УДК 551.465

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МЕЖГОДОВАЯ ИЗМЕНЧИВОСТЬ ТЕРМОХАЛИННЫХ ПАРАМЕТРОВ ВЕРХНЕГО СЛОЯ В АРКТИЧЕСКОМ БАССЕЙНЕ СЕВЕРНОГО ЛЕДОВИТОГО ОКЕАНА

Статья поступила в редакцию 19.03.2019, после доработки 19.07.2019

На основе данных наблюдений проанализированы закономерности изменчивости температуры и солености в верхнем 20-метровом слое океана на временном интервале 1950—2014 гг. Для исследования было выбрано четыре характерных области в центральной части Арктического бассейна и два района на его границе с морем Лаптевых. По результатам анализа показано, что до 1990-х гг., когда большая часть Арктического бассейна была круглогодично покрыта многолетними льдами, временная изменчивость термохалинных параметров в верхнем перемешанном слое в центральном Арктическом бассейне была мала в течение всего года. С середины 1990-х гг. в западной и восточной частях Арктического бассейна наблюдаются разнонаправленные изменения термохалинных параметров в верхнем слое. В западной области в зимний сезон происходит осолонение и охлаждение поверхностных вод, тогда как в восточной Арктике, наоборот, наблюдаются сильное распреснение и соответствующее повышение температуры воды. Одной из основных причин распреснения поверхностных вод в восточной Арктике является сокращение площади многолетних льдов и замещением их однолетними на фоне увеличения общего пресноводного стока рек и изменения характера атмосферной циркуляции в Арктическом бассейне. Осолонение поверхностных вод в западной Арктике связано с увеличением поступления соленых атлантических вод из пролива Фрама и их подъемом к поверхности в условиях возросшей сезонности арктического морского льда, под которой понимается увеличение продолжительности сезона таяния.

Ключевые слова: Северный Ледовитый океан, Арктический бассейн, термохалинные параметры, морской лед, временные ряды.

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INTERANNUAL VARIABILITY OF THERMOHALINE PARAMETERS IN THE DEEP ARCTIC OCEAN

Received 19.03.2019, in final form 19.07.2019

Temperature and salinity variability in the upper 20-meter ocean layer in the 1950—2014 time interval were analyzed on the basis of the observational data. Four typical regions were selected for this study in the central part of the Arctic basin and two regions on its border with the Laptev Sea. The analysis allowed revealing that until the 1990s, when most of the Arctic basin was covered with perennial ice all year round, the temporal variability of the thermohaline parameters in the upper mixed layer in all the considered areas was small throughout the year. Since mid-1990s, multidirectional changes in the thermohaline parameters in the upper layer have been observed in the western and eastern parts of the Arctic basin. In the Western region in the winter season, salinization and cooling of surface waters are happening, whereas in the eastern Arctic, on the contrary, there is strong desalination and a corresponding increase of water temperature. One of the main

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Ссылка для цитирования: *Иванов В.В.*, *Головин П.Н.* Межгодовая изменчивость термохалинных параметров верхнего слоя в Арктическом бассейне Северного Ледовитого океана // Фундаментальная и прикладная гидрофизика. 2019. Т. 12, № 3. С. 13—25

For citation: *Ivanov V.V.*, *Golovin P.N.* Interannual variability of thermohaline parameters in the deep Arctic Ocean. *Fundamentalnaya i Prikladnaya Gidrofizika*. 2019, 12, 3, 13—25

DOI: 10.7868/S2073667319030031

reasons for the desalination of surface waters in the eastern Arctic is a reduction in the area of perennial ice and its replacement by seasonal one against the background of increased riverine water discharge and change in the atmospheric circulation over the Arctic. The salinization of surface waters in the western Arctic is associated with an increase in the supply of saline Atlantic waters from the Fram Strait and their rise to the surface under conditions of increased seasonality of Arctic sea ice, which refers to an increase in the duration of the melting season.

Keywords: Arctic Ocean, Arctic Basin, thermohaline parameters, sea ice, time series.

1. Introduction

The decrease in the volume of the Arctic sea ice in the 1990–2010 changed the energy balance in the "ocean-sea-ice-atmosphere" system. One of the consequences of the occurred changes was the vertical structure transformation of the waters, due to more intense atmospheric effects on the upper layer of the ocean. The general tendency due to atmospheric forcing strengthening, at first glance, should be the deepening of the upper mixed layer, its heat storage increase by the end of the summer season, and ice formation slowdown in the subsequent winter season [1]. However, in reality, the consequences of sea ice reduction are less predictable and regionally dependent. The key role, however, belongs to the ocean upper layer desalination, caused by intensive ice melting and river discharge, coupled with horizontal advection that depends on the atmospheric circulation characteristics [2]. The near-surface (~0–20 m) quasi-homogeneous layer of water is most strongly affected by summer heating, desalination; and, in the modern conditions of the summer ice cover reduction, by the influence of wind waves. In the winter season, the same layer experiences the greatest salinization during ice formation and dynamic effects from drifting ice (turbulent mixing caused by the ice motion). Below 20 m over the most areas of the Arctic Ocean rests the upper boundary of the high-gradient structural zones separating the upper quasi-homogeneous layer from the intermediate warm and saline waters of the Atlantic (AW) and Pacific (PW) origin.

An effective way to assess the effects of sea ice reduction on the vertical structure of water is to analyze the temporal variability of thermohaline parameters. At a fixed point in space, this variability can be traced using continuous observations at anchored buoy stations (for example, the NABOS project: http://nabos.iarc.uaf.edu/). In the Arctic, such observations are few and short. Another historically preceding approach implies a quasi-regular hydrological surveys in a specific area (i.e., the expedition "North" [3]). Such surveys allow: firstly the spatial variability estimation on the scale of the studied area, and secondly, the identification of interannual variability of thermohaline parameters with the proviso that in the case of the study area intersection by a frontal zone, this temporal variability can be "masked" by an unknown spatial variability of the frontal zone position. In the summer, an objective analysis of spatial surveys designed to identify the spatial variability of the thermohaline characteristics is much more complicated, especially in the marginal Arctic seas, due to the intense seasonal signal associated with heating, snow and ice melting, and river runoff. Because of this, the analysis of summer data, even within the boundaries of one sea into which water-abundant rivers discharge (i.e. the Laptev Sea) is very difficult, especially when the observations last over a long period – more than 1–2 months. In such cases, the accuracy of the analysis of the thermohaline characteristics spatial variability is reduced due to the uncertainty input to the temporal variability owing to rapid summer processes. It is especially important to get an undistorted view of the long-term temporal variability in the context of the epochal change of ice conditions in the Arctic Ocean at the turn of the 20th and 21st centuries, when most of the Arctic seas and a significant part of the Arctic basin became ice free in the summer season, and in the winter season covered with first-year ice [4].

According to field observations, the general trends in the thermohaline state change of the Arctic waters upper layer in the summer season in the 2000s, in comparison to those observed in the second half of the 20th century, are desalination in the Pacific sector and salinization in the Atlantic sector [5]. As the main reason for such trends, a steady anticyclonic circulation regime is often suggested, which persists on average over the Arctic Basin from 1997 to the present [6]. A characteristic feature of the surface pressure field is the displacement of the high pressure centre to the Beaufort Sea and the formation of a deep depression over eastern Siberia. In modern western literature, such a structure is referred to by the term "arctic dipole" [7, 8]. Under its action over the East Siberian and Chukchi seas, the southerly winds bringing warm air from the continent predominate and intensify the melting of ice and its drift towards the Pole and the Fram Strait [8]. Another important feature of the arctic dipole is the provision of cloudless weather over the Beaufort Sea. Extra solar radiation coming in the summer season contributes to the melting of an additional amount of ice.

Within the described concept, the ongoing accumulation of freshwater in the upper layer of the Beaufort gyre [9] is mainly due to the anomalously long persistence of the anticyclonic circulation regime [10]. At the same time, in addition to "conservation" of desalinated water in the Beaufort gyre due to local melting, the surface pressure field also contributes to the circulation reinforcement with the river freshwater discharge into this area due to the deviation of the Ob' and Lena flows to the east from their average trajectories [2]. In the Eurasian Basin, on the contrary, there is a shortage of river discharge and an increase in salinity, which also occurs as a result of increased inflow of high-saline Atlantic waters [11]. Thus, despite the desalination (on average) of the upper layer of the Arctic basin as compared to the climatic norm due to increased ice melting, actual changes include both desalination in the Pacific sector of the Arctic and salinization in the Atlantic sector.

The article consists of five sections, including the Introduction. The second section describes the observations used for the analysis. The third section contains a comparative analysis of time series of temperature and salinity in selected areas. The fourth section discusses obtained results in the general context of current climate change. Brief summary conclusions complete the article.

2. Data and methods

In this study, two partially intersecting data arrays were used. The main multiyear hydrological data array (1950–2014) covering the Arctic Basin allowed identification of local areas in distinct regions with sufficient data to obtain reasonable estimates. The initial data set, from which the working array was subtracted for further analysis, is located at the World Oceanographic Data Center (Data Center VNIGMI WDC, Obninsk, RF, http://nodc.meteo.ru/). Four specific regions were selected for the analysis: the Western (W), the Eastern-1 (E-1), and the Eastern-2 (E-2), and the Polar region (P) (see fig. 1). The average size of the selected areas is 150 × 150 km. The areas selection was based on the conditions of the minimum spatial variability of the thermohaline parameters within the area and the maximum distance from the river runoff influence. All the hydrological profiles befalling into a given area were selected from the dataset. The profiles distribution description in these areas is presented in table. The results of the analysis are presented as time dependences of temperature and salinity in a layer of 8–20 m separately for the winter (November–May) and summer (June–October) seasons.

Table

Selected areas in the Arctic basin

Выбранные районы в Арктическом бассейне

	Western 83.50–84.83° N 92.00–105.00° E		North Pole 88.50–89.83° N 00.00–60.00° E		Eastern-1 75.00–76.50° N 150.00–143.00° E		Eastern-2 78.00–79.50° N 160.00–153.00° E	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Number of stations	152	125	1264	885	1713	1036	177	228
Number of profiles in 8–20 m layer (8, 10, 15, 20 m)	191	172	762	234	4004	2014	179	457
Total number of stations	5580							

A shorter, but at the same time, more detailed data set covers the northern and northeastern parts of the Laptev Sea (fig. 1), where the field studies were conducted within the NABOS international program from 2002 to 2018. The data is publicly available on the project website: https://uaf-iarc.org/nabos/. Available data on temperature and conductivity (salinity) measurements allow estimation of the rapid changes observed during the last 15 years when the intensity of Arctic sea ice reduction has accelerated significantly. NABOS measurements were regularly performed in the same locations: in the northern part of the Laptev Sea (L-1: 78.4°±0.10 N, 126.00°±0.5) and the north-eastern part of the Laptev Sea (L-2: 80.0°±0.10 N, 142.30°±0.5) with a vertical resolution of 1 m. Also, the data were averaged in a layer of 8–20 m and visualized as time series of temperature and salinity.

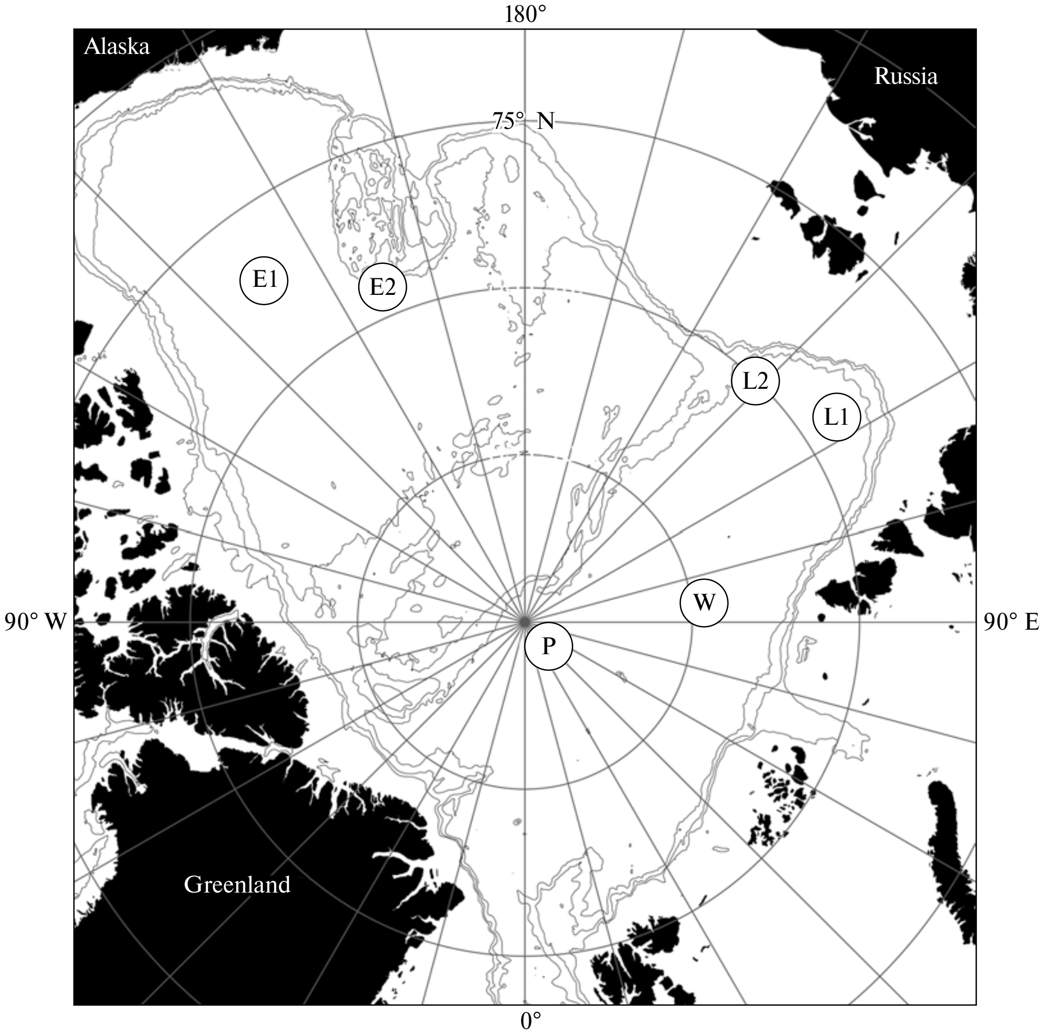

Fig. 1. The relief of the Arctic Ocean (shown isobaths: 500, 1000 and 2000 m). The position of the selected areas for analysis is marked by white circles with an appropriate abbreviation.

Рис. 1. Рельеф дна Северного Ледовитого океана (показаны изобаты: 500, 1000 и 2000 м). Положение выбранных для анализа областей отмечено белыми кружками с соответствующей аббревиатурой.

3. Results

3.1 Changes on a long time scale. Figures 2 and 3 show the inter-annual variability of salinity in selected areas in the winter and summer seasons, respectively. It is noteworthy that, despite the presence of remarkable spatial variability, characterized by the scale of the mean-square deviation (RMS), the temporal variability due to climatic changes is revealed quite reliably in all areas. This is especially conspicuous in the longest winter series (fig. 2). Within both Eastern regions (fig. 2, *a*, *b*) during almost the entire 20th century (until the early 1990s), while the major part of the Arctic Basin was covered with perennial ice all year round, the temporal variability of salinity was small, within 0.5–0.7 practical salinity units (PSU). At the turn of 1990–2000, a sharp decrease in winter salinity by 3.5–4 PSU is observed in these areas. In the 2010s, multidirectional changes occur in the E1 and E2 regions, while maintaining general low background salinity. In the Western region the tendency is opposite. At least from the mid-1970s (and possibly over a longer interval, if we take into account occasional historical data), a monotonous increase in salinity by about 3 PSU (from 1973 to 1990) has been observed. Further, the winter salinity in the Western region remains high, although in the 2010s there is a slight decrease. In the Polar region, similar to the Western one, there is a general trend on increasing salinity about 3 PSU between 1950 and 2014. During the period from 2005 to 2014, when winter observations in this area were carried out annually as part of

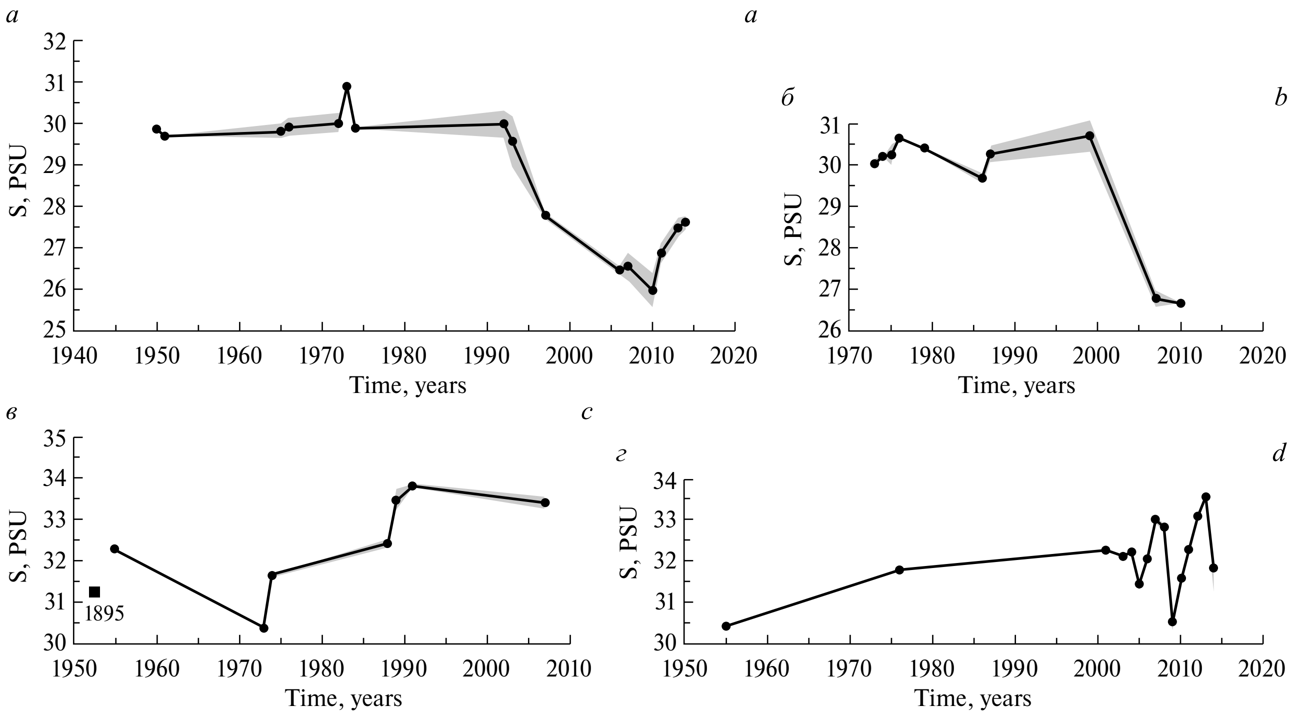

Fig. 2. Temporal variability of salinity of the upper (8–20 m) layer in the winter season in the East-1 region (*a*), in the East-2 region (*b*), in the West region (*c*) and in the Polar region (*d*). The shading shows the standard deviation.

Рис. 2. Временная изменчивость солености верхнего (8–20 м) слоя в зимний сезон в Восточной-1 области (*а*), в Восточной-2 области (*б*), в Западной области (*в*) и в Приполюсной области (*г*). Серой заливкой показано среднеквадратическое отклонение.

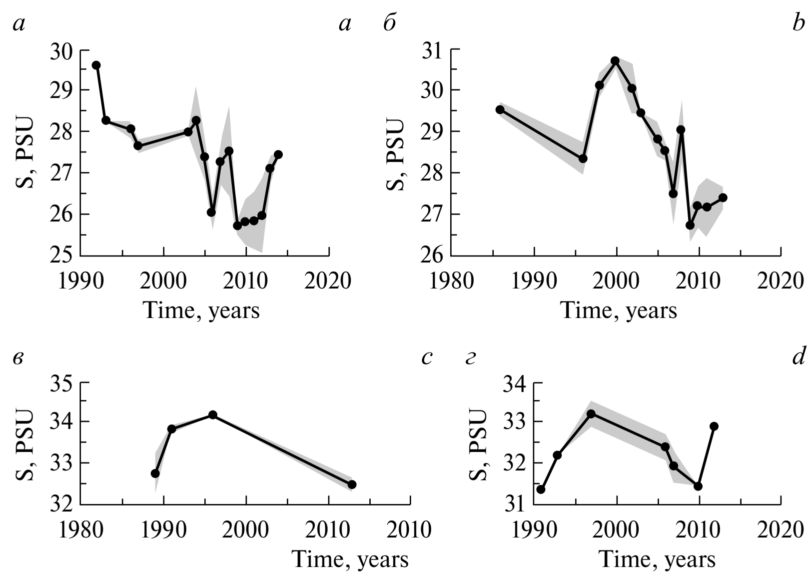

Fig. 3. Temporal variability of salinity of the upper 8–20 m layer in the summer season in the East-1 region (*a*), and in the East-2 region (*b*), in the West region (*c*) and in the Polar region (*d*). The shading shows the standard deviation.

Рис. 3. Временная изменчивость солености верхнего 8–20 м слоя в летний сезон в Восточной-1 области (*а*), и в Восточной-2 области (*б*), в Западной области (*в*) и в Приполюсной области (*г*). Серой заливкой показано среднеквадратическое отклонение.

the Barneo seasonal ice camp (https://tass.ru/info/1075254), sharp annual fluctuations in salinity values, commensurate with the scale of long-term climate changes, have been registered (2–3 PSU). A possible explanation of the nature of these oscillations is discussed in the next section.

Summer observations in the selected areas (see table) are shorter and start from the 1980–1990s. The long-term variability of salinity in the summer season is generally consistent with the temporal variability in the winter. There is strong desalination in both Eastern regions in the 1990s, with a delay of several years in E-2 compared to E-1. It must be emphasized that in the summer season during the 2000–2010s, the spatial variability of salinity increased significantly in both Eastern regions. In the Western region, maximum salinity was observed in the mid-1990s. By 2010, the salinity in this area returned to the values observed in 1990. In the Polar region until 2010, the salinity temporal variability almost repeated that observed in the Western region, but in 2014 the salinity increased again reaching the maximum values. The magnitude of salinity fluctuations in the W and P areas is 2–2,5 times smaller than in the Eastern ones, about 1.5–1.7 PSU. The obtained results are consistent with the findings in [12], based on the analysis of the thermohaline state of the upper layer of the Arctic Basin during anomalous ice conditions in 2012.

The temporal variability of water temperature in the studied regions in the winter and summer seasons is presented in figures 4 and 5. In the winter season, the temperature variability in all regions is insignificant: 0.1–0.3 °C, which is easily explained by the presence of a continuous ice cover. Against this background, opposite interannual trends are observed in the Eastern and Western areas. In the Eastern regions, an increase in temperature (by 0.2 °C) is registered between the mid-20th century and the 2000s, while in the Western part temperature decreased by 0.1 °C during the same period. Such variations are consistent with the salinity changes noted above in the winter season, since in winter the temperature is close to the freezing point for given salinity. There is no apparent temperature trend in the Polar region; however, in the 2000s, intense short-period fluctuations are observed. Conspicuous is the fact that in the summer season there is a noticeable increase in the temperature variability scale in the Eastern regions (up to 1 °C in E-1) while a small (about 0.1 °C) temperature variability is maintained in the Western and Polar regions. However, it is necessary to emphasize that the small amount of data does not allow characterization of the actual variability in these areas unambiguously.

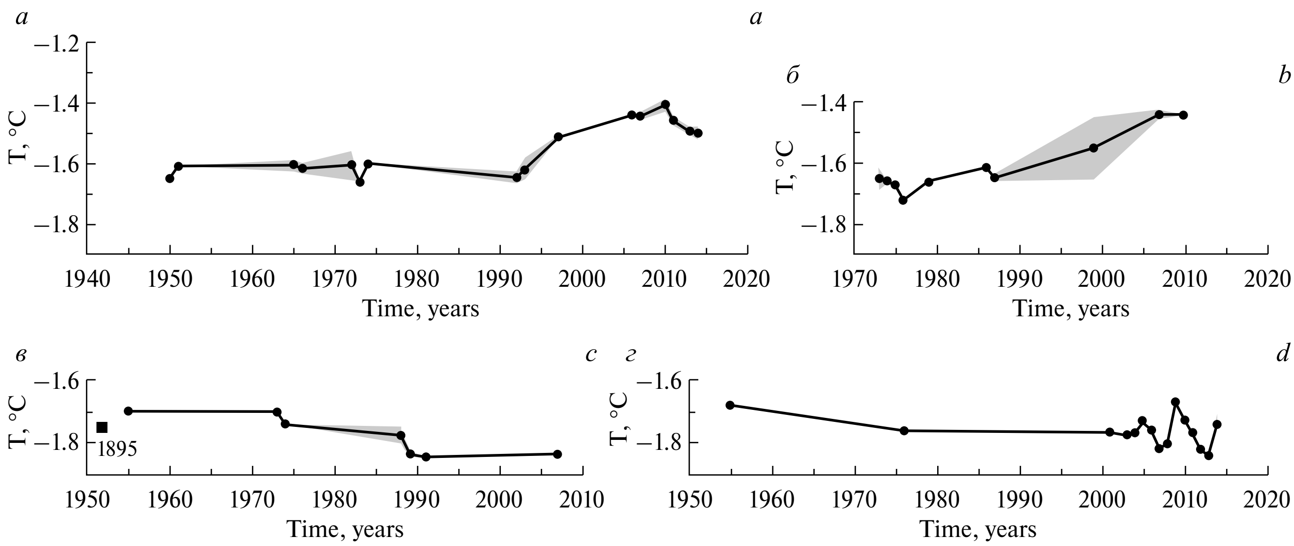

Fig. 4. Temporal variability of the temperature of the upper 8–20 m layer in the winter season in the East-1 region (*a*), in the East-2 region (*b*), in the West region (*c*) and in the Polar region (*d*). The shading shows the standard deviation.

Рис. 4. Временная изменчивость температуры верхнего 8–20 м слоя в зимний сезон в Восточной-1 области (*а*), в Восточной-2 области (*б*), в Западной области (*в*) и в Приполюсной области (*г*). Серой заливкой показано среднеквадратическое отклонение.

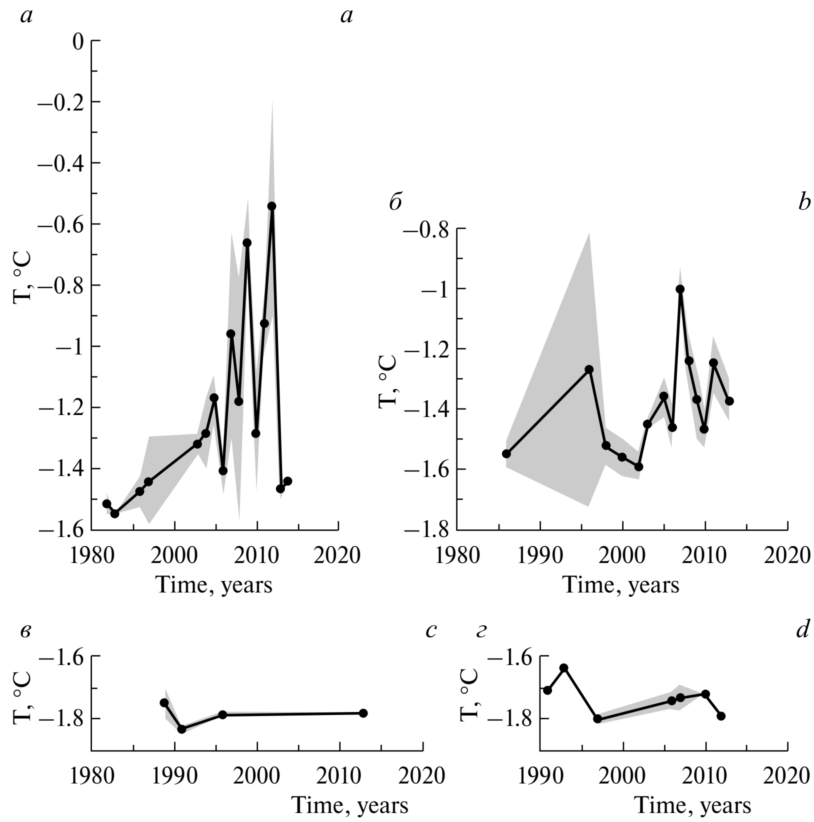

Fig. 5. Temporal variability of the temperature of the upper 8–20 m layer in the summer season in the East-1 region (*a*), in the East-2 region (*b*), in the West region (*c*) and in the Polar region (*d*). The shading shows the standard deviation.

Рис. 5. Временная изменчивость температуры верхнего 8–20м слоя в летний сезон в Восточной-1 области (*а*), в Восточной-2 области (*б*), в Западной области (*в*) и в Приполюсной области (*г*). Серой заливкой показано среднеквадратическое отклонение.

3.2. Changes in the 2000s. The main difference between the observations at points L-1 and L-2 (fig. 6 and 7) from those considered in the previous subsection is the complete elimination of the spatial component of variability since the observations were regularly carried out in practically the same position in August-September. Thus the space averaging was not performed in this case. To a certain extent, this fact explains the greater fluctuations' amplitude observed in both salinity and temperature. Besides, points L-1 and L-2 are located on the periphery of the Arctic basin, where the ice cover interannual variability during the summer seasons in the 2000s was larger in comparison with the central part of the basin. At the L-1 point, the salinity is more uniform over time: the magnitude of the interannual fluctuations is within 31.5±2.0 PSU. At point L-2, this value is 30.6±3.5 PSU with a single "outburst" (by -5 PSU) in 2005. These values are close to the average salinity in the Western region (33.3±1.8 PSU) (fig. 6). Somewhat smaller values are explained by the proximity to the shelf, which results in more significant influence of freshwater flow from the continent.

The scale of water temperature variability in the L-1 and L-2 regions is several times larger than the similar variability scale in all areas of the central basin (fig. 7). The temperature varies from the values close to the freezing point to positive ones. Obviously, the reason for a significant increase in temperature is summer warming in the absence of ice cover. Accordingly, the absolute maximum temperature (1.46 °C) was observed at the L-1 point in 2015, when there was no ice cover in this area for a prolonged period [13].

In general, the observed trends in salinity and temperature in the L-1 and L-2 areas are consistent with similar trends in the Western region in the summer season, i.e. increase in temperature and salinity in the 2000s. The probable causes of the noted changes are discussed in the next section.

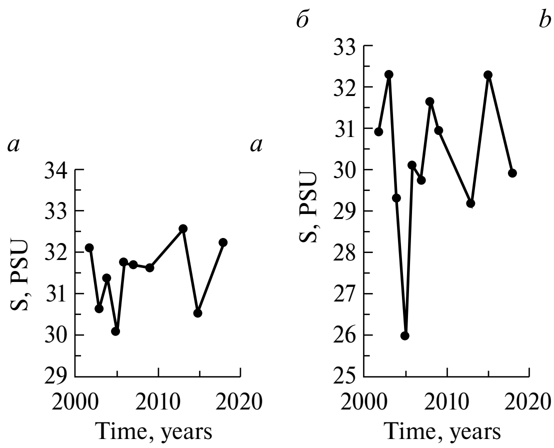

Fig. 6. Temporal variability of the salinity of the upper 8–20 m layer in the summer season at the point L-1 (*a*) and L-2 (*b*).

Рис. 6. Временная изменчивость солености верхнего 8–20 м слоя в летний сезон в точке Л-1 (*а*) и Л-2 (*б*).

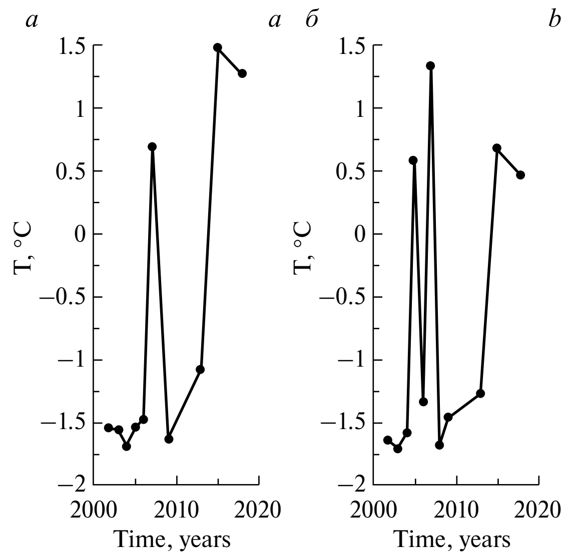

Fig. 7. Temporal variability of the temperature of the upper 8–20 m layer in the summer season at the point L-1 (*a*) and L-2 (*b*).

Рис. 7. Временная изменчивость температуры верхнего 8–20 м слоя в летний сезон в точке Л-1 (*а*) и Л-2 (*б*).

4. Discussion

The main factors determining the thermohaline state of the upper layer of the Arctic basin water (far from the coast) are the processes of ice freezing/melting, energy exchange with the atmosphere, horizontal advection and ice drift. Besides, heat transfer and salt exchange with deep layers may play a significant role in certain areas. The general increase in the seasonality of sea ice cover in the 2000s (see fig. 8 and 9) changed the balance of these factors, which led to multidirectional changes in different geographic areas.

A common characteristic of both winter and summer salinity in both Eastern regions (E-1 and E-2) is a small temporal variability until the early 1990s and a sharp decrease after the 2000. At the same time, winter temperatures increased slightly, while non-periodic fluctuations appeared on the temperature graph in the summer season with the amplitude significantly exceeding the climatic trend. It is well known that in the 20th century, almost the entire central Arctic was covered with ice all year round [15, 16]. In the Eastern regions, this situation started to change in the mid-1990s (fig. 9, *a*). The increase in summer melting led to the desalination of the upper layer in the summer season, which was no longer balanced by the increase in salinity due to the growth of ice throughout the subsequent winter. Significantly increased temperature fluctuations in the summer season in the Eastern regions are related, obviously, to the variability of the ice edge location. In the case of longer preservation of open water, the amount of heat absorbed by the upper water layer increases, this leads to an increase in temperature. This pattern is clearly illustrated by temperature peaks in the summers 2007 and 2015 in L-1 and L-2 (see fig. 7), when these areas were completely ice free for a long time (see fig. 9, *c*). This was reflected in changes of the atmospheric circulation mode and the warm air inflow from the continent in the summer season [17].

The consistent changes in salinity and temperature in the Western region during the winter season are probably due to the so-called "atlantification" of the Nansen Basin, i.e. the strengthening of the influence of the Atlantic waters (AW) on the hydrological regime under conditions of reduced ice cover [18]. Although in the majority of the Arctic basin the warm and salty "core" of the Atlantic water mass is located in the intermediate layer, AW contribute to formation of overlaying and underlaying water masses [19], supplying the "building material" to the surface and deep waters. Taking into account the pathways of Atlantic waters inflow to the Arctic basin, their impact should be the most pronounced in the western part of the Arctic Basin in the so-called Atlantic Arctic [20]. In the summer season, local melting of ice reduces the effect of increasing salinity

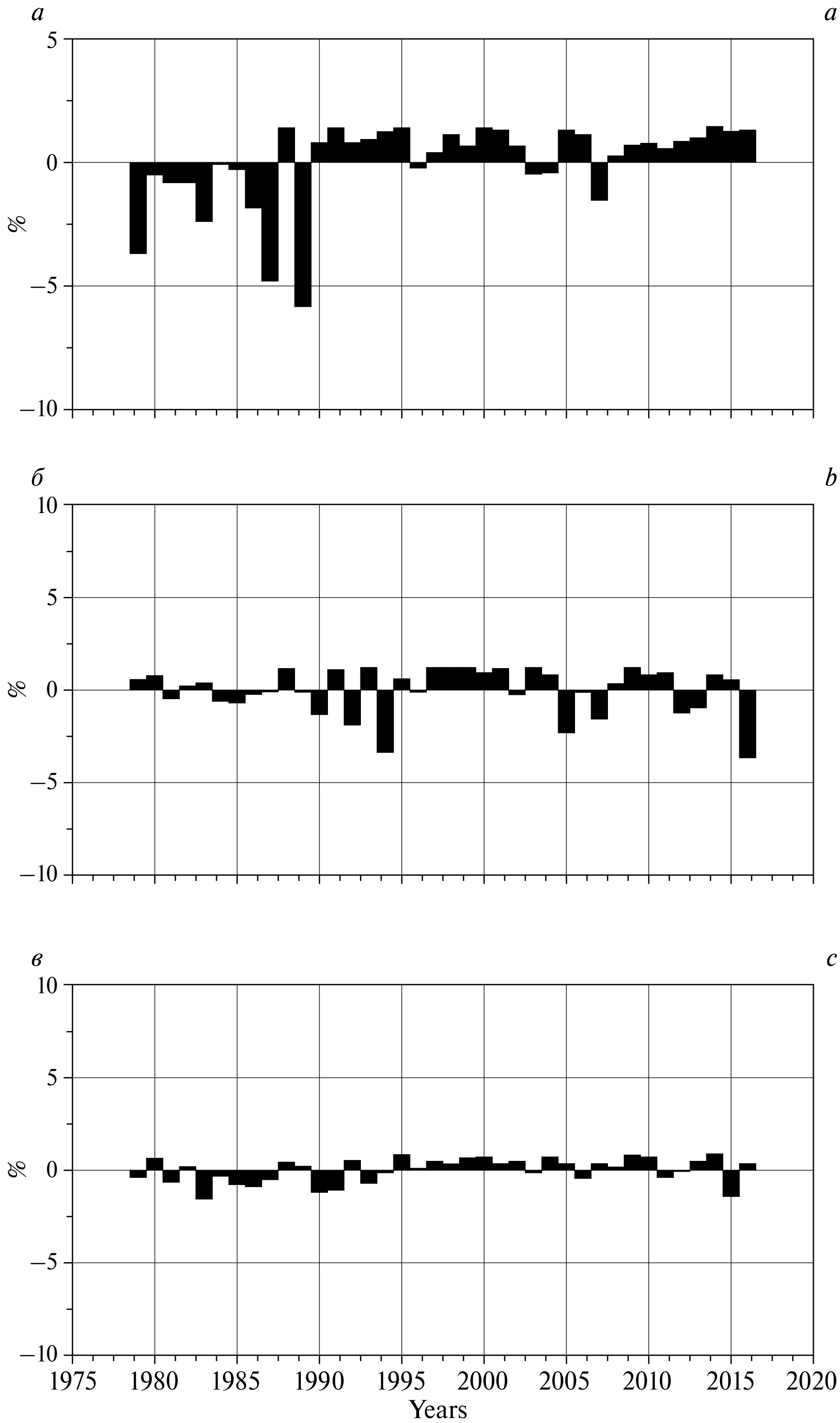

Fig. 8. The area of ice cover normalized by the climate mean value (1979–2016) in March in the areas limited by coordinates 75–80° N, 160–140° W (includes areas E-1 and E-2) (*a*), in the Western region (*b*) and in the area bounded by the coordinates 77–82° N, 125–145° E (includes areas L-1 and L-2) (*c*). Data on the ice area are taken from [6].

Рис. 8. Нормированная на средне-многолетнее значение (1979–2016) площадь ледяного покрова в марте в районах ограниченных координатами 75–80° с.ш., 160–140°з.д. (включает области В-1 и В-2) (*а*), в Западной области (*б*) и в районе, ограниченном координатами 77–82° с.ш., 125–145° в.д. (включает области Л-1 и Л-2) (*в*). Данные о площади льда взяты из [14].

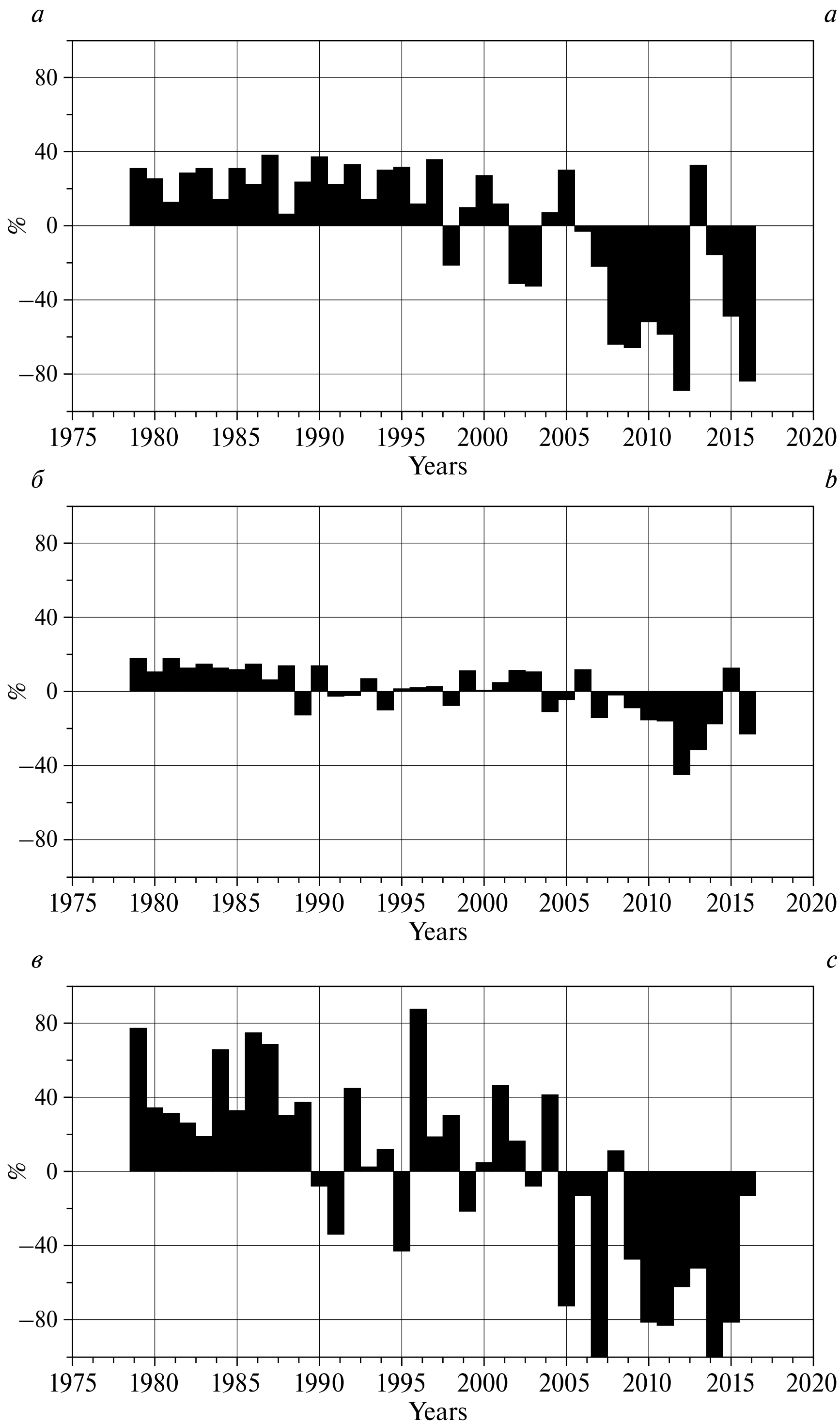

Fig. 9. Normalized by the climate mean value (1979–2016) of the ice cover in September in areas limited by the coordinates of 75–80° N, 160–140° W (includes areas E-1 and E-2) (*a*), in the Western region (*b*) and in the area bounded by the coordinates 77–82° N, 125–145° E. (includes areas L-1 and L-2) (*c*). Data on the ice area are taken from [6].

Рис. 9. Нормированная на средне-многолетнее значение (1979–2016) площадь ледяного покрова в сентябре в районах ограниченных координатами 75–80° с.ш., 160–140° з.д. (включает области В-1 и В-2) (*а*), в Западной области (*б*) и в районе, ограниченном координатами 77–82° с.ш., 125–145° в.д. (включает области Л-1 и Л-2) (*в*). Данные о площади льда взяты из [14].

in the upper layer, resulting in the absence of a clear trend of salinity (see fig. 5, *c*). The low variability of the summer temperature in the Western region is apparently associated with the absence of sustained changes in the ice cover area over the entire range of available observations both in the winter and summer seasons [9] (see fig. 8, *b* and 9, *b*).

The long-term variability of temperature and salinity in the Polar region during the winter season is small during the period from the late 1950s to the late 1990s. As noted in the previous section, until the beginning of the 2000s, weak trends in increasing salinity (~1 PSU) and decreasing temperature (~0.1–0.15 °C) are similar to trends in the Western region. The 2000–2010s are characterized by quasi-periodic fluctuations in salinity and temperature in the winter season with a value of ~2–3 PSU and ~0.2 °C, respectively. In 2014, the spatial variability of salinity (~2 PSU) was observed, unusually large for the winter season, which was comparable to the interannual variability. It should be emphasized that the typical spatial variability of salinity in the winter from 2000 to 2013 was ten times smaller (0.2–0.7 PSU). Interannual temperature fluctuations are consistent with salinity fluctuations and reach 0.15–0.2 °C. Most likely, the interannual fluctuations of temperature and salinity with a period of 4–5 years, revealed in the Polar region, do not have direct link with climatic changes. Such significant interannual fluctuations of the thermohaline characteristics in the winter period, which are formally indicate temporal variability, most likely reflect the spatial variability of the frontal zone. This frontal zone separates surface waters that are desalinated by river flow, reaching the Polar region from the Laptev Sea; and more saline waters, which enter the area from the west. Thus the revealed interannual variability of temperature and salinity characterizes the temporal variability in the frontal zone position relative to the selected area. Apparently, in 2007 and 2008, the front was located east of area P, and consequently, salinity reached 33 PSU (with spatial variability of 0.3–0.5 PSU). In 2009, the front was located to the west, and the selected area P occurred in much less saline waters with a salinity of 30.5 PSU (with a spatial variability of 0.7 PSU). Further, until 2013, there is a gradual increase in salinity, i.e. the thermohaline front shifts to the east and in 2012–2013 high-saline waters (more than 33 PSU) are observed again in area P. In 2014, the average salinity in area P became lower again: the front probably shifted to the west. Given the abnormally high spatial variability of salinity for the winter season, it can be assumed that the frontal zone in 2014 was located directly within the boundaries of region P. In this case, the interannual variability of salinity is 2.5–3.0 PSU (which is comparable to maximum spatial variability of 2.0 PSU), characterizes the magnitude of the salinity difference across the frontal zone.

5. Conclusions

The results of the study can be summarized concisely in the following main conclusions. Until the early 1990s, when most of the Arctic Basin was covered with perennial ice all year round, the temporal variability of thermohaline parameters in the upper mixed layer of 8–20 m in all considered areas was small throughout the year. Since the early 1990s, there have been noticeable changes in temperature and salinity in the winter season, but the direction of these changes is not the same in different areas. In the Western Region, salinization and cooling of surface waters are observed, whereas in the eastern Arctic, on the contrary, considerable freshening is recorded, and a corresponding water temperature rise. The desalination of surface waters in the eastern Arctic is due to a perennial ice reduction, and its replacement by the first-year ice. The salinization of surface waters in the western Arctic is associated with an increase in the of saline Atlantic waters supply from the Fram Strait and their rise to the surface [5, 9]. In the Polar region as a whole, insignificant salinization of surface waters is observed. However, the Polar region is characterized by an unstable frontal zone between the freshened waters to the east and more saline waters to the west. The features of the front shift depend on the prevailing synoptic processes in winter and summer seasons. The presence of the frontal zone substantially masks the real interannual temporal variability of the thermohaline parameters in the subsurface layer of the Polar region. Less ice coverage or complete absence of ice in the summer season in the last two decades increases the spatial variability of temperature and salinity in the surface layer in all areas of the Arctic due to increased thermal and dynamic effects of the atmosphere.

The study was carried out as part of the RFBR project 17-05-41197.

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