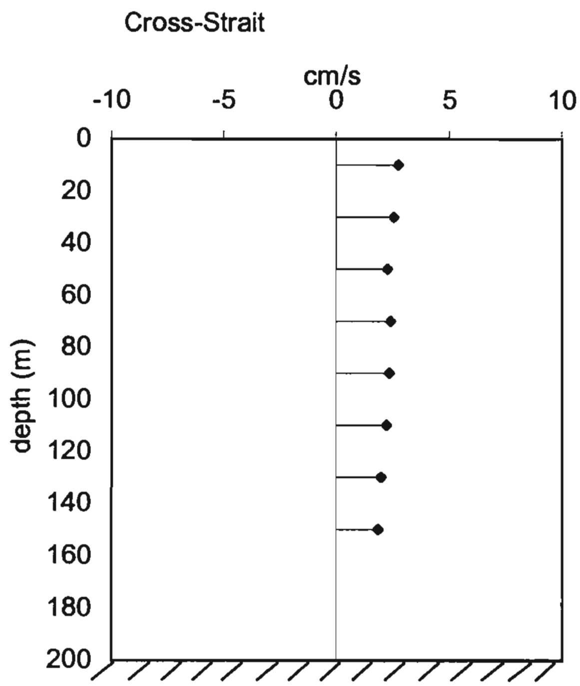


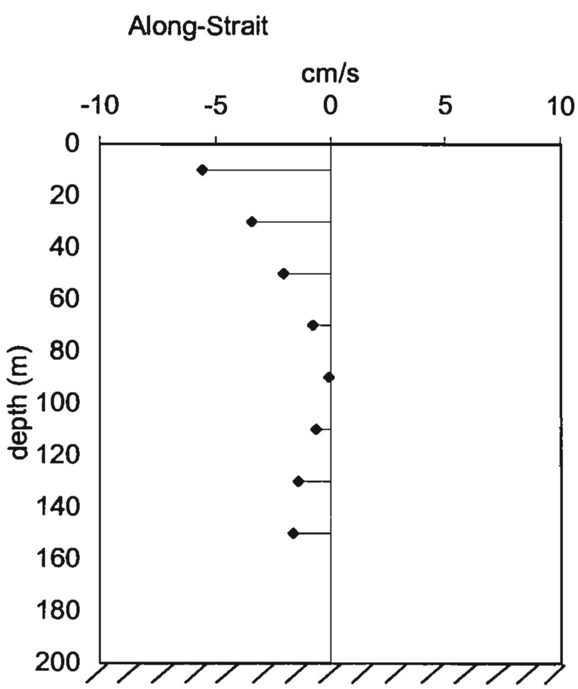
Figure 21: Annual Mean Flows, Aug 1998 - Aug 1999.

South side of Barrow Strait:





North Side of Barrow Strait:



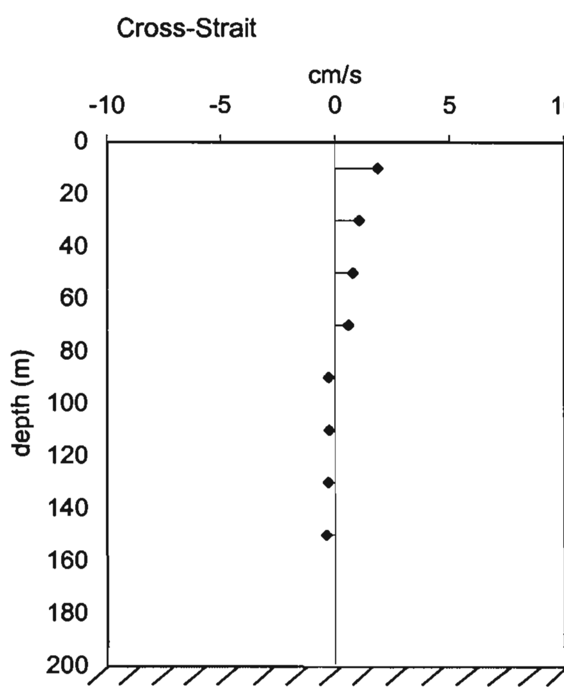
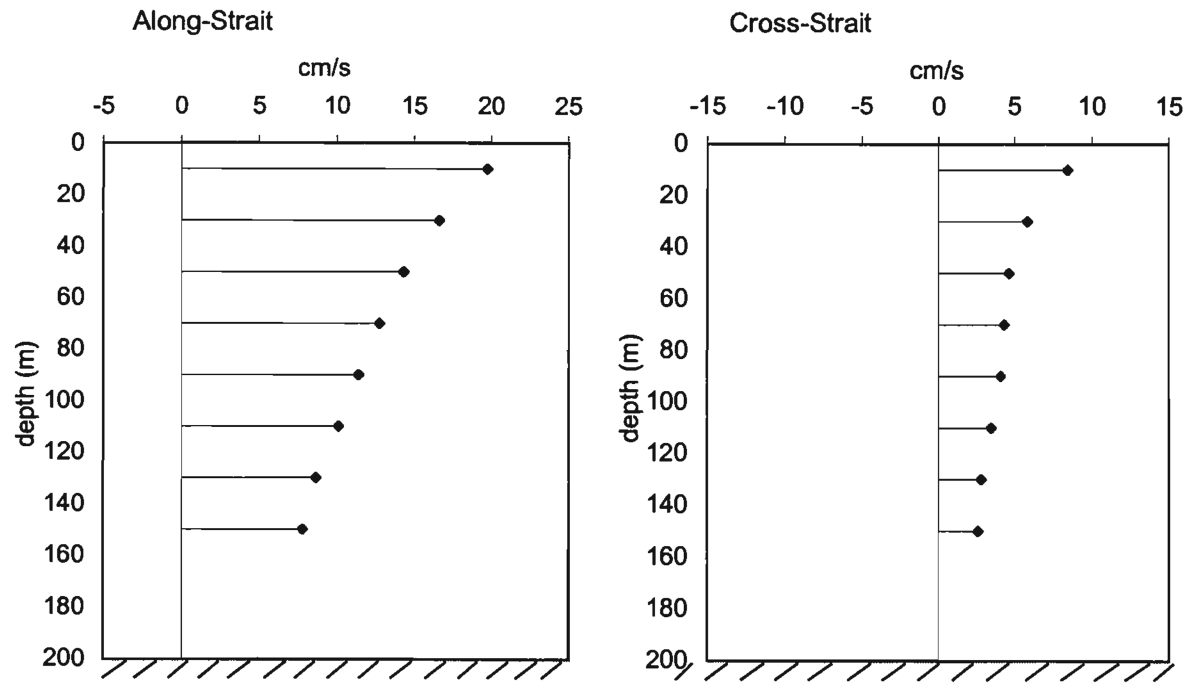


Figure 22: Mean Flows, Late Summer: Aug 1998 - Sep 1998.

South side of Barrow Strait:



North Side of Barrow Strait:

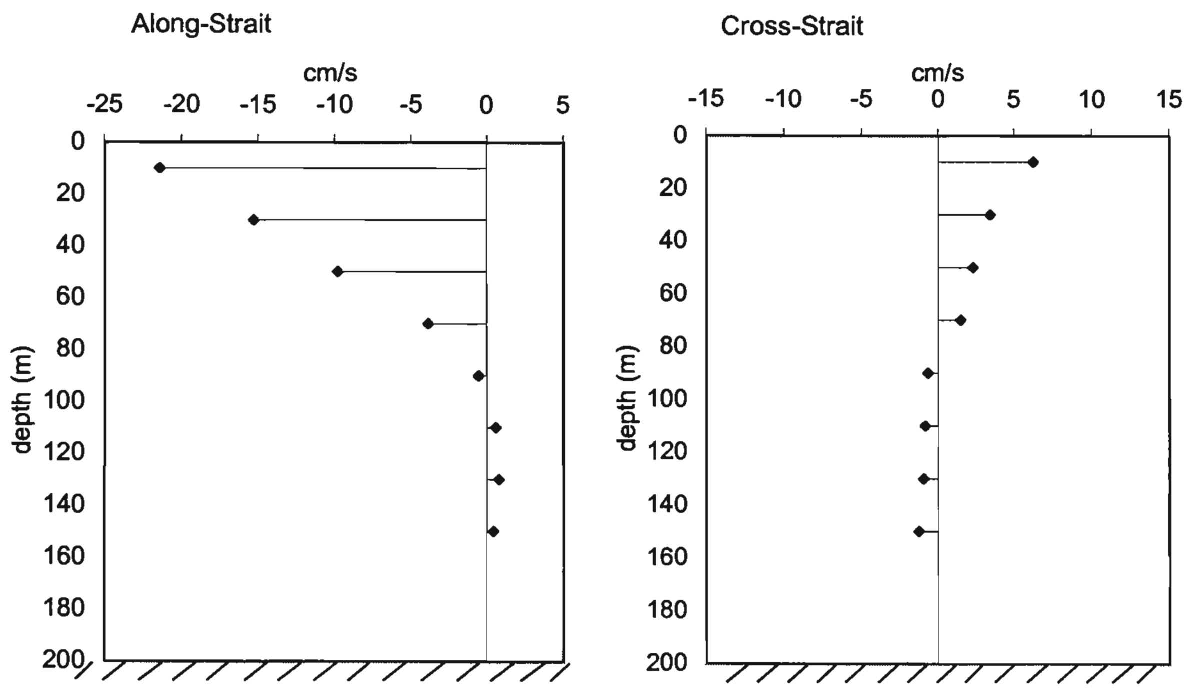
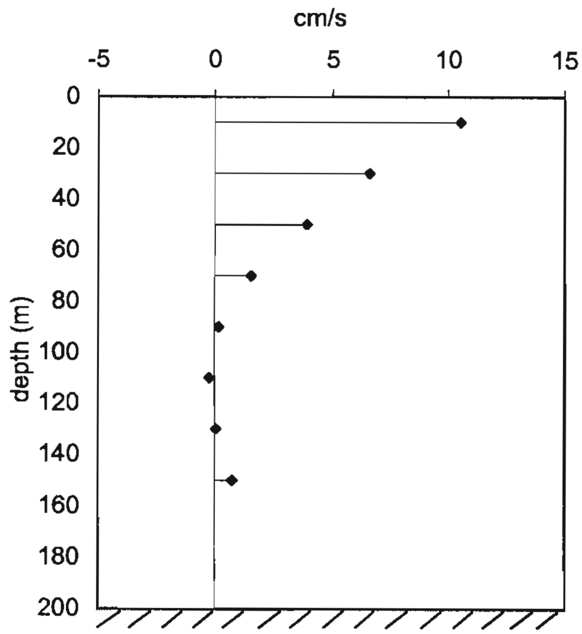


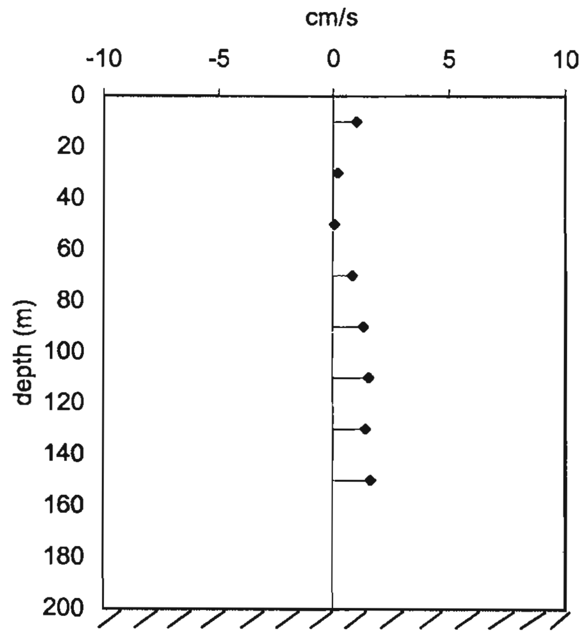
Figure 23: Mean Flows, Fall: Sep 1998 - Dec 1998.

South side of Barrow Strait:

Along-Strait

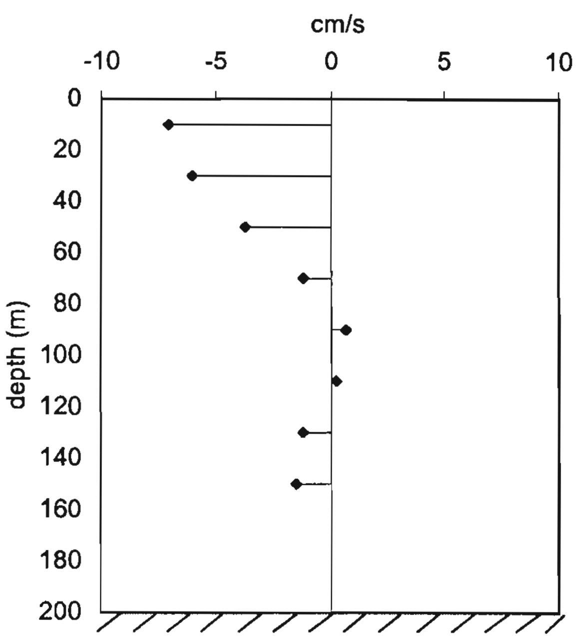


Cross-Strait



North Side of Barrow Strait:

Along-Strait



Cross-Strait

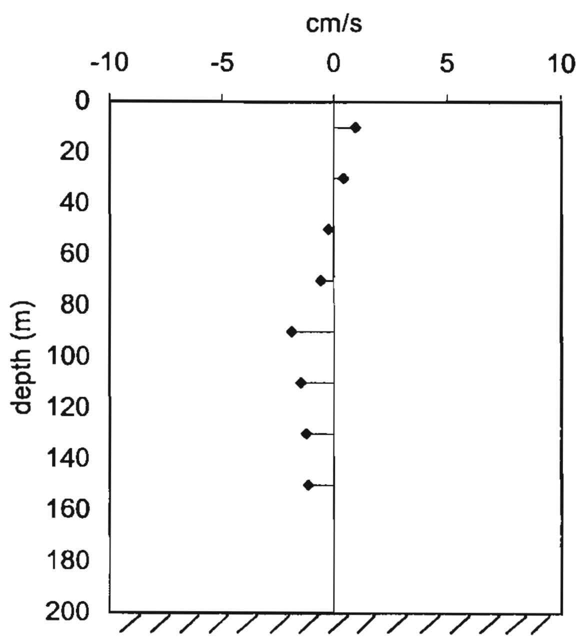
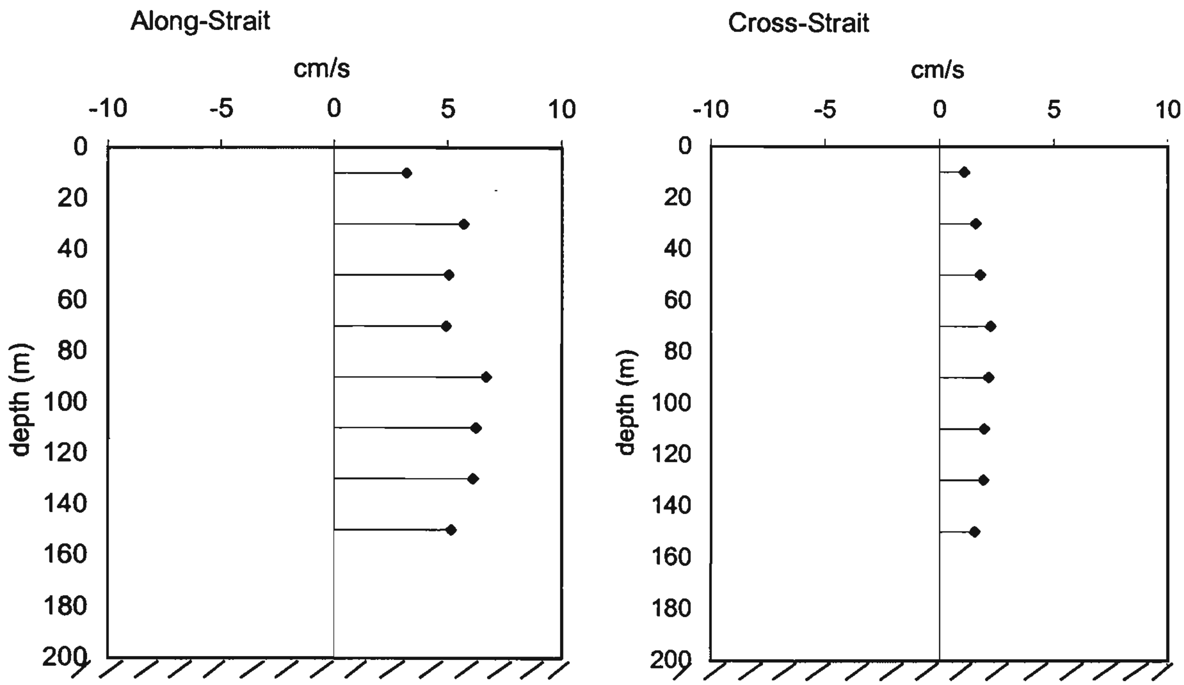


Figure 24: Mean Flows, Winter: Dec 1998 - Mar 1999.

South side of Barrow Strait:



North Side of Barrow Strait:

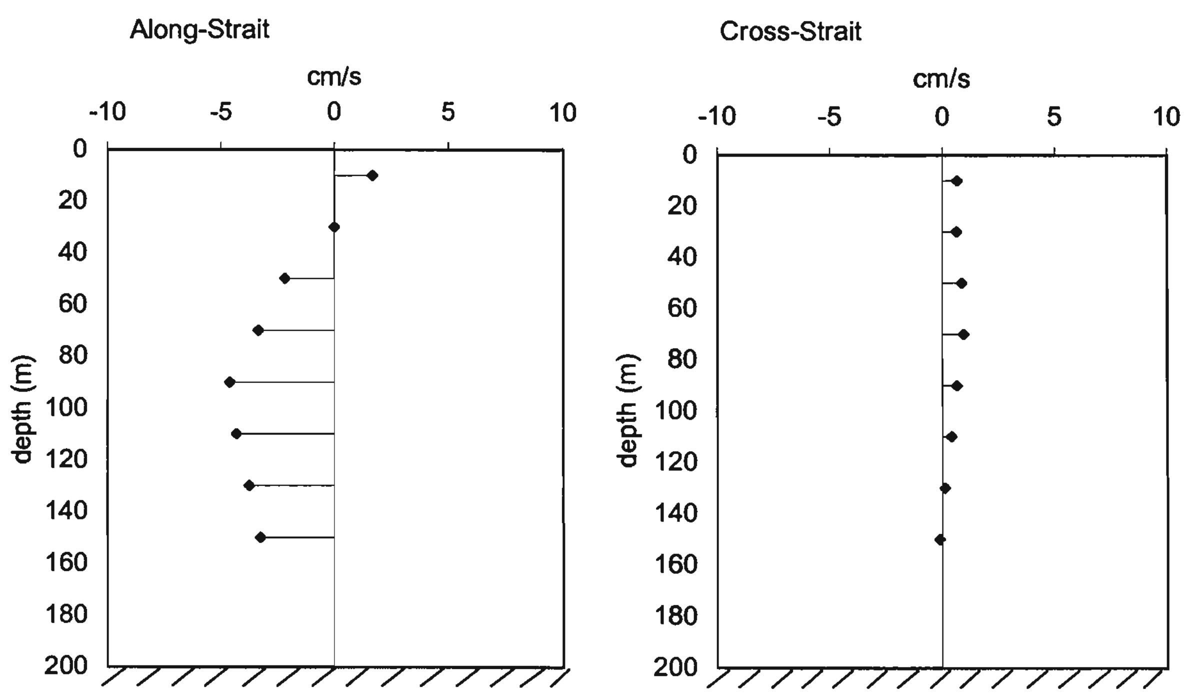
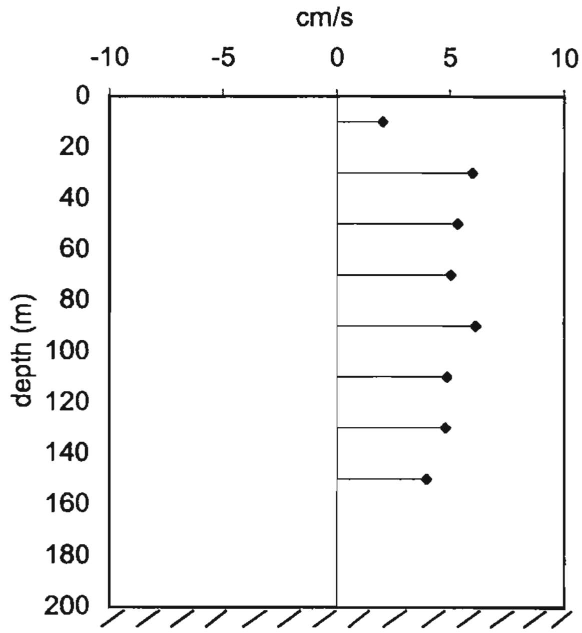


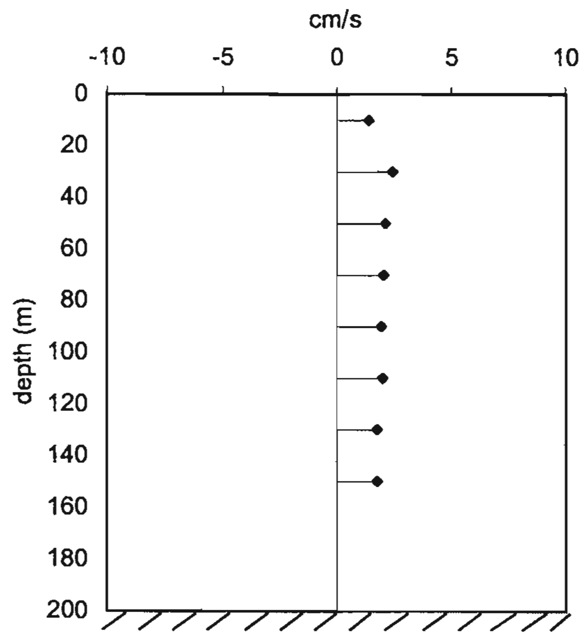
Figure 25: Mean Flows, Spring: Mar 1999 - Jun 1999.

South side of Barrow Strait:

Along-Strait

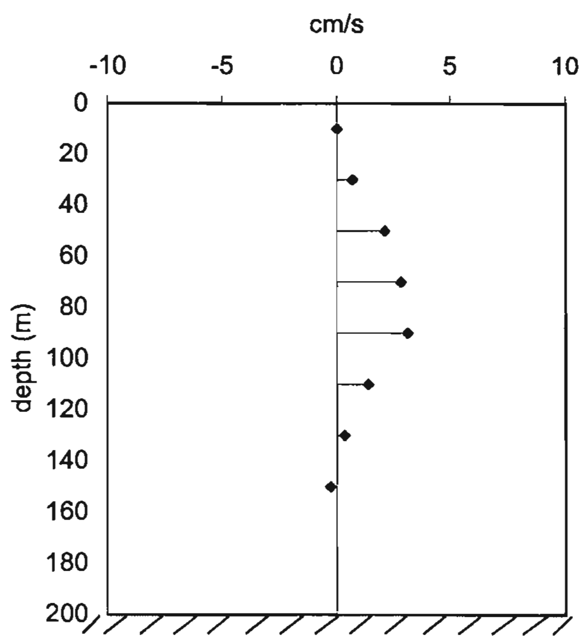


Cross-Strait

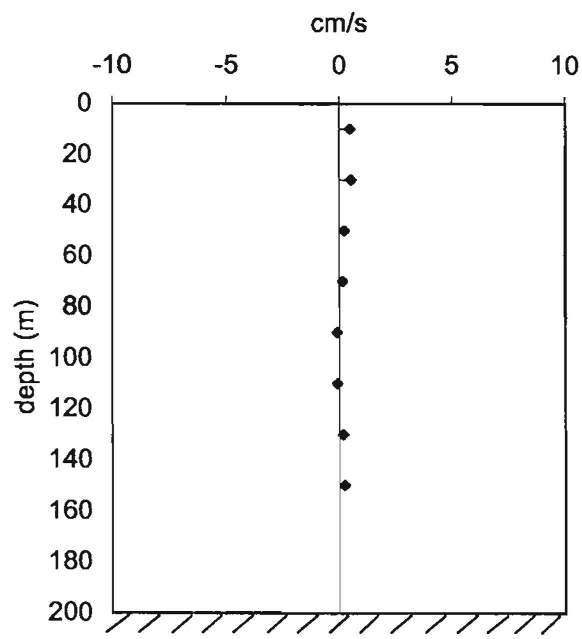


North Side of Barrow Strait:

Along-Strait



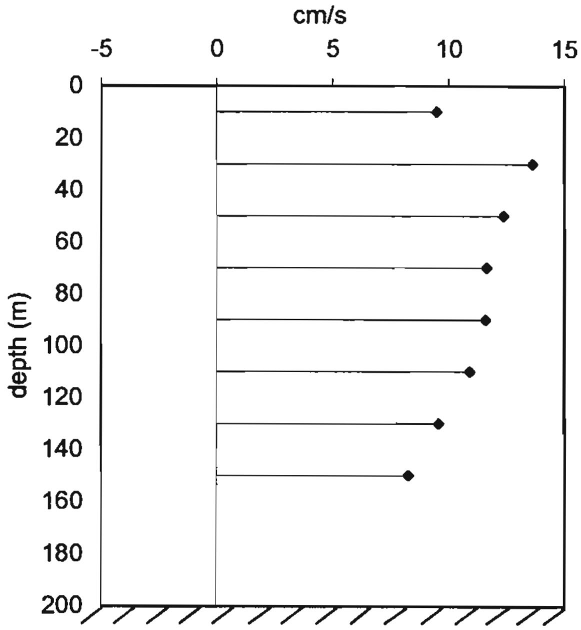
Cross-Strait



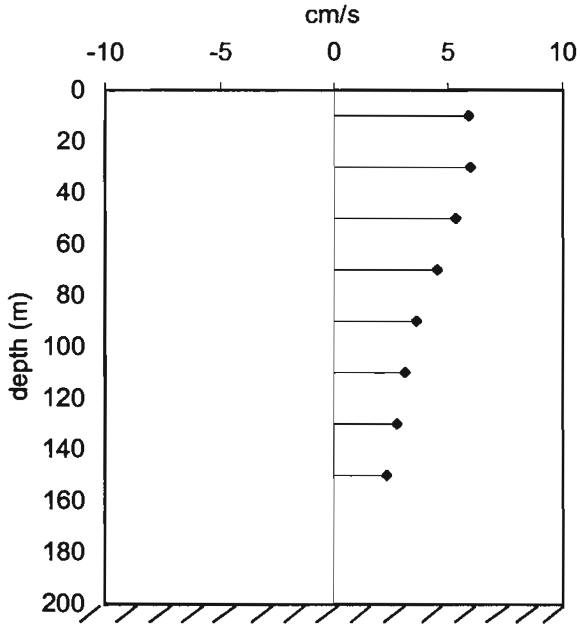
<u>Figure 26:</u> Mean Flows, Early Summer: Jun 1999 - Aug 1999.

South side of Barrow Strait:

Along-Strait

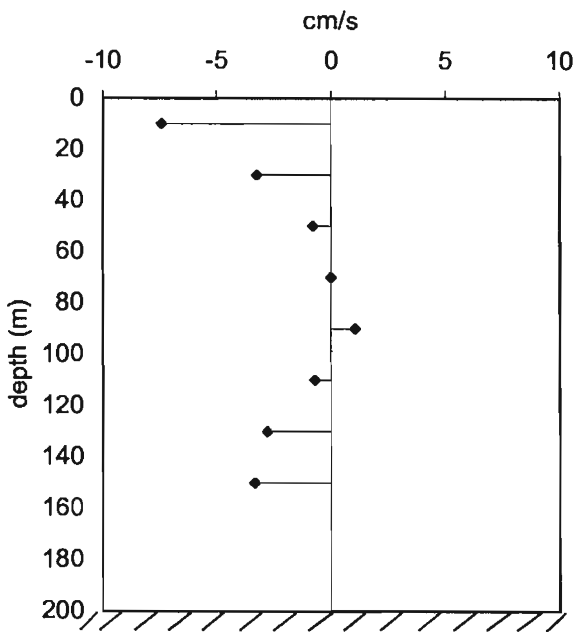


Cross-Strait



North Side of Barrow Strait:

Along-Strait



Cross-Strait

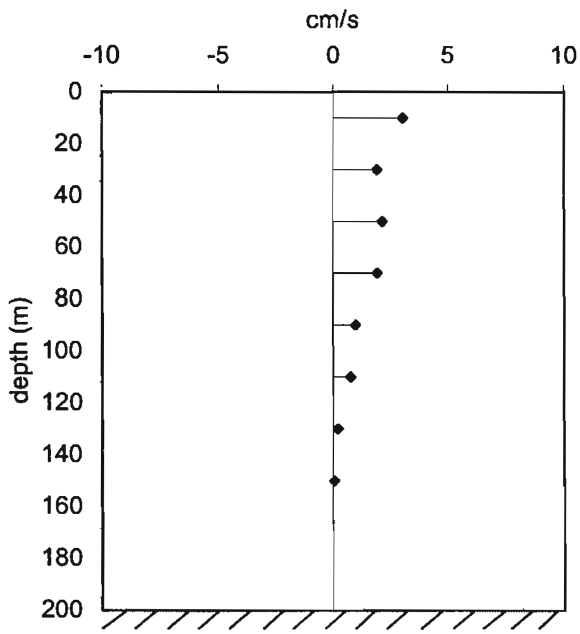
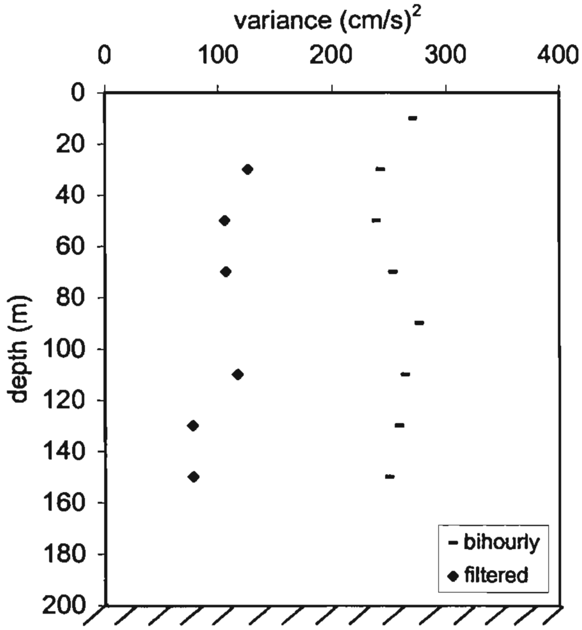


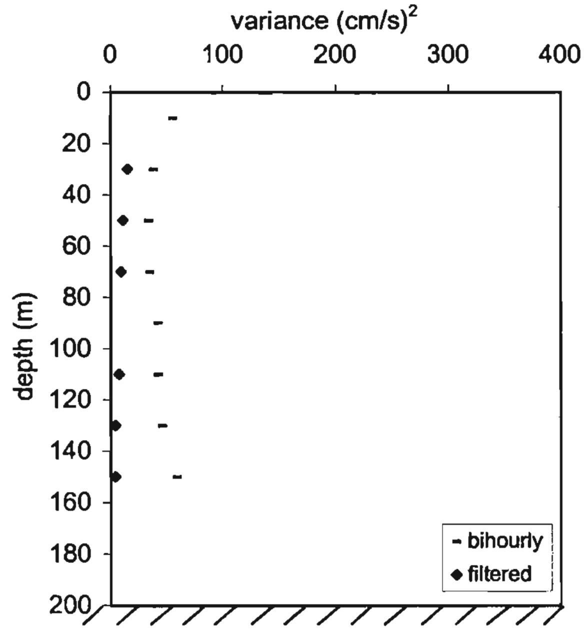
Figure 27: Variance in bihourly and low-pass filtered currents, computed over yearlong records (Aug 1998 - Aug 1999).

South side of Barrow Strait:

Along-Strait

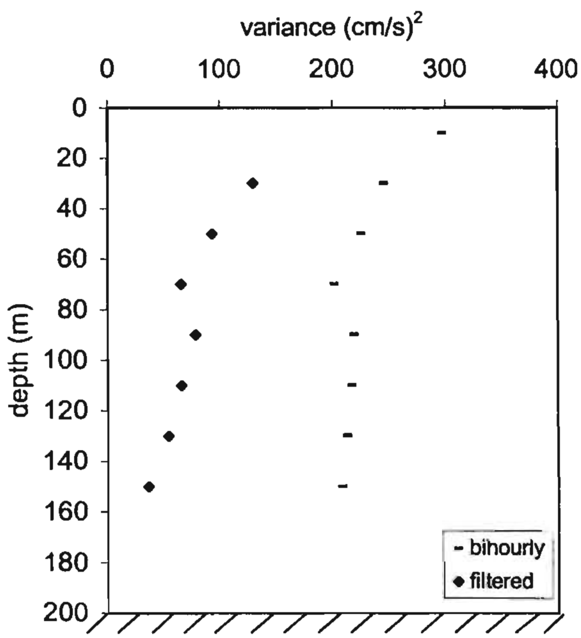


Cross-Strait



North Side of Barrow Strait:

Along-Strait



Cross-Strait

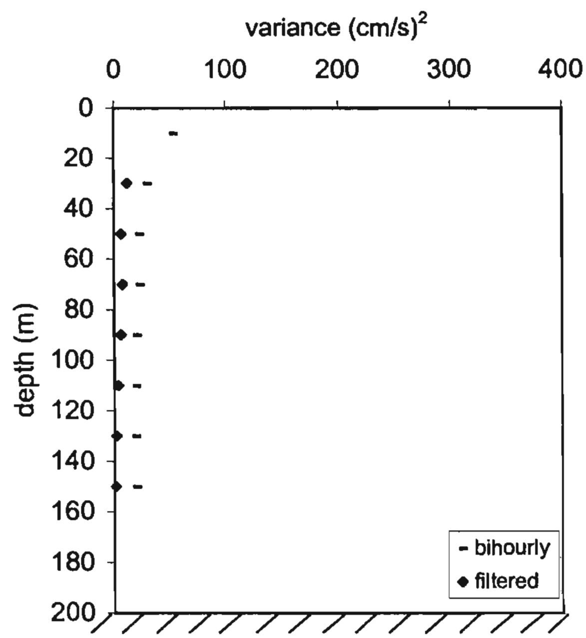
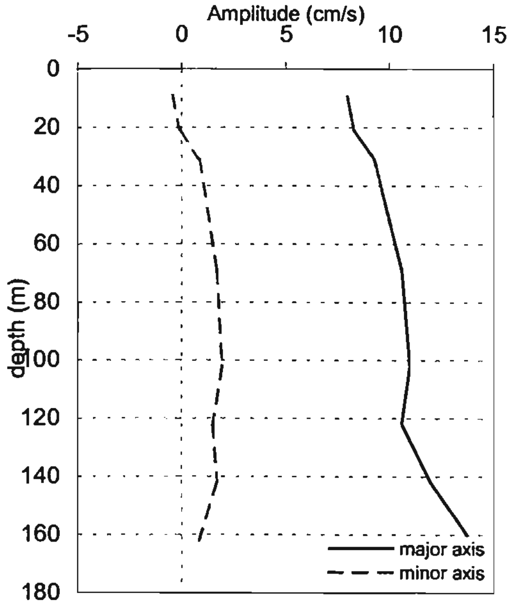
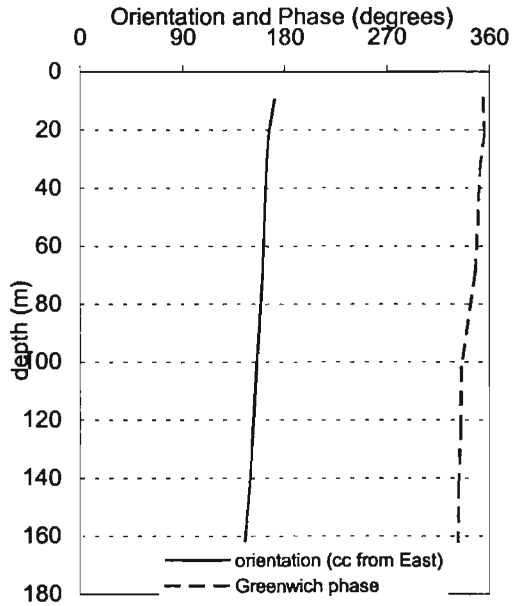


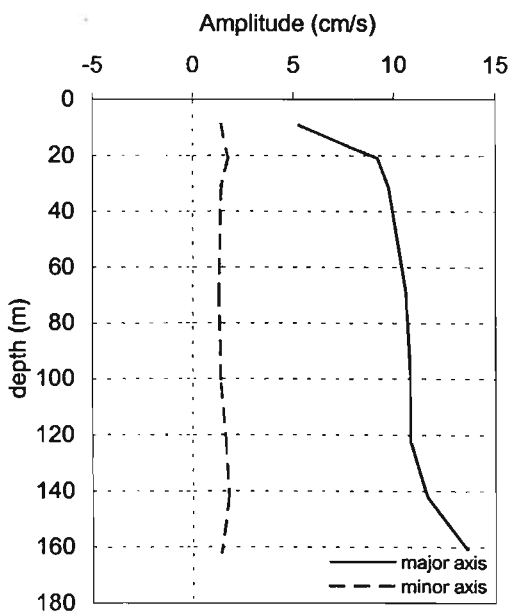
Figure 28 - K1 Tidal constituent, South side of Barrow Strait

For ice-free period (Aug 10, 1998 to Oct 21, 1998):





For solid-ice period (Feb 11, 1999 to Jul 17, 1999):



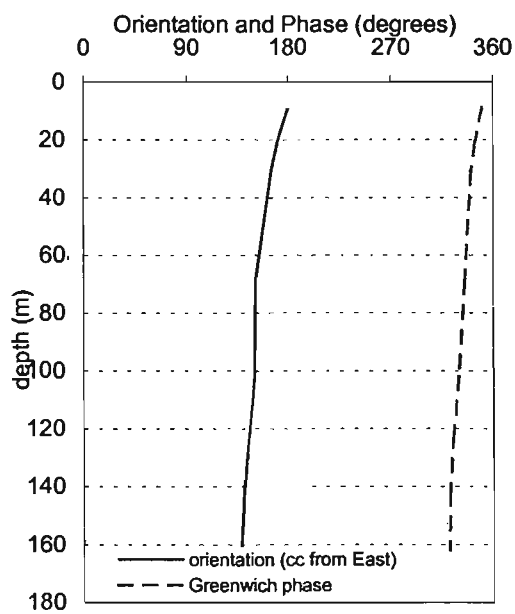
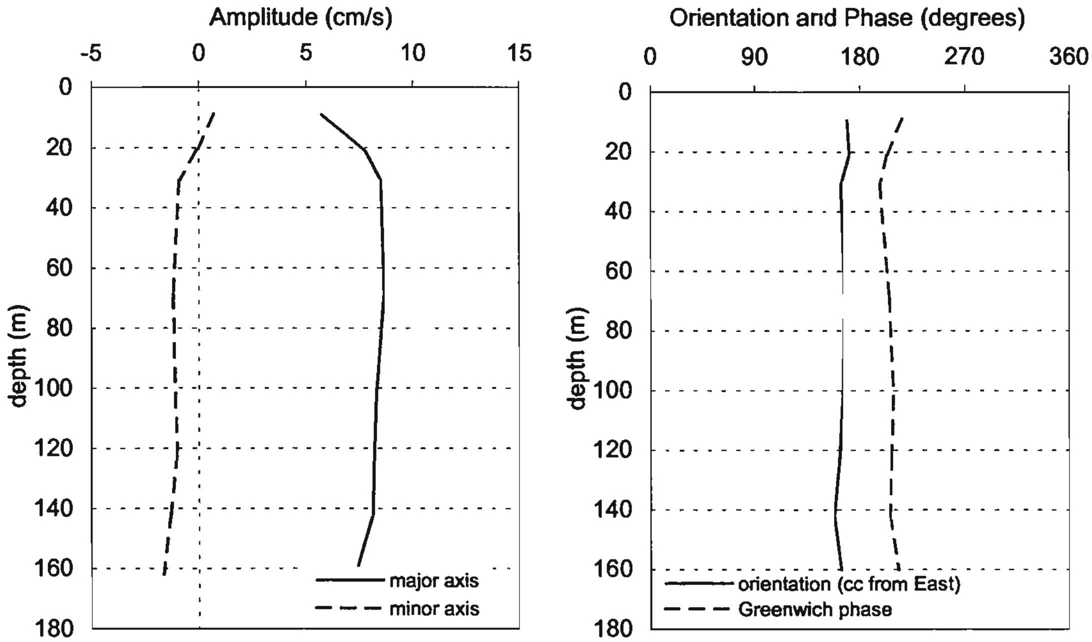


Figure 29 - M2 Tidal constituent, South side of Barrow Strait

For ice-free period (Aug 10, 1998 to Oct 21, 1998):



For solid-ice period (Feb 11, 1999 to Jul 17, 1999):

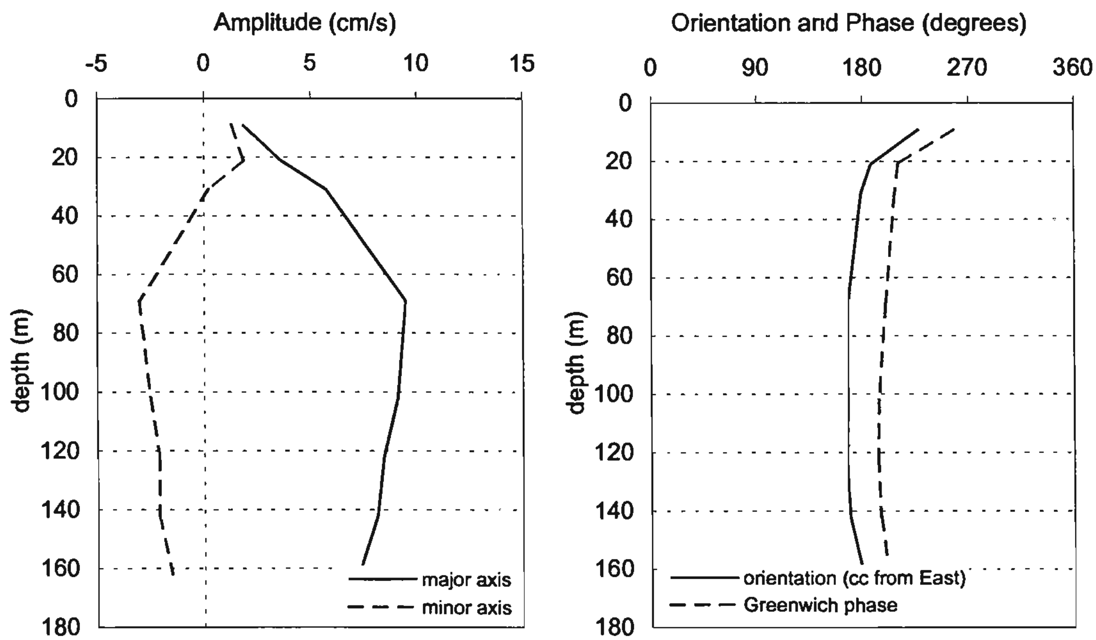
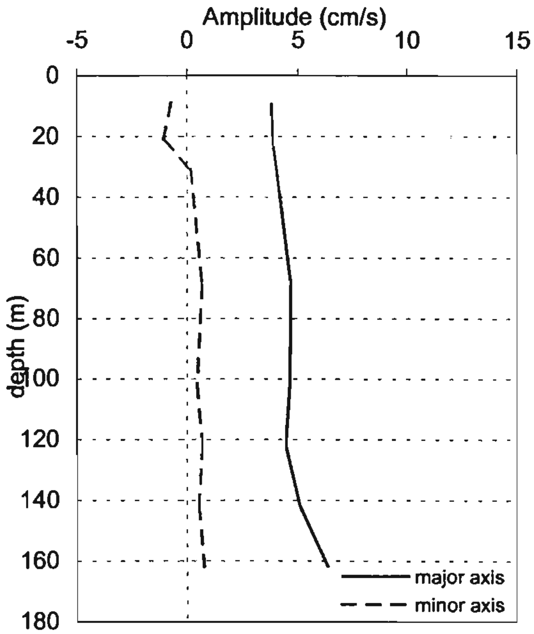
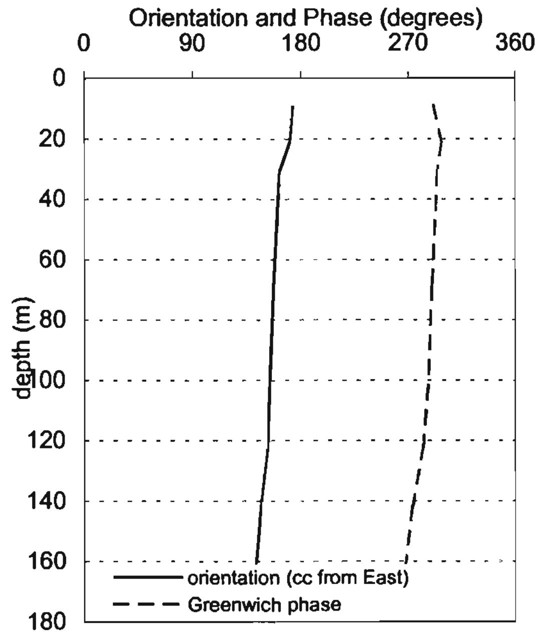


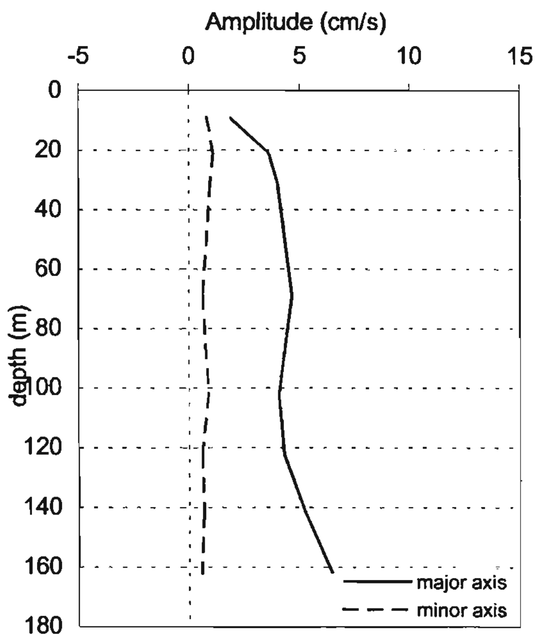
Figure 30 - O1 Tidal constituent, South side of Barrow Strait

For ice-free period (Aug 10, 1998 to Oct 21, 1998):





For solid-ice period (Feb 11, 1999 to Jul 17, 1999):



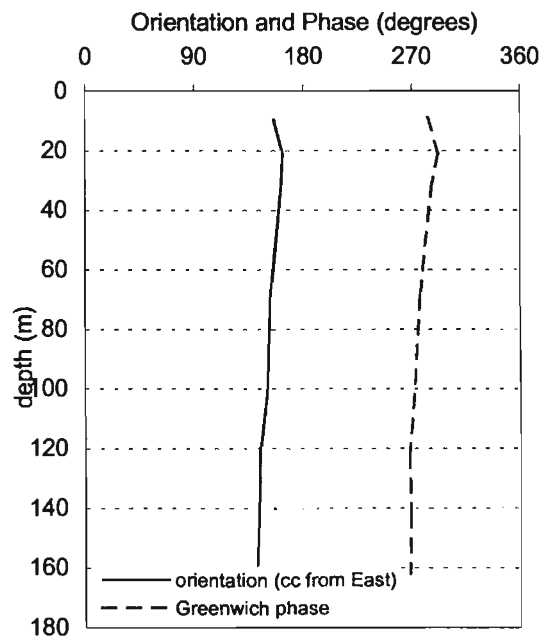
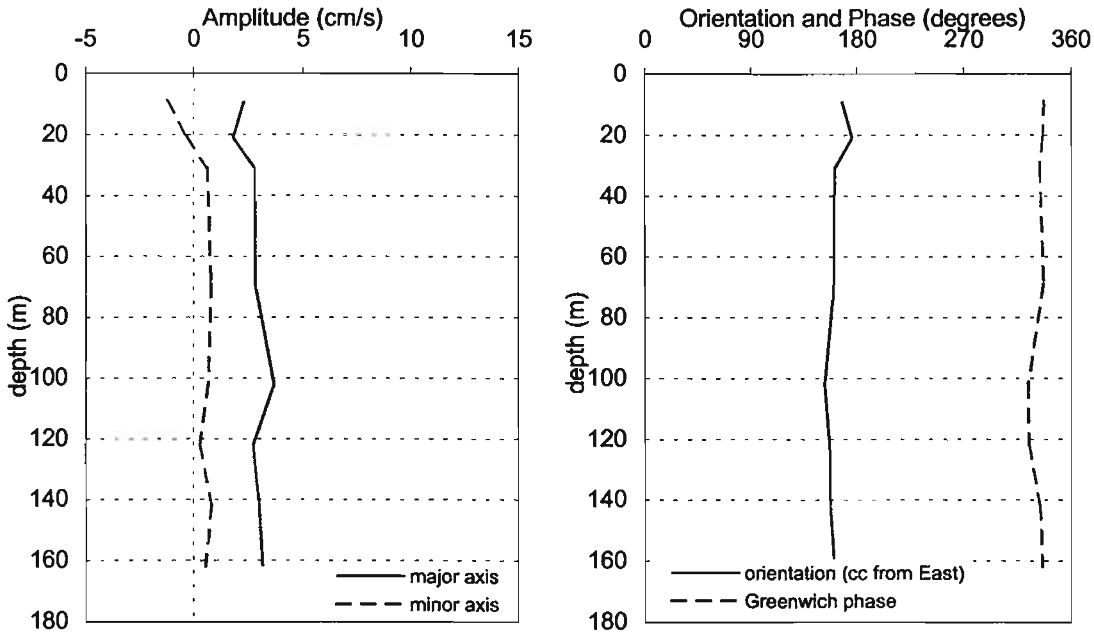


Figure 31 - **P1 Tidal constituent, South side of Barrow Strait**

For ice-free period (Aug 10, 1998 to Oct 21, 1998):



For solid-ice period (Feb 11, 1999 to Jul 17, 1999):

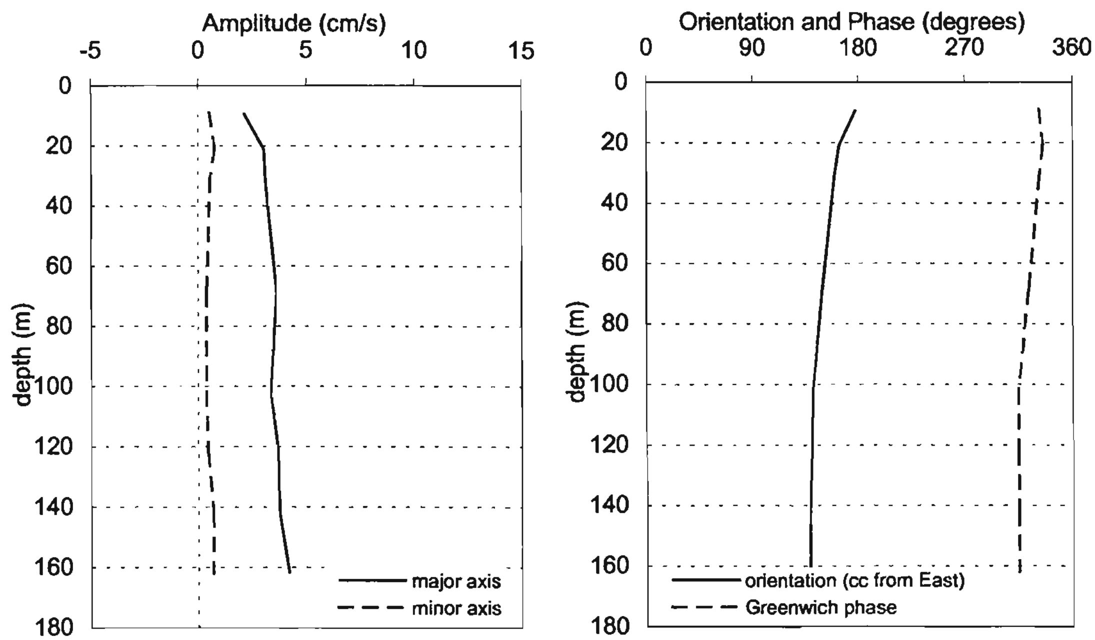
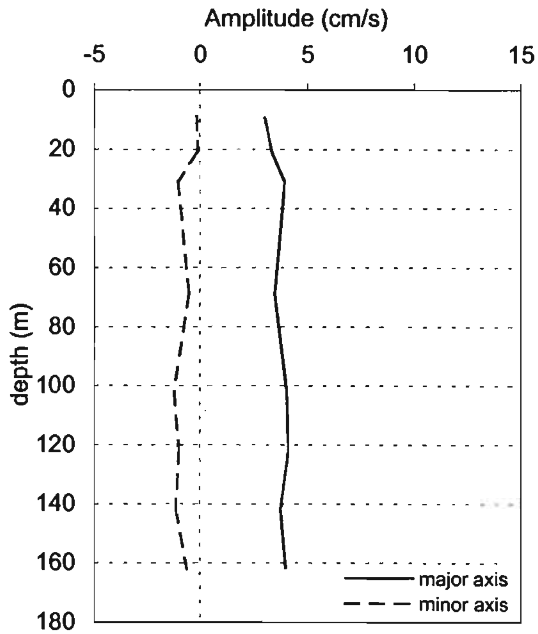
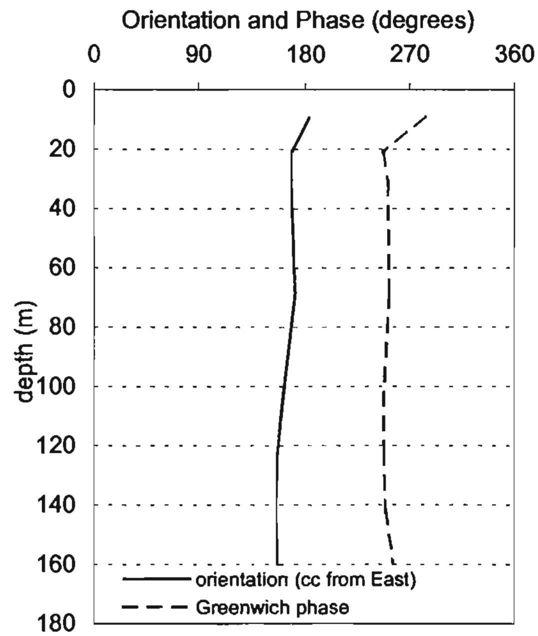


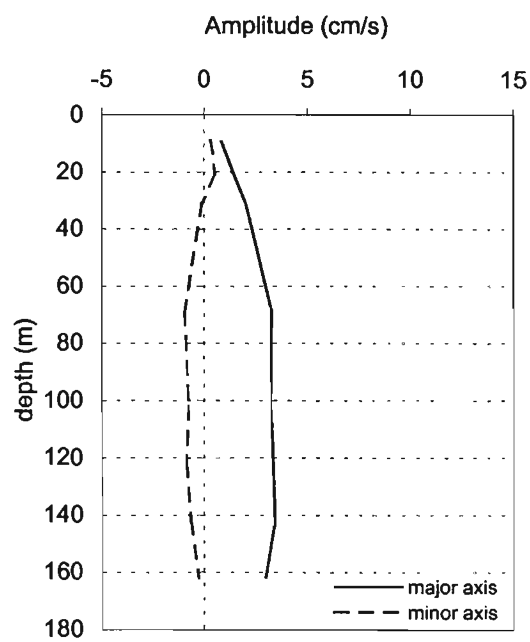
Figure 32 - S2 Tidal constituent, South side of Barrow Strait

For ice-free period (Aug 10, 1998 to Oct 21, 1998):





For solid-ice period (Feb 11, 1999 to Jul 17, 1999):



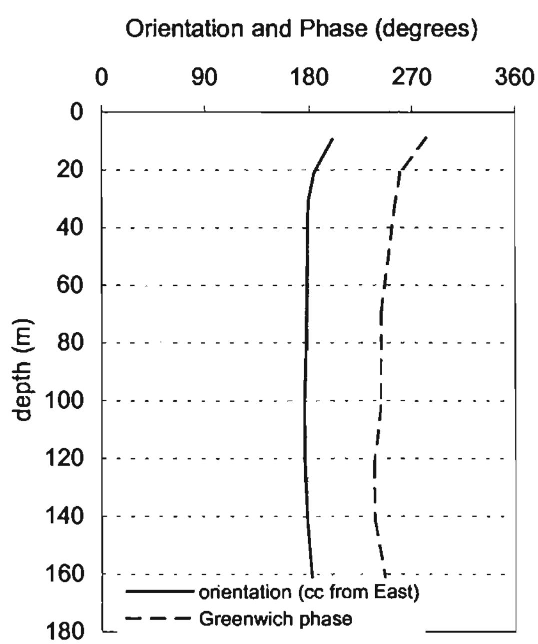
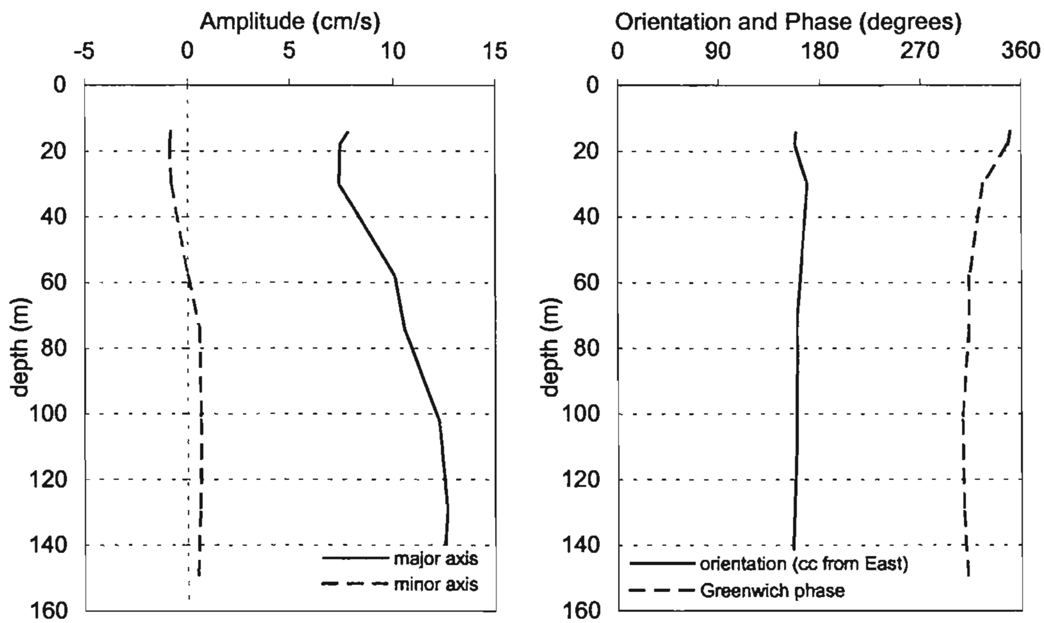


Figure 33 - K1 Tidal constituent, North side of Barrow Strait

For ice-free period (Aug 10, 1998 to Oct 20, 1998):



For solid-ice period (Feb 11, 1999 to Jul 17, 1999):

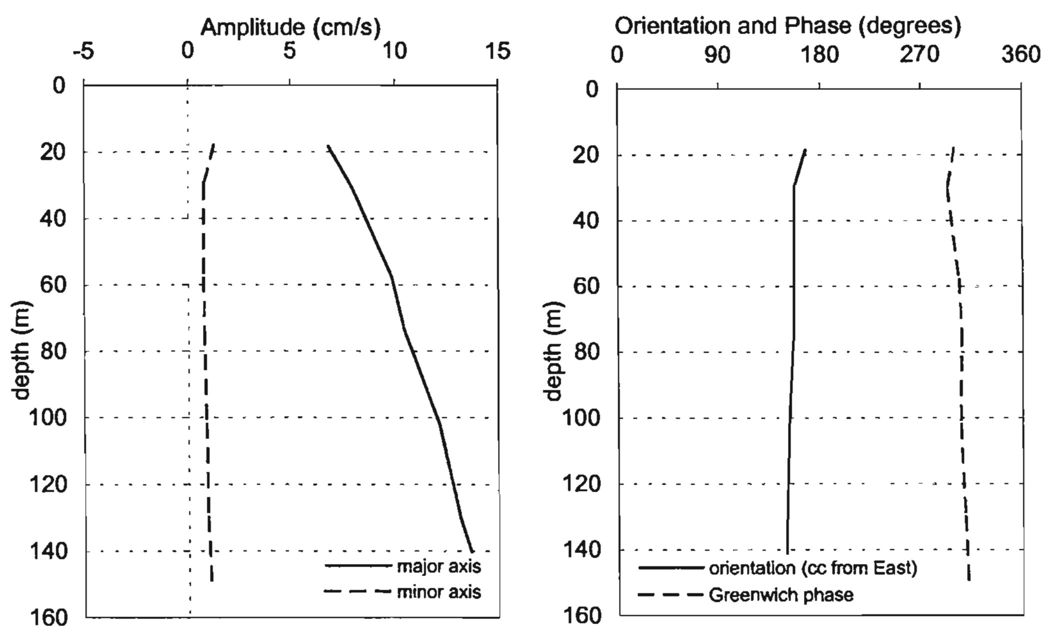
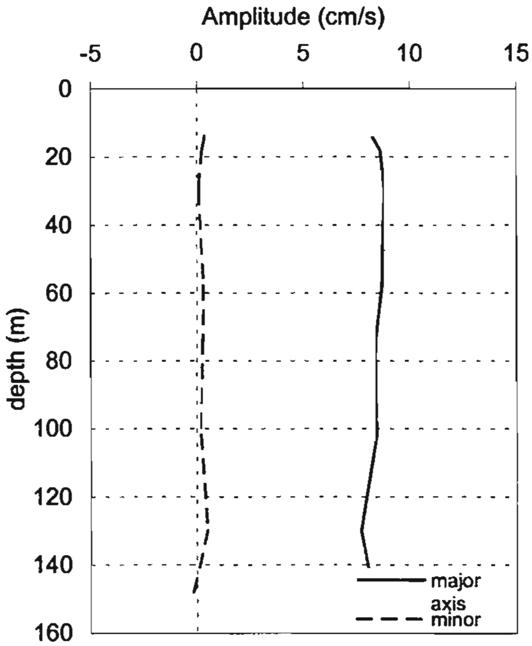
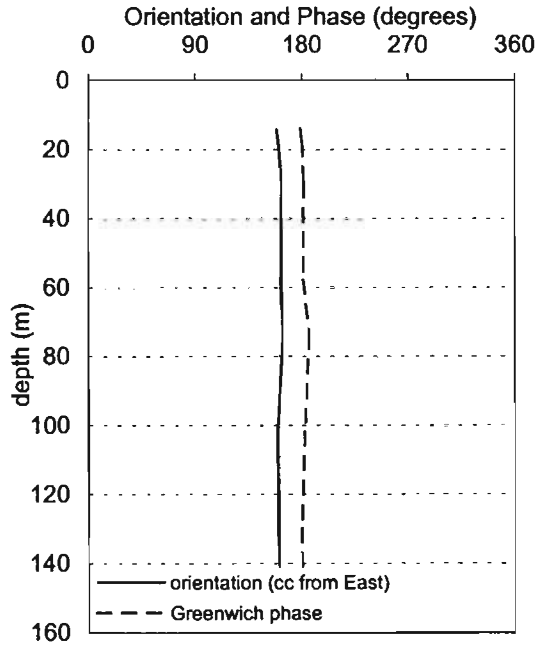


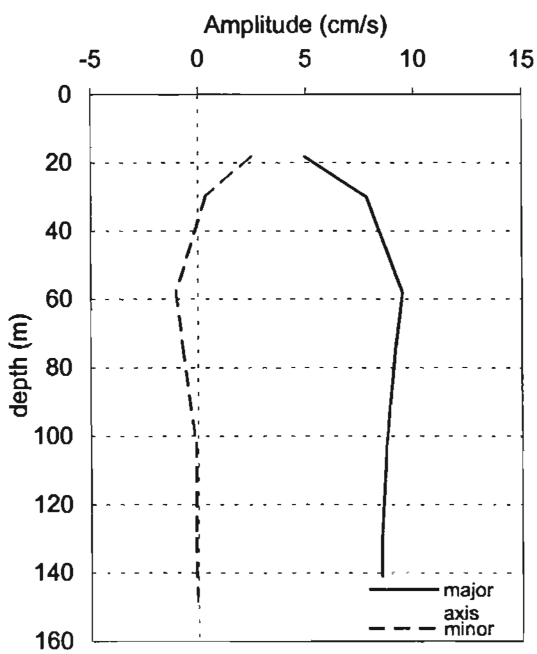
Figure 34 - M2 Tidal constituent, North side of Barrow Strait

For ice-free period (Aug 10, 1998 to Oct 20, 1998):





For solid-ice period (Feb 11, 1999 to Jul 17, 1999):



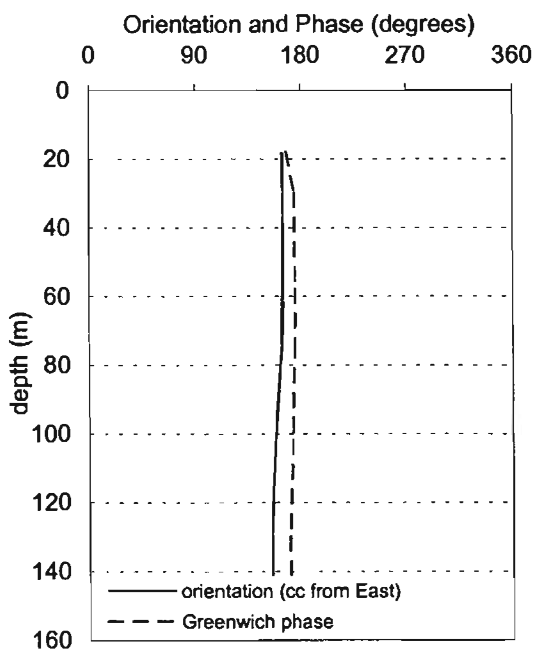
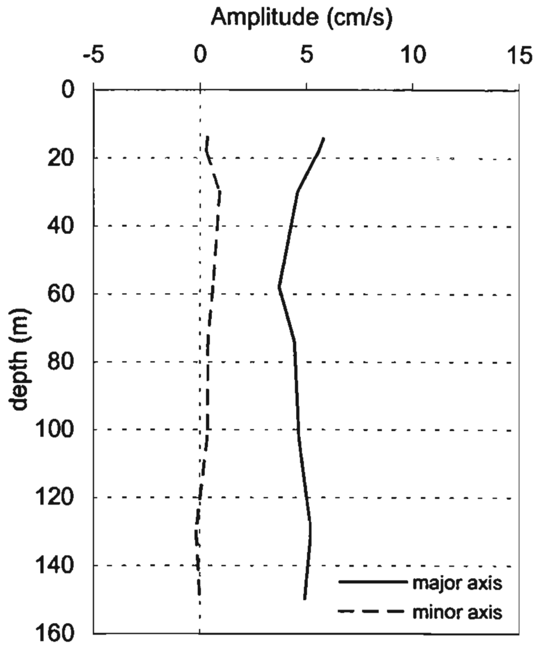
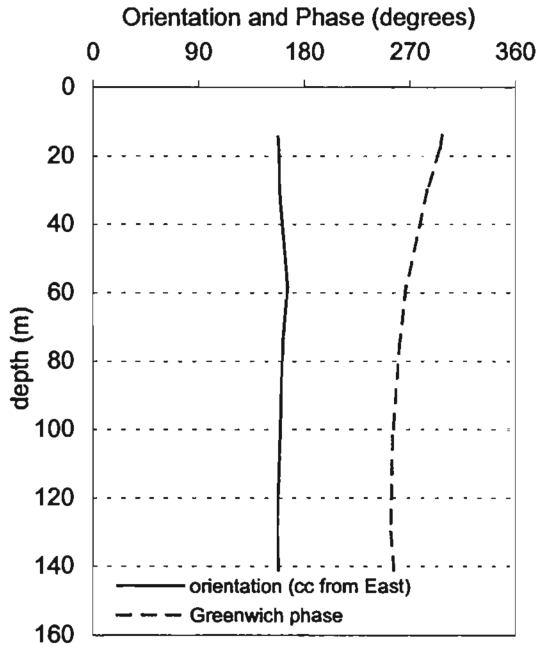


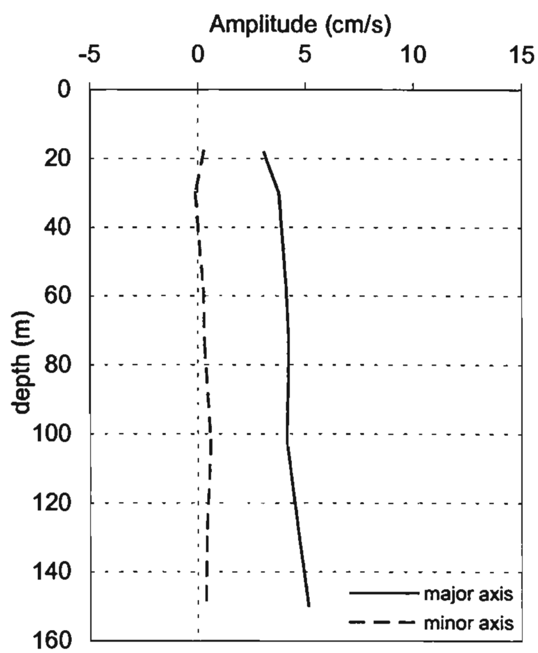
Figure 35 - O1 Tidal constituent, North side of Barrow Strait

For ice-free period (Aug 10, 1998 to Oct 20, 1998):





For solid-ice period (Feb 11, 1999 to Jul 17, 1999):



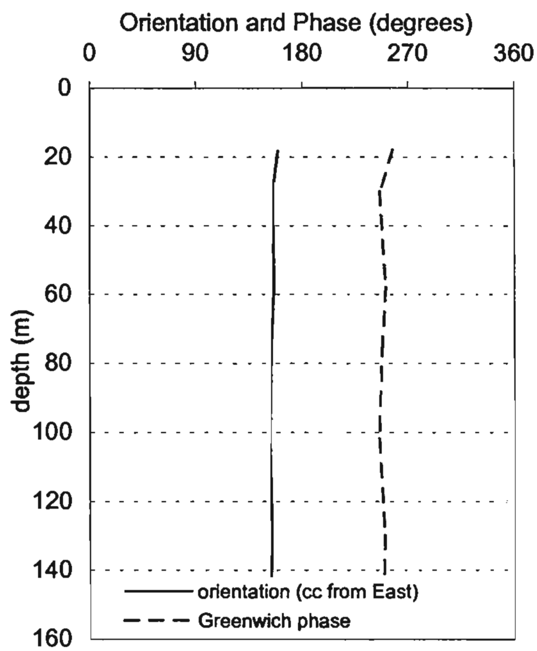
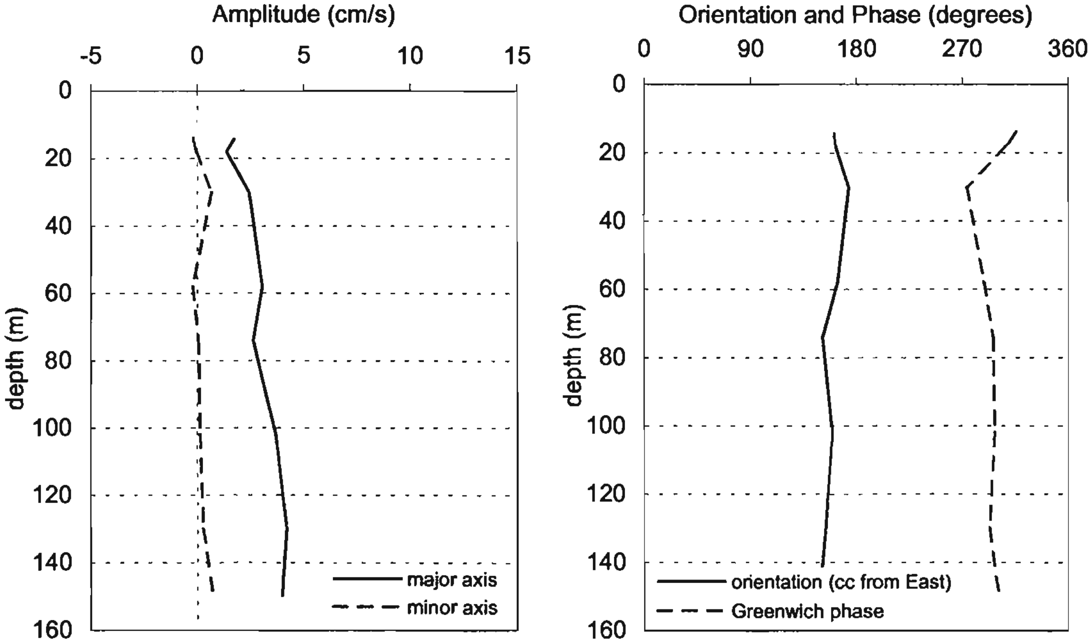


Figure 36 - P1 Tidal constituent, North side of Barrow Strait

For ice-free period (Aug 10, 1998 to Oct 20, 1998):



For solid-ice period (Feb 11, 1999 to Jul 17, 1999):

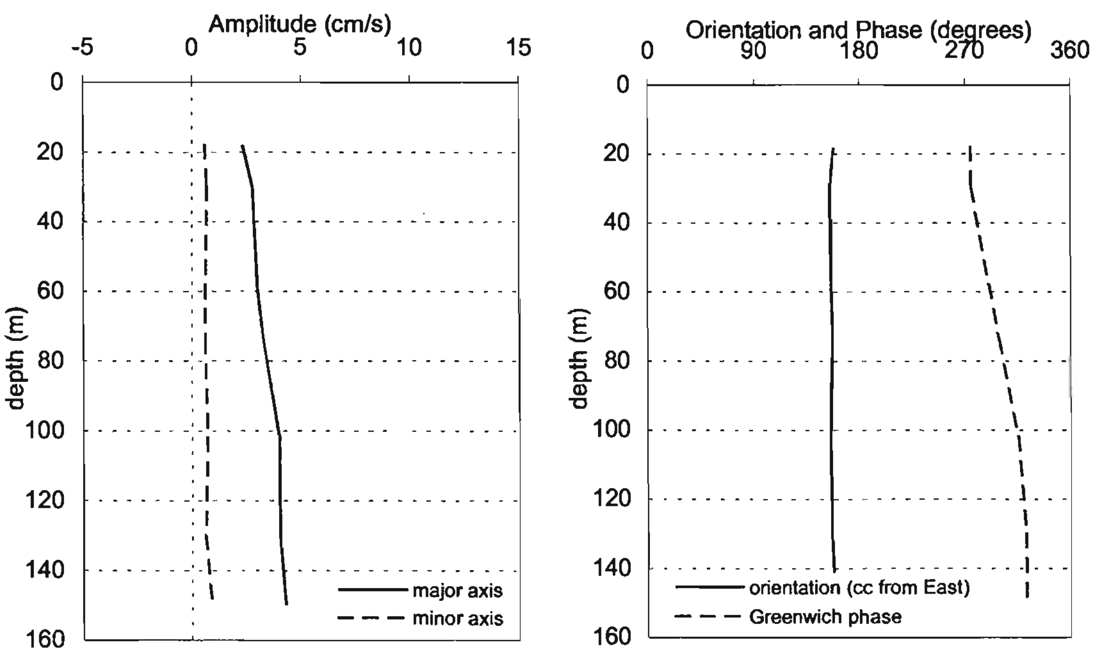
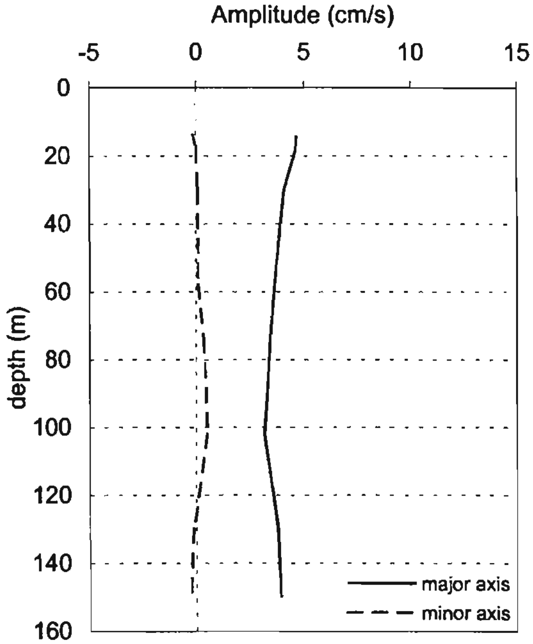
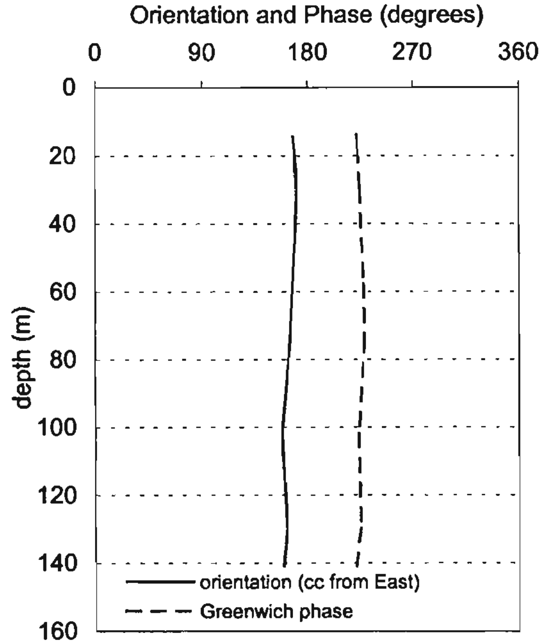


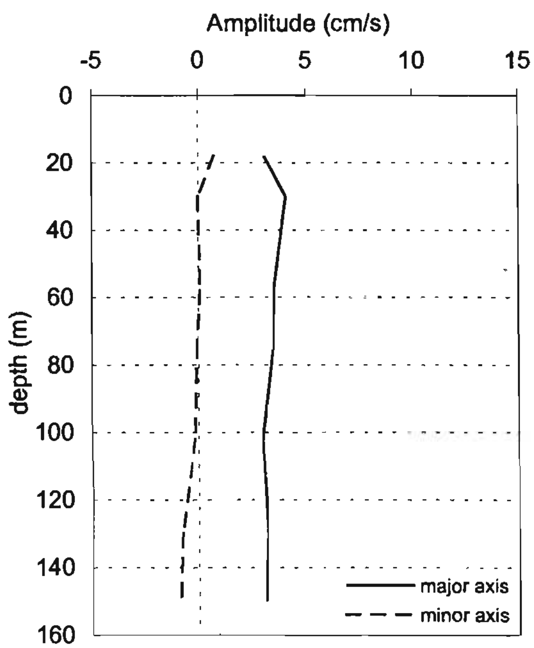
Figure 37 - S2 Tidal constituent, North side of Barrow Strait

For ice-free period (Aug 10, 1998 to Oct 20, 1998):





For solid-ice period (Feb 11, 1999 to Jul 17, 1999):



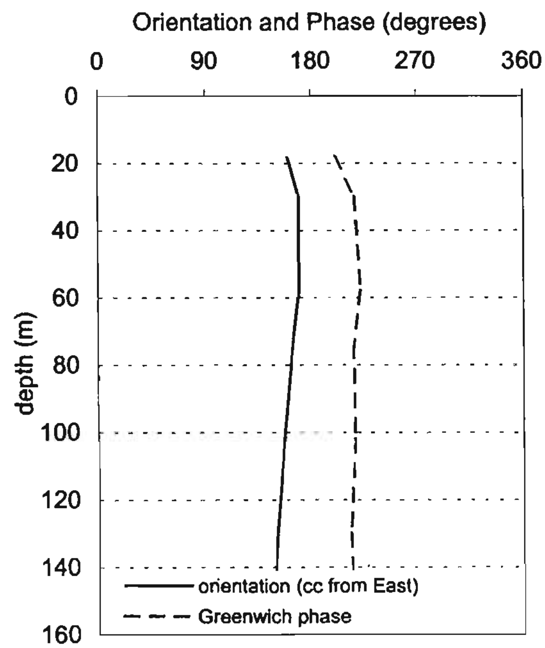


Figure 38 - Ice velocity data, South side of Barrow Strait: Aug 1998 - Aug 1999.

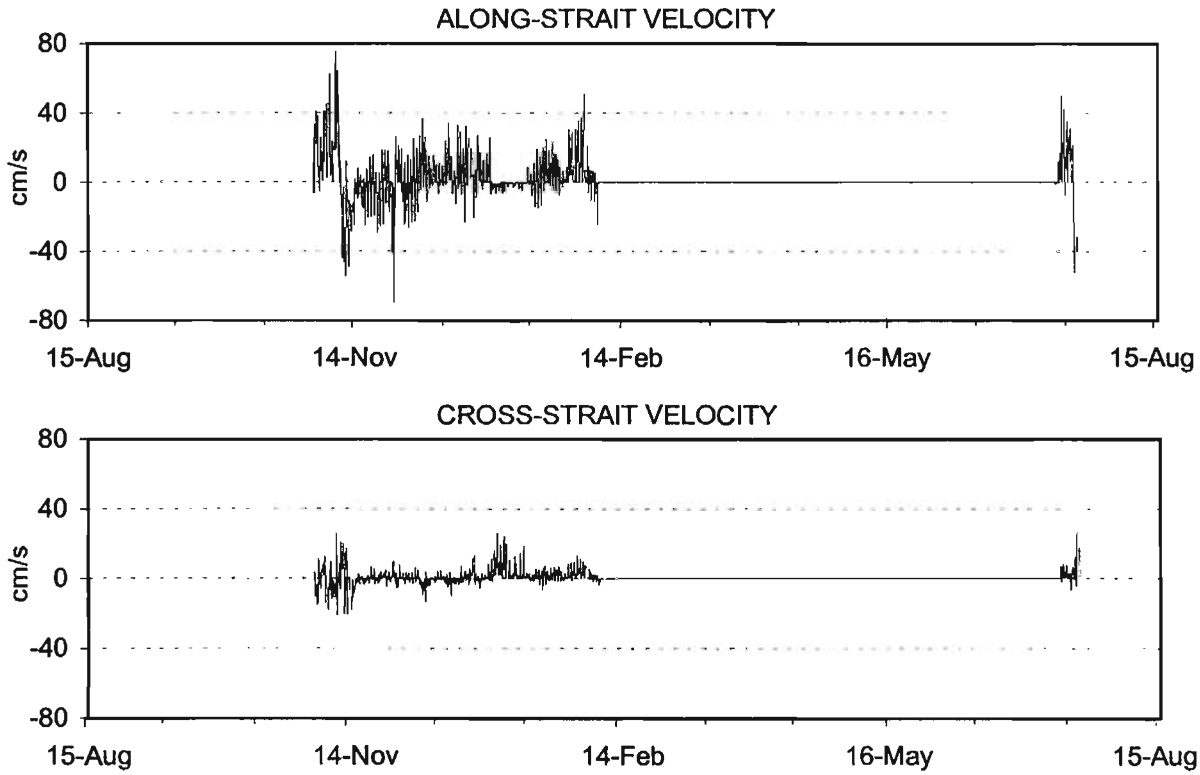


Figure 39 - **Ice velocity data, North side of Barrow Strait: Aug 1998 - Aug 1999.**

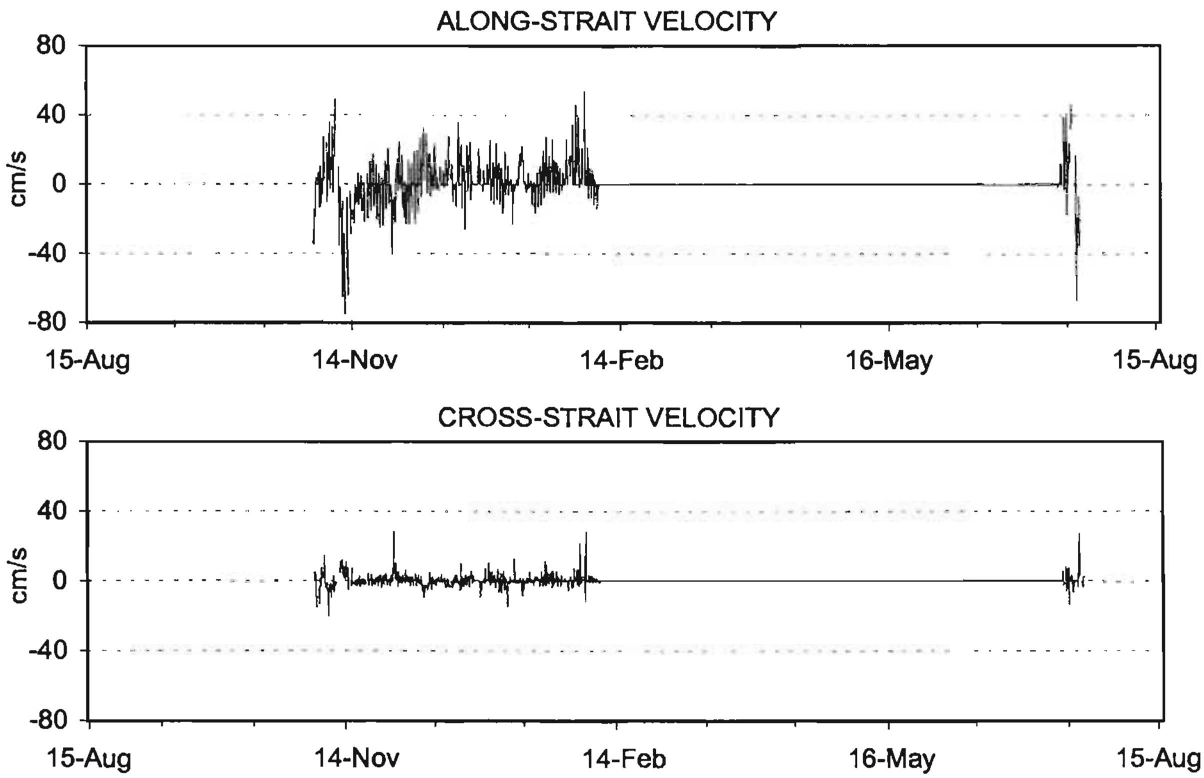


Figure 40 – Eastern Barrow Strait CTD line, Aug 11-12, 1998.

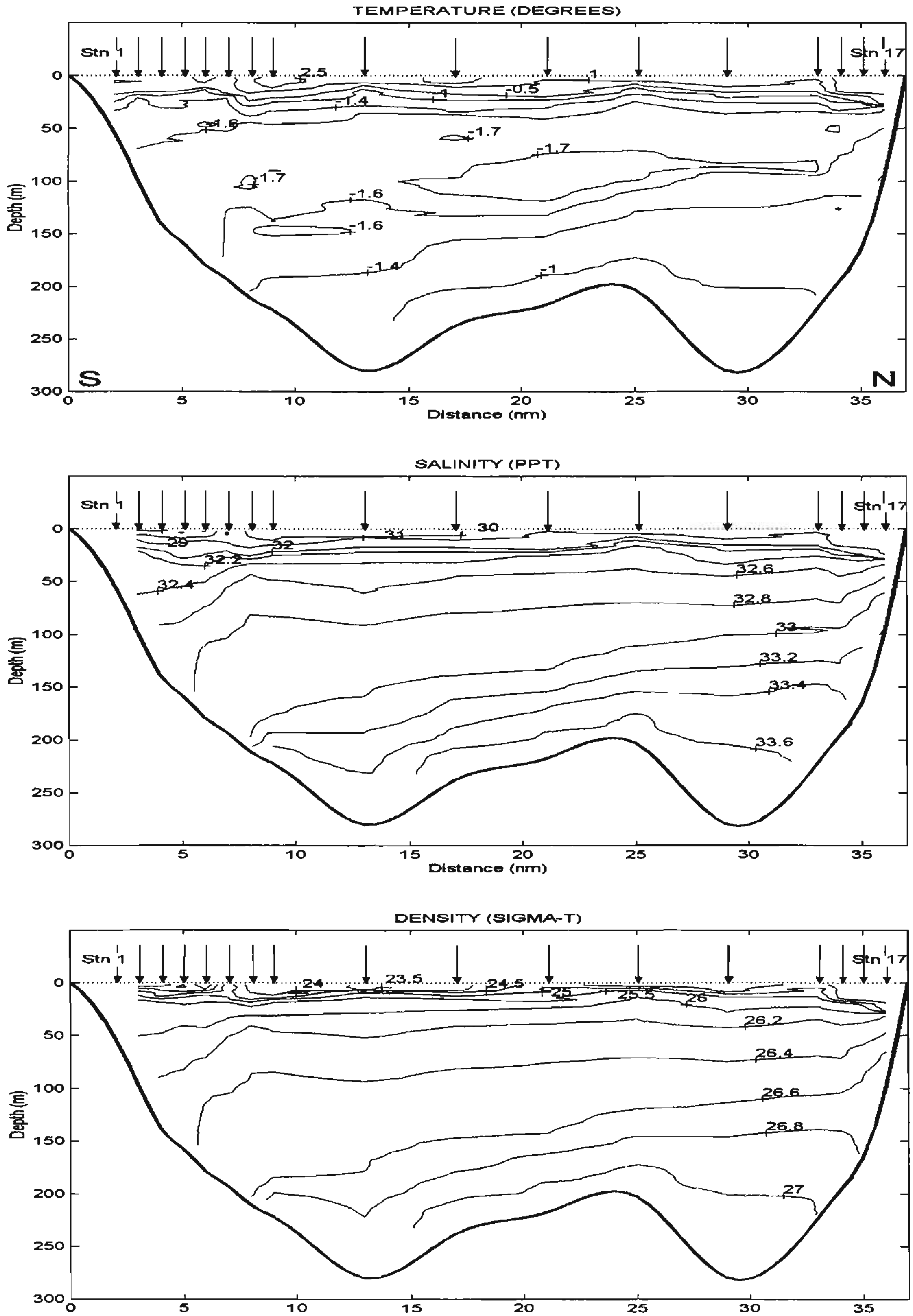


Figure 41 – Western Barrow Strait CTD line, Aug 14, 1998.

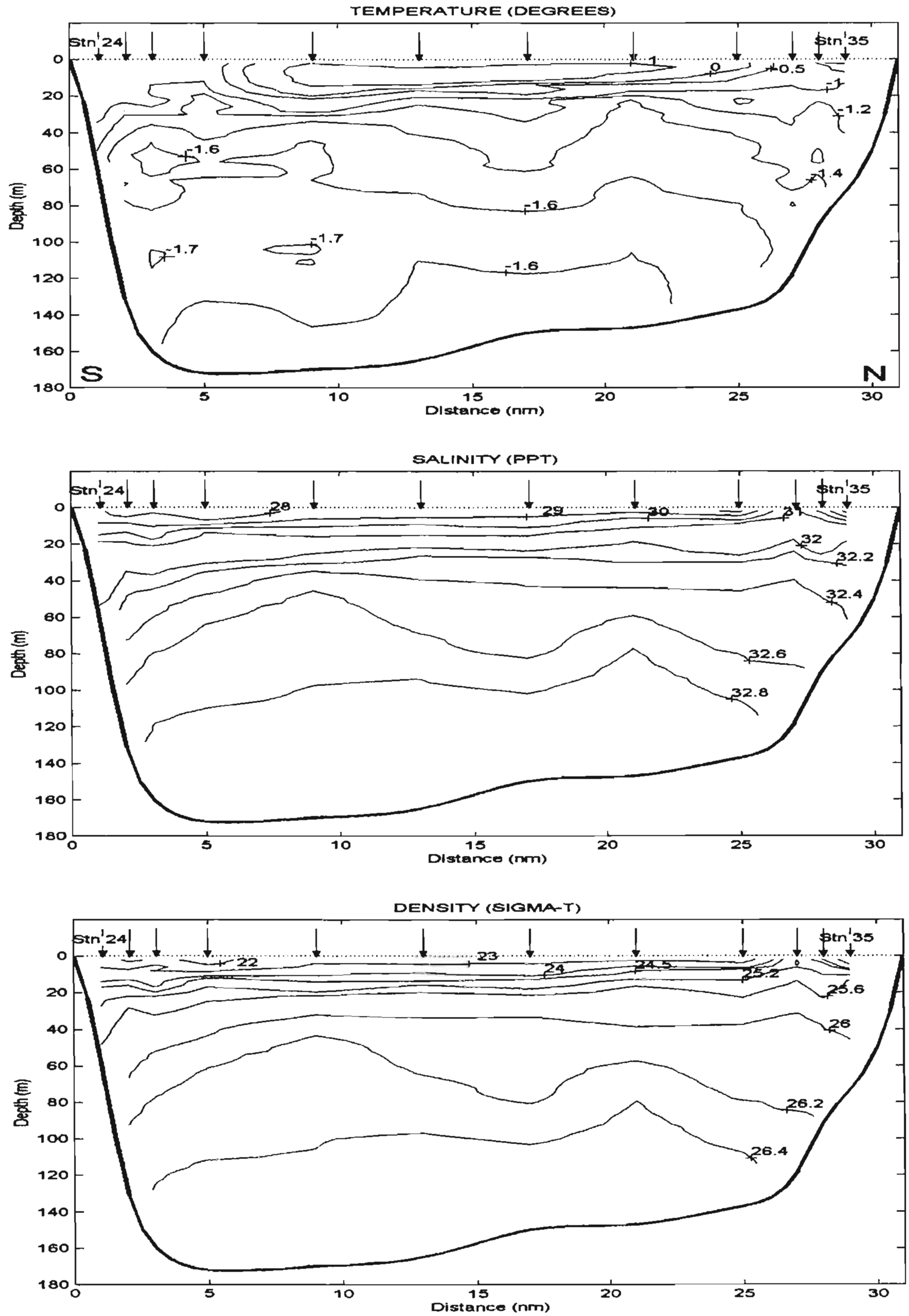


Figure 42 – Wellington Channel CTD line, Aug 12-13, 1998.

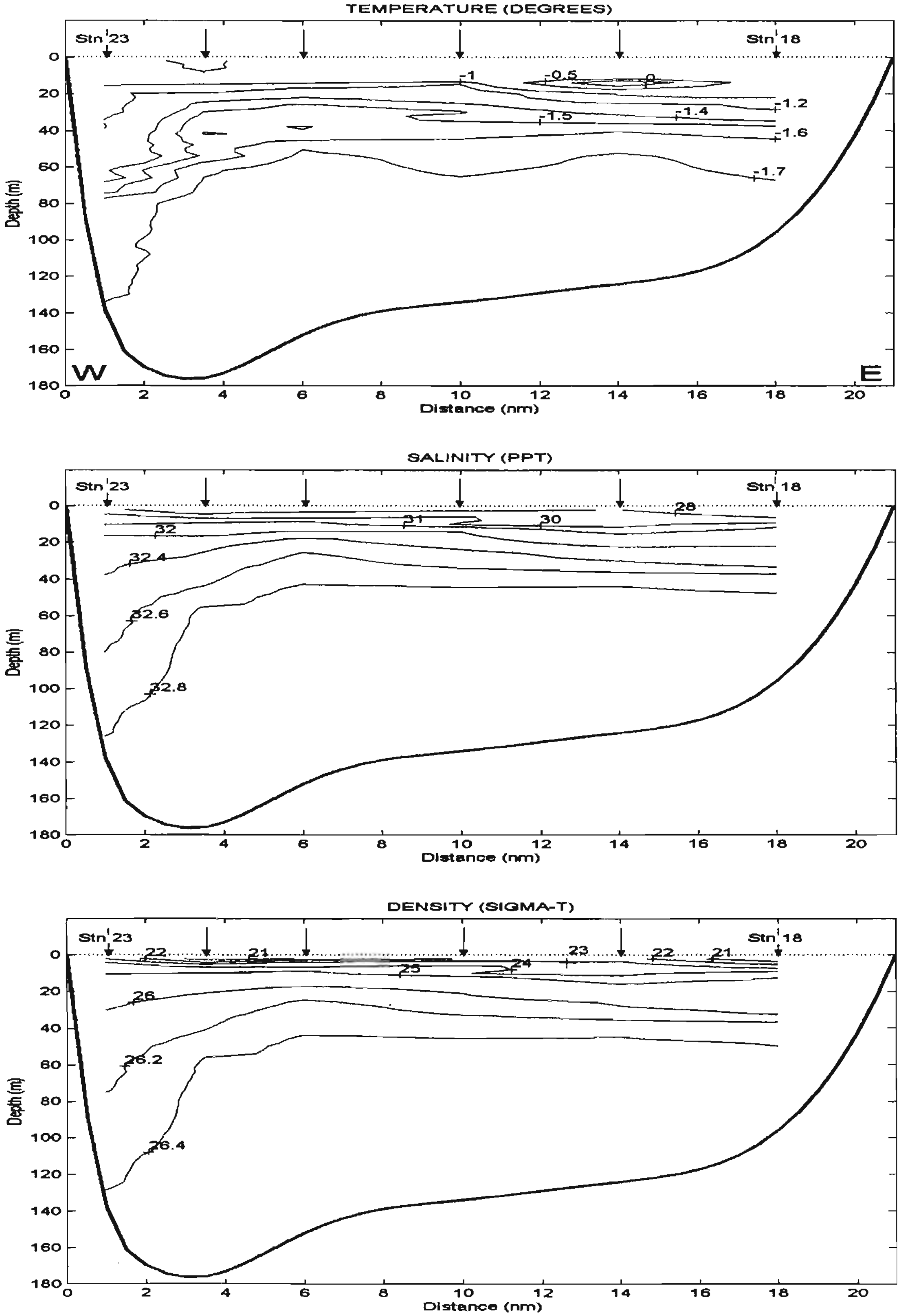


Figure 43 – Eastern Barrow Strait CTD line, Aug 21, 1999.

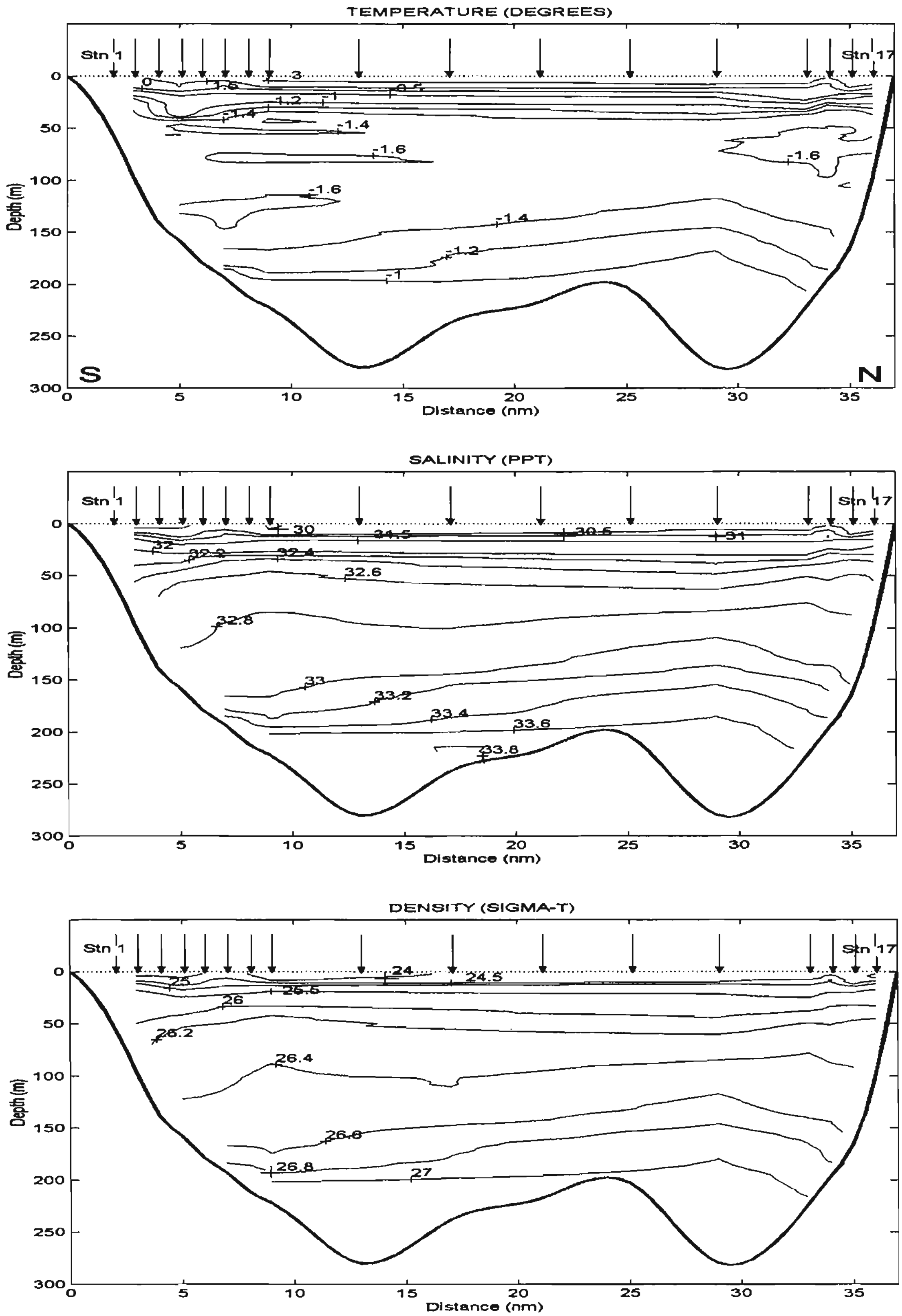


Figure 44 – Western Barrow Strait CTD line, Aug 20, 1999.

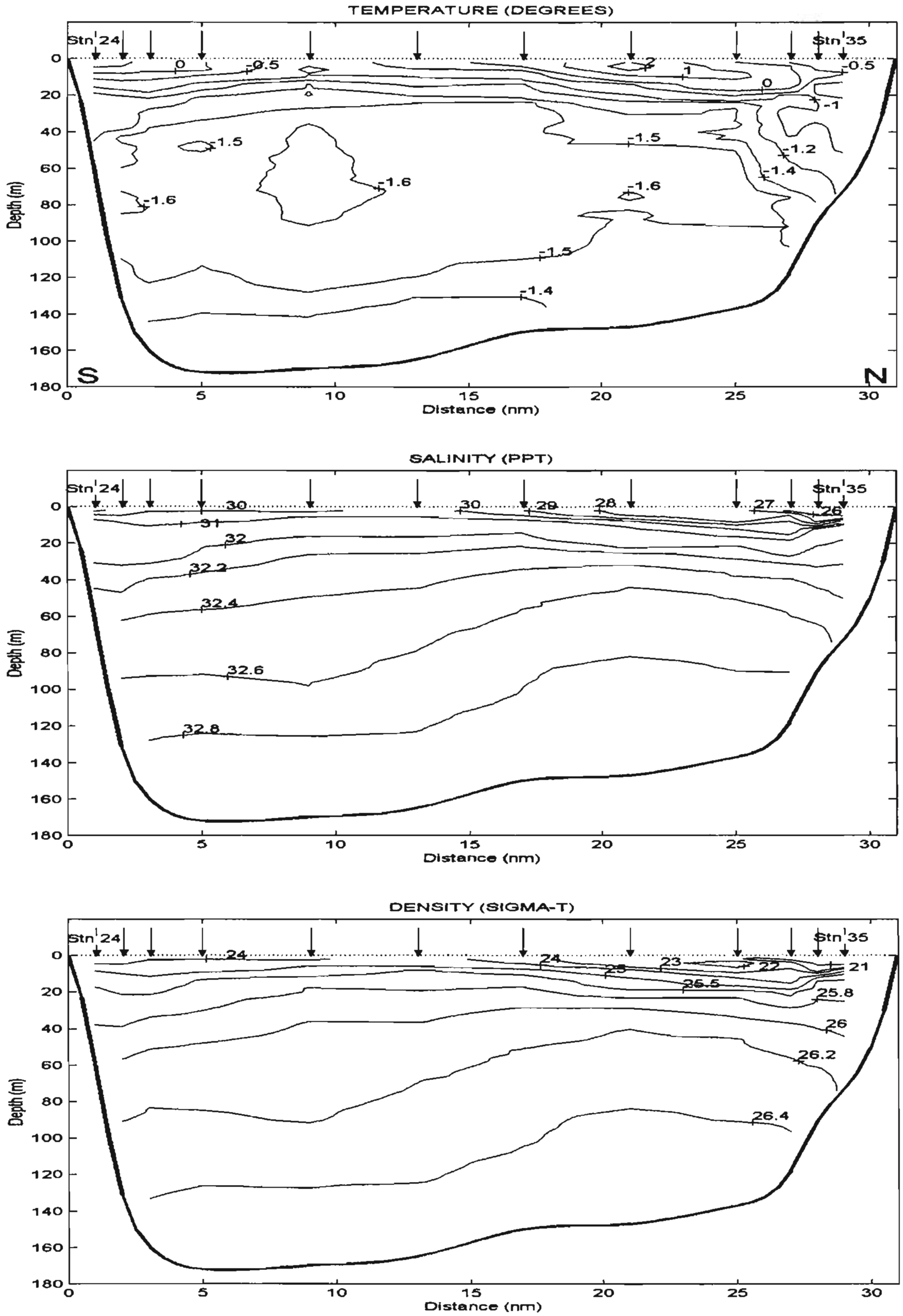


Figure 45 – Wellington Channel CTD line, Aug 19, 1999.

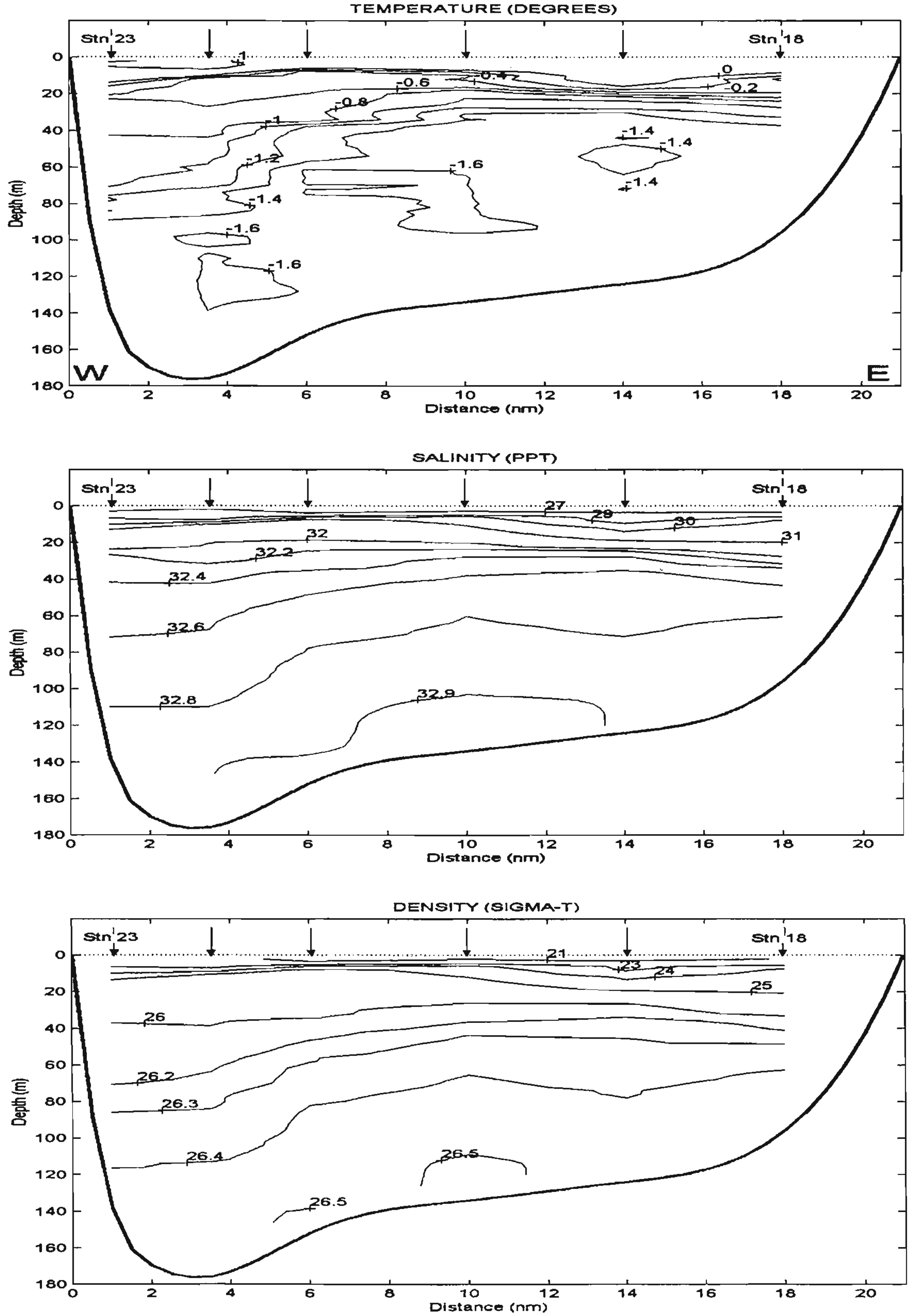


Table 1: North side Barrow Strait, CTD/ADCP statistical summary
Late Summer : 13/08/1998-20/09/1998

	Temperature (degrees C)				Salinity (ppt)				Density (sigma-t)				Along-Strait Velocity (cm/s)				Cross-Strait Velocity (cm/s)			
Depth m	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max
29	-0.12	1.40	-1.70	3.19	31.68	0.83	29.61	32.60	25.42	0.72	23.67	26.23	-15.28	23.24	-94.90	18.10	3.42	6.70	-25.50	31.10
38	-0.43	1.47	-1.71	3.02	31.91	0.76	30.25	32.72	25.62	0.68	24.14	26.33	-12.88	22.28	-90.60	20.80	2.97	5.53	-18.30	26.40
83	-1.61	0.08	-1.76	-1.25	32.71	0.14	32.07	32.93	26.32	0.11	25.79	26.50	-1.20	14.33	-40.90	37.60	-0.46	3.60	-11.90	13.00
148	-1.44	0.10	-1.66	-1.10	33.15	0.14	32.74	33.49	26.67	0.11	26.34	26.94	0.47	13.59	-43.00	34.90	-1.32	3.56	-12.90	9.70
178	-1.24	0.15	-1.58	-0.86	33.38	0.15	32.90	33.70	26.85	0.12	26.47	27.10								

Table 2: South side Barrow Strait, CTD/ADCP statistical summary
Late Summer : 13/08/1998-20/09/1998

	Temperature (degrees C)				Salinity (ppt)				Density (sigma-t)				Along-Strait Velocity (cm/s)				Cross-Strait Velocity (cm/s)			
Depth m	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max
31	-1.18	0.31	-1.59	0.03	32.10	0.27	30.98	32.72	25.81	0.23	24.86	26.32	16.65	21.63	-55.10	64.80	5.83	8.34	-19.20	37.50
44	-1.45	0.13	-1.63	-0.79	32.31	0.15	31.64	32.73	25.99	0.12	25.44	26.33	15.23	19.06	-38.20	67.90	5.13	7.71	-18.20	38.40
69	-1.58	0.06	-1.70	-1.21	32.60	0.10	32.33	32.85	26.22	0.08	26.00	26.43	12.75	18.31	-36.80	57.00	4.34	6.53	-16.70	31.90
81	-1.60	0.05	-1.71	-1.25	32.71	0.08	32.32	32.99	26.32	0.07	25.99	26.54	11.98	18.89	-42.19	51.35	4.21	6.85	-18.50	29.79
162													7.19	15.24	-34.73	40.05	2.61	7.90	-26.64	24.82
170	-1.35	0.31	-1.68	-0.80	33.17	0.32	32.70	33.68	26.68	0.25	26.31	27.08								

Table 3: North side Barrow Strait, CTD/ADCP statistical summary
Fall: 21/09/1998-20/12/1998

	Temperature (degrees C)				Salinity (ppt)				Density (sigma-t)				Along-Strait Velocity (cm/s)				Cross-Strait Velocity (cm/s)			
Depth m	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max
29	-1.01	1.09	-1.77	1.56	31.25	0.57	29.49	32.52	25.11	0.49	23.60	26.16	-6.01	17.77	-70.90	49.40	0.43	7.32	-30.80	29.70
38	-1.10	0.94	-1.78	1.38	31.48	0.48	30.23	32.64	25.30	0.41	24.21	26.26	-5.38	17.17	-67.60	45.70	-0.08	6.91	-29.50	29.60
83	-1.49	0.11	-1.65	-0.60	32.60	0.19	31.53	32.99	26.22	0.16	25.34	26.54	0.33	16.41	-65.90	47.60	-1.81	5.32	-30.10	21.60
148	-1.31	0.12	-1.63	-0.85	33.22	0.20	32.10	33.66	26.72	0.16	25.81	27.06	-1.50	15.27	-54.90	37.90	-1.21	4.01	-14.90	16.90
178	-1.17	0.15	-1.53	-0.75	33.42	0.19	32.82	33.74	26.88	0.15	26.40	27.12								

Table 4: South side Barrow Strait, CTD/ADCP statistical summary
Fall: 21/09/1998-20/12/1998

	Temperature (degrees C)				Salinity (ppt)				Density (sigma-t)				Along-Strait Velocity (cm/s)				Cross-Strait Velocity (cm/s)			
Depth m	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max
31	-1.50	0.33	-1.74	-0.45	31.64	0.30	30.03	32.43	25.44	0.24	24.12	26.08	6.59	17.73	-41.70	65.10	0.20	6.59	-22.80	36.40
44	-1.54	0.22	-1.74	-0.76	31.85	0.31	30.83	32.67	25.61	0.25	24.79	26.28	5.03	16.81	-42.10	67.50	0.12	6.06	-26.60	34.90
69	-1.51	0.06	-1.72	-1.26	32.45	0.21	31.62	32.99	26.10	0.17	25.43	26.53	1.56	15.94	-38.90	65.40	0.84	5.68	-17.80	24.20
81	-1.53	0.05	-1.65	-1.31	32.67	0.13	32.14	33.16	26.28	0.10	25.85	26.67	0.09	16.42	-39.29	57.75	1.29	6.79	-21.37	29.36
162													1.38	16.33	-45.07	44.27	1.67	8.63	-28.16	29.37
170	-0.98	0.24	-1.61	-0.49	33.54	0.22	32.87	33.87	26.97	0.17	26.44	27.21								

Table 5: North side Barrow Strait, CTD/ADCP statistical summary
Winter : 21/12/1998-20/03/1999

	Temperature (degrees C)				Salinity (ppt)				Density (sigma-t)				Along-Strait Velocity (cm/s)				Cross-Strait Velocity (cm/s)			
Depth m	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max
29	-1.74	0.05	-1.79	-1.52	32.46	0.17	31.97	32.69	26.11	0.14	25.72	26.30	0.01	10.91	-34.80	25.30	0.63	3.87	-12.20	15.00
38	-1.71	0.07	-1.79	-1.49	32.55	0.17	31.98	32.84	26.19	0.14	25.73	26.42	-1.07	11.48	-35.40	26.20	0.86	3.80	-13.10	14.10
83	-1.61	0.08	-1.78	-1.39	32.79	0.07	32.56	33.06	26.38	0.06	26.19	26.59	-4.38	13.03	-41.90	28.30	0.69	4.63	-14.20	19.20
148	-1.52	0.12	-1.70	-1.20	33.08	0.11	32.86	33.52	26.62	0.09	26.43	26.96	-3.34	13.86	-51.10	32.70	-0.03	5.27	-13.70	19.90
178	-1.39	0.15	-1.65	-0.91	33.26	0.14	32.95	33.65	26.76	0.11	26.51	27.05								

Table 6: South side Barrow Strait, CTD/ADCP statistical summary, Winter : 21/12/1998-20/03/1999.
Winter : 21/12/1998-20/03/1999

	Temperature (degrees C)				Salinity (ppt)				Density (sigma-t)				Along-Strait Velocity (cm/s)				Cross-Strait Velocity (cm/s)			
Depth m	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max
31	-1.72	0.04	-1.78	-1.48	31.81	0.27	30.93	32.40	25.59	0.22	24.87	26.06	5.73	12.95	-30.20	43.20	1.58	4.21	-10.60	16.70
44	-1.69	0.08	-1.78	-1.40	32.05	0.19	31.70	32.43	25.78	0.15	25.49	26.09	5.47	13.70	-34.40	44.90	1.72	4.57	-11.00	19.80
69	-1.56	0.11	-1.78	-1.38	32.42	0.12	31.79	32.68	26.08	0.10	25.57	26.29	4.94	15.65	-43.00	47.00	2.23	5.97	-14.40	21.90
81	-1.54	0.10	-1.77	-1.39	32.55	0.10	32.06	32.82	26.19	0.08	25.79	26.41	7.09	16.57	-39.50	56.72	2.16	6.37	-18.64	25.68
162													4.41	16.19	-47.26	40.52	1.65	8.74	-34.78	26.69
170	-1.18	0.20	-1.55	-0.60	33.33	0.24	32.78	33.81	26.81	0.19	26.37	27.17								

Table 7: North side Barrow Strait, CTD/ADCP statistical summary
Spring : 21/03/1999-20/06/1999

	Temperature (degrees C)				Salinity (ppt)				Density (sigma-t)				Along-Strait Velocity (cm/s)				Cross-Strait Velocity (cm/s)			
Depth m	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max
29	-1.75	0.02	-1.77	-1.60	32.10	0.10	31.81	32.42	25.83	0.08	25.58	26.08	0.70	10.04	-26.80	26.00	0.51	3.22	-9.30	11.80
38	-1.73	0.03	-1.77	-1.54	32.28	0.14	32.00	32.58	25.97	0.12	25.74	26.21	0.91	11.31	-30.60	30.90	0.32	3.75	-11.60	13.90
83	-1.65	0.06	-1.77	-1.48	32.72	0.05	32.61	32.91	26.32	0.04	26.23	26.48	4.18	12.45	-27.70	39.00	-0.20	4.08	-16.50	12.00
148	-1.37	0.11	-1.61	-1.10	33.23	0.13	32.88	33.48	26.73	0.10	26.45	26.93	-0.16	13.63	-42.40	36.10	0.17	4.11	-10.60	14.40
178	-1.11	0.13	-1.54	-0.67	33.47	0.10	33.11	33.76	26.92	0.07	26.64	27.14								

Table 8: South side Barrow Strait, CTD/ADCP statistical summary
Spring : 21/03/1999-20/06/1999

	Temperature (degrees C)				Salinity (ppt)				Density (sigma-t)				Along-Strait Velocity (cm/s)				Cross-Strait Velocity (cm/s)			
Depth m	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max
31	-1.72	0.03	-1.77	-1.62	32.13	0.11	31.79	32.40	25.85	0.09	25.57	26.07	6.02	10.79	-26.50	36.50	2.43	4.57	-13.30	23.30
44	-1.70	0.03	-1.77	-1.58	32.28	0.11	31.95	32.60	25.97	0.09	25.70	26.23	5.86	11.64	-28.70	37.70	2.25	4.78	-14.00	20.50
69	-1.68	0.05	-1.77	-1.49	32.53	0.06	32.33	32.69	26.17	0.05	26.01	26.30	5.06	13.45	-30.20	39.90	2.05	5.27	-15.20	17.80
81	-1.67	0.07	-1.77	-1.45	32.59	0.06	32.40	32.74	26.22	0.05	26.06	26.34	7.48	13.98	-31.18	38.39	2.37	5.93	-16.41	18.18
162													3.35	14.07	-36.76	36.20	1.80	8.41	-30.22	23.19
170	-1.30	0.15	-1.52	-0.81	33.15	0.22	32.75	33.67	26.67	0.18	26.35	27.06								

Table 9: North side Barrow Strait, CTD/ADCP statistical summary
Summer : 21/06/1999-15/08/1999

	Temperature (degrees C)				Salinity (ppt)				Density (sigma-t)				Along-Strait Velocity (cm/s)				Cross-Strait Velocity (cm/s)			
Depth m	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max
29	-1.48	0.33	-1.76	0.09	32.08	0.38	29.80	32.54	25.80	0.31	23.95	26.18	-3.21	14.10	-49.20	25.40	1.92	5.47	-21.40	30.30
38	-1.54	0.29	-1.76	-0.04	32.26	0.33	30.81	32.75	25.95	0.28	24.73	26.35	-2.32	13.75	-40.60	32.50	1.95	5.00	-13.90	29.40
83	-1.62	0.05	-1.74	-1.46	32.81	0.06	32.59	32.96	26.40	0.05	26.22	26.52	1.36	15.59	-41.40	41.90	0.83	4.15	-9.30	16.60
148	-1.31	0.11	-1.52	-1.04	33.29	0.12	32.95	33.55	26.78	0.09	26.51	26.98	-3.35	15.89	-56.50	34.20	0.09	4.68	-12.80	15.50
178	-1.06	0.17	-1.44	-0.63	33.49	0.13	33.09	33.76	26.93	0.10	26.62	27.13								

Table 10: South side Barrow Strait, CTD/ADCP statistical summary
Summer : 21/06/1999-15/08/1999

	Temperature (degrees C)				Salinity (ppt)				Density (sigma-t)				Along-Strait Velocity (cm/s)				Cross-Strait Velocity (cm/s)			
Depth m	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max
31	-1.54	0.30	-1.76	0.01	32.20	0.18	31.54	32.59	25.90	0.15	25.31	26.22	13.64	14.47	-35.40	47.50	6.01	6.20	-13.90	25.70
44	-1.61	0.16	-1.77	-0.41	32.36	0.13	31.78	32.68	26.03	0.10	25.52	26.29	12.82	15.17	-35.30	49.10	5.64	5.84	-13.80	25.50
69	-1.61	0.07	-1.77	-1.40	32.58	0.08	32.34	32.78	26.21	0.06	26.01	26.37	11.66	15.27	-37.70	48.10	4.54	5.48	-14.10	19.40
81	-1.61	0.08	-1.77	-1.42	32.65	0.06	32.46	32.84	26.27	0.05	26.11	26.42	11.53	14.56	-29.66	46.99	3.98	5.67	-16.31	19.16
162													6.99	14.84	-38.41	39.86	2.31	8.64	-37.63	21.93
170	-1.35	0.19	-1.63	-0.72	32.99	0.26	32.72	33.68	26.53	0.20	26.32	27.08								

Table 11: North side Barrow Strait, CTD/ADCP statistical summary
Year : 13/08/1998-12/08/1999

	Temperature (degrees C)				Salinity (ppt)				Density (sigma-t)				Along-Strait Velocity (cm/s)				Cross-Strait Velocity (cm/s)			
Depth m	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max
29	-1.35	0.89	-1.79	3.19	31.93	0.62	29.49	32.69	25.67	0.53	23.60	26.30	-3.44	15.64	-94.90	49.40	1.05	5.47	-30.80	31.10
38	-1.41	0.80	-1.79	3.02	32.11	0.56	30.23	32.84	25.82	0.47	24.14	26.42	-3.07	15.33	-90.60	45.70	0.88	5.19	-29.50	29.60
83	-1.59	0.10	-1.78	-0.60	32.72	0.14	31.53	33.06	26.32	0.11	25.34	26.59	-0.02	14.80	-65.90	47.60	-0.29	4.67	-30.10	21.60
148	-1.39	0.14	-1.70	-0.85	33.19	0.16	32.10	33.66	26.70	0.13	25.81	27.06	-1.70	14.50	-56.50	37.90	-0.40	4.47	-14.90	19.90
178	-1.20	0.19	-1.65	-0.63	33.40	0.17	32.82	33.76	26.86	0.13	26.40	27.14								

Table 12: South side Barrow Strait, CTD/ADCP statistical summary
Year : 13/08/1998-12/08/1999

	Temperature (degrees C)				Salinity (ppt)				Density (sigma-t)				Along-Strait Velocity (cm/s)				Cross-Strait Velocity (cm/s)			
Depth m	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max
31	-1.58	0.28	-1.78	0.03	31.94	0.32	30.03	32.72	25.69	0.26	24.12	26.32	8.35	15.66	-55.10	65.10	2.56	6.18	-22.80	37.50
44	-1.62	0.16	-1.78	-0.41	32.13	0.28	30.83	32.73	25.84	0.23	24.79	26.33	7.60	15.41	-42.10	67.90	2.39	5.94	-26.60	38.40
69	-1.59	0.10	-1.78	-1.21	32.49	0.15	31.62	32.99	26.14	0.12	25.43	26.53	5.96	15.95	-43.00	65.40	2.40	5.88	-17.80	31.90
81	-1.59	0.09	-1.77	-1.25	32.62	0.11	32.06	33.16	26.24	0.09	25.79	26.67	6.33	16.87	-42.19	57.75	2.47	6.52	-21.37	29.79
162													4.06	15.55	-47.26	44.27	1.89	8.54	-37.63	29.37
170	-1.20	0.26	-1.68	-0.49	33.27	0.31	32.70	33.87	26.76	0.24	26.31	27.21								

Table 13 - Tidal Constants for K1 constituent

North Side

For ice-free period (Aug 10, 1998 to Oct 20, 1998):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
14	7.8	-0.8	159	350
58	10.1	0.0	163	313
102	12.2	0.6	160	307
150	12.4	0.5	156	312

For solid-ice period (Feb 11, 1999 to Jul 17, 1999):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
18	6.8	1.3	167	300
58	9.9	0.7	158	304
102	12.1	0.9	153	305
150	14.1	1.1	149	311

South Side

For ice-free period (Aug 10, 1998 to Oct 20, 1998):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
9	8.0	-0.5	171	354
69	10.6	1.7	161	348
102	11.0	1.9	155	335
162	13.9	0.8	145	332

For solid-ice period (Feb 11, 1999 to Jul 17, 1999):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
9	5.2	1.4	180	350
69	10.6	1.3	151	335
102	10.8	1.4	150	330
162	13.7	1.4	138	321

Table 14 - Tidal Constants for M2 constituent

North Side

For ice-free period (Aug 10, 1998 to Oct 20, 1998):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
14	8.3	0.4	159	179
58	8.7	0.3	162	181
102	8.5	0.2	159	182
150	8.3	-0.3	161	180

For solid-ice period (Feb 11, 1999 to Jul 17, 1999):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
18	4.9	2.4	164	167
58	9.5	-1.0	164	175
102	8.8	-0.1	158	173
150	8.5	-0.1	156	171

South Side

For ice-free period (Aug 10, 1998 to Oct 20, 1998):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
9	5.7	0.7	169	216
69	8.7	-1.2	167	205
102	8.3	-1.1	165	209
162	7.3	-1.7	164	214

For solid-ice period (Feb 11, 1999 to Jul 17, 1999):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
9	1.8	1.2	229	258
69	9.5	-3.1	167	200
102	9.1	-2.5	167	194
162	7.3	-1.5	180	202

Table 15 - Tidal Constants for O1 constituent

North Side

For ice-free period (Aug 10, 1998 to Oct 20, 1998):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
14	5.8	0.3	157	298
58	3.7	0.6	166	267
102	4.7	0.3	159	255
150	4.9	0.0	159	259

For solid-ice period (Feb 11, 1999 to Jul 17, 1999):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
18	3.1	0.3	160	257
58	4.1	0.3	156	251
102	4.2	0.6	152	246
150	5.1	0.4	153	249

South Side

For ice-free period (Aug 10, 1998 to Oct 20, 1998):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
9	3.8	-0.8	173	291
69	4.7	0.7	157	290
102	4.6	0.5	154	287
162	6.4	0.8	142	267

For solid-ice period (Feb 11, 1999 to Jul 17, 1999):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
9	1.9	0.8	155	283
69	4.7	0.6	153	277
102	4.1	0.9	150	272
162	6.5	0.6	141	268

Table 16 - Tidal Constants for P1 constituent

North Side

For ice-free period (Aug 10, 1998 to Oct 20, 1998):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
14	1.8	-0.2	161	316
58	3.1	-0.2	164	288
102	3.7	0.1	160	297
150	4.0	0.7	149	301

For solid-ice period (Feb 11, 1999 to Jul 17, 1999):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
18	2.3	0.6	158	275
58	3.0	0.6	156	290
102	4.0	0.7	156	315
150	4.3	0.9	159	322

South Side

For ice-free period (Aug 10, 1998 to Oct 20, 1998):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
9	2.3	-1.2	167	337
69	2.8	0.8	160	336
102	3.7	0.7	153	323
162	3.2	0.5	160	335

For solid-ice period (Feb 11, 1999 to Jul 17, 1999):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
9	2.1	0.5	178	331
69	3.6	0.4	149	323
102	3.4	0.4	141	314
162	4.2	0.7	139	314

Table 17 - Tidal Constants for S2 constituent

North Side

For ice-free period (Aug 10, 1998 to Oct 20, 1998):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
14	4.7	-0.1	168	222
58	3.6	0.1	167	227
102	3.2	0.5	158	224
150	3.9	-0.3	157	218

For solid-ice period (Feb 11, 1999 to Jul 17, 1999):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
18	3.1	0.7	160	201
58	3.5	0.1	170	222
102	3.0	-0.2	157	217
150	3.1	-0.9	148	215

South Side

For ice-free period (Aug 10, 1998 to Oct 20, 1998):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
9	3.0	-0.2	184	283
69	3.5	-0.5	171	252
102	4.0	-1.2	162	248
162	4.0	-0.6	157	256

For solid-ice period (Feb 11, 1999 to Jul 17, 1999):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
9	0.8	0.3	201	283
69	3.3	-0.9	177	243
102	3.2	-0.7	175	243
162	2.9	-0.3	182	247