Study of the spatial variability in thermohaline characteristics and water structure on the standard sections in the western Barents Sea

V.Ivshin[1], A.Pedchenko[1], Ø. Skagseth[2] & R. Ingvaldsen[2]

[1]Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Murmansk, Russia
[2]Institute of Marine Research (IMR), Bergen, Norway

Introduction

In order to ensure the comparability of observation results and to estimate seasonal and year-to-year variations in oceanographic variables, it was suggested in Stockholm as early as 1899 that measurements should be made at standard depths and on standard sections. At the beginning of the 20th century observations commenced on the Kola Section in the Barents Sea (Knipovich, 1901, 1906), and by the 1930s, a network of such sections had been developed in the area. One of them stretched from the North Cape to Bear Island.

Sections are important not only for research on hydrographic processes, but also for studies of marine ecosystem functioning (Bochkov, 1980; Tereshchenko, 1992, 1996; Adrov, 1993). Observations on the standard sections were used to study water circulation (Kislyakov, 1964, 1969; Kudlo, 1970; Loeng, 1979; Loeng H. et al., 1997, Ingvaldsen R. et al., 1999), water masses (Tsekhotskaya, 1985; Boitsov, 1995), to make hydrographic (Pennin, 1973; Fuks, 1980, Karsakov et al., 2001) and fishery (Mukhina, Dvinina, 1989; Boitsov, 2005) forecasts as well as to solve many other problems. Today, long-term data series such as the Kola Section, the section through the Faroe-Shetland Strait and others are widely used in up-to-date research (Anon, 2005).

The inflow of the Atlantic water masses into the Barents Sea area is the main cause of its peculiar climate and high biological productivity. Using the Fugløy -- Bear Island (FB) and North Cape – Bear Island (NB) Sections located on the western sea border, the characteristics of the Atlantic water masses flowing into the sea can be studied.

Regular observations on FB started in 1964, but since the late 1970s they have been performed, as a rule, six times a year. The NB Section should be related to the unique ones. In total, it has been sampled more than 670 times (Figure 1) in the course of about 80 years.

The first observations on the section were made by the research vessel “Persey” in July 1929 (Figure 2).

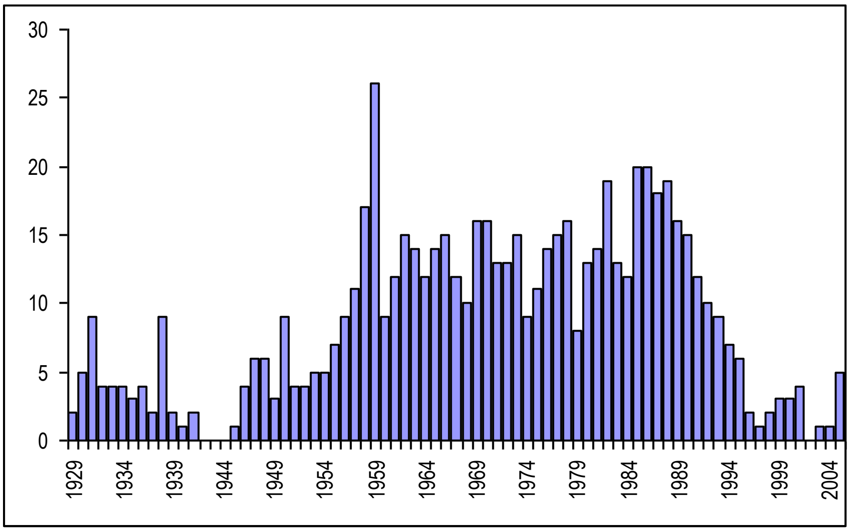

Figure 1. Number of times the North Cape – Bear Island Section has been sampled between 1929 and 2004.

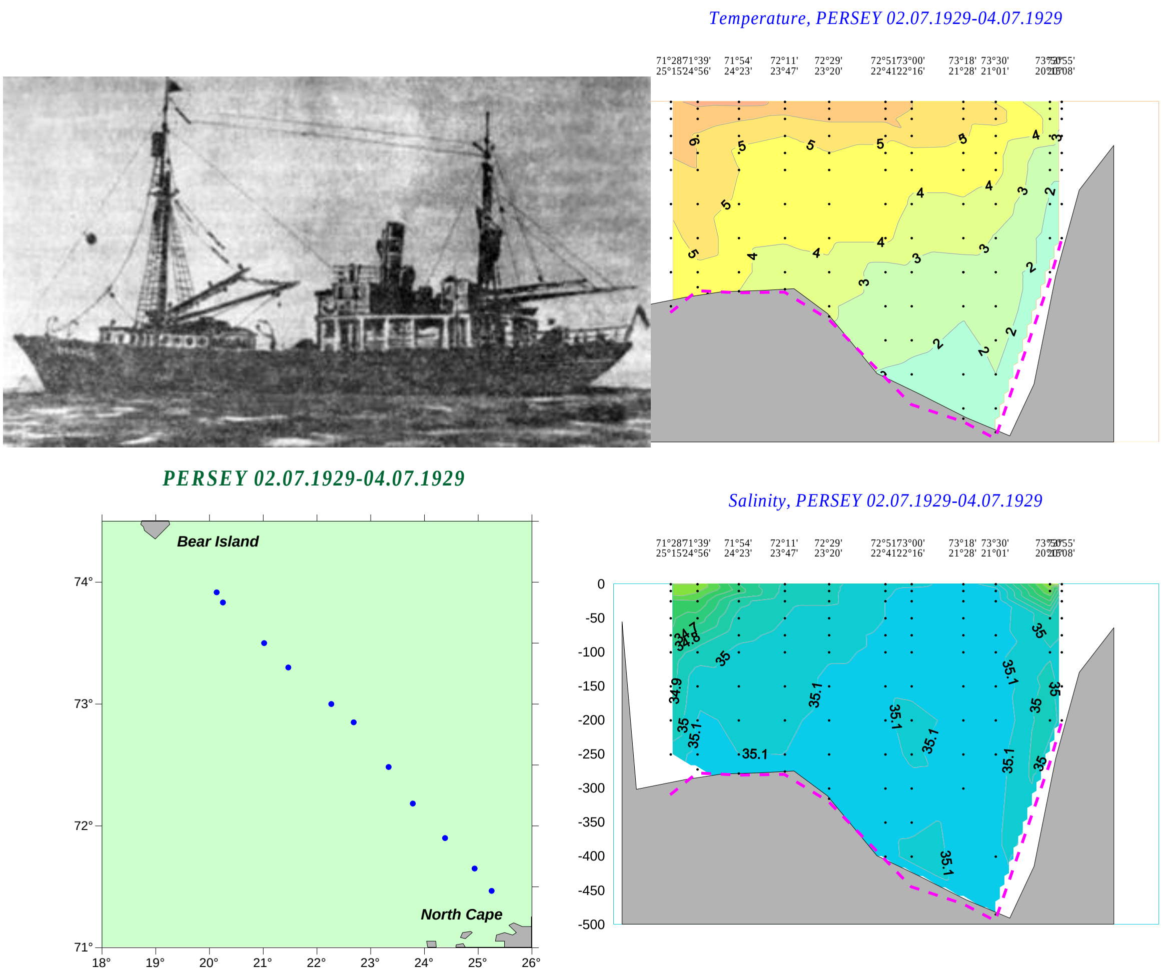

Figure 2. Sampling the North Cape – Bear Island Section in 1929.

Unfortunately, the number of observations on the NB Section has been severely reduced during the past 10-12 years, and at present it is sampled two or three times a year.

One possible means of filling the gaps in data series of a section is to utilise accessible information for another section. For this, it is necessary to study the thermohaline characteristics of these sections.

Materials and methods

This study used data from hydrographic observationsmade on the standard FB (IMR) and NB (PINRO) Sections (Fig.3) in 1977-2005.

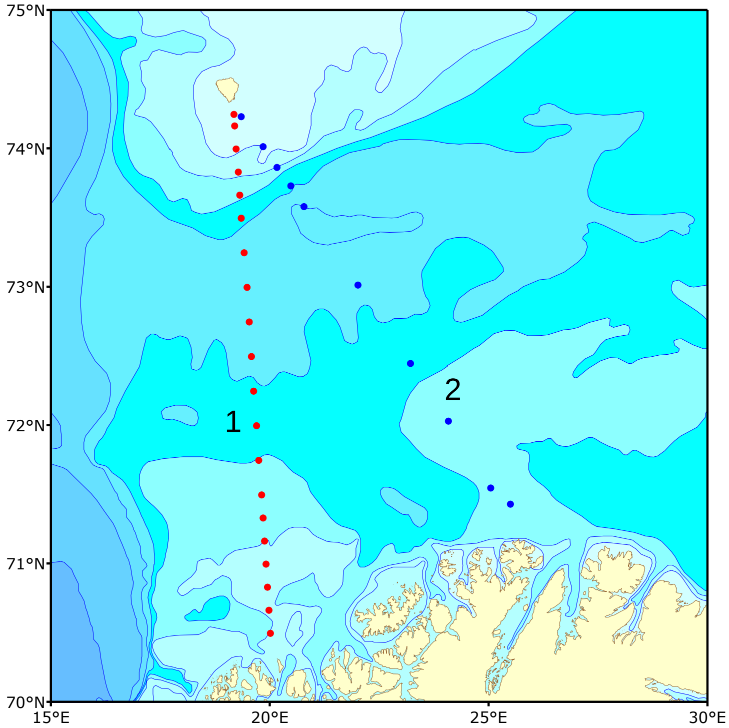

Figure 3. Position of the Norwegian Fugløy – Bear Island Section (1) and the Russian North Cape – Bear Island Section (2).

The positions of standard stations on the sections studied are shown in Table 1. Station numbering starts from the Norwegian coast.

Mean weighted values of water temperature and salinity at Stations 7-15, in the 50-200 m layer in the Fugløy – Bear Island Section were calculated by methods used in PINRO. The series were from 1977-2006 and for different months: January, March, April-May, June, August-September and October. The same was done with the aid of the hydrographic database at PINRO for the North Cape – Bear Island Section.

First, the part of the NB Section whose thermohaline characteristics were most similar to those of the FB Section was found. In general, a correlation field (r_{P1P2}) in the NB Section plane was formed on the basis of the statistical relationship between the two time series: P_1 – time series of temperature/salinity in the FB Section in the month studied; P_2 - time series of temperature/salinity at the standard station (1-10), in the standard layer (0, 10…400 m), in the NB Section in the same month.

Some 1200 sets of correlation coefficients were calculated (T, S * months * standard stations on NB about 80 year Section * standard layers). Using the correlation coefficients calculated, vertical fields were plotted for each month in the NB Section plain, with a net horizontal pitch of 10 miles and 20 miles vertical. In order to sum the correlation fields, the mean field (for the months studied) was plotted by averaging the same named nodes in the network.

Table 1. Positions of standard stations on the Fugløy – Bear Island and North Cape – Bear Island Sections.

Stations	Fugløy – Bear Island			North Cape – Bear Island		
	Latitude	Longitude	Bottom Depth (m)	Latitude	Longitude	Bottom Depth (m)
1	70°30' N	20°00' E	129	71°26' N	25°29' E	298
2	70°40' N	19°58' E	158	71°33' N	25°02' E	288
3	70°50' N	19°56' E	186	72°02' N	24°04' E	278
4	71°00' N	19°54' E	188	72°27' N	23°12' E	311
5	71°10' N	19°52' E	215	73°01' N	22°00' E	429
6	71°20' N	19°50' E	207	73°35' N	20°46' E	491
7	71°30' N	19°48' E	231	73°44' N	20°28' E	419
8	71°45' N	19°44' E	265	73°52' N	20°09' E	260
9	72°00' N	19°41' E	307	74°01' N	19°50' E	129
10	72°15' N	19°37' E	322	74°14' N	19°20' E	65
11	72°30' N	19°34' E	385			
12	72°45' N	19°31' E	398			
13	73°00' N	19°28' E	410			
14	73°15' N	19°24' E	445			
15	73°30' N	19°20' E	476			
16	73°40' N	19°18' E	344			
17	73°50' N	19°16' E	232			
18	74°00' N	19°13' E	139			
19	74°10' N	19°11' E	80			
20	74°15' N	19°10' E	55			

In order to analyze similarities in thermohaline characteristics, the fields of temperature/ salinity standard deviations (analogous to the correlation measures) on the NB Section were calculated and mapped.

Mean weighted values of temperature and salinity in the 50-200 m layer were calculated from the NB Section stations that showed the closest similarity with the thermohaline characteristics of the FB Section. The relationship between the hydrographic characteristics in the sections was quantified by regression analysis performed on the series of averages for the NB Section and the series for the FB Section.

Results

The existing concept of water circulation system at the entrance to the Barents Sea allows us to determine that the thermohaline characteristics of waters in the FB Section line are a "signal", the reaction to which may be observed on the NB Section. The extent of this "scheme" coherence in the temperature field is demonstrated quite well on the fields plotted (Figure 4).

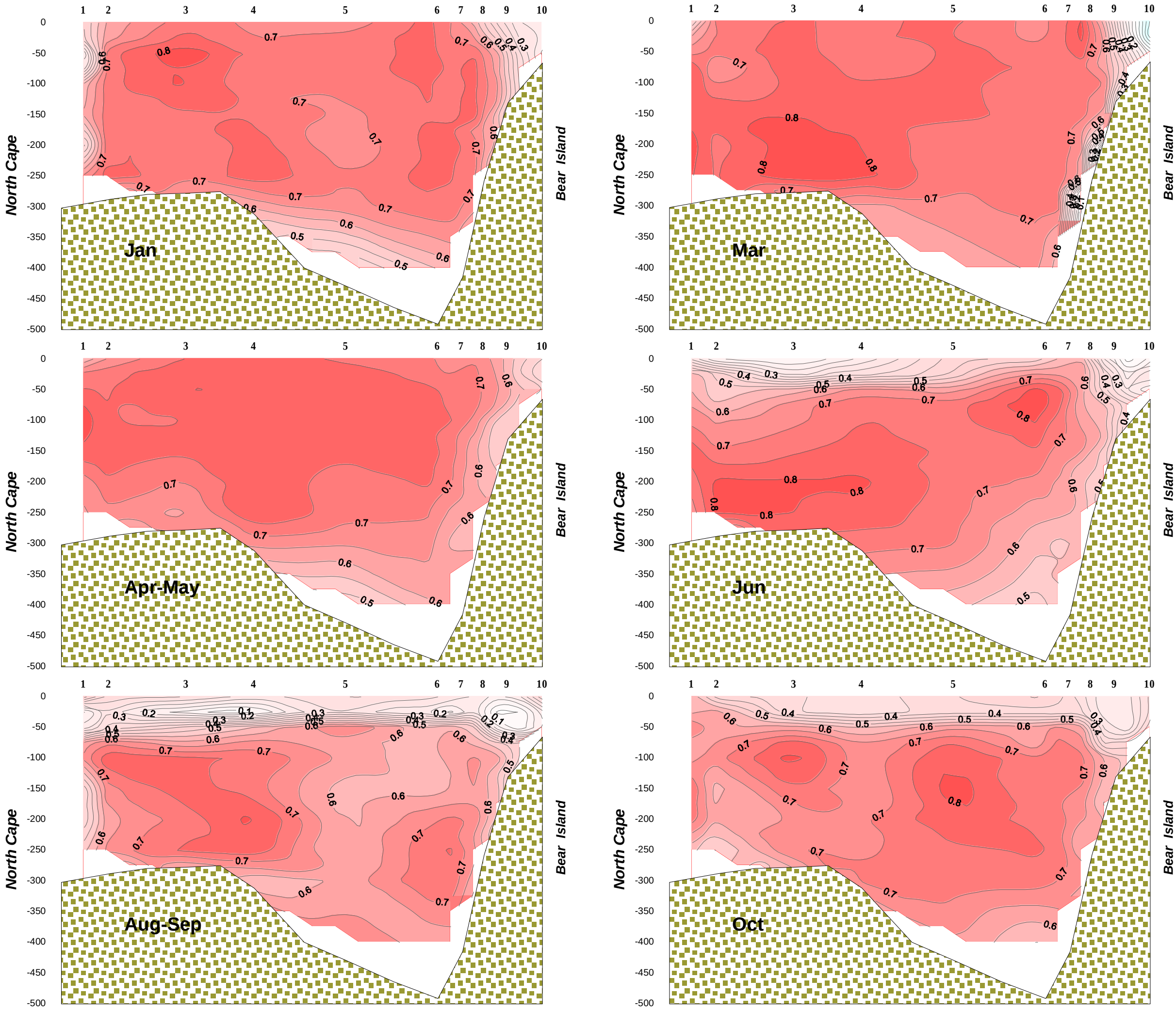

Figure 4. Correlation of water temperature mean weighted values in 50-200 m layer between FB and NB sections in January, March, April-May, June, August-September, October.

The correlation field for January shows the existence of a significant relationship in the wide plane of the NB Section. The highest correlation coefficients (r>0.75) were registered in the area of Station 3, at 50-150 m depths, and, as single local patches, at Stations 4, 6 and 7. In March, the identical area of high correlation coefficients (r>0.75) widens and occupies a large area from Station 1 to Station 5, from the surface down to 250 m. The closest relationship between water temperature on FB (Fugløy-Bear Island) and NB (North Cape-Bear Island) Sections is observed in April-May. Before this period, the only area with insignificant correlation coefficients is Station 10.

When the warm period of a year begins, the structure of the correlation field in the plane of the NB Section varies. A general weakening of the relationship is recorded. Primarily, this concerns the surface layers. In June, two localized areas of higher correlation values (r>0.75) are observed: the first one between Stations 1 and 4, at depths of 150-250 m, the secondin the area of Station 6, in 50-150 m layer. However, in the core of these areas correlation coefficients may exceed 0.8. According to our calculations, August and September are the months of least similarity in temperature on the sections studied; nevertheless, the areas of significant correlation coefficients are quiteextensive. In October a rise in correlation values as compared to August-September is noticed. Maximum correlations are at Stations 3 and 5, within the depth range of 75-200 m.

In general, the similarities in variations in salinity in the two sections are less than the relationship in temperature (Figure 5).

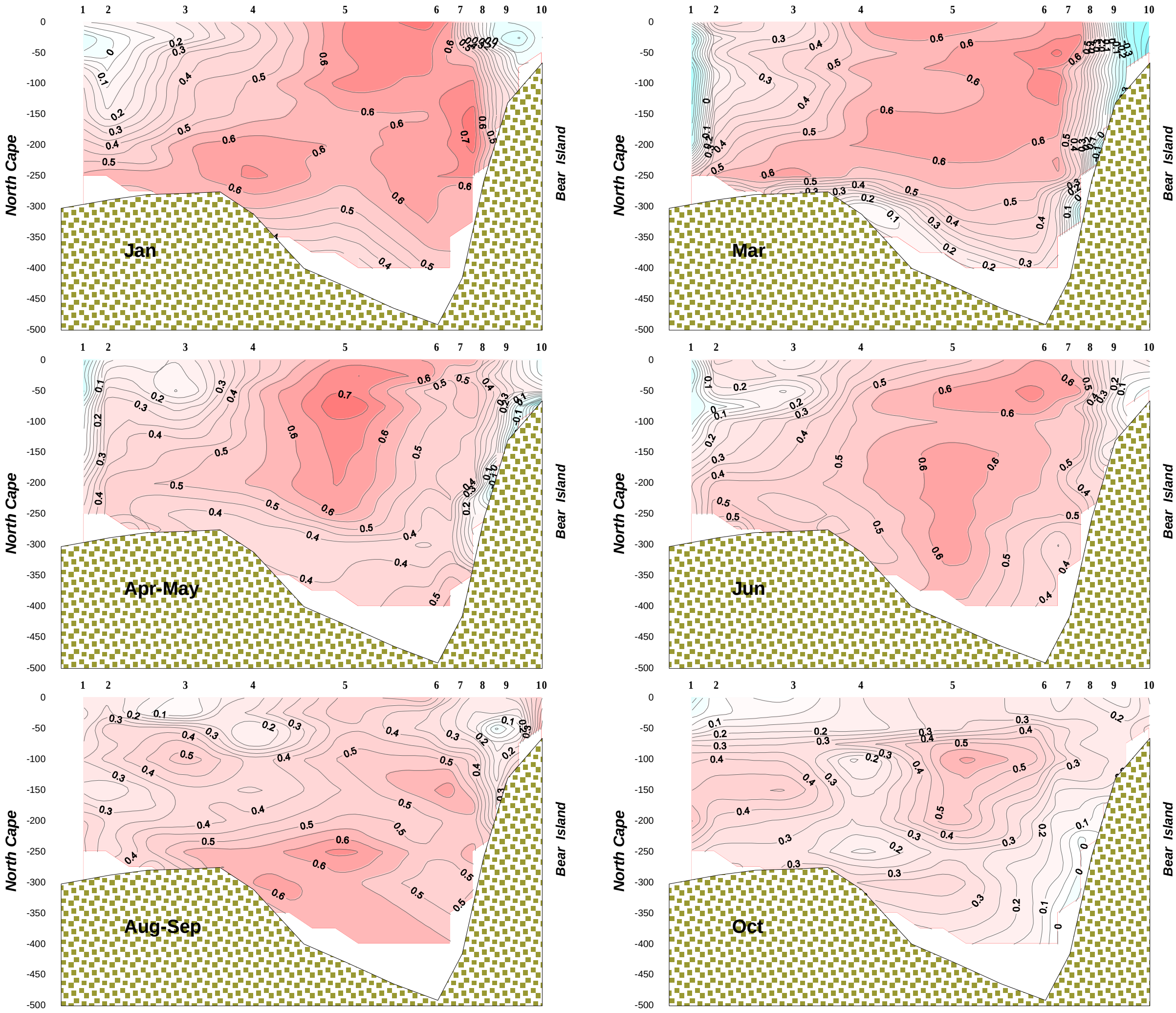

Figure 5. Correlation of salinity mean weighted values in 50-200 m layer between FB and NB Sections in January, March, April-May, June, August-September, October.

Where temperature is concerned, the similarity in salinity variations is higher in the cold period of the year. In January the maximal correlation coefficients (0.6 and higher) are observed at Stations 5 and 6 from the surface to 250 m depth, and at Station 7 at a depth of 200 m (0.7 and higher). At the outermost stations of the section the relationship may be even opposite. In March, the area of higher correlation coefficients is practically the same as in January.

In April-May, there is a general decrease in the closeness of the relationship in comparison with the previous months. The closest relationship between the salinity series is found in the area of Station 5 on the NB Section. In June, the closest relationship is recorded at Stations 5 and 6 on this section. It should be noticed that some embedding occurs in the domain of higher correlation coefficients.If that domain was located in the upper 200 m layer in April-May, it may therefore descend to below 300 m in June. Further embedding of this domain is observed in August-September when its upper border is 200 m deep. On the whole, August may be characterized as a month with a chaotic distribution of correlation coefficients. October is the month with the least agreement in the salinity distribution. That month showed practically no steady domains of significant relationship anywhere on the section plane.

In order to determine the optimal range of averaging data on the NB Section, the average fields of correlation coefficients in studied months were plotted (Figure 6).

As the figures show, the field of higher correlation (r>0.7) in temperature occupies quite a wide area from Station 2 to Station 6, with a core (r>0.75) in the region of Stations 3 - 4, within the 100-250 m depth range. Based on the general plot (Figure 6) and monthly correlation fields (Figure 4), it was decided that averaging at Stations 3 - 6 of the section would be optimal. The involvement of Station 2 may weaken the relationship between the thermal water characteristics, since the correlation coefficients in the summer months (June, August-September, Figure 4) in the surface layer are low.

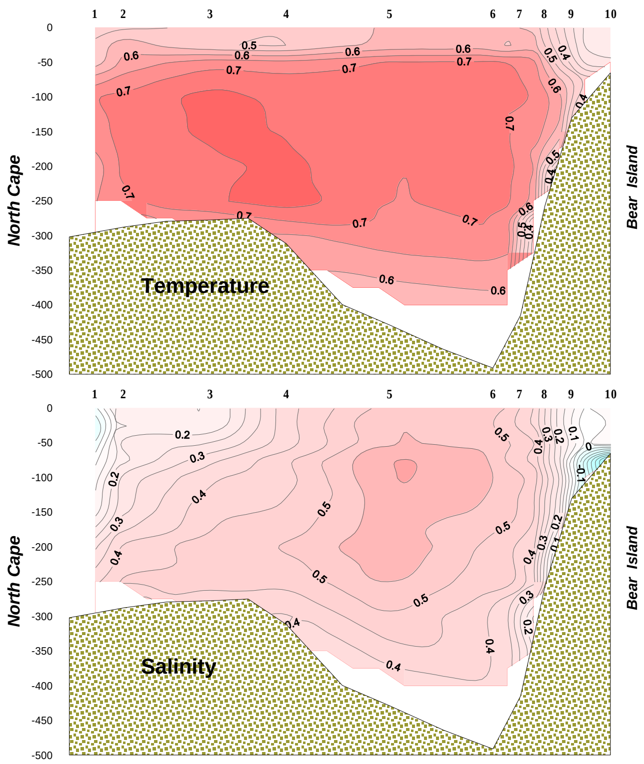

Figure 6. Average distribution of temperature and salinity correlation coefficients on the NB Section.

The average salinity field shows the relationship between the sections quite distinctly. The haline characteristics are most consistent around Station 5, while further from this station the relationship gradually decreases. Stations 4 - 7 were averaged in order to allow for monthly correlation fields (Figure 5) between the haline characteristics of waters at the sections under study. On the basis of the assigned averaging ranges at NB, we performed a regression analysis with characteristics of waters at FB Section (Station 7-15, 50-200 m layer).

The regression analysis (Figure 7) showed that the thermal characteristics of the waters in the sections were highly correlated during the cold period of the year.

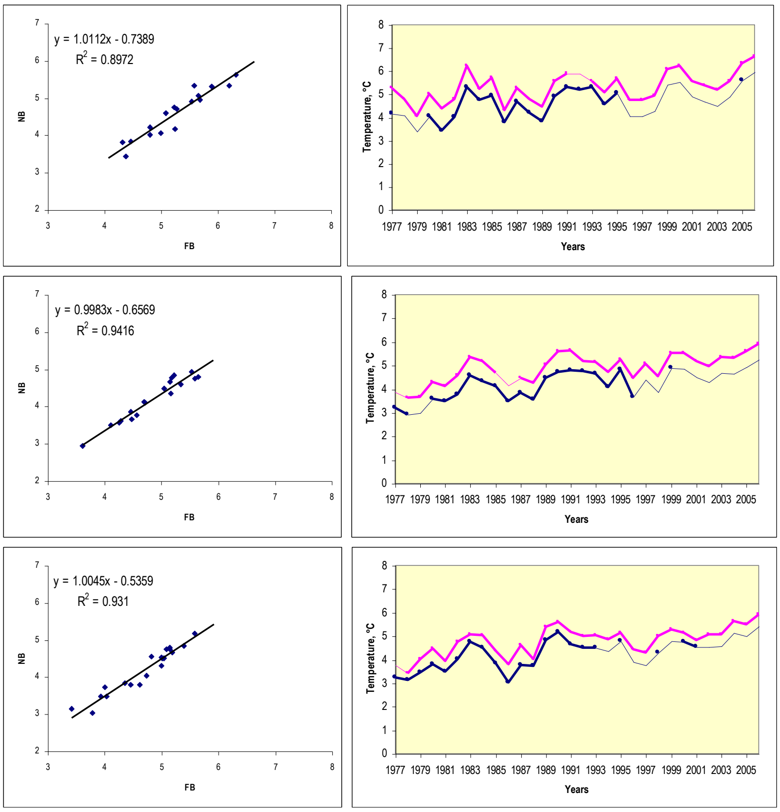

Figure 7. Regression between the average temperature on FB (red line) and NB (dark blue line) sections in January, March, and May, respectively. The thick line shows observed values; the thin line, restored values.

In January, the coefficient of determination between the average values of water temperature was about 0.9. According to the observation data, the water temperature in the FB section in that month was an average of 0.7º C higher than in the NB section, with a standard deviation of 0.2º C. The maximum consistency (R^2>0.94) of the temperature series was obtained in March. The temperature difference between the two sections remained at the same level (0.67º C), with a fall in standard deviation of 0.14º C. A high association of the series (R^2>0.93) was also observed in April - May. The difference in water temperature between the sections fell somewhat,and came to 0.5º C, with a standard deviation of 0.16º C.

The relationship between the thermal characteristics of the different waters decreased in the sections during the warm period of the year (Figure 8).

The multiple correlation coefficient for June was 0.87. Waters in the FB Section were 0.5º C warmer than in the NB Section, with a standard deviation of 0.2º C. Regression equations with a similar determination coefficient (R^2>0.85) were derived for August - September and October. In August – September, the difference between the average water temperature values was 0.55º C (standard deviation –-0.18º C), while in October it was 0.66º C (standard deviation -0.22º C).

The regression analysis of haline characteristics at the sections showed less conjugation of averages (Figure 9).

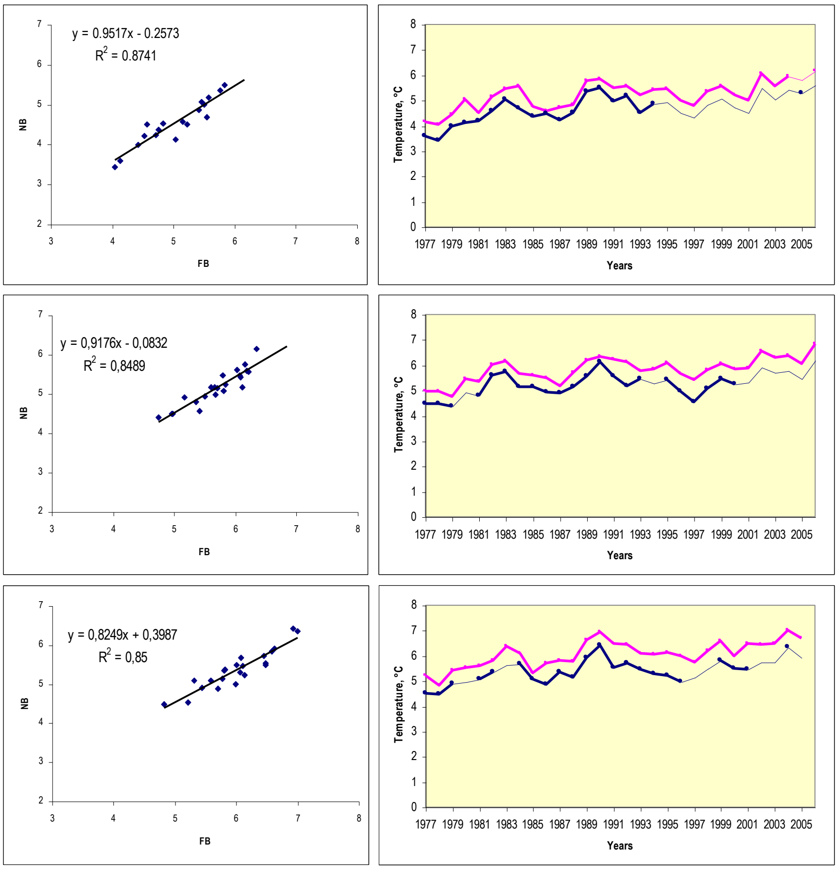

Figure 8. Temperature regressions in June, August, October, respectively. The legend is as in Figure 7.

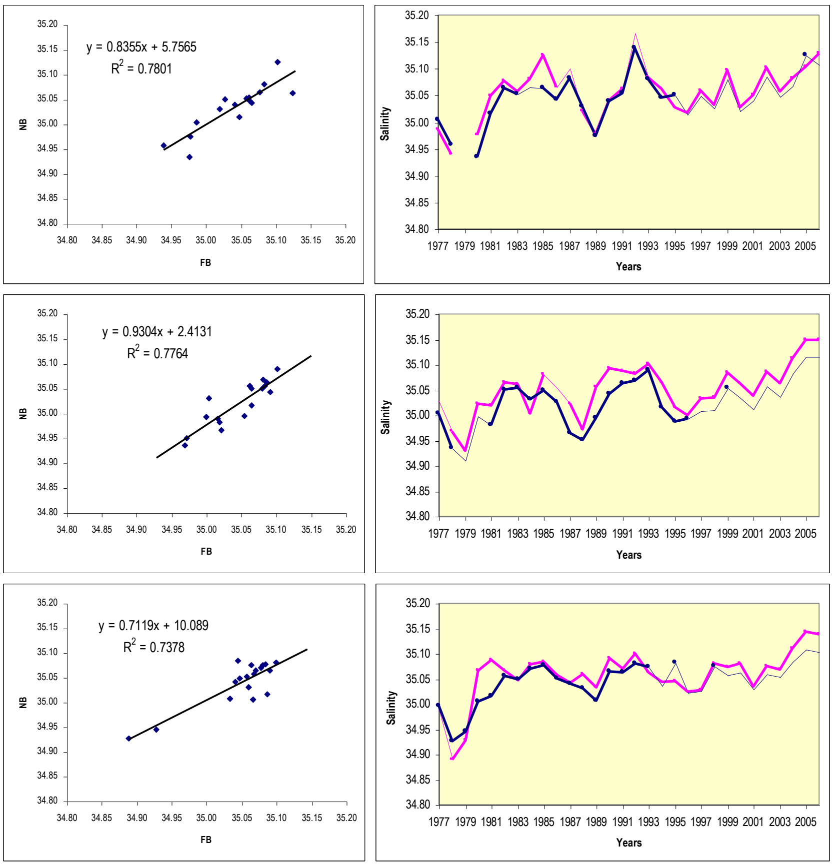

Figure 9. Salinity regression in January, March, May, respectively. Legend is as for Figure 7.

Where temperature was concerned, the consistency of the salinity means was higher during the cold period of the year than during the warm season. The maximum level of the relationship between haline characteristics of waters was found to be in January and May, when the coefficient of determination reached 0.78. In January, the mean salinity values at the sections were practically the same (the difference was 0.007. with a standard deviation of 0.023), and in March, the salinity on the FB Section was 0.026 times higher (standard deviation – 0.022) than on the NB Section. In April - May, the consistency of the salinity series had a coefficient of determination of 0.74. In that month, the salinity of the FB Section was 0.01 higher than on the NB Section and the standard deviation was0.028.

In June and August-September, multiple correlation coefficients between haline characteristics came to about 0.7 (Figure 10).

During those months, the waters on the FB Section had a higher salinity than on the NB Section. In June the difference between salinity means was 0.033 (standard deviation 0.028), and in August - September it was 0.038 (standard deviation 0.025. There were no significant relationships between haline characteristics at the sections studied in October (Figure 10).

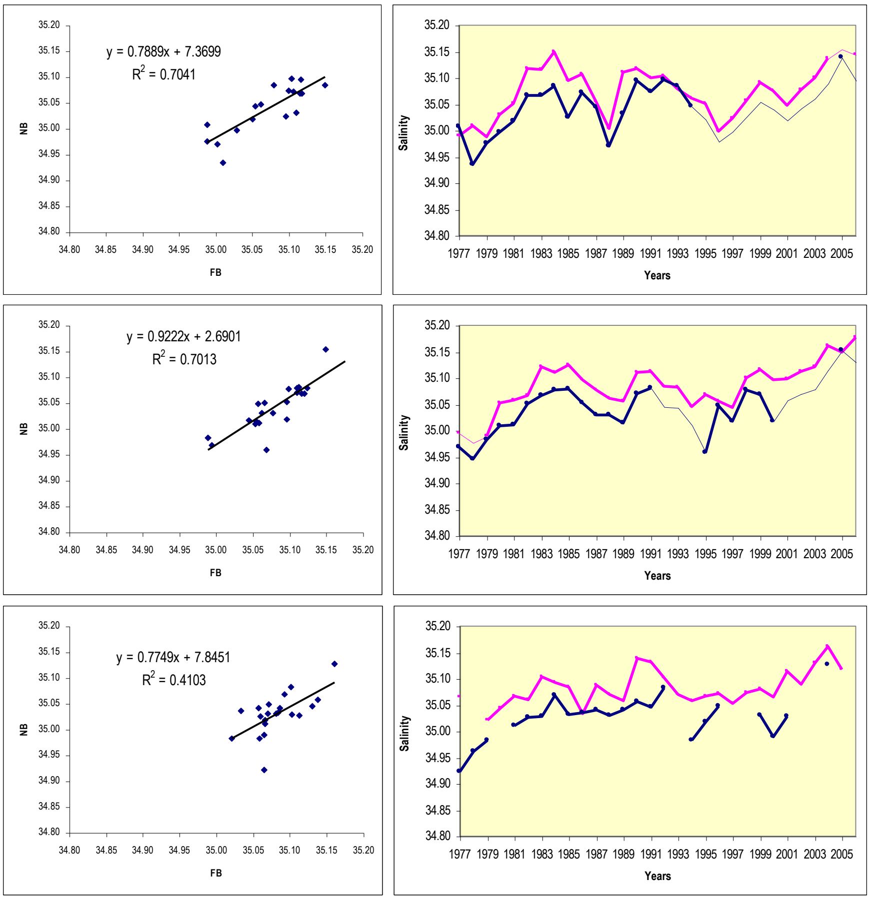

Figure 10. Salinity regression in June, August, October, respectively. Legend is as for Figure 7.

Discussion

This paper considers questions related to the coherence of thermohaline water parameters on the FB and NB Sections in detail.

The close correlation of T, S variables on the sections involves makes it easy to determine the consistency of variations in water temperature and salinity over time. The length and depth range in the area between Stations 7 and 15 of the FB Section used to determine the mean weighted characteristics correspond approximately to those between Stations 3 and 7 on the NB Section (Table 1). Nevertheless, some differences in seasonal differences in hydrographic parameters on the sections (the inflow of Atlantic waters to the continental shelf; the existence of the cold Bear Island Current in the northern part of the section and the warm and freshened coastal Norwegian Current on the boundaries of which the developed frontal zones are formed; freshwater continental flow and formation processes, etc.) suggest that there are a number of peculiar conditions which need to be taken into consideration.

The vertical fields of temperature correlations (Figures 4 and 6) represent thetotal transportation of waters between the two sections quite distinctly. During the cold season January – April the correlation coefficients are relatively high in most of the water column. This is probably the result ofwell-developed mixing processes and, thus of great temperature homogeneity in the vertical dimension. In the warm period (June, August-September, October), during the seasonal thermocline occurrence, the temperature in the upper 30-50 m layer on the NB Section absolutely mismatches the one in the 50-200 m layer on the FB Section. The significant decrease in the correlation fields on the NB Section to the north of Station 8 is the result of effect of the Arctic waters (Ozhigin, Ivshin, 1999) transported by the Bear Island Current. In the coastal southern area of the section, the decrease was weaker, although in some months a significant decrease in correlation coefficients was noticed in the area of Station 1. The local water temperature correlation coefficient maxima were obtained somewhat unexpectedly at depths of 50-350 m at Stations 3 and 4, and additional research beyond the limits of this paper is needed to explain this phenomenon.

The correlation coefficients in the salinity field (Figure 5 and 6) were not as high as for temperature, as expected. Both any inaccuracies in determining salinity differences in the periods of observations had a negative effect on the relationship between the data series. The largest correlation coefficients for salinity were obtained between Stations 7 and 15 on the FB Section, and at Station 5 on the NB Section. The field of significant correlations was located between Stations 4 and 7 on the NB Section in January and March. In April-May and June this narrowed to Station 4-6 of the NB Section, and in August-September and October it was only significant in the area of Station 5. Haline fronts crossing the section in the south near Station 1, and at Station 8-9 in the northern part, can easily be seen in the salinity field correlation plots. One possible reason for the reduction in salinity correlation coefficients in August-September and October may be a weakening of the advection of the Atlantic waters.

The structure of temperature and salinity correlation fields may be found, in particular, through the values of standard deviations of these water parameters (Figure 11 and 12).

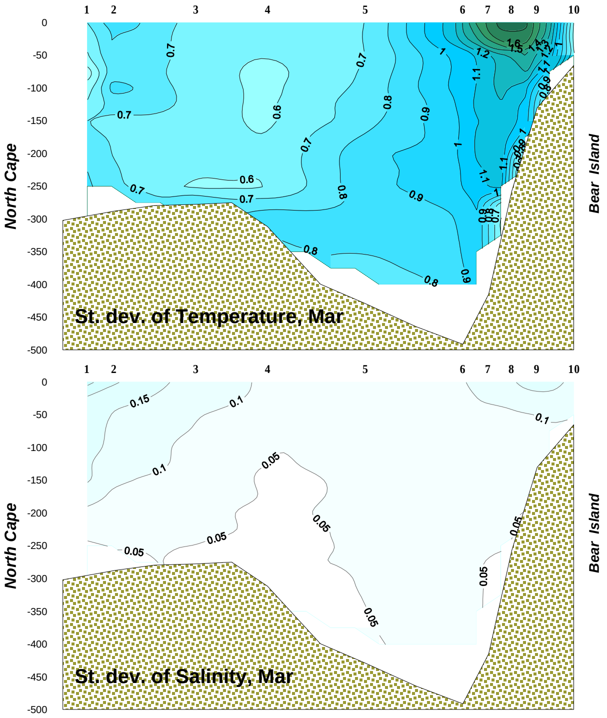

Figure 11. Standard deviations of temperature and salinity in March.

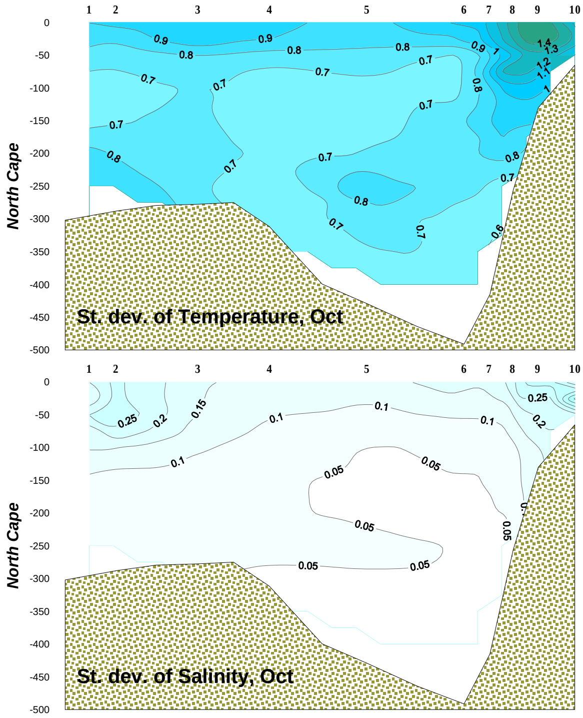

Figure 12. Standard deviations of temperature and salinity in October.

The figures showing the distribution of the standard deviations of temperatureand salinity on the NB Section in the period of the best (March) and weakest (October) relationships distinctly reflect the main peculiarities of water structure. The standard deviations display maxima in the areas of frontal zones and minimum values in the areas of the best contingency of thermohaline characteristics. The positions of the isolines of the temperature and salinity standard deviation values are particularly interesting. In the period with the best parameter contingency (March), the standard deviations show a practically vertical homogeneity. Thus, all the data that are averaged over a station have a similar error. This means that the weightings of each value in the total average are approximately identical. During the period of weak correlations (October), the isolines of standard deviations are characterized by a somewhat horizontal position. In this case, the temperature and salinity values have different weightings in different layers, and the contribution of a separate observation may influence their total average. This in turn will influence the level of relationship (the instability condition appears). When selecting the spatial interval for averaging by section it is therefore necessary to consider not only the extent of the relationship, but the value of the standard deviation.

Allowing for the above-mentioned considerations, averaging the NB Section involved Station 3-6 to analyse the adjustment of thermal characteristics and Station 4-7 to adjust salinity means. Choosing those stations was based on both the correlation coefficient and the analysis of standard deviations. The averaging is mainly intended to provide smoothing, excluding high-frequency constituents that consist of some limiting or erroneous data. The relationship might be improved by diminishing the interval of spatial averaging by the section, but in such a case, any high-frequency constituents might remain and the regression equations obtained would be unstable. One possible approach might be dynamic determination of averaging interval boundaries. But with the aim of filling gaps in time series this approach would be quite difficult to interpret.

Statistically reliable regression equations (Figure 7 and 8) with determination coefficients of 0.85-0.94 were obtained for average water temperature between the two sections for each month. These equations enable us to fill gaps in the time series if there are data from one of the sections are available. Some wider deviations between the averages of the sections at the turn of the 1990s are probably caused by the development of new measuring methods and instruments.

Regression equations characterizing conjugation of salinity values appeared to be less highly correlated (determination coefficients of 0.70-0.78) and completely nonsignificant for October (Figures 9 and 10). As mentioned above, the lack of significant relationships is probably a result of weakening of the Atlantic water flow. The mosaic distribution of salinity correlation coefficients on the NB Section in October (Figure 5) permits us to assume that haline structure of waters on the FB Section in October is different. In this connection, to compare the data for October further, more detailed studies are required.

According to methods used by PINRO, the thermohaline characteristics on the NB Section are estimated on the basis of the data from Stations 2 – 6.

Therefore, in order to check the proposed method and fill the gaps for recent years in the time-series for the NB Section, it would be reasonable to make an attempt to adjust the averages for the NB Section and the initial data from the FB Section.

Conclusions

This study analysed the consistency of water thermohaline parameters on the FB and NB Sections.

Correlation fields of temperature and salinity, as well as of standard deviations of water parameters along the NB Section were calculated and plotted. The optimal ranges of spatial averaging were determined by the distribution of higher correlation coefficients,allowing for standard deviation. The optimal range of averaging for water temperature was the part of the NB Section between Station 3 and Station 6, and for salinity between Station 4 and Station 7.

The regression analysis permitted us to obtain quite reliable statistical relationships (coefficients of determination – 0.85 - 0.94) between the mean water temperatures on the sections for all months studied.

The relationship between the water salinity of the two sections was somewhat weaker(determination coefficients – 0.70 - 0.78), and was insignificant in October. The regression equations obtained allow us to fill the gaps in the time series except for October.

The results suggest the possibility of future studies aimed at filling in the gaps in time series and extending the series of observations on the standard sections.

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