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MOORED CURRENT METER AND CTD OBSERVATIONS FROM BARROW STRAIT, 1999-2000

by

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Abstract

Hamilton, J., S. Prinsenberg and L. Malloch. 2003. Moored current meter and CTD observations from Barrow Strait, 1999-2000. Can. Data Rep. Hydrogr. Ocean Sci. 161 : v + 60 p.

An array of 9 instrumented moorings deployed in the eastern end of Barrow Strait from August 1999 to August 2000 provides yearlong records of current, ice drift, temperature and salinity that extend a data time series started in August of 1998. 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 2000 are also presented.

Résumé

Hamilton, J., S. Prinsenberg and L. Malloch. 2003. Moored current meter and CTD observations from Barrow Strait, 1999-2000. Can. Data Rep. Hydrogr. Ocean Sci. 161 : v + 60 p.

Entre août 1999 et août 2000, une batterie de neuf stations instrumentales ancrées dans l'embouchure est du détroit de Barrow a enregistré des données sur le courant, la dérive de la glace, et la température et la salinité de l'eau. Ces douze mois de données prolongent une série analogue débutée en août 1998. Nous présentons les cartes de contour des observations prises à toutes les trente minutes par des profileurs de courant à effet Doppler et des instruments spécialisés pour la mesure des directions près du pôle. Nous présentons également des cartes de contour de ces mêmes données après leur lissage. Nous faisons l'analyse de marée des données sur le courant. Nous présentons les graphiques des données aux trente minutes et des données lissées de la température, de la salinité et de la densité, mesurées avec les sondes CTP ancrées, ainsi que leur spectre de fréquence. Nous donnons les résultats statistiques suivants : les moyennes, les extrêmes et les écarts-types de tous les paramètres mesurés.

Nous présentons également les coupes transversales de conductivité, température et densité pour les détroits de Barrow et de Wellington produites à partir de données obtenues en 2000, sur des navires.

Introduction

A field 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, was started by BIO investigators in August of 1998. Data from the first year of this study, along with a description of the methods used, have previously been reported [Hamilton et al., 2002]. The moored instrument and ship-based CTD data from the second year of the study are described here.

Yearlong records of current rate and direction, ice drift, temperature, salinity and density from Barrow Strait are presented as unfiltered and low-pass filtered time series plots along with relevant statistical summaries for each season. The moored CTD data are also presented as power spectra. Tidal amplitudes, phases and ellipse orientations as a function of depth are presented 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 6 week 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 (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 measure current rate and direction. A unique strategy was required to obtain reliable direction measurements in this area because of its proximity to the magnetic pole. It is described in detail by Hamilton

[2001]. Two current measurement systems were moored about 1.4 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 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.

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 over the yearlong deployment. Concurrent direction measurements were logged separately with the precision heading reference system, and have been merged with the ADCP speed data for presentation here. The moored CTDs recorded a single temperature, conductivity and pressure observation every hour.

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. These data are compared to data from the NRCAN Geomagnetic Observatory at Resolute that we have used to correct the current direction data for the variation in magnetic declination. This check is to ensure that localized geomagnetic effects do not introduce errors in the transformation of the declination measurements from the Resolute Observatory to the mooring site.

The shallowest mooring on the North side supporting a single MicroCat CTD at 23 m depth was lost; presumably dragged away by ice. All other instrumentation (4 ADCP/compass systems and 9 CTDs) was successfully recovered. The ADCPs and CTDs all provided good quality data for the entire deployment period. However, compass sensor problems limit the quantity and quality of the direction data acquired with both ADCP/compass systems on the South side of the Strait.

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 shallowest 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. Initiation of a compass sample cycle was triggered by the commencement of the bi-hourly ADCP measurement by making use of RDI’s “RDS3 interface” to provide a turn-on pulse to the compass. The compass was programmed to take a 10 s sample at the beginning, the middle, and the end of the 5 minute ADCP sampling interval. This conserved compass battery power, while providing a check to ensure that SUB direction did not change significantly over the 5 minute sampling period. Looking at the yearlong records from the working compasses, the standard deviation computed for the 3 direction measurements taken in a 5 minute sample period was less than 5°, 96% of the time. Based on this analysis, the direction measurement taken in the middle of the 5 minute ADCP sample was used with confidence.

Direction records were then corrected for the variation in magnetic declination using magnetic observatory data from the NRCAN observatory in Resolute. To verify that no geomagnetic anomalies produce localized effects that might effect the accuracy of the transformation technique used [Hamilton, 2001], a comparison of the declination at the mooring site computed from Resolute observatory data to the anchor mounted compass data was made. The period of worst agreement over the yearlong deployment is shown in Figure 3. Over the entire year, the average difference between the two is 0.06 degrees, and the standard deviation of the difference is only 0.6 degrees.

The shallow (79 m) ADCP/Pole compass system on the South side of the Strait did not provide reliable direction data due to a compass EEPROM memory corruption problem. To ascribe a direction to this system, current direction for the deepest bin is taken from the bi-hourly current directions from the corresponding bin of the nearby ADCP/pole compass system moored at 166 m depth, or the nearest bin for which there is reliable rate data. Even if this nearest reliable bin is as much as 20 m deeper, current direction changes with depth through the middle part of the water column at this site are small, so any errors introduced will also be small [Hamilton et al., 2002].

There were also problems with the compass in the deep South-side system though. This compass was intermittent, providing direction for only 80% of the ADCP rate measurements, and failed completely in early February. No current information for the South side is presented after this February failure.

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 6 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 hour for the yearlong deployments. Moorings supporting the ~25 m CTDs were subjected to the greatest dip due to current drag forces acting on the mooring. For the mooring supporting the shallowest CTD on the South side (the equivalent on the North side was lost), excursions were typically small, with the standard deviation in instrument depth over the yearlong deployment being 1 m. (Note that tidal height variation makes a contribution to this variation.) Large excursions of up to 11 m occurred as rare, short duration events.

Post-deployment calibration of the MicroCat CTDs was done by lowering them with a SBE25 CTD. Comparing values after the sensors were allowed to stabilise at 22m depth gave an average difference and standard deviation relative to the SBE25 of 0.014 ppt ± 0.024 for salinity, and –0.0030° ± 0.0148 for temperature.

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, the hourly MicroCat CTD data have been decimated to match the bihourly sampling of currents, and averaging filters of 12 and 13 samples are then applied to all the data sets.

Tidal Analysis

Harmonic tidal analysis of North side current data using Foreman's (1978) method is presented separately for a 190 day period of solid ice cover, and a 46 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 Survey

Three lines consisting of 35 CTD stations in total were completed over August 6-10, 2000 (Figure 1). The instrument used was a portable SeaBird SBE25 CTD with pumped conductivity cell and temperature sensor. Data were sampled and stored at 8 Hz. Standard SeaBird processing is used, and data are binned to 0.5 m.

Data Presentation

Yearlong time series of hourly temperature, salinity and density from the moored CTDs are shown in Figures 4 and 5. A warming and freshening of the top 50 m occurs in late-summer, as in the previous year [Hamilton et. al., 2002]. The signal is similar for the 2 years on the South side, but the extent of the warming and freshening on the North side is not as great as in the previous year, when the density at the 39 m level was 1 kg/m^3 lower over much of the September to November period. As in 1998-1999, temperatures in the upper water column drop back to near-freezing values in early fall, but it is not until early January that salinity increases to typical winter values. Warmer, saltier Atlantic water is again detected by the deep instruments on both sides of the Strait, but unlike the previous year, the deep intrusions on the South side cease in early May.

Power spectra of the moored CTD measurements are shown in Figures 6 and 7. Results from the South side instruments are similar to those from 1998-1999. Temperature variance at tidal frequencies is low except at the deepest instrument. Stronger tidal signals are seen in salinity and density from all instruments, with the ratio in the variance at the diurnal (K1) versus semi-diurnal (M2) frequencies ranging from about 1 to 4 depending on instrument depth.

On the North side, variance in temperature, salinity and density in the semi-diurnal band is typically an order of magnitude smaller than in the diurnal band, and less than in 1998-1999. For example, at the 39 m level on the North side, the energy in the semi-diurnal band is 1/3 of what it was in the previous year.

Large signals in the diurnal band at the deep instruments suggest a periodic vertical displacement of water caused by interaction between topography and the K1 tide. Obtaining a standard deviation from the spectral estimate for salinity in the diurnal band and computing an average salinity gradient from the 81 m and 168 m level CTDs, an amplitude of 11 m is calculated. This is an order of magnitude larger than the vertical displacements generated from tides, or any instrument excursion resulting from mooring dip.

Current data are shown as contour plots in Figures 8-11. Data from the deep and mid-water ADCPs (moored about 1.4 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 8 and 9 display two months of unsmoothed data, revealing both the tidal and lower frequency character of the flow. The white striping in Figure 8 is caused by missing data due to the intermittent behaviour of the compass in the 166 m system on the South side.

Low-pass filtered data (tides removed) are shown in Figures 10 and 11. To produce a useful filtered result for the South side data set, missing points in the bi-hourly data caused by the intermittent compass have been filled by linear interpolation. No data past January are available for the South side because of complete compass failure at that point. Mean flow is predominantly eastward on the South side of the Strait, characterised by 5-10 day episodic events that suggest meteorological forcing as the mechanism. On the North side the low-pass filtered along-strait flow frequently reverses, with 5-10 day periods of westward flow occurring as often as periods of eastward flow.

Missing data near the surface from mid-winter through to late spring (Figure 11) 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. Filling the bihourly data by interpolation has not been attempted here, because of the quantity of missing points.

Smoothed temperature, salinity and current data are shown for each moored CTD level in Figures 12-21. Current time series for the South side extend only to the end of January because of the compass failure discussed earlier. No CTD data are available for the 26 m level on the North side because of the loss of that instrument. The extended period of no current data in Figure 19 is 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 again reaches its maximum in late summer (Figures 12, 13 and 18), but the average upper water column temperature on the North side is 0.6° colder than in the previous year and the mean westerly current is 30% weaker (see Table 1 values from this and the Hamilton [2002] report). In contrast to the upper water column, temperatures from the deep instruments on the North side are warmer in 1999-2000 than in the previous year, with a mean that is 0.5° higher through the winter, and 0.2° warmer in spring.

On the South side the late summer mean easterly current is nearly twice as strong as in the previous year. It is not until the fall that the upper water column is at its freshest, as seen in the shallow CTD record from the South side (Figure 12).

Annual and seasonal mean flows are summarised in Figures 22-27. (Note that what is presented in Figure 22 as the annual mean flow for the South side is an average of just 5½ months data.) For clarity, only every fifth ADCP depth bin has been used to generate the graphs. The pattern of a predominately eastward flow on the south side of the Strait, with a weaker westward flow on the north side is consistent with the previous year's observations, but the eastward flow in 1999-2000 is substantially higher. Mean along-strait flows on the South side are about twice as high from deployment right through to February when the compass system failed, compared to 98-99. The magnitude of the westward flow on the North side is also slightly diminished.

The variance in the bihourly, and low-pass filtered current data for the entire ADCP records are shown in Figure 28. (No values for the filtered data on the South side are presented because smoothing required filling in of the bihourly data using linear interpolation to deal with the intermittent compass. Statistics on the resulting record would therefore be suspect.) Looking at the North side result, it can be seen that tides account for over half of the total variance in the along-strait current speeds.

Tidal analysis results on the ADCP data collected on the Northern side of the Strait are presented as profiles for the 5 largest tidal constituents in Figures 29 - 33. Separate analyses have been done for ice-free and solid ice periods. The K1 and M2 constituents are comparable in magnitude, and ellipse orientations are generally along-strait as expected. 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 34 and 35. 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. The records indicate that ice had stopped moving by mid-December, which is 2 months earlier than in the previous year. In 2000, the start of ice break-up was about 10 days earlier than in 1999.

Results of the August, 2000 ship-based CTD survey along the 3 lines shown in Figure 1 are shown as contoured sections in Figures 36 - 38. Stations are shown as the downward pointing arrows at the surface. Based on the moored MicroCat data, density variation at a particular level over a K1 tidal period in August is ±0.15 kg/m^3 in the top 50 m, and ±0.05 kg/m^3 at mid-depth. If these variations are ascribed to vertical displacement, then given the observed vertical gradients, isopycnal displacement amplitudes of about ±10 m are calculated. Since individual CTD lines took up to 2 days to complete there is a corresponding ±10 m “noise” on the contours shown, but generally, isopycnal slopes are steep enough that Figures 36 – 38 are useful for qualitatively identifying geostrophic flows.

At the eastern end of Barrow Strait, the slope of the isopycnals in Figure 36 indicates geostrophic flow on the South side is eastward, decreasing with depth, and westward on the North side. The density distribution was similar in 1998, but in 1999 the isopycnals were generally level (see Figures 40 and 43 of Hamilton et al. [2002]).

At the western end of Barrow Strait flow is eastward across most of the Strait, with a narrow band of stronger current along the coast at the North side (see Figure 37). In 1998 the isopycnals in western Barrow Strait were fairly level in the upper 1/3 of the water column, undulating at mid-depth and sloping downward from North to South below 100 m. In 1999, the indication is westward flow in the northern third of the Strait, and eastward flow in the southern 2/3 (see Figures 41 and 44 of Hamilton et al. [2002]).

In Wellington Channel, the CTD section suggests a northward geostrophic flow on the western and central parts of the channel. This is in contrast to what was the case in 1998 and 1999. The contoured CTD lines from those years (Figures 42 and 45 from Hamilton et al. [2002]) indicate a southward geostrophic flow on the western side and a weaker northward flow on the eastern side.

Acknowledgements

We thank Brian Petrie for his valuable input on this report, and Dave Greenberg, who along with Brian provided internal review. We also thank Larry Newitt (NRCAN) for providing the Resolute Observatory magnetic declination data.

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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.

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).

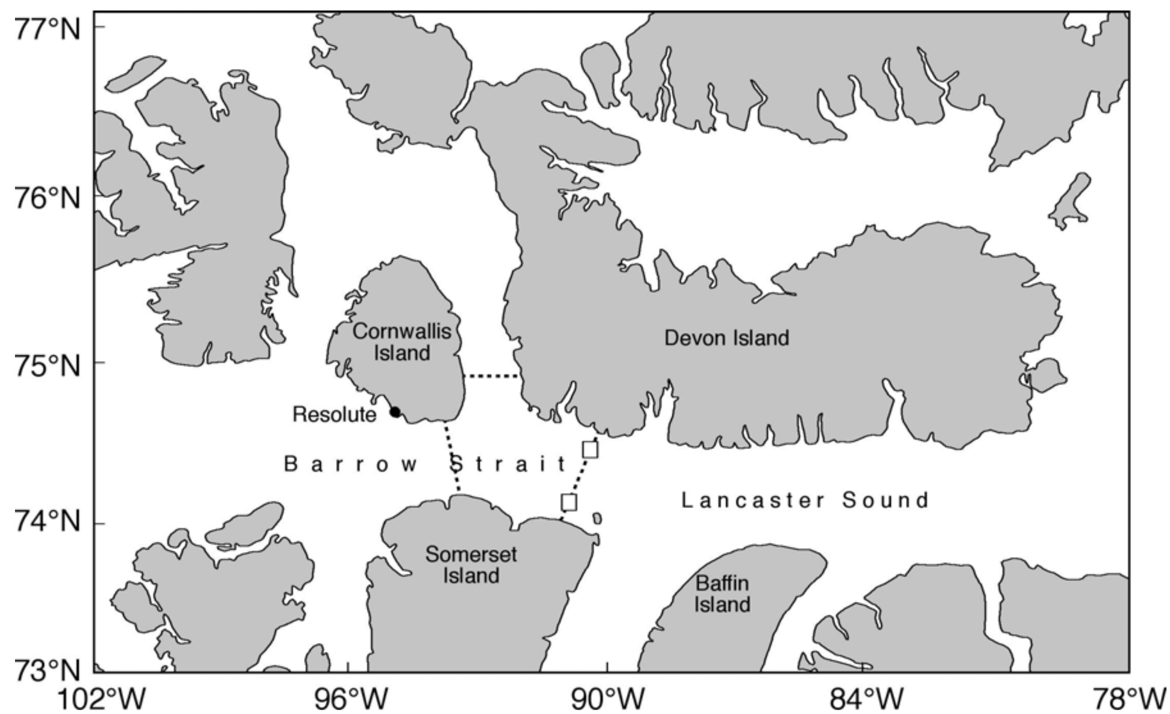
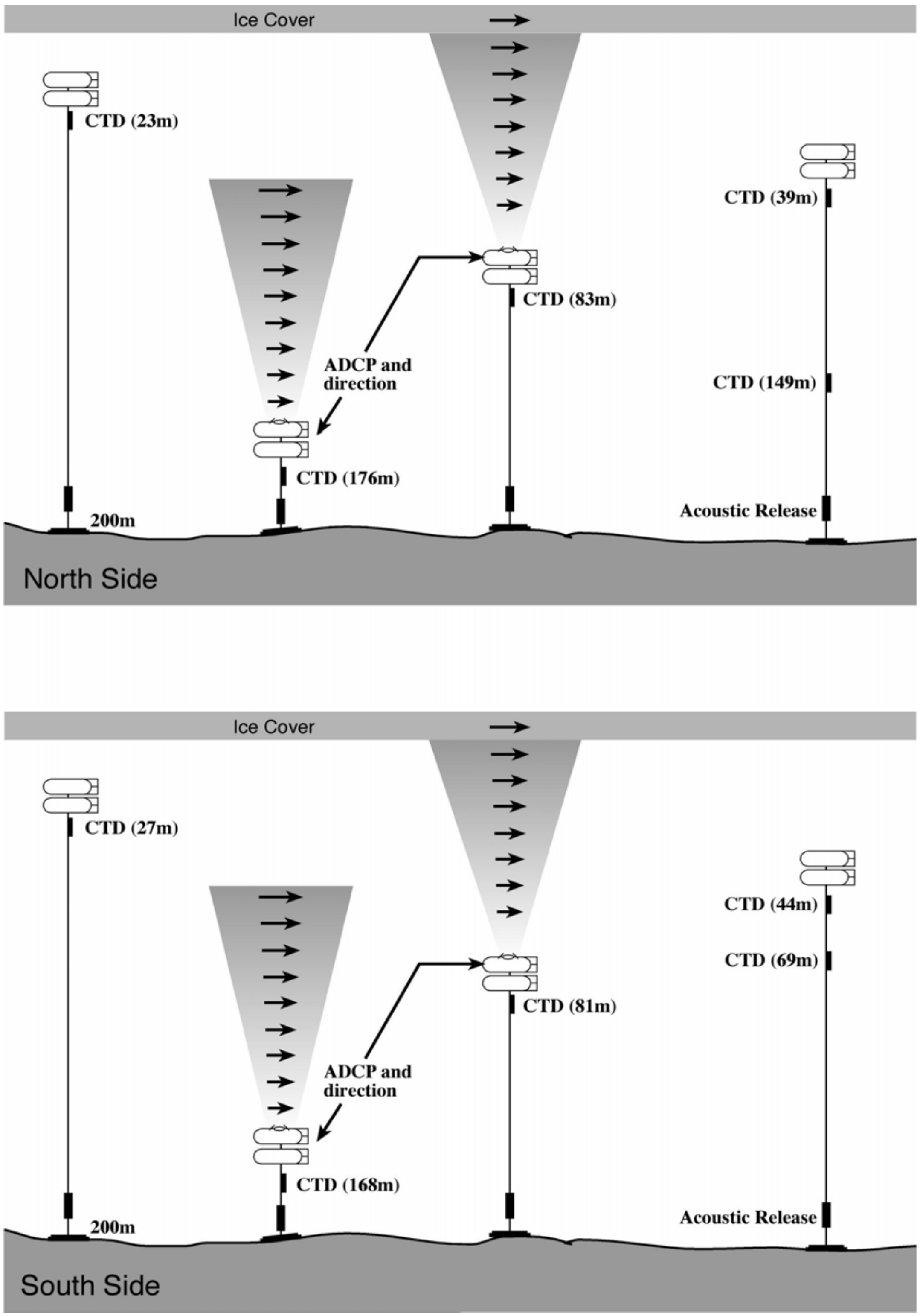


Figure 2. Illustration of the instrumented moorings deployed around the 200 m contour on both sides of Barrow Strait. A ninth mooring (not shown) was deployed to measure the variation



in the position of the North magnetic pole.

Figure 3 - The variation in declination as measured with the anchor-mounted compass, compared to that calculated from Resolute Geomagnetic Laboratory data (NRCAN).

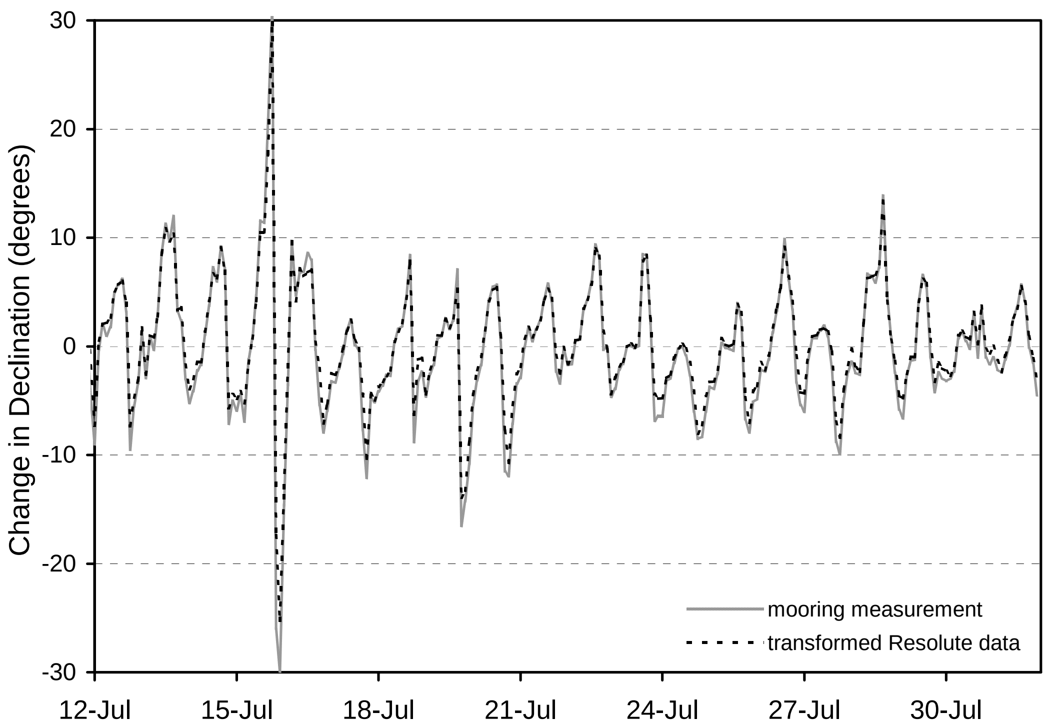


Figure 4 - Moored bihourly CTD data from South side of Barrow Strait: Aug 1999 - Aug 2000.

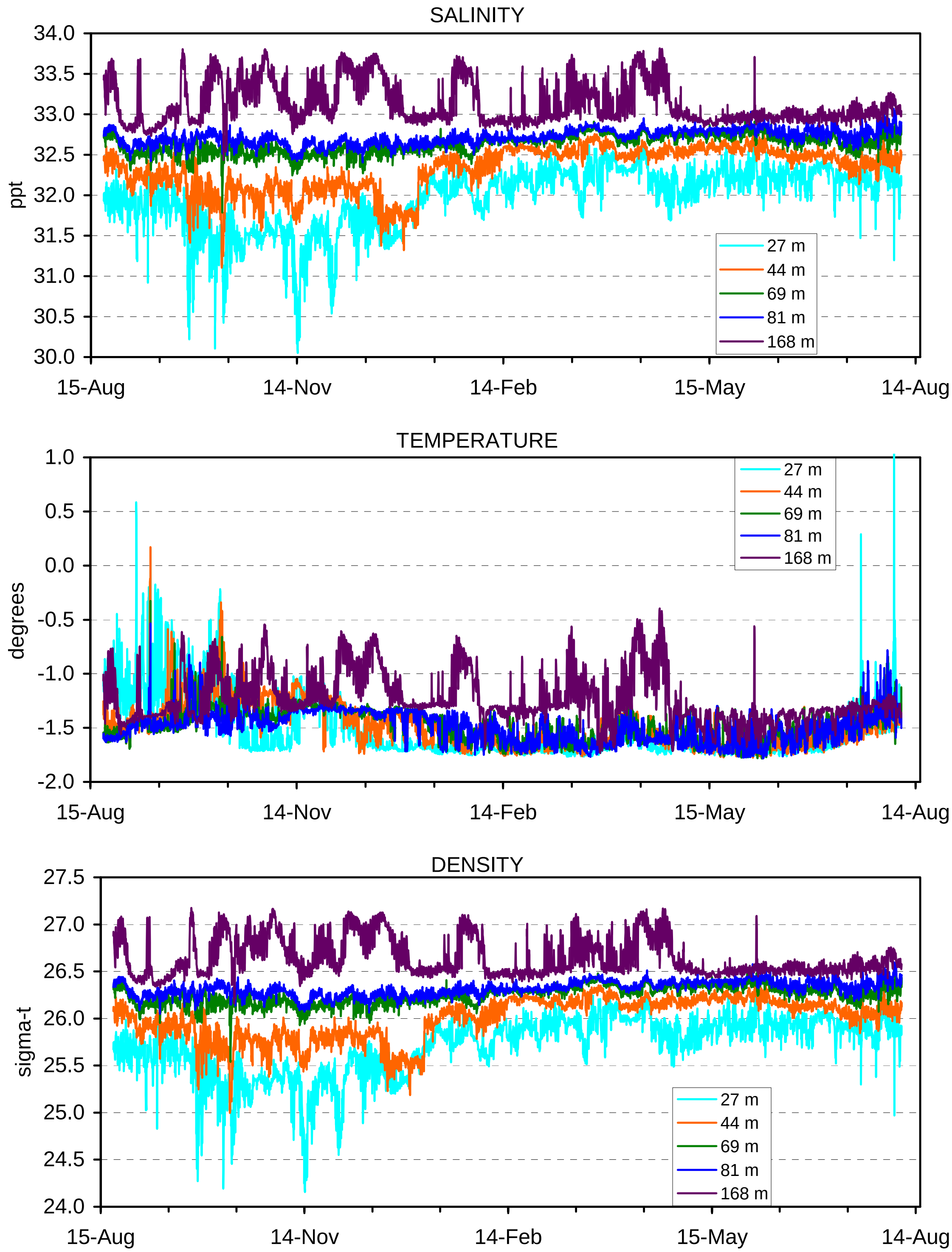
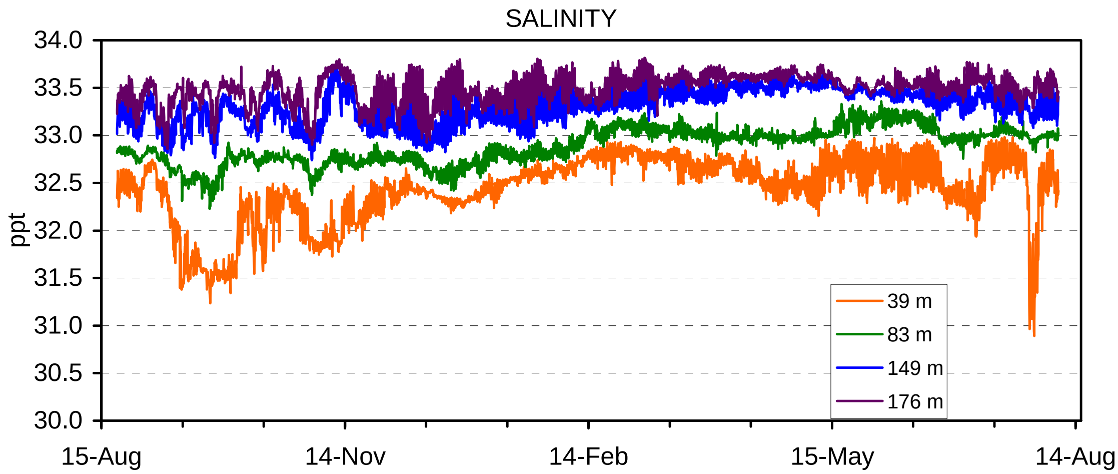
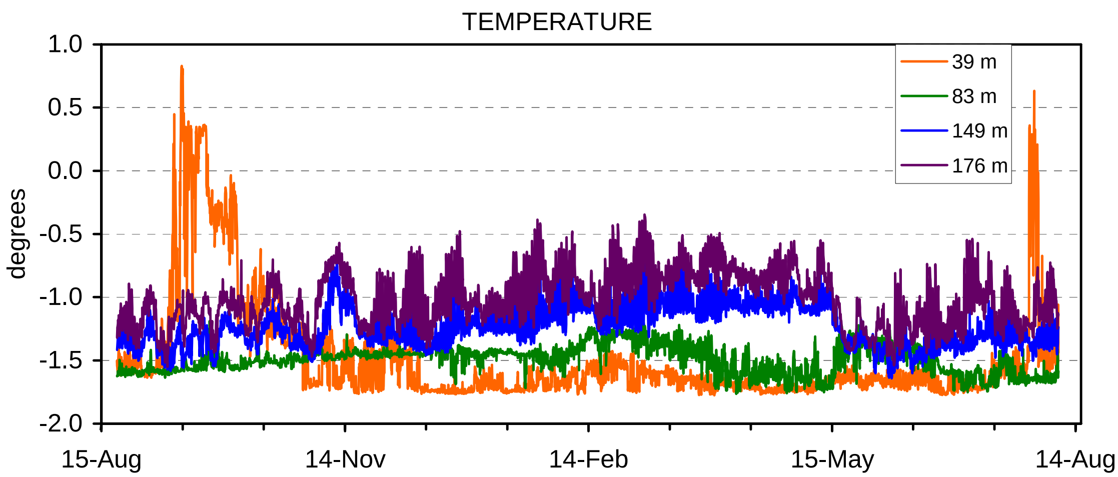
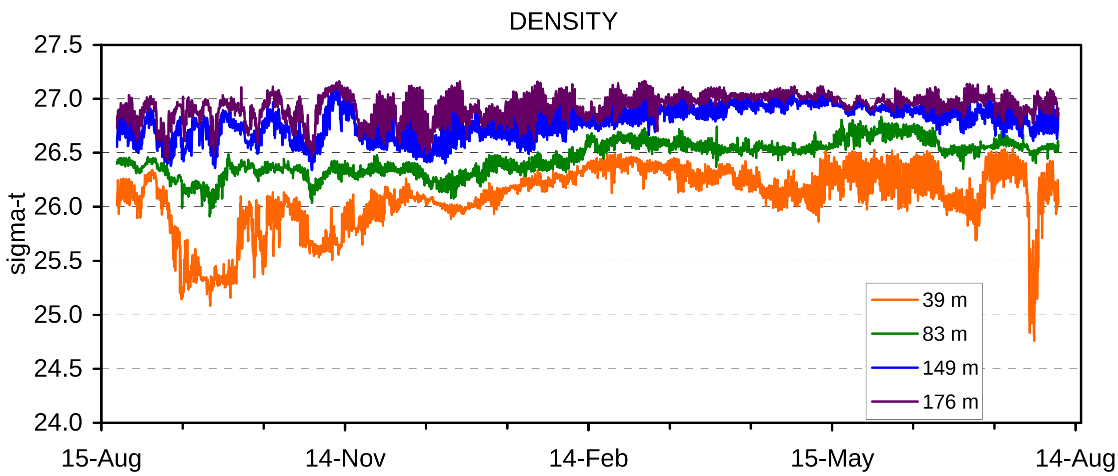


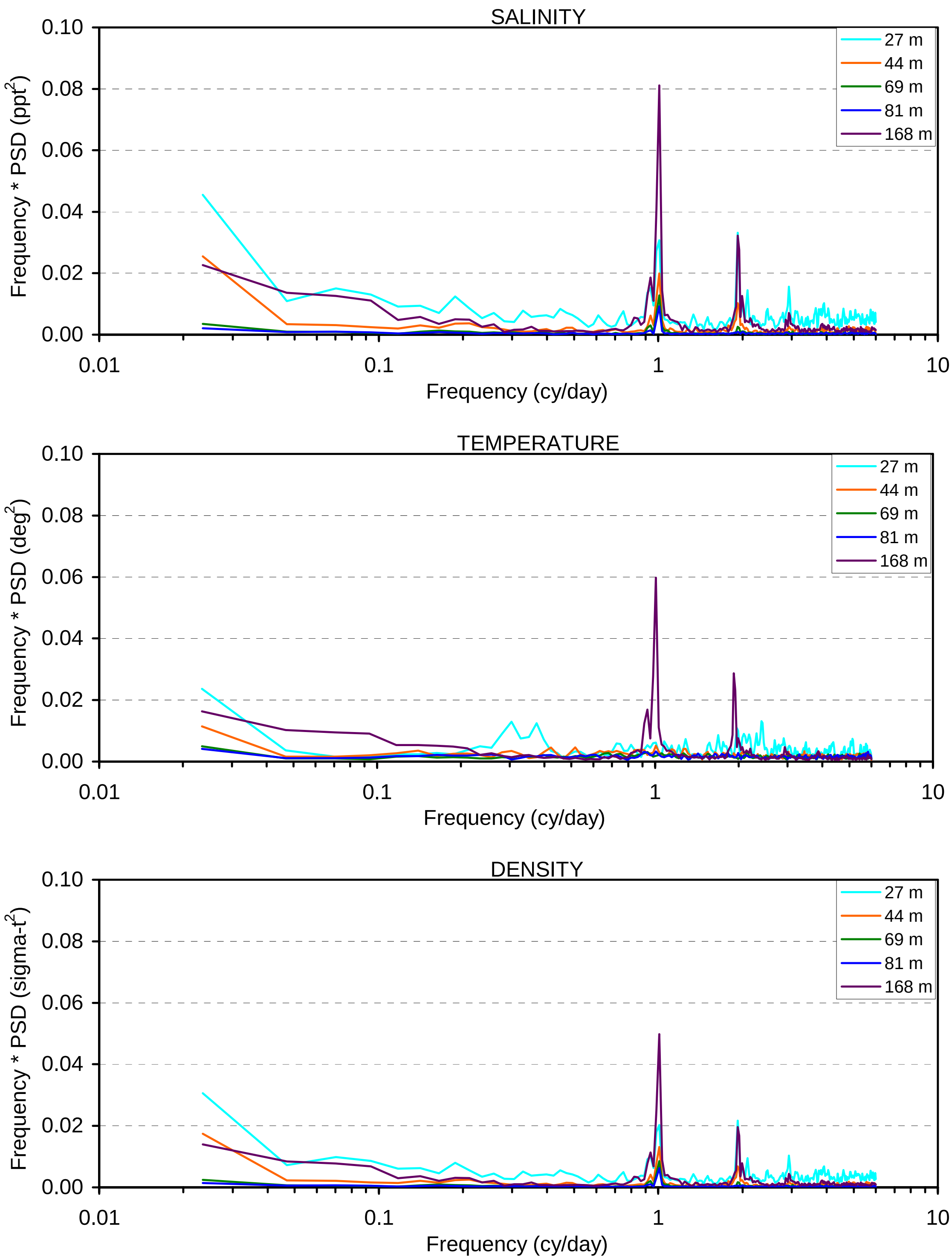
Figure 5 - Moored bihourly CTD data from North side of Barrow Strait: Aug 1999 - Aug 2000.



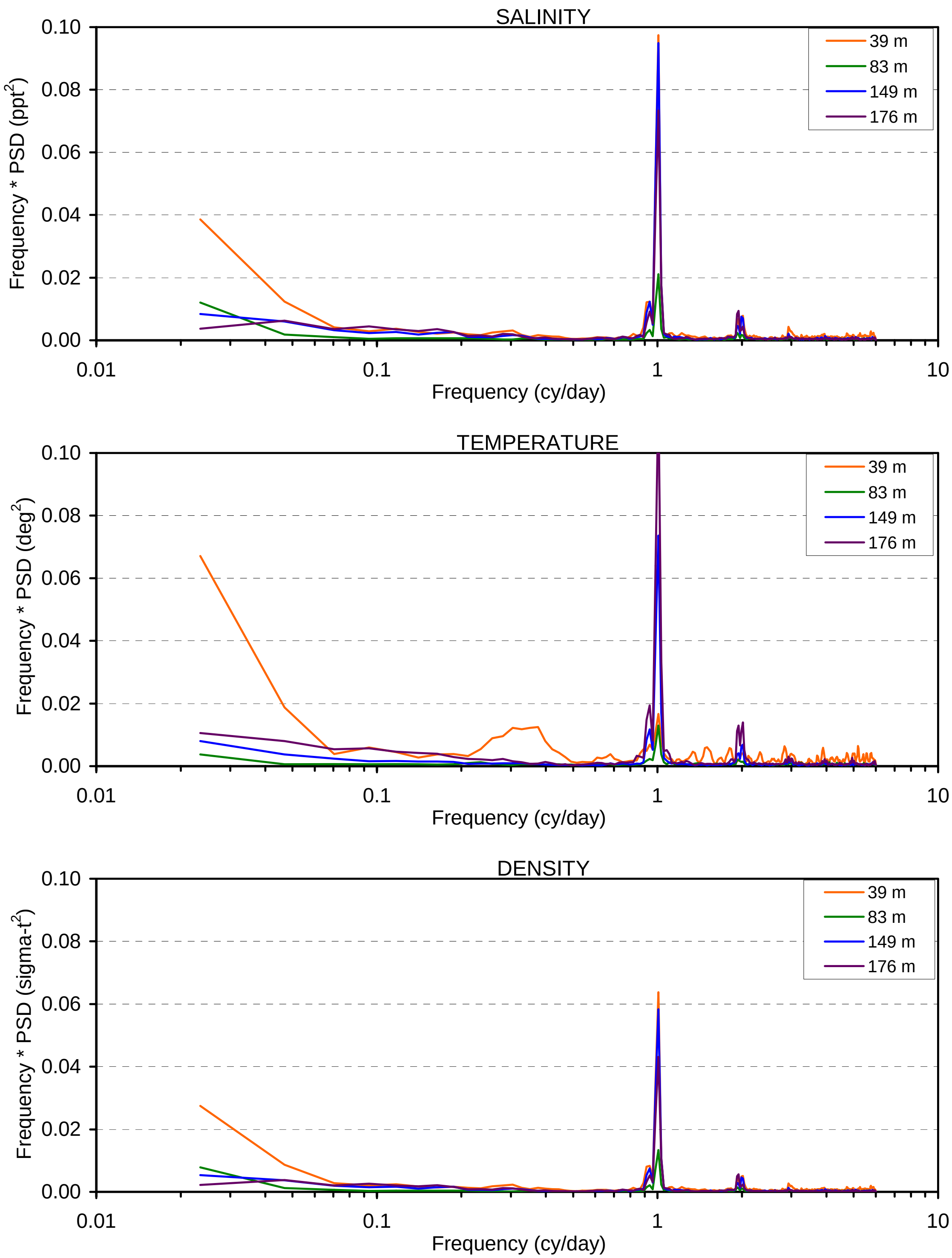




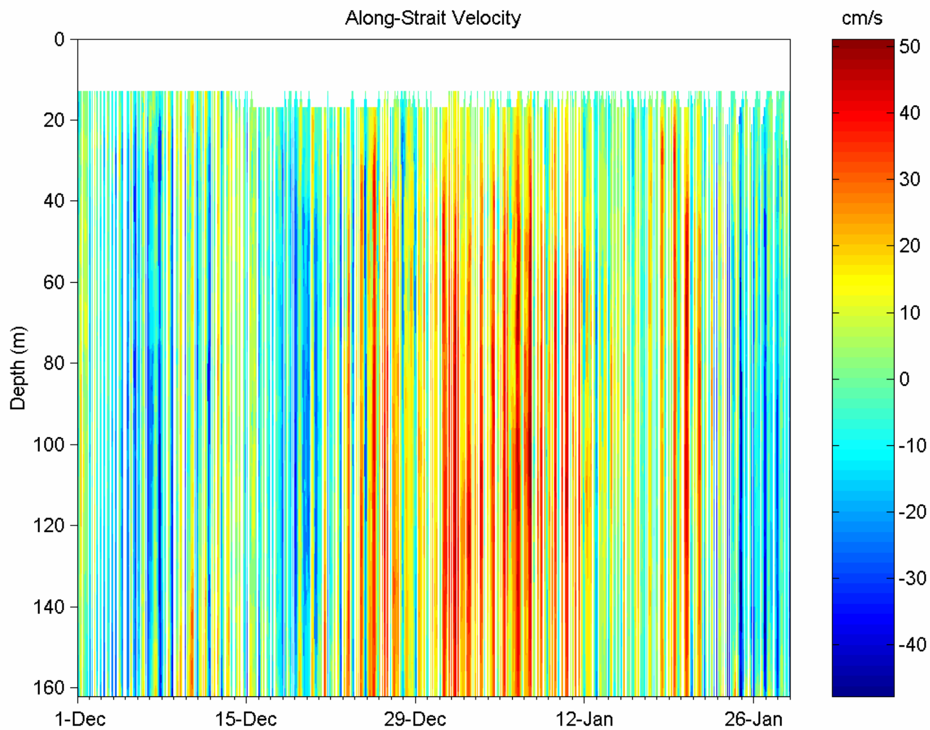
<u>Figure 6</u> - Power Spectra of moored bihourly CTD data from South Side of Barrow Strait: Aug 1999 - Aug 2000.



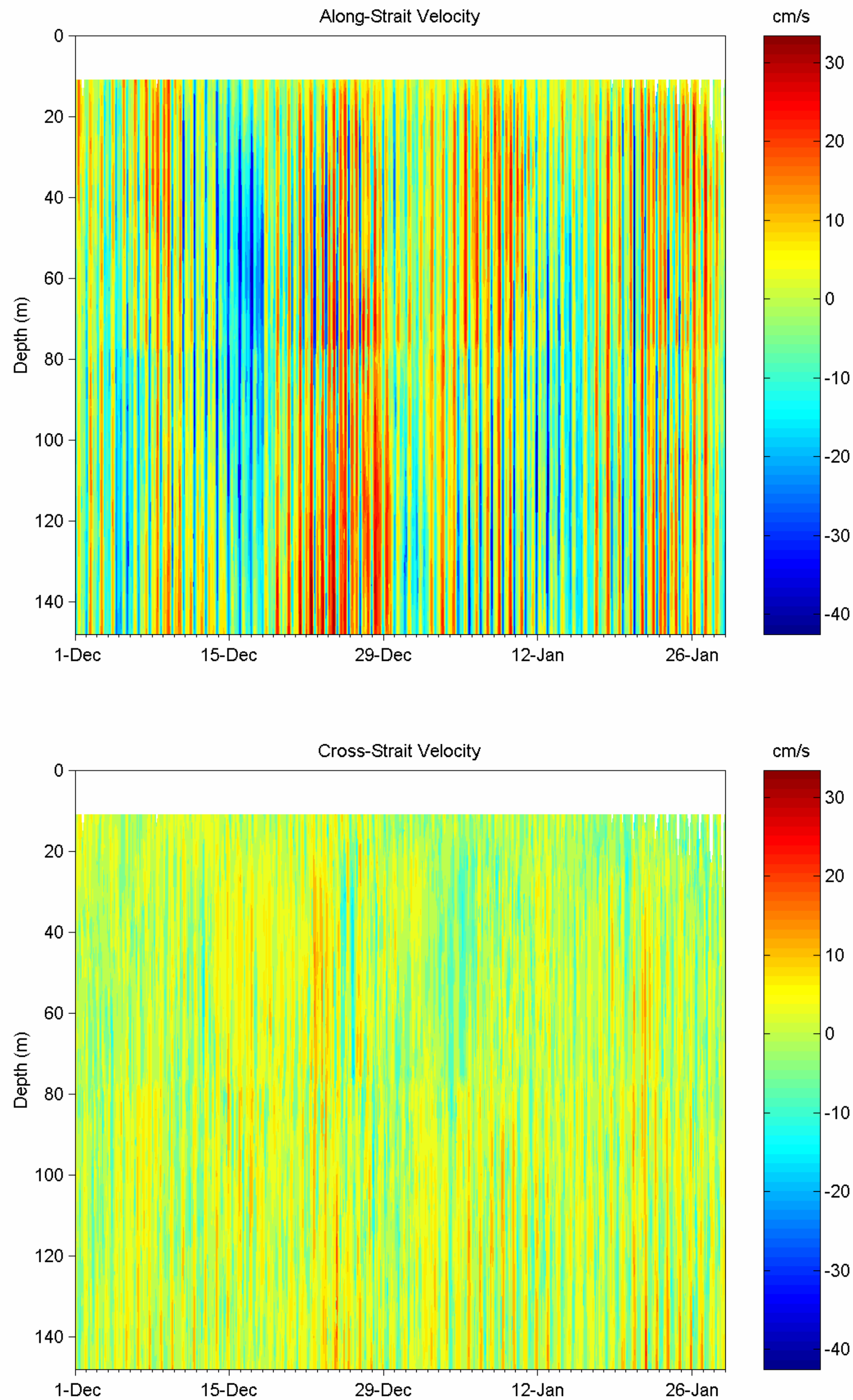
<u>Figure 7</u> - Power Spectra of moored bihourly CTD data from North Side of Barrow Strait: Aug 1999 - Aug 2000.



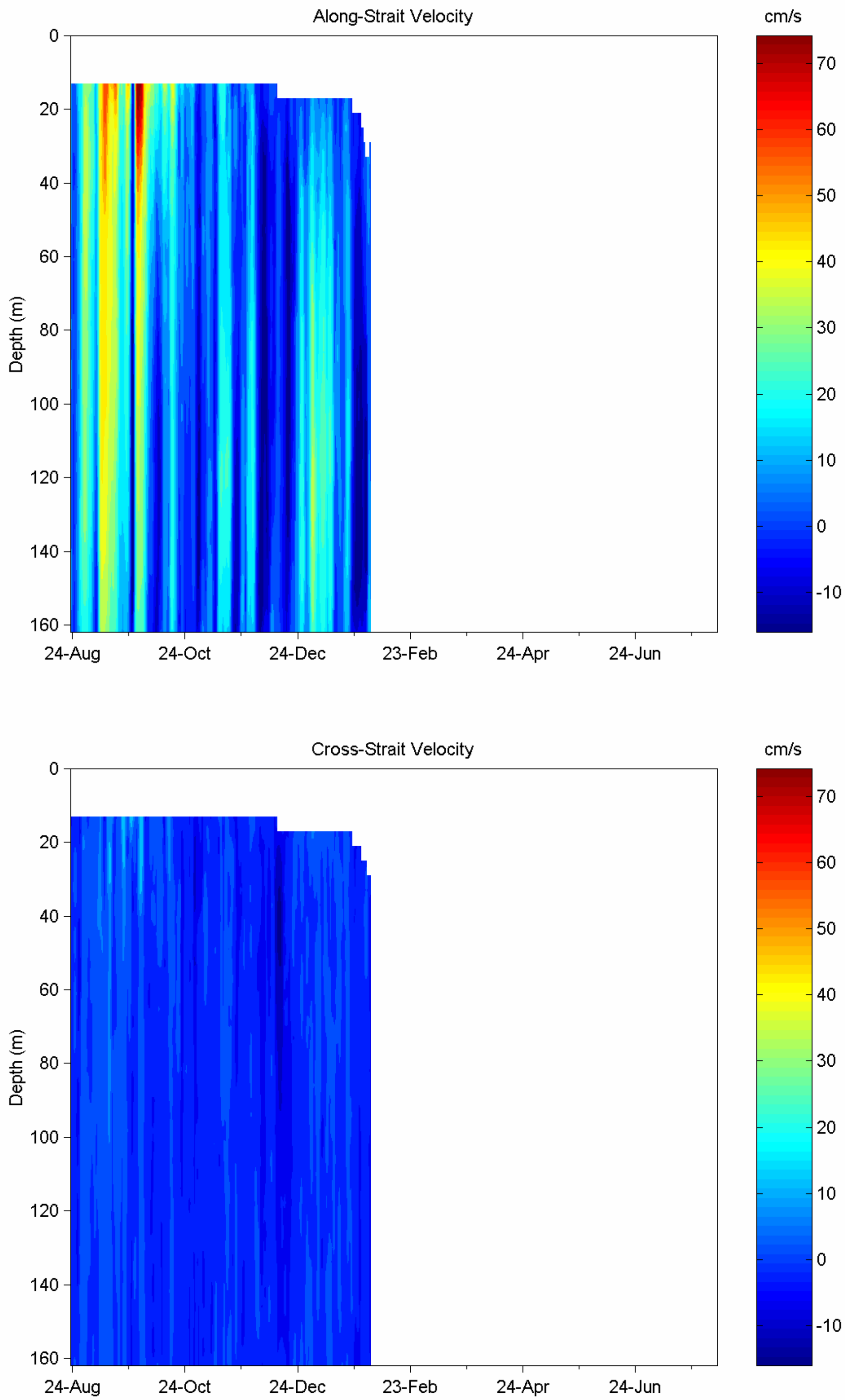
<u>Figure 8</u> - Bihourly current data, South side of Barrow Strait: Dec 1, 1999 – Jan 29, 2000.



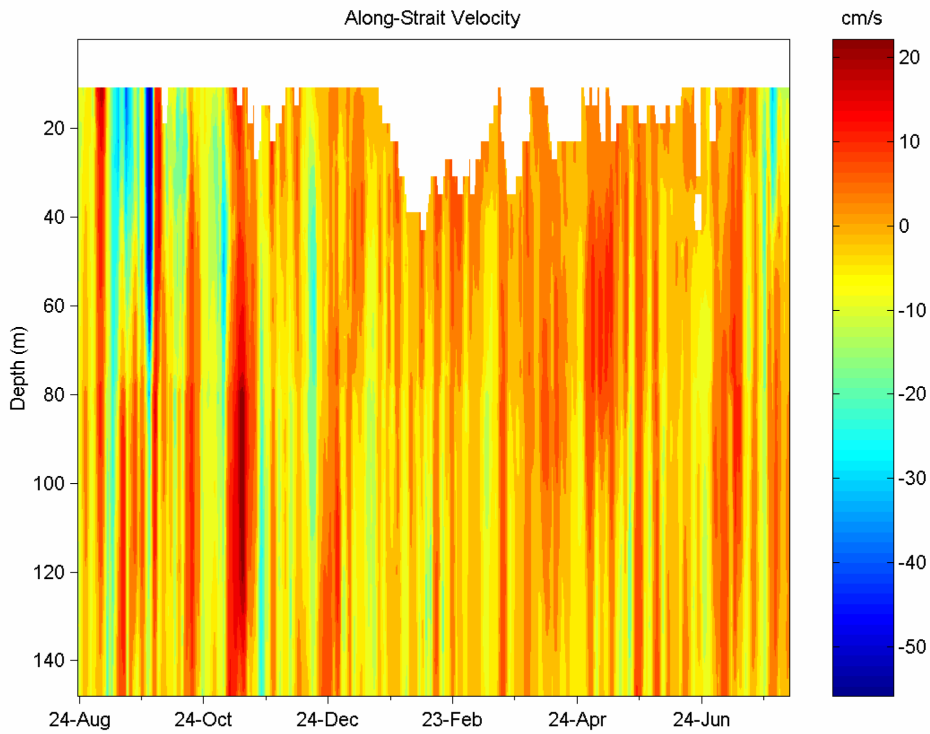
<u>Figure 9</u> - Bihourly current data, North side of Barrow Strait: Dec 1, 1999 – Jan 29, 2000.

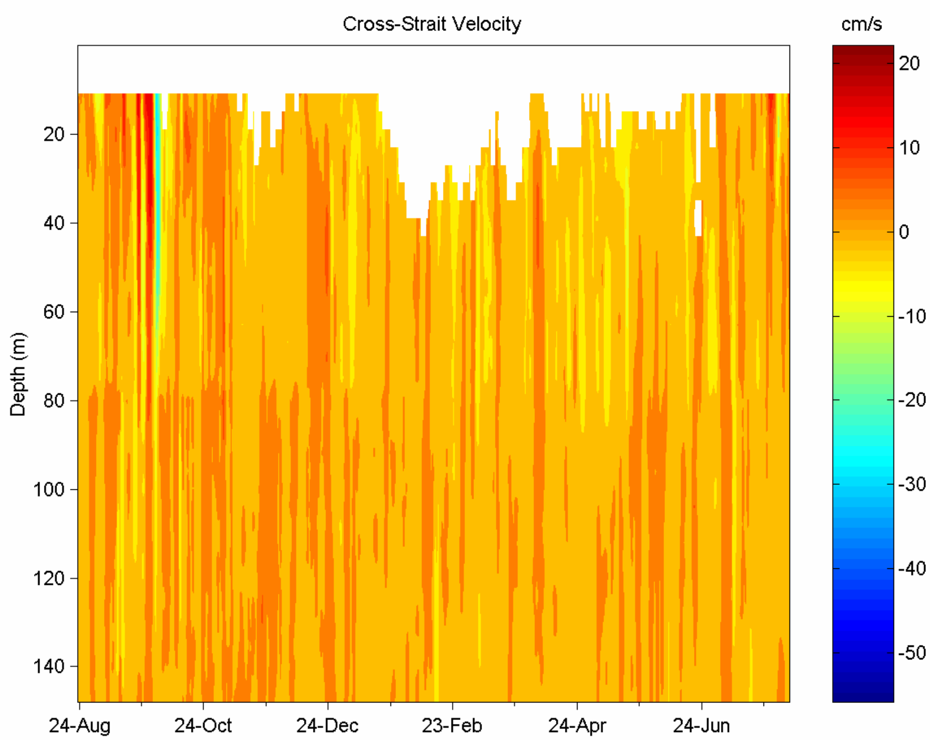


<u>Figure 10</u> – Low-pass filtered currents, South side of Barrow Strait: Aug 1999 – Aug 2000.

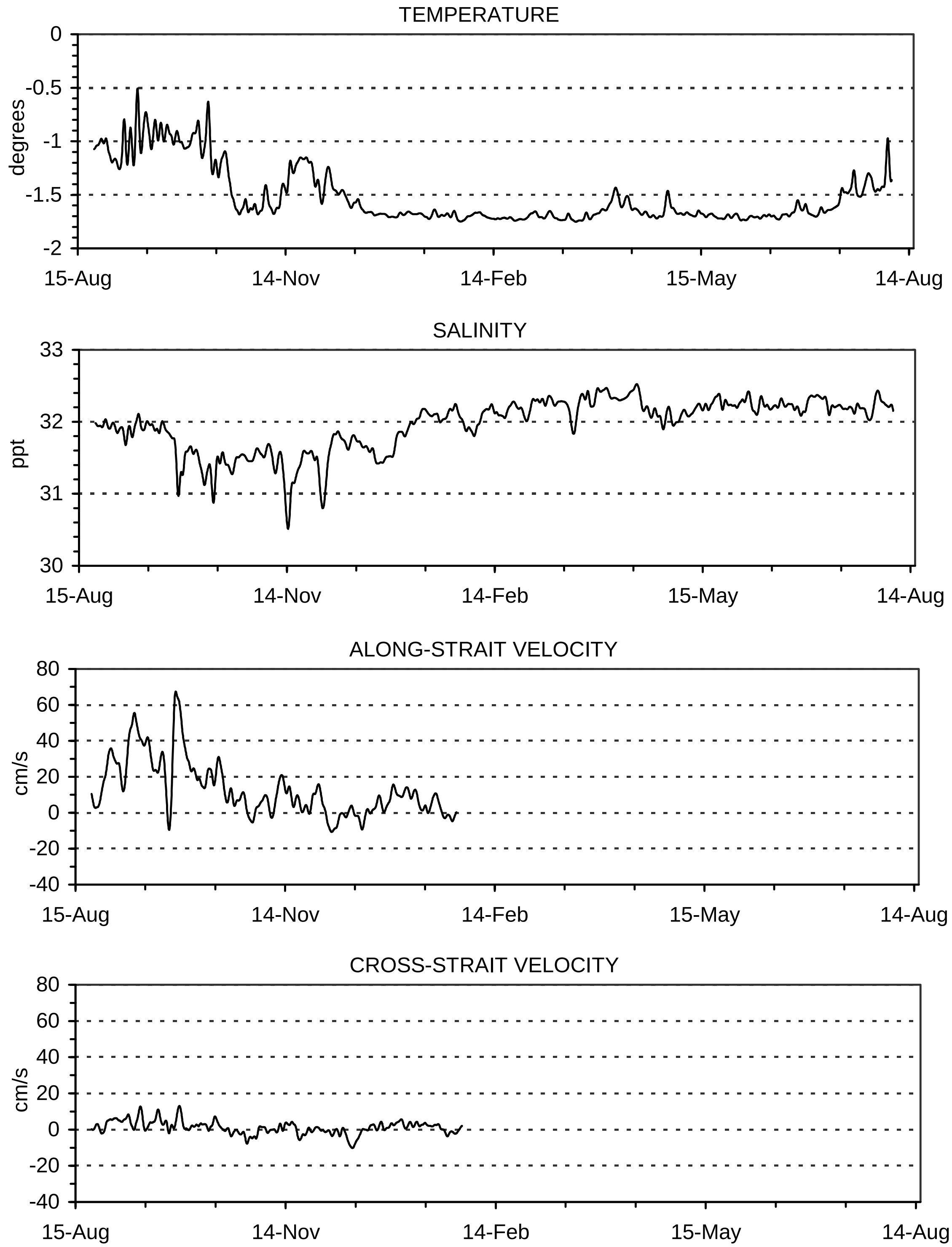


<u>Figure 11</u> – Low-pass filtered currents, North side of Barrow Strait: Aug 1999 – Aug 2000.

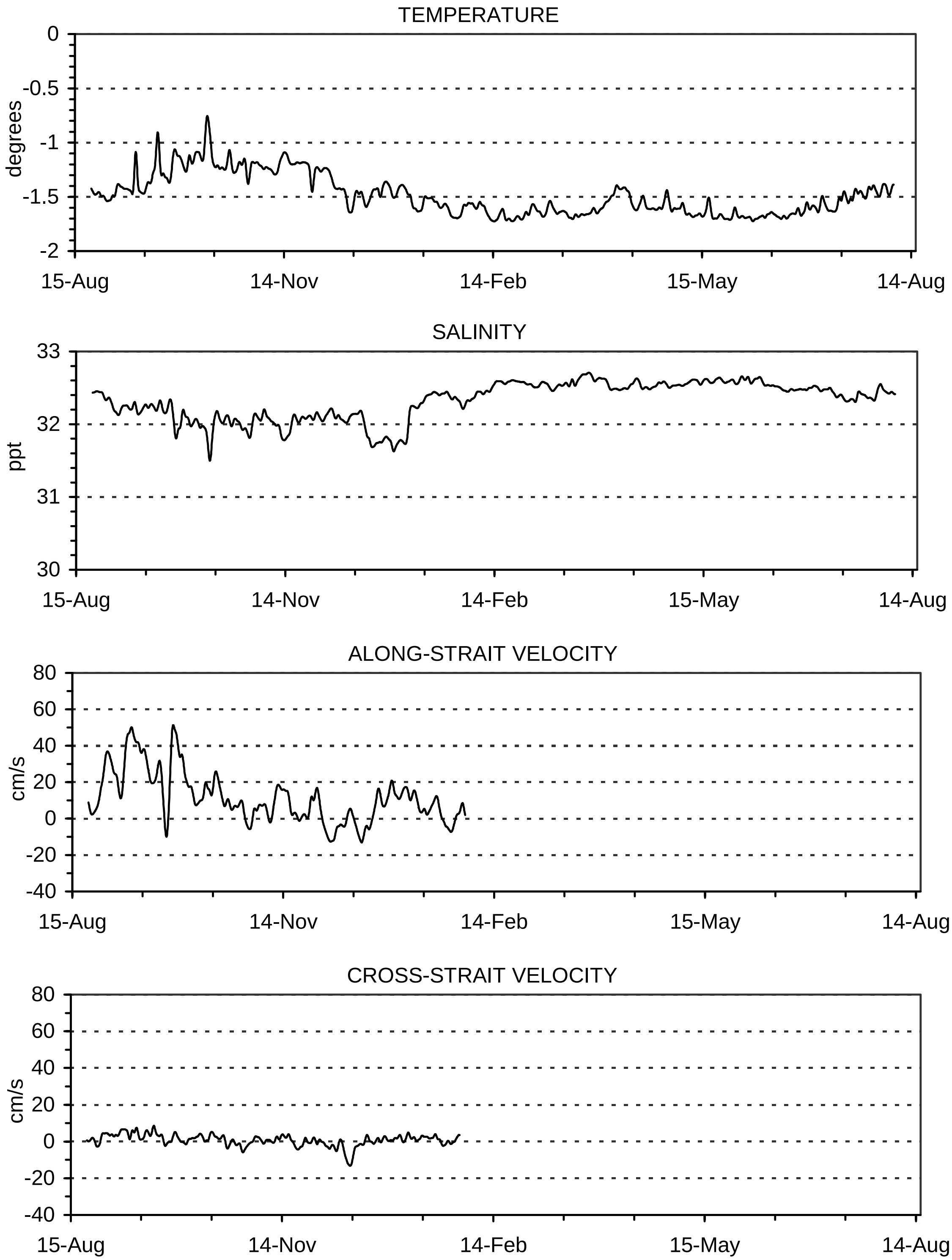




<u>Figure 12</u> - Low-pass filtered T,S and current data from 27m depth, South side of Barrow Strait: Aug 1999 - Aug 2000.



<u>Figure 13</u> - Low-pass filtered T,S and current data from 44m depth, South side of Barrow Strait: Aug 1999 - Aug 2000.



<u>Figure 14</u> - Low-pass filtered T,S and current data from 69m depth, South side of Barrow Strait: Aug 1999 - Aug 2000.

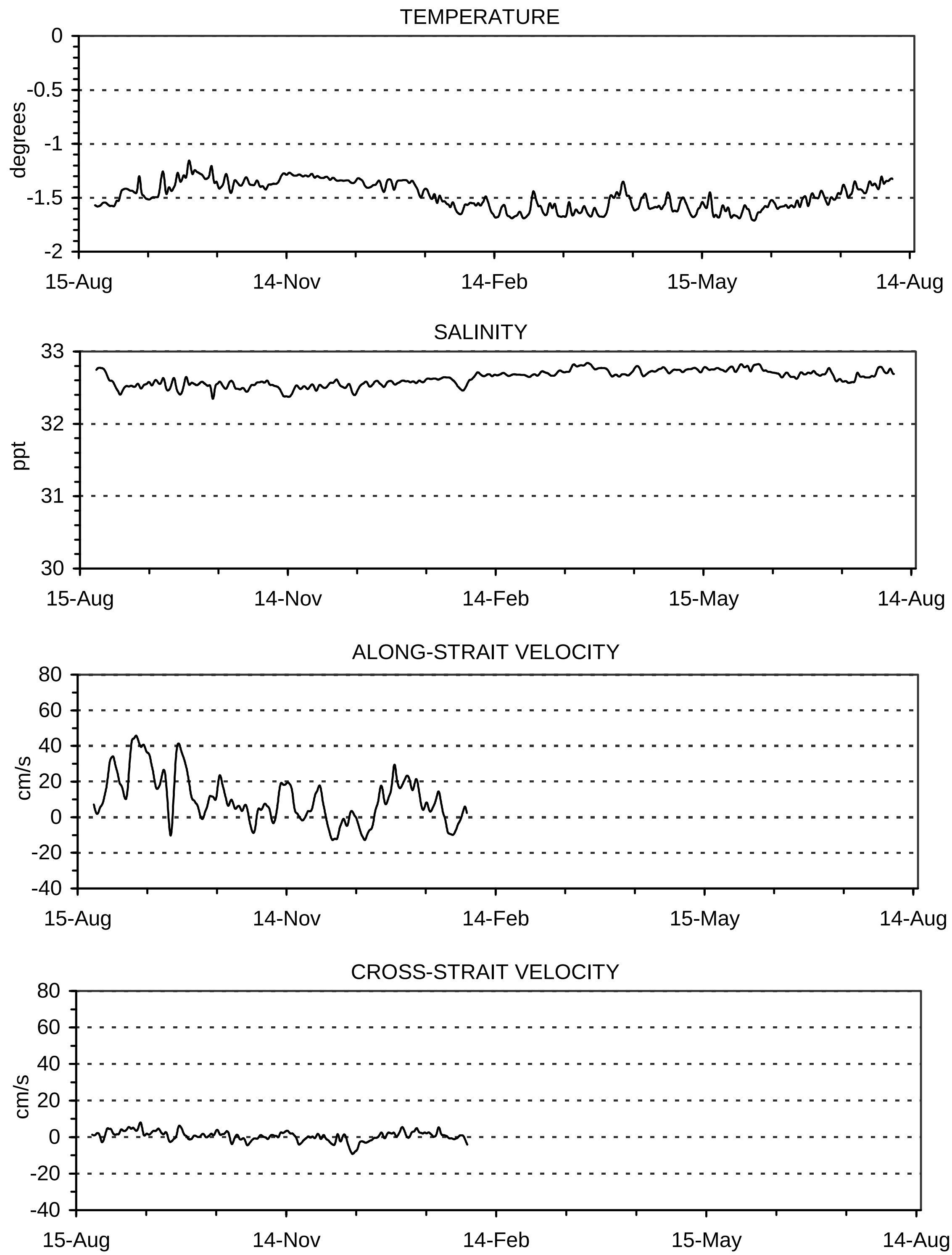
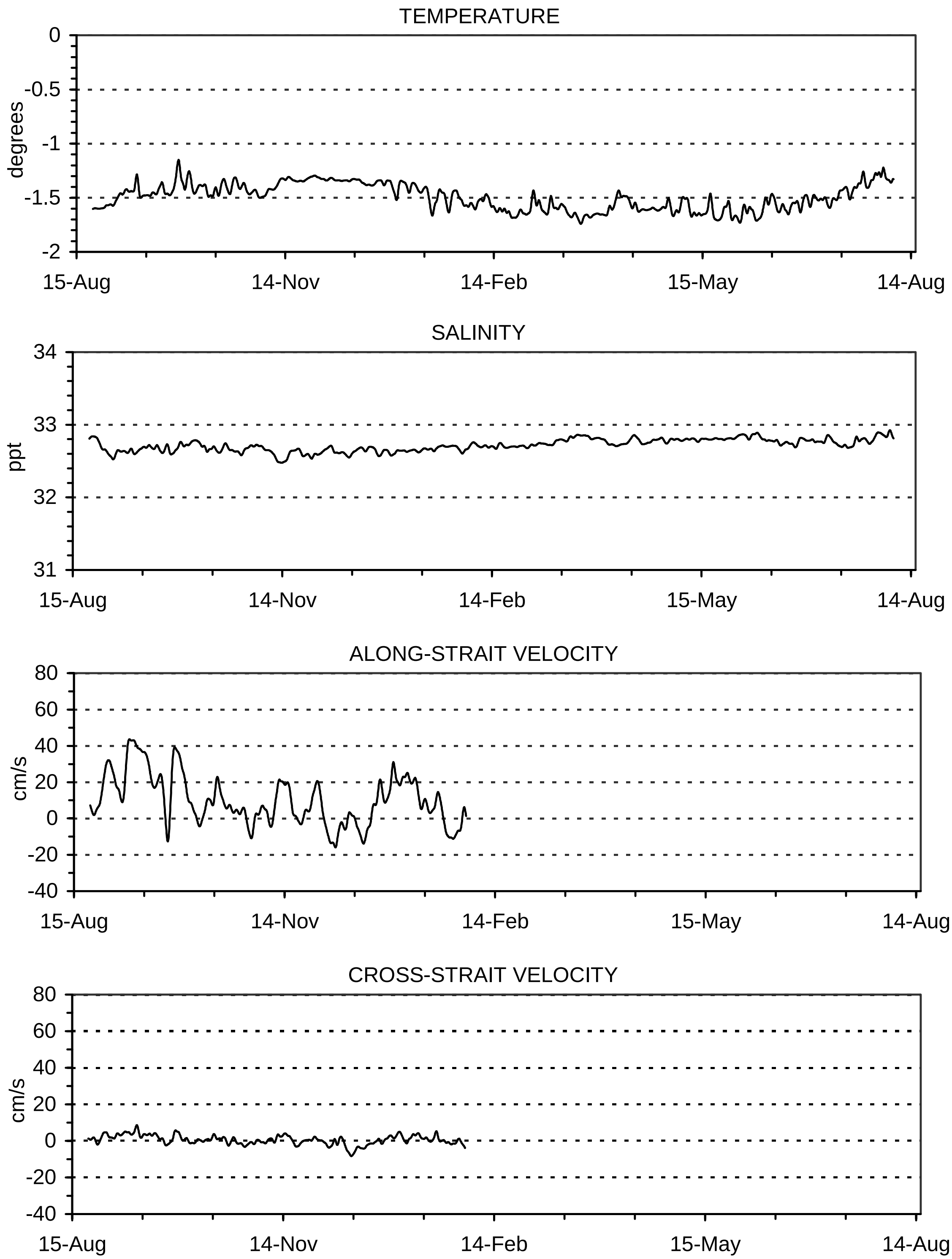
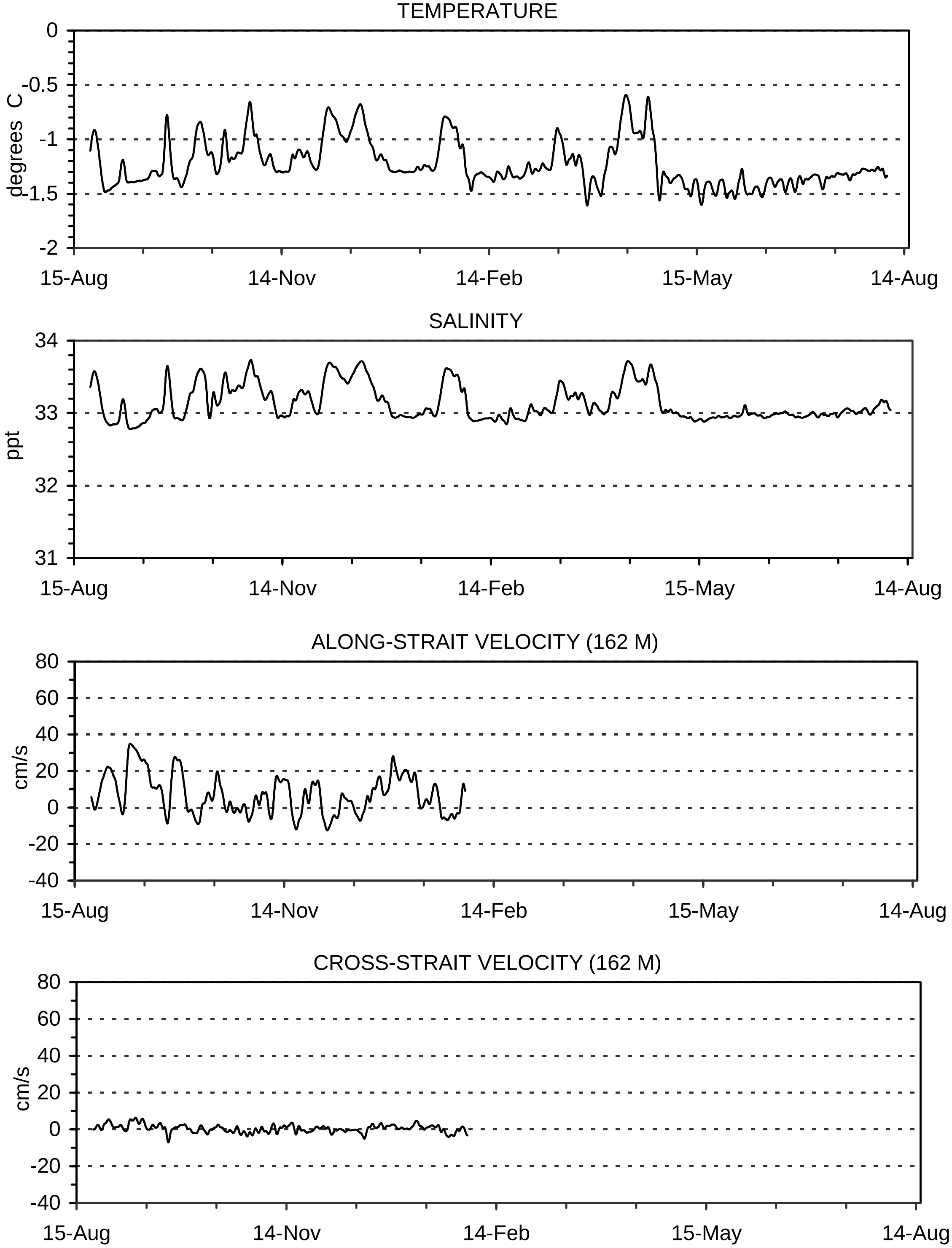


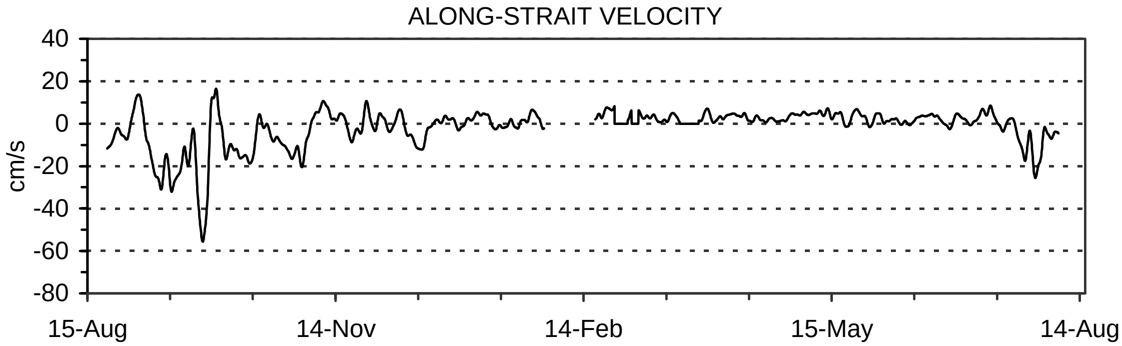
Figure 15 - Low-pass filtered T,S and current data from 81m depth, South side of Barrow Strait: Aug 1999 - Aug 2000.

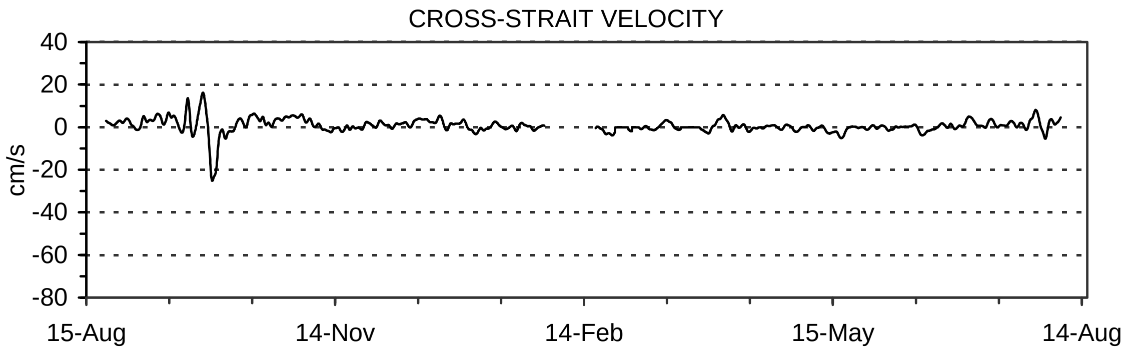


<u>Figure 16</u> - Low-pass filtered T,S and current data from 168m depth, South side of Barrow Strait: Aug 1999 - Aug 2000.

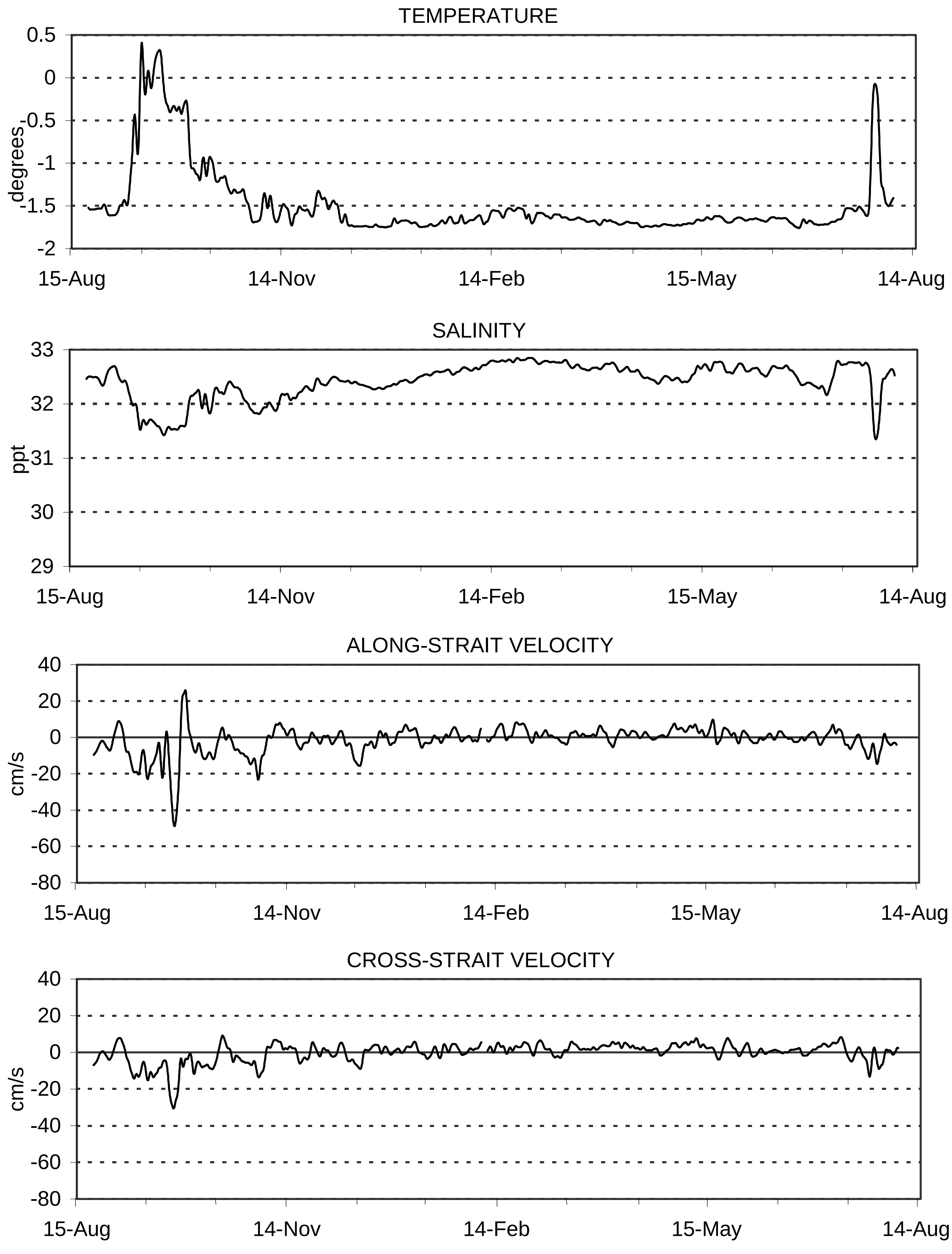


<u>Figure 17</u> - Low-pass filtered current data from 26m depth, North side of Barrow Strait: Aug 1999 - Aug 2000.

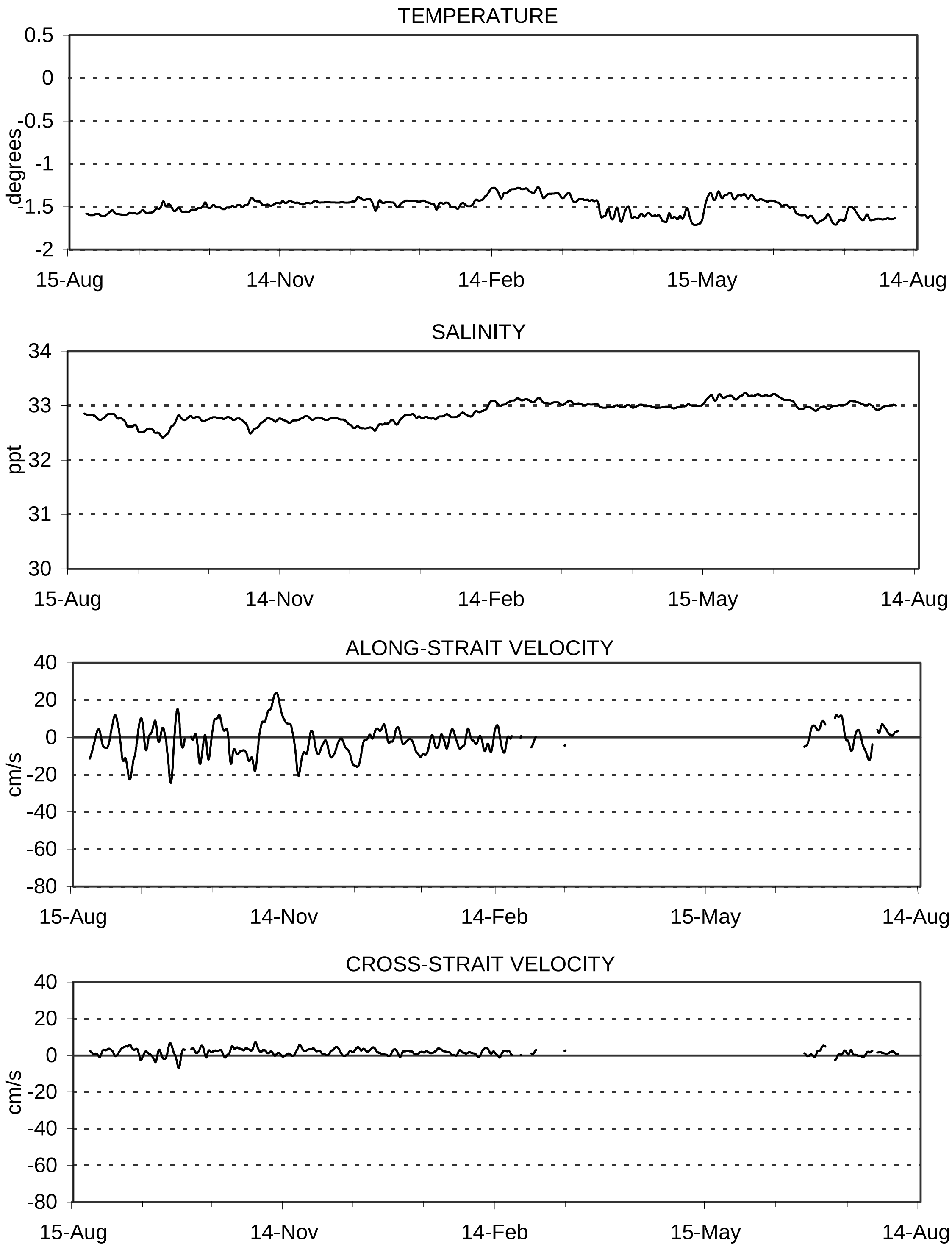




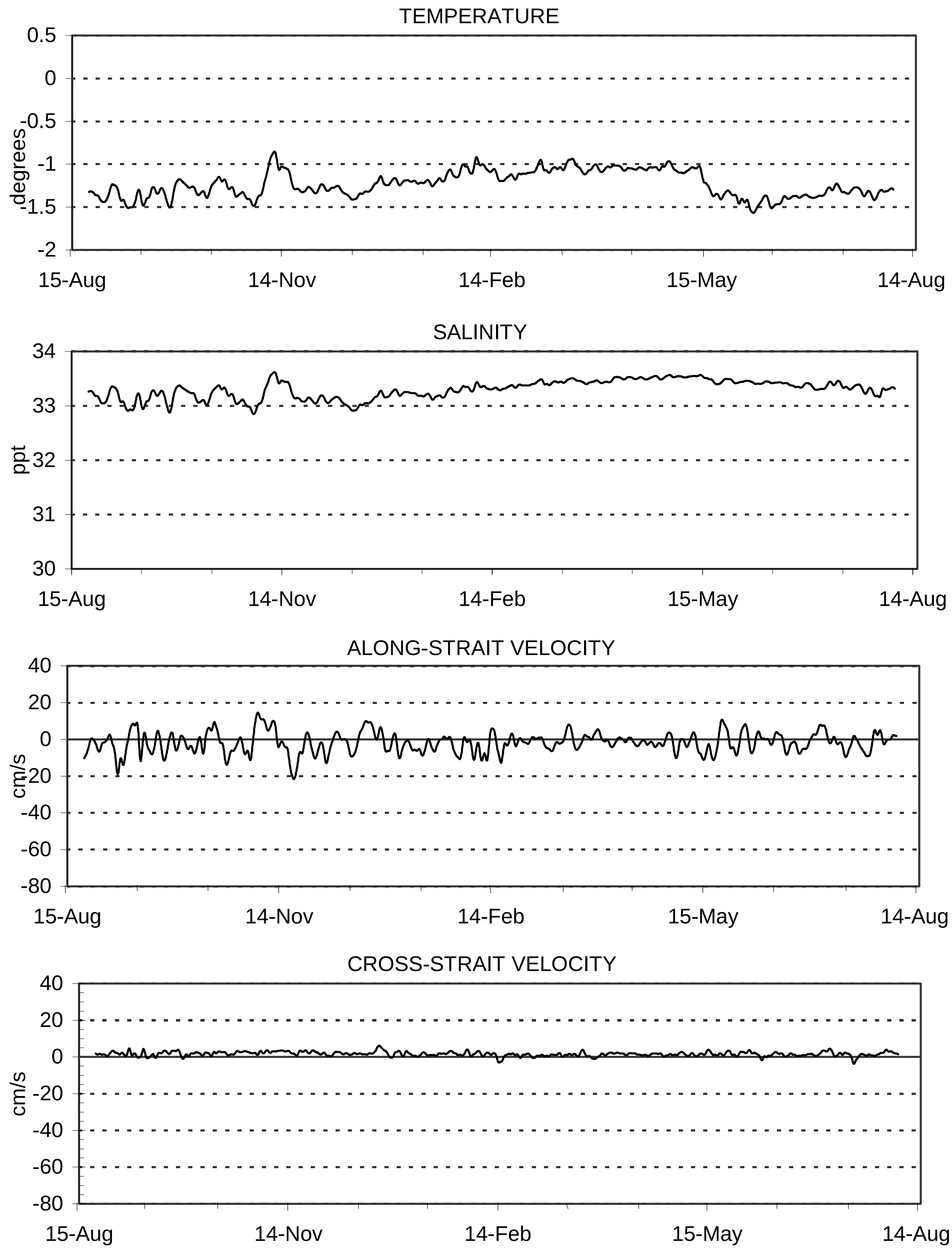
<u>Figure 18</u> - Low-pass filtered T,S and current data from 39m depth, North side of Barrow Strait: Aug 1999 - Aug 2000.



<u>Figure 19</u> - Low-pass filtered T,S and current data from 83m depth, North side of Barrow Strait: Aug 1999 - Aug 2000.



<u>Figure 20</u> - Low-pass filtered T,S and current data from 149m depth, North side of Barrow Strait: Aug 1999 - Aug 2000.



<u>Figure 21</u> - Low-pass filtered T and S data from 176m depth, North side of Barrow Strait: Aug 1999 - Aug 2000.

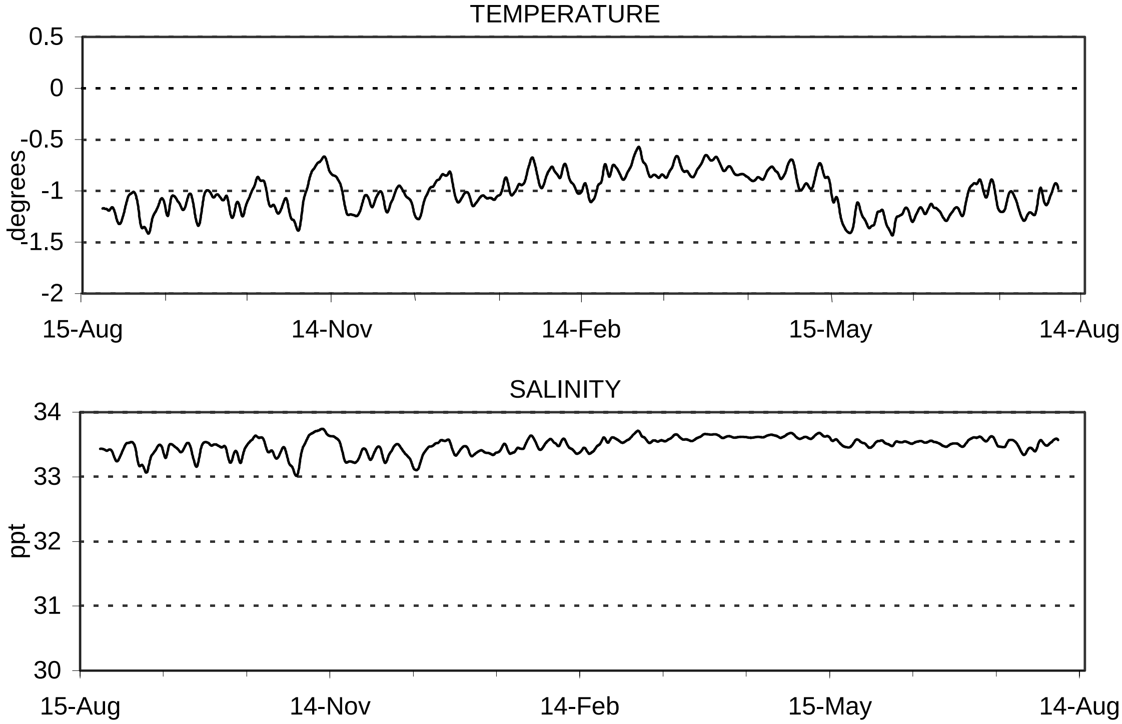
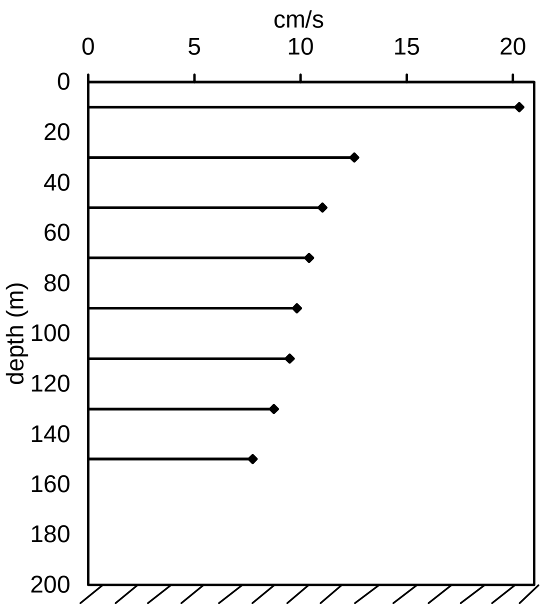


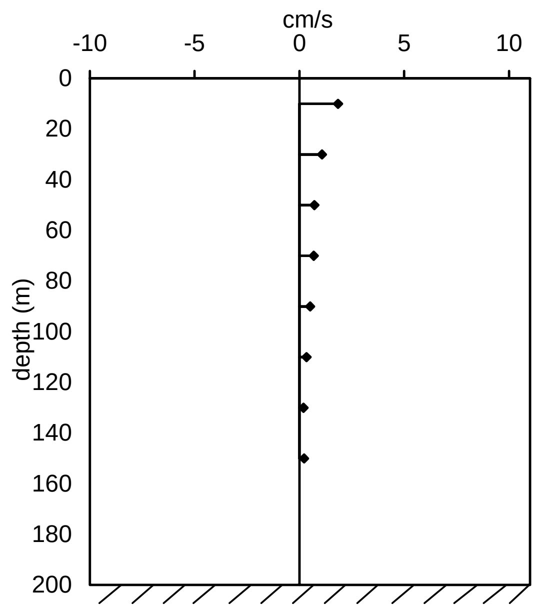
Figure 22: Annual Mean Flows, Aug 1999 - Aug 2000.

South side of Barrow Strait: (based on Aug-Jan data only)

Along-Strait

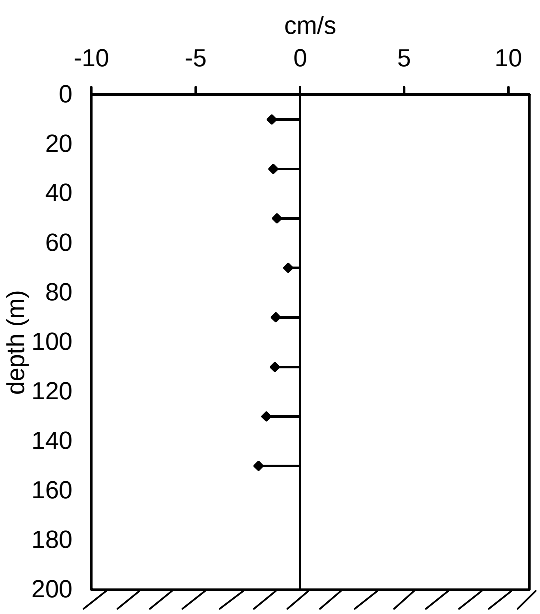


Cross-Strait



North Side of Barrow Strait:

Along-Strait



Cross-Strait

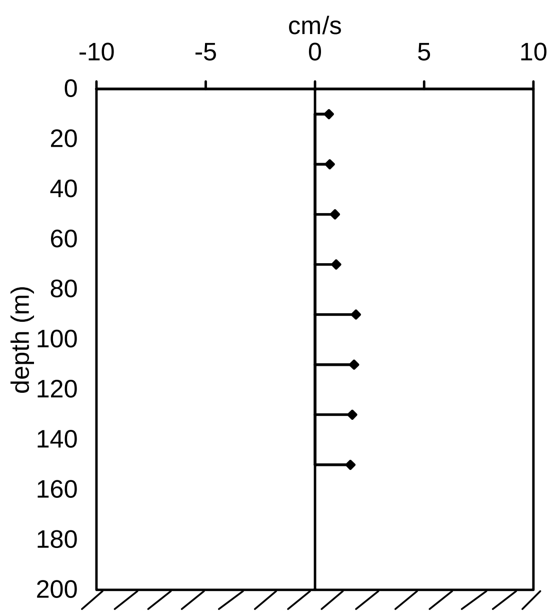
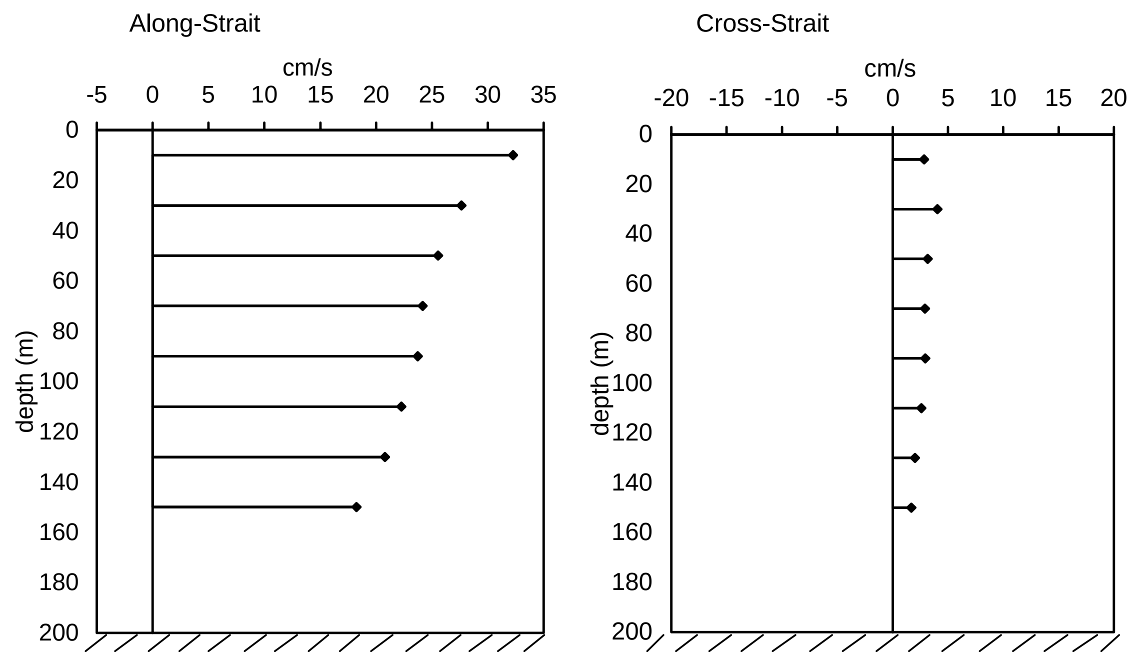
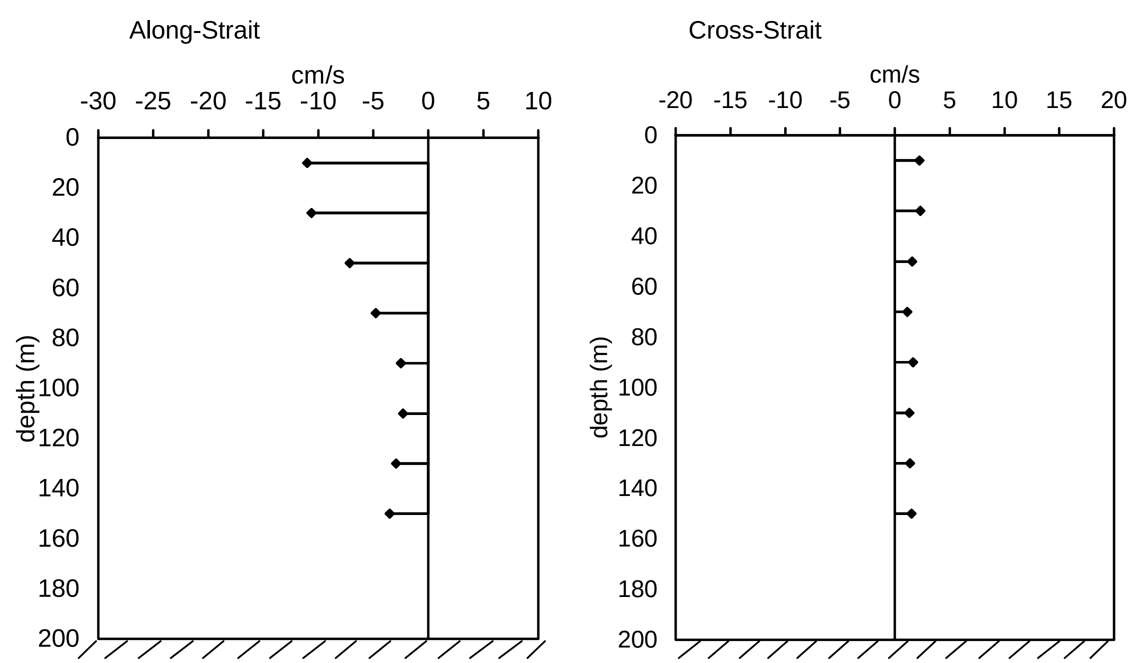


Figure 23: Mean Flows, Late Summer: Aug 1999 - Sep 1999.

South side of Barrow Strait:

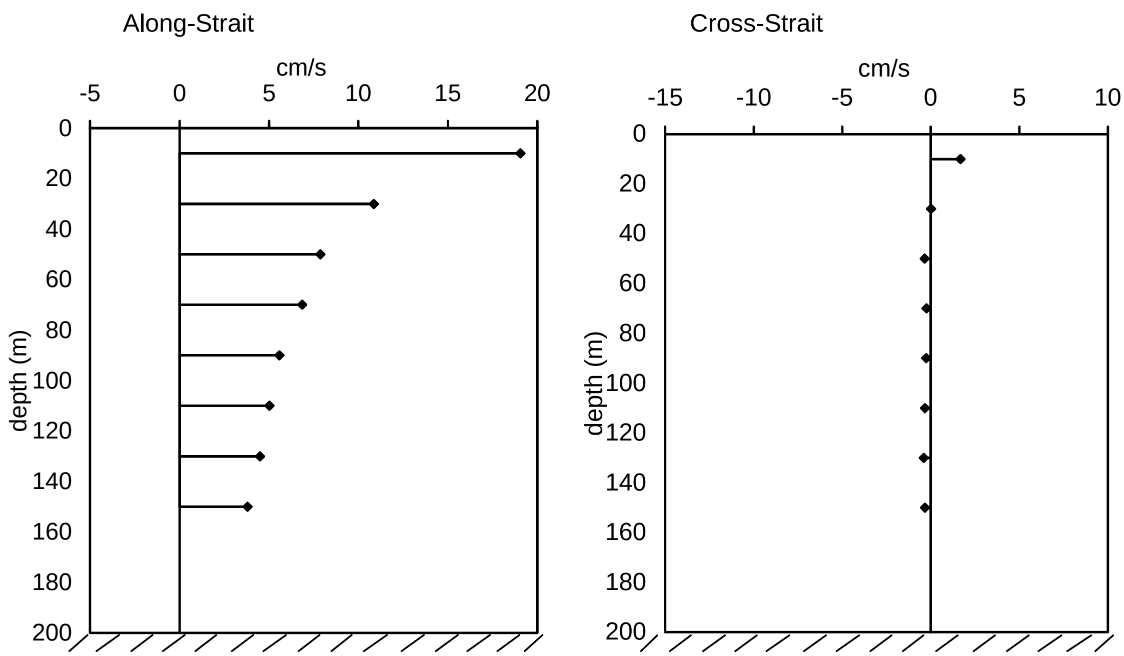


North Side of Barrow Strait:



<u>Figure 24:</u> Mean Flows, Fall: Sep 1999 - Dec 1999.

South side of Barrow Strait:



North Side of Barrow Strait:

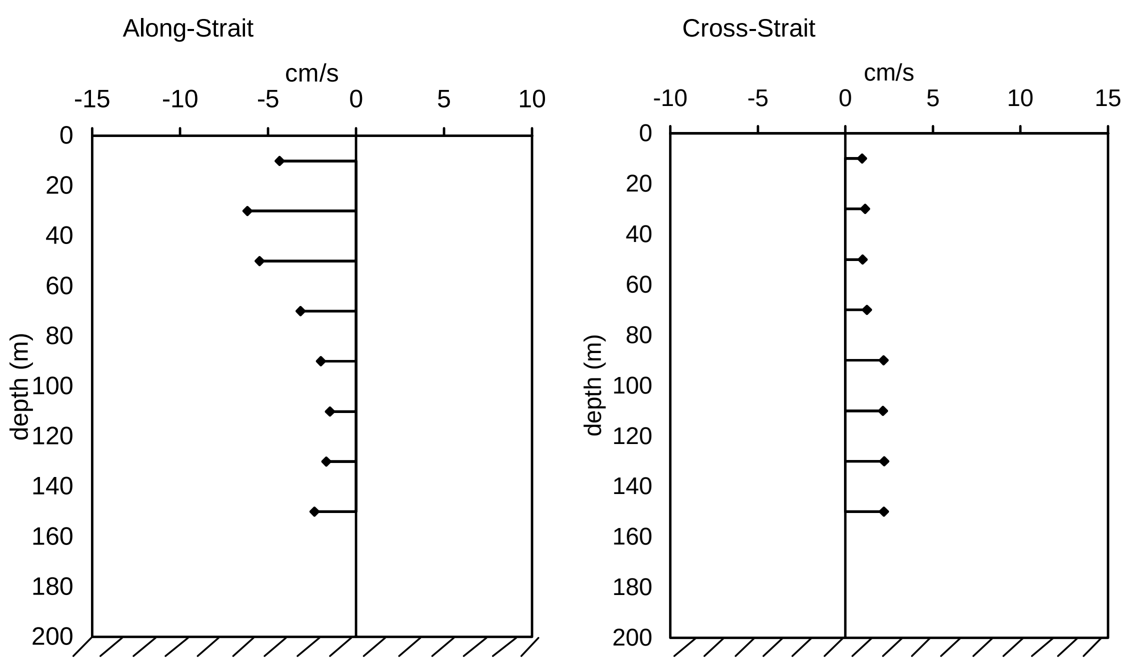
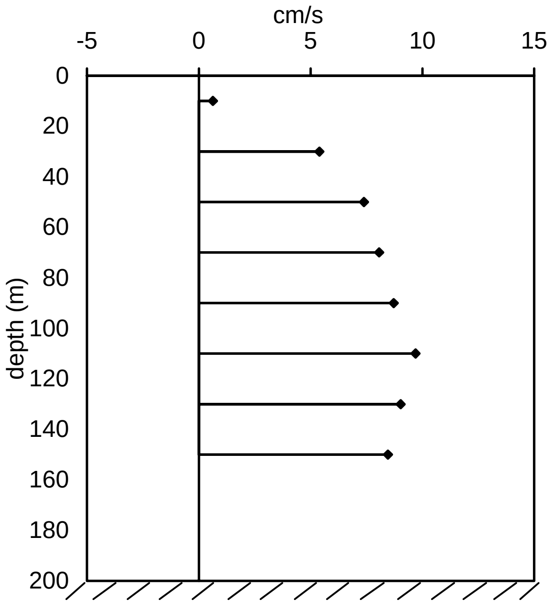


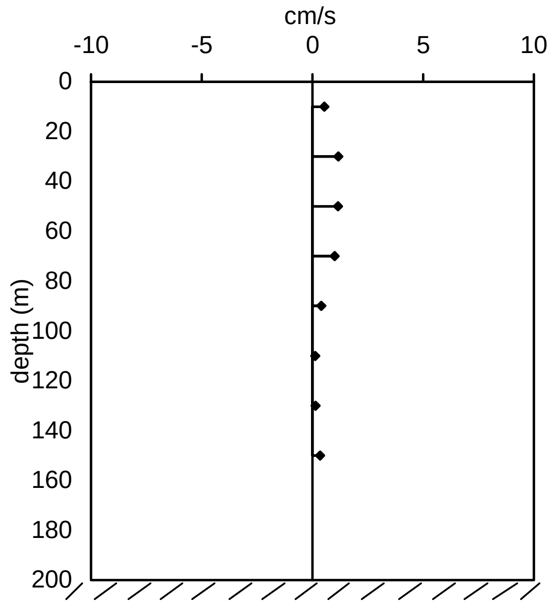
Figure 25: Mean Flows, Winter: Dec 1999 - Mar 2000.

South side of Barrow Strait: (based on Dec - Jan data only)

Along-Strait

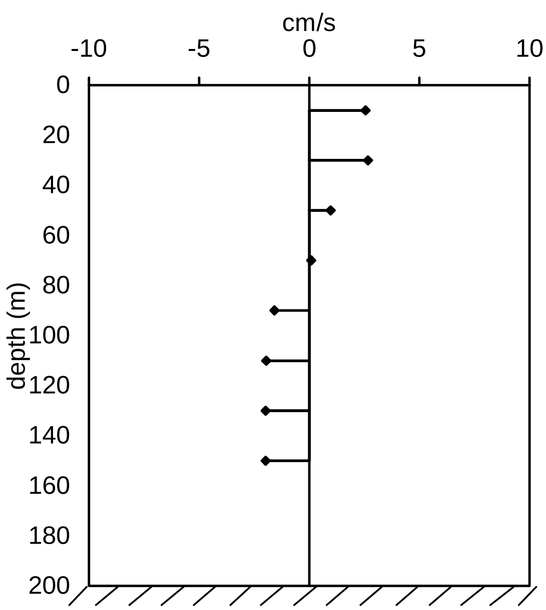


Cross-Strait



North Side of Barrow Strait:

Along-Strait



Cross-Strait

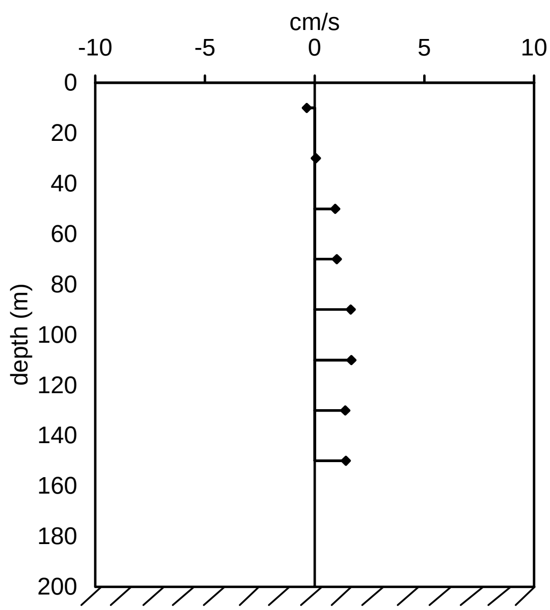
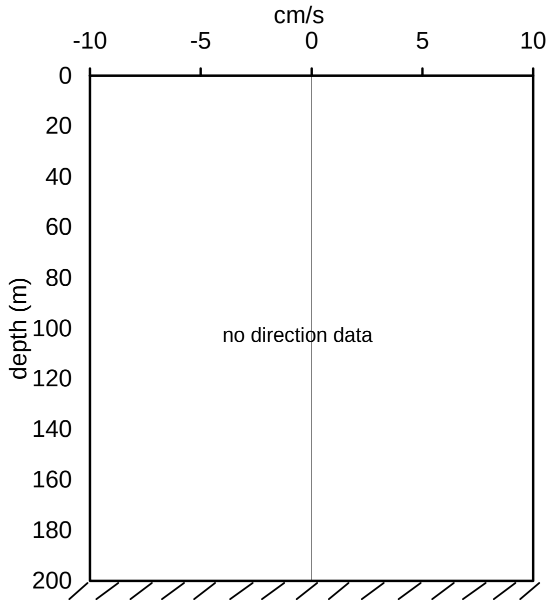


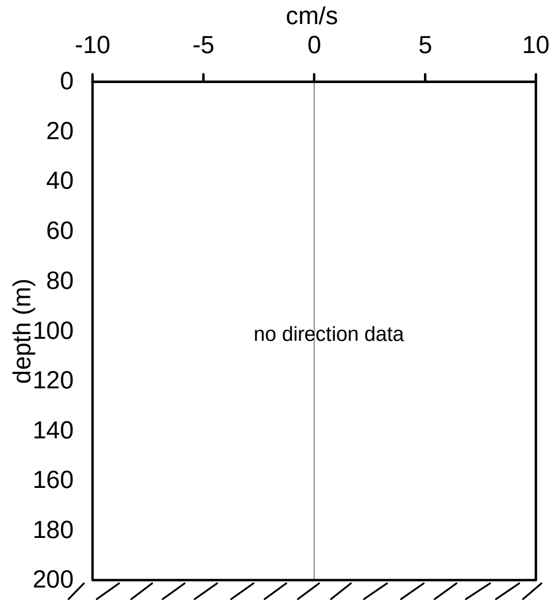
Figure 26: Mean Flows, Spring: Mar 2000 - Jun 2000.

South side of Barrow Strait:

Along-Strait

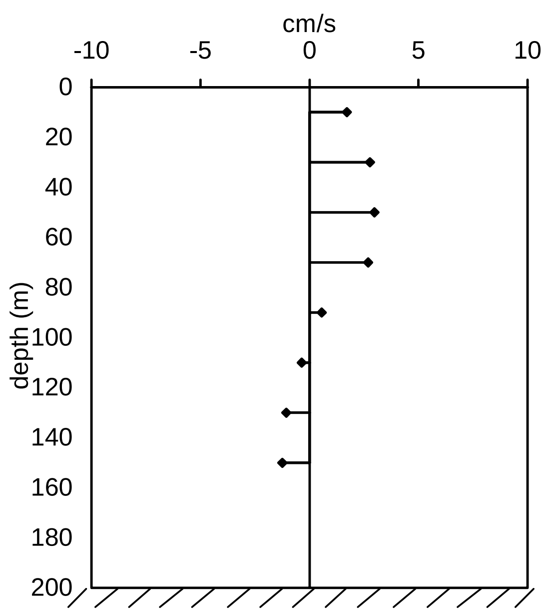


Cross-Strait



North Side of Barrow Strait:

Along-Strait



Cross-Strait

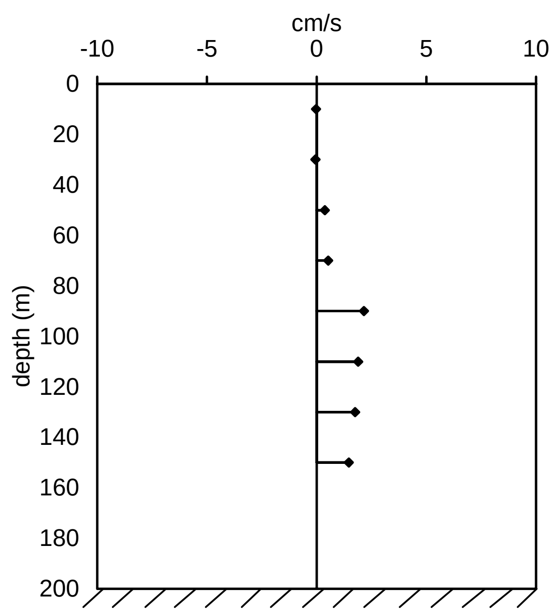
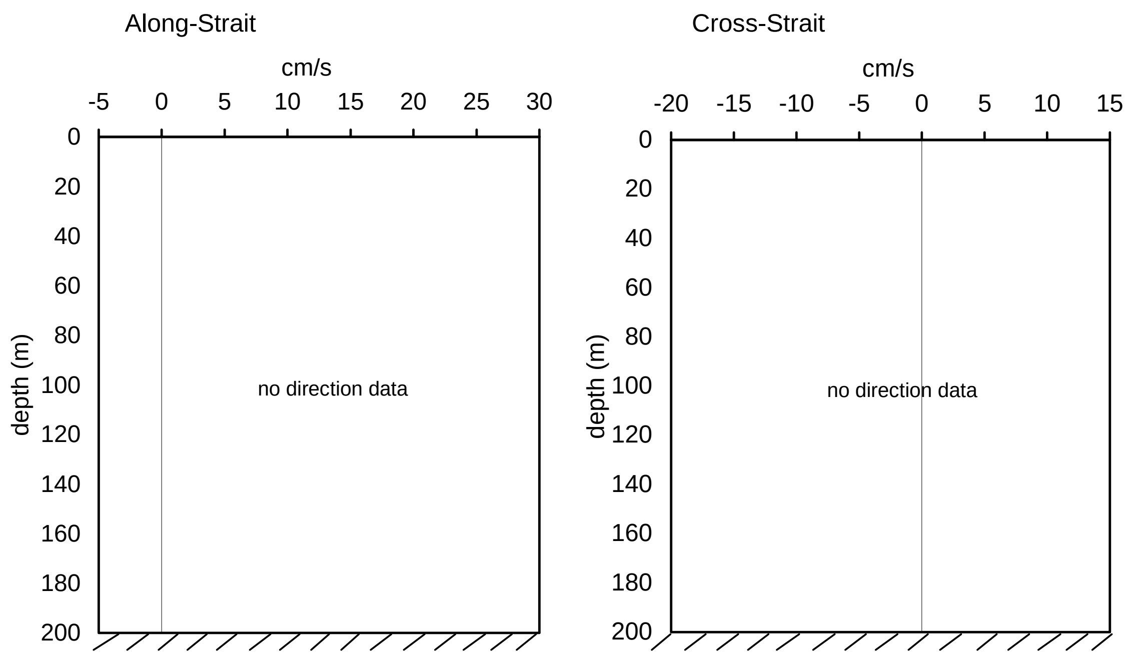
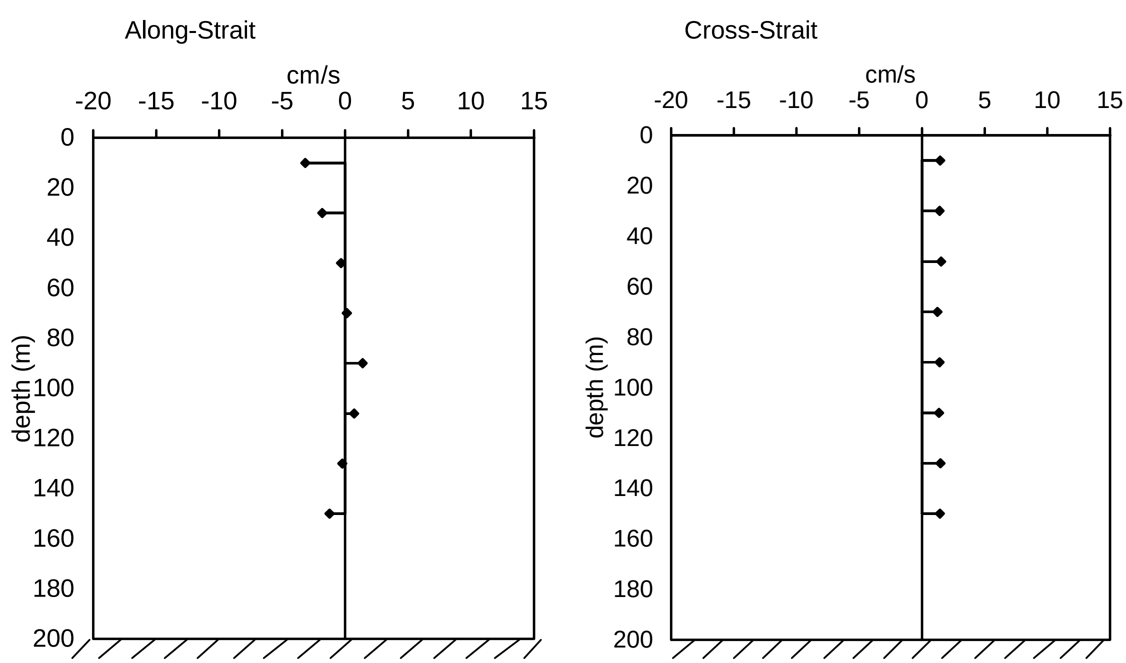


Figure 27: Mean Flows, Early Summer: Jun 2000 - Aug 2000.

South side of Barrow Strait:



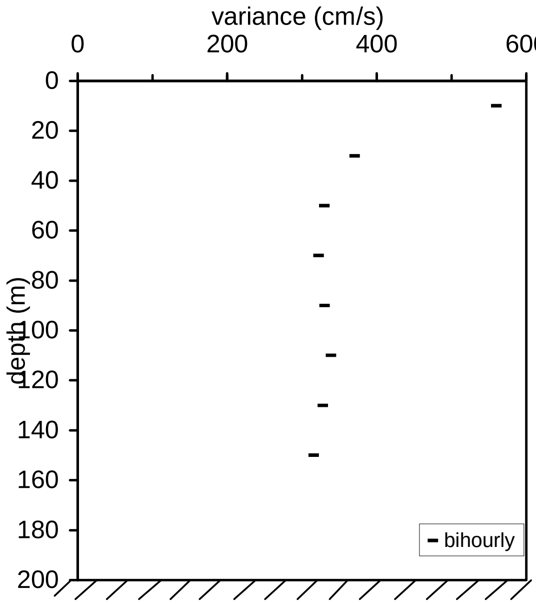
North Side of Barrow Strait:



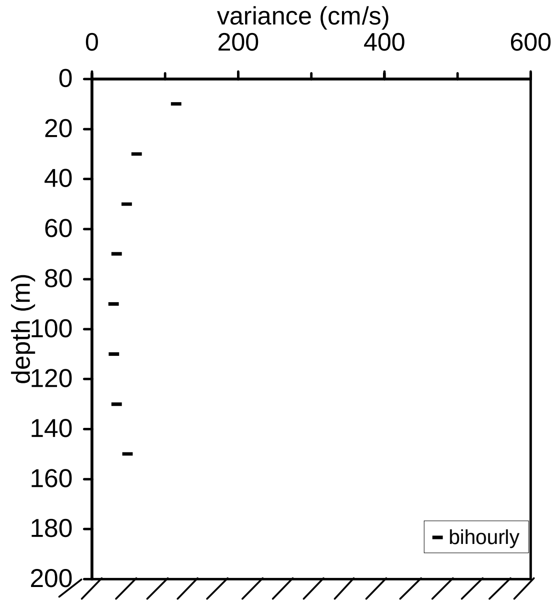
<u>Figure 28:</u> Variance in bihourly and low-pass filtered currents, computed over yearlong records (Aug 1999 - Aug 2000).

South side of Barrow Strait: (based on Aug-Jan data only)

Along-Strait

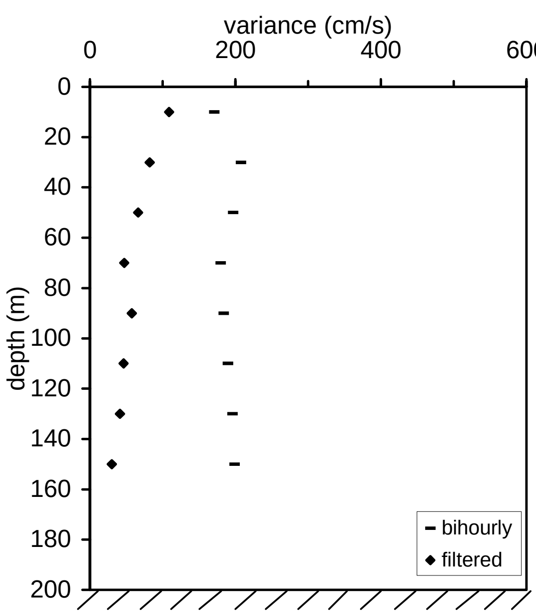


Cross-Strait

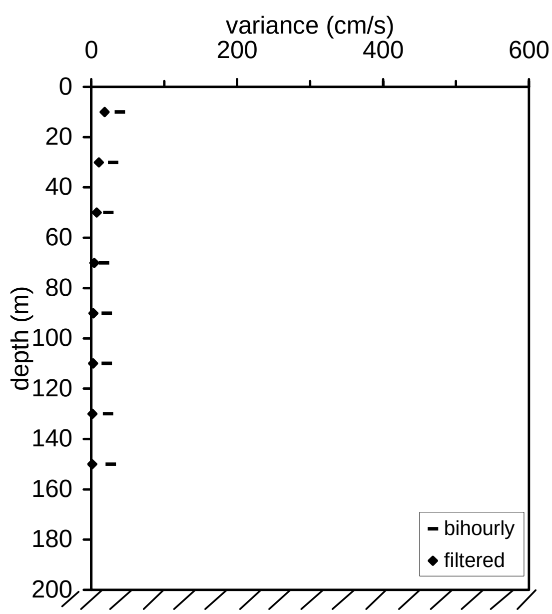


North Side of Barrow Strait:

Along-Strait

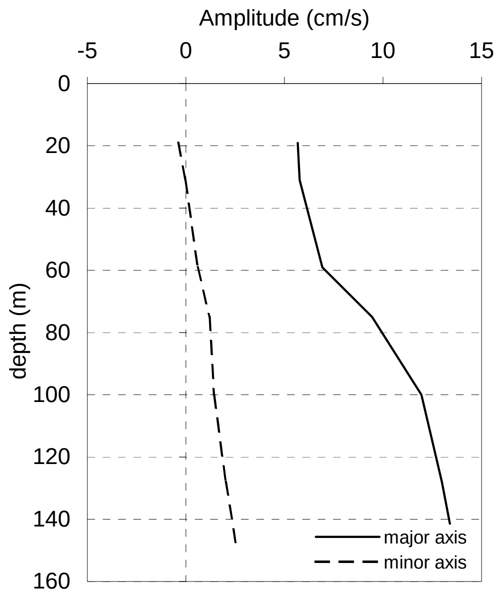


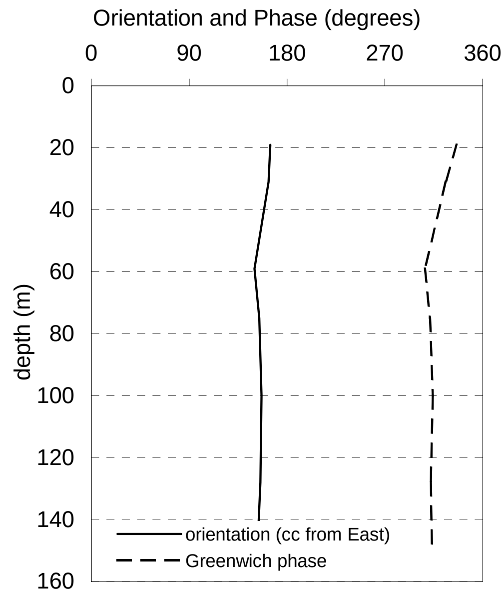
Cross-Strait



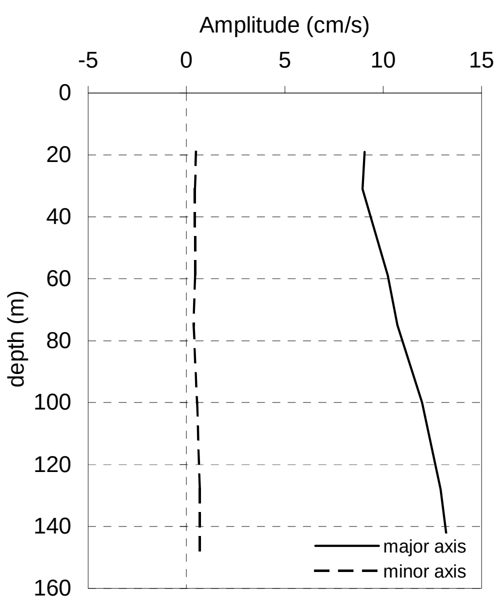
<u>Figure 29</u> - K1 Tidal constituent, North side of Barrow Strait

For ice-free period (Aug 19, 1999 to Oct 4, 1999):





For solid-ice period (Dec 15, 1999 to Jul 2, 2000):



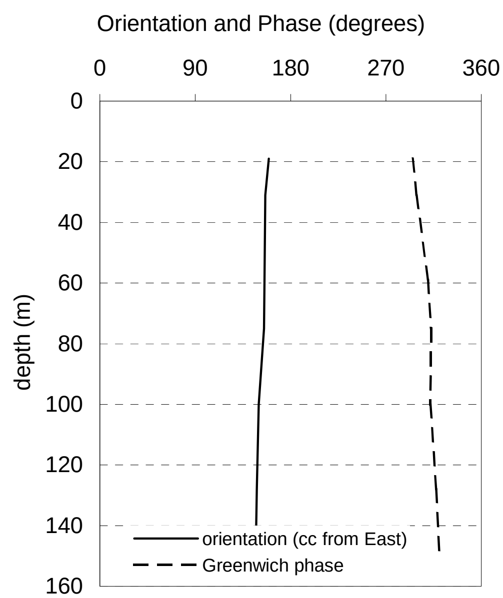
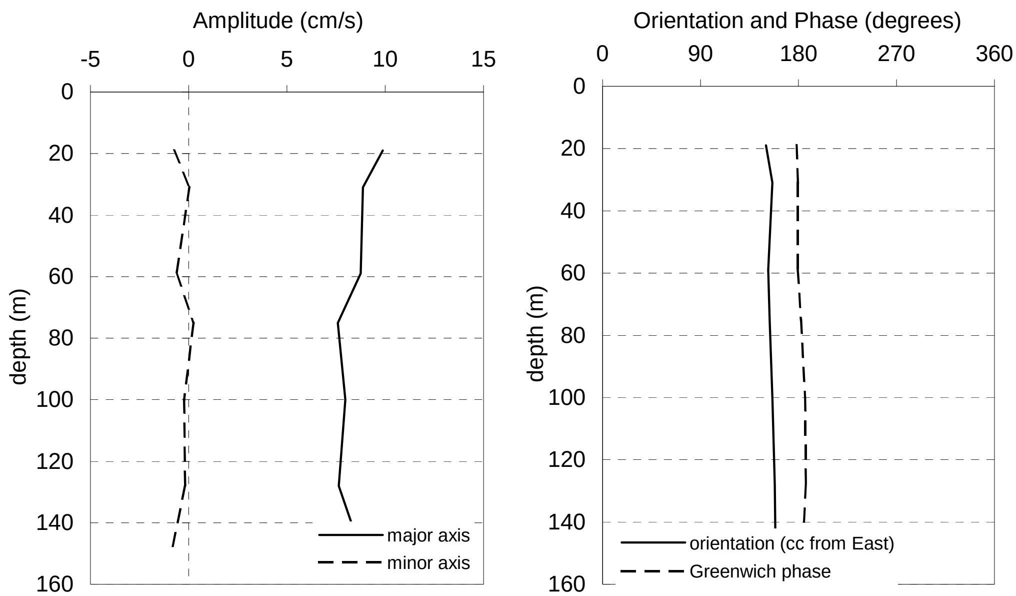


Figure 30 - M2 Tidal constituent, North side of Barrow Strait

For ice-free period (Aug 19, 1999 to Oct 4, 1999):



For solid-ice period (Dec 15, 1999 to Jul 2, 2000):

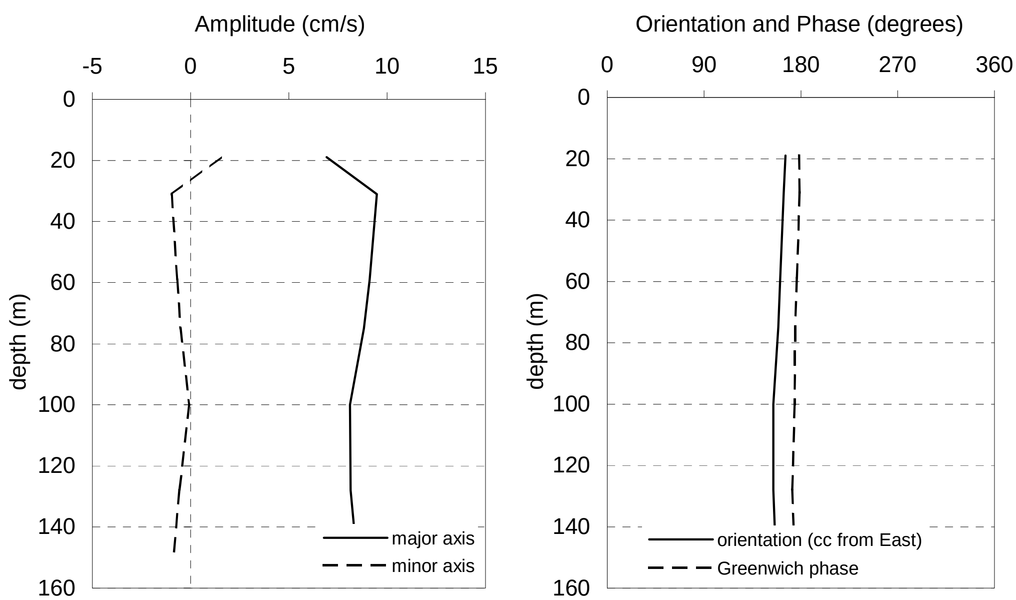
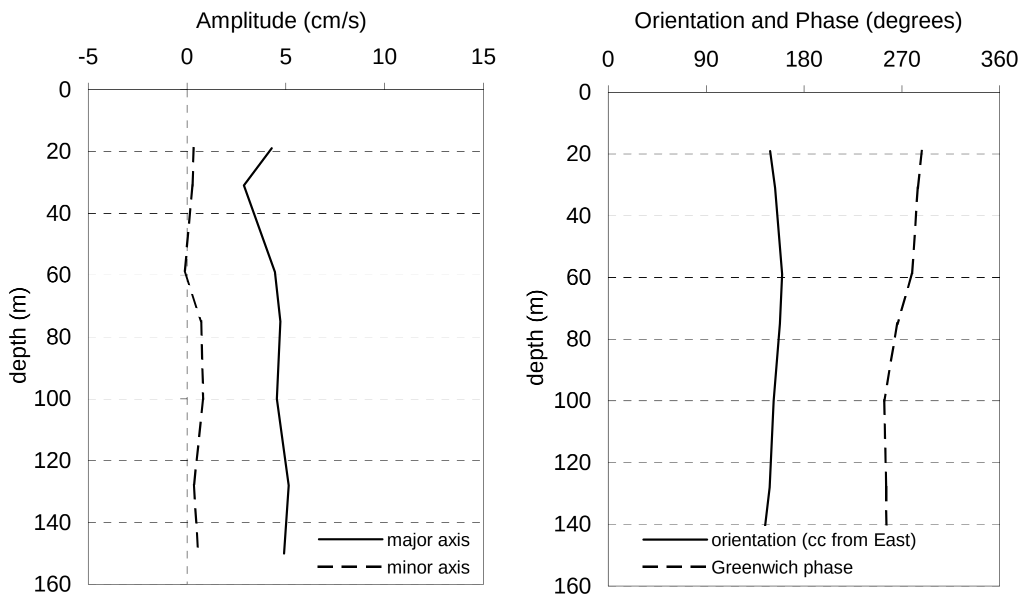


Figure 31 - O1 Tidal constituent, North side of Barrow Strait

For ice-free period (Aug 19, 1999 to Oct 4, 1999):



For solid-ice period (Dec 15, 1999 to Jul 2, 2000):

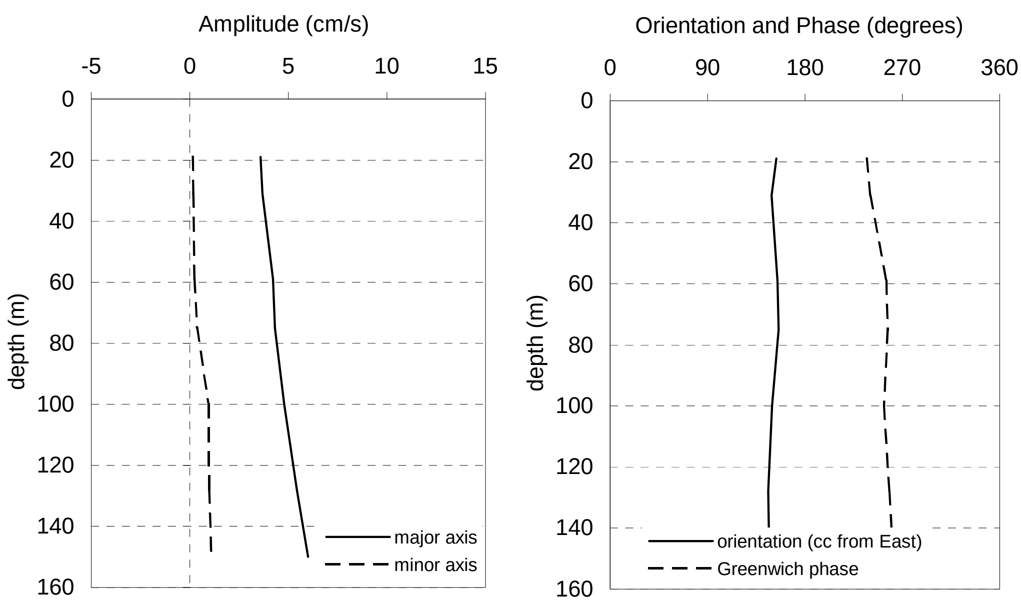
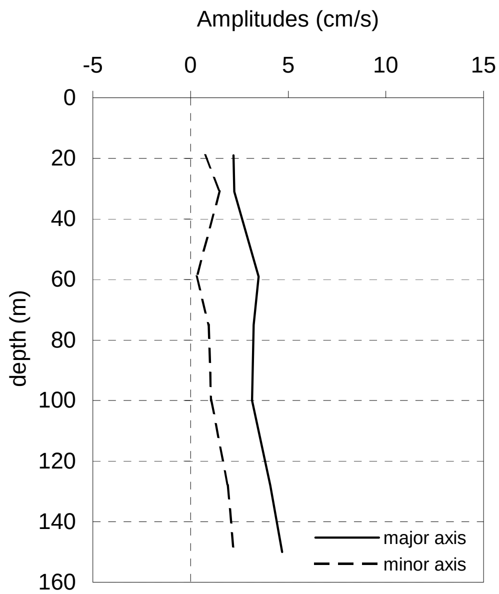
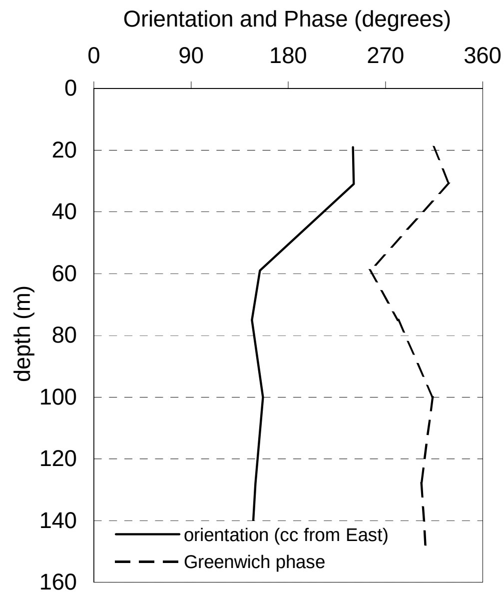


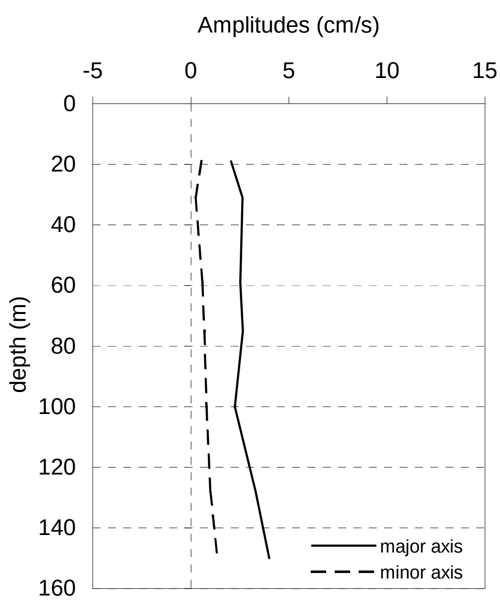
Figure 32 - P1 Tidal constituent North side of Barrow Strait

For ice-free period (Aug 19, 1999 to Oct 4, 1999):





For solid-ice period (Dec 15, 1999 to Jul 2, 2000):



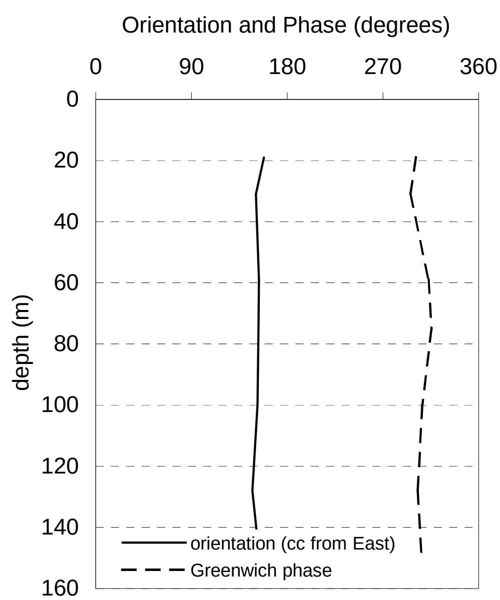
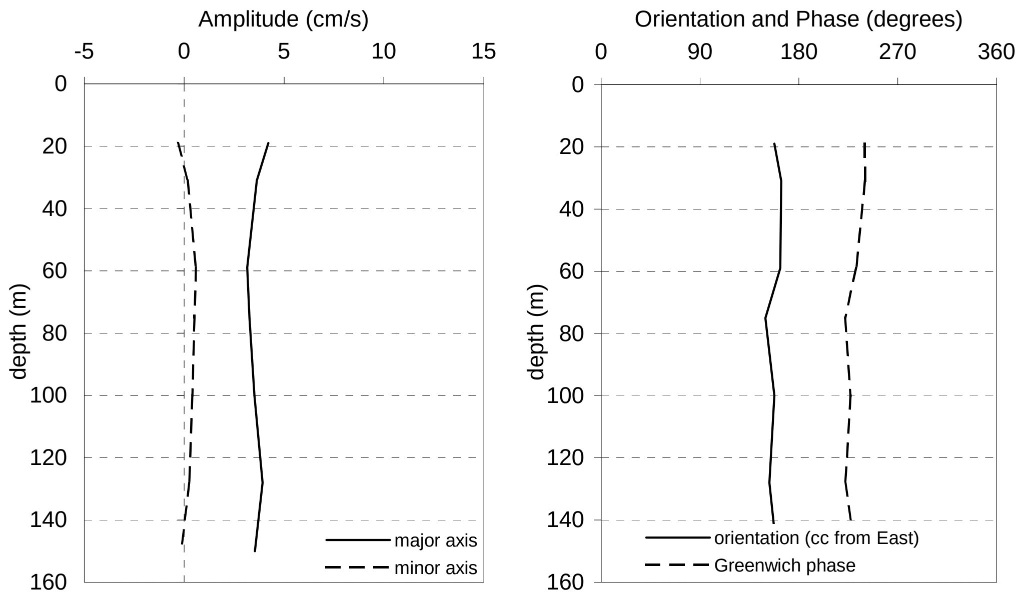
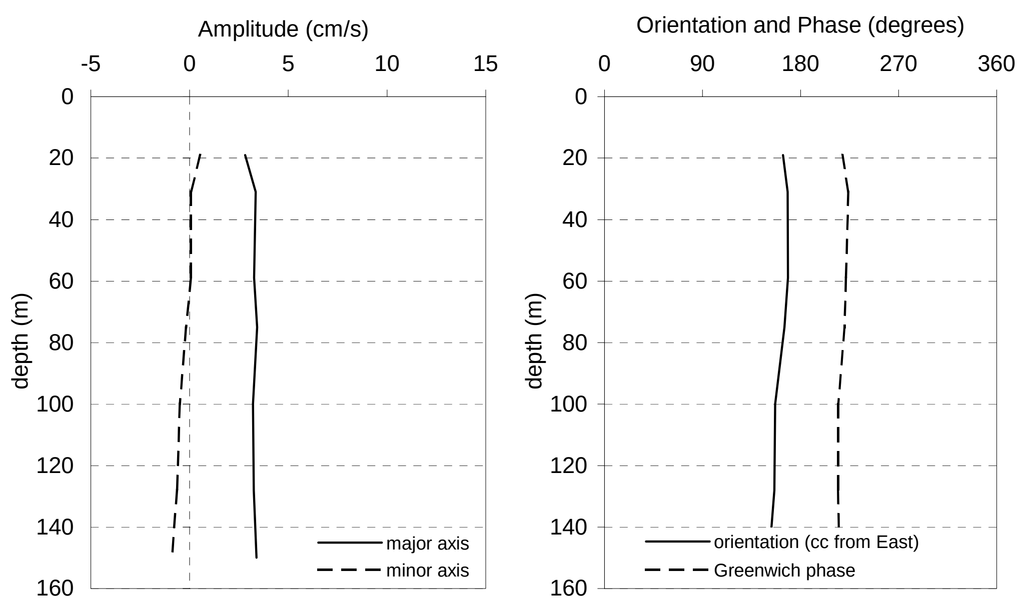


Figure 33 - S2 Tidal constituent, North side of Barrow Strait

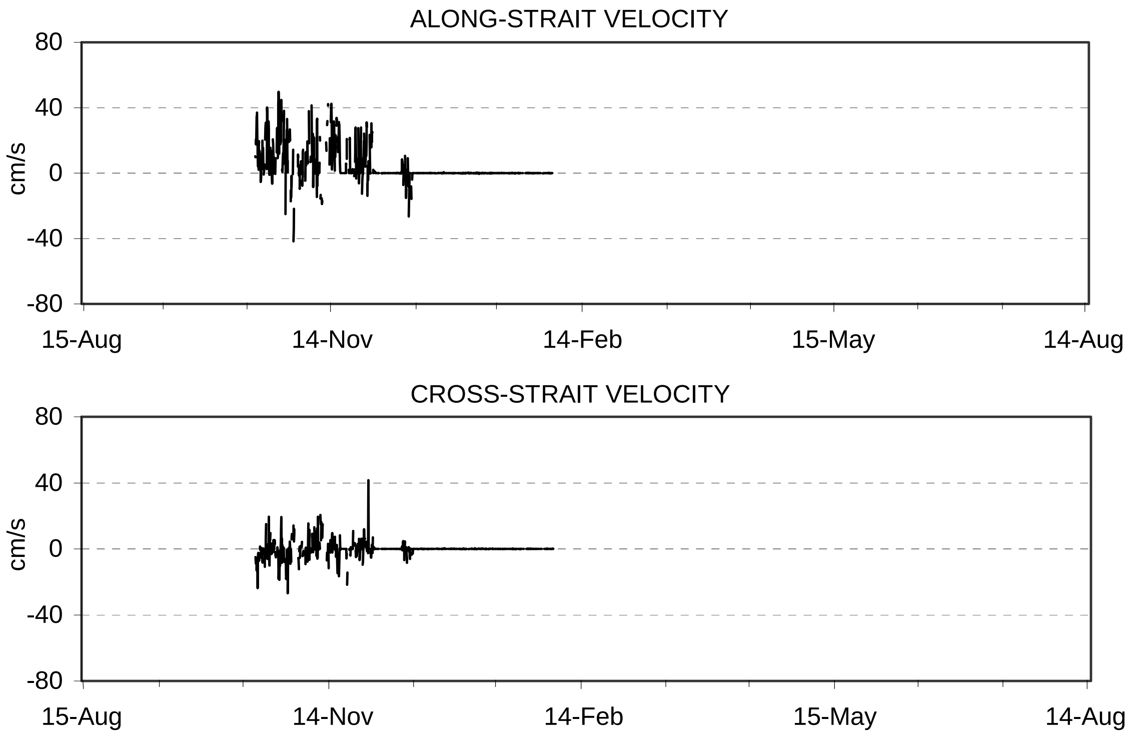
For ice-free period (Aug 19, 1999 to Oct 4, 1999):



For solid-ice period (Dec 15, 1999 to Jul 2, 2000):



<u>Figure 34</u> - Ice velocity data, South side of Barrow Strait: Aug 1999 - Aug 2000.



<u>Figure 35</u> - Ice velocity data, North side of Barrow Strait: Aug 1999 - Aug 2000.

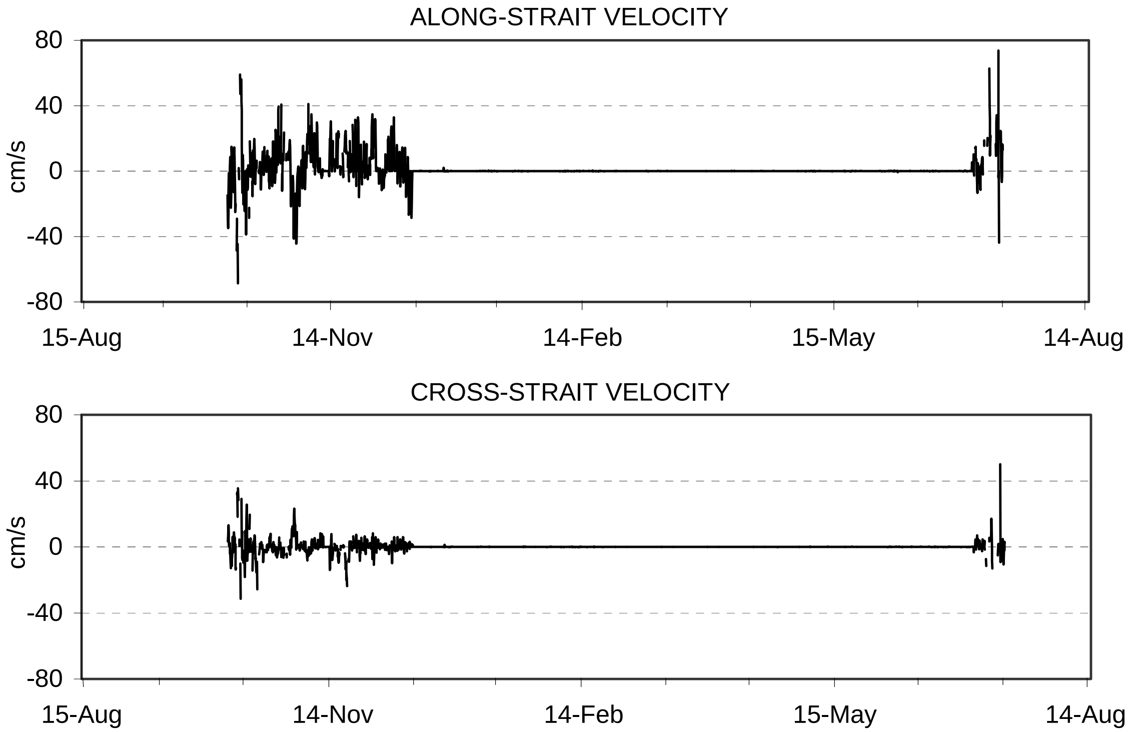


Figure 36 – Eastern Barrow Strait CTD line, Aug 6-8, 2000.

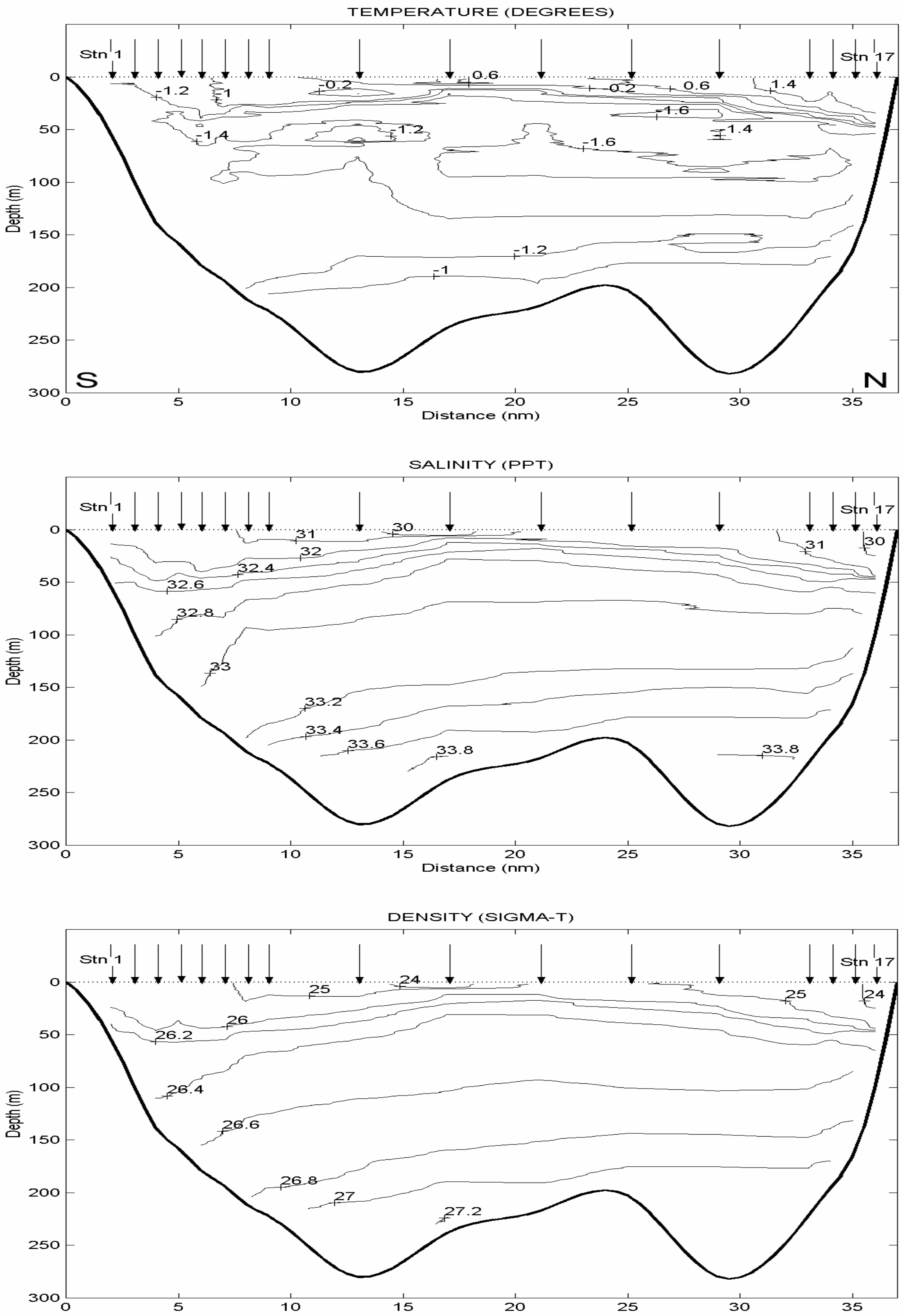


Figure 37 – Western Barrow Strait CTD line, Aug 8-9, 2000.

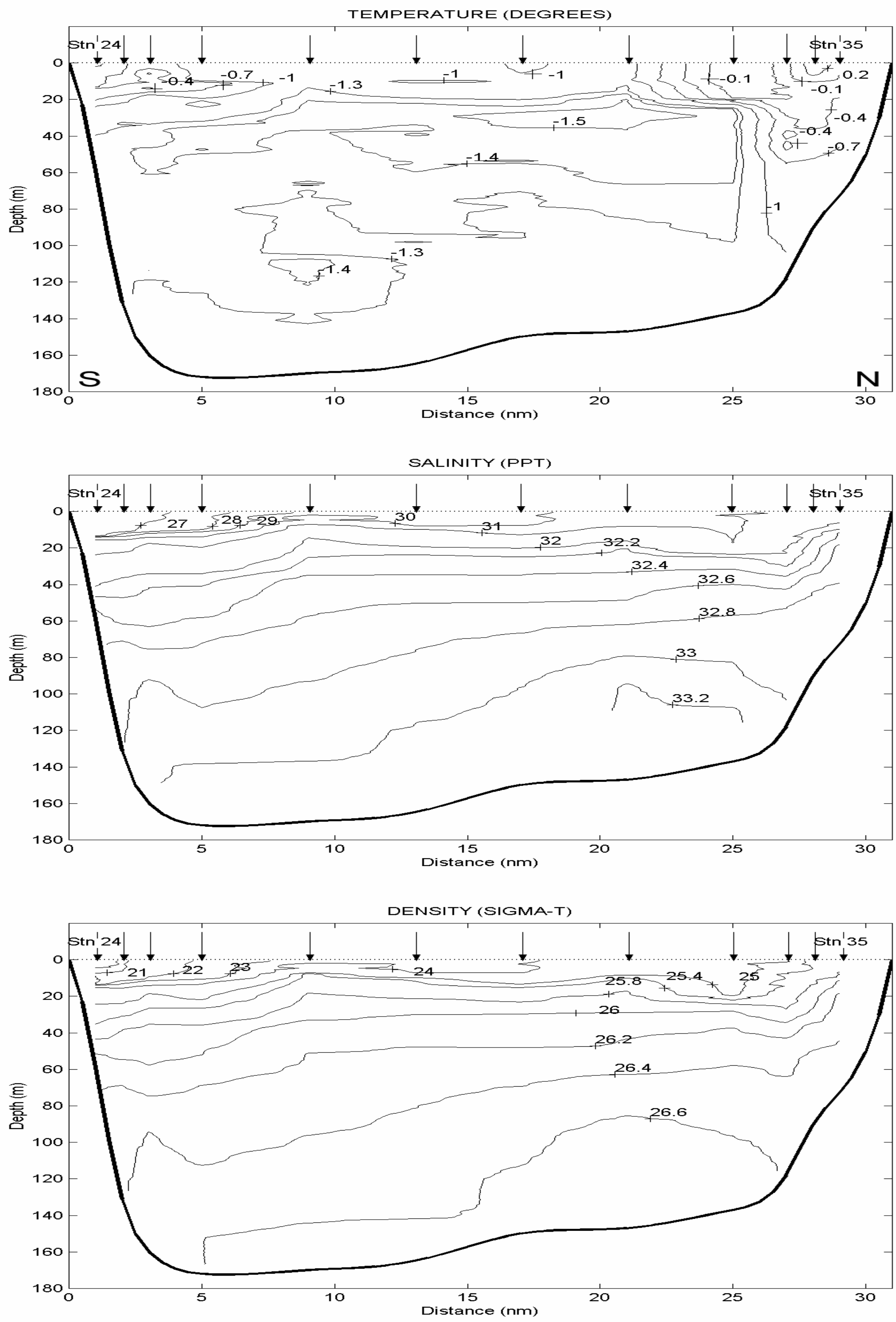


Figure 38 – Wellington Channel CTD line, Aug 9-10, 2000.

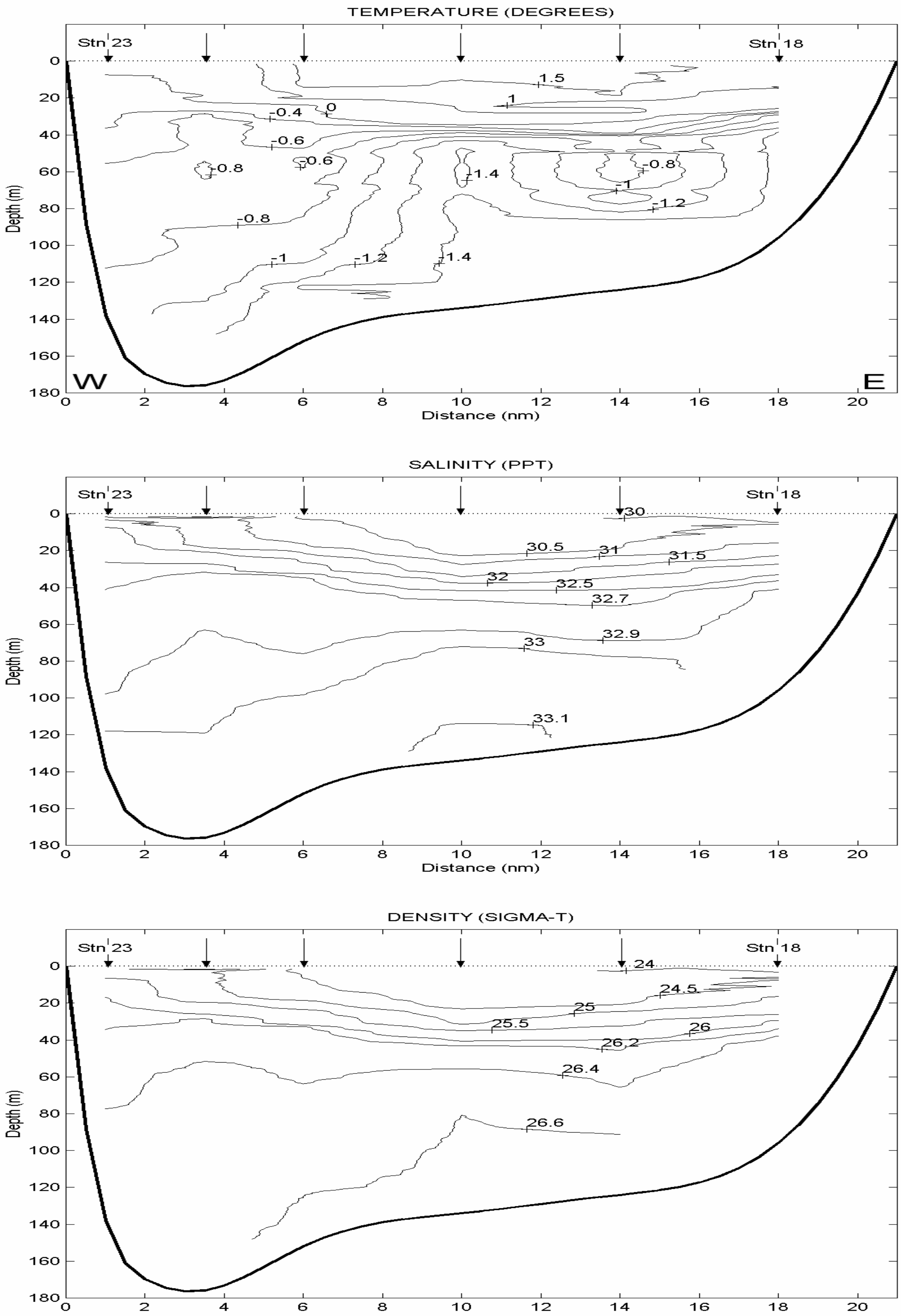


Table 1: North Side Barrow Strait, CTD/ADCP statistical summary
Late Summer : 21/08/1999-20/09/1999

	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
27						instrument		lost					-11.12	16.02	-55.48	33.10	2.53	6.19	-13.69	30.91
39	-1.08	0.71	-1.64	0.83	32.25	0.38	31.38	32.74	25.92	0.33	25.14	26.34	-9.22	14.24	-42.34	32.49	1.87	5.18	-16.12	21.83
83	-1.58	0.03	-1.64	-1.42	32.72	0.12	32.31	32.89	26.32	0.10	25.99	26.46	-2.61	13.86	-45.49	32.39	1.77	4.73	-14.25	18.08
149	-1.38	0.10	-1.58	-1.10	33.13	0.17	32.15	33.47	26.65	0.13	25.86	26.92	-3.50	13.38	-43.67	26.92	1.53	5.29	-15.59	18.74
176	-1.18	0.13	-1.55	-0.89	33.38	0.15	32.86	33.62	26.84	0.12	26.43	27.03								

Table 2: South Side Barrow Strait, CTD/ADCP statistical summary
Late Summer : 21/08/1999-20/09/1999

	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
27	-1.01	0.33	-1.50	0.58	31.92	0.17	30.92	32.36	25.66	0.14	24.83	26.00	27.65	18.47	-24.58	74.08	4.05	8.04	-21.93	26.38
44	-1.41	0.21	-1.68	0.17	32.28	0.13	31.87	32.61	25.96	0.11	25.57	26.23	26.06	18.53	-17.84	70.51	3.31	7.14	-23.15	22.16
69	-1.50	0.11	-1.70	-0.33	32.58	0.11	32.31	32.84	26.20	0.09	25.95	26.42	24.17	17.61	-21.97	65.37	2.91	5.82	-20.11	20.33
81	-1.50	0.10	-1.63	-0.54	32.68	0.09	32.42	32.87	26.28	0.08	26.05	26.44	23.66	17.26	-21.69	67.93	3.08	5.46	-18.88	18.38
162													16.33	16.04	-29.66	48.73	1.99	7.16	-18.50	20.80
168	-1.31	0.18	-1.56	-0.75	33.01	0.26	32.73	33.69	26.55	0.20	26.33	27.08								

Table 3: North Side Barrow Strait, CTD/ADCP statistical summary
Fall: 21/09/1999-20/12/1999

	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
27						instrument		lost					-6.05	16.52	-73.01	40.63	1.19	7.57	-42.94	30.04
39	-1.24	0.53	-1.76	0.36	32.09	0.31	31.24	32.65	25.80	0.27	25.08	26.26	-5.98	16.48	-74.85	44.52	1.07	7.03	-42.07	35.37
83	-1.48	0.05	-1.59	-1.19	32.70	0.11	32.23	32.92	26.31	0.09	25.91	26.49	-2.12	14.63	-41.23	38.98	2.19	4.87	-15.77	23.59
149	-1.27	0.14	-1.55	-0.73	33.17	0.19	32.74	33.74	26.68	0.15	26.34	27.12	-2.36	14.18	-36.11	36.23	2.21	4.31	-12.17	16.65
176	-1.07	0.18	-1.47	-0.57	33.41	0.19	32.90	33.80	26.87	0.15	26.47	27.16								

Table 4: South Side Barrow Strait, CTD/ADCP statistical summary
Fall: 21/09/1999-20/12/1999

	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
27	-1.33	0.30	-1.72	-0.22	31.48	0.34	30.05	32.17	25.31	0.27	24.15	25.86	10.86	19.70	-37.90	84.94	0.00	8.28	-24.21	35.84
44	-1.24	0.18	-1.74	-0.34	32.04	0.17	31.10	32.53	25.77	0.14	25.00	26.16	8.32	17.26	-35.84	80.52	-0.17	7.02	-23.10	21.98
69	-1.33	0.09	-1.54	-0.66	32.52	0.09	31.79	32.76	26.15	0.07	25.54	26.35	6.86	16.18	-33.06	64.98	-0.24	5.48	-21.35	23.42
81	-1.38	0.09	-1.57	-0.82	32.65	0.08	32.41	32.87	26.26	0.07	26.06	26.44	6.13	16.73	-37.68	60.92	-0.20	5.07	-15.37	21.40
162													3.70	16.75	-40.86	44.33	-0.30	9.09	-27.93	19.90
168	-1.09	0.23	-1.46	-0.54	33.31	0.28	32.02	33.81	26.78	0.22	25.74	27.17								

Table 5: North Side Barrow Strait, CTD/ADCP statistical summary
Winter : 21/12/1999-20/03/2000

	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
27							instrument	lost					2.79	11.41	-34.47	36.00	-0.17	3.89	-13.94	13.29
39	-1.66	0.08	-1.77	-1.42	32.62	0.19	32.18	32.93	26.24	0.15	25.89	26.49	1.92	11.75	-40.38	30.88	0.56	4.07	-18.40	13.39
83	-1.41	0.09	-1.72	-1.19	32.89	0.18	32.19	33.23	26.46	0.14	25.89	26.73	-1.59	12.17	-35.13	26.17	1.59	4.40	-12.70	15.62
149	-1.13	0.14	-1.44	-0.63	33.30	0.15	32.82	33.71	26.78	0.12	26.40	27.09	-1.98	14.22	-42.61	36.67	1.43	5.97	-14.04	25.22
176	-0.90	0.18	-1.25	-0.35	33.50	0.14	33.09	33.82	26.93	0.10	26.61	27.17								

Table 6: South Side Barrow Strait, CTD/ADCP statistical summary
Winter : 21/12/1999-20/03/2000
(Velocity statistics calculated from data spanning 21/12/99 - 30/01/00 only)

	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
27	-1.70	0.04	-1.77	-1.55	32.03	0.26	31.33	32.55	25.76	0.21	25.20	26.19	5.39	11.76	-28.51	43.99	1.17	5.84	-19.95	21.41
44	-1.59	0.11	-1.76	-1.33	32.32	0.31	31.32	32.71	26.00	0.25	25.19	26.32	7.05	14.90	-36.24	46.51	1.04	6.12	-16.39	20.57
69	-1.53	0.13	-1.75	-1.30	32.64	0.08	32.37	32.87	26.25	0.07	26.03	26.45	8.06	17.05	-38.08	51.09	1.00	5.98	-14.51	16.68
81	-1.52	0.13	-1.75	-1.31	32.69	0.07	32.16	32.87	26.30	0.06	25.87	26.45	8.79	17.37	-38.15	49.54	0.57	5.68	-23.42	17.18
162													8.14	17.17	-47.69	42.48	0.68	8.74	-32.80	19.66
168	-1.21	0.18	-1.69	-0.56	33.10	0.25	32.01	33.73	26.62	0.19	25.74	27.11								

Table 7: North Side Barrow Strait, CTD/ADCP statistical summary
Spring : 21/03/2000-20/06/2000

	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
27						instrument		lost					2.84	11.07	-30.35	31.00	-0.37	3.60	-15.33	10.69
39	-1.68	0.05	-1.78	-1.54	32.61	0.16	32.15	32.97	26.23	0.13	25.87	26.53	2.80	11.89	-38.78	30.91	0.36	4.00	-13.49	13.43
83	-1.51	0.13	-1.77	-1.22	33.06	0.10	32.79	33.36	26.60	0.08	26.37	26.84	0.30	12.61	-50.60	30.67	2.55	4.07	-10.25	19.02
149	-1.19	0.19	-1.64	-0.77	33.48	0.07	33.30	33.66	26.93	0.05	26.79	27.06	-1.24	13.29	-38.62	34.57	1.46	4.34	-11.43	19.40
176	-0.99	0.25	-1.54	-0.49	33.58	0.07	33.41	33.75	27.00	0.05	26.87	27.12								

Table 8: South Side Barrow Strait, CTD/ADCP statistical summary
Spring : 21/03/2000-20/06/2000

	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
27	-1.67	0.07	-1.77	-1.34	32.24	0.17	31.69	32.66	25.94	0.14	25.49	26.28								
44	-1.62	0.10	-1.78	-1.32	32.57	0.07	32.33	32.81	26.20	0.06	26.00	26.40								
69	-1.59	0.10	-1.78	-1.30	32.74	0.06	32.54	32.93	26.34	0.05	26.17	26.49			no	direction		data		
81	-1.61	0.10	-1.78	-1.30	32.80	0.05	32.61	33.03	26.38	0.04	26.23	26.58								
168	-1.29	0.28	-1.73	-0.40	33.11	0.25	32.84	33.81	26.63	0.19	26.42	27.17								

Table 9: North Side Barrow Strait, CTD/ADCP statistical summary
Summer : 21/06/2000-15/08/2000

	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
27					instrument lost								-2.31	14.12	-55.54	26.91	1.63	5.75	-21.19	28.22
39	-1.50	0.42	-1.77	0.63	32.46	0.36	30.89	32.98	26.11	0.30	24.76	26.54	-1.35	13.63	-39.76	31.00	1.71	5.15	-17.38	20.04
83	-1.62	0.07	-1.75	-1.41	32.99	0.06	32.75	33.23	26.55	0.05	26.35	26.73	1.42	14.46	-41.22	35.10	1.38	5.04	-13.33	22.88
149	-1.34	0.09	-1.50	-1.02	33.33	0.13	31.51	33.58	26.81	0.11	25.33	27.00	-1.29	15.46	-38.37	38.56	1.49	6.19	-22.44	24.55
176	-1.11	0.17	-1.41	-0.54	33.52	0.10	33.24	33.77	26.95	0.07	26.74	27.14								

Table 10: South Side Barrow Strait, CTD/ADCP statistical summary
Summer : 21/06/2000-15/08/2000

	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
27	-1.52	0.23	-1.74	1.32	32.22	0.15	31.20	32.74	25.92	0.12	24.97	26.32								
44	-1.53	0.12	-1.75	-1.01	32.43	0.09	32.14	32.75	26.09	0.07	25.84	26.35								
69	-1.46	0.11	-1.73	-0.84	32.67	0.08	32.41	32.98	26.28	0.07	26.07	26.52				no direction data				
81	-1.45	0.15	-1.74	-0.78	32.78	0.08	32.56	33.07	26.37	0.07	26.18	26.60								
168	-1.34	0.07	-1.63	-1.19	33.01	0.08	32.84	33.27	26.55	0.07	26.41	26.76								

Table 11: North Side Barrow Strait, CTD/ADCP statistical summary
Year : 21/08/1999-07/08/2000

	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
27							instrument lost						-1.44	14.47	-73.01	40.63	0.62	5.58	-42.94	30.91
39	-1.49	0.44	-1.78	0.83	32.43	0.35	30.89	32.98	26.08	0.29	24.76	26.54	-1.29	14.27	-74.85	44.52	0.91	5.23	-42.07	35.37
83	-1.49	0.11	-1.77	-1.19	32.89	0.19	32.19	33.36	26.45	0.15	25.89	26.84	-1.19	13.65	-50.60	38.98	1.88	4.67	-15.77	23.59
149	-1.23	0.17	-1.64	-0.63	33.30	0.19	31.51	33.74	26.78	0.15	25.33	27.12	-1.92	14.10	-43.67	38.56	1.65	5.16	-22.44	25.22
176	-1.02	0.22	-1.55	-0.35	33.49	0.15	32.86	33.82	26.93	0.12	26.43	27.17								

Table 12: South Side Barrow Strait, CTD/ADCP statistical summary
Year : 21/08/1999-07/08/2000
(Velocity statistics calculated from data spanning 21/08/1999 - 30/01/00 only)

	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
27	-1.51	0.30	-1.77	1.32	31.96	0.39	30.05	32.74	25.70	0.32	24.15	26.32	12.53	19.25	-37.90	84.94	1.07	7.81	-24.21	35.84
44	-1.48	0.21	-1.78	0.17	32.33	0.27	31.10	32.81	26.00	0.22	25.00	26.40	11.28	18.34	-36.24	80.52	0.80	6.94	-23.15	22.16
69	-1.48	0.15	-1.78	-0.33	32.63	0.12	31.79	32.98	26.25	0.10	25.54	26.52	10.40	17.95	-38.08	65.37	0.68	5.81	-21.35	23.42
81	-1.49	0.14	-1.78	-0.54	32.72	0.10	32.16	33.07	26.32	0.08	25.87	26.60	10.29	18.28	-38.15	67.93	0.66	5.46	-23.42	21.40
162													7.24	17.39	-47.69	48.73	0.39	8.71	-32.80	20.80
168	-1.23	0.23	-1.73	-0.40	33.14	0.27	32.01	33.81	26.65	0.21	25.74	27.17								

Table 13 - Tidal Constants for K1 constituent

North Side

For ice-free period (Aug 19, 1999 to Oct 4, 1999):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
19	5.7	-0.4	165	336
59	6.9	0.6	150	307
100	12.0	1.4	157	314
150	13.7	2.6	153	313

For solid-ice period (Dec 15, 1999 to Jul 2, 2000):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
19	9.1	0.5	160	295
59	10.2	0.4	155	310
100	12.0	0.5	150	312
150	13.4	0.7	147	321

<u>Table 14</u> - Tidal Constants for M2 constituent

<u>North Side</u>

For ice-free period (Aug 19, 1999 to Oct 4, 1999):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
19	9.9	-0.7	150	178
59	8.7	-0.6	152	179
100	8.0	-0.2	156	186
150	8.8	-0.9	159	184

For solid-ice period (Dec 15, 1999 to Jul 2, 2000):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
19	6.9	1.5	166	178
59	9.1	-0.7	161	176
100	8.1	-0.1	155	174
150	8.5	-0.9	157	174

Table 15 - Tidal Constants for O1 constituent

North Side

For ice-free period (Aug 19, 1999 to Oct 4, 1999):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
19	4.3	0.3	149	288
59	4.4	-0.1	160	279
100	4.5	0.8	152	254
150	4.9	0.6	141	256

For solid-ice period (Dec 15, 1999 to Jul 2, 2000):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
19	3.6	0.1	154	237
59	4.2	0.2	155	255
100	4.8	1.0	150	253
150	6.0	1.1	147	261

<u>Table 16</u> - Tidal Constants for P1 constituent

<u>North Side</u>

For ice-free period (Aug 19, 1999 to Oct 4, 1999):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
19	2.2	0.7	240	314
59	3.5	0.3	154	255
100	3.1	1.0	156	314
150	4.7	2.2	146	308

For solid-ice period (Dec 15, 1999 to Jul 2, 2000):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
19	2.0	0.5	158	301
59	2.5	0.6	153	313
100	2.3	0.8	152	307
150	4.0	1.4	154	306

Table 17 - Tidal Constants for S2 constituent

North Side

For ice-free period (Aug 19, 1999 to Oct 4, 1999):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
19	4.2	-0.3	158	240
59	3.2	0.6	163	232
100	3.5	0.4	158	227
150	3.5	-0.1	160	231

For solid-ice period (Dec 15, 1999 to Jul 2, 2000):

Depth m	Major Amplitude cm/s	Minor Amplitude cm/s	Orientation degrees cc from East	Greenwich Phase degrees
19	2.8	0.5	164	218
59	3.3	0.1	169	222
100	3.2	-0.5	157	214
150	3.4	-0.9	151	215