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MARINE PHYSICS

Structure and Variability of the Lena River Plume in the South-Eastern Part of the Laptev Sea

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Abstract—This work is focused on structure and seasonal variability of the most freshened part of the Lena plume in the south-eastern part of the Laptev Sea, namely, at sea area adjacent to the eastern part of the Lena Delta and in the Buor-Khaya Bay. Based on in situ hydrological data, it is shown that accumulation of the freshwater discharge of the Lena River occurs in the Buor-Khaya Bay during the summer period. In autumn reduced salinity in this semi-isolated and shallow gulf remains significantly longer time than in the area adjacent to the eastern part of the Lena Delta that is not typical for large river plumes. As a result, the Buor-Khaya Bay plays a role of a reservoir of freshwater discharge during long autumn-winter period. Moreover, this gulf is a secondary source of freshened and warm water in the south-eastern part of the Laptev Sea which volume is similar to the discharge volume of the Lena River during the autumn-winter drought.

Keywords: river plume, surface salinity, seasonal variability, Laptev Sea, Lena River, Buor-Khaya Bay

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1. INTRODUCTION

The Arctic Ocean, which occupies only 3% of the surface area and 1% of the volume of the World Ocean, receives very large continental runoff, accounting for more than 11% of the total river runoff into the World Ocean [14, 20]. As a result, a freshened surface layer and significant vertical salinity gradients are formed in the Arctic Ocean [9, 12]. Because sea ice in the deep-water part of the ocean forms only when a constant halocline exists that limits thermal convection [11], salinity stratification in the Arctic plays a key role in the variability of the ice cover and regional albedo, which affects climatic processes on a global scale [27]. In addition, salinity stratification limits the ascending heat flux from warmer deep Atlantic and Pacific waters, which also affects ice cover formation in the Arctic [13, 36]. Freshwater runoff also has a significant impact on many regional processes in the Arctic, especially in coastal and shelf areas, such as water circulation, transport of particulate and dissolved matter, primary production, distribution of anthropogenic pollution, acidification, and deposition of terrigenous material [25–28, 30–33, 39–41, 43].

The Lena is the second largest river flowing into the Arctic Ocean, and the eighth largest in the world in terms of river runoff. The length and area of the Lena River basin is 5100 km and 2490000 km^2, respectively. The average annual runoff volume of the Lena into the Laptev Sea is estimated at 590 km^3 [1, 21, 34]. The Lena is the largest river in the world, completely flowing in the permafrost region. Therefore, the main supply of the Lena River comes from snow and rainwater, while the supply from groundwater is impeded by permafrost [1]. Thus, the intra-annual variability of discharge in the lower reaches of the Lena is characterized by freshet from June to October with peak values in June (40% of annual runoff) and several rather high rainfall floods in autumn [34]. During the drought period from November to May, the lower reaches of the Lena River freeze, and during this period, less than 15% of annual runoff enters the sea [34]. The average annual and maximum recorded of river discharge values are 17100 and 220000 m^3/s, respectively [1, 18]. The high average annual concentration of suspended particulate matter (SPM) in Lena water (40 g/m^3) determines the large values of freshwater ((17–21) × 10^6 t/yr) and sediment (5 × 10^6 t/yr) discharge [21].

As it flows into the Laptev Sea, the Lena River forms a vast delta, one of the largest river deltas in the world (Fig. 1). The Lena Delta has a complex morphology, consisting of hundreds of distributaries, with an area and longshore length of 32000 km^2 and 500 km, respectively [1, 8, 18]. The largest Lena Delta distributaries are the Trofimovskaya, Bykovskaya, and Sardakhskaya in the eastern part of the delta, which receive 80–90% of the Lena's runoff [1, 18].

As the Lena flows into the sea, a surface freshened water mass is formed, called the Lena plume. The outer boundary of the Lena plume is conditionally drawn along the 15 PSU isohaline, where, generally, there is a sharp salinity gradient between the freshened surface layer and underlying saline waters. In the summer–autumn period, the Lena plume occupies an area of hundreds of thousands of square kilometers in the Laptev and East-Siberian seas [34]. In the winter–spring period, during the drought period on the Lena River, the plume area significantly contracts to the southeastern Laptev Sea. Together with Lena runoff, a large amount of terrigenous sediments, nutrients, and anthropogenic pollution is carried into the Laptev Sea [4, 8, 18, 21]. Thus, spreading of the Lena plume has a significant effect on the physical, chemical, and biological processes both directly in the near-delta and adjacent shelf areas [6, 7, 19], and on the scale of the entire Laptev Sea [2, 15, 33, 38, 39] and Asian sector of the Arctic Ocean [16, 17, 29, 41], which is discussed in numerous studies. Nevertheless, many important aspects of both the internal structure and dynamics of the Lena plume itself remain insufficiently studied. In this paper, the authors study the seasonal variability of the structure of the most freshened part of the Lena plume in the southeastern part of the Laptev Sea, namely, in the water area adjacent to the eastern part of the Lena Delta (its boundary is indicated by the dotted line in Fig. 1), and in Buor-Khaya Bay (its boundary is indicated by the solid line in Fig. 1).

2. MATERIALS AND METHODS

The study is based on field data acquired during 12 sea expeditions onboard the R/V *Danube* in September 1999, the R/V *Nikolay Kolomeitsev* in August–September 2000, the R/V *Ivan Kireev* in August–September 2004, the PTS *Auga* in September 2005, R/V *Neptun* in September 2006, as part of the Russian–Swedish expedition ISSS0, to R/V *Yakov Smirnitsky* in July–August 2008, PTS *TB-0012* in August 2008, PTS *TB-0012* in August–September 2009, cruise 57 of the R/V *Akademik Lavrentiev* in September–October 2011, the R/V *Viktor Buinitsky* in September 2012, cruise 78 of the R/V *Akademik Lavrentiev* in October 2016, and cruise 73 of the R/V *Akademik Mstislav Keldysh* in October 2018 in the Laptev Sea, east of the Lena Delta, and in Buor-Khaya Bay (Fig. 1). In addition, the data obtained during seven spring tractor-sledging expeditions in Buor-Khaya Bay in March–April 2002, April 2007, April 2011, March–April 2012, April 2013, April 2014, and April–May 2015 were used.

A *Memory STD* (*ALEC Electronics*) CTD instrument was used to measure the vertical temperature and salinity distribution in 1999, 2000, and 2002. On sea expeditions in 2004, 2005, 2006, 2007, 2012, as well as on spring tractor-sledging expeditions in 2007, 2011, and 2012, an *SBE19* (*Sea Bird Electronics*) CTD instrument was used. On sea expeditions in 2008 and a spring tractor-sledging expedition in 2013, a *YSI-6920* (*Yellow Springs Instrument*) CTD instrument was used. an *XR-620* (*Rinko*) CTD instrument was used on spring tractor-sledging expeditions in 2014 and 2015. *SBE9* (*Sea Bird Electronics*) CTD instrument was used on sea expeditions in 2011, 2016 and 2018. In addition to the above measurements, the study used vertical thermohaline measurements from the World Ocean Database (WOD) [10], obtained in the studied region in January (1977, 1982, and 1983), February (1977–1982), and July (in 1955–1959, 1965–1969, 1977, 1981, and 1983). On sea expeditions, the surface salinity at a depth of 2 m was used as the salinity, and on winter tractor-sledging expeditions, at a depth of 0.5 m from the bottom of the ice; the ice thickness was 2–2.5 m. For analysis of the mesoscale variability of surface salinity in the water area adjacent to the eastern part of the Lena Delta, the 2018 expedition also used temperature and salinity measurements at a depth of 2–3 m along the vessel's route using a flow-through system equipped with a *SBE21* (*Sea Bird Electronics*) thermosalinograph [3, 30].

3. RESULTS

3.1. Seasonal Variability. The field data obtained during the 19 expeditions were used to construct average monthly maps of the surface salinity distribution in the study region in March, April, August, September, and October. The quantitative distribution of hydrological data for these months is non-uniform. Most of the available data were obtained on 12 sea expeditions during the open water period, namely, in August–October. Hydrological measurements during this period cover the entire studied area. Conversely, most measurements obtained during the seven spring tractor-sledging expeditions (March and April) covered only the area near the delta, and only in 2002 most of Buor-Khaya Bay was explored. Thus, the summer–autumn months are the most studied, the March–April period is less studied, and there are no data on the winter period, nor on the beginning of the summer high water season (Table 1). Therefore, for January, February, and July, surface salinity maps were constructed using hydrological data from the WOD database.

Figure 2a shows the surface salinity distribution in January. Four stations were in southwestern Buor-Khaya Bay, and one station, in the center. The maximum salinity (15 PSU) is observed in the central part of Buor-Khaya Bay; at other stations, the salinity is 5–10 PSU. Figure 2b shows the salinity distribution in February, plotted from measurements at 18 stations, predominantly located in the southwestern part of the studied area; one station is in the center of the bay and one at the mouth of the Bykovskaya distributary. The maximum salinity values (12 PSU) were recorded in the central part of Buor-Khaya Bay; in the southwest-

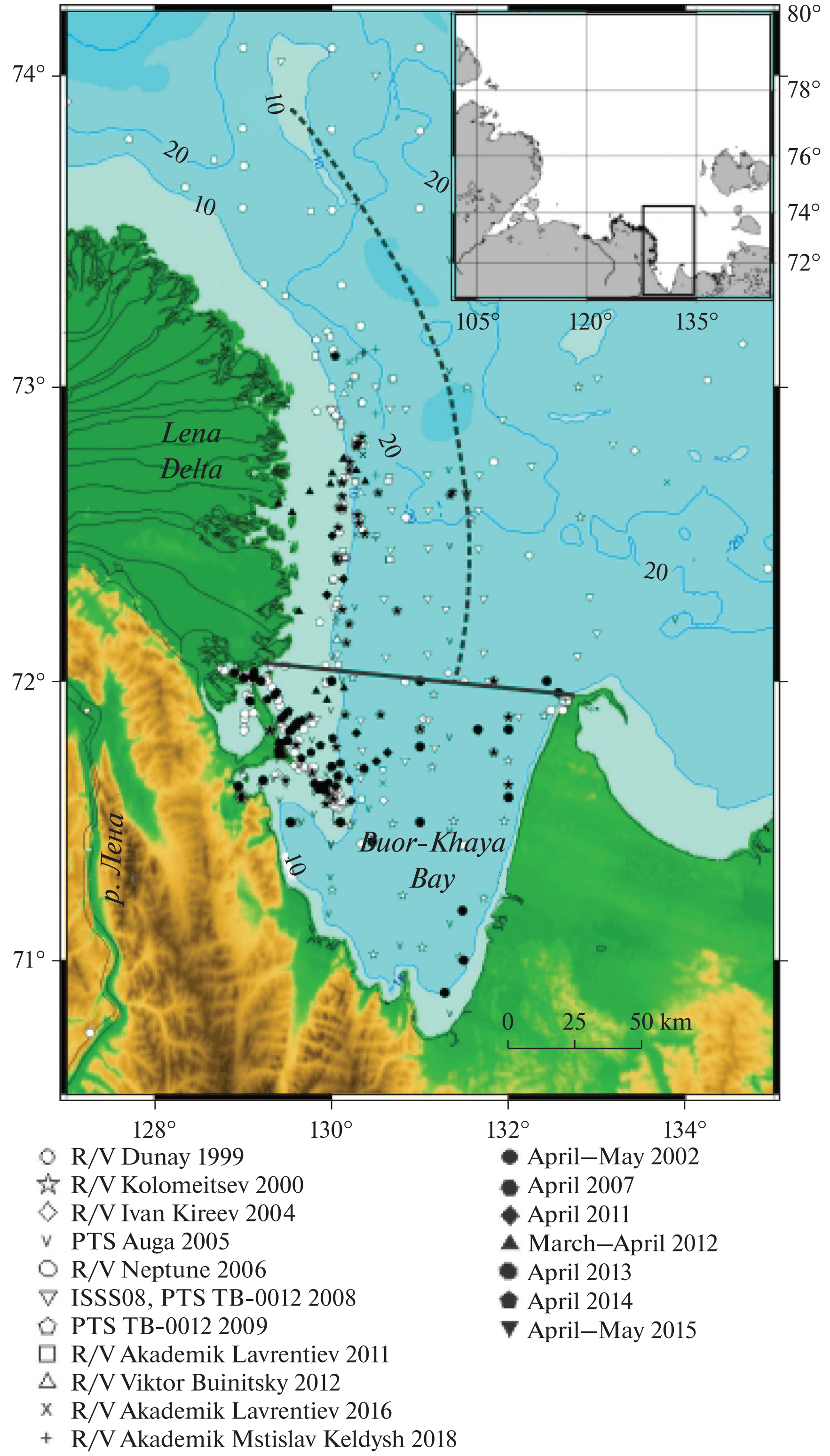

Fig. 1. Location of studied area in southeastern part of Laptev Sea (upper right corner). Inset: bottom topography of studied area and layout of hydrological stations of 18 expeditions in 1999–2018. Dashed line, boundary of estuarine area. Solid line, Buor-Khaya Bay.

Table 1. Distribution of stations by months and years of expeditionary measurements

	March	April	May	June	July	August	September	October
1999							20	
2000						14	25	
2002		20	5					
2004						23	3	
2005							53	
2006							67	
2007		53					2	
2008						57		
2009						21	21	
2011		15					27	
2012	8	5					9	
2013		15						
2014		30						
2015	5	27						
2016							9	7
2017								
2018								11

ern part of the bay, salinity varies from 7 to 11 PSU. The minimum values (2.2 PSU) were noted near the Bykovskaya distributary.

The surface salinity distribution in March is shown in Fig. 2c. Thirteen stations cover the area near the delta between the Bykovskaya and Trofimovskaya distributaries. Salinity near the distributaries is within 1–5 PSU; at stations farther from the distributaries, the salinity reaches 10–11 PSU. April is the most studied month when the studied area is covered with fast ice. Hydrological stations cover almost all of Buor-Khaya Bay, but are mainly concentrated in the delta area. Figure 2d shows the salinity distribution in April. The relatively saline waters (15–20 PSU) of Buor-Khaya Bay are separated from the freshened waters in the water area adjacent to the eastern part of the Lena Delta (1–5 PSU) by a distinct front 50 km east of the delta.

The surface salinity distribution in July, attributed to the initial freshet period on the Lena River, is shown in Fig. 2d. The maximum salinity values (20–25 PSU) were recorded in regions to the north and northeast of the Lena Delta. At the stations nearest the delta, the salinity values are close to 0 PSU. In the center of Buor-Khaya Bay, the surface salinity does not exceed 3 PSU. Figure 2f shows a map of surface salinity for August. During this period, more than 100 hydrological stations were made in the entire studied area of the Laptev Sea. The maximum salinity values (15–25 PSU) are confined to the regions to the north and northeast of the Lena Delta. The minimum salinity values are noted in the eastern and southeastern parts of the delta area (1–3 PSU), further to the east the salinity slightly increases. The majority of Buor-Khaya Bay has a surface salinity of 3–6 PSU.

Figure 2g shows the salinity distribution in September, which is also one of the most studied periods, during which more than 100 hydrological stations were made. As in August, the maximum salinity values (15–25 PSU) were recorded north and northeast of the Lena Delta. In Buor-Khaya Bay, the salinity is slightly elevated compared to August (5–8 PSU). The most freshened (1–5 PSU) area, located in the near-delta water area, decreases in size and becomes a narrow strip. Already at a small distance from the delta to the east (25–50 km), the salinity values increase to 15–20 PSU. For October, the field hydrological data are significantly less than for September (Fig. 2h). Most of them are concentrated in the estuarine area. There are two stations in the central part of Buor-Khaya Bay, the surface salinity of which is 5–8 PSU. In the area adjacent to the Lena Delta, salinity values range from 12 to 16 PSU.

The available field data were used to calculate the average temperature and salinity values along horizons with a resolution of 1 m. The vertical temperature and salinity profiles were constructed from them, illustrating the seasonal behavior of these characteristics in the southeastern Laptev Sea, adjacent to the eastern part of the Lena Delta, and in Buor-Khaya Bay (Fig. 3). From January to May, the waters in these areas have a relatively similar structure. In both water areas, salinity in the surface layer mainly varies from 0–1 to 12–16 PSU. Nevertheless, the stratification of the Lena Delta (with a clear two-layer structure) is much stronger than in Buor-Khaya Bay (with a relatively uniform

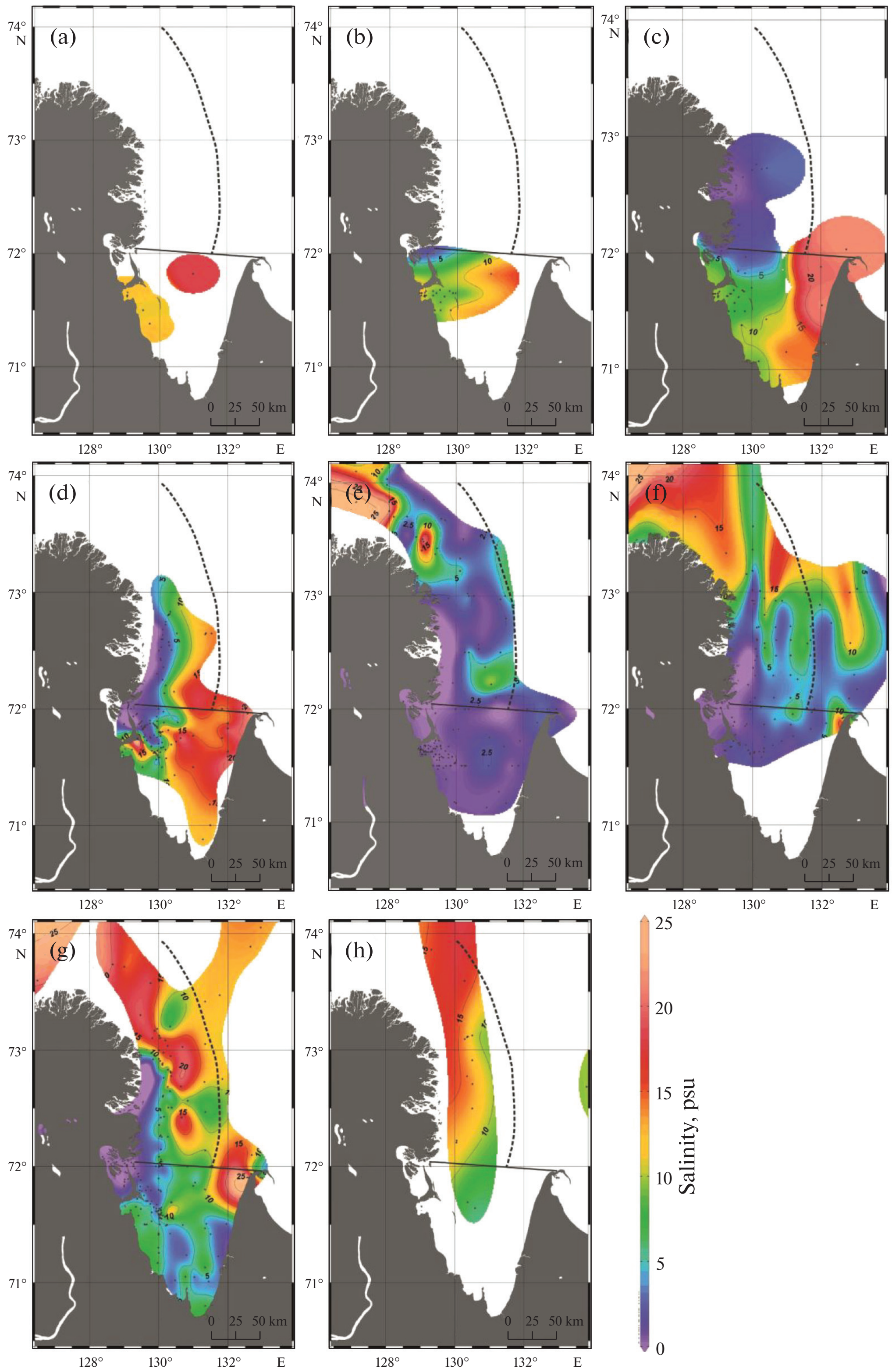

Fig. 2. Average monthly distribution of surface salinity in January (a), February (b), March (c), April (d), July (e), August (f), September (g), and October (h) in water area adjacent to eastern part of Lena Delta, and in Buor-Khaya Bay based on data from World Ocean Data Base (a, b, e) and data from expeditions (c, d, f, g, h). Points indicate measurement sites. Dashed line, boundary of estuarine area. Solid line, Buor-Khaya Bay.

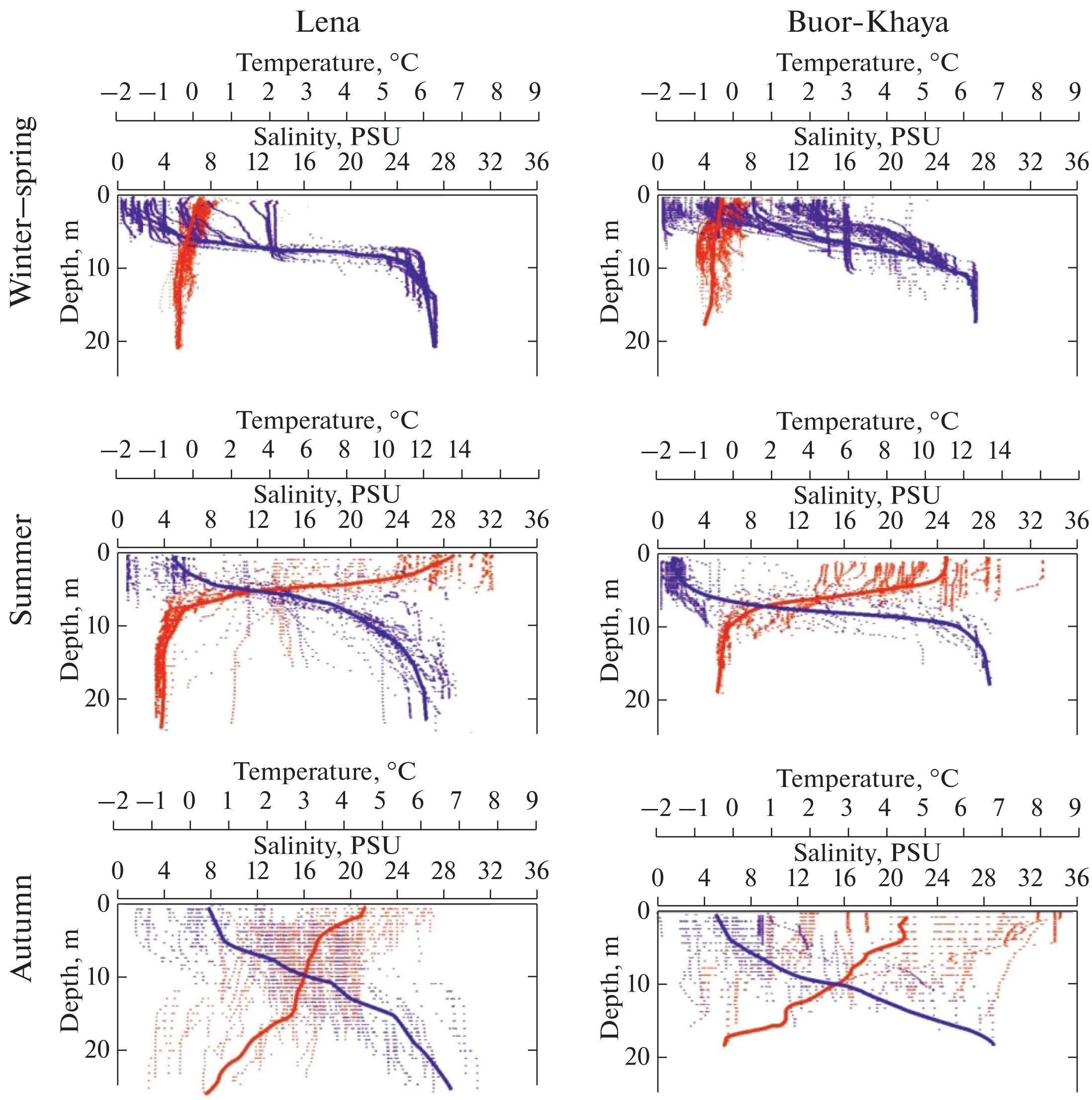

Fig. 3. Typical vertical temperature (red lines) and salinity (blue lines) profiles in water area adjacent to eastern part of Lena Delta (left) and in Buor-Khaya Bay (right) in winter–spring (top), summer (middle), and autumn (bottom).

stratification in the 0–10 m layer). Such differences in the vertical structure are apparently caused, first, by the inflow of a small, but significant for the formation of stratification, amount of freshwater runoff from the Lena Delta during the winter–spring drought period and, second, by the advection of saline waters in this area from the eastern Laptev Sea. Conversely, for the relatively isolated Buor-Khaya Bay, the influence of both freshwater runoff and saline water advection should be significantly less.

Below the surface layer, salinity gradually increases up to 25–27 PSU in the bottom layer at the deepest stations (15–20 m deep). The sea temperature decreases relatively uniformly from the surface to the bottom, while in the water area adjacent to the eastern part of the Lena Delta, temperatures are slightly higher (–0.5 to 0.5°C) than in Buor-Khaya Bay (–1 to 0°C).

During the summer, there is a distinct two-layer structure throughout the studied region. The salinity of the surface layer in the water area adjacent to the eastern part of the Lena Delta takes minimum values (0–6 PSU) recorded throughout the year. At a depth of 5–8 m, salinity increases sharply to 20–22 PSU, and in the bottom layer reaches 27–28 PSU. In Buor-Khaya Bay, the surface salinity also has minimal seasonal values (0–4 PSU) and, after a sharp salinity jump at a depth of 6–7 m, it increases towards the bottom to 27–28 PSU. The average temperature in the near-delta area varies from 10–16°C at the surface to –1°C at the bottom, and in Buor-Khaya Bay, from 4–14°C at the surface to –0.5°C at the bottom.

In the autumn, the two-layer structure is preserved throughout the study region. The average surface salinity in the water area adjacent to the eastern part of

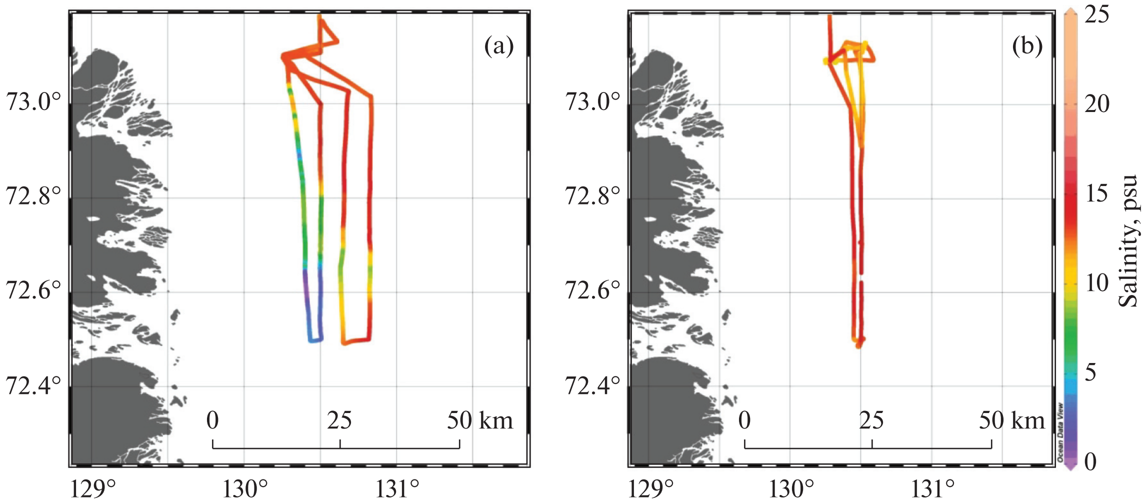

Fig. 4. Distribution of surface salinity for October 1–3 (a) and October 3–5, 2018 (b) along ship's transect east of Lena Delta.

the Lena Delta increases to 8 PSU. In Buor-Khaya Bay, the average surface salinity increases less strongly, 5 PSU. The average salinity in the bottom layer is 28–29 PSU for both studied water areas. The average surface temperature in both areas is 4.5°C, and the temperature of the bottom layer is 0.5°C in the delta area and –0.5 in Buor-Khaya Bay.

3.2. Mesoscale Variability. To assess the mesoscale variability, continuous measurements of temperature and salinity in the surface layer, obtained during the 73rd cruise of the R/V *Akademik Mstislav Keldysh* in 2018, were analyzed. In the period of October 1–5, measurements were taken along six parallel meridional transects from 72.5° to 73.5° N at various distances (from 35 to 50 km) east of the Lena Delta. The temperature and salinity distributions showed significant spatial heterogeneity, apparently caused by the inhomogeneity of the sizes of the delta distributaries and continental runoff from them (Fig. 4). The areas with minimum temperature and salinity values were confined to the largest distributaries, the Trofimovskaya and Sardakhskaya. In addition, the observed non-uniform distribution of thermohaline characteristics of the surface layer is also controlled by regional circulation, including the intense eddy dynamics typical of frontal zones [23, 24, 44]. Indeed, the distribution of the thermohaline characteristics in the surface layer was characterized by significant gradients; in a number of areas 5–7 km long, salinity and temperature varied by more than 5 PSU and 1°C, respectively. The maximum salinity values during measurements at the research site were 15–16 PSU.

During the expedition, the response of the most freshened near-delta part of the Lena plume was recorded (with salinity less than 10 psi) formed by the influx of river runoff from the Lena Delta during the autumn low water season on the variability of the local wind impact. During September 30–October 1, a very weak (~2–3 m/s) easterly wind was observed. Measurements in the surface layer along four transects during this period showed that the near-delta part of the Lena plume extended eastward. The salinity of the surface layer increased monotonically with the distance of the transects from the coast from 0–10 PSU on the closest transect up to 8–16 PSU on the farthest. During October 2–3, the wind increased to 8 m/s and changed direction to the north. Measurements along two transects during this period showed a significant increase in salinity by 8–10 PSU in the operations area. Apparently, as a result of wind action, the near-delta part of the plume was pressed to the coast; its boundary shifted by a distance of 20 km in less than a day.

4. DISCUSSION AND CONCLUSIONS

The paper describes the structure of the Lena plume in the water area adjacent to the eastern part of the river delta and in Buor-Khaya Bay. Field hydrological data established pronounced seasonal variability of surface salinity in the study region. In the winter–spring period, the maximum seasonal salinity values are observed in the surface layer in the entire study region (Figs. 2a–2d, 3). The beginning of the summer freshet in the lower reaches of the Lena causes a sharp increase in freshwater runoff from its delta distributaries into the sea. This leads to significant freshening of the surface layer in the water area adjacent to the eastern part of the Lena Delta (Fig. 2e). Later, during the summer period, this forming freshened layer reaches the shallow Buor-Khaya Bay, fills it from surface to bottom in its shallow southern part and forms a freshened surface layer up to 12 m deep in its deeper northern part (Figs. 2e, 2f, 3). This leads to a decrease in salinity and accumulation of freshwater runoff in the bay.

From the beginning of freshet in the Lena Delta (in June) to the end of the ice season (in the first half of

August), the Lena plume is shielded by ice from wind action and its distribution is primarily determined by gravitational forces. During high water, there is a sharp and prolonged (over the span of a month) release of fresh water along the entire perimeter of the eastern part of the Lena Delta. The incoming fresh water under the action of gravitational forces directed from the delta spreads in a relatively uniform layer in the surface layer of the sea and rather quickly forms a freshened area with zonal and meridional lengths of hundreds of kilometers. In summer, the boundary of the Lena plume is located hundreds of kilometers from the delta and Buor-Khaya Bay [32]. A similar mechanism behind the primary formation of the freshened surface layer during the high water period for the Ob and Yenisei rivers flowing into the Kara Sea was described in [29]. As a result, freshened water flows into Buor-Khaya Bay adjacent to the delta at the beginning of summer as a direct result of gravitational forces.

The autumn drop in Lena River runoff leads to a gradual increase in the salinity of the surface layer in a relatively deep-water area to the east of the delta, as a result of its vertical mixing with the underlying more saline waters and lateral mixing with more saline waters to the north (Figs. 2g, 2h, 3). This leads to a decrease in the area of the most freshened part of the surface layer (with a salinity less than 10 PSU), formed by the decreased, but still incoming river runoff from the Lena Delta. The location of the boundary of this area near the eastern part of the Lena Delta is unstable and can shift by tens of kilometers in less than a day as a result of wind action (Fig. 4). This leads to significant spatial variability of surface salinity in this area on a mesoscale timeline and apparently intensifies vertical mixing between the most freshened near-delta part of the Lena plume and the underlying more saline waters.

At the same time, in autumn, the salinity in Buor-Khaya Bay increases faster than in shallow water near the Lena Delta (due to continued river runoff from the delta), but slower than in a relatively deep-water area located to the east of the river delta (Fig. 2g, 2h, 3). Apparently, this is caused by a significantly less intense inflow of saline sea water into the shallow and semi-isolated Buor-Khaya Bay compared to the open and deeper water area to the east of the Lena Delta. As a result, the average surface salinity in Buor-Khaya Bay (4–6 PSU) is less than the average surface salinity in the water area east of the Lena Delta (8–9 PSU) (Fig. 2b). Subsequently, in the absence of inflow of freshened water, the salinity in the bay increases to the maximum seasonal values and remains stable until the beginning of the summer high water season.

According to estimates obtained by numerical simulation of the Lena plume [19], at a wind speed of more than 4 m/s, the spreading of the Lena plume is largely determined by the wind (in comparison with gravitational forces), and at a wind speed of more than 8 m/s, it is almost completely governed by the wind. In the studied area during the ice-free period (August–October), according to observations at the Tiksi meteorological station in 2005–2020, winds greater than 4 m/s are observed for 58% of days, and winds greater than 8 m/s are observed for 20% of days. In the open part of the sea, the wind speed is significantly higher than on the coast in Tiksi. Thus, in the southeastern Laptev Sea, the average number of days with a wind speed greater than 15 m/s is 28, from August to October, i.e., about a third of the entire ice-free period [34].

The drift velocity of Lena plume spreading under the influence of wind u_w can be estimated by the equation $u_w = \sqrt{\frac{\rho_a}{\rho_p}\frac{C_{10}}{C_{Da}}}U$, where ρ_a is their density, C_{10} is the sea surface roughness coefficient, C_{Da} is the coefficient of bottom friction for shallow water, and U is the wind speed [42]. Setting $C_{10} = 1.2 \times 10^{-3}$, $C_{Da} = 2 \times 10^{-3}$, we find that $u_w = (1.3/10^3 \times 1.2 \times 10^{-3}/(2 \times 10^{-3}))^{0.5}U = 0.03U$. Thus, the typical speeds u_w are estimated as from 0.15 (with a wind speed of 5 m/s) to 0.45 m/s (with a wind speed of 15 m/s). According to the meteorological station in Tiksi, from 2005 to 2020, in September, winds contributing to the accumulation of freshened waters in Buor-Khaya Bay (from southwest to north) are observed for 61% of the time, and winds taking freshened water from the bay (from northeast to south), 32% of the time. Thus, the wind in the studied region contributes to the accumulation of freshened waters in Buor-Khaya Bay.

An important mechanism for the transport of freshened waters in the studied area is also the geostrophic current directed south along the eastern part of the Lena Delta. A similar current, which forms during the period of low runoff in late summer and autumn, also contributes to the accumulation of freshened waters in Buor-Khaya Bay. The speed of a similar geostrophic longshore current u_g for the Lena plume can be estimated by the equation $u_g = \frac{g}{f}\frac{\rho_s - \rho_p}{\rho_s}\frac{h}{L}$, where g is gravitational acceleration, f is the Coriolis frequency, ρ_p and ρ_s are the water density of the plume and surrounding sea, h is the thickness of the longshore current, and L is the width of the longshore current [35]. On average, for the Lena plume in September (the month with the greatest amount of field data), this speed u_g is estimated as from $10/(1.4 \times 10^{-4}) \times 1.5/10^3 \times 5/(5 \times 10^3) \sim 0.1$ m/s to $10/(1.4 \times 10^{-4}) \times 3.5/10^3 \times 5/(5 \times 10^3) \sim 0.25$ m/s.

Thus, the speeds of wind currents for the considered region of the Lena plume at the end of summer and autumn are of the same order of magnitude as the speeds of geostrophic currents. Nevertheless, the role of wind transport appears to be more significant for spreading of the plume, which is consistent with the conclusions in [19]. However, the above estimates of the current speed in the Lena plume are rather arbi-

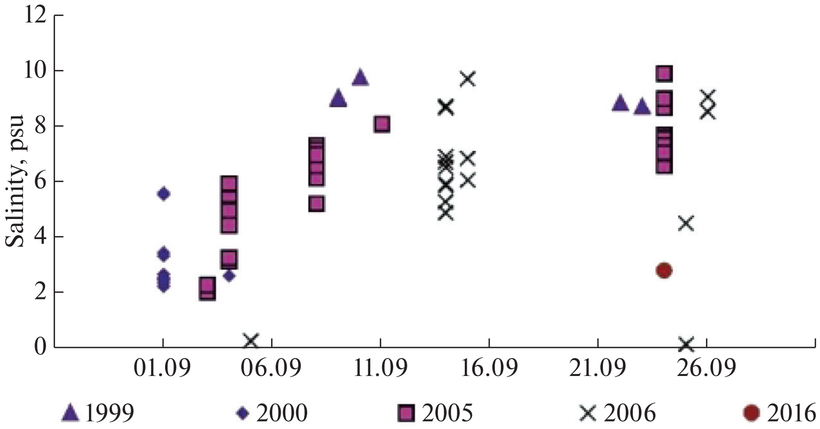

Fig. 5. Surface salinity values in September based on data from 5 expeditions in 1999, 2000, 2005, 2006, and 2016.

trary, since they do not take into account many important conditions, such as the time of establishment of the geostrophic current, the complex morphology of the coast and seafloor (the influence of capes and islands of the delta, as well as shallow water, on the current), inhomogeneity of the salinity field in the plume and surrounding sea, etc. More accurate estimates of the direction and speed of circulation in the Lena plume in the studied area require specialized field measurements of the current speed.

The structure of waters in the bay in autumn is characterized by low spatiotemporal variability on a mesoscale timeline. In particular, the maximum variation in salinity in Buor-Khaya Bay within the limits of daily measurements in September was 5 PSU (Fig. 5), while in the near-delta area, the variation in salinity during measurements on October 1–5, 2018, was 10–15 PSU at a distance of 10–20 km. In Buor-Khaya Bay during the autumn period, such sharp horizontal salinity gradients do not form like in the near-delta area due to the remoteness of Buor-Khaya Bay from the source of the continental runoff. Because of this, under the influence of the wind, the surface salinity in Buor-Khaya Bay is characterized by lower horizontal gradients and, thus, significantly lower spatiotemporal variability on the mesoscale timeline, in comparison with the near-delta area.

The relatively small amount of runoff from the Lena River during the low water season from late autumn to late spring continues to form a freshening area, but only in a small area immediately adjacent to the delta (Figs. 2b–2d). Already 25–50 km east of the delta, the Lena runoff does not have such a significant effect on surface salinity, and in September–October, it increases to 10–15 PSU or more (Figs. 2g, 2h). The surface salinity in Buor-Khaya Bay remains less than 10 PSU in September and October, while in winter and spring, a surface salinity greater than 15 PSU was observed in March and April only in the eastern part of the bay (Figs. 2a–2d).

Thus, the freshwater runoff accumulating in Buor-Khaya Bay during the summer period lasts longer than in the relatively deep-water area east of the Lena Delta. Thus, Buor-Khaya Bay, due to its geographical position, morphology, and bottom topography, acts as a kind of stable reservoir of fresh river water in the summer–autumn period. If we define the line between Cape Buor-Khaya and the entrance to the Bykovskaya distributary of the Lena as the boundary of Buor-Khaya Bay, then, according to the IBCAO digital bottom topography database [22], the area of Buor-Khaya Bay is about 11 000 km^2. The vertical distribution of the mean salinity anomaly in autumn (Fig. 3) and the bottom topography of Buor-Khaya Bay were used to calculate the total volume of accumulated fresh river water in Buor-Khaya Bay during the summer–autumn period, which was 84 km^3.

This significant volume accounts for 14% of the total annual runoff of the Lena River and exceeds the total annual flow of the large Yana and Olenek rivers flowing into adjacent areas of the Laptev Sea. Moreover, this volume is comparable to the total runoff from the Lena River in August and September. Thus, Buor-Khaya Bay acts as a significant secondary source of freshened and warm water in the southeastern Laptev Sea, at least in autumn. This apparently prolongs the period of inflow of freshened and warm water into the southeastern Laptev Sea and affects thermohaline circulation, ice formation, coastal thermal abrasion, the state of underwater permafrost, and many other regional physical, biological, and geochemical processes. By mid-spring, freshened and warm waters are already absent in Buor-Khaya Bay, which speaks to their dissipation from October to April. For a more accurate assessment of the dissipation time of these waters in the bay, it is necessary to carry out additional field measurements over the bay's entire water area in winter.

A similar effect, described for the Lena plume and Buor-Khaya Bay, is due to a combination of three main factors. First, the almost complete cessation of river runoff for a long period (more than six months) leads to significant seasonal fluctuations in salinity, namely: the Lena plume has time to mix very strongly with incoming saline water. Second, the formation of the Lena plume by a deltaic rather than estuarine river leads to winter–spring mixing of its plume and an increase in salinity directly at the source, i.e., near the Lena Delta. The third factor is the presence of a large, in area and volume, but relatively shallow (the depth is comparable to the thickness of the Lena plume) and isolated bay (Buor-Khaya Bay) near the Lena Delta.

It is the combination of these three factors that leads to a unique situation atypical for plumes of other large rivers: runoff near the river has already decreased, but a large volume of freshened water, accumulated far from the freshwater source, continues to flow into the sea for a long period. In a sense, analogs of Buor-Khaya Bay as a secondary source of continental runoff may be the Gulf of Ob and the Amur Gulf, where a significant amount of freshened water is also preserved in the winter–spring period and water exchange with the Kara Sea and the Sea of Okhotsk, respectively [5, 29]. However, in this case, accumulation occurs in the estuary and the secondary source of continental runoff coincides with the primary one, which distinguishes this example (and similar examples of estuarine rivers) from the Lena River and Buor-Khaya Bay. The combination of all three factors, except for the Lena, is not found in a single river whose annual flow exceeds 100 km^3, i.e., none of the 30 largest rivers in the world.

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