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Seasonal Features of the Novik Bay Hydrological Regime (Russky Island, Peter the Great Bay, Sea of Japan)

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Purpose. The paper is aimed at studying the hydrological regime of the Novik Bay (Russky Island, Peter the Great Bay, Sea of Japan).
Methods and Results. Regular ship and ice cover CTD observations (more 1000 water column profiling stations) carried out in the Novik and Amur bays in 2013–2018 were used. Weather conditions in the region under study were analyzed based on the data of the Vladivostok weather station archive (WMO_ID=31960). Quantitative estimates of the drift and gradient currents in the bay are represented.
Conclusions. Seasonal changes in the thermohaline stratification of the Peter the Great Bay coastal waters are conditioned by the monsoon climate features. The Novik Bay hydrological regime is additionally affected by its isolation and shallowness, as well as by the Russky Island relief. Weak water dynamics in the bay is observed during the summer monsoon (April – August) which is the result of the south winds being blocked by the hills. The autumn-winter monsoon (when northerly winds prevail) causes a wave of water in the bay, which, in its turn, blocks its circulation. The winter Siberian cold anticyclone forms the ice cover in the bay, and it is in this ice-forming season that the salinity increase in the bottom layer is observed. In the shallow southern part of the Novik Bay, the process of ice formation begins. The downwelling flow of salty heavy water directed to the north out of the bay along the bottom relief is compensated by the counter flow of fresh waters from the Amur Bay which inflow to the upper sub-ice layer. The freeze-up period is most favorable for water renewal. The efficiency of this process is additionally influenced by a heat flow from bottom sediments and by the ice conditions in the adjacent water areas of the Peter the Great Bay.

Keywords: Novik Bay, Amur Bay, Peter the Great Bay, hydrological regime, circulation, CTD data, sea ice cover

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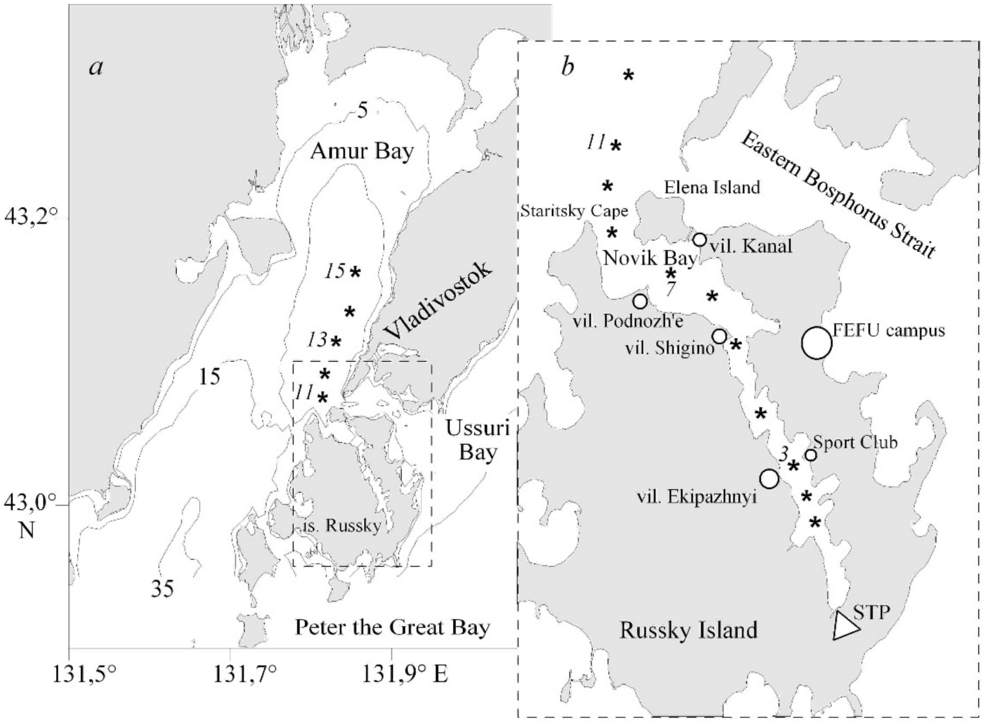
Introduction. The intensive development of the urban infrastructure of Vladivostok, including the Russky Island, has led to an increase in the anthropogenic load on the adjacent waters of the Peter the Great Bay. Ecological problems are especially relevant for the closed bays that are part of the Amur Bay. The location and relief of the Novik Bay make it stand out: its water area, 12 km deep, juts out into Russky Island and resembles a narrow fjord about 1 km wide with an average depth of 10–12 m (Fig. 1). In the bay, closed by hills on almost all sides, there are no intense waves, which favored its exploitation by the navy for a long time. The special status of this territory was cancelled in 1993, and it became possible to carry out scientific research in the Novik Bay.



F i g. 1. Region under study: Amur Bay, Novik Bay (the marked rectangular area) (*a*); the enlarged image of the marked area (*b*). Numbers with asterisks indicate location of the ship hydrological stations (observation points) at the axial section NA in the Amur and Novik bays (2013–2018), triangle – location of the sewage treatment plants (STP) of the FEFU campus; isobaths are for 5, 15 and 35 m

The first studies included the assessment of ecological state of the water area and examination of invertebrates breeding conditions in the bay [1–4]. In chemical-ecological surveys, seasonal variability of the dissolved oxygen concentrations was observed: oxygen deficiency in summer and its increase during the autumn-winter monsoon, when north winds increase. In winter, under the ice established are hydrochemical conditions favorable for aquatic organisms [3].

The seasonal hypoxia in the adjacent waters of the Amur Bay and the Eastern Bosphorus Strait [5, 6] influence the ecological state of the Novik Bay, which explains the spring-summer deterioration of oxygen indicators in its [3]. The seasonal features of the thermohydrodynamic regime of the waters of the Peter the Great Bay supplying the Novik Bay with fresh waters were discussed in detail in a number of works [7–12]. In general, it should be noted that the renewal of waters in the Peter the Great Bay occurs most intensively during the autumn-winter monsoon due to the cooling and rise of the deep waters of the Sea of Japan [11].

The contribution of tides to the processes of water circulation in the studied area of the Peter the Great Bay [9] against the background of monsoon winds is insignificant.

The aim of the study was to get insight of the seasonal features of hydrological regime of the Novik Bay, as well as the adjacent part of the Amur Bay.

Materials and methods. Field observations in the Novik Bay and the Amur Bay were carried out regularly from January 2013 to March 2018 (more than1000 water column profiling stations). In summer, the observations were carried out from R/V *Atlas* and *Malakhit*, in winter – from the ice cover. The distribution of observations according to the seasons is uneven, 80% falls on operations from the ice cover. The location of vessel observation points on the longitudinal axial section of the Novik Bay – Amur Bay (section NA) is shown in Fig. 1.

In winter, observations were carried out only in the Novik Bay (the Amur Bay ice covers were regularly destroyed by ships) and included up 30–50 profiling stations (observation points) located on axial NA and 2–4 cross sections (Sport Club – vil. Ekipazhnyi, vil. Kanal – vil. Podnozh'e, etc.). From November 2016 to March 2018 in the Novik Bay weekly observations were carried out. In the absence of ship support the mooring walls of vil. Kanal (6 m depth) and a Sport Club (4 m depth) were used.

Hydrological parameters were measured by CTD probes: XR-620 (Rihard Brancker Research Ltd., Canada), ASTD102 (JFE Advantech Co. Ltd., Japan) and SBE 19plus (Sea-Bird Electronics, Inc., USA). Their sensors were regularly checked at the calibration bench by the metrological laboratory of Pacific Branch of the "VNIRO". The CTD data processing was performed using original software *. The temperature and salinity data archive has a depth resolution of 0.5 m, and their values are determined with an accuracy of no worse than ±0.003°C, ±0.005 psu and ±0.05 m, respectively. In winter, the ice cover thickness was measured using a ruler (accuracy ±0.5 cm).

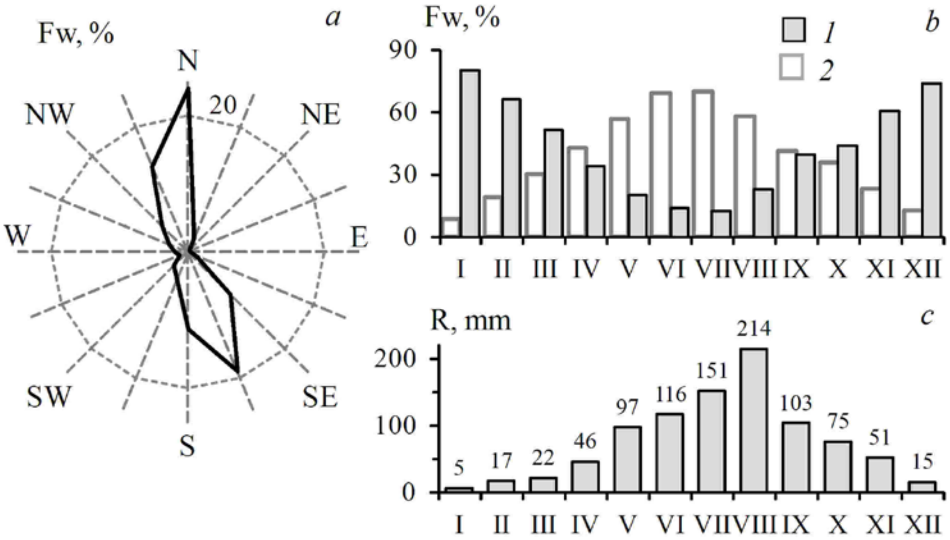
The observation points coordinates were determined by the Garmin eTrex navigator. To analyze the weather conditions, the archive WMO_ID = 31960 ** was used, which contains continuous series of urgent (eight times a day) observations at the Vladivostok meteorological station since February 2005.

Results and their discussion. The Sea of Japan and its coastal regions, including the Peter the Great Bay, are characterized by a monsoon climate: in spring and summer, humid sea air with southern winds, and in autumn and winter – dry continental air with northern winds. The frequency of wind direction, calculated from the urgent observations at the Vladivostok meteorological station from January 2011 to December 2020 (Fig. 2, *a*, *b*), is characterized by two narrow sectors of dominant directions. The N-NW wind predominated from October (44%) to March (51%) with a maximum share in January (80%), and S-SE – from April (43%) to August

* Lazaryuk, A.Yu. and Kosheleva, A.V., 2014. *Correction of Data from Deep-Water Hydrological Observations of CTD-Probes ("CTD-Data Processing")*. [computer program] POI FEB RAS. The Certificate on Official Registration of the Computer Program No. RU2014619779 (in Russian).

** Raspisanie Pogody, Ltd. *Weather Archive Vladivostok.* 2021. [online] Available at: https://rp5.ru/Архив_погоды_во_Владивостоке [Accessed: 20 October 2021].

(58%) at 70% recurrence in July. The averaged values of the mean wind speed module in the selected directions, N-NW and S-SE, were in equal limits: from 6.0 m/s in March and June to 6.7 m/s in January and April.

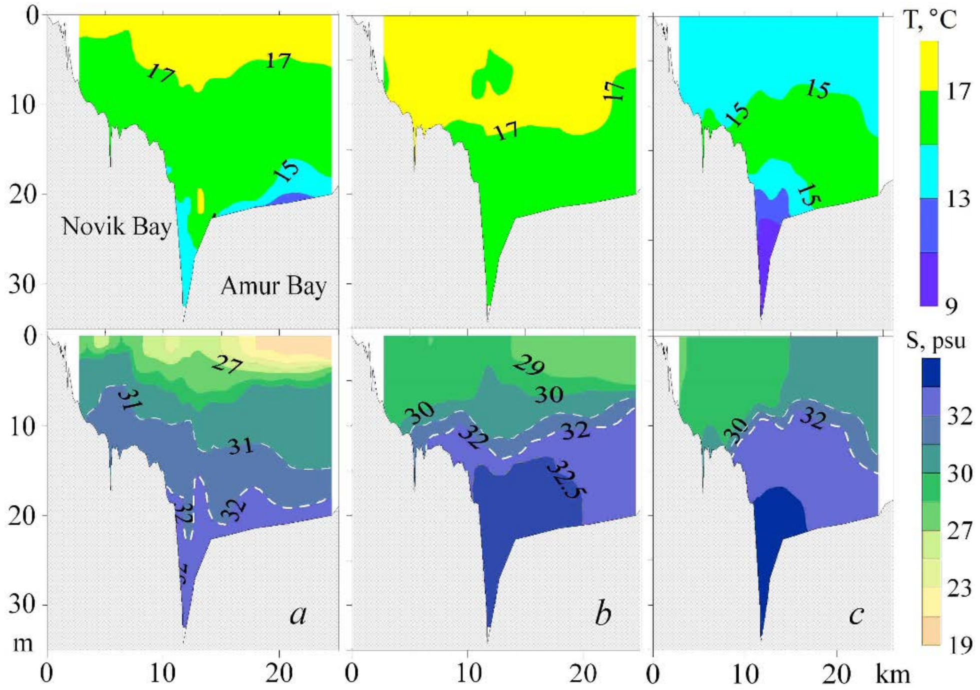


F i g. 2. Frequencies of the wind directions (*Fw*) (*a*) derived from the urgent observations; monthly averages of wind direction *Fw* for the N-NW (*1*), S-SE (*2*) sectors (*b*) and monthly averages of total precipitation *R* (*c*) based on the weather data archive, WMO_ID=31960 (2011–2020) **

For this 10-year period, the average annual precipitation was 912 mm/year, with more than half falling for three summer months – 481 mm (Fig. 2, *c*). The main sources of precipitations in July – August are tropical cyclones.

However, even with heavy precipitation, slight desalination of the surface layer is observed the Novik Bay, primarily due to the small catchment area; the ratio of the water surface area of the bay to the catchment area is 1: 4. During this period, in the northern part of the Novik bay, there is an inflow of waters with low salinity from the Amur Bay, which has a larger catchment area (1:40 according to the data of [5]). In summer, the surface water layer (0–5 m) of the northern part of the Novik Bay adjacent to the Amur Bay is characterized by greater desalination in relation to the southern part of the Novik Bay; the interface between the identified parts is vil. Shigino (see Fig. 1, *b*). On average, the salinity difference between the northern and southern parts of the Novik Bay in the warm season reaches 1.5 psu. This value increased two to three times during heavy rainfalls when tropical cyclones enter the southern regions of Primorye.

The thermohaline distribution at the axial section *NA* obtained on September 8, 2016 (Fig. 3, *a*) illustrates the effect of flooding on the Razdolnaya and the Amba rivers, formed by typhoon Lionroc (total precipitation from August 30 to September 1, exceeds 120 mm **).



F i g. 3. Temperature (*T*) and salinity (*S*) at the axial section *NA* measured by the *XR*-620 probe on September, 8 (*a*), September, 29 (*b*) and October, 11 (*c*), 2016

Subsequent observations carried out on the axial section NA in 2016 (Fig. 3,*b*, 3, *c*) show that at the beginning of the autumn-winter monsoon in the Amur Bay, the surface desalinated layer formed by the river flood disappears. And the salinity in the northern part of the Novik Bay increases, assuming the salinity values of the adjacent Amur Bay. At the same time, the salinity of the innermost part of the Novik Bay, on the contrary, decreases. According to CTD data, from September 8 to October 11, 2016, the integral salinity in the 0–10 m layer in Novik Bay decreased by 0.5 psu from 30 to 29.5 psu, and in Amur Bay it increased from 28 to 30.5 psu.

Thus, according to the described salinity dynamics, it is easy to imagine the northern monsoon influences the studied part of the Peter the Great Bay. At the same time, in the Amur Bay observed are the surging effects [8, 10] and the upwelling influence [11], both contributing to the cooling and salinization of the bay waters. Meanwhile, northern winds in the Novik Bay form surges and block the waters in its southern part. As a result of the aforementioned processes, the sign of the spatial salinity gradient in the Novik Bay from October to mid-December (before the ice cover is set) changes, and the salinity of the northern part of the bay is 1–0.5 psu higher than that of the southern one.

No direct measurements of the current velocity in the Novik Bay were carried out; therefore, the quantitative estimations of the water circulation scale due to the wind surge during the period of northern winds (October – December) will be given below. Note that the horizontal scales of the bay are small and the Rossby number, which reflects the ratio of inertial forces to Coriolis forces, is much greater than unity. Consequently, the geostrophic balance plays a secondary role [13]. Estimates of the scale of water circulation on average are given below, since the complexity of the coastline, as well as many interacting factors, do not allow to build an adequate mathematical model of the detailed bay water circulation at the modern level, taking into account the interaction with surrounding water areas.

As a coordinate system, the vertical plane is taken along the section *NA*, the *z* axis is directed vertically, the *l* axis is along the section to the bay exit with a general direction to the north. The horizontal speed *v* corresponds to the speed along the *l* axis.

A wind surge estimate for the considered water area will be obtained on the basis of classical approximations [13]. In the equation of horizontal balance of inertia forces and wind stress of friction $\frac{\partial p}{\partial l} + \frac{\partial \tau_z}{\partial z} = 0$ instead of pressure p the expression for p derived from the hydrostatic equation $\partial p = -\rho g \partial z$, is substituted. Then the formula for estimating the angle of water surface inclination due to the wind surge will take the form: $tg\alpha = \frac{\delta z}{\delta l} \approx \frac{\tau}{\rho g H}$. Further, taking into account the formula for the tangential wind stress on the sea surface $\tau = C_d \cdot \rho_{\mathrm{a}} \cdot W^2$, the final expression is obtained

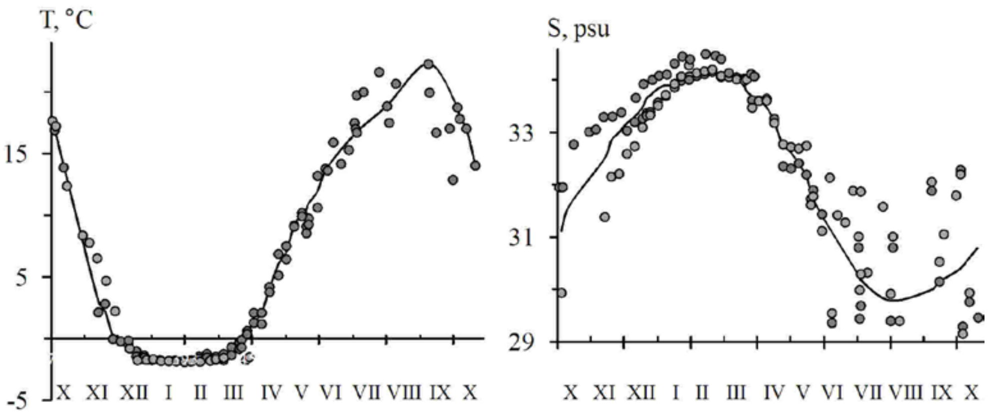
$$tg\alpha \approx C_d \cdot \frac{\rho_{\mathrm{a}}}{\rho} \cdot \frac{W^2}{gH} \ , \tag{1}$$

where C_d is the sea surface resistance coefficient; ρ_{a} and ρ are the density of air and water; W is surface wind speed at a standard height of 10 m; g is free fall acceleration; H is the characteristic depth of the bay.

Urgent observations of the October – December 2011–2020 ** in 90% of cases showed the average wind speed in northern directions less than 11 m/s. In this dynamic range (W <11 m/s) the drag coefficient $C_d \approx 1.24 \cdot 10^{-3}$ [14] and at a characteristic water layer H ~ 10 m the tangent of the surface inclination angle (1) in the Novik Bay will be about 10^{-6}. This gives an excess of the level in the bay $\delta H = L \cdot \mathrm{tg}\,\alpha \approx 10^{-2}$ m on its characteristic length L ~ 10 km. Thus, during the autumn-winter monsoon, in the absence of an ice cover, the wind surge in the Novik Bay is approximately equal to 1 cm / 10 km.

According to the conclusions presented in [13, 15], up to 10% of the available potential energy can turn into kinetic and the estimates of the current velocity due to the factor considered correspond to those calculated by the expression $v^2/L \approx 0{,}1 g \cdot \mathrm{tg}\,\alpha$. Hence, with a wind surge in the bay, an estimate of the horizontal velocity $v \sim 10^{-2}$–10^{-1} m/s is obtained.

For the northern part of the Novik Bay the annual thermohaline variations (Fig. 4) of the 0–5 m layer were calculated using CTD data 2016–2018. The CTD measurements were carried out at observation point 7 (depth 14 m) of the axial section *NA* and from the quay wall of the vil. Kanal (depth 6 m) (see Fig. 1, *b*). As you can see, seasonal fluctuations in temperature and salinity are in antiphase with each other: an increase in temperature is accompanied by a decrease in salinity and vice versa. The maximum temperature (24–25°C) occurs at the end of summer. Its greatest growth, up to 8 °C/month, was recorded in April – May and in October – November, an equally rapid drop to freezing temperature is observed. The minimum temperature (–1.84°C) at profiling station 7 was recorded in the upper under-ice layer between 1–5 m horizons on January 27, 2015 (with averaged salinity values of ≈ 34.28 psu).



F i g. 4. Annual variations of temperature (*T*) and salinity (*S*) in the water layer (0–5 m) of the Novik Bay based on the CTD-data obtained at the profiling stations in the vicinity of the vil. Kanal (Russky Island) in 2016–2018

During the warm period, June - September, the surface salinity of the northern part of the Novik Bay varied in the range from 29 to 32 psu. Such abrupt salinity changes are not caused by local precipitation, as might have been expected, but primarily by the multidirectional water circulation of the Amur Bay. In the following autumn months, due to the winter monsoon intensification, the salinity of the Novik Bay is stably increased due to the inflow of cold saline waters from the Ussuri Bay through the Eastern Bosphorus Strait. CTD data on December 6, 2017, showed the highest salinity in the Novik Bay surface water layer in the absence of ice cover at it temperature of –0.73°C – 33.66 psu.

The Primorye weather from October to March is determined by the Siberian high (cold anticyclone). Depending on the change in this baric anomaly position and scale, the continental cold advection to the coastal regions of the Sea of Japan increases or decreases. In particular, during cold outbreaks caused by the Siberian high displacement to the south, the surface temperature on the coast drops sharply to –20°C or less [16]. According to the Vladivostok meteorological station for the 2010s, the average air temperature for the winter season is about –10°C. For the period observations 2013–2020, the coldest winter was 2012/13 (–12.9°C), and the relatively warm (–7.2°C) was the winter of 2018/19.

Accordingly, in winter, the processes of heat exchange and ice formation directly determine the hydrological regime of Novik Bay. As a rule, at the end of November, when the air temperature is below –5°C, and the water temperature at a salinity of at least 32.5 psu drops to –1.8°C, an ice cover forms in the inner part of the bay. In a month, under favorable weather conditions, the entire surface of the Novik Bay water area is covered with a thin ice layer (up to 20 cm).

When the ice thickness increases (initially up to 2–3 cm/day), a heavy cold brine is rejected. During this period, the integral ice salinity (determined from the melted fragment of the ice core) averages 8–10 psu [17]. The cold brine inflow into the under-ice layer of water increases the salt content in it and contributes to a decrease in temperature.

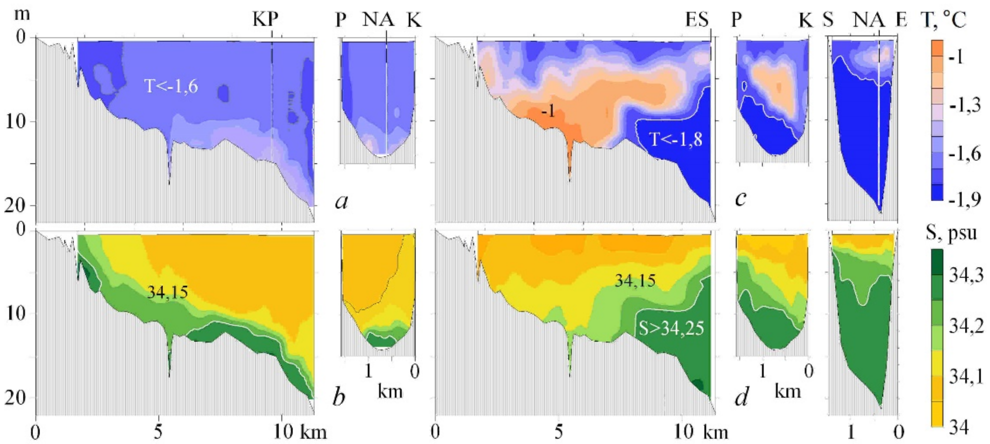
At the same time, the ice cover reduces the heat flux from the under-ice water layer to the atmosphere, and in shallow waters the temperature increases due to heat exchange with bottom sediments. The bottom silt accumulates heat during the warm period (April – September) and returns it to the overlying water layer as it cools. For example, in the Amur Bay at a bottom depth of 7 m, the maximum heat flow from the bottom sediments, up to 12 W/m^2, is observed in December, and in the following winter months the heat input to the bottom layer decreases linearly [7]. Accordingly, in the shallow Novik Bay, an intense heat exchange with bottom sediments slows down the ice formation process. Thus, the growth of ice in its innermost part at the beginning of the season (December) was observed at an average daily air temperature of less than –5°C, and by the end of the season (February), under favorable hydrological conditions in the bay, this limit increased to –2°C [17].

As a rule, by mid-February, the activity of the Siberian anticyclone decreases, the cold air inflow to the coastal areas decreases, and the growth of ice is noticeably reduced (less than 2 cm per week). Depending on the amount of incoming cold accumulated in winter ($\Sigma(-T_a)$ – the so-called sum of frost degree-days, where T_a is the average daily air temperature), the average values of the ice cover thickness in the bay, measured at the end of February, ranged from 27 cm ($\Sigma(-T_a) \approx 648°C \cdot$ day, 2019) to 66.5 cm ($\Sigma(-T_a) \approx$ 1163°C · day, 2013), and the salinity of the under-ice layer reached a seasonal maximum of 34.6 psu (2018).

When ice builds up, cold brine enters the water column and partially accumulates at the bottom (Fig. 5, *b*). It is important to note that more intensive cooling begins from the shallow innermost part of the Novik Bay, where the first ice forms. Therefore, in the southern part, more saline and, accordingly, denser waters are formed, which, due to hydrostatic pressure, begin to move along the bottom relief to the exit from the bay. In this case, the bottom gradient flow, shifting to the north, is pressed against the eastern coast of the bay, and the counter, compensatory flow in the upper under-ice layer – to the western one (Fig. 5, *a*, *b*).

As the dense waters move northward, the temperature in the bottom layer increases by 0.1–0.3°C (Fig. 5, *a*) due to the heat coming from bottom sediments. As a result, when the ice grows, the water columns in the Novik Bay have a characteristic two-layer thermohaline structure: a cold, but less salty upper layer and a bottom layer, relatively warm and saltier. The waters of the Amur Bay are also characterized by a similar subglacial two-layer stratification, but with large thermohaline gradients [8].

When the growth of the ice thickness stops, the brine is not rejected, but the heat from precipitation continues to enter the bottom layer, and convective processes gradually destroy the two-layer structure of water column [8]. In March, thermohaline parameters show tendencies in the opposite direction: an increase in temperature and a decrease in salinity (Fig. 4).



F i g. 5. Temperature (*a*, *c*) and salinity (*b*, *d*) measured by the *ASTD*102 probe on the axial section *NA* and on the cross-sections vil. Kanal – vil. Podnozh'e (KP) and Elena Island – Staritsky Cape (ES) on February, 1 (*a*, *b*) and February, 23 (*c*, *d*), 2017

CTD data on the axial section NA allow us to make a quantitative estimate of the possible flow velocity generated by the pressure gradient. For a gradient flow, the equation of motion $-v\frac{\partial v}{\partial l} = -\frac{1}{\rho}\cdot\frac{\partial p}{\partial l} \approx \frac{\partial \rho}{\rho}\cdot\frac{gH}{L}$ [13] and the sought upper estimate of its velocity corresponds to the expression

$$v = \sqrt{g \cdot H \cdot \frac{\delta\rho}{\rho}}, \qquad (2)$$

where $\delta\rho = \rho_L - \rho_0$ is a characteristic horizontal difference in the water densities at the innermost of the bay, ρ_0, and at its inlet, ρ_L. In particular, according to CTD data on February 01, 2017 (Fig. 5, *a*, *b*), this difference was $\delta\rho \approx -0.10$ kg/m^3 per 10 km, and the estimated velocity of the gradient flow was $v \sim 10^{-1}$ m/s.

Note that the considered gradient mechanism of water removal from the bay operates almost constantly during the freeze-up period. It is also notable that dynamic estimates of currents generated by the wind surge (formula (1)) and the density difference (formula (2)) are of the same order.

The period of stable low negative water temperatures lasts at least two months (see Fig. 4). Thus, a longer freeze-up has a favorable effect on the bay self-purification process. At the same time, the blocking effect of the northerly wind-induced surge is weakened when the shear stress work of the wind is blocked by the ice surface. Therefore, later dates of the freeze-up onset (for example, due to climatic trends) worsen the ecological situation in the Novik Bay due to the weakening of its water circulation.

In the time interval from the end of winter to the beginning of spring, water renewal in the Novik Bay also depends on the features of hydrological regime of the adjacent water areas: the Amur Bay and the Eastern Bosphorus Strait. As a rule, in February these areas begin to free themselves from the ice cover [18]. At the same time, the temperature atmospheric background continues to remain negative and the surface water layer freed from ice becomes denser. The compaction of water column occurs not only due to cooling, but also due to salinization, since the prevailing north wind contributes to the removal of the initial forms of ice into the open part of Peter the Great Bay. When the denser waters of the Amur Bay or the Eastern Bosphorus Strait penetrate into the ice-covered Novik Bay, the bottom gradient current may overlap and, accordingly, the circulation of its waters may slow down.

From 2013 to 2018, the effect of blocking the Novik Bay water area was recorded twice – in 2014 and 2017. The weekly hydrological surveys of 2016/17 winter revealed some of its features. At the beginning of the winter, the ice cover formation in the bay was inhibited by relatively warm weather conditions (the average air temperature in December 2016 was $T_{\mathrm{a}} \approx -7.7$°C), and the waters of its northern part retained an increased density: $\rho_L > \rho_0$. Intensive ice growth (6 cm per week) from 17 cm (December 28) to 40.5 cm (January 25), caused by cold outbreaks, $T_{\mathrm{a}} \geq -16.5$°C, changed the sign of the density gradient between parts of the bay and contributed to the formation of the bottom stream of high-saline waters directed to the north.

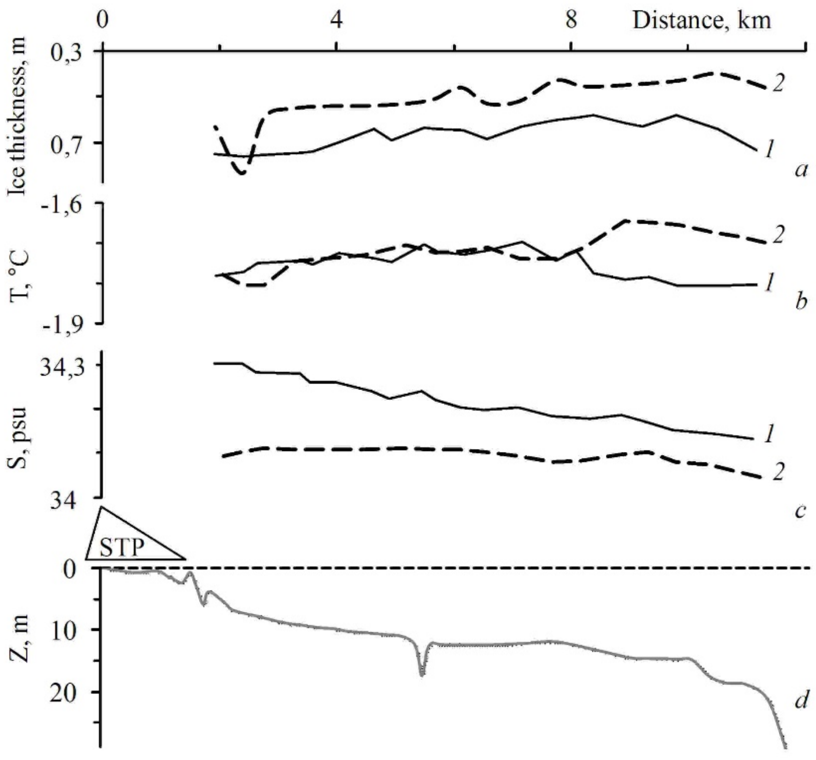
In the innermost part of the bay (observation points *1–3* of section *NA*), the compaction of water by cold brine continued until January 25 ($\rho_0 \approx 1027.61$ kg/m^3), when the density difference reached extremes ($\delta\rho \approx -0.25$ kg/m^3) and the corresponding estimate the velocity of the gradient flow (2) ($v \sim 15$ cm/s). However, already a week later, the value of the density gradient decreased 2.5 times due to the appearance of colder (–1.82°C) dense ($\rho_L \approx 1027.51$ kg/m^3) waters in the adjacent area of the Amur Bay (Fig. 5, *a*, *b*).

The weakening of the under-ice dynamics slowed down the advection of heat entering the bottom layer from bottom sediments, and negatively affected the ice formation process, reducing the ice growth rate by three times. Its average thickness per week increased by only 2 cm to 42.6 cm (February 1), despite the persistently negative surface air temperature, $-12.5 \leq T_{\mathrm{a}} \leq -4.7$°C. During the next week (the first week of February), the atmospheric background also remained negative, $-9.9 \leq T_a \leq -1.7$°C, nevertheless, the ice growth in the Novik Bay stopped, and the integral temperature in the under-ice layers of its southern part increased from –1.67 to –1.53°C. Accordingly, the density of the under-ice layer at the profiling stations at the beginning of axial section *NA* decreased to $\rho_0 \approx 1027.56$ kg/m^3 (February 8).

At the same time, the water column of the Amur Bay continued to thicken ($\rho_L \approx 1027.54$ kg/m^3) and the gradient flow from the bay was almost stopped. Further cooling (–1.85°C) and salinization (34.29 psu) of the water column of the Amur Bay formed a reverse gradient flow in the bottom layer of Novik Bay. Its movement to the south contributed to a partial return of relatively warm (down to –1.2°C) highly saline (34.20 psu) bottom waters to the southern part of the bay.

According to the CTD data of February 23 (Fig. 5, *c*, *d*), the dense waters of the Amur Bay penetrated into the Novik Bay, filling almost all of its northern part at the horizons below 2–7 m, and blocked the waters of the southern part. As a result, the spatial density gradient changed sign and reached its maximum: $\delta\rho \approx 0.20$ kg/m^3 per 10 km. The rise in temperature in the blocked layers to –1°C and the accompanying convection triggered the destruction of the ice cover. This process within the Novik Bay water area was uneven: in particular, the average ice thickness on 3.5–7 km of the section NA decreased by 3 cm, from 40 to 36.8 cm, and on 7–11 km – by 1.5 cm. The decrease in the ice cover thickness in the northern part of the bay from 42.6 to 41.1 cm was facilitated by relatively warm, down to –1.2°C, waters entering the under-ice layer from the blocked southern part (Fig. 5, *c*). It should be noted here that the process of ice melting occurred despite a relatively low atmospheric temperature background in February 2017, $T_a \approx -7.1$°C (with variations from –12 to +2°C) **.

Thus, during the freeze-up period, the intensity of water circulation in the Novik Bay and the efficiency of its water exchange with the adjacent Amur Bay directly depend on the magnitude and sign of the water density gradient between its southern and northern parts.



F i g. 6. Ice thickness (*a*), temperature (*b*) and salinity (*c*) of the water column; bottom topography (*d*) on the axial section *NA* in the Novik Bay based on the observation data of February 23, 2013 (*1*) and February 24, 2016 (*2*). Triangle with inscription “STP” denotes location of the sewage treatment plants of the FEFU campus

The results of long-term observations also showed an increased anthropogenic impact, in addition to natural factors determining the hydrological regime of the Novik Bay. The effect is directly related to the sewage treatment facilities of the FEFU (Far Eastern Federal University) campus, which, since autumn 2013, have been discharging wastewater into the innermost part of the Novik Bay up to 10^3 m^3/day [4]. The additional source of fresh water disrupts natural circulation of the bay waters. In winter, in the presence of ice cover, a regular inflow of fresh water significantly reduces salinity in the thin under-ice layer. As a result, ice growth accelerates at the periphery of the penetration zone of these waters. Thus, according to the data of ice surveys which were carried out in the Novik Bay annually at the end of February, in the absence of an additional fresh water source (winter 2013), the ice thickness in the innermost part exceeded the average level along the axial section by only 10–12%. And after the start of treatment facilities these differences reached 40% or more (Fig. 6, *a*). In addition, freezing of fresh or brackish waters, in contrast to salty ones, occurs at elevated temperatures and brine is released in much smaller quantities. These processes do not result in the increase of salinity and density in the southern part of the bay (Fig. 6, *c*) and in winter they inhibit water exchange with the adjacent Amur Bay, reducing the efficiency of its self-purification.

Conclusion. Thus, the results obtained from our measurements and quantitative estimations allow us to draw the following conclusions:

1. The thermohaline changes in the water layer (0–5 m) of the Novik Bay have a characteristic seasonal cyclicality: the temperature is positive from April to November (maximum 25°C at the end of August) and negative from mid-November to March (minimum –1.84°C in January) with an average annual value of about 8.5°C. Salinity is characterized by a minimum in summer (29 psu in August) and a maximum in winter (34.6 psu in February). The increase in salinity in winter is associated with the brine rejection during the freeze-up period.

2. A feature of the Novik Bay – low thermal inertia (due to its small volume) in relation to the adjacent Amur Bay – leads to faster cooling and heating of waters, which creates conditions for gradient currents, especially in winter when ice cover is created.

3. The location and shape of the Novik Bay of the Russky Island complicate the water exchange with the adjacent Amur Bay for almost the entire year. The bay is closed from southerly winds of the summer monsoon by mountains which impede the surge current. The northerly winds of the winter monsoon cause a surge of water from the Amur Bay and block the far innermost part of the bay where water stagnation is observed. Quantitative estimates corresponding to the range of wind velocities in the northern directions of 4–11 m/s typical for the study area showed the surge height in the bay of no more than 1 cm / 10 km, and the drift current velocities up to 10 cm/s.

4. In winter, the ice cover in the Novik Bay is formed mainly during cold intrusions caused by the Siberian anticyclone. During the freeze-up period, the water column of the Novik Bay is, as a rule, colder and saltier than in the adjacent waters of the Amur Bay, due to the shallowness, its proximity to the coast and the brine released. As a result, due to the spatial density gradient, a flow of highly saline waters in the bottom layer, directed northward towards

the exit from the bay, is formed. This flow contributes to the water area self-purification process, which is confirmed by the data of chemical and ecological studies. The quantitative estimates of the gradient flow rate, based on CTD data, did not exceed 15 cm/s at an extreme density difference $\delta\rho \approx -0.25$ kg/m^3.

5. The most favorable period for the renewal of the Novik Bay waters is its freeze-up. When the duration of this period is shorter or the sign of the density gradient changes, for example, due to the penetration of denser waters of the Amur Bay into the northern part of the bay, the efficiency of self-purification of the studied water area decreases. The self-purification process is also negatively affected by the desalination of the bay southern part waters by the sewage treatment facilities of the FEFU campus.

The performed study confirms the importance of limiting the anthropogenic load on the Novik Bay due to a weak natural ability for self-purification.

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