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# Spatial-temporal variability of ice cover of the Bering sea

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**Abstract.** In this paper, we study the spatial and temporal variability of the Bering sea ice cover. The Bering sea is a major transportation importance as a link in the Northern sea route in turn every activity at sea, meeting the challenges of hydro-meteorological research and predictions in this region largely depend on the knowledge about ice conditions. Observing changes in the ice environment can also serve to assess climate change. For the study, the methods of mathematical statistics applied to data on the amount of ice as a percentage for the Bering sea area in the 1x1 degree grid for the period November 1981 to April 2014. In the course of the work, the trend component of the time variability of sea ice was identified, spectral and harmonic analysis was performed, and autocorrelation analysis was performed. As a result, for long-term variability, the existence of a trend in the development of ice conditions was revealed, and the presence of a linear trend is unlikely. Analysis of local trends showed a decrease in ice cover in the period 1992-2003, after 2003 there was a large positive trend. Spectral analysis 4 peaks of the spectrum for each were calculated characteristics of harmonics. The sum of harmonics gives a good result when combined with the original data. Long-term variability is low-inertia. when performing an auto forecast for average annual values with a 10-year lead time, it was noted that the prognostic model does not give good results.

## 1. Introduction

Sea ice covers about 80-90% of the surface of the Bering sea, and it has never been observed that the Bering sea is completely covered with a solid ice cover. Ice fields are usually up to 2 meters thick, but undergrowth and hummock, especially near the coast, can increase the thickness of the ice to 5-10 meters [1]. The area occupied by ice is relatively constant until April, and by the end of July, the sea is completely free of ice.

Due to the severe ice conditions in the Bering sea, the study of the hydrometeorological situation is an important task for ensuring economic activity in this region. Increasing requirements for information about the state of ice require a more detailed study of the ice situation in the region [2].

## 2. Research materials and methods

When creating an archive of data on the amount of ice in the Bering sea, we used the average monthly remote sensing data on the amount of ice as a percentage from the site of Columbia University in a 1x1 degree grid for the period from November 1981 to April 2014. The average monthly data was averaged to the average annual data, and work was carried out with them.

For most methods of time series analysis, one of the main requirements for a series is its stationarity. at the first stage of time series analysis, its non-stationarity is evaluated, and when it is detected, the series is converted to a stationary one. In the course of the work, all the characteristics of a nonlinear trend as a linear regression are calculated, all the characteristics of a nonlinear trend as a multiple



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nonlinear regression are calculated, the significance of each trend is estimated by evaluating the correlation coefficients, which of the trends (linear or non-linear) is preferable, and the value of the trend is calculated (if a linear trend is preferred) [2].

If there is a need to identify only cyclic components in the process under study, spectral or harmonic analysis is used, without first calculating the autocorrelation function. At the heart of harmonic analysis is the idea of decomposing any series into a Fourier yard without a remainder. To perform spectral analysis, you need to remove the trend from the original series (if it is significant) or change the value (if the trend is not significant), so we will work with the received number of deviations from the trend. Using the Statistica package, a periodogram is calculated for a number of deviations. the table defines the periods corresponding to the " peaks " of the spectrum. For each of the obtained periods, the characteristics of the harmonic are calculated separately: amplitude, phase, harmonic dispersion, contribution to the total dispersion of the series, the significance of the harmonic, and the harmonic equation is formulated. For each moment of time, the series for all harmonics are calculated and their sum is found. As a result, a combined graph of a similar series and the sum of harmonics is constructed.

The internal structure of the series is analyzed on the basis of autocorrelation. First, the trend is removed from the original series. if it is significant, the series is divided into 2 samples-dependent and independent. For a dependent sample, the autocorrelation function (ACF), ACF significance levels [3] are calculated, a combined graph of ACF and significance levels is constructed, and the correlation radius and periodicity are determined using the graph. And then the analysis internal structure: estimated inertia, the frequency and the type of process is determined by the ability of touristic and maximum lead-time, we formulate the equation of autoregression, 1 order, after the model calculations estimated its quality. For an independent sample: it is calculated using the equation of the autoregression model of the characteristic value, the standard error of the independent forecast is determined, and the possibility and quality of the autoregression is evaluated [4].

### 3. Research result

When analyzing the trend component of the average annual ice content of the Barents sea, it was found that the linear trend  $Q_{ice} = 0,12t - 222.06$  at the level of significance of 5% according to the student's criterion, it was not significant, the trend value is about  $1,25 \frac{\%}{year}$  (Tabl.1). For Figure.1 it is also well noted that the trend component does not have a significant impact on the change in ice cover.

**Table 1.** Regression analysis indicators for the allocation of a linear trend for the period 1981-2014

Regression statistics					
Multiple R		0,29			
R-square		0,08			
Normalized R-square		0,06			
Standard error		3,89			
Observations		33			

Analysis of variance					
	df	SS	MS	F	Significance Of F
Regression	1	46,55	46,55	3,06	0,09
Remains	31	470,80	15,18		
Subtotal	32	517,35			

	Coefficients	Standard error	t-statistics
Y-intersection	-222,05	142,28	-1,56
The Variable X 1	0,12	0,07	1,75

$$\begin{array}{ccc} t \text{ critical} & & t \text{ empirical} \\ 2,03 & > & 1,92 \end{array}$$

Further, 2 local trends were identified for the period 1992-2003 (table.2) and 2004-2012 (table.3). Trend for the period 1992-2003  $Q_{ice} = 0,44t + 901.12$  at the level of significance of 5% according to the student's criterion, it is not significant. Trend for the period 2004-2012  $Q_{ice} = 1,49t - 2972.66$  at a significance level of 5% according to the student's criterion, it was significant, which indicates that the ice cover increased by about  $1,4 \frac{\%}{year}$ .

**Table 2.** Regression analysis indicators for the allocation of a local trend for the period 1992-2003

Regression statistics	
Multiple R	0,39
R-square	0,15
Normalized R-square	0,07
Standard error	3,82
Observations	12

#### Analysis of variance

	df	SS	MS	F	Significance Of F
Regression	1	27,48	27,48	1,87	0,20
Remains	10	146,55	14,65		
Subtotal	11	174,0373			

	Coefficients	Standard error	t-statistics
Y-intersection	901,12	639,46	1,40
The Variable X 1	-0,43	0,32	-1,36

$$\begin{array}{ccc} t \text{ critical} & & t \text{ empirical} \\ 2,20 & > & 1,56 \end{array}$$

**Table 3.** Regression analysis indicators for identifying a local trend for the period 2004-2012

Regression statistics					
Multiple R					0,86
R-square					0,75
Normalized R-square					0,72
Standard error					2,49
Observations					9

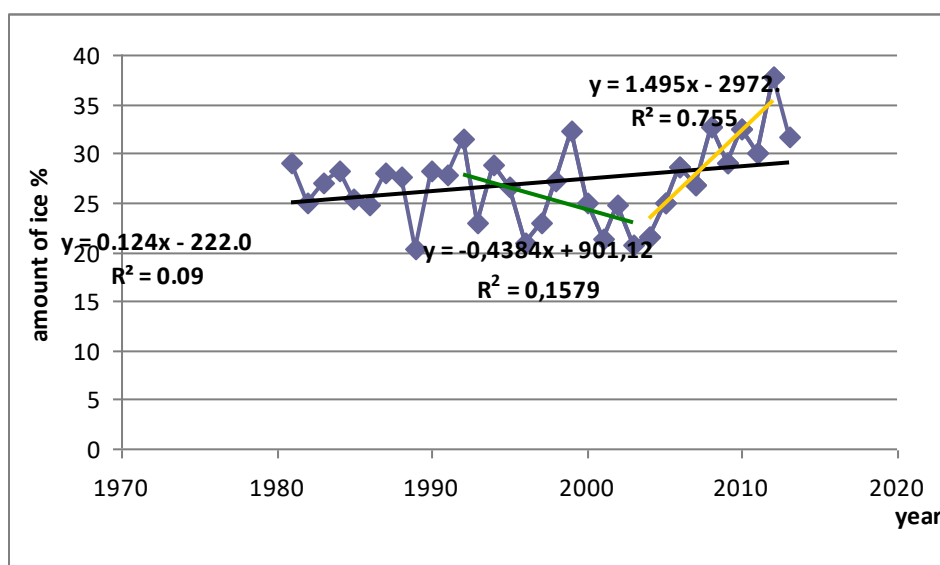
Analysis of variance					
	df	SS	MS	F	Significance Of F
Regression	1	134,10	134,10	21,61	0,002
Remains	7	43,43	6,20		
Subtotal	8	177,53			

	Coefficients	Standard error	t-statistics
Y-intersection	-2972,66	645,71	-4,60
The Variable X 1	1,49	0,32	4,64

t critical		t empirical
2,30	<	10,04

**Figure 1.** The course of changes in the amount of ice for the period 1981-2014 with linear and local trends

Estimation of the nonlinear trend (Fig.2) for the average annual values of ice cover according to the student's criterion at a significance level of 5%, it showed that the nonlinear trend

$Q_{ice} = 0,02t^2 - 0.66t + 29.49$  significant (table.4). For further research, if the non-aligned trend is

significant and the linear trend is insignificant, the non-aligned trend will be removed from the original series, since it is the most significant when forming the trend component in the original series [5].

**Table 4.** Regression analysis indicators for identifying a non-linear trend for the period 1981-2014

Regression statistics					
Multiple R					0,55
R-square					0,31
Normalized R-square					0,26
Standard error					3,44
Observations					33

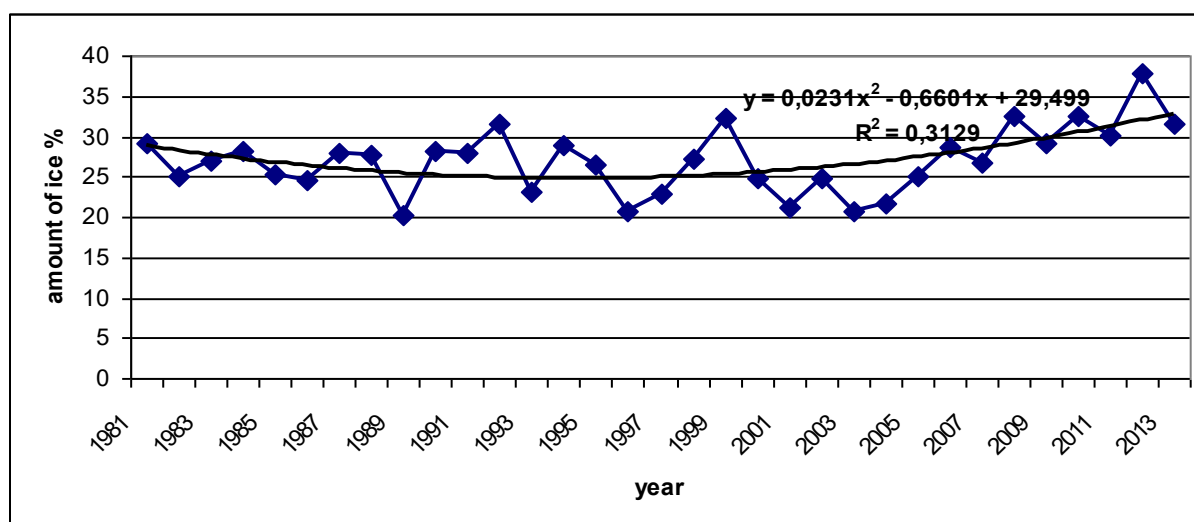
Analysis of variance					
	df	SS	MS	F	Significance Of F
Regression	2	161,88	80,94	6,83	0,003
Remains	30	355,47	11,84		
Subtotal	32	517,35			

	Coefficients	Standard error	t-statistics
Y-intersection	29,49	1,91	15,42
The Variable X 1	-0,66	0,25	-2,54
The Variable X 2	0,023	0,01	3,12

t critical		t empirical
2,03	<	4,67

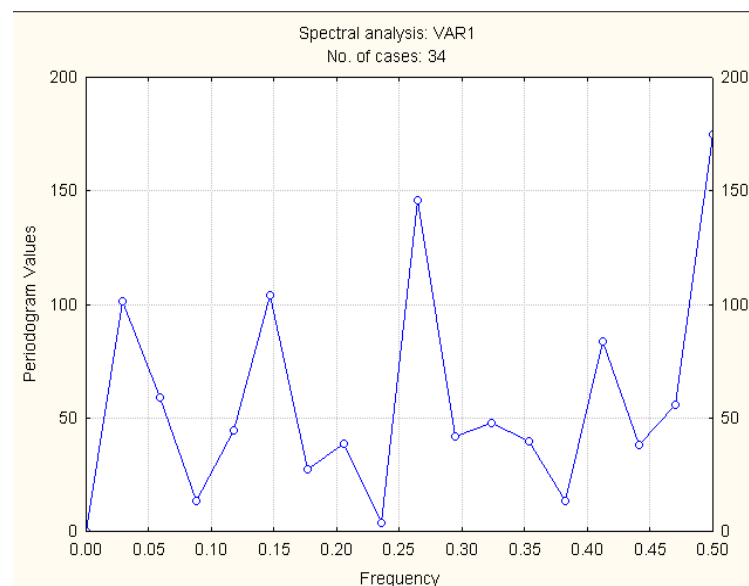


**Figure 2.** The course of changes in the amount of ice for the period 1981-2014 with a nonlinear trend

After removing the trend component, a spectrum table was obtained using the Statistica package (table.5) and a periodogram is constructed (Fig.3). As a result, 4 spectrum peaks were identified with periods of 34, 6.8, 3.7, and 2.43 years.

**Table 5.** Results of the spectral analysis obtained using the Statistica package for the Arctic range for the period 1981-2014

	Frequency	Period	Cosine	Sine	Periodog	Density	Hamming
0	0		0	0	0	53,1574	0,035714
1	0,029412	34	-0,42427	2,40613	101,4813	63,6726	0,241071
2	0,058824	17	1,07221	-1,52741	59,2043	55,6694	0,446429
3	0,088235	11,33333	0,48941	-0,73296	13,2049	38,2598	0,241071
4	0,117647	8,5	1,55799	0,44006	44,5566	51,3224	0,035714
5	0,147059	6,8	0,31237	-2,45773	104,3459	65,7729	
6	0,176471	5,66667	1,03216	-0,73914	27,3986	48,3809	
7	0,205882	4,85714	0,19556	-1,49049	38,4168	33,6613	
8	0,235294	4,25	0,09141	-0,47503	3,9781	48,739	
9	0,264706	3,77778	-0,88208	-2,79643	146,1673	79,3289	
10	0,294118	3,4	1,16397	-1,04576	41,6237	66,9174	
11	0,323529	3,09091	0,20352	-1,66603	47,8901	46,6423	
12	0,352941	2,83333	-0,81366	-1,28959	39,5263	36,9066	
13	0,382353	2,61538	-0,49506	-0,73817	13,4298	38,7833	
14	0,411765	2,42857	-1,59883	-1,54001	83,774	53,1672	
15	0,441176	2,26667	-0,2136	-1,47761	37,8921	57,2254	
16	0,470588	2,125	-1,77339	-0,35092	55,5567	81,0393	
17	0,5	2	-3,20612	0	174,7467	107,5048	

**Figure 3.** Periodogram

For each of the periods, the harmonic characteristics were calculated (table.6-9), after which it was concluded that at a significance level of 5% according to the student's criterion, only the first harmonic with a period of 34 months is significant. Other harmonics were insignificant. A combined graph of the original series and the sum of harmonics (Fig.4) showed good results only for the repeatability of the course of the series.

**Table 6.** Characteristics of the 34-year-old harmonic

W1=0.18		
a		2,32
b		-1,64
A		2,85
stage		0,95
D		4,07
V		0,28
t critical		t empirical
2,04	<	16,76
$G_1 = 2.85 * \cos(0.18t - 0.95)$ - the equation of harmonic		

**Table 7.** Characteristics of the 6.8 year harmonic.

W2=0.92		
a		-1,87
b		0,95
A		2,10
stage		-1,09
D		2,21
V		0,15
t critical		t empirical
2,04	>	0,06
$G_2 = 2.10 * \cos(0.92t + 1.09)$ - the equation of harmonic		

**Table 8.** The characteristics of the harmonics of 3.7 years.

W3=1.66		
a		-0,84
b		-0,84
A		1,19
stage		-0,78
D		0,71
V		0,05
t critical		t empirical
2,04	>	0,59
$G_3 = 1.19 * \cos(1.66t + 0.78)$ - the equation of harmonic		

**Table 9.** Characteristics of the 2.43 year harmonic

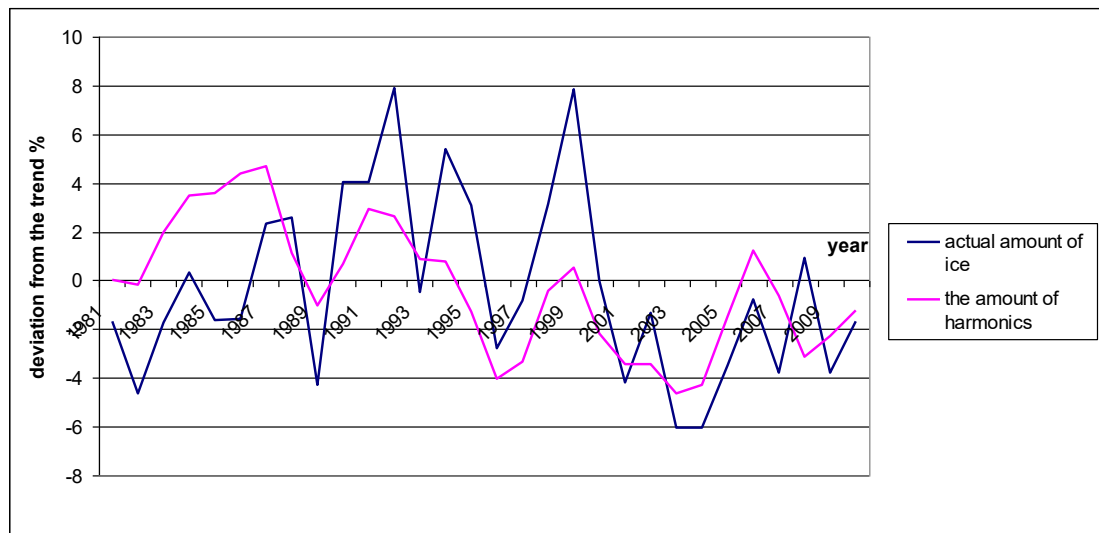
W4=2.58	
a	-0,12
b	-0,12
A	0,18
stage	-0,78
D	0,01



$$V = 0,001$$

$$t_{\text{critical}} = 2,04 > t_{\text{empirical}} = 0,005$$

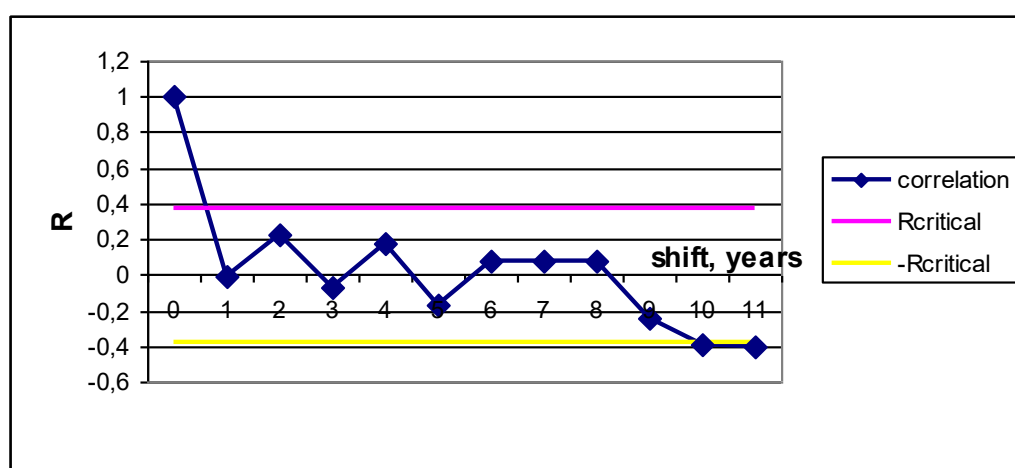
$$G_4 = 0.18 * \cos(2.58t + 0.78) - \text{the equation of harmonic}$$



**Figure 4.** Combined graph of the original series and the sum of harmonics

To analyze the residuals for the autocorrelation function, we consider our series of average annual values to be short, so the number of shifts is defined as  $\tau_{\max} = \frac{1}{3} N$ . The obtained number of shifts is

11. the calculated correlation coefficients were used to plot the correlation coefficient dependence on the shift (Fig.5).



**Figure 5.** A graph of the correlation coefficient from the shift

The inertia of the process is about 1 year, which means that the process of changing the ice level will be low-inertia, and the ice level will not remain in its previous state for a long time. The chart

highlights 2 local highs for the period on shifts 2 and 4 years. This indicates that there are two periodic components in the process. The forecast is 10 years ahead of time for the model, since it is in this shift that the correlation coefficient is significant. Calculating the parameters of autoregressive (table.10) the equation auto forecast a was compiled  $Q_i + 10 = -0.607Q_i + 0.485$ .

**Table 10.** Autoregression indicators

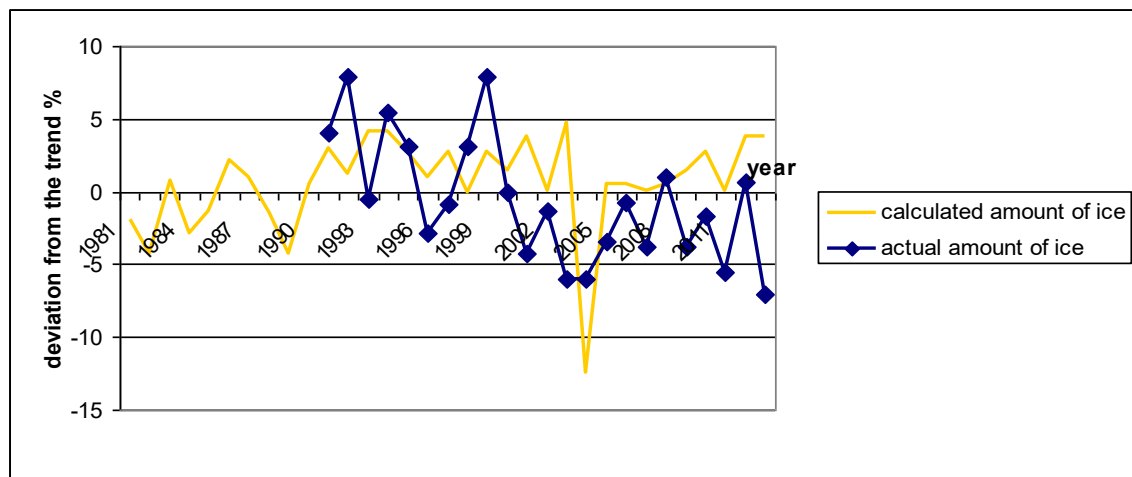
Regression statistics	
Multiple R	0,52
R-square	0,28
Normalized R-square	0,24
Standard error	3,65
Observations	20

Analysis of variance					Significance
	df	SS	MS	F	Of F
Regression	1	93,88	93,88	7,03	0,01
Remains	18	240,38	13,35		
Subtotal	19	334,26			

	Coefficients	Standard error	t-statistics
Y-intersection	0,48	0,85	0,56
The Variable X 1	-0,60	0,22	-2,65

With the forecast 10 years in advance, checking the regression coefficients for significance, the free coefficient was not significant, and the dependent coefficient was significant according to the student's criterion at a significance level of 5%. It follows that the model is not very good quality. The significance test also showed that the error variance exceeds the model variance and the model is adequate. The internal structure of the series does not change over time, so models can be used for further forecasting [6]. Evaluation of the coefficient of determination showed that it is very small, so the model does not sufficiently describe the process and the forecast will not be of high quality (Fig.6).



**Figure 6.** Actual and calculated using the auto forecast model with a 10-year lead time, the amount of ice in the Bering sea

#### 4. Conclusions

For long-term variability, the existence of a directional trend in the development of sea ice conditions was revealed and the presence of a trend component was verified. Based on the results of calculations, we see that the presence of a linear trend in this case is unlikely. This may be due to the activation of ice formation processes during the ice formation period, slowing down - during the maximum ice accumulation period (March), in our case, the trend is a small positive value, which indicates an increase in ice cover from 1981 to the present time. If we analyze local trends, then in the period 1992-2003, the trend indicates a decrease in the Bering sea ice cover. The period from 2004 to 2012 shows a large positive trend, so there is an increase in ice availability.

From the spectral analysis, we identified 4 explicit peaks of the spectrum and calculated the characteristics of harmonics for them. For average annual values, all harmonics except the first one were not significant, but in General, the combination of the initial data with the sum of harmonics was not bad.

Long-term low-inertia variability, i.e., the Arctic does not keep its previous state for a long time, determined the type of process "red noise", which indicates the possibility of making an auto forecast. According to the forecast model with a 10-year lead time, the curves almost repeat each other, but when checking the model was not very good and the forecast is not of high quality.

The development and implementation of modern models of processing meteorological data in conjunction with risk assessment techniques[7, 8] that minimize damage when making managerial decisions, allow you to effectively plan economic and economic activities and significantly reduce costs associated with the elimination of adverse meteorological consequences.

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