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ORIGINAL RESEARCH ARTICLE

Surface layer desalination of the bays on the east coast of Novaya Zemlya identified by shipboard and satellite data

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Summary This study examined the influences of continental and island river runoff as well as glacial meltwater runoff on the water surface layers of the Kara Sea in different bays on the eastern coast of Novaya Zemlya, an archipelago off the coast of Russia. High-resolution satellite and shipboard data obtained in 2015 were used to determine the sources of desalination (glacial meltwaters and river waters), which can be distinguished by the type of correlation (positive, negative, or none) seen between salinity and the coloured dissolved organic matter fluorescence intensity. Examples of the various situations that can occur in the bays are provided and discussed.

1. Introduction

In recent years, interest in Arctic sea exploration has been growing. International scientific groups have performed numerous studies that have produced significant advances in our understanding of the on-going processes (Amon, 2003; Carmack et al., 2016; Flint, 2010; Granskog et al., 2015; Lisitzyn and Vinogradov, 1994; Matsuoka et al., 2017; Nummelin et al., 2016). Particular attention is being paid to the Kara Sea, where the hydrological regime is significantly determined by the influence of runoff from Siberian rivers (Amon, 2003; Fichot et al., 2013; Kubryakov et al., 2016; Osadchiev et al., 2017; Zatsepin et al., 2010, 2015).

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Summer runoff from the Ob and Yenisei rivers carries fresh water (continental runoff) with a high dissolved organic carbon (DOC) content into the Kara Sea (Belyaev et al., 2010; Drozdova et al., 2017; Fichot et al., 2013). These waters form a surface desalinated layer (SDL) that occupies a significant portion of the water area (Burenkov and Vasilkov, 1994; Carmack et al., 2016; Polukhin and Makkaveev, 2017; Zatsepin et al., 2010, 2015). In some years, when there is a western distribution of the SDL, its waters can reach the shores of Novaya Zemlya (Kubryakov et al., 2016; Zatsepin et al., 2015). In addition to reduced salinity, increased DOC concentration is an indicator of this SDL (Amon, 2003; Burenkov et al., 2010a; Gonçalves-Araujo et al., 2016). Within the SDL, a strong negative correlation exists between the salinity and DOC concentration (Amon, 2003) and between the DOC concentration and coloured dissolved organic matter (CDOM) fluorescence intensity (Pugach et al., 2018), meaning measurements of the CDOM fluorescence intensity (I_{fl}) can be used as a proxy for the DOC concentration (Gonçalves-Araujo et al., 2016; Kowalczuk et al., 2010; Pugach et al., 2018). As a consequence, there is a strong anti-correlation between salinity and the CDOM fluorescence intensity at the 373 nm excitation wavelength (Glukhovets and Goldin, 2014).

A number of studies have been devoted to investigating desalination processes in the Arctic and northern sea waters, which were conducted using various methods: hydrological, using conductivity-temperature-depth (CTD) profiles (Granskog et al., 2015; Zatsepin et al., 2010, 2015); hydro-chemical (Dai and Martin, 1995; Makkaveev et al., 2015; Polukhin and Makkaveev, 2017); optical (Burenkov et al., 2010a; Gonçalves-Araujo et al., 2016; Sagan and Darecki, 2017); satellite (Burenkov et al., 2010a, 2010b; Fichot et al. 2013; Kubryakov et al., 2016; Matsuoka et al., 2017; Osadchiev et al., 2017; Pozdnyakov et al., 2005; Zatsepin et al., 2015); hydro-biological (Demidov et al., 2018); geological (Bröder et al., 2016; Kravchishina et al., 2015; Politova et al., 2012); and modelling (Kubryakov et al., 2016; Nummelin et al., 2015; Nummelin et al., 2016). Fluorescent methods (Kowalczuk et al., 2010), including excitation — emission matrices or EEMs (Amon, 2003; Coble, 2007; Drozdova et al., 2017) and lidars (Pelevin et al., 2017), also play an important role. The relative simplicity of measuring fluorescence intensity allows the development of express methods that can be implemented in flow-through fluorimeters. These instruments can quickly gather large amounts of data with a high spatial resolution along the vessel's route (Burenkov et al., 2010a; Lorenzen, 1966).

The overwhelming majority of studies in the Kara Sea are performed in open water areas. However, there is also great interest in studying the mesoscale processes occurring in the bays on Novaya Zemlya due to the presence of an additional factor influencing the desalination — island runoff, in the form of small rivers and thawed glacial water.

In a recently published paper (Sagan and Darecki, 2017), the inherent optical properties and distributions of suspended matter in two fjords of Spitsbergen are reported. The authors showed that despite the different hydrological conditions in the two fjords, the glacial and small river runoff had a decisive influence. They found distinct differences in the suspended matter composition of the two fjords. The mineral fraction dominated in the first fjord, while in the second, the mineral and organic contributions were approximately equal. Their study demonstrated the high variability in the optical properties that can be found in the waters of the closely situated fjords and the efficiency of using optical methods for their investigation. Murray et al. (2015) and Stedmon et al. (2015) have similarly reported interesting

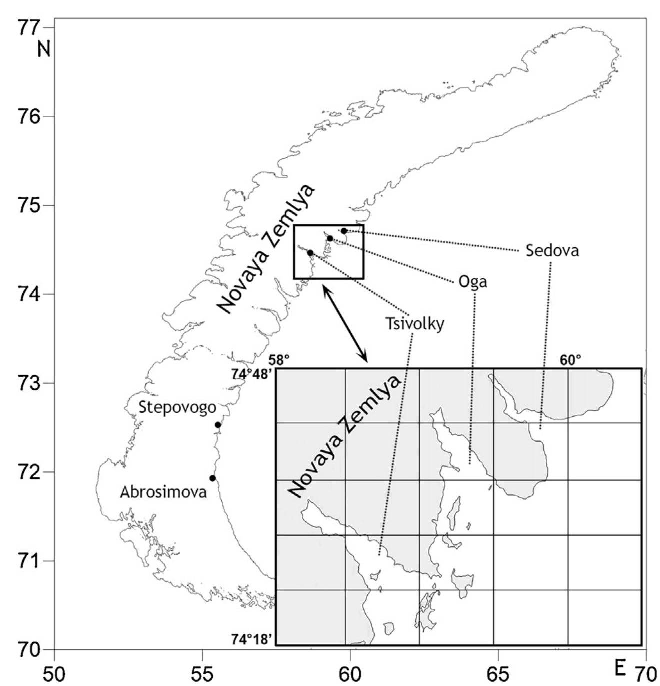

Figure 1 Location of the bays (represented by points) on the east coast of Novaya Zemlya. Inset: an enlargement of the North Island bays.

results on the effect of thawed glacial waters in Greenland bays.

There are also glaciers on the northern island of the Novaya Zemlya Archipelago, and their impact can be significant. Their thawed waters are characterized by a high amount of suspended matter originating from the shores of Novaya Zemlya (Kravchishina et al., 2015). Thus, in the bays having glaciers, a high concentration of suspended matter is a marker for glacial meltwater. These traits make it possible to effectively record the areas they occupy by both contact and remote sensing methods (Gordon and Morel, 2012).

In contrast to the Spitsbergen fjords and Greenland bays, the bays on the east coast of Novaya Zemlya have one more factor that affects the water structure. In addition to island runoff, the surface layer can be affected by waters from the continental SDL, which under certain conditions can reach the eastern coast of the Archipelago and penetrate into the bays. Because of the relatively small size of these bays (width is ~10 km), an additional requirement for the research methods to investigate them is a high spatial resolution of the shipboard and satellite methods. Their joint use makes it possible to obtain a detailed picture of the spatial structure of these local desalinated regions.

Performing this work became possible thanks to a unique combination of circumstances. In a fairly short period of time, we had an opportunity to obtain shipboard data in five of the bays in the Novaya Zemlya Archipelago. Meanwhile, a new Multispectral Instrument ocean-colour scanner installed on the Sentinel-2 satellite was launched shortly before the research began, allowing us to use its data in our study. During this period in 2015, there was also a strong western transfer of the SDL that coincided with quite rare cloudless conditions over the areas of the bays being investigated, allowing us to obtain satellite data close to the same period as the shipboard studies.

Hence, this study examined the combined influences of continental runoff from the Ob and Yenisei rivers and island runoff from small rivers and glacial meltwater on the desalination of the surface waters in the bays of east coast of Novaya Zemlya using continuous shipboard measurements and high-resolution satellite ocean-colour data.

2. Material and methods

2.1. Research area

Shipboard data were collected during the 63rd cruise of the r/v 'Akademik Mstislav Keldysh' from August to October 2015. Underway measurements were made both in open areas of the Kara Sea and in Sedova, Oga, Tsivolky, Stepovogo, and Abrosimova Bays on the east coast of Novaya Zemlya (Fig. 1). Satellite data from the same period were also analysed for these bays.

This area is available for research using satellite data for only a short period each year, with the beginning (July to early August) determined by the discharge of the Kara Sea from the ice cover, and the end (late September to October) marked by the presence of continuous cloud cover, which prevents the use of the ocean-colour scanners.

2.2. Shipboard data collection

A flow-through system developed at the Ocean Optics Laboratory of the Shirshov Institute of Oceanology (Goldin et al., 2015) was used to conduct the shipboard measurements. It consists of a two-channel flow-through fluorimeter (FTF-2) with high-brightness LEDs and a thermosalinograph (Expert-002). The complex provides continuous measurements of the fluorescence intensities of the CDOM and chlorophyll *a* in the near-surface layer along the ship's route, as well as the seawater's salinity (S) and temperature (T). The chlorophyll fluorescence intensity was not used in this work.

The fluorescence intensity is measured in a fixed spectral range that includes the maxima of the fluorescence band. A high-brightness LED (373 nm, $FWHM_{CDOM}$ = 15 nm) working in continuous mode was used as the source of excitation in the FTF-2, and a photomultiplier was used to record the fluorescence radiation. The emission detection range was determined by a coloured glass optical filter (transmittance maxima — 480 nm, $FWHM_{CDOM}$ = 150 nm). The device provides the I_{fl} measurements in relative units. The combination of excitation wavelength and registration method used allows the instrument to primarily register the fluorescence of the terrestrial humic-like DOC component (Coble, 2007).

The water-intake system ensured the water flow over the instrument was at depth of 1—2 m. The data-averaging interval was 15 s, and the relative error in the I_{fl} measurements was <1%. The random error did not exceed 0.01 PSU in determining the salinity or 0.01°C in recording the temperature. The calibration of the thermosalinograph was corrected based on the probe CTD measurements at the stations.

2.3. Satellite data collection

The satellite images shown are based on high-resolution data from the Multispectral Instrument ocean-colour scanner installed on the Sentinel-2 satellite (https://scihub.copernicus.eu). Averaging during image processing provided a spatial resolution of 40 m. Due to frequent cloudiness over the areas of the bays being investigated, the quantity of available satellite data at the required quality was very limited. Therefore, all available data for the given regions and times were analysed. No atmospheric corrections were performed, as it was not necessary for solving the set tasks.

Local areas desalinated with glacial meltwater contain an increased concentration of suspended matter (Kravchishina et al., 2015). For instance, Blagopoluchiya Bay, located on the North Island of the Novaya Zemlya Archipelago, is relatively close to those in our study and has a similar structure. When it was investigated, the direct determinations of the suspended matter concentrations showed the thawed glacial waters contained 9.8 mg/L of suspended matter, whereas the surface layer of the inner waters of the bay contained only 1.3—2.3 mg/L. The lowest concentrations of suspended matter (0.2—0.5 mg/L) are found in the western (near Novaya Zemlya) and northern parts of the Kara Sea (Burenkov et al., 2010b). This raised concentration of particles can be sensed by satellite data because it leads to increased backscattering (Burenkov et al., 2010b; Sagan and Darecki, 2017) brings to an increase in the water-leaving radiance. Because the satellite data was processed in a graphics editor, the

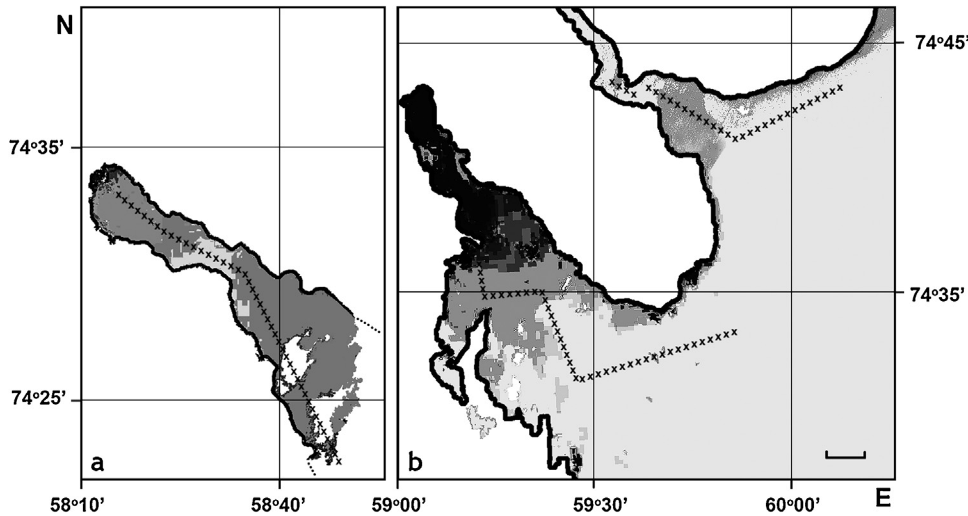

Figure 2 Images constructed from the Sentinel-2 data: (a) Tsivolky Bay, 24 September 2015; (b) Oga (left) and Sedova (right) Bays, 22 September 2015. Black crosses indicate scheme of the sections of the route (transects) for which correlations between the salinity and fluorescence intensity of the coloured dissolved organic matter were calculated. Scale bar = 3 km.

areas of increased brightness (i.e., increased particle concentration) corresponding to the position of locally desalinated regions due to glacial meltwater runoff are identified in grey-scale.

Maps of the CDOM absorption spatial distribution were used to show the propagation of the SDL caused by continental river runoff reaching the shores of Novaya Zemlya. Those maps are based on data from the Moderate Resolution Imaging Spectrometer (MODIS) ocean-colour scanner using the regional algorithm (Vazyulya et al., 2014). This semi-analytical algorithm for solving the inverse problem uses the R_{RS} MODIS data for the wavelength range ≥488 nm; $R_{RS}(412)$ and $R_{RS}(443)$ are not used, as the probability of atmospheric correction errors for them is high.

The satellite values for $R_{RS}(\lambda)$ and the water-leaving reflectance $\rho(\lambda)$ values, which are determined during the shipboard measurements, are connected by formulas derived by Lee et al. (1998), where $R_{RS}(\lambda) = 0.518\ \rho(\lambda)/(1 - 1.562\ \rho(\lambda))$. The formula $\rho(\lambda) = 0.0922\ \pi\ b_b(\lambda)/a(\lambda)$ was used for the relation between the spectral values of the reflectance $\rho(\lambda)$, seawater absorption $a(\lambda)$, and backscattering $b_b(\lambda)$ coefficients (Morel and Gentili, 1993). The inverse problem of finding $a(\lambda)$ and $b_b(\lambda)$ is solved using low-parametric models in which these seawater coefficients are represented as a superposition of the contributions of the main components. The absorption coefficient $a(\lambda)$ is defined as the sum of the absorption values of pure sea water, CDOM, and the phytoplankton pigments, while $b_b(\lambda)$ is defined as the superposition of the backscattering by pure sea water and the suspended particles. The contribution of chlorophyll is accounted for by using a regional algorithm (Kuznetsova et al., 2013). An iterative approach was used to improve the accuracy when estimating the slope of the absorption spectrum. As a result of solving the inverse problem, two parameters are defined: $a_g(443)$ and $b_{bp}(555)$.The development and validation of the algorithm was performed with the shipboard measurement data, which contain no errors from atmospheric correction; the algorithm was tested on both the shipboard and satellite data and showed acceptable results.

In the regional algorithm (Kuznetsova et al., 2013), the chlorophyll concentration was calculated with the formula $\ln(\mathrm{Chl}) = -3.07\ \ln[R_{RS}(531)/R_{RS}(547)] + 0.148$. This formula was derived based on the satellite data for R_{RS} that directly measured the chlorophyll concentrations in the Kara Sea in 2007 and 2011.

All MODIS satellite data processing was performed in the SMCS software package (Sheberstov, 2015), which is a system for the acquisition, processing, storage, and analysis of satellite and field bio-optical data developed at the Ocean Optics Laboratory of the Shirshov Institute of Oceanology.

Due to frequent dense clouds over the Kara Sea, the satellite maps were averaged over a time interval corresponding to the same period as the in situ measurements. The L2 satellite data was retrieved from the NASA website (http://oceancolor.gsfc.nasa.gov), and the L3 maps were produced by averaging the L2 data over a grid with 3 × 3 km bins. This relatively low resolution can eliminate the gaps that arise due to clouds.

Data from the INTERIM reanalysis (Dee et al., 2011) were used to estimate the effect of surface wind on the distribution of the desalinated waters.

3. Results and discussion

The shipboard studies of the three bays (Sedova, Oga, and Tsivolky) on the east coast of North Island in Novaya Zemlya (shown in Fig. 1) were conducted successively from 25 to 29 September 2015. The Sentinel-2 data closest in time (22 and 24 September 2015) to those of the expedition were selected for the analysis. Due to clouds, only pairs of bays were exposed on the satellite images from those dates. However, Oga Bay, located in the centre, was visible on both images, which allowed us to correlate the results of the processing.

The maps of the total upwelling radiance shown in Fig. 2 were constructed with data from the B2—B4 channels. The intensity of the total upwelling radiance is shown in grey-

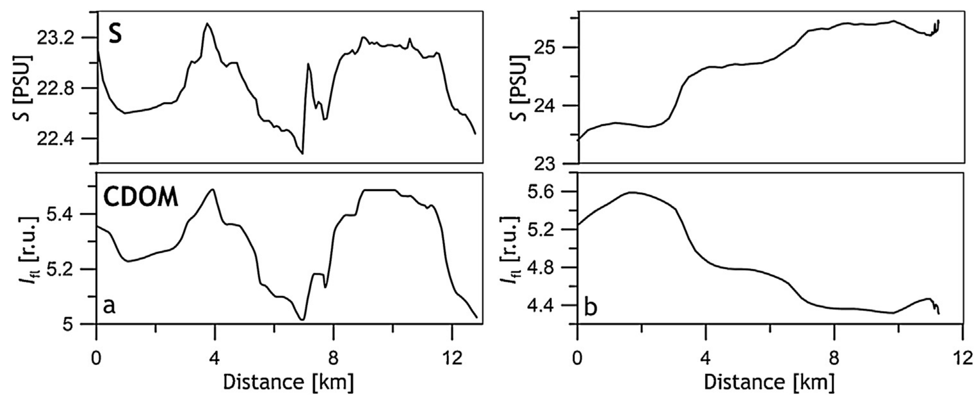

Figure 3 Distributions of the salinity (S) and fluorescence intensity (relative units) of the coloured dissolved organic matter (CDOM) along a section of the transect where it crosses desalinated areas in (a) Oga Bay and (b) Sedova Bay. See Fig. 2 for the transect routes.

scale, with the darker tones corresponding to a greater intensity. These darker areas correspond to the more intensive backscattering caused by the increased concentration of suspended matter in local areas desalinated by glacial meltwater. As mentioned previously, Kravchishina et al. (2015) recorded a similar increase in the concentration of suspended matter in the nearby Blagopoluchiya Bay. Likewise, an increase in the concentration of suspended matter due to the influence of thawed glacial waters has also been reported in the fjords of Spitsbergen (Sagan and Darecki, 2017). These authors recorded an increase in the light attenuation coefficient (from 5.81 m^{-1} up to 26.5 m^{-1}), with a significantly smaller increase in the coefficient of light absorption by particles (from 0.1 m^{-1} up to 0.22 m^{-1}). Importantly, the changes in the values of the light attenuation coefficient were much larger for the fjord with the dominant mineral suspension contribution. These data confirm there is increased suspended matter content in thawed glacial waters.

The analysis of the surface wind maps (1—2 days preceding and coinciding with the high-resolution satellite data and shipboard data) showed a low wind speed of less than 7 m/s that varied greatly in its direction. Therefore, the wind had no influence on the spatial distribution of the suspended matter and the propagation of the SDL in the bays during the data collection period.

Glacier tongues directly contact the waters of the Oga and Tsivolky Bays, while the waters in Sedova Bay do not interact with a glacier. The satellite image processing made it possible to rank the volumes of glacial meltwater in the bays. The largest runoff came from the 'Goluboy' glacier into Oga Bay, while a much smaller volume came into Tsivolky Bay from the 'Serp i Molot' glacier (the darkest areas inside the bays in Fig. 2). Sedova Bay does not receive any glacial meltwater, but a small island river (tens of kilometres in length) flows into it. This river's influence is manifested in the form of a darkened area in the middle of the bay (Fig. 2).

The salinity and CDOM fluorescence intensity distributions along the Oga Bay transect were derived from the shipboard data. The distributions shown in Fig. 3a are where the transect crosses an area desalinated by the waters from glacial meltwater runoff (Fig. 2). The salinity distribution confirms the presence of a small amount of desalination (~1 PSU) in the Oga Bay waters. The freshly melted glacial waters in the Novaya Zemlya North Island bays contain no DOM (Drozdova et al., 2017). Therefore, the positive correlation between the S and I_{fl} indicates that the desalination of this region was due to glacial meltwater. An example of another type of relation that is characteristic for desalinated terrestrial runoff waters forming a SDL (Glukhovets and Goldin, 2014) is shown in Fig. 3b.

In 2015, there was a western distribution of the SDL. Fig. 4 shows the spatial distribution of the CDOM absorption [a_{CDOM} (443)] that characterized the location of the SDL at the time. The map was drawn using MODIS data averaged over the period from 28 August to 28 September 2015. To better fill the map, we used 3 × 3 km spatial averaging. As can be seen from the map, the waters of the SDL formed by the waters of the continental river runoff reached most of the eastern shore of Novaya Zemlya. In particular, the three North Island bays investigated in this study were under the influence of the SDL.

Data from the array of shipboard measurements were used to produce scatter diagrams of the salinity and CDOM fluorescence intensity in Sedova, Oga, and Tsivolky Bays (Fig. 5). It should be noted that the amount of desalination in the bays was relatively small (1—3 PSU). Different types of relations were found in the three bays. First, S and I_{fl} were negatively correlated (R^2 = 0.91) in Sedova bay. This type of relation is usual for SDL waters in the open portion of the Kara Sea. In Oga Bay, there was a positive correlation (R^2 = 0.83) between S and I_{fl}. This type of relation is due to the dominant influence being glacial meltwater, which as mentioned earlier, does not contain CDOM. As can be seen in Fig. 2, the local desalinated region occupies a significant portion of the bay. No correlation (R^2 = 0.22) was seen between S and I_{fl} in the eastern part of Tsivolky Bay (east of 58.6°E). The lack of correlation in this case resulted from the magnitude of the impacts by the thawed glacial and river water runoffs being comparable. The thawed glacial waters entered the eastern part of Tsivolky Bay from its southern shore near the entrance.

Additional information to identify the sources of desalination in the surface layer is provided by the water temperature. Fig. 6 shows scatter diagrams for the bays investigated on the northern island of Novaya Zemlya, with the colours representing the seawater temperature. Frames highlight

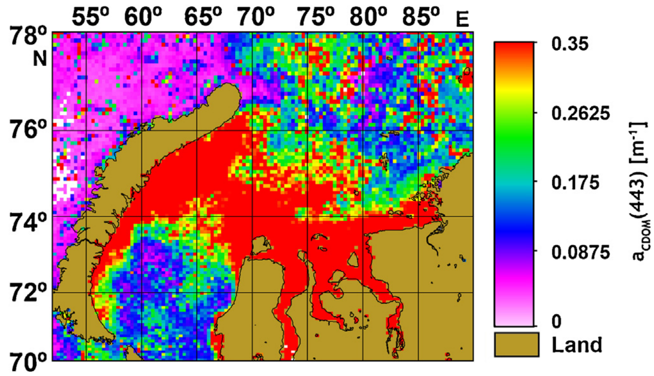

Figure 4 Spatial distribution of the coloured dissolved organic matter absorption in the Kara Sea region (MODIS data averaged from 28 August to 28 September 2015).

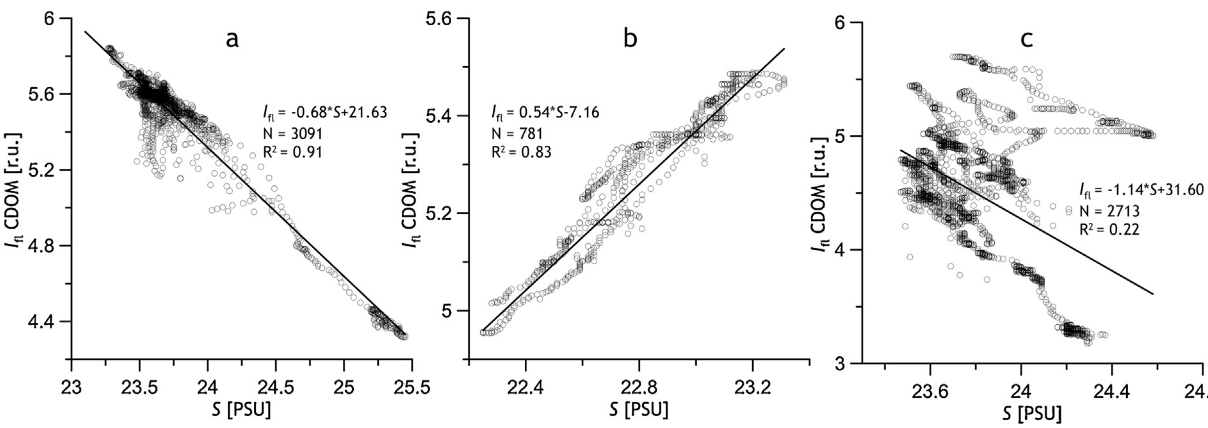

Figure 5 Scatter diagrams of the salinity (S) and coloured dissolved organic matter (CDOM) fluorescence intensity (relative units) in Novaya Zemlya bay waters (Kara Sea) based on shipboard data collected with a flow-through system in 2015: (a) Sedova Bay, 25—26 September; (b) Oga Bay, 26—27 September; and (c) Tsivolky Bay, 28—29 September.

the waters corresponding to the different bays. The temperature variability can be seen as the vessel moves from the entrance of the bay towards the interior (direction of arrows). It should be noted that all of the transects began in sections corresponding to warmer waters with a range of initial temperatures that correspond to temperatures typical of SDL waters in the open areas of the Kara Sea. As the vessel progressed forward into the bays, the temperatures decreased monotonically.

The transect into Sedova Bay (Fig. 6a) began in warm, relatively salty water with average CDOM fluorescence intensities. These waters correspond to the SDL. Inside the bay, the waters became colder and less salty, and the fluorescence signal increased. This appears to be due to the influence of runoff from a small river on Novaya Zemlya, which is clearly visible in Fig. 2. Its waters contain significantly less suspended matter than the thawed glacial waters in the neighbouring Oga Bay.

The temperature distribution in the Oga Bay (Fig. 6a) confirms that the source of desalination in this bay is thawed glacial waters. When moving into the bay, the values of T, S, and I_{fl} all decreased.

Based on the shipboard data for Tsivolky Bay, two different regions were distinguishable for the eastern and western portions of the bay (Fig. 6b). The border between them is located at approximately 58.6°E. The temperatures of the waters east of this border were lower than the temperature of the SDL waters and close to the temperature of the waters in Oga Bay. This is apparently due to the contribution of thawed glacial waters in this region. The western area is located in the heart of the bay and occupied by colder saltier waters. Presumably, these waters entered further into the Bay at the beginning of the summer season before the SDL arrived. The available data is insufficient for a more detailed analysis of these waters' origin. According to the satellite data for the western part directly near the glacier tongue (there were no shipboard measurements for that area) exposed a local area that is affected by thawed glacial waters (the dark area in Fig. 2). A similar distribution was recorded in a Greenland fjord (Murray et al., 2015), where the concentration of suspended matter in the immediate proximity of the glacier was almost four times higher than is typical for most of the fjord.

The main feature of the South Island of Novaya Zemlya is the absence of glaciers. As a consequence, there are no

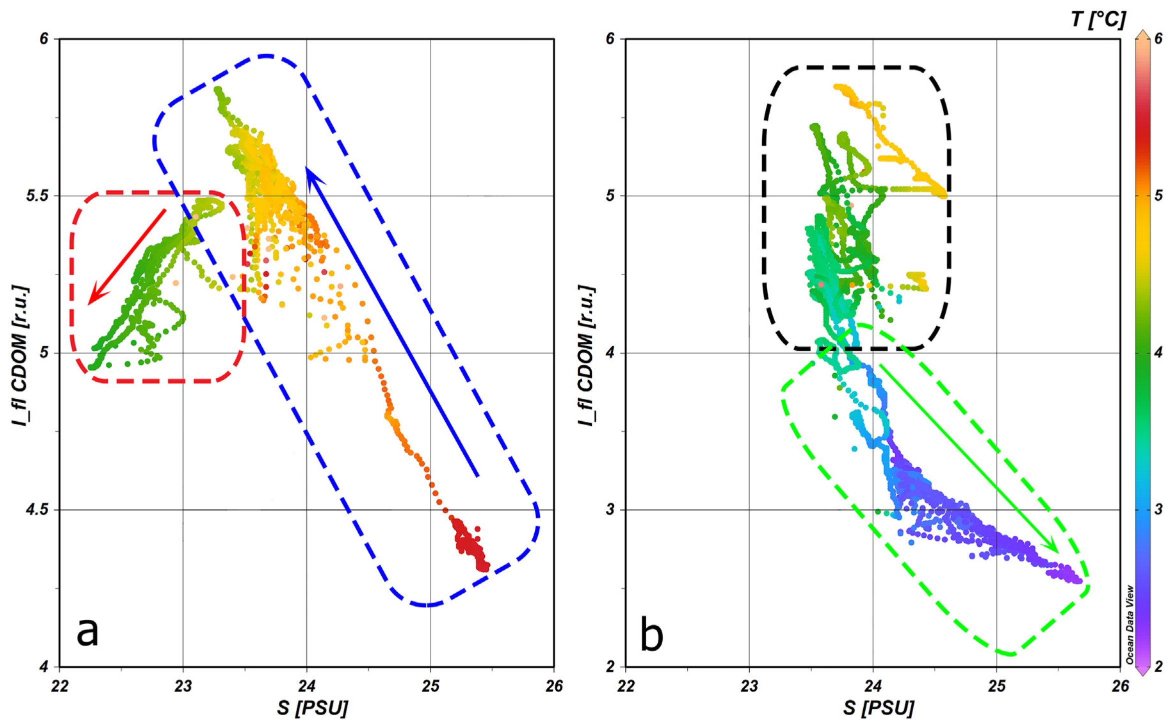

Figure 6 Scatter diagrams of the salinity (S) and coloured dissolved organic matter (CDOM) fluorescence intensity. Colour represents temperature as shown in the scale on the right. Frames indicate the waters: Sedova Bay (blue), Oga Bay (red), eastern Tsivolky Bay (black), and western Tsivolky Bay (green). Arrows correspond to the direction of travel for the transects into the bays. The figure was drawn using ODV (Schlitzer, 2017).

thawed glacial waters desalinating the waters of the bays. Therefore, the only possible desalination factor is caused by river runoff, both island and continental. It is known that the island rivers dry up in the summer once the snow thaw has ended (Coulson et al., 2014). The ship measurements were performed in the eastern parts of the two South Island bays from 30 September to 5 October 2015. Thus, only two types of relations between the S and I_{fl} are possible in the South Island bays: a negative correlation or the absence of a correlation.

The results of the shipboard measurements in Stepovogo Bay showed the presence of a strong anti-correlation between S and I_{fl} ($R^2 > 0.92$). At the same time, the surface water temperature (3—5°C) corresponded to those typical for SDL waters, and a 4 PSU desalination of the water was registered. It follows from Fig. 4 that during the shipboard research period, the Stepovogo Bay was inside the SDL area. Together, these features indicate that the desalination of the surface layer of the eastern part of the Stepovogo Bay was caused by the influence of continental runoff.

In contrast, there was no correlation between S and I_{fl} ($R^2 < 0.04$) in Abrosimova Bay. In this case, low water temperatures (1—3°C), a lack of desalination (S = 31—32 PSU), and low I_{fl} values (<1 r.u.) were recorded. The spatial distribution of $a_{CDOM}(443)$ seen in Fig. 4 indicates that the Abrosimova Bay was near the southern boundary of the SDL. Thus, the absence of a correlation is explained not by the combined effect of glacial melt and river waters, as in the eastern part of Tsivolky Bay, but by a lack of influence by either source of desalination. The bay is occupied by cold salty seawater with a low CDOM content.

Table 1 Characteristics of the markers and sources of desalination in the bays investigated on Novaya Zemlya. The second column shows the types of correlations found between S and I_{fl} that were specific to each bay. The ranges provided for T, S, and I_{fl} correspond to the changes as the vessel moved into the bay.

Bay	Corr. type	T change [°C]	S change [PSU]	I_{fl} change [r.u.]	b_b [m^{-1}]	Dominant source
Sedova	Negative	5.5—4.5	25.5—23.3	4.5—6	Upper middle	SDL and a small island river
Oga	Positive	4.5—4	23.5—22.2	5.5—5	High	Glacial meltwater
Tsivolky (E)	None	5—3	~24	5.6—4	No data	None (mixture)
Tsivolky (W)	Negative	3—2	24—25	4—2.5	Medium	Marine waters
Stepovogo	Negative	3—5	31—27	1—2	No data	SDL
Abrosimova	None	3—1	31—32	<1	No data	Marine waters

The marker characteristics and concluded sources of desalination in the specific bay water surface layers are summarized in Table 1.

4. Conclusions

This study examined the desalination processes that influence the surface water layers in five bays on the east coast of the Novaya Zemlya Archipelago. The surface desalination layer results in a density stratification that prevents vertical mixing, effectively shielding the underlying water column from interacting with the atmosphere, which has a significant effect on the ecosystem. Several sources of desalination are possible: continental river runoff, which can reach the eastern shores of Novaya Zemlya as a SDL that penetrates into the bays; glacial meltwater from the glaciers on the North Island of Novaya Zemlya; and runoff from small rivers on the islands of the Archipelago.

The ratio of the contributions of the different freshwater sources entering the seawater can cause different situations: the dominance of glacial meltwater, the dominance of water desalinated by river runoff, a comparable influence by both, or an absence of desalination. All of these possible situations were detected in the bays investigated. In Sedova Bay, the desalination was due to the dominant influence of continental river runoff with an admixture of island river runoff, while the source of desalination in Oga Bay was thawed glacial water. In the eastern part of Tsivolky Bay, comparable contributions of continental runoff and glacial meltwater were recorded, while in the western extremity of the bay directly near the glacier tongue, a local area was occupied by thawed glacial waters. The only source of desalination in Stepovogo Bay was the continental river runoff, while desalination in Abrosimova Bay was absent.

It is important to note that the influence of the different desalination processes in each of the bays was distinctly individualized. Thus, each bay requires its own study.

A similar pattern was recorded for the Norwegian fjords of Spitsbergen (Sagan and Darecki, 2017), where research in two fjords found the quantitative and qualitative composition of the suspended particles and the light absorption and attenuation coefficient distributions differed significantly.

It is interesting that the continental river runoff, which is a source 500—600 km away from the bays we investigated, plays such a significant role in the desalination processes, dominating in two of the bays and providing a noticeable contribution in a third.

It is also noteworthy that it was the use of correlations between salinity and CDOM fluorescence intensity to identify the sources of desalination that allowed us to effectively divide the influences of the river runoff and thawed glacial waters. Another effective tool was the high-resolution MSI ocean colour scanner on the Sentinel-2 satellite for determining the position and size of areas affected by the glacial meltwater. In most cases, this combination of ship and satellite methods allowed us to identify the dominant source of desalination.

It would be further advisable to supplement the complex of shipboard methods with spectral fluorescence measurements (EEMs), which have been used to successfully determine the origin of other waters in the Arctic basin (Coble, 2007; Drozdova et al., 2017; Gonçalves-Araujo et al., 2016).

Our measurements were performed in 2015, when there was a significant western transfer of the SDL from continental runoff. In other years with other types of transfer, these waters may not reach the shores of Novaya Zemlya, and the resulting desalination processes in the bays will be substantially different from those obtained in this work. This emphasizes the importance of continuing this study to understand the inter-annual variability of the desalination processes in the bays on the east coast of Novaya Zemlya.

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