Proceedings of the 26th International Conference on
Port and Ocean Engineering under Arctic Conditions
June 14-18, 2021, Moscow, Russia

General tendencies of the ice extent changes in the Russian Arctic seas

Anna Timofeeva[1], Alexander Yulin[1], Maria Sharatunova[1], Eugenia Pavlova[1], Tatiana Sheveleva[1]
[1]Arctic and Antarctic Research Institute St. Petersburg, Russian Federation,

ABSTRACT

This paper considers sea ice extent (SIE) of Northern Sea Rout seas: the Kara, the Laptev, the East-Siberian and the Chukchi seas. Arctic and Antarctic Research Institute (AARI) data archive based on air reconnaissance (since 1930s) and satellite observations (since late 1970s) were used. Averaged SIE for the period July-September was analyzed since 1946. All of considered seas have strong interannual variability of SIE. SIE has well-defined and statistically significant linear trend of decreasing. Since 2005 abruptly shrink of SIE is revealed. Two periods were distinguished for analysis: years 1946-2004 and 2005-2020, caused by significant changes of SIE in Arctic seas. Thus changes during period 2005-2020 are determined as statistically significant, sustainable and never observed before for 75 years of observations. Mean level of SIE has abruptly decreased since 2005 in 1.6 times, but characteristics of amplitude and standard deviation changed slightly, so SIE oscillate of similar range, but at lower mean level. That allows to distinguish this event as a special extremely easy type of ice conditions development. SIE values for each 10-day period during the summer season were averaged for periods 1946-2004 and 2005-2020, and the difference between two periods was found. The earlier start and more intensive and faster clearing process of the Arctic seas was determined. This led to the earlier (25-30 days) clearance from ice of seas areas and to the enhancement of the ice-free period duration. Frequency of seas total clearance from ice cover increased significantly (to 60-90%).

KEY WORDS: sea ice extent changes, ice conditions, sea ice cover decrease, Arctic seas, ice-free period.

INTRODUCTION

Economic activity in the Russian Arctic seas is intense. The volume of cargo transportation on the Northern Sea Rout (NSR) increased and peaked in 2020 (33 million tons). Ice conditions have changed significantly over the last decades in the Arctic seas. The ice cover of the Arctic Ocean is currently intently studying. Until the XXI century, a number of researchers have noticed an oscillatory nature of changes of the ice area in the Arctic Ocean (Gudkovich et al., 1972, 2005; Karklin et al., 2001; Frolov et al., 2007; Ivanov et al, 2018). A period of fluctuations is 30-35 years, and the start of next cooling cycle would be observed again in 2015-2020. However the reduction of ice cover during last period is much more intense in comparison to the previous period of low ice extent in 1920-1950s (Yulin et al., 2019). Numerous studies have convincingly shown dramatic decrease of Arctic ice cover (Stroeve et al., 2012; Comiso, 2012; Petty, et al., 2018; Alekseev 2015).Drastic changes in the compound of Arctic sea ice are revealed (Kwok et al. 2009; Kwok& Untersteiner, 2011; Ivanov et al, 2013; Vinogradnaya et al., 2020). During the XX century multiyear ice prevailed in the ocean at maximum ice cover development time, in April. Recent decades are characterized by a steady predominance of one-year ice, the ratio between old and one-year

ice has become approximately 37% and 63% respectively. A number of authors suppose ice cover in the Arctic ocean could be seasonal in the future (Ivanov et al, 2013; Yulin et al., 2019).Some authors (Alekseev et al, 2015; Ashik et al., 2015; Timofeeva et al., 2020;) define 2005 as the onset of a new state of climate system accompanied significant changes in both oceanic and atmospheric processes, including a sharp increase of the positive air temperature anomaly and the rapid reduction of the ice cover. The strongest reduction of ice cover occurs in September, at the end of the melting season (Serreze, et al., 2016; Stroeve et al, 2014.). Arctic seas entire regime of ice cover development is significantly affected: ice formation onset (Egorov & Pavlova, 2019), ice thickness growth (Ricker, 2015), melting and other regime characteristics in the Arctic seas (Dumanskaya, 2017; Yulin et al., 2019; Tretyakov ,2019). Siberian shelf seas and its regime have a great practical importance for economic activity at Northern Sea Route. This paper considers SIE of official NSR seas: Kara, Laptev, East-Siberian and the south-western part of the Chukchi Sea (hereinafter referred to as the Chukchi Sea) as the most significant area of the Sea with shipping and economic activities

DATA AND METHODS

The research uses data from the sea ice archive of the AARI. The archive contains information about ice cover distribution as maps and SIE quantitative estimates of the Arctic seas. Sea ice cover monitoring were carried out according to methodology developed in AARI at early 1930s and described in the (Manual for the accomplishment of ice air reconnaissance, 1981). Since the late 1970s the air reconnaissance surveys have been progressively ceased and replaced by satellite monitoring (Boradachev & Shilnikov, 2001).

Caused by start in early 1930s and some features of air reconnaissance exploration the boundaries of Arctic seas were adopted as differ from the official boundaries of seas adopted in 1960 (Borders of the Seas and Oceans, 1960). Within these areas (AARI boundaries) ice cover characteristics were monitored and calculated. By the reason of continuities of data series even modern monitoring results are calculated within these AARI boundaries. Seas areas within the boundaries of AARI are shown in Figure 1. Available data archive allows us to consider continuous observational series along the NSR for each ten-days period from July to September. Time series cover period for 75 years, since 1946 to the present.

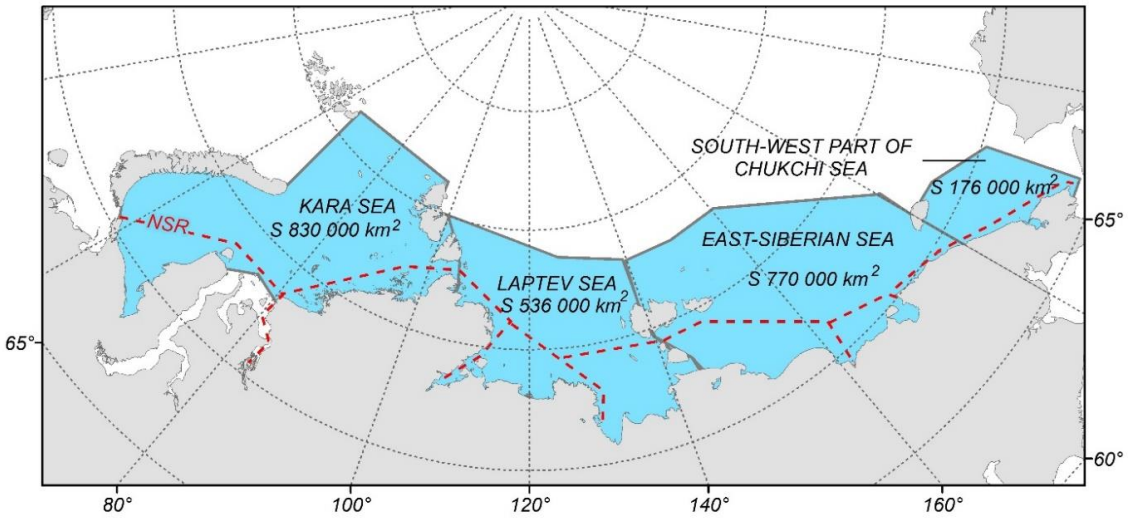

Figure 1. Areas of the Arctic seas adopted in AARI boundaries.

RESULTS

Interannual variability of sea ice extent in Russian Arctic seas.

SIE seasonal course in the Arctic Seas is well detected. During winter season Arctic seas are completely covered by ice of different thickness (and the values of ice extent are close to 100%). Melting processes starts in June, continue intense in July and August, and ends in September-October, then new ice formation starts.

Averaged SIE for the period July-September has good correlation to September minimum extent and seems to be more informative indicator than the single months or minimum SIE by the reason of compilation of seasonal changes values inside.

Figure 2 shows the empirical distribution function of the SIE for all considered seas in summer for a 75-years' time series, since 1946. It is obvious the SIE distribution is far from normal, strongly biased, and has a two-modal character. The first mode 61-65% and the second mode 36-40% characterize higher and lower SIE in the seas correspondingly.

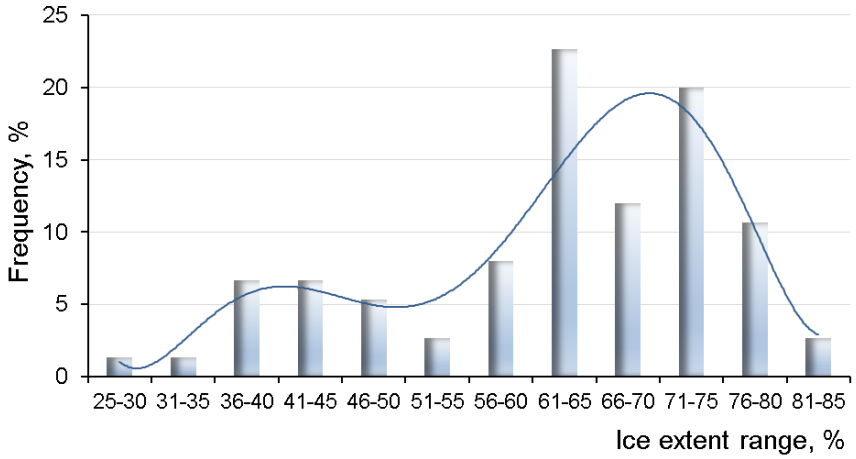

Figure 2. Distribution of averaged seas ice extent of summer season (July-October)

Table 1 shows the main statistical characteristics of SIE for each of considered seas and for all seas in general. The strongest interannual variability of SIE was revealed in the Laptev Sea, the amplitude is 85%, value of standard deviation is 19.3. Chukchi Sea has the lowest fluctuations, the amplitude is 58%, value of standard deviation is 13.9.

Table 1. Main statistical characteristics of sea ice extent (in %) in Arctic seas

Statistical characteristic	Seas				Average
	Kara	Laptev	East-Siberian	Chukchi	
Mean, %	45	49	71	41	52
Minimum, %	9	4	25	13	13
Maximum, %	85	89	97	70	85
Amplitude, %	76	85	72	58	73
Standard deviation	17,4	19,3	18,5	13,9	17,3

Interannual variability of seas averaged SIE during summer season (July-September) is presented in Figure 3. The graph shows well-defined and statistically significant (significance level 0.01) linear negative SIE trend, about 30% over the entire observations series or 4%

over a decade. Polynomial approximation of degree 3 describes well interannual fluctuations of SIE and allows to take into account up to 72% of the total variance.

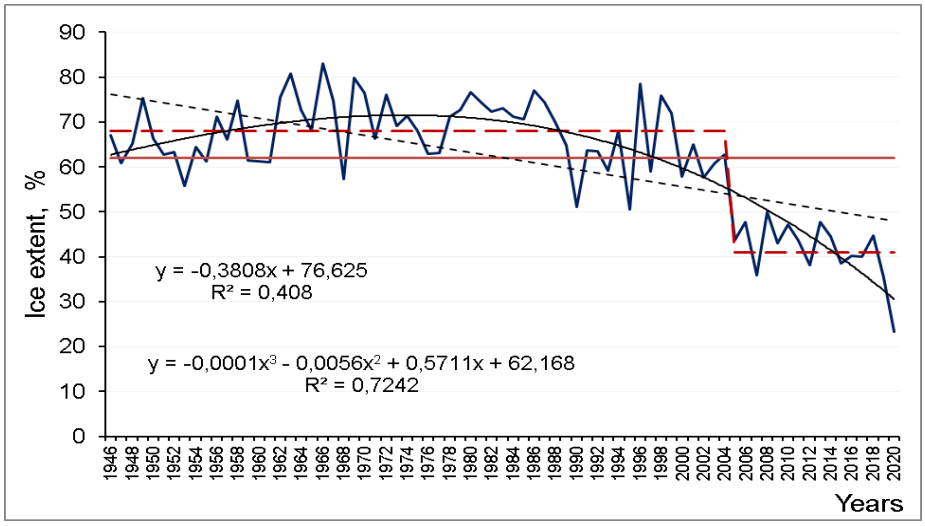

Figure 3. Interannual variability of seas averaged ice extent during summer season.

Some authors (Frolov et al., 2009; Karklin et al., 2001; Gudkovich et al., 2005;Ivanov et al, 2018) describe climate fluctuations in the Northern hemisphere during the XX century as an alternation of relative «cooling» and «warming» periods. During the «cool» period SIE increases (in the beginning of the century; 1960-1980s), while during the «warm» period sea ice cover decreases (1920-1950s; since the 1990s.). Sea ice cover reduction during last period was very intense. Some authors (Alekseev et al., 2015; Ashik et al., 2015) especially note significant changes of oceanic and atmospheric processes, positive air temperature anomaly and the rapid reduction of the ice cover since 2005. Figure 3 shows good agreement to previous investigations. On the plot time period, 1940-1950s is characterized by decrease SIE in Arctic seas, 1960-1980s shows enhanced SIE, and since 1990s SIE is reducing and then abruptly shrink since 2005.

Time series were tested for stationarity (the invariance of the statistical characteristics of the series in time) because of significant differences of SIE. Available observations were divided into two samples: 1946-2004. (59 values) and 2005-2020 (16 values). The non-equivalence of the samples does not contradict the stationarity checking requirements. Both samples were tested for stationarity by mathematical expectation and variance. Hypothesis of the series stationarity was rejected because Student's t-test showed the empirical value of the criterion is greater than the critical value for the significance level 0.01. The difference between the means of two samples is statistically significant, that allows us to consider period 2005-2020 as significantly dissimilar in comparison to 1964-2004 period.

Fischer's F-test of variances equality of two samples shows the opposite result: the empirical criterion is less than the critical value. Two samples variance comparison demonstrates similarity for 1946-2004 and for 2005-2020 periods. The difference of two variances (as variability degree) is statistically insignificant for a significance level of 0.01. The entire observations series since 1946-2020 is stationary by variance.

Changes of SIE in Russian Arctic seas during period 2005-2020 are distinguished as statistically significant in comparison to the period 1946-2004. Mean seasonal SIE during 1946-2004 is 68% with range of fluctuations 51%-83%. Mean level of SIE has abruptly decreased since 2005 of 26% or 1.6 times (to 42% with fluctuations range 23%-50%). The

current trend is sustainable and continues throughout recent period of 2005-2020. Characteristics of amplitude and standard deviation have changed slightly, SIE oscillates in a similar range, but at a lower mean level. All information is presented in Table 2.

Table 2. Main statistical characteristics of SIE (in %) in two investigated periods

Statistical characteristic	Average sea ice extent, %		
	Period 1946-2004	Period 2005-2020	Changes value (difference)
Mean, %	68	42	-26 (in 1,6 times)
Minimum, %	51	23	-28 (in 2,2 times)
Maximum, %	83	50	-23 (in 1,7 times)
Amplitude, %	32	27	-5 (in 1,2 times)
Standard deviation	7,4	6,5	-0,9 (in 1,2 times)

Seasonal changes of sea ice extent

The difference between two periods was found in averaged 10-days SIE values during the summer season (Table 3). SIE at the end of May is close to 90-100%, seas are completely covered by ice. Ice-free areas in the Laptev and the East Siberian seas appear mainly due to polynya development. In the Kara and the Chukchi seas vast ice-free areas often develop due to heat income from Atlantic and Pacific regions and melting processes.

Figure 4 shows seasonal course of SIE averaged for two periods (1946-2004 and 2005-2020) for summer season in the Russian Arctic seas. In 2005-2020 period more intense and earlier ice-clearing processes are detected in comparison to 1946-2004 period. Some authors (Gudkovich et al., 2013; Egorov , 2020) has already noted about these features of summer ice conditions development.

Table 3. Average sea ice extent (in %) for each 10-day period during the summer season in the Russian Arctic seas for two periods:1946-2004 and 2005-2020

Sea	Periods	Sea ice extent values by months 10-day periods (%)											
		June			July			August			September		
		1	2	3	1	2	3	1	2	3	1	2	3
Kara	1946 -2004	94	92	88	85	80	71	60	49	41	35	31	31
	2005-2020	86	80	73	60	49	32	22	14	9	6	5	5
	Difference	8	11	15	25	31	39	38	35	32	29	26	26
Laptev	1946 -2004	94	92	89	86	82	73	62	49	41	36	35	35
	2005-2020	86	81	76	69	59	43	28	18	12	8	7	7
	Difference	8	11	13	17	23	30	34	31	29	28	28	28
East-Siberian	1946 -2004	98	97	96	95	94	91	85	78	71	65	62	60
	2005-2020	95	94	93	92	87	75	53	40	27	20	15	13
	Difference	3	3	3	3	7	16	31	38	44	45	47	47
Chukchi	1946 -2004	91	85	72	63	52	42	34	29	23	19	18	16
	2005-2020	79	62	54	39	28	18	12	7	3	1	1	1
	Difference	12	15	18	24	23	24	22	22	21	18	17	15

Comparison between two periods indicates an earlier start of melting process during 2005-2020: the Kara, the Laptev and the Chukchi seas have 8-12% lower ice extent in comparison to 1946-2004 period. The East Siberian Sea has 3-5% lower (Table 3). Further this difference intense of ice cover decrease until the September.

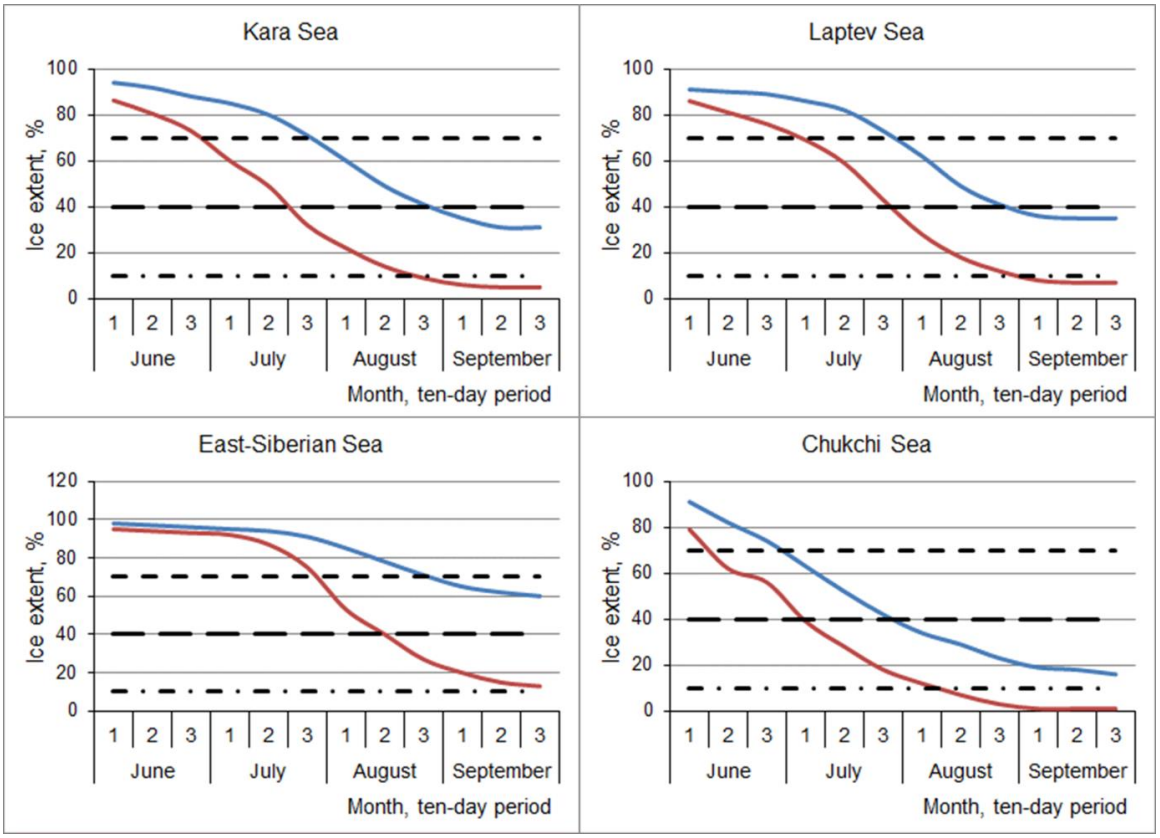

Figure 4. Seasonal course of sea ice extent averaged for periods 1946-2004 and 2005-2020

According to the NSR navigational rules the coastal areas become available for navigation of all ice categories vessels with a decrease of SIE up to 70% (Rules of navigation, revision 2020). During the period 1946-2004, the 70% SIE is reached in early July in the Kara and the Laptev seas, in early August in the East Siberian Sea, and in mid-June in the Chukchi Sea (Figure 4). Since 2005 it occurs in 2-3 10-days periods earlier

The most of navigational routes (coastal, central and offshore) become available after the clearing of 2/3 part of the sea. Therefore, reduction of ice cover to 30-40% is important. On average this event occurs in early July in the Chukchi Sea, in late July - early August in the Kara and the Laptev Seas, in mid-August in the East Siberian Sea. During the period 2005-2020 sea area clears about 3 decades earlier than in 1946-2004 period.

The earlier start and intensive melting process during summer season causes mostly ice free area (SIE less 10%) of Arctic seas to early September. Such event observed rare enough during the period 1946-2004: 20% of all years in Kara and Laptev Seas, 15% in East Siberian Sea, 40% in Chukchi Sea The repeatability of SIE less 10% increased since 2005: in Kara and Chukchi seas to 90%, in the Laptev Sea to 75%, in the East Siberian Sea to 60%.

Drifting residual and old ice edge shifts to the north significantly (1.0-2.0° in latitude, or 110-220 km) at the end of the melting period in September (Vinogradnyaya, 2020). Figure 5 shows seas entire northern part remained ice covered until the end of the XX century in September, during recent two decades has been completely and regularly cleared of ice cover. Figure 6 shows difference of the SIE for each summer 10-days period between 2005-2020 and 1946-2004 periods for 4 Russian Arctic seas. The plot allows assessing the intensity of SIE changes in summer during recent years

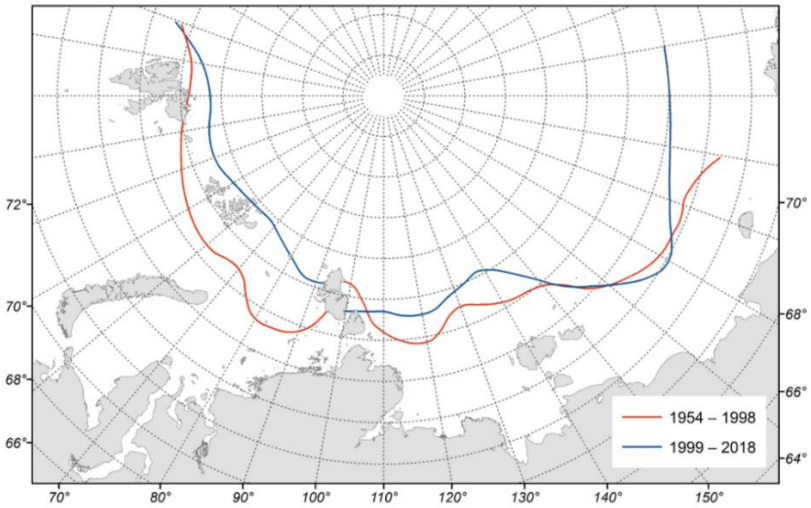

Figure 5. Repositioning of the drifting ice edge in September for two periods: 1954-1998 (red line) and 1999-2018 (blue line) (Vinogradnyaya, 2020)

The Kara and the Laptev seas have intense SIE decrease in comparison to 1946-2004 period of observations in the first half of summer. The difference maximum occurs in the end of July - beginning of August. SIE of the East Siberian Sea has changed slightly in the first half of summer. But since the beginning of August changes increase dramatically till maximum in September. Seasonal course of SIE changes smoother and plainer in the Chukchi Sea with some increasing during the middle of summer.

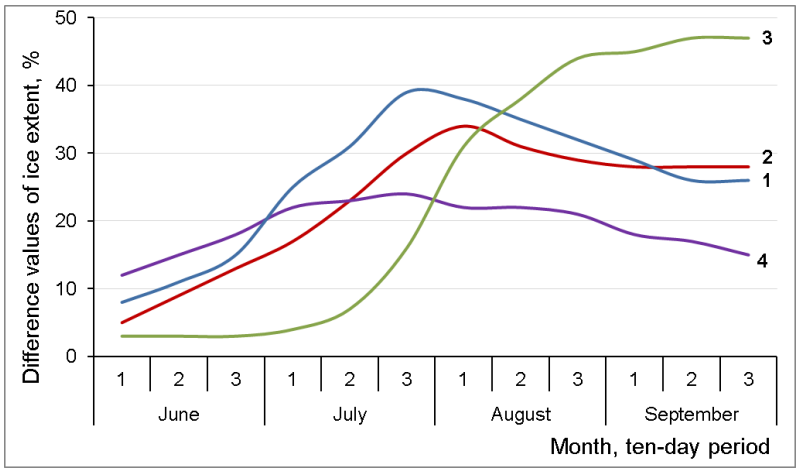

Figure 6. Decrease of average sea ice extent for each 10-days period of summer season during the period 2005-2020 in comparison to the period 1946-2004. (1-Kara Sea, 2-Laptev Sea, 3 – East Siberian Sea, 4 – Chukchi Sea)

CONCLUSIONS

Averaged SIE in the Russian Arctic Seas was analyzed for July-September period since 1946 for.All considered seas have strong interannual SIE variability. The amplitude varies from 58% (the Chukchi Sea) to 85% (the Laptev Sea), averaged by seas standard deviation is 17,3. SIE has well-defined and statistically significant negative trend, about 30% over the entire observations series or 4% over a decade. SIE decreased during 1940-1950s in the Arctic seas. 1960-1980s was a period of its enhancement, since 1990s SIE is reducing and abruptly shrink since 2005.

Time series were tested for stationarity. Two periods were selected for analysis: 1946-2004 and 2005-2020 periods with significant SIE changes . Both samples were tested for stationarity by mathematical expectation and variance. Student's t-test showed the difference between means of two samples is statistically significant, that allows to consider period 2005-2020 as significantly dissimilar in comparison to1946-2004 period. Fischer's F-test of variances equality of two samples demonstrates similarity of ice extent variability for 1946-2004 and 2005-2020 periods. The entire observations for 1946-2020 is stationary by variance. Thus changes in SIE during the period 2005-2020 are distinguished as statistically significant in comparison to the period 1946-2004. The mean level of SIE has abruptly decreased since 2005 by 26% or 1.6 times, but the amplitude and standard deviation have changed slightly. So SIE oscillates in a similar range but has a lower mean level. This investigation also confirms the definition of 2005 as the onset of a new phase accompanied by rapid reduction of the ice cover.

SIE changes in summer during the period 2005-2020 in the Arctic seas are exceptionally sustainable during the period 2005-2020 in the Arctic seas and have never been observed before in the Arctic seas for 75 years of observations. That allows us to distinguish this event as a special, extreme type of sea ice conditions development.

SIE for each 10-day period in summer were averaged for periods 1946-2004 and 2005-2020. A difference between the periods was found. The earlier start and the more intensive and faster-clearing process was determined of the Arctic seas. This lead to the earlier (25-30 days) sea clearance from ice and also to ice-free period duration extension. The sea's total clearance from ice frequency increased significantly (to 60-90%). The residual and old ice edge has shifted toward the north in September.

The changes in the intensity of SIE in summer during recent years were assessed. The most intense decrease of SIE was revealed in the first half of summer in the Kara and the Laptev Seas, in the second half of summer in the East Siberian Sea, and smoother enough during the whole summer in the Chukchi Sea. Earlier sea ice melting (about 30 days) plays a great role in navigation for vessels of all ice categories.

REFERENCES

Alekseev G.V., Aleksandrov E.I., Glok N.I., Ivanov N.E., Smolyanickij V.M, Harlanenkova N.E., Yulin A.V., 2015. Arctic Sea Ice Cover in Connection with Climate Change., *Izvestiya, Atmospheric and Oceanic Physics*, vol. 51, no. 9, pp. 889–902. (in Russian). https://doi:10.1134/S0001433815090029.

Alekseev, G. V., Radionov, V. F., Alexandrov, E. I., Ivanov, N. E., and Kharlanenkova, N. E., Climate change in the Arctic under global warming. *Arctic and Antarctic Research*. 2015. № 1(103): 32-42. (in Russian)

Ashik I. M., Ivanov V. V., Kassens H., Makhotin M. S., Polyakov I. V. General results of Arctic Ocean oceanological studies in the last decade. *Arctic and Antarctic Research*. 2015. № 1(103): 42-56. (In Russ).

Boradachev V.Ye., Shilnikov V.I. History of air reconnaissance in the Russian Arctic. SPb.: *Gidrometeoizdat,* 2001. (in Russian).

Comiso, J.J. Large decadal decline of the arctic multiyear ice cover. *J. Clim*. 2012, 25, 1176–1193.

Dumanskaya I.O., 2017. Ice conditions of the seas of the Asian part of Russia. *Moscow: IG–SOCIN*, 640 p. (in Russian).

Egorov A.G., 2020. The Russian Arctic seas ice age composition and thickness variation in winter periods at the beginning of the 21st century. *Arctic and Antarctic Research*. 66(2), pp. 124-143. (in Russian) https://doi.org/10.30758/0555-2648-2020-66-2-124-143.

Egorov A.G., Pavlova E.A. Change in the time of stable ice formation in the Russian Eastern Arctic seas at the beginning of 21st century. *Arctic and Antarctic Research*. 2019; 65(4):389-404. (in Russian.) https://doi.org/10.30758/0555-2648-2019-65-4-389-404

Frolov I., Gudkovich Z., Karklin V., Kovalev E. Smolyanitsky V., 2009. Climate Change in Eurasian Arctic Shelf Seas. Centennial Ice Cover Observations. *Praxis Publishing Ltd. UK, Chichester*.

Gudkovich Z. M., Karklin V. P., and. Frolov I. E., 2005. Intra-Secular Changes of Climate and the Ice Cover Area of the Eurasian Arctic Seas and Their Possible Causes. *Meteorology and Hydrology*, 6, pp.5-14. (in Russian).

Gudkovich Z.M., Karklin V.P., Mironov E.U., Ivanov V.V., Losev S.M., 2013. Development of ice and weather conditions in the Arctic during 2007–2013. *Arctic and Antarctic Research*, 96 (2), pp. 90–103. (in Russian).

Gudkovich Z.M., Kirillov A.A., Kovalev E.G., Smetannikov A.V., Spichkin V.A., 1972. Basics of long-term forecasting methods for the Arctic seas. *Gidrometeoizdat*: Leningrad. (in Russian).

Ivanov V. V., Alekseev V. A., Alekseeva T. A., Koldunov N. V., Repina I. A., Smirnov A. V., 2013. Does Arctic Ocean Ice Cover Become Seasonal? *Issledovaniya Zemli iz Kosmosa*, 4, pp. 50–65. (in Russian).

Ivanov V.V., Alekseyenkov G.A., Korzhikov A.Ya., 2018. On improvement of the microcirculation method for long-range weather forecasting in the Kara Sea. *Hydrometeorological research and Forecasts* (*Trudy Hydrometcentra Rossii*), №4 (370), pp. 105-121. ISSN 2618-9631 (in Russian.).

Karklin V.P., Yulin A.V., Karelin I. D., Ivanov V.V. Climatic fluctuations of ice cover extent in the Siberian shelf Arctic seas. *Trudy AANII*. Proc. AARI. 2001, 443: 05-11. (in Russian).

Kwok R., Cunningham G.F., Wensnahan M., Rigor I., Zwally H.J., Yi D., 2009. Thinning and volume loss of the Arctic Ocean sea ice cover. *Journal of Geophysical Research*. Vol. 114. № C07005. https:// doi:10.1029/2009JC005312.

Kwok R., Untersteiner N., 2011.The thinning of Arctic sea ice. *Physics Today* , 64, pp. 36–41. https://doi.org/10.1063/1.3580491.

Manual for the accomplishment of ice air reconnaissance. - L.: *Gidrometeoizdat*, 1981

Petty, A. A., Stroeve, J. C., Holland, P. R., Boisvert, L. N., Bliss, A. C., Kimura, N., and Meier, W. N.: the Arctic sea ice cover 2016: a year of record-low highs and higher-than-expected lows, *The Cryosphere*, 12(2), 433-453, http://doi.org/10.5194/tc-12-433-2018, 2018.

Ricker, R., Hendricks, S., Girard-Ardhuin, F., Kaleschke, L.,Lique, C., Tian-Kunze, X., Nicolaus, M., and Krumpen,T.: Satellite observed drop of Arctic sea ice growth in winter 2015–2015, *Geophys. Res. Lett.*, 44, 3236–3245,https://doi.org/10.1002/2016GL072244, 2017a.

Rules of navigation in the waters of the Northern Sea Route (revision 2020), *Ministry of Transport of Russia,* 2020. Moscow. (in Russian).

Serreze, M. C., Stroeve, J., Barrett, A. P., and Boisvert, L. N.: Summer atmospheric circulation anomalies over the Arctic Ocean and their influences on September sea ice extent: A cautionary tale, J. *Geophys. Res.-Atmos.*, 121, 11463–11485, https://doi.org/10.1002/2016JD025161, 2016.

Stroeve J. C., Markus, T., Boisvert, L., Miller, J., and Barrett, A., 2014. Changes in Arctic melt season and implications for sea ice loss. *Geophysical Research Letters.,* 41(4), pp. 1216-1225, https://doi:10.1002/2013GL058951.

Stroeve J. C., Serreze, M. C., Holland, M. M., Kay, J. E., Malanik, J., and Barrett, A. P., 2012: The Arctic's rapidly shrinking sea ice cover: a research synthesis. *Climate Change*, 110, pp. 1005–1027, https://doi:10.1007/s10584-011-0101-1.

Stroeve, J. C., Markus, T., Boisvert, L., Miller, J., and Barrett, A.: Changes in Arctic melt season and implications for sea ice loss. *Geophys. Res. Lett.*, 41(4), 1216-1225, http://doi.org/10.1002/2013GL058951, 2014.

Timofeeva, A., Ivanov, V., Yulin, A., and Khotchenkov, S., 2020. Multiyear variability of atmospheric processes and ice cover in the Laptev Sea since 1942 to 2019, *EGU General Assembly 2020*, Online, EGU2020-12269. https://doi.org/10.5194/egusphere-egu2020-12269.

Tretyakov V.Yu., Frolov S.V., Sarafanov M.I., 2019. The variability of ice conditions along the northern sea route for the period 1997-2018. *Arctic and Antarctic Research*, 65 (3), pp. 328-340. (in Russian). https://doi.org/10.30758/0555-2648-2019-65-3-328-340.

Vinogradnaya E. S., Egorova E. S., Sheveleva T. V., Yulin A.V. Variability of the spring old ice and fall residual ice boundary in the Arctic Ocean over the current period of climate changes // *Russian Arctic*. - 2020. - No. 9. - pp. 41-55. (In Russian). https://doi:10.24411/2658-4255-2020-12094.

Yulin A.V., Timofeeva A.B., Pavlova E.A., Sharatunova M.V., Hotchenkov S.V., 2019. Interannual and seasonal changes the ice cover in the Russian Arctic seas in the modern climatic period. *Proceedings of the VI All-Russian Conference on Applied Oceanography*. *Trudy GOIN № 220*, pp. 44-60. ISSN: 0371-7119 (in Russian.).

Yulin A.V., Vyazigina N. A., Egorova E. S. Interannual and seasonal variability of the Arctic sea ice extent according to satellite observations // *Russian Arctic*. - 2019. - No. 7. - p. 26-35 (in Russian). https://doi:10.24411/2658-4255-2019-10073.