

Conference Paper

Influence of the Barents Sea Frontal Zones on Chlorophyll Concentration in Spring

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Abstract

In spring of 2016, 2018 and 2019, chlorophyll *a* (Chl *a*) content was studied in the 0-50 m layer on the vast Barents Sea area - to the north of 75° N. Standard sampling was carried out at 11 oceanographic transects, including 52 stations. Due to the negative ice anomalies and the high-latitude position of the ice edge, original data on Chl *a* concentration for spring period were obtained in hard-to-reach and previously unexplored areas of the Barents Sea. The investigation area covered the Marginal Ice Arctic zone, as well as the area where the Polar Front was located quasi-stationary. The effect of the Marginal Ice Arctic and Polar frontal zones on the distribution of Chl *a* concentration was revealed. The strongest factor influencing the distribution of chlorophyll was the Polar Front. It divided mainly Arctic and Atlantic waters. The highest pigment concentrations corresponded to the Arctic water mass and exceeded the content of pigment in water of Atlantic origin by an order of magnitude. The impact of the Marginal Ice Arctic Front was not so obvious - the content of Chl *a* in waters of various genesis differed, but not more than by a factor of 2.

Keywords: Chlorophyll *a*, Polar Front, frontal zones of the Barents Sea, ice edge

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1. Introduction

Studying the process of spring development of micro-phytoplankton and its pigment composition makes it possible to obtain a more complete picture of seasonal succession and the production cycle of the Barents Sea, since most of the annual biomass of Arctic phytoplankton is produced during the spring succession cycle. An indicator of the total abundance of phytoplankton is the amount of Chl *a*.

There are several frontal zones within the way of Atlantic water penetration into the Arctic Basin in the Barents Sea [1, 2]. The Polar frontal zone has a climatic character and is well traced throughout the year. It separates mainly Atlantic and Arctic waters. Data on hydrological and phytoplankton observations in the Barents Sea for waters beyond 75 °N are extremely limited, as these areas are difficult to access and are covered by ice for most of the year.

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Phytoplankton investigations in the ice edge zone are of particular interest, for it is a unique biotope where two components of the primary producers are inseparably linked, the pelagic and ice flora that create the primary organic matter of the Barents Sea. The ice edge is a hydrodynamically active zone covered by ice fields that make it difficult or impossible to conduct in situ research in this area. The Marginal Ice Arctic frontal zone is seasonal and occurs in the warm season. Due to ice melting, a layer of cold freshened water forms on the surface near the ice edge, the horizontal distribution boundary of which is expressed by high gradients of hydrological characteristics and forms the Marginal Ice Arctic Front.

The aim of this work was to study the distribution of Chl a concentration in the pelagial of the Barents Sea related to the zone of influence of the ice edge and frontal zones.

2. Methods and Equipment

Phytoplankton investigations were carried out in spring (April–May) of 2016, 2018 and 2019 during cruises on R/V "Dalnie Zelentsy" in the Barents Sea (Figure 1).

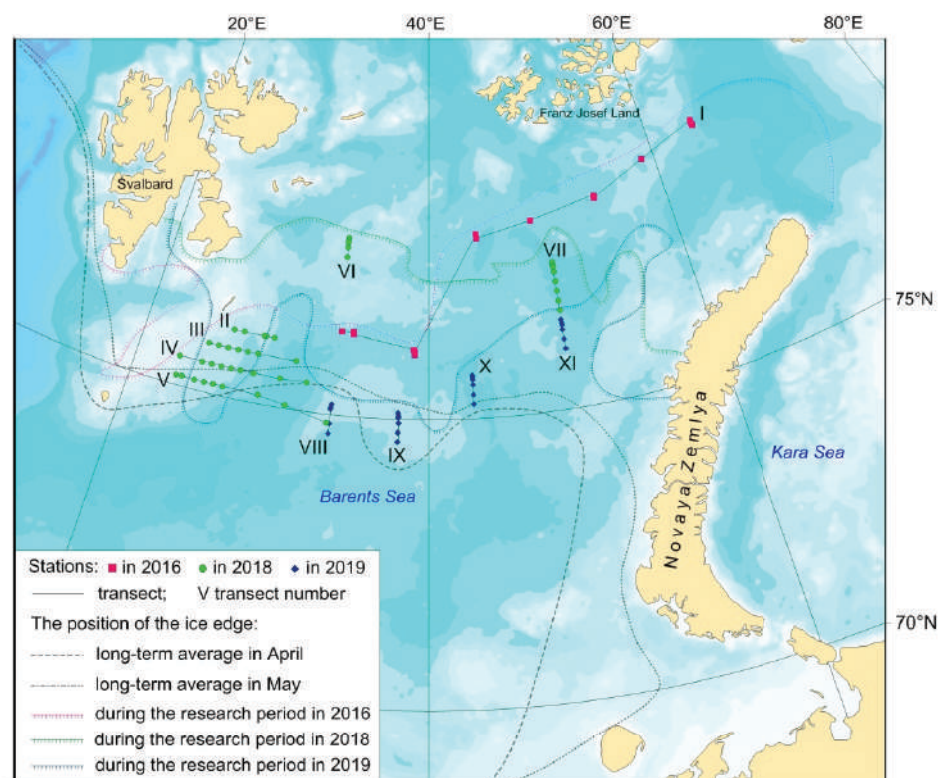


Figure 1: Location of fulfilled transects and ice conditions.

In the course of many years of research in a difficult ice environment, standard sampling was carried out at 52 stations, combined into 11 oceanographic transects. Since 1983 to the present, large negative ice cover anomalies have been observed in the Barents Sea [3].

In 2016, the ice edge in the eastern part of the Barents Sea receded north to the latitude 79° N. According to the AARI review ice maps (http://www.aari.ru/odata/_d0015.php), in April such a northern position of the ice edge in the east of the Barents Sea has not been noted since 1997, earlier data are not available.

West of 40° E the ice spread much further south, the ice edge was located along the parallel of 76° N and went on the western border of the sea far to the south, almost reaching the Bear Island. Such ice edge position is not typical for the Barents Sea. Due to the powerful warming effect of Atlantic water in the west, the ice usually recedes north in the western part of the sea faster than in the eastern.

During the research period in 2018, the ice edge was also located much north of its mean annual position at this time of the year. Over the entire water area of the sea, it was located mainly in the latitudinal direction between 77° and 78° N and reached 75.5° N only in the area of the Novaya Zemlya Archipelago.

The year 2019 was more ice-covered than the previous few years, however negative anomalies in ice cover were also noted. The ice edge crossed the parallel of 75° N in several places, both in the west and in the east of the sea.

Due to the position of the ice edge in the years of research in such high latitudes, original data for the spring time were obtained in hard-to-reach and previously unexplored areas of the Barents Sea.

Seawater sampling in the 0-50 m layer and sample processing were carried out according to standard hydro-biological methods. Chl a concentration was determined by spectrophotometric method [4]. The temperature and salinity of water masses were measured using the CTD-profiler SBE 19 plus. Gradient method and classical TS-analysis were used for water mass identification and determination of their boundaries [5]. Horizontal gradients of temperature and salinity five times higher than climatic gradients for the Barents Sea (0.01 °C/km and 0.001 ‰/km) were taken as a criterion for the presence of a frontal zone on the sea surface [6].

3. Results

Transect I was completed in the ice edge zone in April 2016 (Figure 2). According to the data on ice situation and our observations, the transect I was dominated by brash

ice, young and annual ice. Difficult ice conditions in investigated water area hampered sampling near the ice edge.

The investigation of thermohaline characteristics of the water column at stations along Transect I showed presence of interaction between various types of seawater. Stations 16, 17, 19, 22, 24, 25 were located in the Marginal Ice Arctic frontal zone. Maximum horizontal gradients of sea surface temperature and salinity exceeding climatic gradients were determined between stations 16 and 17, and 24 and 25, indicating a front line between these stations.

The stations 16, 22 and 24 were located in the zone of influence of surface Arctic water with negative temperature and low salinity, and stations 25, 17 and 19 were located in Atlantic water with higher temperature and salinity. The rest of the stations (27-54) of transect I were located in Arctic water, frontal zones between these stations were not identified.

The Marginal Ice Arctic Front influenced the distribution of Chl a concentration in the studied water area. The highest Chl a content along transect I corresponded to the surface Arctic water (Table 1). In Arctic water, concentrations of this pigment exceeded those in water of Atlantic origin by a factor of 2. The distribution of Chl a in the 0-50 m layer was fairly uniform.

The investigation of phytoplankton in April 2018 along transects II, III, IV, V (Figure 3) were carried out on a polygon near the slope of the Svalbard Bank, where according to numerous studies [2, 7, 8] the Polar Front is quasi-stationary. The research polygon included 19 stations located between 74.8° - 76.2° N and 23° - 33.3° E.

The Polar front divided Arctic water from water of Atlantic origin in a layer of 0-50 m. The frontal zone was shifted from the average long-term position, which is typical in the conditions of modern climatic changes [8]. Western polygon stations (37, 39, 23, 25, 13, 15, 6) located in Arctic water. Eastern polygon stations (41, 27, 16, 17, 18, 21, 22, 8, 10, 3, 2, 1) were referred to the Atlantic water mass.

The highest Chl a concentrations were registered along transects II and III corresponding to water of the Arctic Basin. The average pigment content varied in the range of 2-5 mg/m³, uniformly distributed in the water column (Table 1). Maximum Chl a concentrations also related to Arctic water along transects IV, V. In the 0-10 m layer the average content of investigated pigment varied from 2.5 to 3.8 mg/m³, decreasing with depth to 1 mg/m³. In water of Atlantic origin along the all transects average Chl a concentration was 1 mg/m³. Thus, border of the Polar Front separated water of the Arctic Basin with the highest Chl a content from the Atlantic water mass where pigment concentrations were significantly lower.

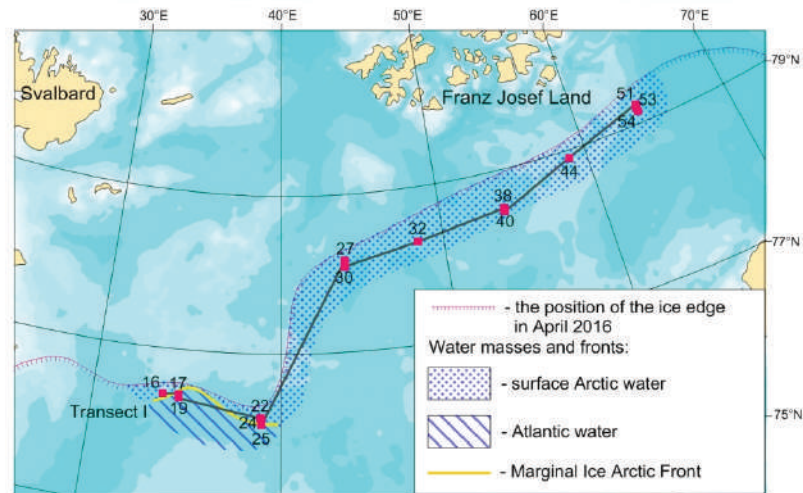


Figure 2: Water masses along Transect I (depth 0-50 m), 2016.

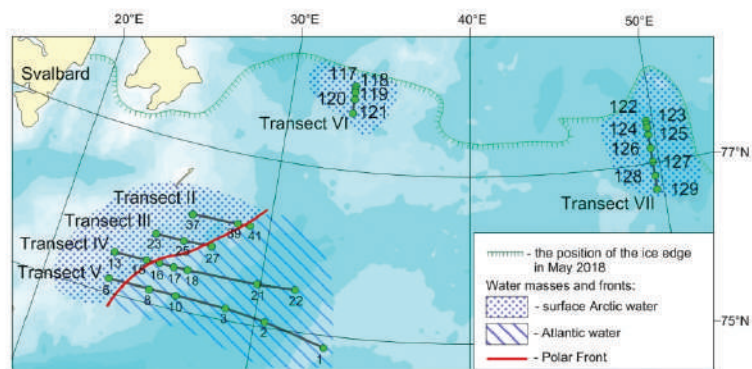


Figure 3: Water masses along the transects fulfilled in 2018 (depth 0-50 m).

In May 2018, samples were collected in the zone of influence of the ice edge, along transects VI and VII (Figure 3). At all stations along transects VI and VII the surface layer (0-50 m) was represented by Arctic water. Average Chl a concentration along transect VI varied from 1 to 2 mg/m³ in the 0-50 m layer, along transect VII from 2 to 4 mg/m³ (Table 1). A significant difference (2 times as high) in Chl a concentrations between the transects could possibly be due to their location and the beginning of the spring ice-edge bloom in the eastern part of the water area. Higher Chl a concentrations are known to be typical for the southeastern Barents Sea where a mass development of phytoplankton with Chl a concentrations reaching sometimes 6 mg/m³ is observed in spring along the ice edge () [9].

In April 2019 water samples were collected along transects VIII, IX, X, XI located near the ice edge. (Figure 4).

Transect VIII was located in the area of the Polar frontal zone. The influence of warm surface Atlantic currents was observed at the southern stations of the transect

TABLE 1: Average Chl a concentration (mg/m³) and hydrological conditions (IE, PFZ, MIAFZ) along transects.

	Depth, m			
	0	10	25	50
Water masses	Transect I (IE / MIAFZ)			
Arc	0.57±0.20	0.62±0.17	0.57±0.23	0.44±0.15
A	0.34±0.03	0.31±0.04	0.29±0.04	0.28±0.07
	Transect II (PFZ)			
Arc	3.57±3.00	5.36±0.15	3.57±2.86	2.28±2.76
A	0.56*	0.65*	0.07*	0.55*
	Transect III (PFZ)			
Arc	2.53±0.97	2.80±1.13	2.75±1.06	2.19±0.36
A	0.72*	0.62*	0.67*	0.71*
	Transect IV (PFZ)			
Arc	2.52±0.45	2.56±0.70	1.72±0.99	1.38±0.68
A	0.54±0.28	0.59±0.36	0.44±0.32	0.40±0.21
	Transect V (PFZ)			
Arc	3.79*	2.82*	0.88*	0.68*
A	0.54±0.30	0.52±0.22	0.48±0.28	0.40±0.24
	Transect VI (IE)			
Arc	1.84±1.38	1.97±1.40	1.89±0.51	0.98±0.26
	Transect VII (IE)			
Arc	3.42±1.40	3.47±1.08	4.00±1.36	2.00±1.56
	Transect VIII (IE / PFZ)			
A	0.13±0.05	0.15±0.01	0.11±0.13	0.12±0.03
Bar	0.23±0.03	0.18±0.00	0.26±0.02	0.20±0.06
	Transect IX (IE / MIAFZ)			
Arc	0.42±0.10	0.49±0.10	0.42±0.11	0.35±0.08
Bar	0.22±0.03	-	0.25±0.07	0.22±0.04
	Transect X (IE)			
Bar	0.18±0.05	0.18±0.03	0.22±0.07	0.15±0.05
	Transect XI (IE)			
Arc	0.27±0.10	0.30±0.15	0.31±0.13	0.21±0.19

Note: * single value

IE -- ice edge, PFZ -- Polar frontal zone, MIAFZ -- Marginal Ice Arctic frontal zone, Arc -- arctic water mass, A -- Atlantic water mass, Bar -- Barents water mass.

and became less pronounced when moving north. At stations 26 and 27 at depths of 65 and 115 m, respectively, there was a thermocline separating warm Atlantic water from the underlying Barents Sea water. At the northern stations 22, 23, 24, the water column was homogeneous and had characteristics corresponding to the Barents water mass. Calculating the maximum horizontal temperature gradients made it possible to determine position of the Polar Front line on the sea surface. The front passed between

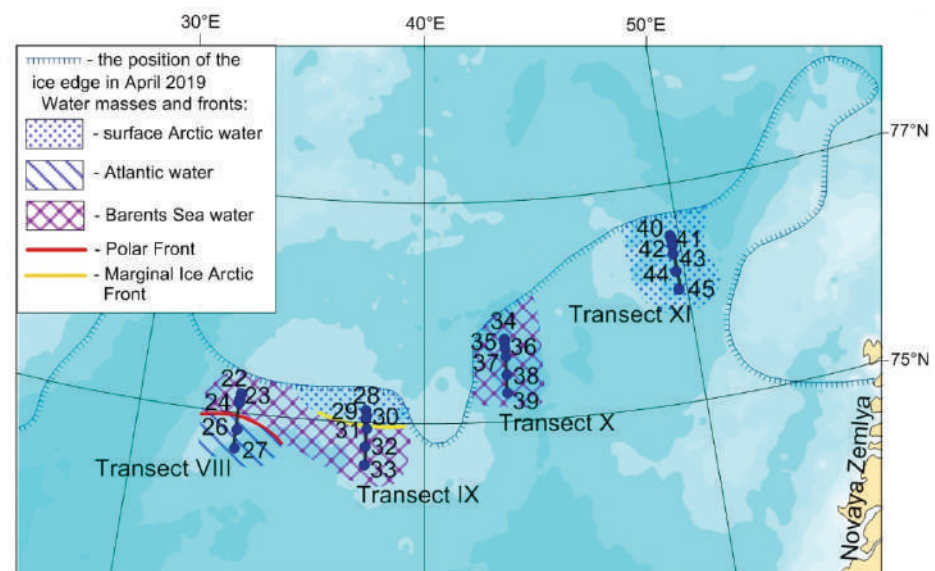


Figure 4: Water masses along the transects completed in 2019 (depth 0-50 m).

stations 24 and 26 and separated Barents Sea water with a pigment content of about 0.2 mg/m^3 from Atlantic water (0.1 mg/m^3).

There was a difference in structure of the water column between the northern (28, 29, 30) and southern stations (31, 32, 33) along transect IX. At southern stations 32 and 33, the waters were well mixed from surface to bottom. At station 31 the waters were also well mixed, but had slightly lower temperature with the same salinity values. At northern stations located in close vicinity to ice edge, cold freshened Arctic water were located on the surface. Below lay Barents water. Between stations 30 and 31 on the sea surface, the Marginal Ice Arctic Front was determined, expressed both in the temperature field and in the salinity field. The Marginal Ice Arctic Front separated Arctic water with average Chl a concentrations of 0.4 mg/m^3 from the Barents Sea water where the pigment content was about 0.2 mg/m^3 (Table 1).

This stratification ceased to be traced to transect X and at stations 34-39 the water column was homogeneous from surface to bottom and was occupied by water of Barents Sea origin. Chl a concentration in Barents Sea water was about 0.2 mg/m^3 (Table 1). A similar structure of the water column was observed at all stations along transect XI: there were surface water of the Arctic Basin to depths of 75-120 m underlain by the Barents Sea water. The average Chl a concentration in Arctic water was low and varied in a small range of $0.2\text{--}0.3 \text{ mg/m}^3$ (Table 1).

4. Discussion

The climatic Polar front had the strongest influence on the distribution of Chl a concentration in the studied water area. Along those transects where the front line passed between Arctic and Atlantic waters, its influence was most obvious. Atlantic water was characterized by low chlorophyll content about 0.1-0.7 mg/m³.

Almost along the all transects chlorophyll content in Arctic water significantly exceeded that in Atlantic water. The average pigment concentration in the Arctic water mass near the Polar Front area varied from 1 to 5 mg/m³. The obtained values correspond to the known literature data. So in May 1993 in the northeastern and central parts of the Barents Sea, Chl a concentration in Atlantic water was less than 1 mg/m³ while in Arctic water varied from 1 to 5 mg/m³ [10].

In May 2016 along the eastern transect we observed the beginning of phytoplankton spring bloom, when the chlorophyll concentration reached about 4 mg/m³ and was 2 times as high as its values along the transect located to the west. It is known that increased values of Chl a concentration are typical for the southeastern Barents Sea, where mass development of phytoplankton (chlorophyll concentrations reach 6 mg/m³) occurs along the ice edge in springtime [9]. "The marginal bloom" as a phenomenon is a very short process. According to data derived from satellite sensing, the active phase at each specific point lasts no more than 5-6 days [11]. The data obtained within one succession cycle may differ significantly and reflect the complex spatiotemporal organization of the marginal bloom. Thus, according to [12], in May 1999 at sites of the surface layer located from each other at a distance of only few kilometers chlorophyll concentrations differed from each other by an order of magnitude and the phytoplankton community was at different stages of the succession cycle. It is known that in the central and northern Barents Sea one spring maximum of phytoplankton development is recorded and most of the annual biomass of Arctic micro-phytoplankton is produced precisely during the spring succession cycle. According to different authors, the maximum level of peak values in springtime can reach about 13 mg/m³ in the northwestern Barents Sea [13], about 14 mg/m³ during sub-ice microalgae bloom in the central part of the sea [10], and up to 10.6±1.5 mg/m³ in the north of the sea in the Marginal Ice Arctic zone and ice fields [14]. During our investigations such high chlorophyll concentrations were not recorded. Probably we observed the beginning of the spring bloom that was only starting its way to its culmination.

The influence of the Marginal Ice Arctic Front on the distribution of Chl a concentration was less pronounced in the studied area. The highest chlorophyll content corresponded

to surface Arctic water (0.4–0.6 mg/m³) and was approximately 2 times higher than its values in water of Atlantic origin and Barents water. Barents Sea water along the all transects was characterized by low chlorophyll content of around 0.2 mg/m³.

5. Conclusion

Long-term investigations of Chl a content in the pelagic zone of the Barents Sea during spring time covered areas located in hard-to-reach areas north of 75° N, affected by the Polar frontal zone and the ice edge.

The Polar front was the most powerful factor influencing the Chl a distribution and concentration within the research period. The Polar Front acted as a powerful boundary dividing water masses with different quantitative parameters of the pigment under study. The front line separated the more productive water of the Arctic Basin, with average Chl a concentration of about 1-5 mg/m³, from the Atlantic water where Chl a content was substantially lower. Marginal Ice Front also separated water masses with different levels of Chl a content though it had less influence on the distribution of Chl a.

Overall, Chl a concentration in Arctic water exceeded its levels in waters of other origin (Atlantic, Barents Sea) by no more than twice.

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Conflict of Interest

The authors have no conflict of interest to declare.

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