Chapter 5
Structure and Variability of the Atlantic Water on the Transects

The Atlantic Water can be easily distinguished from other water masses occurring in the investigated region. It is characterized mostly by much higher temperature and salinity. The higher temperature is a factor which reduces the water density; the higher salinity increases the density. For the AW, temperature is the prevailing factor—it makes the AW less dense than the surrounding waters. It results from high ratio between the thermal expansion coefficient α:

$$\alpha = \frac{1}{\rho}\left(\frac{\partial \rho}{\partial T}\right)_{p,S} \tag{5.1}$$

and the salinity contraction coefficient β (modification of volume due to change in salinity):

$$\beta = \frac{1}{\rho}\left(\frac{\partial \rho}{\partial S}\right)_{p,T} \tag{5.2}$$

where ρ is water density. S and T are salinity and temperature respectively. The result of the above is the salinity inversion—the more saline AW lays above less saline and colder intermediate and deep waters (Fig. 5.1). Such stratification makes the column more susceptible to convection (Druet 1994).

Figure 5.1 shows water column structure at several stations in the centre of the Atlantic Domain where the inflow of the Arctic and Polar Water is negligible, and closer to the Arctic Front where the AW is colder and less saline. The AW layer thickness varies from 200 to 700 m. The warmest AW occupies the surface layer and it is bounded by the summer thermocline at 60 m. The proper thermocline and halocline which separates the AW layer from the intermediate water lies at the depth of ca. 600 m. Below that depth there are stratified intermediate waters and homogenous deep waters. At the profiles which are situated closer to the domain boundary, the halocline and thermocline are less distinct and at smaller depths.

Collecting the data along hydrographic transects (sections) is a standard method of oceanographic survey. Transects are most often located across straits, perpendicularly to the direction of currents and isobaths. On the basis of previous studies

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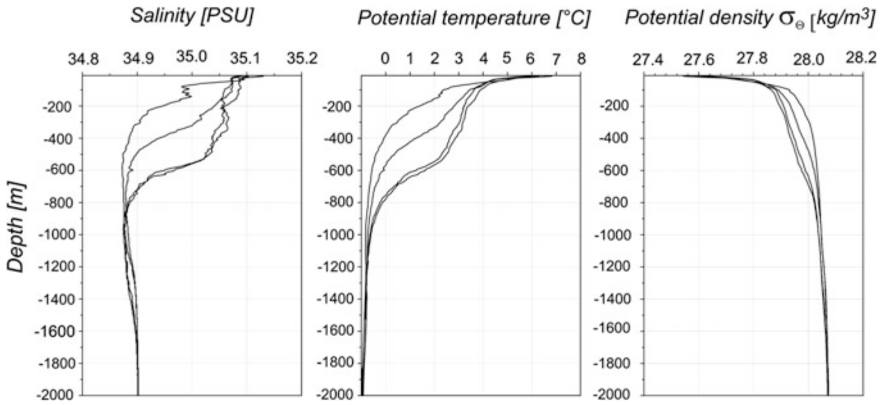


Fig. 5.1 Salinity (PSU), temperature (°C) and potential density (kg/m^3) profiles taken on transect 'K' in 2001

of the WSC, the majority of transects was performed perpendicularly to the presumed direction of current. A series of stations repeated year by year made it possible to measure horizontal fields of temperature and salinity which picture the spatial distribution and properties of water masses well. The stations are arranged along transects, which provides a better representation of vertical distribution of water masses, their structure and mutual relations. Furthermore, time series of the AW properties at individual transects allow for some (limited) tracing of signal.

5.1 Transect '*H*'

Transect H runs along the parallel 73°30′N. According to the previously introduced division, it covers the northern section of the southern part of the study area. The transect is situated in the northern part of the main area where the AW flows into the Barents Sea through the BSO. In the western part of the transect, meridional pattern of all the isolines prevails while fluxes into the Barents Sea dominate in the eastern part (see horizontal distributions). An exemplary section from 2004 shows the water mass structure at the transect 'H' (Fig. 5.2). As in all other zonal transects, west is to the left. The transect covers the Atlantic Domain from the Arctic Front to the Barents Sea shelf. The lower AW boundary is marked with bold isolines: 0 °C isotherm and 34.92 isohaline. The AW vertical extent is most frequently limited by the 34.92 isohaline, since the 0 °C isotherm is usually situated below that line. The AW extends over a width of more than 450 km, covering 202 km^2 of the transect 'H'. The AW mean temperature is 3.96 °C and its mean salinity is 35.07.

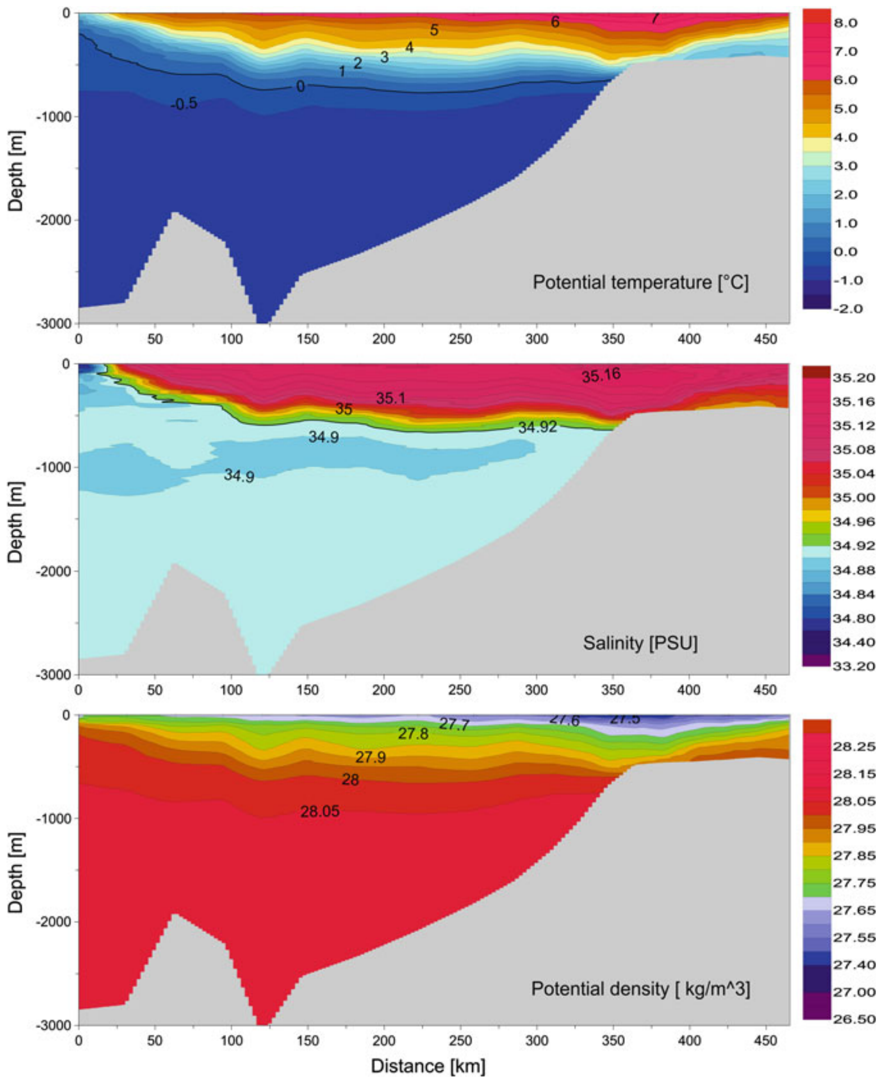


Fig. 5.2 Temperature, salinity and potential density on transect ‘H’ along the parallel 73°30′N. July 2004, r/v Oceania. The 0 °C isotherm and 34.92 isohaline are bold

The impact of the bottom topography upon the distributions of hydrographic properties is clearly distinguished at both ends of the transect. In the western part the location of the Arctic Front, dividing the Atlantic Water and the Arctic Water coincides with a line of underwater ridges. The front is recognized by the inclination of isotherms, isohalines and isopycnals in relation to isobaric surfaces. Due to differences in horizontal and vertical scale, the front slope on the figure is excessive. Along a distance of 100 km the isolines sink by less than 500 m; the

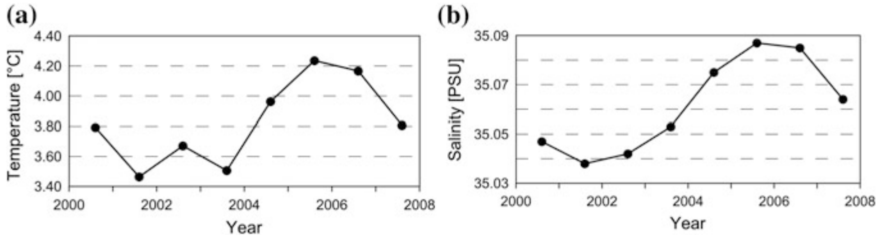


Fig. 5.3 Time series of mean temperature (**a**) and salinity (**b**) of the Atlantic Water at transect 'H' along the parallel 73°30′N in July 2000–2007

front slope is therefore 0.5 %. In the central part of the transect the AW layer thickness reaches 650 m. The region of the warmest and most saline AW—the WSC core—is located above the continental slope, above the 500–650 m isobaths. The maximum AW temperature and salinity in that region are 7.5°C and 35.18, respectively—35.18. It is a continuation of the AW flow along the edge of the Norwegian shelf.

The section shows that the AW layer is locally and that isolines are inclined in relation to the isobars. Geostrophic baroclinic currents are related to the inclination of isopycnal surfaces in relation to isobaric surfaces (baroclinicity). The strongest baroclinic flows may be expected near the Arctic Front. The inclination of isopycnals indicates a strong northward (towards the figure) flow component. A mesoscale anti-cyclonic eddy is visible above the 125th kilometre of the transect. Another area of baroclinicity is visible above the shelf break. Its inclination from left to right indicates a northward flux component. The second area of baroclinicity above the shelf indicates the presence of sub-surface flow with a southward component.

Time series of mean temperature and salinity of the AW layer at that transect are similar as in the entire domain (Figs. 4.7, 4.8), however, the difference is that the first symptoms of the AW cooling are visible at the transect 'H' already in 2006, together with the decrease in salinity (Fig. 5.3).

5.2 Transect '*K*'

The exemplary transect along the parallel 75°N, from the longitude 05 to 17°E, is shown in Fig. 5.4. The reason why the limit values of $T > 0$ °C and $S > 34.92$ were chosen for definition of the AW layer is clearly visible. These are the ranges of the strongest vertical gradients of those values, separating intermediate water from the AW layer. At that transect the AW covers the width of approximately 340 km and the area of 145 km^2. The AW mean temperature is 3.08 °C and mean salinity is 35.02. In the centre of the domain the AW layer thickness reaches values between 500 and 700 m. The AW layer is thicker on the western side, near the Arctic Front, and in the east, above the shelf slope of the Barents Sea. These

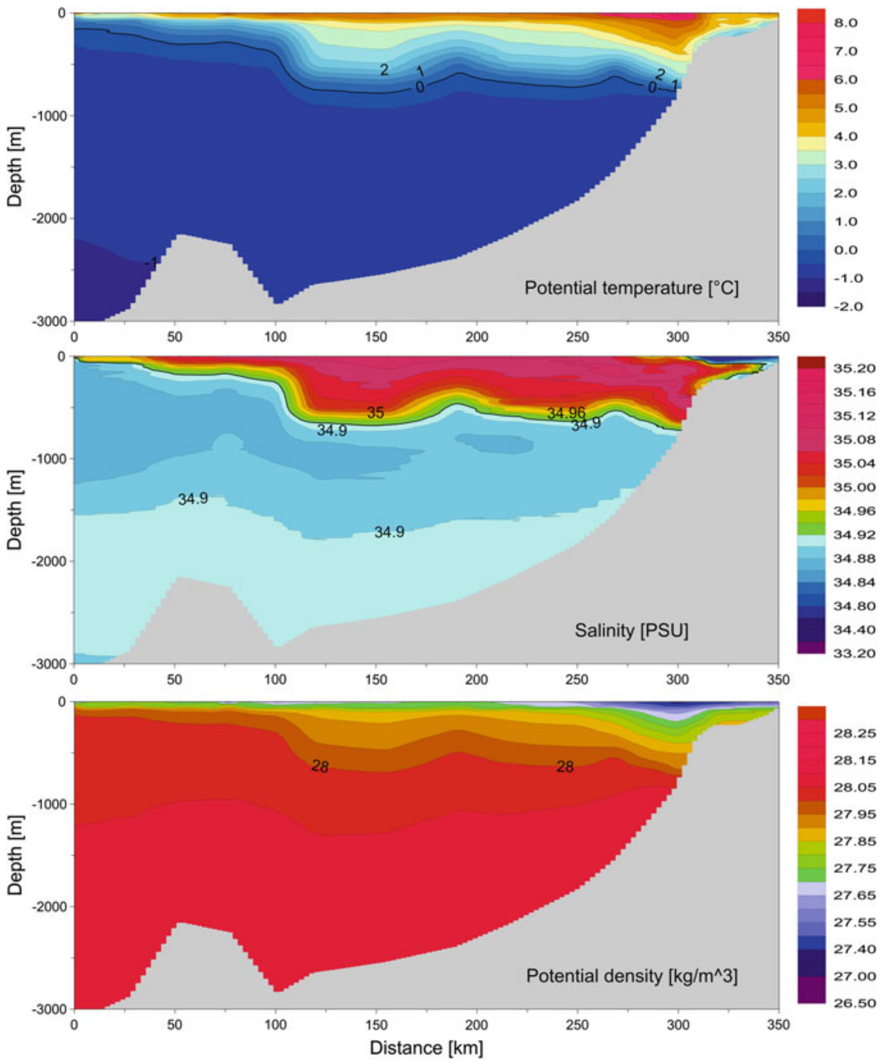


Fig. 5.4 Temperature, salinity and potential density on transect 'K' along the parallel 75°N. July 2001, r/v Oceania. The 0 °C isotherm and 34.92 isohaline are bold

maxima represent two branches of the West Spitsbergen Current. The warmest and most saline water flows above the slope, along the 600–800 m isobaths. This transects also features a bottom topography—including in particular the underwater ridge situated on the 50th kilometre—which limits the Atlantic Domain and reflects the location of the Arctic Front. The jet streams, generated by the difference in the water density on both sides of the front and strong baroclinicity, are connected with the front. In the discussed case the most intense currents should

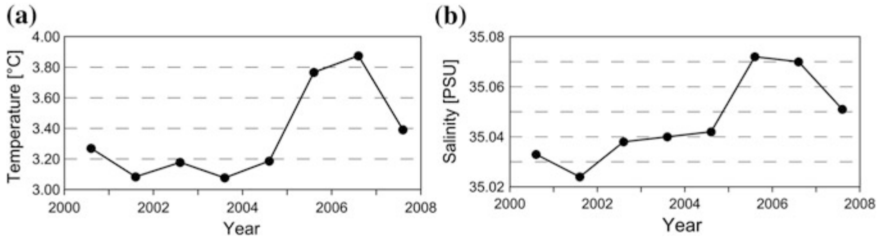


Fig. 5.5 Time series of mean temperature (**a**) and salinity (**b**) of the Atlantic Water on transect 'K' along the parallel 75°N in July 2000–2007

occur on the 100th kilometre of the transect, in the area of the steepest inclination of the front, therefore, the strongest baroclinicity. Changes in the AW layer thickness in the centre of the transect indicate a southward component of baroclinic flow. On the eastern side, above the Barents Sea shelf, a surface inflow of less saline Polar Water is visible.

Similarly to horizontal distributions, the structure and properties of the AW observed on transects change in time. Between 2000 and 2004 the AW mean temperature remained at 3.08–3.27 °C. Temperature rose significantly by 0.6 °C between 2004 and 2005 (Fig. 5.5). The decrease in temperature already observed in 2006 at the transect 'H', did not yet occur at the transect 'K'; temperature kept rising until its decrease in 2007. The strongest rise of AW salinity was observed in 2005, an insignificant decrease began already in 2006.

5.3 Transect '*N*'

The section along the 76°30′N parallel (transect 'N') is a hydrographic section near Spitsbergen which has been explored by the IOPAS for the longest time. The measurements there have been taken since 1996. More attention is devoted to the analysis of the AW properties at that transect due to the length of time series and a special role of that sea region. It is a sort of gateway into the Fram Strait where different WSC branches converge. On transects further up north, the currents may not be so easy to distinguish.

The coverage of the western part with measurements varied in different years, mostly due to variable ice conditions. Since 2000, the transect has been measured between 004°E and the Spitsbergen shelf, and it covered the entire Atlantic Domain.

Similarly as in the case of the transect 'K', the AW spreads at a width of approximately 340 km (Fig. 5.6). However, the proper width of the Atlantic Domain is smaller, approximately. 280 km, and its average area is 143 km^2. The transition zone between the AD and the Arctic water is the Arctic Front which begins at the 60th kilometre of the transect; the Atlantic Water west of the AF recirculates into the Greenland Sea. The AW layer thickness reaches 670 m.

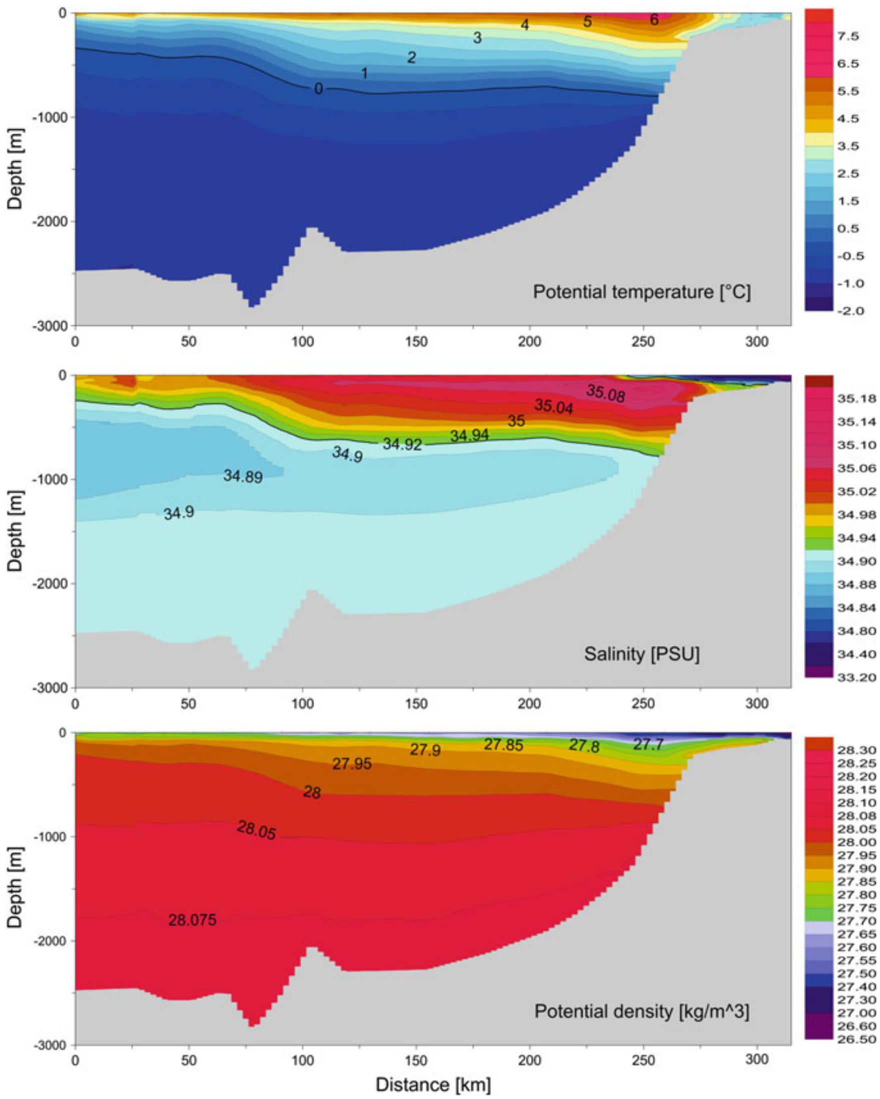


Fig. 5.6 Potential temperature, salinity and potential density on transect 'N' along the parallel 76°30′N. 1996–2007 summer mean, data gathered aboard r/v Oceania. The 0 °C isotherm and 34.92 isohaline are bold

Similarly to the previous transects, two zones of baroclinicity and resulting baroclinic currents are clearly distinct: above the Knipovich Ridge (the western WSC branch) and above the Spitsbergen slope (the WSC core).

Temporal variability of the AW properties along that transect has been analysed and presented in different ways. Mean values (Fig. 5.6) as well as anomalies of temperature (Fig. 5.7) and salinity (Fig. 5.8) have been calculated for the entire transect; the AW properties have been calculated at various depths and for selected parts of the transect. Finally, the time-space (Hovmoeller) diagrams of the AW layer temperature, salinity and heat content have been presented.

All obtained time series of derived parameters clearly show warmer and colder periods as well as an unprecedented increase in temperature and salinity since 2004 with a sudden drop in 2007.

Changes of the AW properties do not occur at the entire transect at the same time. In some years they are more intense in the western part, in others—in the eastern one. Only since 2004 has the warming and increase in salinity occurred in the entire area, however, those changes were more pronounced in some regions. The Hovmoeller diagram (Fig. 5.9) depicts the increase in the AW temperature and salinity. It clearly shows that a part of the transect—from the 75th to the 275th km—is sufficient to analyse the parameters of the AW flowing towards the Fram Strait (which is the most important as regards the climate variability). The AW core can be distinguished at the 270th km, the central branch, claimed by the author (Chap. 8)—at the 230th km, and the western branch—at the 110th km of the transect. West of the 75th kilometre, recirculation of the Return Atlantic Water can be observed.

Between the summer of 1996 and 2007 the linear trend of mean AW temperature was 0.08 °C/year, and of its mean salinity was 0.0067 1/year. Two periods of temperature increase were observed: 1998–1999 and 2004–2006. The lowest mean temperature and salinity of the AW at the transect N occurred in 1997: 2.07 °C and 34.97, respectively (Fig. 5.10). A sudden rise of temperature—up to 3.41 °C—was observed in 1999. Another temperature and salinity minima occurred in 2003: 2.48 °C and 35.01, respectively. Then, there was an increase, and in 2006 both values reached 3.72 °C and 35.07, respectively. A local AW temperature maximum in 1999 is noticeable. It was accompanied by an increase in salinity, however, it was not so sudden as the increase in temperature. The analysis of hydrographic conditions in 1999 shows that the AW are at the section that year was the smallest ever recorded (84 km^2 as compared to the average 114 km^2) and the calculated mean AW temperature included the warmest fractions of the flow, thus, it was artificially increased. Despite such a high temperature, the AW transported little heat in 1999 (Fig. 5.14).

Transect ‘N’ can be regarded as representative for the entire investigated area. In the period between 2000 and 2007 the correlation between the AW temperature at the transect and the mean temperature of the AW layer in the entire AREX study area equals **0.96**, and for salinity the correlation coefficient equals **0.83**.

Similarly as for the entire AW volume in the AREX study area, the AW temperature at the transect ‘N’ was related to air temperatures at the Polish Polar Station in Hornsund. The similarity between the time series of AW temperature and annual mean of air temperature in Hornsund is very high (Fig. 5.11).

The correlation coefficient between both values equals **0.92** and is even higher than for the entire AW mass. The result is even more valuable considering the fact that it has been obtained from a longer time series. For detrended data r = **0.86**.

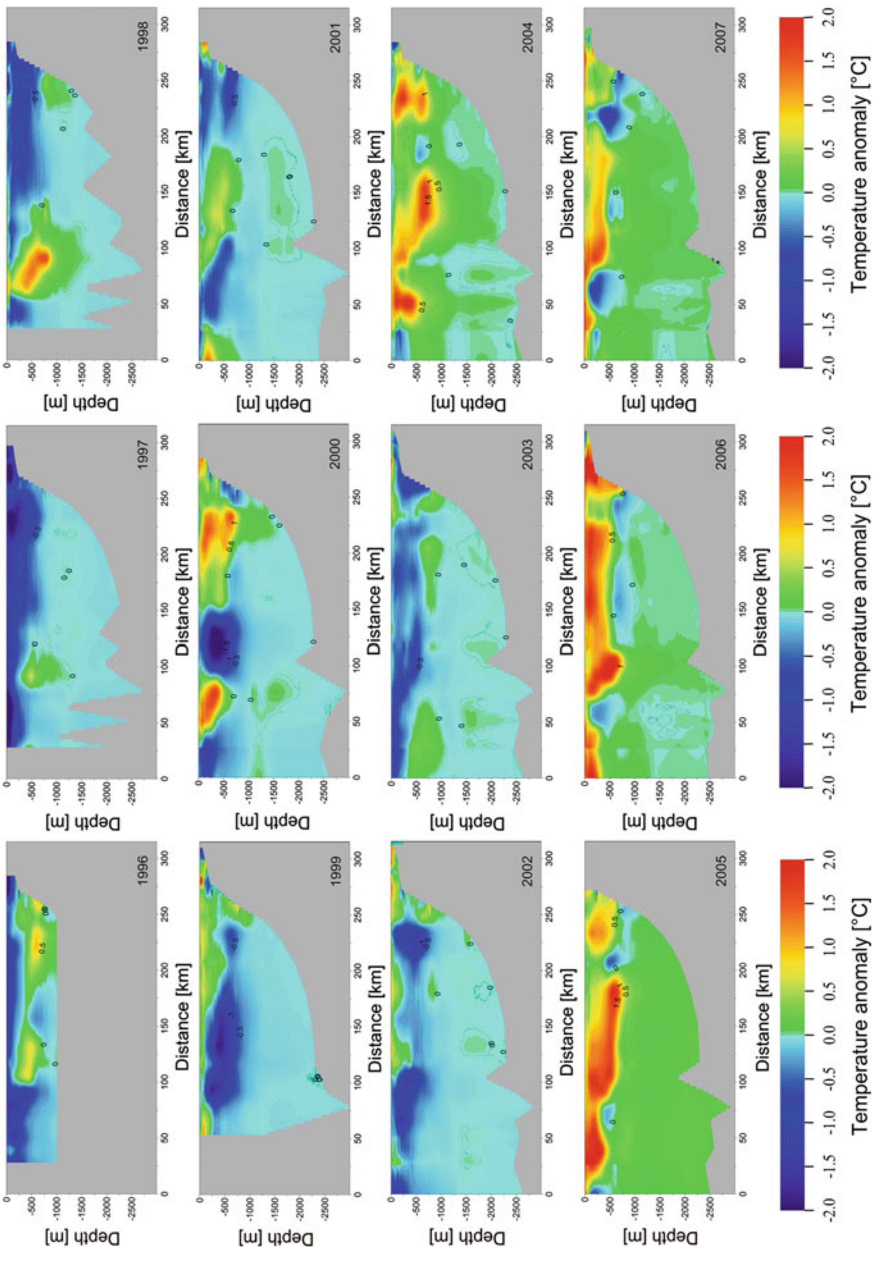


Fig. 5.7 Temperature anomalies (°C) in June–July on transect 'N', calculated in relation to the 1996–2007 mean

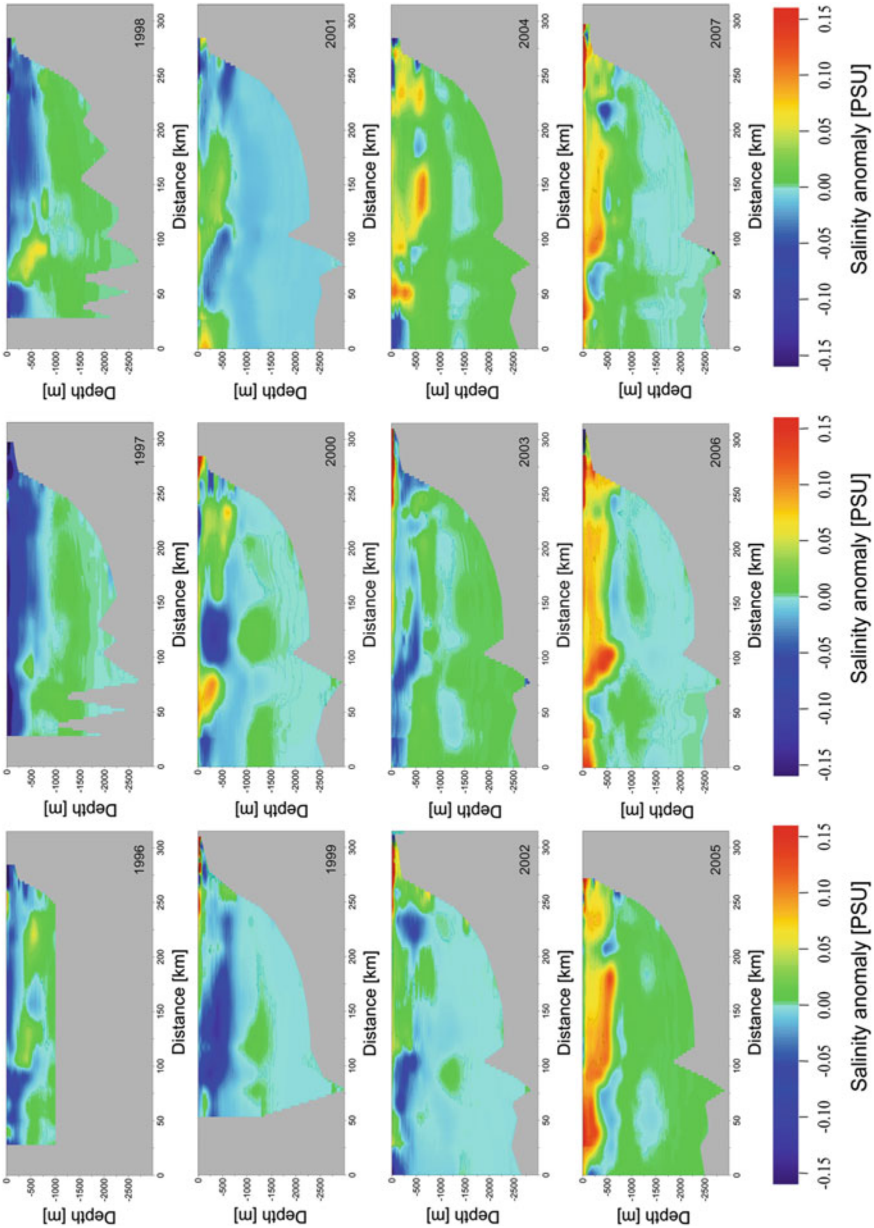


Fig. 5.8 Salinity anomalies (PSU) in June–July on transect ‘N’, calculated in relation to the 1996–2007 mean

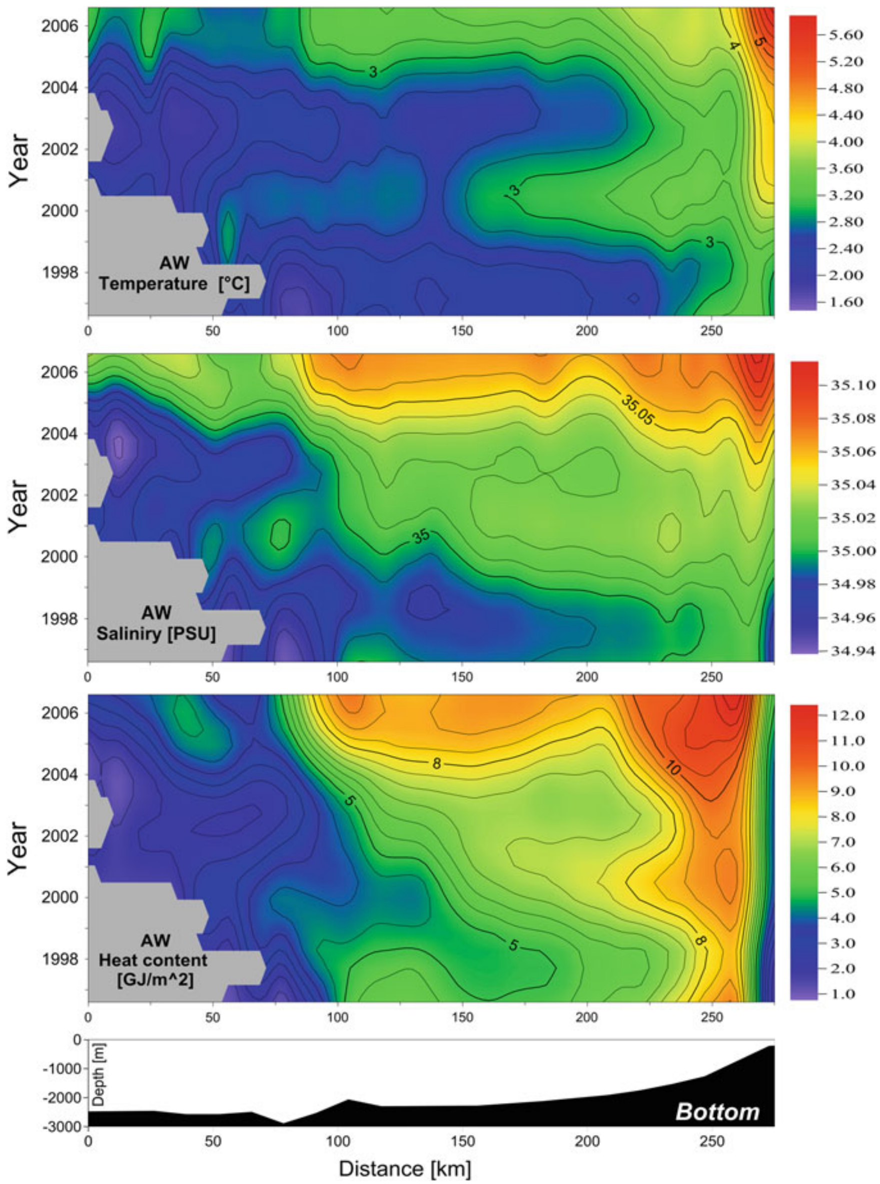


Fig. 5.9 Hovmoeller diagrams of temperature (°C), salinity (PSU) and heat content (GJ/m^2) of the AW layer on transect 'N' from the period 1996–2007. The *bottom* profile is shown. *Grey areas* mean lack of data or non-occurrence of the AW (in 1997)

Annual means of air temperature were calculated from monthly means, from January to December, the AW temperature was measured in July of the given year, in the middle of that period. Therefore, a question arises whether the AW

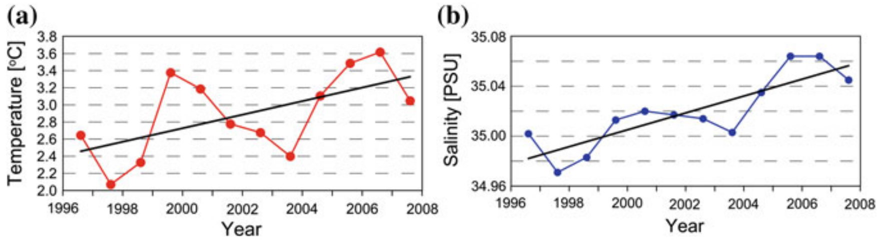


Fig. 5.10 Time series of mean temperature (**a**) and salinity (**b**) of the Atlantic Water on transect 'N' along the parallel 76°30′N, between the 75th and the 275th of the transect, July 1996–2007. Linear trends are marked

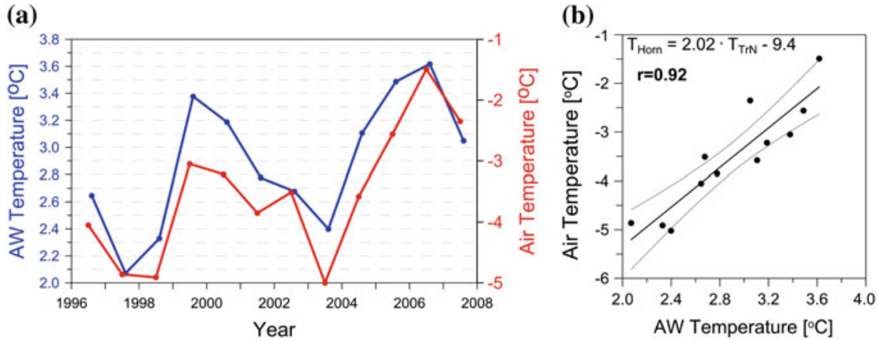
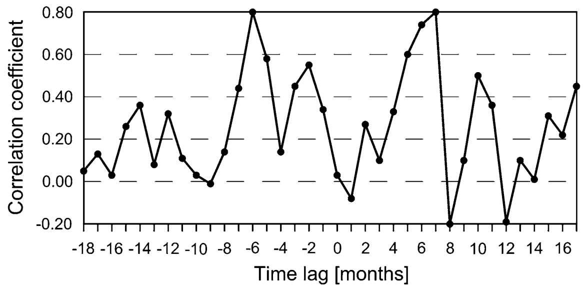


Fig. 5.11 **a** Time series of annual mean air temperature at the Polish Polar Station in Hornsund (*red line*) and the Atlantic Water mean temperature at the transect N. **b** Regression of the both values. The 95 % confidence level is marked

Fig. 5.12 The coefficient of correlation between monthly mean air temperature in Hornsund and the AW temperature at the transect N for various time lags



temperature influences the annual mean air temperature in Hornsund, or is it the other way round—the AW temperature is modified by the weather. The correlation between monthly averaged air temperatures in Hornsund and mean AW temperature on transect N (Fig. 5.12) was examined. The results with negative time lag represent correlations between the AW and monthly means of air temperature in Hornsund in months preceeding the hydrographic measurements, the positive time lag results represent correlations with months following the measurement. The highest correlations occur in winter months (time lag of −6 and +6 months).

The correlation coefficient between mean air temperature in three (December, January, February) winter months and the AW temperature the following summer equals **0.72**. For the AW temperature and the air temperature in 3 months of the following winter, r is equal to **0.80**. The results show that the interaction between the ocean and the atmosphere is bidirectional, however, the ocean impacts the air temperature stronger. Once again, the great importance of the AW for the local climate is confirmed. The result also show that the hydrographic data from the transect 'N' are particularly significant, both for oceanography and climatology.

In order to trace the change in mean temperature and salinity in different regions of section 'N', 3 parts were selected, each of 20 km width. The three parts include: the core, between the 255th and the 275th km of the transect, the central part—between the 210th and the 230th km and the western part—between the 90th and 110th km of the transect. The diagram (Fig. 5.13) clearly shows that the mean AW temperature at the transect results from a combination of mean temperatures in various parts of the transect which are influenced by different WSC branches. The western branch is colder and less saline than the core and the central WSC flow, the temperature and salinity variability is higher here. In some cases (e.g. in 2002), the values are out of phase—the increase of T and S in the core or in the central part coincides with the decrease in the western part. The variability in the western part may be related to the shift of the Arctic Front or mesoscale activity in that region. The properties in the central part are closest to the mean ones, hence the good correlation between that part and the means of all the parameters from the entire transect. The largest correlation coefficient of **0.98** was found between mean salinity and salinity in the central part, the correlation between temperatures is much lower (Table 5.1). The relations may be significant while attempting to restore the AW mean temperature from incomplete coverage of the transect.

In 2007 the values of temperature and salinity fell in all WSC branches. In the western part the temperature decrease began already in 2006.

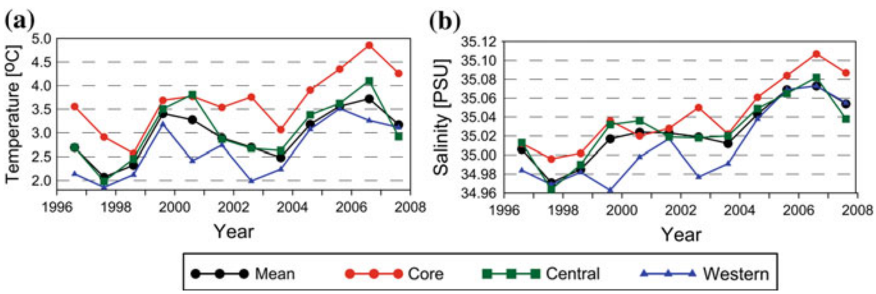


Fig. 5.13 Transect 'N'. Time series of the AW temperature (**a**) and salinity (**b**) in three areas of the transect and the mean value

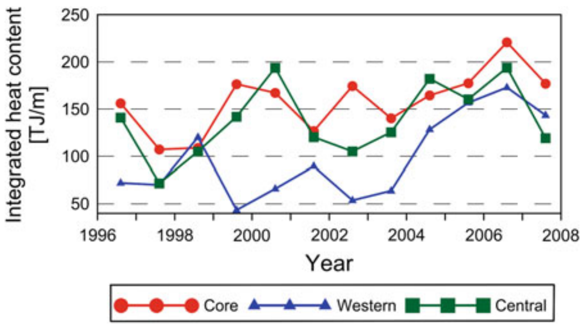


Fig. 5.14 Time series of integrated heat content (TJ/m) of the AW layer in the three areas of transect 'N'

Table 5.1 The value of the correlation coefficient r between mean properties of the AW from the entire transect 'N' and properties from individual parts of the transect

Part	Temperature	Salinity	Heat content
Core	**0.90**	**0.95**	0.75
Central	**0.97**	**0.98**	**0.83**
Western	**0.89**	**0.88**	**0.79**

The diagram of integrated heat content in the AW layer in individual parts of the transect (Fig. 5.14) shows that the lowest heat content (and probably the smallest heat transport) was initially in the western part. Since 2004 the branch strengthened to an unusual extent, nearly levelling its heat content to that observed in other parts. In 2006 it must have happen due to the increased AW layer thickness, since the temperature in that part decreased (Fig. 5.13).

5.4 Transect '*EB*'

Transect 'EB' is a section located nearest to the Arctic Ocean usually measured by the IOPAS. The transect is situated in the Fram Strait and overlaps the line of current meters installed by the Alfred Wegener Institute (AWI) on moorings. The IOPAS has been performing systematic measurements since 2000, however, similarly to other sections, in cold years their extent to the west was limited by ice cover. Usually, a 160 km long section (Fig. 5.15) was measured between 01°30′E and 09°E latitude. The section crosses the Atlantic Domain at the final stage of the AW advection into the Fram Strait, and in the region where the AW recirculates towards the west or south-west. The area of the warmest and the most saline AW above the Spitsbergen slope (above the 800 m isobath) reflects the WSC core. The western branch is visible above the underwater ridge. The AW recirculates as the RAW, westward of the underwater ridge.

Despite the fact that the data are incomplete, mean temperature and salinity of the AW at the transect are presented (Fig. 5.16). Similarly to the previous sections,

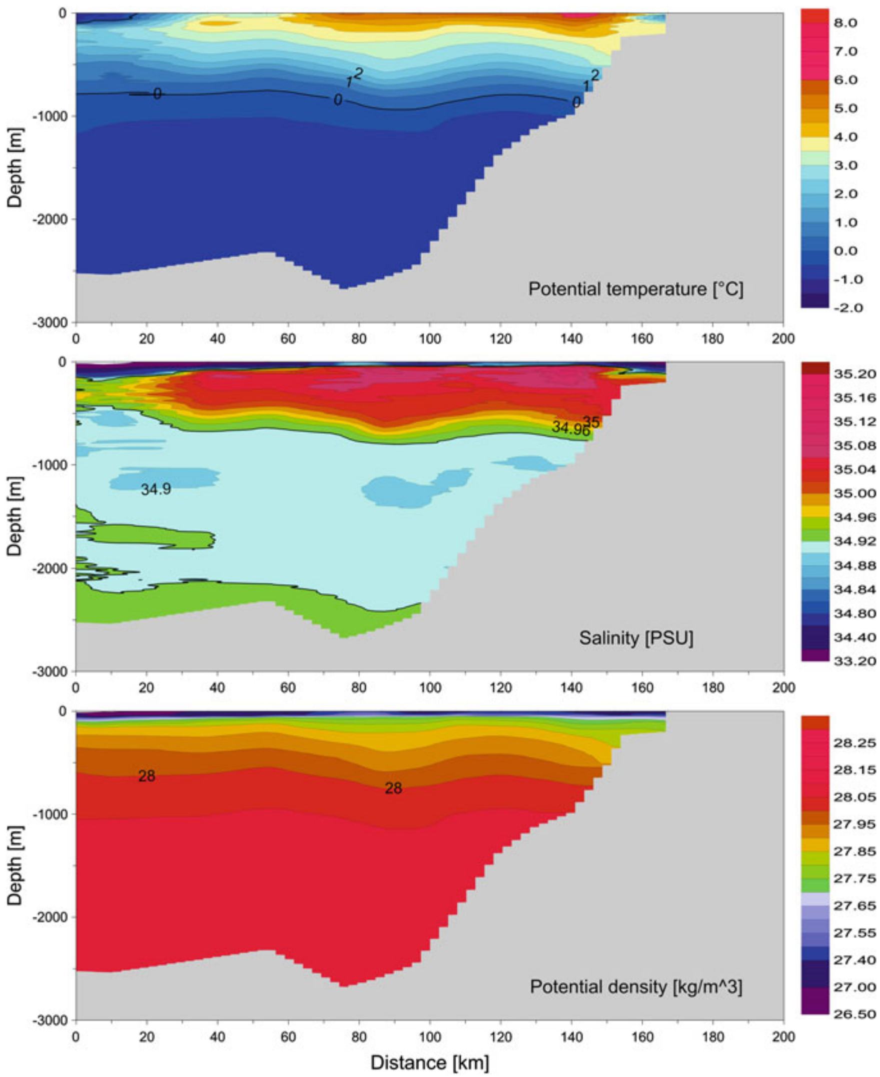


Fig. 5.15 Potential temperature, salinity and potential density on transect ‘EB’ along the parallel 78°50′N. Summer 2004, r/v Oceania. The 0 °C isotherm and the 34.92 isohaline are bold

including in particular 2005 and 2006, the increase in the AW temperature and salinity, and decrease of the values in 2007 is distinct here. The mean temperature and salinity in the eastern and western part of the transect were also calculated. The western part was defined as a section between 04° and 06°E latitude, and the WSC core as located between 07° and 09°E latitude. The difference in temperature and salinity of the both parts can be clearly seen (Fig. 5.17). The largest differences in temperature are in 2000 and 2003, the differences diminish after 2003.

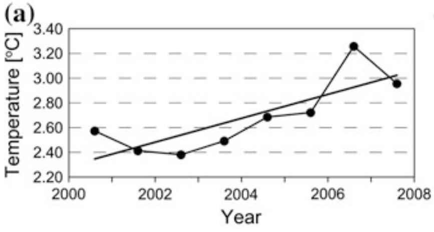


Fig. 5.16 Time series of mean temperature (**a**) and salinity (**b**) of the Atlantic Water on transect 'EB' along the parallel 78°50′N, July 2000–2007

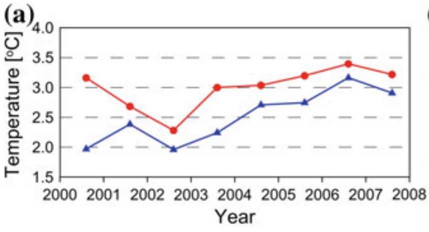


Fig. 5.17 Time series of mean temperature (**a**) and salinity (**b**) of the Atlantic Water on transect 'EB' along the parallel 78°50′N, July 2000–2007. The eastern branch (core)—*red line*, the western branch—*blue line*

5.5 Transect '*V1*'

Transect 'V1', which closes the Barents Sea Opening, is described briefly below in order to present the Atlantic Water advection in a more complex way. The data gathered by r/v Oceania in 2004 will be used for that purpose. The transect was described by Piechura (1993) and Schlichtholtz and Goszczko (2005). The data from 2005, used to complete the time series, were gathered by the Institute of Marine Research in Bergen at the end of May. The earlier date of measurements may be the reason of lower AW temperature at that transect in 2005 (Fig. 5.18).

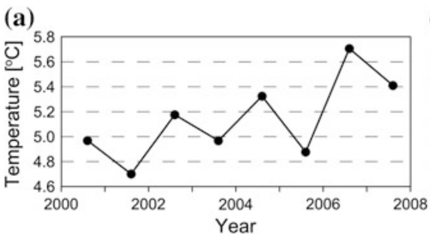


Fig. 5.18 Time series of mean temperature (**a**) and salinity (**b**) of the Atlantic Water on transect 'V1' along the meridian 20°E, July 2000–2007. The 2005 data were gathered by the IMR in May 2005

Transect 'V1' is meridional, from the northern coast of Norway—on the right of the figure, to the Bear Island. That 400 km long section crosses the main route of the Atlantic Water inflow into the Barents Sea. During its eastward advection, the AW is subject to a very strong transformation—cooling and decrease of salinity which contributes significantly to formation of deep and intermediate waters. (Rudels et al. 1994; Schauer et al. 1997, Masłowski et al. 2004). The water flows from the Barents Sea into the AO through the St. Anna trough and joins the AW inflow through the Fram Strait. The volume transport through the BSO is comparable with the volume transport through the Fram Strait. It flows through a 500 m deep trough in the shelf of the Barents Sea (Fig. 5.19). The inclination of all isolines suggests an intense baroclinic flow "towards the picture", thus, eastward. The warmest water is located on the Norwegian shelf. However, that is not only the Atlantic Water. The warm and low saline water is transported by the Norwegian Coastal Current. Low salinity of the NCC results from the advection of the fjord water mixed with water transported from the Baltic Sea (Masłowski and Walczowski 2002). The AW is the warm and saline water mass, separated by the 34.92 isohaline, which occupies the major part of the transect. Less saline Polar Water appears from the side of the Bear Island.

5.6 The 'Core' Transect

The transformation of the AW during its northward advection has influence upon its physical and chemical properties—mostly temperature and salinity. At lower latitudes the AW is warmer and more saline than in the north. That is obvious. However, the water also carries a seasonal signal, originating from the area of its ultimate formation, probably in the Subpolar Gyre. Hence the complex diagram of the AW temperature at the Svinoy Section (Orvik and Skagseth 2005). It also influences the spatial and temporal variability of the AW properties in the study area. During advection, the water also acquires its own seasonal signal; the exchange of heat with the atmosphere is enhanced in winter, it occurs with various intensity in different regions, the intensity of exchange is significantly modified by the atmospheric circulation—the wind forcing, air temperature and humidity. Therefore, the AW temperature maximum in time series from the Fram Strait occurs only in autumn, and the variability is quite complex. Assuming that it is an advective signal, it should somehow manifest upstream, south of the Fram Strait. On a hydrographic section of adequate length and resolution, the AW temperature should have a shape of a sloping sinusoid (or overlapping sinusoids) with an amplitude increasing northward (the amplification effect occurs along the northward advection). The salinity field should not obtain a distinct seasonal signal in the Nordic Seas, mean salinity on sections should decrease as the water mass flows northwards. The distance between maxima of such signal (wave length) depends on mean advection velocity. The latter value is, however, based on observations of

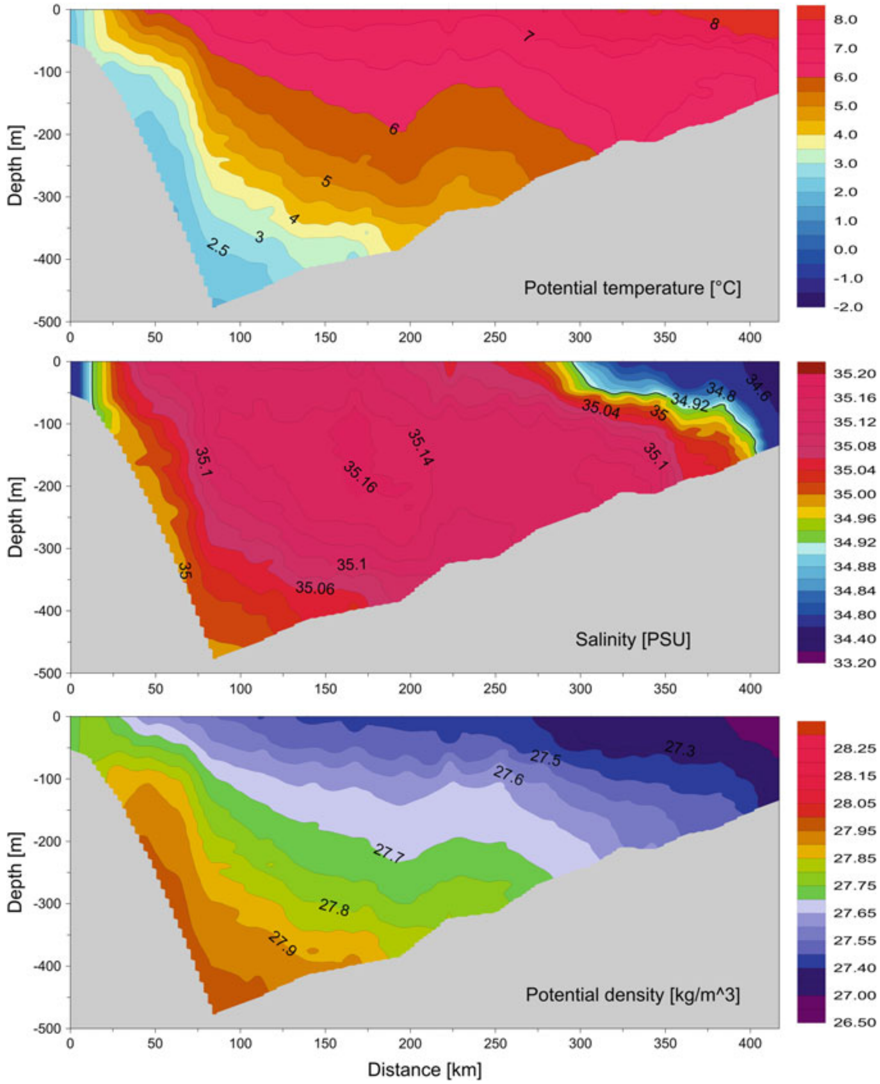


Fig. 5.19 Potential temperature, salinity and potential density on transect 'V1' between Norway and the Bear Island. Summer 2004, r/v Oceania. 34.92 isohaline is bold

specific structures propagating through the moorings with current meters (Polyakov et al. 2005) or observed at the hydrographic sections (Walczowski and Piechura 2007). The advection velocity is usually equal to a few (2–4) cm/s. In terms of the present study it is a very significant parameter, since it conditions any relationship between the observations performed in two subsequent summer seasons. With mean advection velocity of 4 cm/s, the structures observed at 70°N will pass 80°N already after a year. Furthermore, the propagation velocity may differ in various parts of the WSC. It also changes in an annual cycle.

A decision was made to investigate the variability of the AW properties in the core flowing along the continental slope. In order to perform complete sections, the coldest (2003) and the warmest (2006) years were chosen. The measurement points located in the core centre were selected from each section. These are the stations above the continental slope, at a depth of 600–1,000 m. Distributions of hydrographic properties at the sections are shown on Fig. 5.20. The sections vary significantly, both as regards temperature and thickness of the AW layer. In cold 2003 the 6 °C isotherm lies between 162 m and 36 m, and in the warm 2006 the 6 °C is located at a depth from 261 m in the southern part to 157 m up north. There is a similar slope of slope in deeper layers. Salinity curves are somewhat more complicated, however, in general, the inclination of the isohalines is similar to isotherms. Yet, it is difficult to find a seasonal signal. There may be two reasons for that—either it does not exist, or the horizontal distance between the stations is too large.

5.7 Meridional Variability

Integrated values are the most certain criteria for describing water mass properties. That enables reduction of the impact of mesoscale structures or other local processes upon the final result. It also concerns the hydrographic sections, although in that case the dynamics of the sea region has a stronger influence upon the result. Narrowing down the field of observation to smaller and smaller areas poses a risk of obtaining artificial or local results which do not reflect the general trends. Therefore, a description of meridional variability begins with integrated values—mean AW properties on sections measured by the IOPAS. This gives a certainty that objective criteria for evaluation of the processes are applied. Some of the properties were described or shown in another form (as time series) in the preceding chapter, however, thanks to the new arrangement, an integral image can be obtained. Data from the following zonal sections were used: 'H', 'K', 'N' and 'EB'. The same time period was chosen—2000–2007. The first diagrams (Fig. 5.21) show the AW temperature and salinity averaged both in space, at on the investigated sections, and in time for the entire period of study.

The average difference in temperature between the southern and northern section is equal to 1.28 °C, and in salinity 0.052, respectively. A nearly linear decrease of the AW temperature and salinity means (calculated from the entire section and all years) can be observed along the increasing latitude. For temperature it is 0.24 °C per one degree of latitude (0.21 °C/100 km), and for salinity: 0.01 per one degree of latitude (0.009 1/100 km). Standard deviation shows that the greatest variability occurs at the section 'N' along parallel 76°30'N, both for temperature and salinity. A temperature and salinity increase greater than the average occurs in the southern part of the study area. It may be a manifestation of

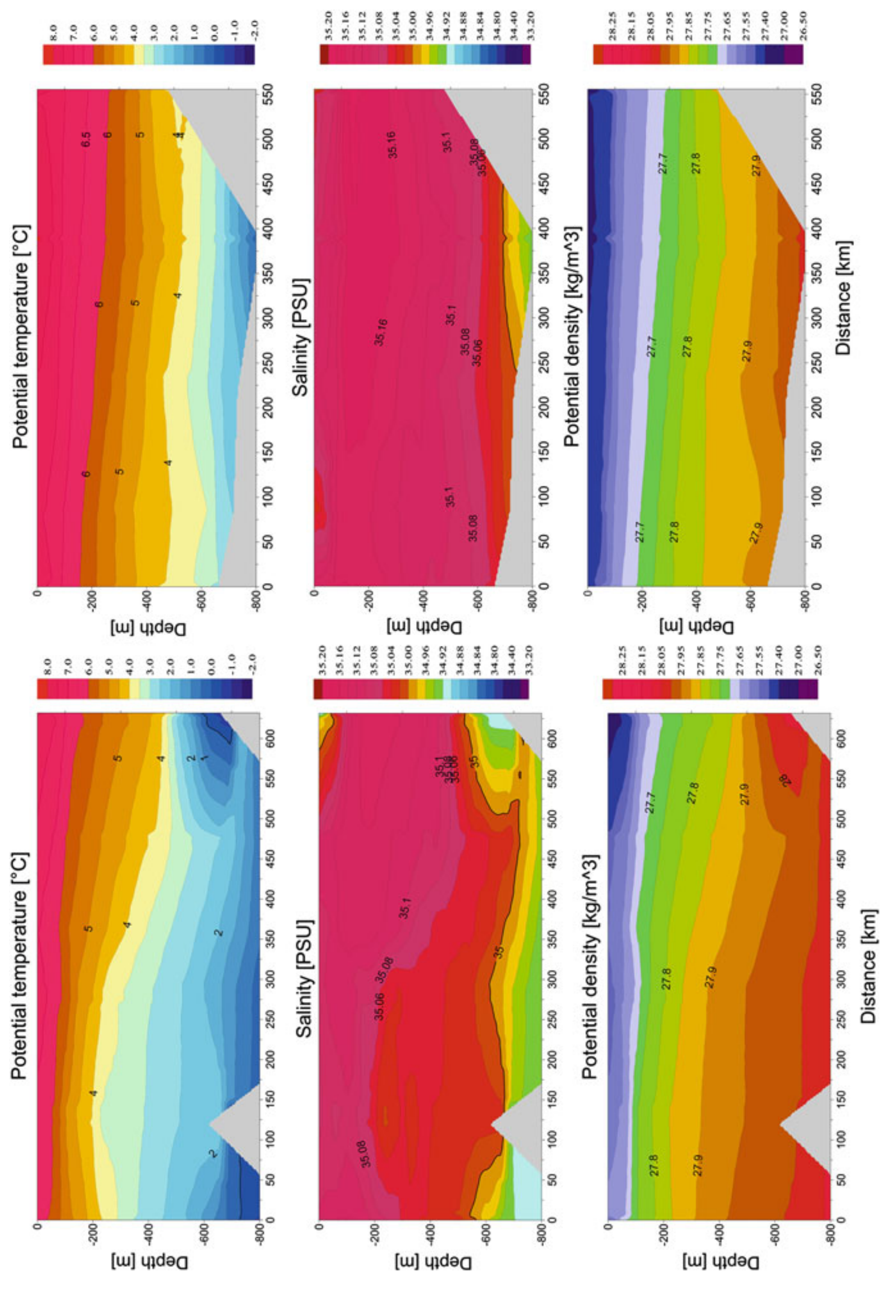


Fig. 5.20 Potential temperature (°C), salinity (PSU) and potential density (kg/m^3) on sections along the WSC core. 2003 (**a**), 2006 (**b**)

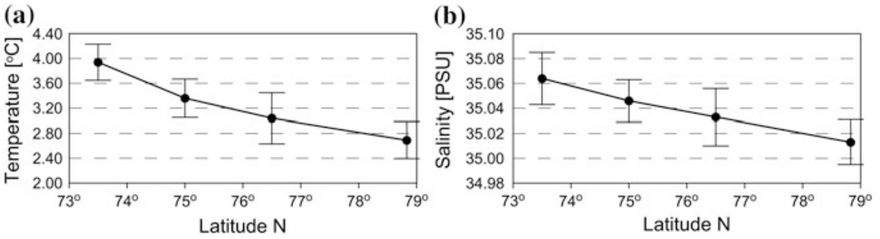


Fig. 5.21 Mean from July 2000–2007: temperature (**a**) and salinity (**b**) of the Atlantic Water on subsequent zonal sections across the WSC. Standard deviations of the presented values are marked

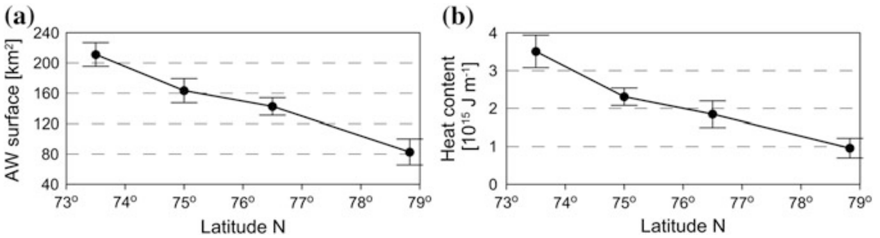


Fig. 5.22 Mean from July 2000–2007: area of section (**a**) and heat content (**b**) of the Atlantic Water on subsequent zonal sections across the WSC. Standard data deviations are marked

the effect of the AW cooling (as described further in the present paper) in the Bear Island Trough.

Also the area of the section occupied by the Atlantic Water at each transect decreases almost linearly along latitude (Fig. 5.22). The AW section area decreases almost threefold on a distance of 600 km, standard deviations, hence the interannual variability of the area, are low. Mean heat content (specified per one metre of the section thickness), decreases even more, since it is a function of section area and temperature. Similarly to temperature, of the mean heat content in the southern part is stronger (Fig. 5.22). The diagrams give the idea of the scale of change in the northward heat and volume flux and, most of all, of the scale of exchanges that occur on the boundaries of the Atlantic Domain, the Barents Sea and the Greenland Sea. It is distinct that the processes of exchange have not been properly appreciated so far.

The diagrams showing temperature change as a function of latitude in subsequent years (Fig. 5.23) confirm that the decrease of temperature towards the north is almost linear, and the angles of inclination of plot lines for individual years are very much similar to the average value. The largest change of inclination of plot lines occurs at the transect N. It is well visible particularly in 2003, when temperature is extremely low.

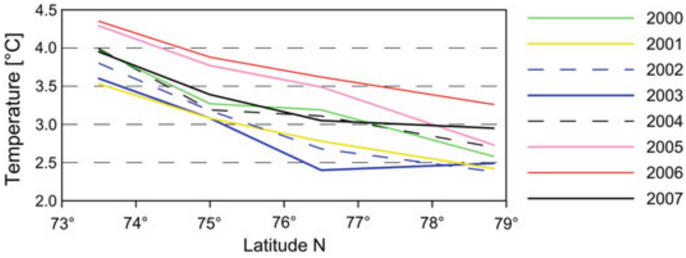


Fig. 5.23 Change in the AW mean temperature in function of latitude, calculated on transects H, K, N, EB in subsequent years

Figure 5.23 shows that the years 2001–2003 were cold along the entire length of the study area, 2000 and 2004 were years of temperature close to average and temperatures in 2005 and 2006 were much above the average. In 2005 the warming could be seen at lower latitudes; in summer 2006 temperature in the Fram Strait reached extremely high value never recorded before. That was attributed mostly to the propagation of anticyclonic eddies of unprecedented size, carrying great temperature and salinity anomalies (Walczowski and Piechura 2006, 2007). In 2007 cooling proceeded gradually from the south.

5.8 Correlations Between the Properties of the Atlantic Water Studied at the Transects

In further part a decision was made to investigate whether there are any relations between the properties of the AW at the transects. The figure presenting time series of temperature and salinity at individual transects (Fig. 5.24) shows the similarity between the time series. The values of mean temperature and salinity at all transects rose from 2005 to 2006 and decreased afterwards. The greatest deviation from the mean was revealed by temperature and salinity at the transect N in 2003 when both values were significantly lower as compared to other sections.

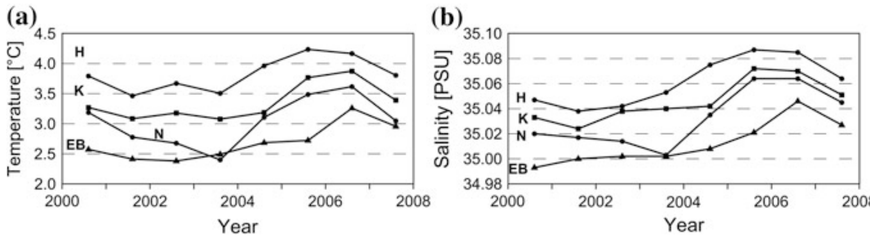


Fig. 5.24 Time series of mean temperature (**a**) and salinity (**b**) of the AW at the transects 'H', 'K', 'N' and 'EB'

Table 5.2 The correlation coefficients r between the AW mean temperature at pairs of transect

Transect	K (2000–2007)	N (2000–2007)	EB (2000–2007)
H (2000–2007)	**0.81**	**0.93**	0.51
K (2000–2007)		**0.86**	0.64
N (2000–2007)			**0.74**

Table 5.3 The correlation coefficients r between the AW mean salinity at pairs of transect

Transect	K (2000–2007)	N (2000–2007)	EB (2000–2007)
H (2000–2007)	**0.77**	**0.77**	0.37
K (2000–2007)		**0.73**	0.56
N (2000–2007)			0.63

Table 5.4 The correlation coefficients r between mean temperature and mean salinity of the AW at transects

Transect	H (2000–2007)	K (2000–2007)	N (2000–2007)	EB (2000–2007)
H (2000–2007)	**0.87**	0.69	**0.78**	0.43
K (2000–2007)		**0.91**	0.68	0.37
N (2000–2007)			**0.96**	0.58
EB (2000–2007)				**0.80**

Correlations and p-tests between the T and S time series of all the transect pairs were calculated for detrended data. The results are given in Tables 5.2, 5.3 and 5.4. Correlations on significance level below 0.05 are marked bold, below 0.01—bold and underlined.

Correlations on significance level below 0.05 were obtained for the temperature–temperature and salinity–salinity pairs for transect pairs nearest to each other: H–K, H–N, K–N; and for the pair N–EB—only for the temperature–temperature pair. It is interesting that the correlation between temperatures on transects H–N is higher than the correlation between transects H–K which are closer to each other. That applies also to the correlation between salinity on transect H and temperature on transect N. That may be a manifestation of the sought seasonal signal carried by the AW, since for salinity on transects H–N the correlation is only slightly higher than for transects H–K. Unfortunately, there are not enough data to state the above with full certainty. Besides, if the same signal phase was observed at the transects H and N (e.g. some "recorded" subsequent summer signals, as suggested by Fig. 5.21), the propagation velocity would be very low. To travel 3 degrees of latitude per year (from 73°30′ to 76°30′), the average propagation velocity should be around 1 cm/s. The shift of correlation of temperature in relation to salinity cannot be seen—T and S correlate very well on each transect (Table 5.4).

Calculating correlations (and autocorrelations for pairs of the same transects) with 1 year time lag also gives interesting results (Tables 5.5, 5.6).

Table 5.5 The correlation coefficients r of the AW mean temperature at individual transects with 1 year time lag

Transect	H (2001–2007)	K (2001–2007)	N (2001–2007)	EB (2001–2007)
H (2000–2006)	−0.02	0.50	0.32	0.53
K (2000–2006)		0.05	0.02	0.54
N (2000–2006)			0.22	0.40
EB (2000–2006)				−0.11

Table 5.6 The correlation coefficients r of the AW mean salinity at individual transects with 1 year time lag

Transect	H (2001–2007)	K (2001–2007)	N (2001–2007)	EB (2001–2007)
H (2000–2006)	0.23	0.38	0.70	0.67
K (2000–2006)		−0.16	0.09	0.56
N (2000–2006)			0.24	0.65
EB (2000–2006)				−0.16

Table 5.7 The correlation coefficients r of mean salinity and temperature (columns) of the AW shifted by 1 year

Transect	H (2001–2007)	K (2001–2007)	N (2001–2007)	EB (2001–2007)
H (2000–2006)	0.42	0.70	0.71	0.67
K (2000–2006)		0.17	0.22	**0.79**
N (2000–2006)			0.23	0.50
EB (2000–2006)				−0.06

The value of the autocorrelation function for 1 year time lag is very low—it means that based on 1 year's study of a single transect we cannot conclude on the AW properties in the following or the preceding year. However, salinity at the transect N can be predicted with high probability based on the salinity data from the transect H in the preceding year. It is quite a general rule that in the case of one-year time lag between the transects situated in the north in relation to those in the south, the more distant transects are correlated better. It indirectly confirms the thesis that time needed for propagation of the signal from the south to the north approximates to 1 year. The highest r (although on the significance level above 0.05) is for the temperature of H–EN and K–EN pairs, and for the salinity of H–N, H–EB and N–EN pairs. It suggests that mean salinity and temperature of the AW in the Fram Strait react with 1 year lag in relation to processes which occur south of transect EB. The strongest correlations are obtained between salinity and temperature in the following year. In this case the correlation coefficient increases significantly as the distance between the sections increases (Table 5.7).

When the study area was divided into two parts, the temperature in the northern part also reacted with 1 year lag in relation to salinity in the southern part (Chap. 4).

5.8.1 Correlations in the Eastern WSC Branch

For the eastern branch (core) of the WSC, mean AW properties were calculated in the WSC core, in a similar way as for the entire transects. A section of 50 km width has been selected from each transect to cover the area of the highest temperature and salinity. This selection of the data subset alone causes the data to be less representative than the data from the entire transect, since the position of the shifts in relation to the shelf and its width vary in years. However, a decision was made not to distinguish any regions separately for each year, since that may lead to subjective selection of data. Temperature and salinity time series from the WSC core (Fig. 5.25) at individual transects differ significantly. Transect H, which lies farthest to the south features the lowest variability, although it is situated in the range of impact of the Barents Sea. The difference between the minimum in 2001 (4.15 °C) and the maximum in 2006 (4.88 °C) equals 0.73 °C, and standard deviation: 0.24 °C. For the purpose of comparison: at the transect N temperature reaches minimum in 2003 (3.05 °C), maximum in 2006 (4.10 °C) and its standard deviation is 0.45 °C. It indicates that variability of properties of the AW flowing from the NwASC is relatively low. However, there is a significant change in properties of the AW as it continues northwards. Temperature and salinity decreases, differences between the properties in different years grow. It is sometimes referred to as "signal amplification".

In most cases, the correlation coefficients for the WSC core temperatures are lower than the ones for mean temperatures from the entire transect (Table 5.8). A significant correlation was obtained for the pair N–EB. The correlation coefficients

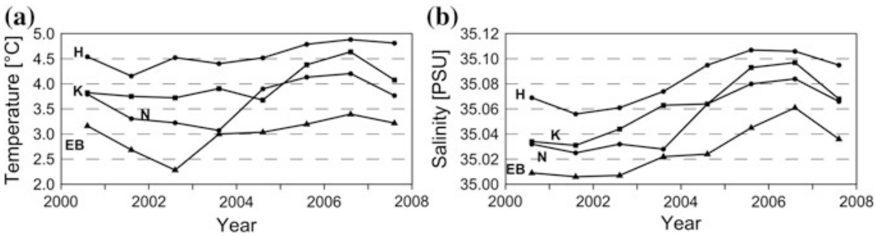


Fig. 5.25 Time series of mean temperature (**a**) and salinity (**b**) of the AW in the WSC core on transects H, K, N and EB

Table 5.8 The correlation coefficients r between the AW mean temperature of transect pairs in the WSC core

Transect	K (2000–2007)	N (2000–2007)	EB (2000–2007)
H (2000–2007)	0.42	0.62	0.57
K (2000–2007)		0.50	0.60
N (2000–2007)			**0.77**

Table 5.9 The correlation coefficients r between the AW mean salinity of transect pairs in the WSC core

Transect	K (2000–2007)	N (2000–2007)	EB (2000–2007)
H (2000–2007)	**0.75**	**0.89**	0.59
K (2000–2007)		0.59	**0.71**
N (2000–2007)			**0.73**

Table 5.10 The correlation coefficients r of the AW mean temperature on individual transects in the WSC core with 1 year time lag

Transect	H (2001–2007)	K (2001–2007)	N (2001–2007)	EB (2001–2007)
H (2000–2006)	−0.50	0.39	−0.12	0.42
K (2000–2006)		−0.15	−0.12	0.08
N (2000–2006)			0.24	0.32
EB (2000–2006)				0.11

Table 5.11 The correlation coefficients r of the AW mean salinity on individual transects in the WSC core with 1 year time lag

Transect	H (2001–2007)	K (2001–2007)	N (2001–2007)	EB (2001–2007)
H (2000–2006)	0.24	0.11	0.52	0.57
K (2000–2006)		−0.12	0.35	0.29
N (2000–2006)			0.15	0.49
EB (2000–2006)				−0.19

for salinity are comparable, and for the pair H–N the correlation coefficient reaches **0.89** (Table 5.9).

Autocorrelations and correlations between the same properties of the AW at various transects calculated with 1 year time lag have usually lower values (Tables 5.10, 5.11).

5.8.2 The Western Part of the WSC

The same calculations as for the eastern part were performed for the western part of the WSC (Fig. 5.26), (Tables 5.12, 5.13).

Similarly to the entire transects, also in the western part the concurrent correlations between temperatures for pairs H–K, H–N and K–N are the highest. In the case of salinity only the K–N pair indicates a correlation at the significance level below 0.05, while for the correlation with a time lag, only the salinity of the H–N pair exceeds that level. However, it is typical that in all the cases with time lag, correlations for transect EB are larger in the western part than in the core. For salinity of the N–EB pair, the coefficient of correlation reaches 0.72 (Table 5.14).

All the operations yield interesting, yet incomplete, results.

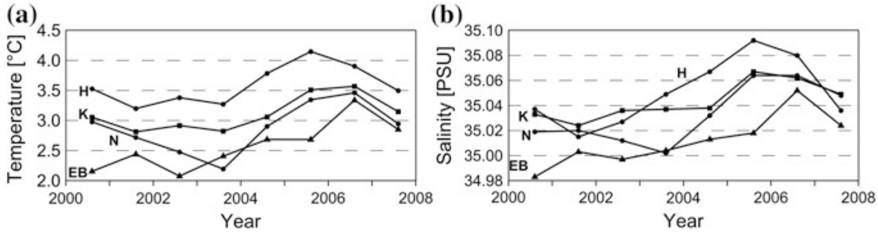


Fig. 5.26 Time series of mean temperature (**a**) and salinity (**b**) of the AW west of the WSC core on transects H, K, N and EB

Table 5.12 The correlation coefficients r of the AW mean temperature for transect pairs west of the WSC core

Transect	K (2000–2007)	N (2000–2007)	EB (2000–2007)
H (2000–2007)	<u>**0.84**</u>	<u>**0.84**</u>	0.25
K (2000–2007)		<u>**0.90**</u>	0.45
N (2000–2007)			0.60

Table 5.13 The correlation coefficients r of the AW mean salinity for transect pairs west of the WSC core

Transect	K (2000–2007)	N (2000–2007)	EB (2000–2007)
H (2000–2007)	0.69	0.67	0.12
K (2000–2007)		**0.74**	0.35
N (2000–2007)			0.53

Table 5.14 The correlation coefficients r between the AW mean temperature and the AW mean temperature with 1 year time lag for transects situated west of the WSC core

Transect	H (2001–2007)	K (2001–2007)	N (2001–2007)	EB (2001–2007)
H (2000–2006)	0.15	0.57	0.59	0.66
K (2000–2006)		0.03	0.09	0.55
N (2000–2006)			0.26	0.40
EB (2000–2006)				−0.24

Correlations without a time lag.

1. Most of the correlation coefficients between the investigated mean values from the entire transects are higher than the coefficients between the analogical values from "partial" transects.
2. The highest correlations, both for mean temperature and salinity were found between transect H and N;
3. In the western part there are also high correlations between transects K and N. They do not exist in the WSC core.
4. In the WSC core, there are large correlations between transects N and EB.

Correlations calculated with time lag

1. The value of the autocorrelation function is very low in all cases;
2. Both for mean salinity and temperature 1-year time lag did not increase the correlation coefficients. They are comparable or lower than respective coefficients calculated without the time lag;
3. The correlation coefficients in the western part are higher than in the entire transects or in the eastern part;
4. There are stronger correlations between salinity at the southern transects and temperature at the northern ones in the following year (Table 5.7).

The results give basis to draw a few more general conclusions concerning the nature of spatial and temporal variability of the AW properties in the given area.

1. Based on data from one year one cannot predict mean values of the AW in the following year on the same transect, since temperature and salinity in the following year are not correlated with temperature in the current year.
2. Based at temperature at the transects one can predict with some probability the temperature and salinity in the downstream region. In this particular case, one can predict the AW mean temperature and salinity at the transect 'N' in the same year with high probability, for instance from transect H data. These values are well correlated (Fig. 5.27).
3. Despite the long periods of variability and advective nature of "the ocean climate" in the study area, the possibility of predicting temperature at northern transects in the following year based on the temperature data from the southern transects is limited. The same is with salinity. 1-year time lag was observed for some pairs of transects, however, the correlation coefficients were at the significance level above 0.05. Correlations in the WSC core were even lower. They increased slightly in the western part. In that case the correlation between the values of mean salinity at transects H and N in the following year was 0.77 (Table 5.15).

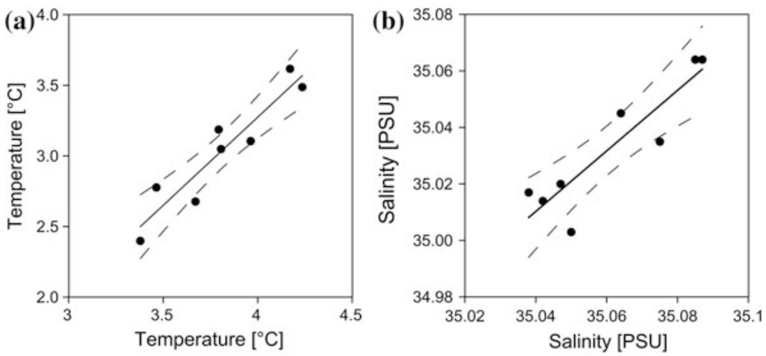


Fig. 5.27 Regression of mean temperature (**a**) and salinity (**b**) of the AW of the H–N transects pair. The data are not detrended. 95 % confidence intervals are marked

Table 5.15 The correlation coefficients r between the AW mean salinity and the AW mean salinity with 1 year time lag for transects situated west of the WSC core

Transect	H (2001–2007)	K (2001–2007)	N (2001–2007)	EB (2001–2007)
H (2000–2006)	0.25	0.46	**0.77**	0.66
K (2000–2006)		−0.17	0.02	0.64
N (2000–2006)			0.27	0.72
EB (2000–2006)				−0.14

$$T_N = 1.2479 * T_H - 1.7177 \quad r = 0.937$$
$$S_N = 1.0717 * S_H - 2.5420 \quad r = 0.814$$

It is worth emphasizing again that the time series we have at our disposal are short, hence, not statistically robust. However, they are the only series from such a large area. Time series are extended each year and the measurement will be the best way to verify the presented relationships. There are a lot of questions. It is not completely clear why the correlation is generally higher (without any time lag) for more distant transects at (K–N) than closer to each other (H–N). Is it a seasonal signal occurring at an average distance of 2.5-3 degrees of latitude (275-330 km). That is a too short distance taking into account the described AW advection velocity. On the other hand, according to observations, the temperature isoline shifted northwards with average annual velocity of 1 cm/s (Walczowski and Piechura 2007), which is in conformity with the above distances. However, shifting of isotherms does not necessarily mean that there is a movement of water; during advection some heat is released to the atmosphere, thus the shifting of isotherms is slower than the movement of water particles. The issue will be addressed in Chap. 8.

Obtaining correlations between the data with 1-year time lag is a very valuable result. According to the statistics, we are capable of maintaining some continuity of observations by performing measurements only once per year. Water masses observed one year in the south or in the central part of the study area may be observed the following year in the northern part, in the Fram Strait area. It concerns in particular the processes occurring in the western part of the WSC where the average advection velocity is lower. There is a higher correlation between the values of salinity, since that property is more conservative. For instance, transect 'EB' shows the unique role of processes in Fram Strait and in the entire region west of Spitsbergen. The highest correlations with other sections were obtained at that transect for 1-year time lag in particular. It confirms the thesis that the upstream region (south of the 78°N parallel) may be a sort of a buffer for the AW.

5.9 Summary

This chapter focuses on presentation and analysis of variability of the AW properties on spatial scales smaller than the one applied in Chap. 4. Therefore, mainly the variability at transects has been presented. They mostly include zonal sections, from the most southern ones to the northern ones. Two meridional transects have also been used: transect V1 between Norway and the Bear Island, and a virtual Core transect, developed for the purpose of the present work.

Similarly to mean values from the entire study area, a distinct warming in the 2004–2006 period is visible, a phase lag can be also seen in the propagating signal. In order to determine the structure of warming, time series of the AW properties at the same transects but in different parts (western, central and eastern) were studied. In the case of the transect N time series, the Hovmoeller diagram was used.

The data from transects were used for more detailed analysis of the transformation which the Atlantic Water undergoes along its northward advection. A linear decrease of the AW mean properties, such as temperature, salinity, heat content or the cross-section area occupied by the AW, was found.

Relationships and evidence to confirm the advection-driven propagation of signal was sought with use of a series of correlations between the AW properties at transects. The most valuable result is the correlation between water properties on sections H and K (the southern study area) and the AW properties in the northern study area the following year, increasing on its way northwards. It confirms once more that the average time of signal propagations through that region is approximately 1 year. That applies mostly to the western branch; in the WSC core the signal propagation speed is higher.

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