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ОРИГИНАЛЬНАЯ СТАТЬЯ ORIGINAL ARTICLE

Dissolved silicon and nitrogen in glacial rivers and water of Blago bay (Russian Arctic, Novaya Zemlya): origin, variability and spreading

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Summary

Hydrochemical studies of watercourses and the water area of Blagopoluchia bay (Novaya Zemlya, Arctic, Russia) have been carried out. The concentrations of nutrients in rivers and streams are higher than those in the water area of Blagopoluchia bay. It is shown that the concentration of silicon in constantly flowing rivers is 1–13 µM, the concentration of NO_3 — 0.5–8, for small and temporary streams these values are higher and are in the range of 18–46 µM Si, 1–11 µM NO_3^-. The influence of streams and rivers flowing into Blagopoluchia Bay on the water area of the bay is local and extends to 1 km from the mouth, and does not influence the Kara Sea nutrient content.

Keywords: Kara Sea, Novaya Zemlya, nutrient signal, nutrients, river flow, streams.

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INTRODUCTION

According to the Arctic Monitoring and Assessment Programme report [1], the rise in the average sea and land surface temperatures in the Arctic was 3 times higher than in any other region of the Earth. Currently, the frequency of events associated with the exchange of water and ice at the sea-land interface has increased in the Arctic, for example, the intensity of the melting of the Greenland ice sheet has increased [2].

From 1971 to 2019, the annual temperature increase in the surface layer averaged 3.1 °C in the Arctic, and for the northern part of Novaya Zemlya and the northern part of the Barents Sea, the value is 10.6 °C [1]. The retreat of marine-type glaciers in the Novaya Zemlya archipelago has increased in the last 20 years. From the end of the 20th to the beginning of the 21st century the area of glaciers on Novaya Zemlya decreased by 1,000 km^2, and the volume of ice mass by 380 km^3 [3, 4]. Icelandic researchers have shown that with an increase in the average annual temperature by 1 °C, the intensity of mechanical weathering of rocks affected by the flow of glacial rivers increases from 8 to 30 %, thus suggesting a significant relationship between rock weathering and climate change [5].

In terms of the connection between rivers and aquatic ecosystems, the water areas near the Greenland Ice Sheet are the best studied. For example, the transport of nitrates through snow and ice to the ocean is being studied. The source of nitrates, according to the authors, is microbiological processes occurring on the surface of the ice sheet. For the Kargenvagge tract in northern Sweden (Swedish Lapland) it was shown that crystalline schists can be a source of inorganic forms of nitrogen [6].

In addition, it was possible to identify changes in the silicon cycle in the Arctic ecosystem of the Greenland Ice Sheet; subglacial weathering processes are of great importance as a source of silicon for the ecosystem. [7] and [8] explore the lakes of the Greenland Ice Sheet with different nutrition (snow or glacier). Lakes differ both in nutrient content and in turbidity. All the factors presented affect the species composition of the hydrobionts inhabiting these lakes.

The phenomenon of connection between glaciers, small rivers and the sea for the Russian Arctic has not been studied at all. For many years, certain regions of the Arctic were inaccessible for research. The research program "Ecosystems of the Russian Arctic" ran for 13 years from 2007 to 2018. For the first time, hydrophysical and hydrochemical studies of the adjacent water areas of Novaya Zemlya were made [9, 10].

Rapid changes in the cryosphere affect the productivity of ecosystems [11] and species interactions [12] in the Arctic. Such rapid changes lead to changes in the carbon and greenhouse gas cycle [13, 14]. The unique ecosystems associated with the ice boundary are at risk. The Kara Sea is a marginal sea of the Arctic Ocean, located on the shelf of Eurasia, bordering the Barents Sea in the west, the Laptev Sea in the east, the total sea area is 883 thousand km^2, 80 % of the sea area is shelf, with an average depth of 127 m, the greatest depth observed in the St. Anna Trench — up to 620 m. The total volume of the Kara Sea is estimated at 112 thousand km^3. The boundaries of the sea are distinguished both along the coastlines and along the extreme points of the islands of Severnaya Zemlya and Novaya Zemlya.

Novaya Zemlya, a submerged mountain range, is the largest archipelago in the European Arctic consisting of two islands, Severny and Yuzhny. The coastline of Novaya Zemlya is significantly indented by fjord-type bays.

Blagopoluchia Bay (object of current study) is located on the eastern coast of Severny island of Novaya Zemlya. It was discovered in 1921 by a Soviet hydrographic expedition on board the R/V Taimyr. The bay's length is about 11 km, the width at the entrance is 7 km. Most of the year the bay is covered with ice. In the central part of the bay, the maximum depth reaches more than 170 m. The bay is partially isolated from the Kara Sea by Kamny Island located at the entrance to the bay [15]. The location of Blagopoluchia bay is shown in Figure 1.

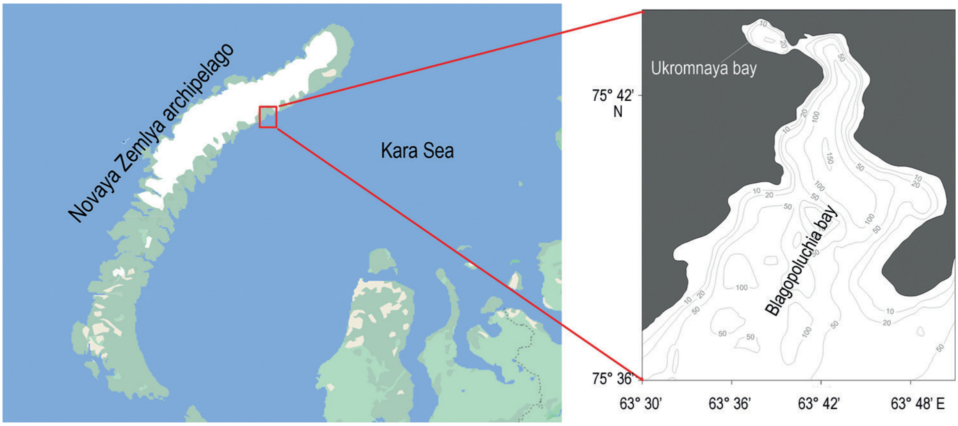

Fig. 1. Scheme of location of Blagopoluchia Bay on the Novaya Zemlya archipelago and in the Kara Sea
Рис. 1. Схема расположения залива Благополучия на о. Северный, Новая Земля и в Карском море

There is little literature on the ecology of Blagopoluchia Bay. It is known by oxygen and hydrogen isotope methods that the source of desalination in the bay is glacial runoff. In 2007, during an expedition within the project "Ecosystems of the Russian Arctic", high concentrations of nutrients were detected for the first time in the Blagopoluchia Bay watercourses. The concentration of nitrates was in the range of 1–15 μM, dissolved silicon 22–50 μM. These values were higher than the average concentrations of NO_3^- and Si in the adjacent water area of the Kara Sea and aroused interest. Laboratory experiment was carried out. The experiment confirmed that the rocks of Novaya Zemlya can be a source of nutrients in the watercourses [14, 16].

The aim of the current study is to identify common characteristics and differences in the hydrochemical composition of watercourses flowing into Blagopoluchia Bay and determine the degree of influence of watercourses on the water area of Blagopoluchia Bay.

MATERIAL AND METHODS

The work is based on hydrochemical data obtained during cruises of the R/V Akademik Mstislav Keldysh and cruises of the R/V Professor Shtokman (Table 1). The open part of Blagopoluchia Bay and Ukromnaya Bay are separated from each other by a narrow bar with 2 m depth [17].

Water samples in the rivers and in the marine part of the Bay were taken with a plastic Niskin and then transferred into specially prepared glass and plastic bottles with screw caps, canned, if necessary, and stored at a low temperature without access to light or in a freezer. Water samples from rivers were preliminarily filtered through Millipore filters with a pore size of 0.45 μm. The water temperature and salinity were measured using a CTD probe SeaBird SBE19plus. The water temperature and salinity during the landings were determined using a portable salt thermometer.

Determination of dissolved silicon was performed by a blue molybdenum complex. Traces of silica are determinable down to 0.28 μM SiO_3^{2-} liter^{-1} with an error of ±3 %. Determination of dissolved forms of nitrogen (nitrates) was carried out colorimetrically using the Griess reagent after reduction of nitrates to nitrites in cadmium reducers. The precision of the method is 0.02 μM [18]. Total titratable alkalinity (Alk) was determined by direct titration — the Bruevich method with visual determination of the end point of titration [19].

Table 1

Cruises performed by the Institute of Oceanology of the Russian Academy of Sciences in the course of research under the program "Ecosystems of the Siberian Arctic"

Таблица 1

Рейсы, выполненные Институтом океанологии им. П.П. Ширшова РАН в ходе исследовательской программы «Экосистемы Сибирской Арктики»

Year	Vessel	Dates of cruises
2007	RV "Akademic Mstislav Keldysh" 54 cruise	05.09–07.10.2007
2013	RV "Professor Shtockman" 125 cruise	Aug–Sept 2013
2014	RV "Professor Shtockman" 128 cruise	26.08–10.10.2014
2016	RV "Akademic Mstislav Keldysh" 66 cruise	11.07–20.08.2016
2017	RV "Akademic Mstislav Keldysh" 69 cruise	22.08–3.10.2017
2018	RV "Akademic Mstislav Keldysh" 72 cruise	16.08–20.09.2018

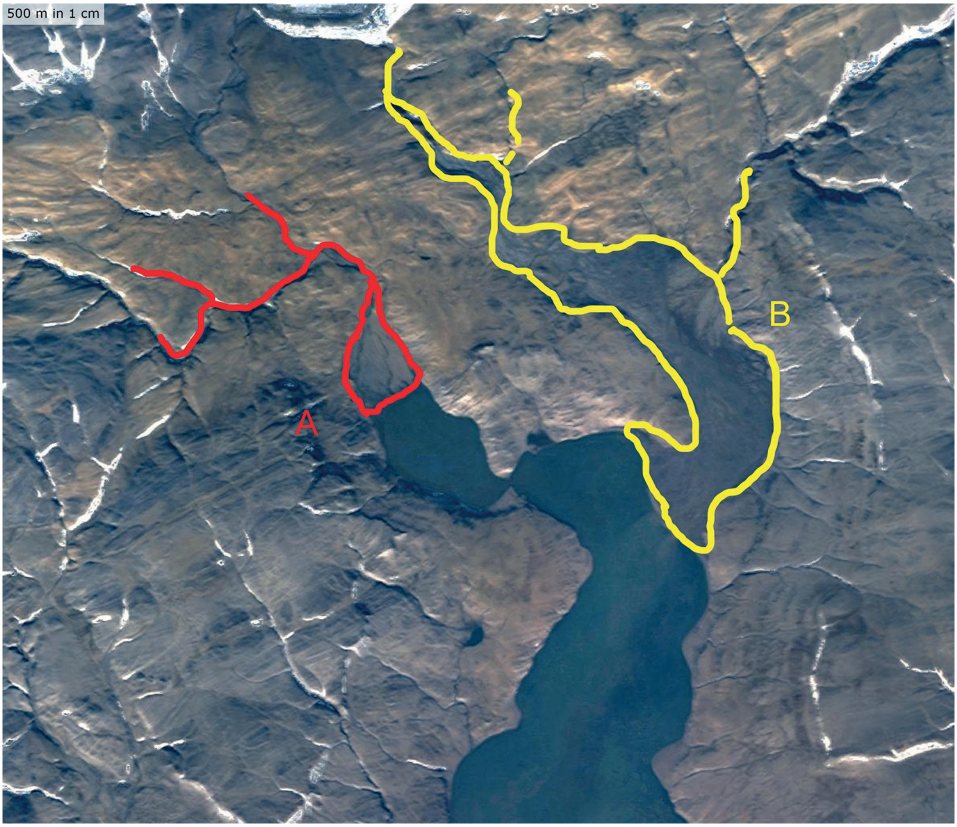

Fig. 2. Rivers flowing into Blagopoluchia Bay. On the left, the red line (A) — the river flowing into Ukromnaya Bay (flows from the Nally Glacier), on the right, the yellow line (B) — Bazoviy spring (a large river)

Рис. 2. Реки, впадающие в залив Благополучия. Красным слева отмечена река Укромная (А), справа желтой линией отмечен ручей Базовый (В)

Water sampling from the rivers (Figure 2) was carried out during landings, water sampling in the open part of the bay was carried out directly from the vessel. The watercourses in Blagopoluchia Bay belonged to 2 main groups — rivers (the Ukromnaya River and the Bazovy Creek, Figure 2) fed by glaciers and small streams that do not have a name,

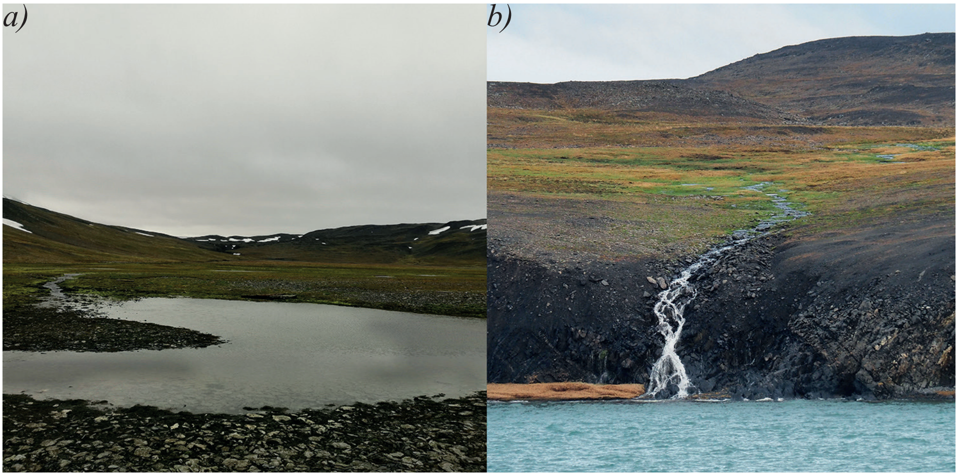

Fig. 3. Two different types of Blagopoluchia Bay watercourses: rivers (*a*) and small creeks (*b*) photographed by the author

Рис. 3. Два различных типа водотоков, впадающих в залив Благополучия: реки (*a*) и мелкие ручьи (*b*), фотографии автора

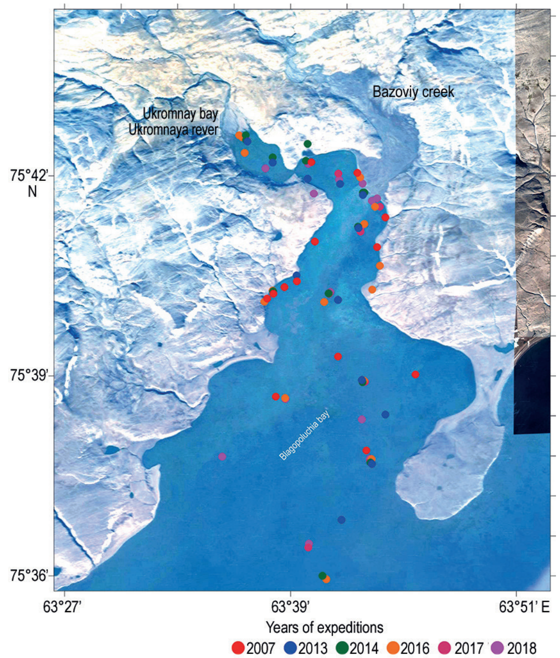

Fig. 4. Layout of stations in Blagopoluchia Bay

Рис. 4. Расположение станций на берегу и в акватории залива Благополучия fed mainly by snow, the difference between the two types of watercourses is shown in Figure 3. Location of the sampling places look at figure 4.

Previously, it was shown that the chemical composition of the watercourses in the bays of Novaya Zemlya is formed as a result of leaching of chemical elements from rocks. The main nutrient elements entering the water area of Blagopoluchia Bay with watercourses (according to the results of laboratory experiments) are dissolved silicon and the nitrate form of nitrogen.

RESULTS AND DISCUSSION

Variability of the hydrochemical parameters of the rivers and streams in Blagopoluchia Bay

The concentrations of dissolved silicon in the watercourses of Blagopoluchia Bay in 2007 were in the range from 22 μM to 50 μM, in 2013 this range was 6.4–38.3 μM, in 2014 5.3–26.8, in 2016 23–36 μM, in 2017 the concentration range was 10–46 μM, in 2018 11–33 μM.

The concentrations of nitrate nitrogen in the watercourses of Blagopoluchia Bay in 2007 ranged from 1 μM to 15 μM, in 2013 this range was 3.04–8.14 μM, 2014 1.86–5.5, 2016 3.7–11.2 μM, in 2017 the concentration range was 0.1–3.1 μM, in 2018 1–15 μM. Graphically, the data is presented in Figures 5 and 6, the boundaries of the bars show the minimum and maximum values, the line in the middle of the bars shows the average value.

A series of experiments were conducted with the shales forming the bedrock of the glacial streams. The aim of the experiments was to identify the possibility of leaching

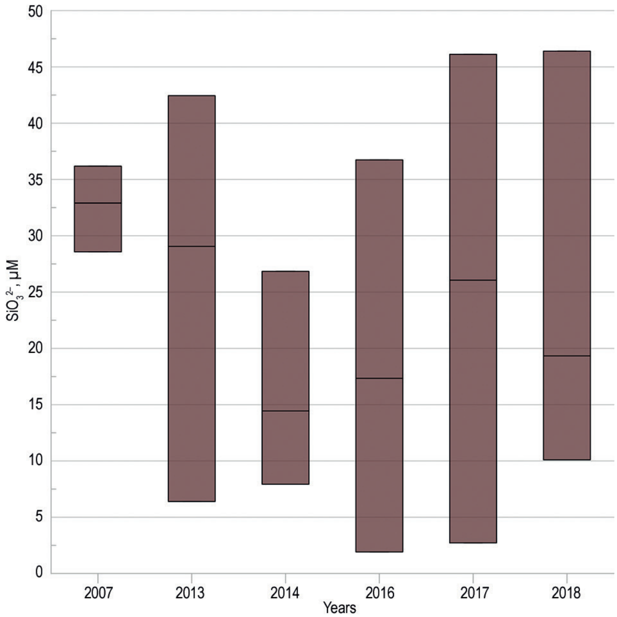

Fig. 5. Silicon concentrations ranges in the watercourses of Blagopoluchia Bay, 2007–2018
Рис. 5. Концентрации кремния в водотоках залива Благополучия, линией показано среднее значение, 2007–2018 гг.

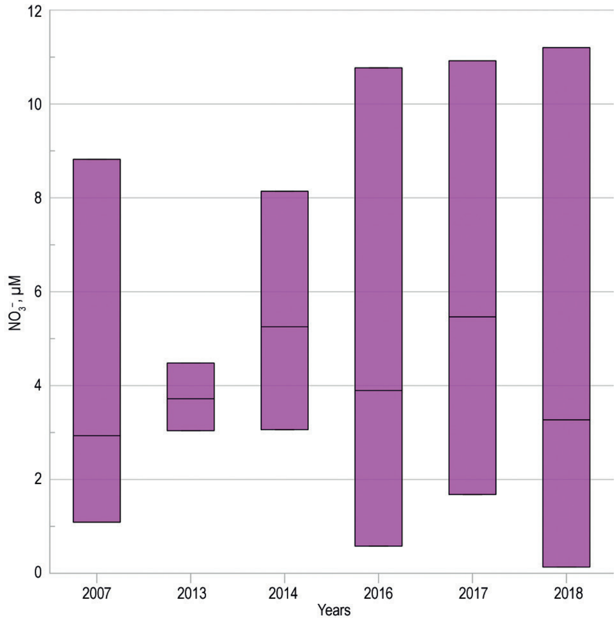

Fig. 6. Nitrates concentrations ranges in the watercourses of Blagopoluchia Bay, 2007–2018
Рис. 6. Концентрации нитратного азота в водотоках залива Благополучия, линией показано среднее значение, 2007–2018 гг.

nutrients from various rocks. The leaching experiments are described in [13, 16], the main result of these experiments being the proven possibility of leaching silicon and nitrogen from rocks. In addition, not only was the possibility of leaching biogenic elements proved, but also the leaching rate was calculated, which was 1.6 μM SiO_3^{2-} ·m^2/day, for nitrate nitrogen (NO_3^-) this value was at the level of 0.4 μM·m^2/day [13, 16].

The concentrations of silicon and nitrogen reached the highest values in 2016–2018, they were also significant in 2007. There are two different type of watercourses: *small and temporary* watercourses or *comparably larger and constantly flowing*. Stream sampling points are plotted on the Blagopoluchia Bay map; the values next to the points represent the concentrations of dissolved silicon and nitrates (Figures 7, 8). The average values of nutrient concentrations in watercourses of different types are given in Table 2. A diagram of the silicon content and total alkalinity (Figure 9) of the watercourses show that the waters of constantly flowing rivers Ukromnaya and the Bazovy stream on average contain a smaller amount of dissolved silicon and nitrate nitrogen than the small and temporary watercourses.

Table 2

Comparison of concentrations of dissolved silica, nitrates in small watercourses and rivers

Таблица 2

Сравнение концентраций растворенного кремния, нитратного азота в малых и больших водотоках

Rivers (Ukromnaya, Bazoviy)	Small watercourses (streams)
1–13 μM SiO_3^{2-} STDev 3.77	18–46 μM SiO_3^{2-} STDev 8.09
0.5–8.14 μM NO_3^- STDev. 2.1	1.15–11.2 μM NO_3^- STDev 3.14

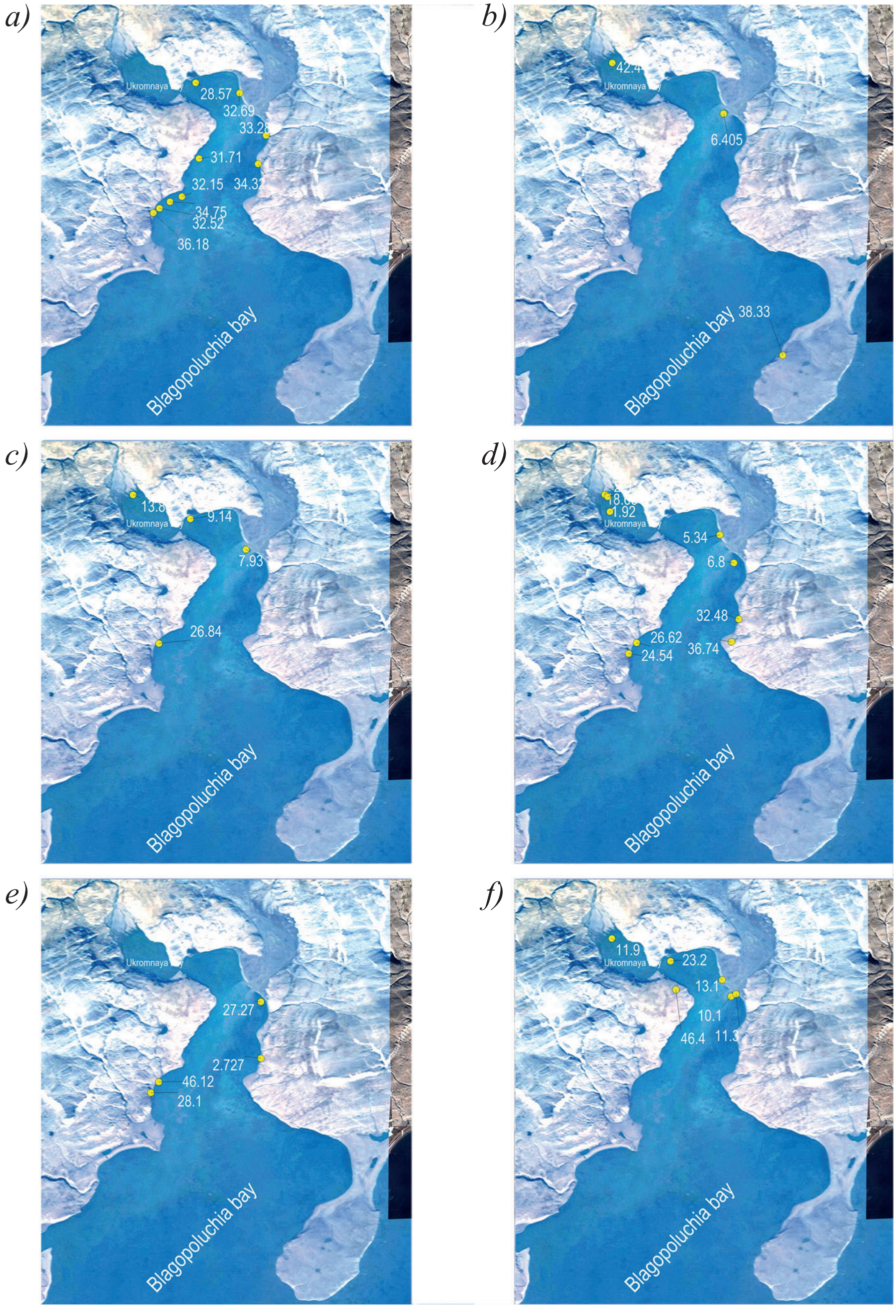

Fig. 7. Map of the distribution of dissolved silicon concentrations in the watercourses of Blagopoluchiya Bay (2007–2018). Yellow circles indicate sampling locations. Letter indices mark the years of observation: *a*) 2007, *b*) 2013, *c*) 2014, *d*) 2016, *e*) 2017, *f*) 2018

Рис. 7. Карта распределения концентраций растворенного кремния в водотоках залива Благополучия (2007–2018). Желтыми кругами отражено местоположение отбора проб. Буквенными индексами отмечены годы наблюдений: *a*) 2007, *b*) 2013, *c*) 2014, *d*) 2016, *e*) 2017, *f*) 2018

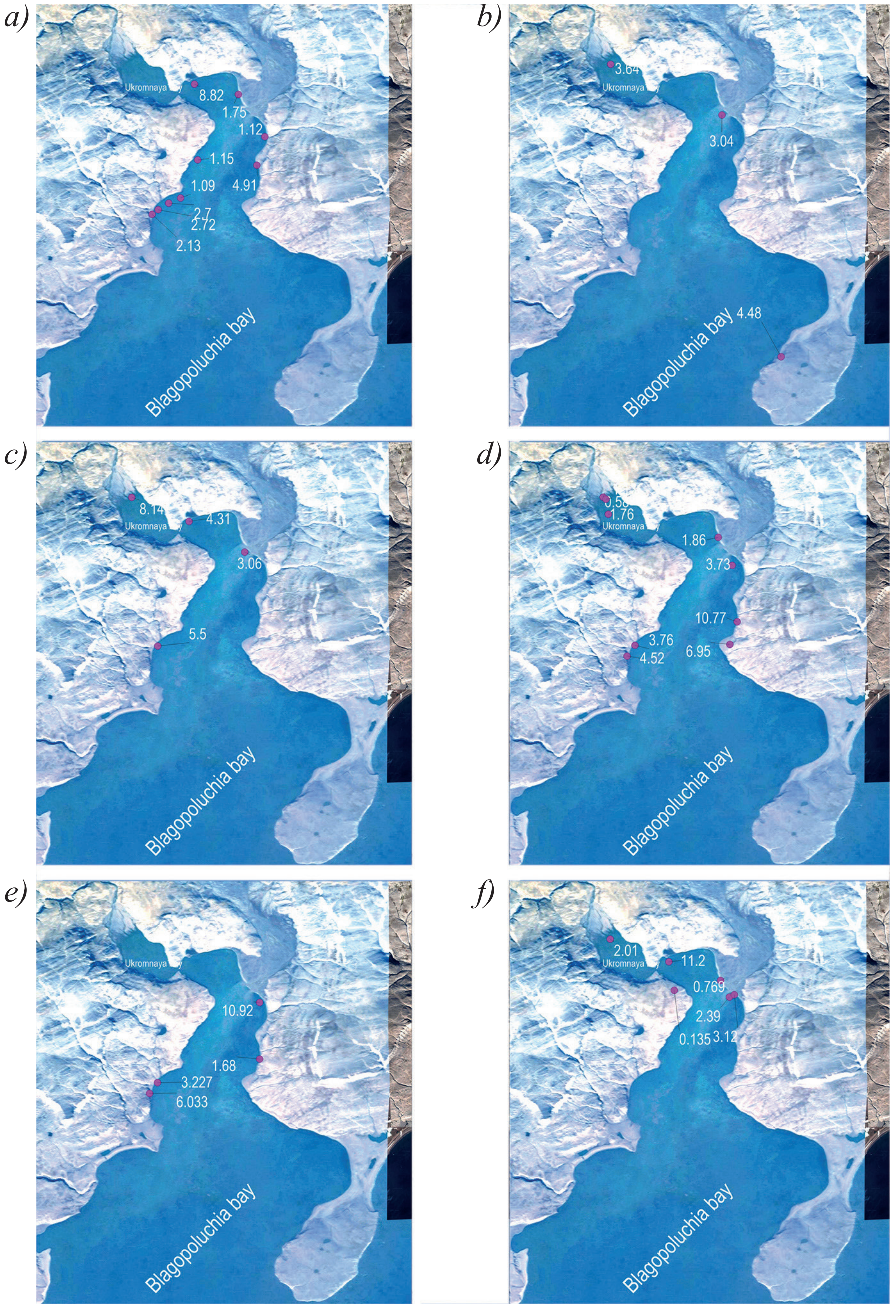

Fig. 8. The map of nitrate nitrogen concentrations in watercourses of Blagopoluchia Bay (2007–2018). Magneta circles indicate sampling locations. Letter indices mark the years of observation: *a*) 2007, *b*) 2013, *c*) 2014, *d*) 2016, *e*) 2017, *f*) 2018

Рис. 8. Карта распределения концентраций нитратного азота в водотоках залива Благополучия (2007–2018). Розовыми кругами отражено местоположение отбора проб. Буквенными индексами отмечены годы наблюдений: *a*) 2007, *b*) 2013, *c*) 2014, *d*) 2016, *e*) 2017, *f*) 2018

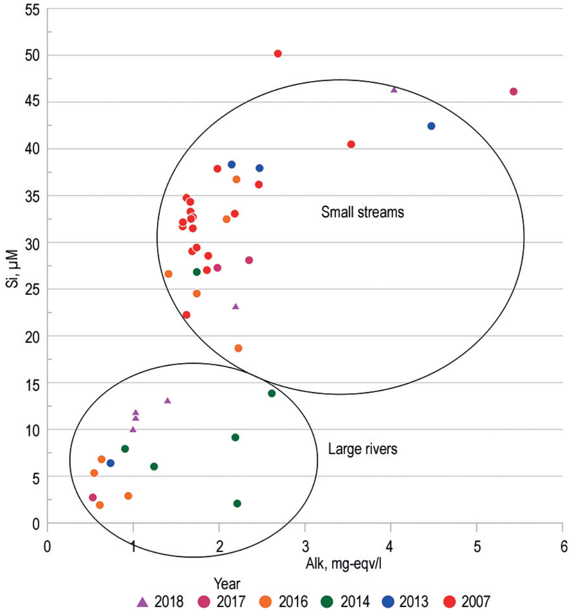

Fig. 9. The Alk-Si Diagram for the watercourses of Blagopoluchia Bay (2007–2018)
Рис. 9. Диаграмма общей щелочности – концентрации кремния для водотоков залива Благополучия (2007–2018)

Also, the parameter of the total alkalinity range in the rivers is 1 – 1.1 mg-eq/l, for the small and temporary watercourses Alk = 1.8^{-2} mg-eq/l.

The results of a study conducted in Templefjord (Svalbard) are largely similar to those of the current work. The main rock in Templefjord Bay is limestone, with which a nutrient leaching experiment was also carried out. It is shown that, on average, limestone releases 1.6 µM SiO_3^{2-}·m²/day and 5 µM NO_3^- ·m²/day. In addition, according to the authors (Pogojeva), the main source of biogenic elements in the Templefjord is rivers containing 46–58 µM SiO_3^{2-}, µM 5–9 µM NO_3^-. Also, a significant source of nutrients is the abrasive slopes of a recently retreating glacier, the waters of which contain 55 µM Si, 2 µM NO_3^- [14, 20].

According to several authors [21, 22], the concentration of nutrients (N, Si, P) and metals (Fe, Mn) in watercourses is determined by the rock underlying the catchment area of the watercourse. For the most silicon-rich rivers of the Greenland Ice Sheet (concentration up to 500 µM), the main rock underlying the watershed is basalt, and gneisses are also represented. According to our data, the rivers of Novaya Zemlya contain a smaller amount of nutrients, which may be associated with another rock of metamorphic origin, ankeritolite schist.

The average value of the concentrations of dissolved silicon in the rivers flowing from the Greenland Ice Sheet is 26 µM, while the maximum value is 540 µM, the average concentration of nitrate nitrogen, conversely, is lower for the rivers of the Greenland Ice Sheet — it is at the level of 2.5 µM. Measurements in the glacier-fed Saqqap Sermersua River showed that the Si:N:P ratio was 112:8:1, which is different from the standard 15:16:1 stoichiometric ratio typical of diatoms. Thus, melt water flowing from glaciers cannot be a significant source of nutrients [23].

Hydrochemical characteristics in the marine area of Blagopoluchia Bay

The Kara Sea belongs to oligotrophic seas [11, 24], whose nutrient concentrations are significantly lower than those both in bays and in the glacial watercourses of Novaya Zemlya [13, 16, 27].

Sections showing a spatial distribution of silicon and nitrates are given in Figures 10, 11. Using these sections, one can determine the range of influence of the source of nutrient elements and the depth of the layer with elevated (compared to the open Kara Sea) concentrations of nitrate nitrogen and dissolved silicon.

The vertical distribution of nutrient concentrations in Blagopoluchia Bay in 2007–2018 is as follows: the surface layer is enriched in nutrients in the area of Ukromnaya Bay and the adjacent water area, the thickness of the enriched layer (relative to the average concentrations of the Kara Sea) is 10–15 meters. On average, the concentration of nutrients

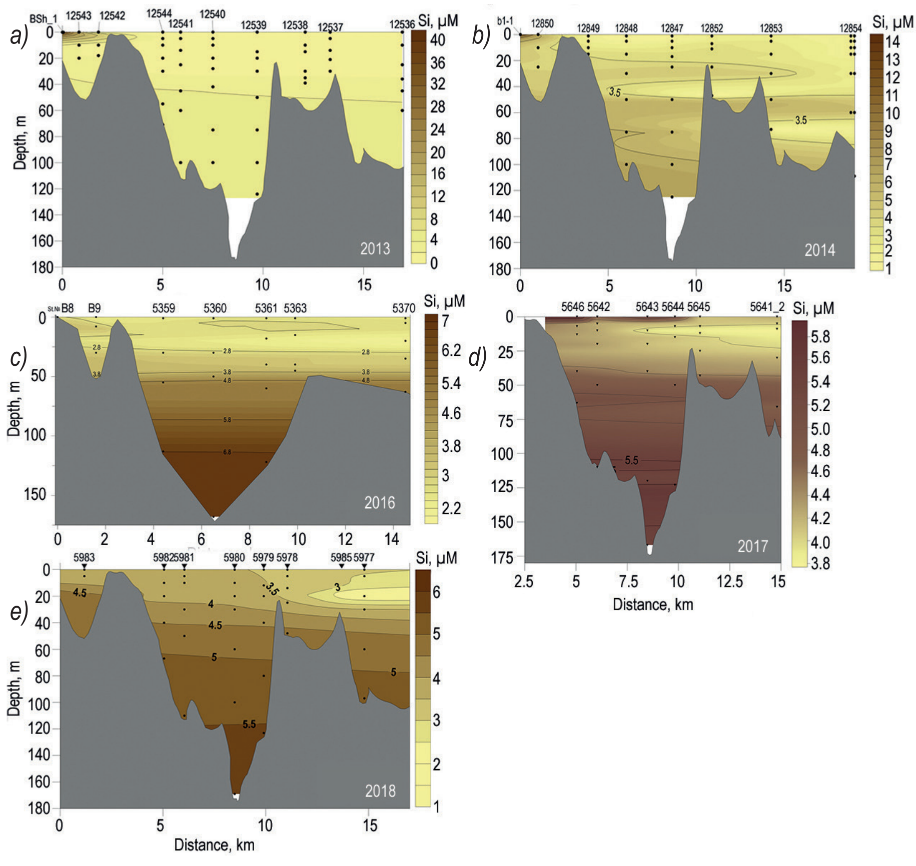

Fig. 10. Hydrochemical sections across Blagopoluchia Bay, letter indices indicate different years of observations: *a*) 2013, *b*) 2014, *c*) 2016, *d*) 2017, *e*) 2018. The highest concentrations of dissolved silicon were found in the upper 10–15 m water layer, in Ukromnaya Bay and at the outlet of Ukromnaya Bay. This pattern is most clearly visible in figures *a*), *b*), *d*) and *e*)

Рис. 10. Гидрохимический разрез через залив Благополучия, буквенные индексы означают различные годы наблюдений: *a*) 2013, *b*) 2014, *c*) 2016, *d*) 2017, *e*) 2018. Высокие концентрации кремния локализованы в верхних 10–15 м, в бухте Укромная и на выходе из бухты Укромная. Эта закономерность наиболее хорошо видна на рисунках *a*), *b*), *d*) и *e*)

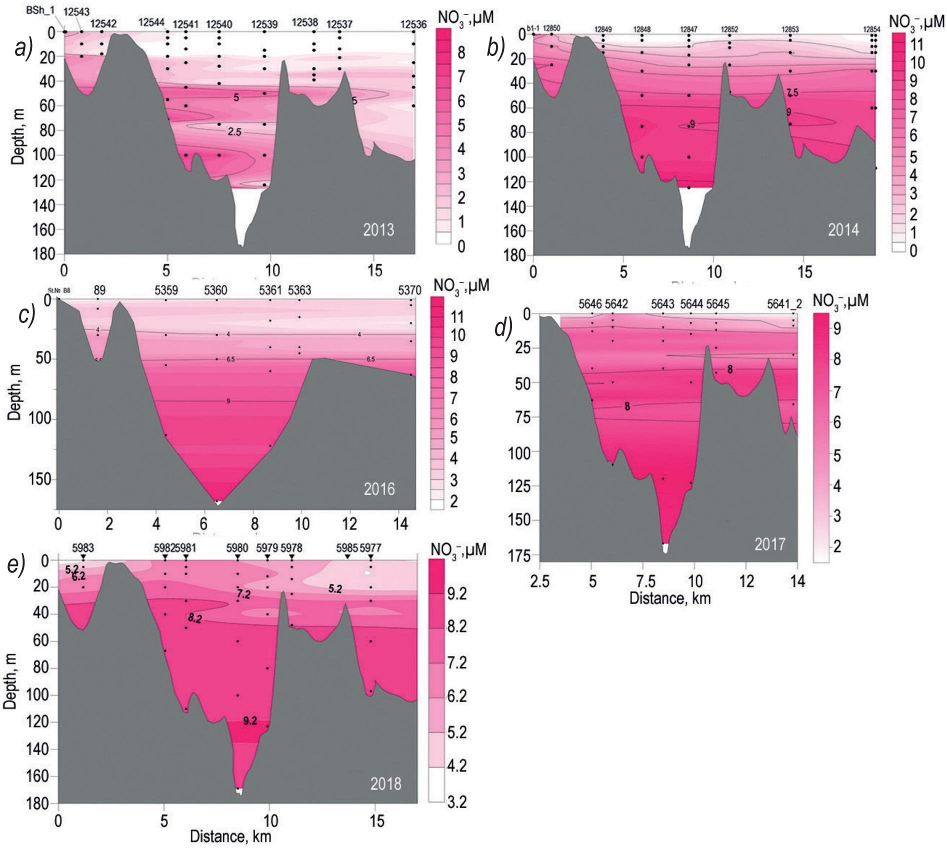

Fig. 11. Hydrochemical section through Blagopoluchiya Bay, letter indices indicate different years of observations: *a*) 2013, *b*) 2014, *c*) 2016, *d*) 2017, *e*) 2018. High levels of nitrate nitrogen are localized in the upper 10–15 m, in Ukromnaya Bay and at the exit from Ukromnaya Bay. This pattern is especially clearly visible in Figure *a*). An interesting observation is the presence of relatively high concentrations of nitrate nitrogen in the upper layer in the middle part of the bay in figures *d*), *e*)

Рис. 11. Гидрохимический разрез через залив Благополучия, буквенные индексы означают различные годы наблюдений: *a*) 2013, *b*) 2014, *c*) 2016, *d*) 2017, *e*) 2018. Высокие нитратного азота локализованы в верхних 10–15 м, в бухте Укромная и на выходе из бухты Укромная. Эта закономерность особенно хорошо видна на рисунке *a*). Интересным наблюдением является наличие относительно высоких концентраций нитратного азота в верхнем слое в средней части залива на рисунках *d*) и *e*)

in Ukromnaya Bay is higher than in Blagopoluchia Bay. Usually the concentration increases with the depth to the values 4–5 μM Si, 2–9 μM NO_3^-.

The average concentration of dissolved silicon in the upper layer of Ukromnaya Bay (the inner part of Blagopoluchia Bay) is 6–10 μM; for dissolved nitrates, this value is in the range of 4–6 μM. Further, from Ukromnaya Bay towards the Kara Sea, the concentration of dissolved silicon and nitrate nitrogen in the upper 10–15 m layer decreases, reaching concentrations close to analytical zero in the outer part of the bay (normal values for the Kara Sea). See Figure 10, 11.

In 2013, the content of silicon in the waters of Blagopoluchia Bay was in the range from 2 to 36 μM, the highest content of silicon was observed in Ukromnaya Bay, near the source (Ukromnaya River). Outside Ukromnaya Bay, the content of dissolved silicon was 0–2 μM; towards the depth, the content of silicon increased and at a depth of 40 meters it was 6 μM. In 2014, the silicon content in the waters of Blagopoluchia Bay ranged from 0 to 6 μM, reaching a maximum in Ukromnaya Bay; in the upper 20 m water layer, the silicon concentration reaches 3.5 μM, increasing to 6 μM with depth. The maximum of dissolved silicon in 2016 was also observed in Ukromnaya Bay (up to 4 μM), in the upper 10–15 m water layer the concentration of dissolved silicon reached 2 μM, with depth it increased to 7 μM. In 2017, the concentration of dissolved silicon was in the range of 3 to 6 μM, reaching a maximum in the surface waters of Blagopoluchia Bay and below the pycnocline. In 2018, in the surface layer of Blagopoluchia Bay the concentration of dissolved silicon was 4 μM in the secluded and northern parts of Blagopoluchia Bay; in the outer part of the bay, it was close to analytical zero. The maximum of dissolved silicon in 2018 was observed at a depth of 120–140 m.

The upper 10–15 m water layer in all the years of observation contains 0–1 μM of nitrate nitrogen, at the same time, in 2013, 2014, 2016, an increased concentration of nitrate nitrogen of 4 μM is observed in Ukromnaya Bay, in the northern part of the bay outside Ukromnaya Bay, the concentration of nitrate nitrogen in the upper 10–15 meters it reaches 2 μM, with depth the concentration of nitrate nitrogen increases to 9 μM. All the hydrochemical sections across Blagopoluchia Bay are shown in Figures 10, 11.

Distance of influence of watercourses in Blagopoluchia Bay

The distance of nutrient signal spreading from the watercourses flowing into Blaopoluchia Bay is different and has its own patterns. It can be seen from the sections across Blagopoluchia Bay that the nutrient signal can be detected most often inside Ukromnaya Bay, or in the northern part of the bay at the exit from Ukromnaya bay. The range of penetration of river waters into the water area of the bay was determined by us according to the literature data: in the Kara Sea, the average concentration of dissolved silicon is 4–5 micromoles, according to some authors who have previously studied the Kara Sea, it is silicon that is a marker of river waters. Thus, the boundary of the influence of river waters was determined by us as a silicon content of more than 5 micromoles (average concentration in the west Kara Sea) [25]. The table below shows the values of the propagation distances of the nutrient signal in Blagopoluchia Bay in different years. See distances in Table 3.

Table 3

Distance of the nutrient signal spreading in Blagopoluchia Bay (2013–2018)

Таблица 3

Расстояние распространения биогенного сигнала в заливе Благополучия (2013–2018)

Year	Distance of nutrient signal spreading, km
2013	1 km, in Ukromnaya bay
2014	1 km, in Ukromnaya bay
2016	1 km, in Ukromnaya bay
2017	10 km, central part of Blagopoluchia Bay
2018	7 km, northern part of Blagopoluchia Bay

In our opinion, there are several reasons why the watercourses affect only Ukromnaya Bay (see 2013–2016): 1) features of the bottom orography that prevent free advection of waters from Ukromnaya Bay. Ukromnaya Bay and the main water area of Blagopoluchia Bay are separated by shallow water with a depth of 0.5 meters. 2) features of the circulation of waters in Blagopoluchia Bay [26]. The main finding is that the waters from the Kara Sea flow along the eastern coast and exit the bay along the western coast of Blagopoluchia Bay. Most likely, in the course of this circulation, advection of waters from the Kara Sea occurs, which interferes with the detection of the nutrient signal at the outer part of Blagopoluchia Bay.

According to the literature data available for the fjords of the Greenland Ice Sheet, the distance of influence of the watercourses is determined by the fjord boundary. For the Godthab fjord, the nutrient signal is visible at a distance of 20 km, which is primarily determined by the difference in the location of the mouths of the watercourses. For Young Sound Fjord, the distance of source influence (increased silicon concentrations) is also 20 km [23]. The depth of the influence of the watercourse reaches 10–15 m and is within the plume distributed in the surface part of the section. These facts are consistent with the data on the bays of Novaya Zemlya.

At the same time, the lack of response from the Greenland fjord ecosystem [23] in terms of the lack of growth in primary production is worth noting. Turbidity is the reason for the lack of primary production. Turbidity determines the availability of light to primary producers. According to modern data, the primary productivity for the bays of Novaya Zemlya is often lower than that of the adjacent water area of the Kara Sea. However, there is no restriction on nutrients. Thus, according to our data, the nutrient influence of watercourses on the water area of the Kara Sea is local and does not occur beyond the boundaries of Blagopoluchia Bay.

CONCLUSION

Within the framework of the project “Ecosystems of the Russian Arctic”, a study was made of the influence of watercourses of glacial origin in Blagopoluchia Bay (archipelago Novaya Zemlya) on the spatial variability of nutrients and the hydrochemical structure of waters.

Watercourses are a significant source of biogenic elements for Blagopoluchia Bay. Small and temporary streams bring more nutrients to Blagopoluchia Bay than the large and constantly flowing ones. The structure of the waters is influenced both by the streams themselves and by the general morphology of the bay. Blagopoluchia Bay contains a semi-closed Ukromnaya bay, which accumulates nutrients from the incoming river water.

The distance of the influence of the watercourses on the hydrochemical structure of the bay is also a variable value; according to our observations, it ranged from 1 km to 7 km; the watercourses’ influence is local and they do not bring nutrients to the Kara Sea.

Competing interests. The author states that there are no competing interests between the co-authors.

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Растворенный кремний и нитратный азот в ледниковых водотоках и акватории залива Благополучия (Российская Арктика, Новая Земля): происхождение, изменчивость и распространение биогенного сигнала

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Резюме

Проведены гидрохимические исследования водотоков и акватории бухты Благополучия (Новая Земля, Арктика, Россия). Концентрации биогенных элементов в реках и ручьях выше, чем в акватории бухты Благополучия. Показано, что концентрация кремния в постоянно текущих реках составляет 1–13 μM, концентрация NO_3 — 0,5–8, для малых и временных водотоков эти значения выше и находятся в пределах 18–46 μM SiO_3^{2-}, 1–11 μM NO_3^-. Влияние ручьев и рек, впадающих в залив Благополучие, на акваторию залива носит локальный характер и распространяется до 1 км от устья. Разгрузка водототоков, богатых биогенными элементами, не влияет на содержание биогенных элементов в Карском море. Возможной причиной локального влияния водотоков на акваторию залива Благополучия является рельеф дна, морфология залива и ветровая обстановка на момент измерений.

Ключевые слова: биогенные элементы, биогенный сигнал, водотоки, Карское море, Новая Земля, речной сток.

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РАСТВОРЕННЫЙ КРЕМНИЙ И НИТРАТНЫЙ АЗОТ В ЛЕДНИКОВЫХ ВОДОТОКАХ И АКВАТОРИИ ЗАЛИВА БЛАГОПОЛУЧИЯ (РОССИЙСКАЯ АРКТИКА, НОВАЯ ЗЕМЛЯ): ПРОИСХОЖДЕНИЕ, ИЗМЕНЧИВОСТЬ И РАСПРОСТРАНЕНИЕ БИОГЕННОГО СИГНАЛА (РАСШИРЕННЫЙ РЕФЕРАТ)

ВВЕДЕНИЕ

Согласно данным международной программы мониторинга и оценки Арктики (AMAP)*, повышение температуры в Арктике идет в 3 раза быстрее, чем в остальных регионах Земли. Интенсивность таяния ледников выросла в Гренландии и в Исландии. Для Новой Земли повышение средней температуры составило 3,1 °C с 1971 г. Стремительное повышение температуры в Арктике увеличило общий уровень таяния ледников, например, на Новой Земле. Сокращение ледников на Новой Земле составило 1000 $км^2$, а сокращение общего объема 380 $км^3$. Вода, образующаяся в результате таяния ледников, вызывает каскад изменений в экосистеме, например, механический и химический сток в реках Исландии за последние 40 лет вырос на 30 %. В то же время усиливается привнос реками азота (показано на примере Северной Швеции), металлов, растворенного кремния (на примере Гренландии). В Российской Арктике влияние увеличения стока рек на акватории Северного Ледовитого океана остается неизученным. Институтом океанологии РАН были произведены исследования Карского моря и Новой Земли в рамках программы «Экосистемы Российской Арктики», которая длилась с 2007 по 2018 г. Данные, полученные в этих экспедициях, вошли в текущий материал. Предыстория работ в заливе Благополучия, обсуждаемых в данной статье, следующая: в 2007 г. были обнаружены высокие концентрации нитратного азота, растворенного кремния в водотоках, впадающих в залив. Так, концентрация нитратного азота достигала 15 µM, растворенного кремния — до 50 µM. Анализа данных 2013–2018 гг. не производилось.

Цель данного исследования выявить основные гидрохимические характеристики и различия водотоков, впадающих в залив Благополучия Новой Земли. Необходимо определить степень влияния водотоков на прилегающую к заливу Благополучия акваторию Карского моря.

МАТЕРИАЛЫ И МЕТОДЫ

Залив Благополучия расположен на о. Северный архипелага Новая Земля. Работа базируется на данных, полученных в ходе экспедиций исследовательского судна «Академик Мстислав Келдыш» и исследовательского судна «Профессор Штокман» в 2007, 2013, 2014, 2016, 2017, 2018 гг. Пробы воды отбирались как из водотоков,

* URL: https://www.amap.no/documents/download/6887/inline (дата обращения 01.09.23)

впадающих в залив Благополучия, так и из мористой части залива. Методики, используемые для гидрохимического анализа содержания азота, кремния, фосфора, были стандартными. Расположение точек пробоотбора приведено в основной части статьи. Водотоки, из которых отбирались пробы, были двух основных видов: крупные, имеющие значительную водосборную площадь (к таким рекам относится река Укромная и ручей Базовый), относительно постоянные и мелкие, имеющие снеговое питание, временные.

РЕЗУЛЬТАТЫ

Были получены средние концентрации биогенных элементов (азота и кремния) в крупных реках (Укромная и ручей Базовый) и в мелких ручьях. Результаты были разными: в крупных реках (Укромная, Базовый) концентрации кремния составляли 1–13 µM SiO_3^{2-} STDev 3.77, азота 0.5–8.14 µM NO_3^- STDev. 2.1, в то время как для мелких рек эти показатели равны 18–46 µM SiO^{-} STDev 8.09 и 1.15–11.2 µM NO_3 STDev 3.14 для кремния и азота соответственно. Стандартное отклонение приведено для каждого диапазона и обозначено STDev.

В дополнение к полученным результатам по средним содержаниям биогенных элементов была построена диаграмма концентраций кремния – общей щелочности, по которой водотоки, впадающие в залив Благополучия, также разделились на 2 группы. По нашему мнению, такое разделение связано с гидродинамикой водотоков: постоянные и крупные водотоки в меньшей степени выщелачивают горные породы, чем временные.

В ходе работы было оценено влияние привноса биогенных элементов водотоками на акваторию Карского моря. Расстояние обнаружения повышенных концентраций кремния и азота варьировалось и составляло в разные годы от 1 до 7 км от источника. Различие в расстоянии влияния водотока на акваторию залива мы связываем с ветровой обстановкой в момент измерений, однако этот тезис требует дополнительных доказательств.

ЗАКЛЮЧЕНИЕ

В рамках проекта «Экосистемы Российской Арктики» проведено исследование влияния водотоков ледникового происхождения в заливе Благополучия (архипелаг Новая Земля) на пространственную изменчивость биогенных веществ и гидрохимическую структуру вод.

Водотоки являются важным источником биогенных элементов для залива Благополучия. Малые и временные ручьи приносят в бухту Благополучия больше питательных веществ, чем крупные и постоянно текущие. На структуру вод влияют как сами ручьи, так и общая морфология залива. В губе Благополучия имеется полузакрытая бухта Укромная, аккумулирующая питательные вещества из поступающей речной воды.

Дальность влияния водотоков на гидрохимическую структуру залива также является величиной переменной; по нашим наблюдениям, она составляла от 1 км до 7 км. Влияние водотоков локально, и они не приносят биогенные вещества в Карское море.