# Variability of the ice area and the possibility of achieving an ice-free regime in the Barents Sea

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**Abstract.** The results of the analysis of the interannual variability of the Barents Sea ice area, including trends in the area of sea ice distribution for the period 1979-2018 based on remote sensing data, are presented. The analysis of trends is based on a dimensionless trend index, which allows comparing different areas of sea ice distribution. Estimates of the Barents Sea ice-free regime in January and August are presented on the basis of extrapolation of trends for the period 1979-2018. The ice-free regime of the Barents Sea in January is expected in 2055, in August - 2026.

## 1 Introduction

In modern conditions, changes in climatic characteristics occur sequentially, changes in one of the components of the ocean-atmosphere system through feedback leads to changes in others. According to sources, as a result of intensifying polar phenomena, the area of Arctic sea ice is rapidly decreasing. Since the Arctic is a region for the development of natural resources, a long-term assessment of the forecast of climatic parameters is required for their development [1]. One of the most important parameters affecting the work in the Arctic region is sea ice. Currently, there are complex models for sea ice forecasting, but it is necessary to develop alternative approaches using statistical methods [2].

The purpose of this work is to estimate the variability of the area of distribution of the sea ice area of the Barents Sea and to forecast its ice-free regime in winter and summer using January and August as examples [2].

## 2 Methods and materials

Remote measurement methods are the main source of information about sea ice in polar regions. Measurements in the microwave range, compared to measurements in other ranges, provide the most comprehensive data set, since it works well in cloudy and bad weather and at night, which is typical for polar regions. Additional advantages are the availability and continuity of data observations [3, 4].

Monthly data on the area of sea ice distribution since 1979 are freely available on the website https://neptune.gsfc.nasa.gov. This work uses data to estimate the maximum (January) sea ice distribution and minimum (August) sea ice distribution for the Barents Sea [5].

The interannual variability of the sea ice distribution in the Arctic is largely inertial in nature, as a result, linear trends describe most of the dispersion of the cover time series. In this case, a simple statistical trend method can be used to predict the area of ice. Its basis is an assumption of stationarity (immutability) of climatic conditions for the entire forecasting period. This method allows to calculate forecast estimates of the ice area for practically any given year, including the date when the sea enters the ice-free regime [6-9].

As a rule, a trend coefficient depending on the sea ice area is used to assess trends. But due to a large variability of the sea ice area, quantitative comparison of trends becomes impossible. To do this, a trend index is introduced, which represents the ratio of the trend spread to its mean value and is expressed in conditional units [10, 11]

$$I = 100 a_1 n / \overline{X} \quad (1)$$

Here $a_1$ is the coefficient of the linear trend equation, n is the length of the series.

## 3 Results

Statistical estimates of sea ice distribution trends in the Barents Sea for January and August for the period 1979-2018 are presented in Figure 1-3 shows the temporal variability of sea ice distribution area in January and August for the period 1979-2018 for the Barents Sea with expressed linear and nonlinear trends, as well as trend equations. According to linear and nonlinear trends, the year of ice-free sea regime for January and

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August is calculated, the results of calculations are listed in Table 1, extrapolation of the trend is shown in Figure 3-4.

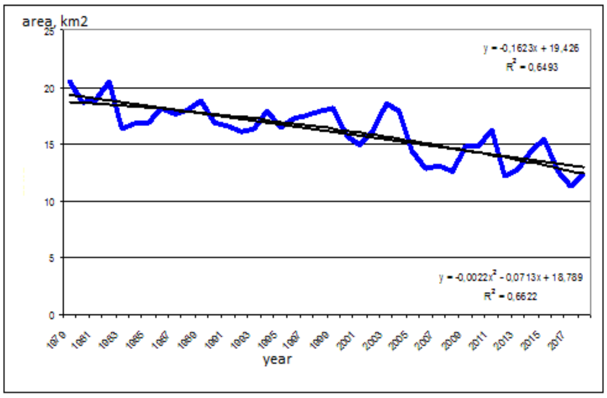


**Fig.1.** Temporal variability of the sea ice distribution area in January in the Barents Sea for the period 1979-2018 with linear and nonlinear trends

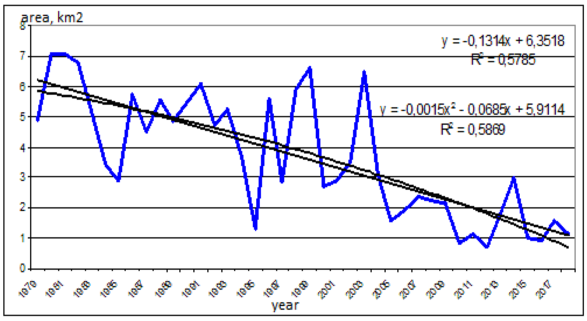


**Fig. 2.** Temporal variability of the sea ice distribution area in August in the Barents Sea for the period 1979-2018 with linear and nonlinear trends

**Table 1.** Characteristics of the linear trend of the sea ice distribution area ($10^5$ km2/year) for the Barents Sea in January and August for the period 1979-2018.

| year | January | | | | August | | | |
|---|---|---|---|---|---|---|---|---|
| | Average $\bar{x}$ | $R^2$ | $a_1$ | trend index | Average $\bar{x}$ | $R^2$ | $a_1$ | trend index |
| 1979-2010 | 16.78 | 0.52 | -0.15 | -28.61 | 4.22 | 0.4 | -0.124 | -94.03 |
| 1979-2011 | 16.76 | 0.49 | -0.14 | -27.57 | 4.13 | 0.44 | -0.129 | -103.08 |
| 1979-2012 | 16.63 | 0.54 | -0.15 | -30.67 | 4.03 | 0.48 | -0.136 | -114.74 |
| 1979-2013 | 16.51 | 0.57 | -0.158 | -33.49 | 3.96 | 0.5 | -0.135 | -119.32 |
| 1979-2014 | 16.45 | 0.58 | -0.15 | -32.83 | 3.93 | 0.49 | -0.128 | -117.25 |
| 1979-2015 | 16.43 | 0.56 | -0.15 | -33.78 | 3.86 | 0.52 | -0.131 | -125.57 |
| 1979-2016 | 16.32 | 0.59 | -0.15 | -34.93 | 3.78 | 0.55 | -0.133 | -133.7 |
| 1979-2017 | 16.19 | 0.62 | -0.159 | -38.3 | 3.72 | 0.56 | -0.131 | -137.34 |
| 1979-2018 | 16.09 | 0.65 | -0.162 | -40.27 | 3.66 | 0.57 | -0.131 | -143.17 |

The interannual variability is expressed by the sum of the trend, cyclical and random components. The random component is predicted for a small number of steps, which is not suitable for the task. The cyclic component is expressed by the sum of significant harmonics and their calculation for a long time.

The results of the search for significant harmonics of the Barents Sea in January are listed in Table 2, in August in Table 3. The results of extrapolation of the sea ice distribution area in January and August for the Barents Sea are shown in Figure 3-4.

**Table 2.** Estimates of the contribution to the variance of the time series of January harmonics and trend values for the sea ice distribution area of the Barents Sea for the period 1979-2018.

| Barents Sea, January | |
|---|---|
| Harmonic period, years | Contribution, % |
| 5,7 | 21 |
| 4 | 11 |
| Trend | 64 |
| Sum | 96 |

**Table 3.** Estimates of the contribution to the variance of the time series of the August harmonics and trend values for the sea ice distribution area of the Barents Sea for the period 1979-2018

| Barents Sea, August | |
|---|---|
| Harmonic period, years | Contribution, % |
| 5,7 | 12 |
| Trend | 58 |
| Sum | 70 |

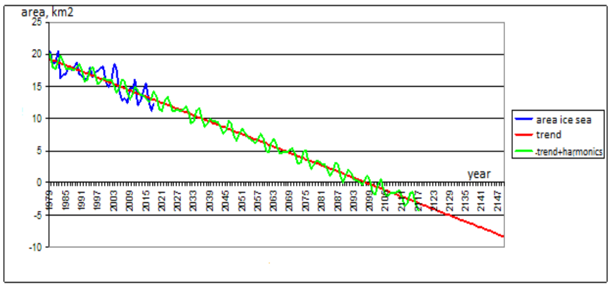


**Fig. 3**. Extrapolation of the January sea ice distribution area for the Barents Sea

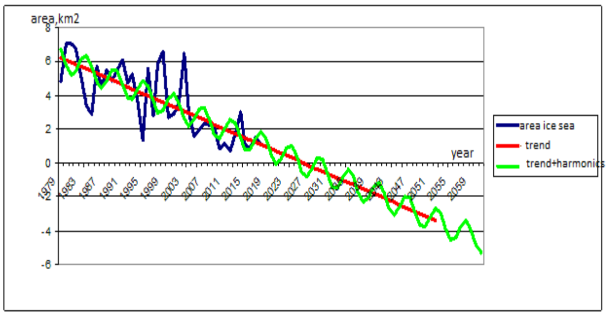


**Fig. 4.** Extrapolation of the August sea ice distribution area for the Barents Sea

## 4 Discussion

For the area of sea ice distribution in January for the period 1979-2018, linear and nonlinear trends were constructed and tested for significance according to the

Student's criterion. For a linear trend t*=14.5>tcrit=2.02 - the trend is significant, for a nonlinear trend t*=15.8>tcrit=2.02 - the trend is significant. So there is a tendency to decrease the area of ice by 0,16km2 /year. For August for the period 1979-2018, according to the Student's criterion, trends were checked for significance, for a linear trend t*=11.4>tcr=2.02 - the trend is significant, for a nonlinear trend t*=12.1>tcr=2.02 - the trend is significant. So there is a tendency to decrease the ice area by 0.13 km2/year.

According to linear and non-linear trends, the sea is calculated to go ice-free, which in January with a linear trend will occur in 2097, and with a non-linear trend faster in 2055. In August, the ice-free regime with a linear trend will occur in 2026, and with a non-linear trend in the current year 2021.

To assess the stability of the trend, the trend index is calculated. In Table 1, the maximum and minimum trend values are selected for January, the maximum for 2018 and the minimum for 2011. According to them, the output to the ice-free mode was calculated, so with the minimum trend, the output to the ice-free mode will occur in 2114, and with the maximum trend in 2097. For August, the maximum and minimum trend values are a1, the minimum is 2010 and the maximum is 2012. According to them, the ice-free regime was calculated in August, so with a minimum trend, the ice-free regime will occur in 2028, and with a maximum trend in 2025. The difference in these estimates does not go beyond the trend errors, which indicates a good quality forecast.

Next, a harmonic analysis was performed, significant harmonics for January were identified. Harmonics contribute about 32% to the variance of the series, together with the trend they describe 96% of the original series. The curve of the sum of significant harmonics is extrapolated to the year of ice-free operation, the results are shown in Figure 3. The ice-free regime for January, taking into account harmonics, will occur in 2099. For the values of the August ice area, significant harmonics have been identified, which together with the trend describe 70% of the variance of the original series. The curve of the sum of significant harmonics is extrapolated to the year of ice-free operation, the results are shown in Figure 4. The ice-free regime will take place in 2025.

## 5 Conclusion

Linear and nonlinear trends are significant for the area of sea ice distribution in the Barents Sea in January, with a trend value of 0,16 km2/year. The ice-free regime in January with a linear trend will occur in 2097, with a non-linear one - in 2055. With the minimum trend, the ice-free regime will occur in 2114, and with the maximum in 2097, that is, with a difference of almost 20 years. Taking into account the harmonics, the ice-free mode will be reached in 2099.

For August, trends are also significant, with a trend value of 0.13 km2/year. With a linear trend, the ice-free regime will occur in 2026, with a non-linear one – in 2021. With the minimum trend, the ice-free regime will occur in 2028, and with the maximum in 2025, with a difference of 3 years. Taking into account the harmonics, the output will occur in 2025.

In modern conditions of the development and development of the Arctic, further study of the interannual variability of ice is of great importance in a wide range of tasks for the development of the Arctic zone. In the future, the introduction of the described statistical methods into a geographic information system to automate calculations and apply greater variability in the selection of heterogeneous data sets [12, 13, 14, 15].

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