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ACCESS

Arctic Climate Change, Economy and Society

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Thematic Priority: Ocean.2010-1 “Quantification of climate change impacts on economic sectors in the Arctic”

D2.11 – Historical ice conditions and its influence on navigation on NSR

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PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	X

Contents

1 Analysis the historical data of ice conditions of navigation along the Northern Seas Route during XX and beginning of the XXI centuries

The Northern Sea Route passes through the Kara, Laptev, East-Siberian and Chukchi Seas with total length of navigation through the open water of 3277 nautical miles. It stretches from the straits of Novaya Zemlya and the meridian of the Cape Zhelaniya in the west to the Bering Strait in the east (66°00′ N, 168°58′37″ E).

Selection of the best navigational route is determined by its economical efficiency of the exploitation. Therefore the optimal navigational route is selected by a vessel according to the current hydrometeorological and ice conditions, minimal consumed time and expenses, maximal safety of the vessel and transported cargo (Buzuev et all. 1988).

During the autumn-spring period the most important parameter to select an optimal navigational route is ice conditions. The following sea ice characteristics are mostly influencing on the selection:

- minimal total ice concentration;
- minimal hummocks concentration;
- maximal stage of ice melting;
- minimal size of the ice floes;
- maximal amount of the young ice;
- presence of the polynyas, leads and cracks.

The Northern Sea Route is a wide area covered the Siberian Arctic Seas and somewhere boundary parts of the Arctic Basin. Multiyear experience of navigation in the Arctic Seas determined the main variants of the routes at which favorable conditions for shipping can form. These routes have now modern hydrographic support and are the recommended (“standard”) routes. However in reality the best (optimal) route differs from the standard route depending on the ice and weather conditions. In most cases, the optimal route is either a combination of the segments of recommended routes or is one of them. Figure 1 shows standard routes of navigation in summer and winter.

As a first part of the work in the frame of the ACCESS project the ice conditions along the easiest navigational routes of the NSR are analysed.

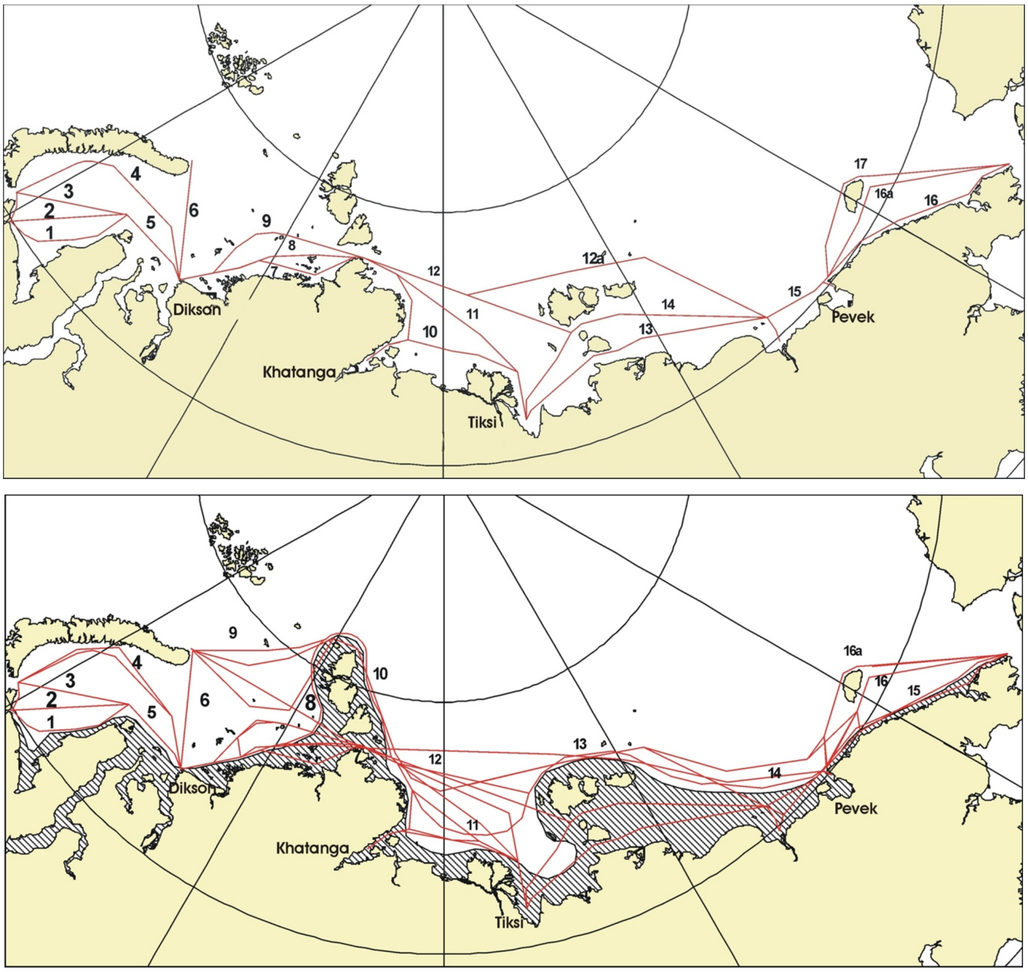


Figure 1 Location of the standard navigation routes along the NSR

1.1 Classification of the ice conditions of navigation

Sea ice characteristics are analyzed in two ways to define various conditions of navigation: are calculated as average multiyear values or grouped by types. Grouping by types gives more detailed and significant imagination about ice conditions along the NSR. There are three types of ice conditions: easy, average and difficult.

In June-October first-year ice is prevailed along the NSR, its concentration and area is changing temporary and spatially. The most difficult navigation is passing through the ice with total concentration of 9-10 tenths (very close and compact ice), 7-8 tenths (close ice) and fast ice. Therefore the major parameter characterized ice conditions of navigation during this period is total ice concentration.

In February-May the whole NSR is covered by close and compact ice of various ages. Total ice concentration is changing slightly and is not the important parameter characterizing the condition of ice navigation. The difficulties of ship motion are increasing in relation to increase of ice age (i.e. thickness) as total ice concentration remains changeless. Therefore the classification during this period is based on ice age.

1.2 Data and methods

Table A1 (attachments). In the table A1 statistics (mean, maximal and minimal values, standard deviation) of the percentage of different ice concentration, ice thickness, hummocks concentration and ice melting stage along the Northern Sea Route (with total length from the Kara Gate to the Bering strait of 3277 nautical miles) during the June-October are shown.

Information was obtained by visual air reconnaissance in second decade of each month from 1946 to 1979. Length of the route in different ice conditions chosen on the easiest way for navigation along the standard routes of the NSR was used as initial data for processing.

Regular air reconnaissance was organized in the USSR in 1934 monthly during the summer period and once per some months of the winter period. During 1930th-1960th the frequency of flights was predominantly once per month and later it had been increased to 2-3 times per month. Beginning from 1960th air reconnaissance had been done every 5-10 days during the summer period.

In 1970th – 1980th new instrumental methods started to be applied – aerial photography and side-looking radar. From the beginning of 1970th remote sensing methods were developed and satellite data were included to the air reconnaissance maps. At the beginning of 1990th air reconnaissance was over and satellite data became to be the base information for the sea ice AARI charts.

Sea ice thickness, hummocks concentration and stage of ice melting were determined for the prevailed ice, i.e. first-year ice.

Total ice concentration (percentage of the sea surface covered by ice). Its value is estimated visually in tenths, where 1 tenth corresponds to 10% sea surface covered by ice, but in terms of navigation the main gradations are: 0 - open water, 1-3 - very open ice, 4-6 – open ice, 7-8 – close ice, 9-9.5 - very close ice and 10 - compact pack ice.

Hummocks concentration is observed using a Russian 5-point scale (1 point ~ 20% of sea surface covered by hummocks), where hummocks concentration equal 0 corresponds to level ice; 5 points means that the ice cover is completely covered by hummocks.

The estimation of the stage of ice melting is based on the account of the external characteristics describing changes of ice surface as a result of its melting: occurrence of the melt ponds and stage of theirs development, presence of snow cover, etc. Stage of ice melting of the ice cover is estimated by a Russian national 5-unit scale. The stage of ice melting equal 0 corresponds to no ice melting, 1-2 units – first melt ponds, 2-3 – ice surface is getting darker, more melt ponds are appearing, 3-4 – snow melted, maximum melt ponds on the ice surface, surface starts drying, 4-5 – melt ponds melted through, surface is dry, ice formations are deeply sunk in water, and the snow is gone (Guide, 1981).

Tables A2-A6 (attachments). The other database has been used to get data for the Tables A2-A6. Complex information from sea ice charts, obtained by visual air reconnaissance, and satellite images was averaged monthly during the period 1970-2001. Amount of air reconnaissance since 1970 reduced, and the most part of information about sea ice along the NSR was obtained from satellite images. This fact allowed us to process less amount of sea ice parameters: total ice concentration and amount of fast ice.

Ice concentration for the period 1970-2011 was determined as for the whole length of the NSR as for separate areas of the NSR. The NSR was separated by areas according to the positions of the largest ice massifs (Table 1, Figure 2):

Table 1. Parts of the NSR.

Parts of the NSR	Borders
Novozemelskiy (NZ)	South-western Kara Sea. Borders: straits of the Novaya Zemlya archipelago (in winter – ice edge in the Barents Sea) – line connected cape Gelaniya and Dikson island.
Severozemelskiy (SZ)	North-eastern Kara Sea. Borders: line connected cape Gelaniya and Dikson island – cape Cheluskin (in winter-spring period – eastern fast ice edge in the Vilkitskiy strait)
Taymirskiy (T)	Laptev Sea. Cape Cheluskin (in winter-spring period – eastern fast ice edge in the Vilkitskiy strait) - the line of longitude 140E.
Novosibirskiy (NS)	Western East-Siberian Sea. The line of longitude 140E - the line of longitude 160E.
Aionskiy (A)	Eastern East-Siberian Sea. Line of longitude 160E – the line connecting cape Billings and cape Blossom (Vrangel island).
Vrangelevskiy (Vr)	Chukchi Sea. The line connecting cape Billings and cape Blossom (Vrangel island) – Bering strait.

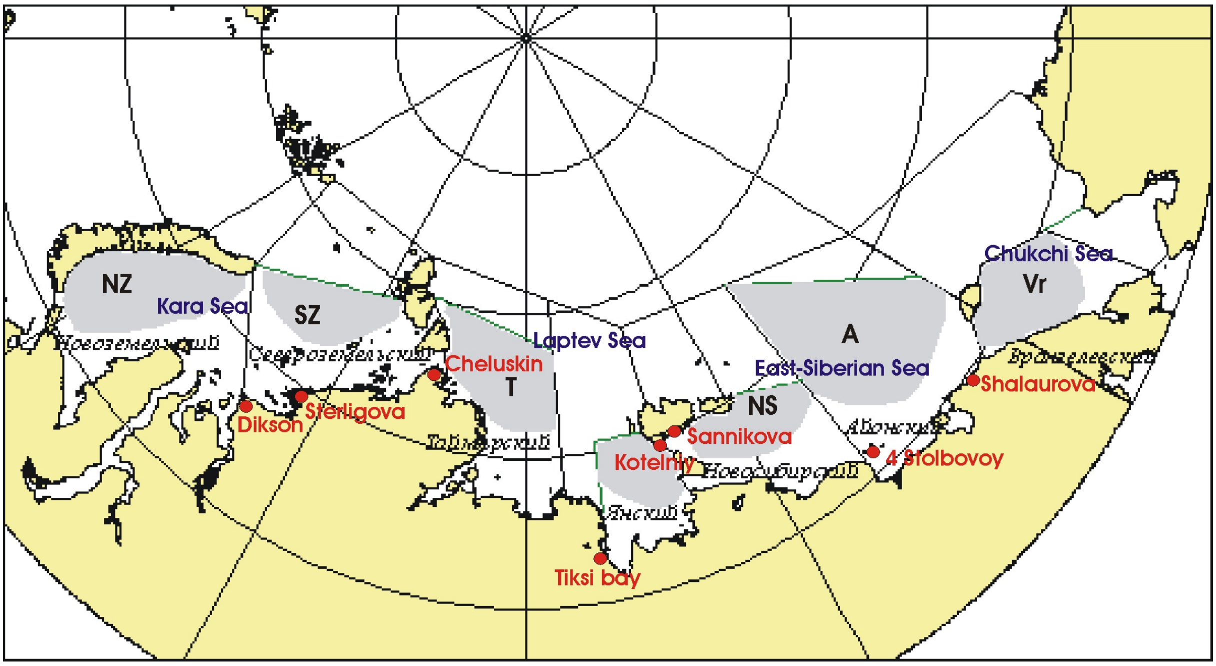


Figure 2. Scheme of the parts of the NSR according to positions of the main ice massifs in the Arctic Seas (remark: in the south-western Laptev Sea is Janskiy massif, it is not in the Table 1, because of the NSR is passing to the north of thismassif). NZ – Novozemelskiy, SZ – Severozemelskiy, T – Taymirskiy, NS – Novosibirskiy, A – Aionskiy, Vr – Vrangelevskiy ice massifs.

1.3 Results

1.3.1 1946-1979 data massive (Table A1)

Based on Table A1 (see attachments) the most favourable ice conditions for the transit navigation are forming in summer period, particularly in August-September, when length of the compact ice along the NSR is reaching the minimal values. However, favourable conditions of navigation are only forming during the easy years (its repeatability in August and September is 61 and 67% correspondingly), when length of the compact ice along the NSR is decreasing to 12-84 miles. The summer ice is usually destroying because of melting and it is presented by separate narrow dams, distributed along the whole NSR. In some years compact ice can be absent at all, resulted to possibility of non-icebreaking navigation. But years with easy ice conditions are not often. During the years with average ice conditions (repeatability in August and September 30%) the length of navigational route is 438 and 358 miles correspondingly. During the years with difficult ice conditions (repeatability in August and September 9 and 3%) the length of compact ice along the NSR is more than 700 miles.

1.3.2 1970-2011 data massive (Tables A2-A6)

The most important sea ice parameter for navigation during the summer period is total ice concentration. This period the distribution of total ice concentration significantly influences on selection of the optimal navigational route and values of ice concentration are used as a criterion of icebreaker support conditions.

The mostly difficult navigation is occurred in the fast ice and very close and compact ice (with total ice concentration more than 9 tenths). The length of navigational routes in such ices during the summer-autumn navigational period is presented in Figures 3-7.

In spite of high interannual variability of this characteristic, in 1970-2011 the definite negative trend of the length of navigation in the most difficult ice conditions is observing. The most important contribution to this tendency is made by sea ice changes during the period 2005-2011.

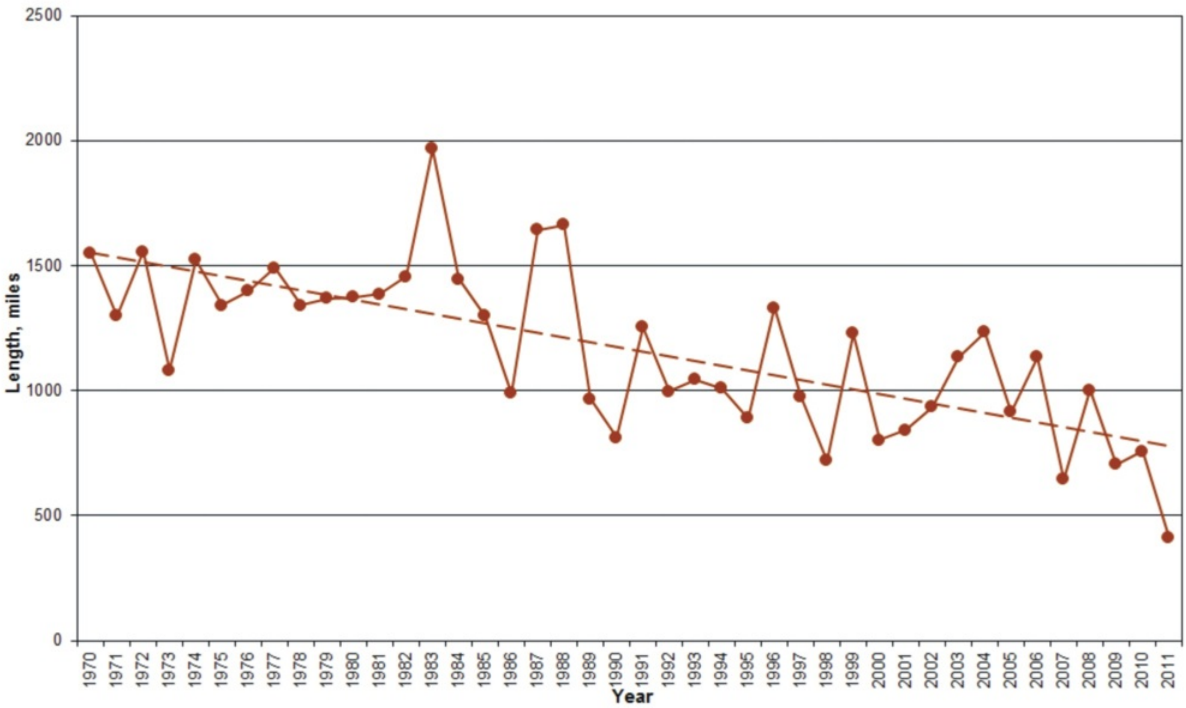


Figure 3. Length of the navigation route in floating ice with total ice concentration more than 9 tenths and in fast ice in June

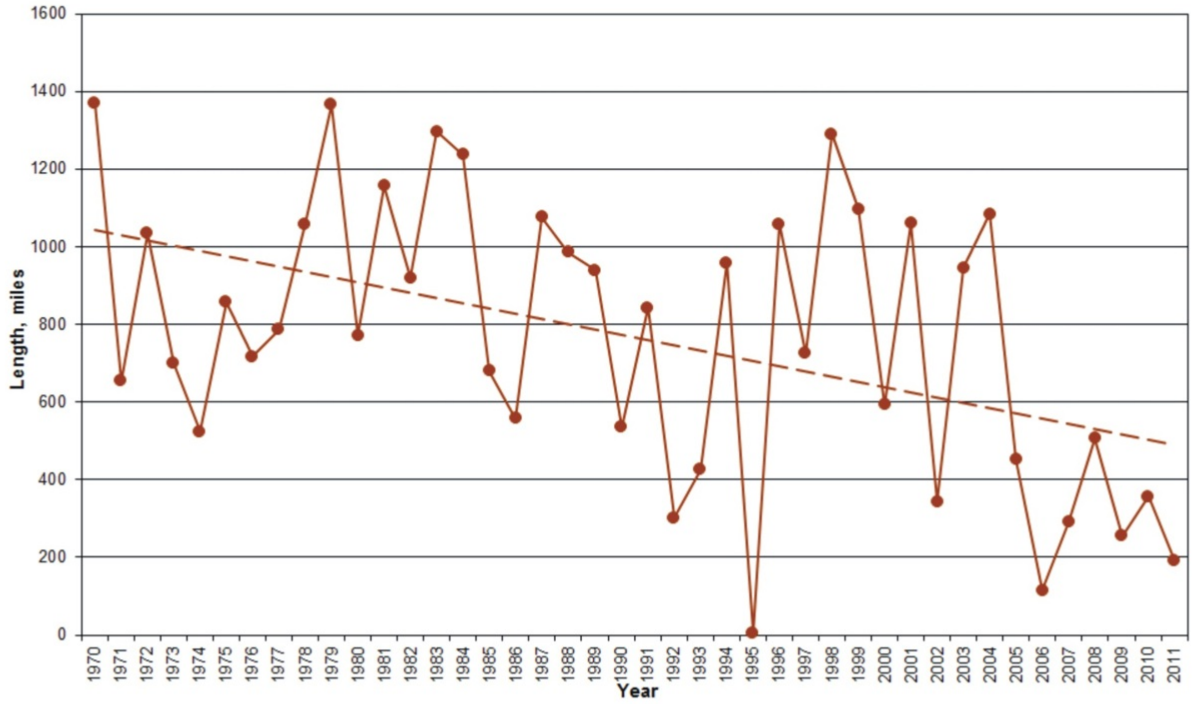


Figure 4. Length of the navigation route in floating ice with total ice concentration more than 9 tenths and in fast ice in July

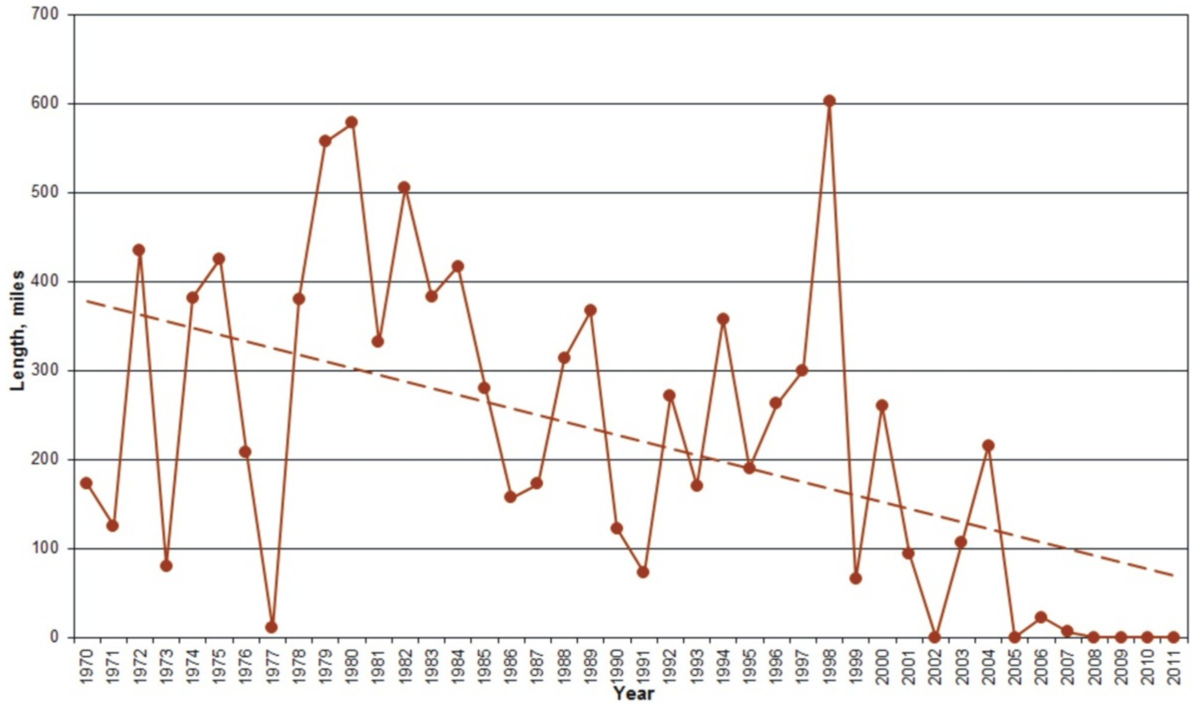


Figure 5. Length of the navigation route in floating ice with total ice concentration more than 9 tenths and in fast ice in August

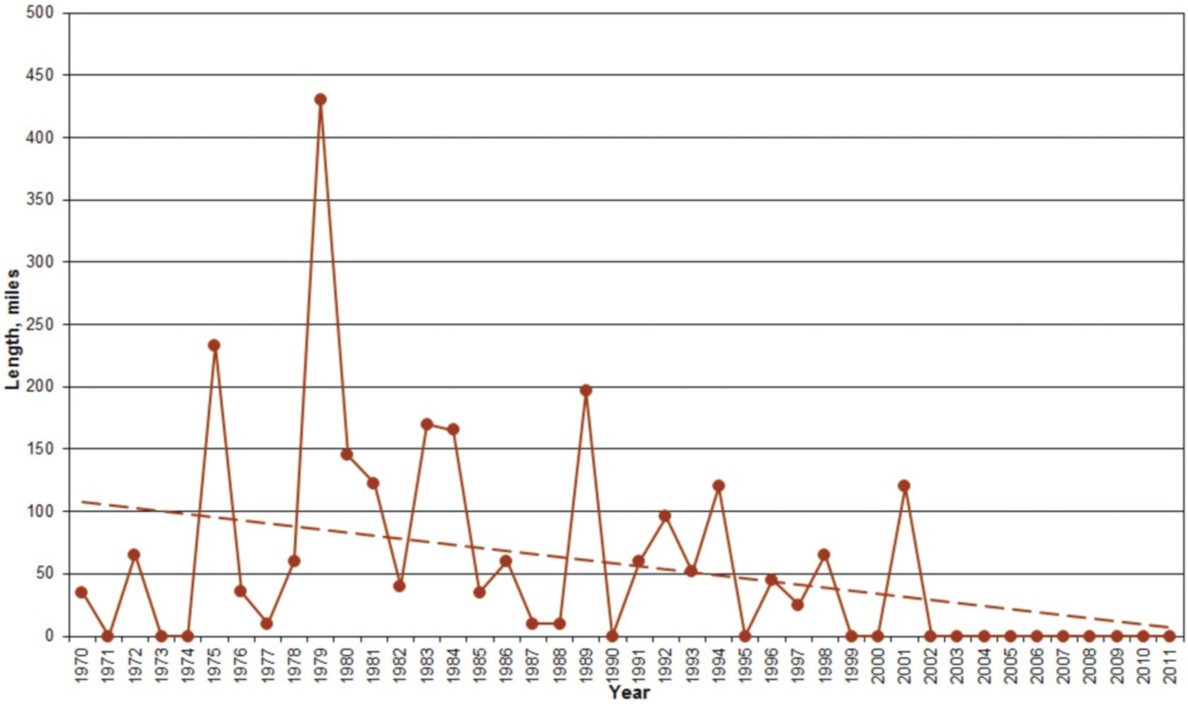


Figure 6. Length of the navigation route in floating ice with total ice concentration more than 9 tenths and in fast ice in September

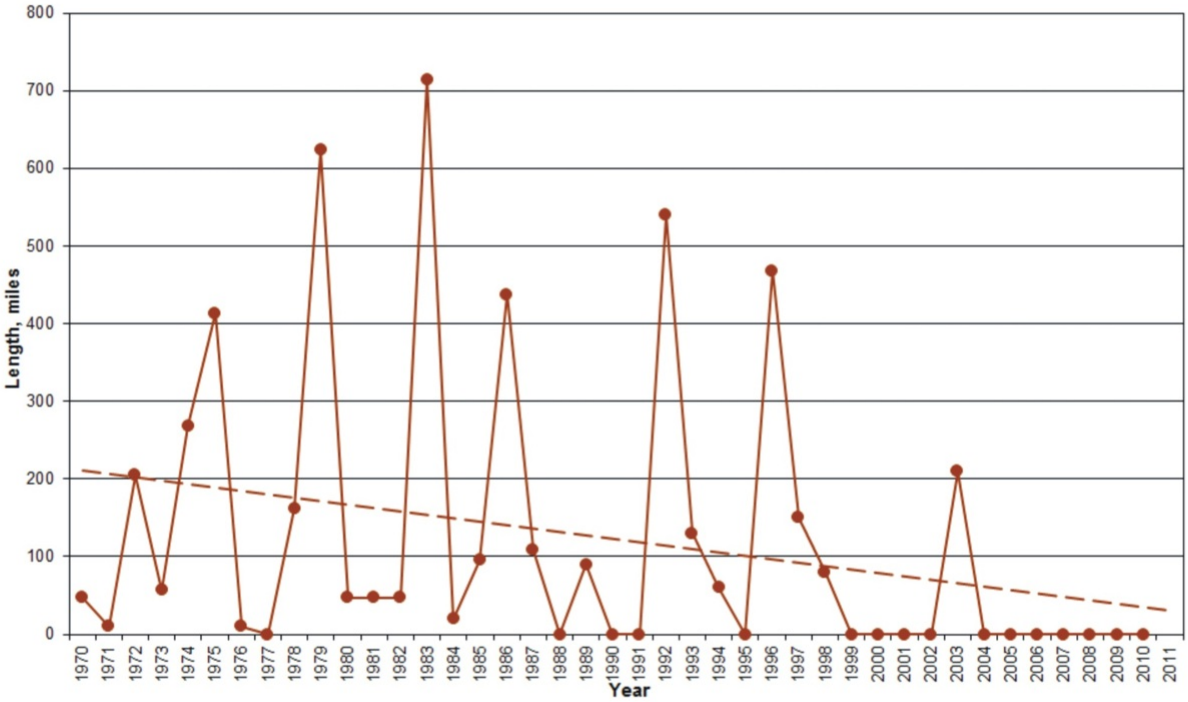


Figure 7. Length of the navigation route in floating ice with total ice concentration more than 9 tenths and in fast ice in October

Statistics of the navigational route length variability in the most difficult conditions along the whole NSR are presented in Table 2.

Table 2. Statistics of the length of navigation in the floating ices with total ice concentration more than 9 tenths and in fast ice along the NSR, miles

Month	Minimum	Maximum	Average	Standart deviation, σ
June	412	1967	1165	325
July	5	1369	765	361
August	0	602	224	178
September	0	430	58	86
October	0	713	123	189

The values of standard deviation of the navigational route length in the most difficult conditions shows that even during the favorable period (2000-2011) and in the summer period very difficult ice conditions of navigation can episodically form along some parts of the NSR (Figures 8-12).

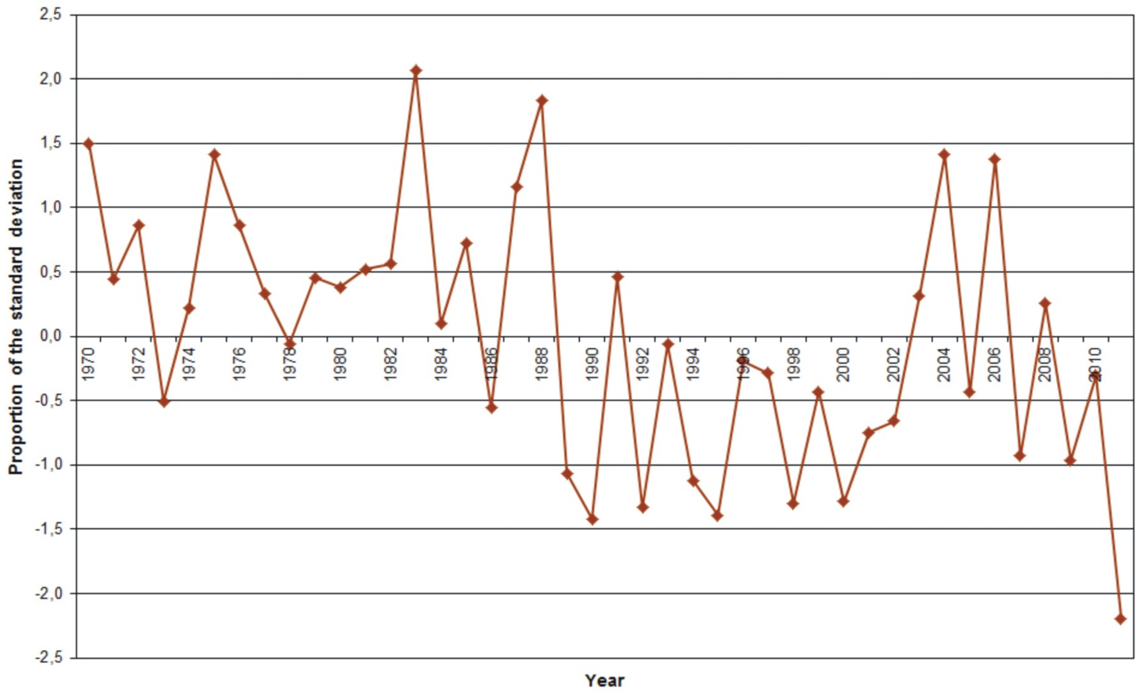


Figure 8. Variability of proportion of the standard deviation $\sigma_{9\text{-}10,\ \text{fast ice}}$ in June

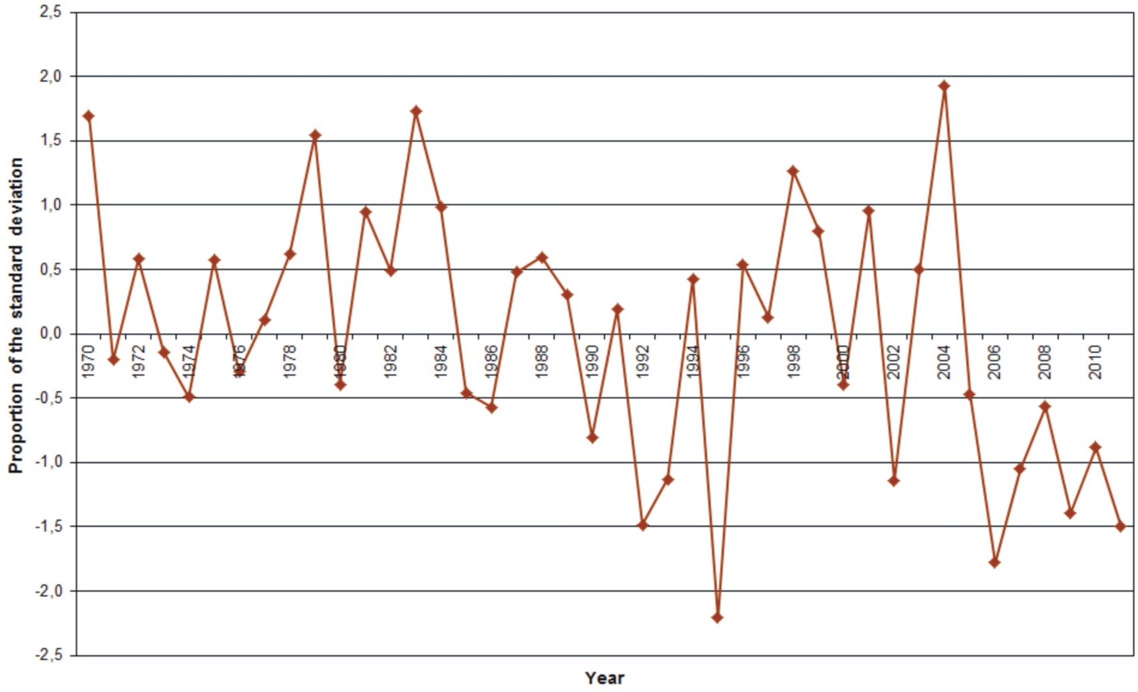


Figure 9. Variability of proportion of the standard deviation $\sigma_{9\text{-}10,\ \text{fast ice}}$ in July

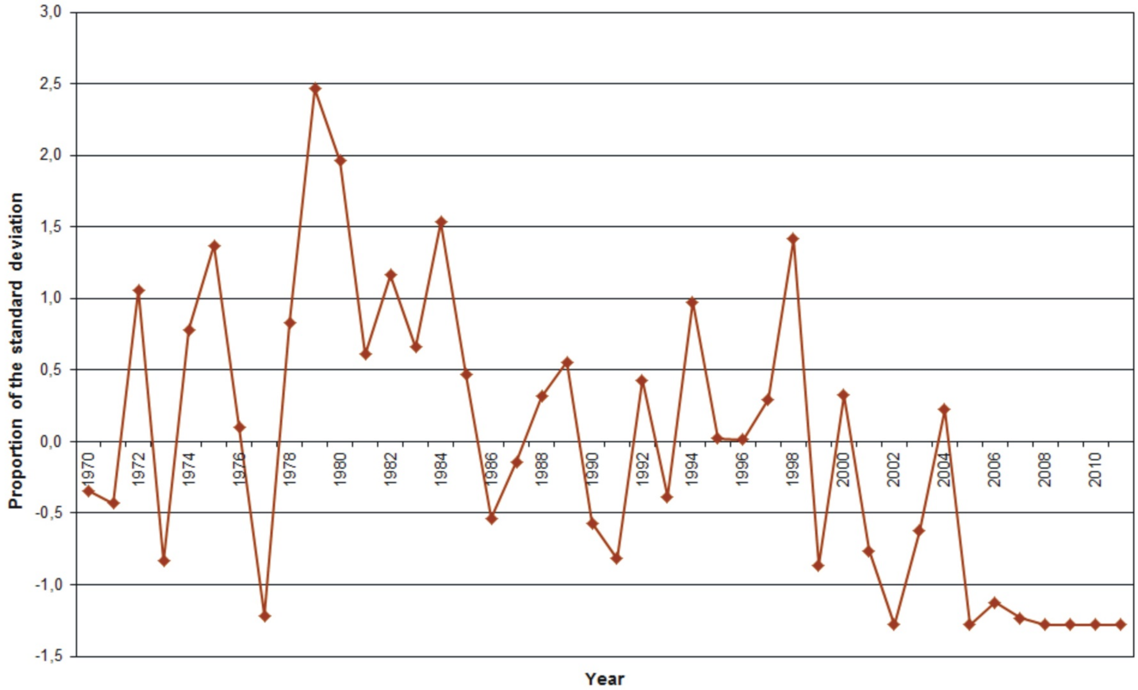


Figure 10. Variability of proportion of the standard deviation $\sigma_{9\text{-}10,\ \text{fast ice}}$ in August

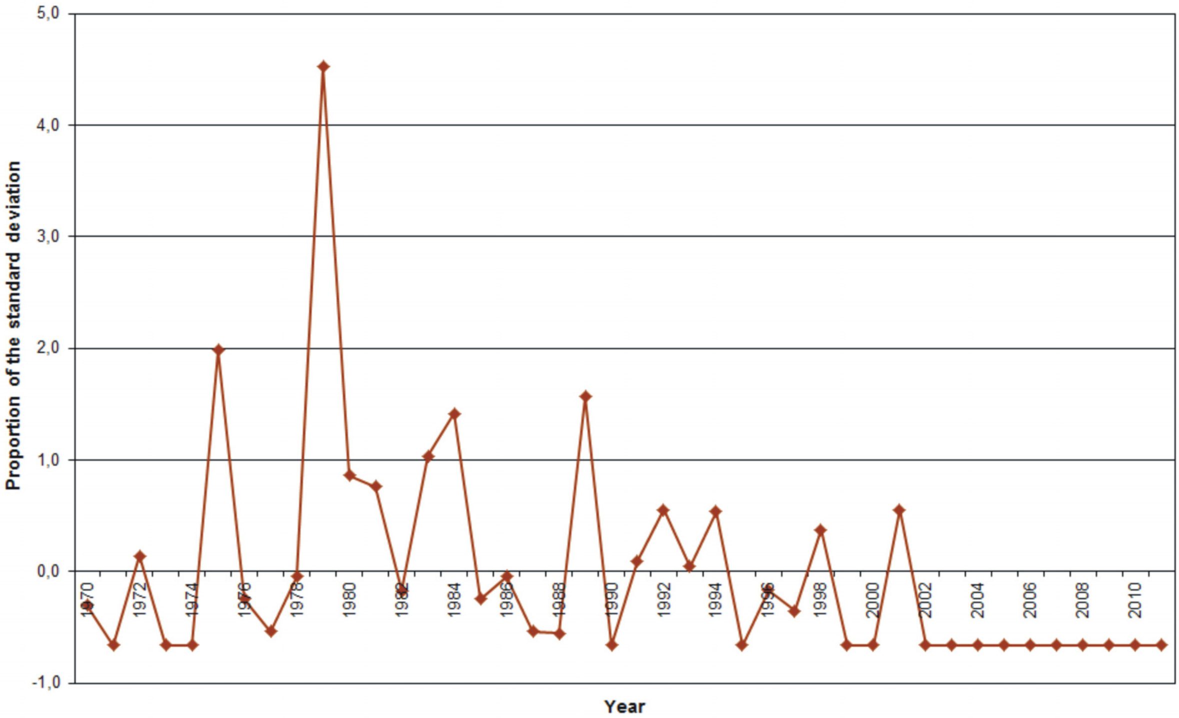


Figure 11. Variability of proportion of the standard deviation $\sigma_{9\text{-}10,\ \text{fast ice}}$ in September

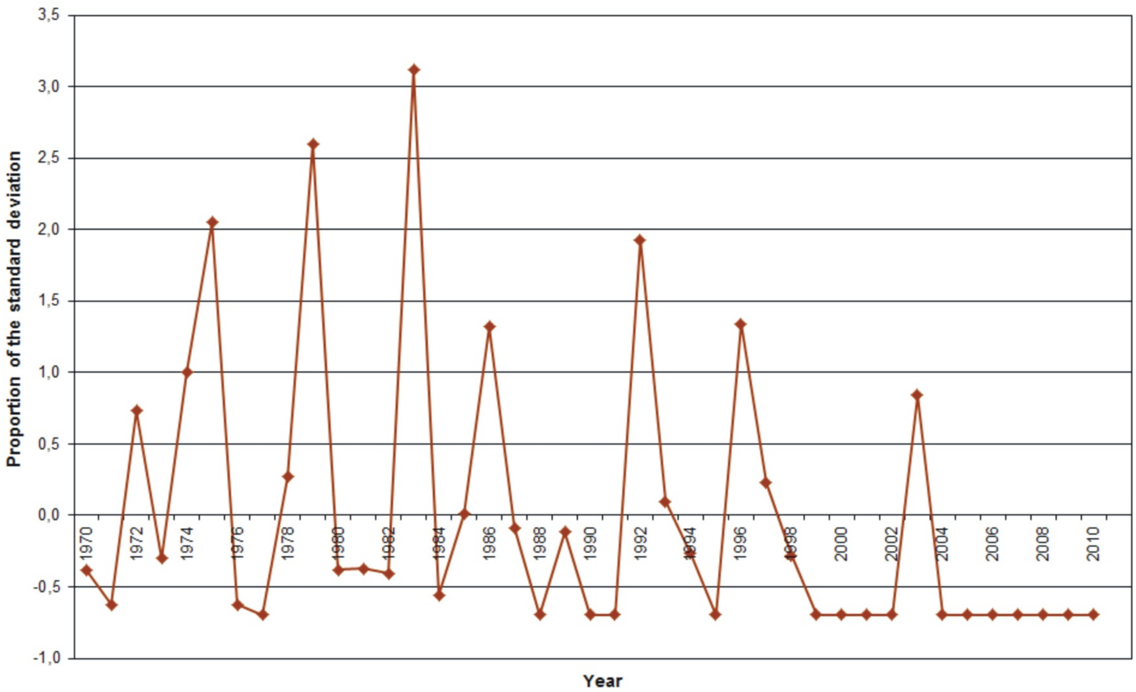


Figure 12. Variability of proportion of the standard deviation $\sigma_{9\text{-}10,\ \text{fast ice}}$ in October

If we take $\sigma_{9\text{-}10,\ \text{fast ice}}$ as a measure of the difficult ice conditions we get an imagination about dynamic of the ice difficulties during the periods 1970-1879, 1980-1989, 1990-1999 and 2000-2011 (Table 3).

Table 3. Repeatability of the major positive and negative anomalies of the navigational route length in floating ice with total ice concentration more than 9 tenths and in fast ice during the period 1970-2011 along the NSR and its parts in summer period (amount of years)

Month	Period	The total NSR		Western part if the NSR		Eastern part of the NSR	
		Positive	Negative	Positive	Negative	Positive	Negative
June	1970-1979	2	0	1	0	3	0
	1980-1989	3	1	4	1	3	3
	1990-1999	0	5	0	2	1	3
	2000-2011	2	2	1	2	1	4
July	1970-1979	2	0	2	0	2	1
	1980-1989	1	0	1	1	2	0
	1990-1999	1	3	1	2	1	3
	2000-2011	1	5	2	3	1	4
August	1970-1979	3	1	2	1	3	0
	1980-1989	3	0	3	1	5	0
	1990-1999	1	0	2	1	1	0
	2000-2011	0	8	1	7	0	0
September	1970-1979	2	0	1	0	2	0
	1980-1989	3	0	3	0	2	0
	1990-1999	0	0	1	0	0	0
	2000-2011	0	0	1	0	0	0
October	1970-1979	3	0	2	0	2	0
	1980-1989	2	0	0	0	2	0
	1990-1999	2	0	1	0	1	0
	2000-2011	0	0	1	0	0	0

The most important conclusion is about significant increase of the repeatability of the years with negative anomaly of the $\sigma_{9\text{-}10,\ \text{fast ice}}$ since 1990. This tendency is distinctly observing during June-August. At the same time the repeatability of the years with positive anomaly is changing insignificantly. Consequently, in spite of summer improving of the ice conditions along the western and eastern parts of the NSR the repeatability of difficult ice conditions is in general persisting (Table 3).

The other important parameter is length of the navigational route through the open water along the NSR. This parameter as well as lengths of the navigation in the compact and fast ice is used to define the necessary ice class of the vessels and planning of the icebreaker support.

The values of navigational route length through the open water presented in Figures 13-17 show its increasing during 1970-2011. The mostly distinct positive trend is observing during the period of maximal ice melting – in August and September (Figures 15 and 16).

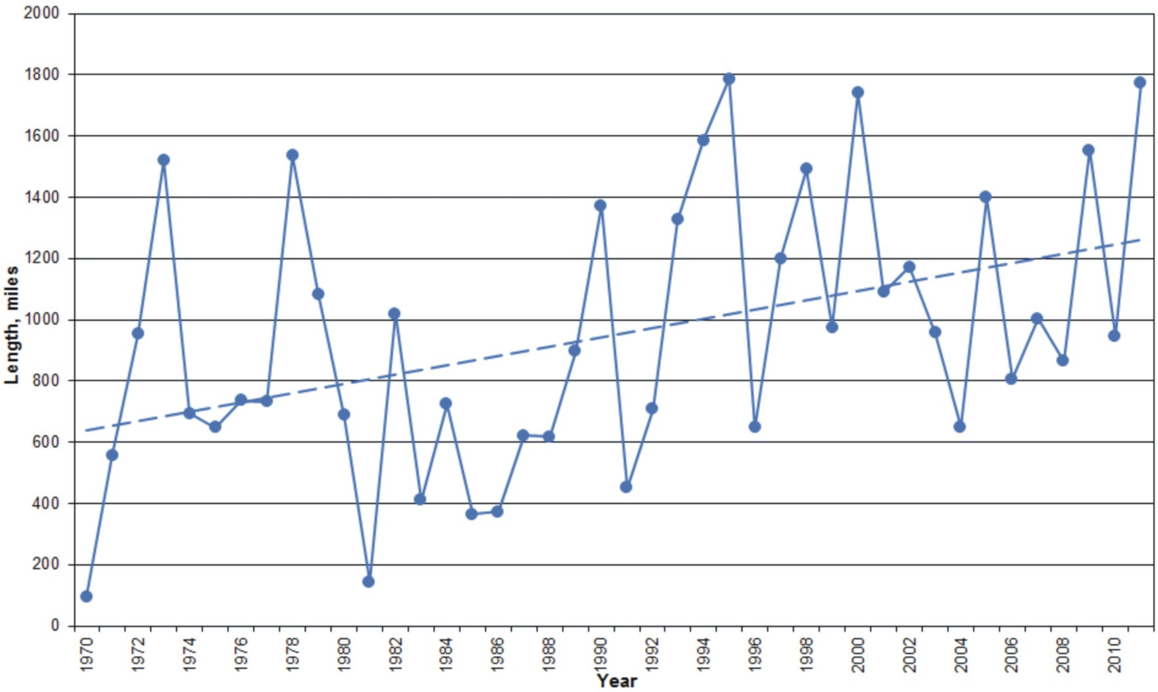


Figure 13. Length of the navigation route through the open water in June

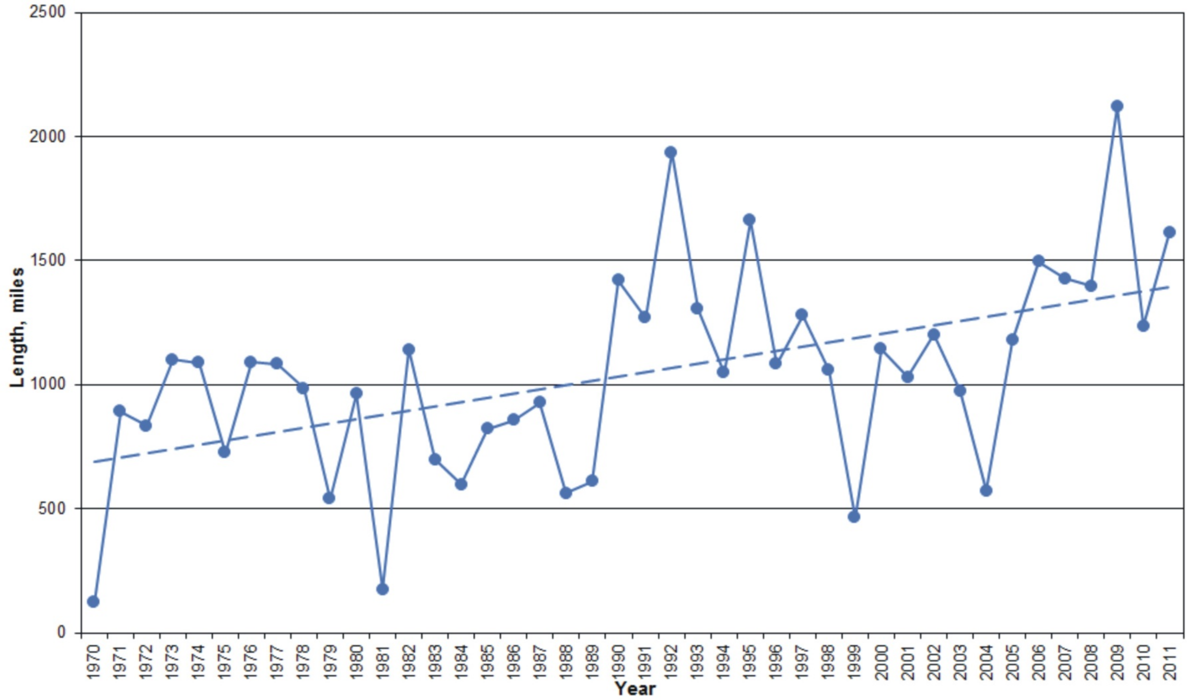


Figure 14. Length of the navigation route through the open water in July

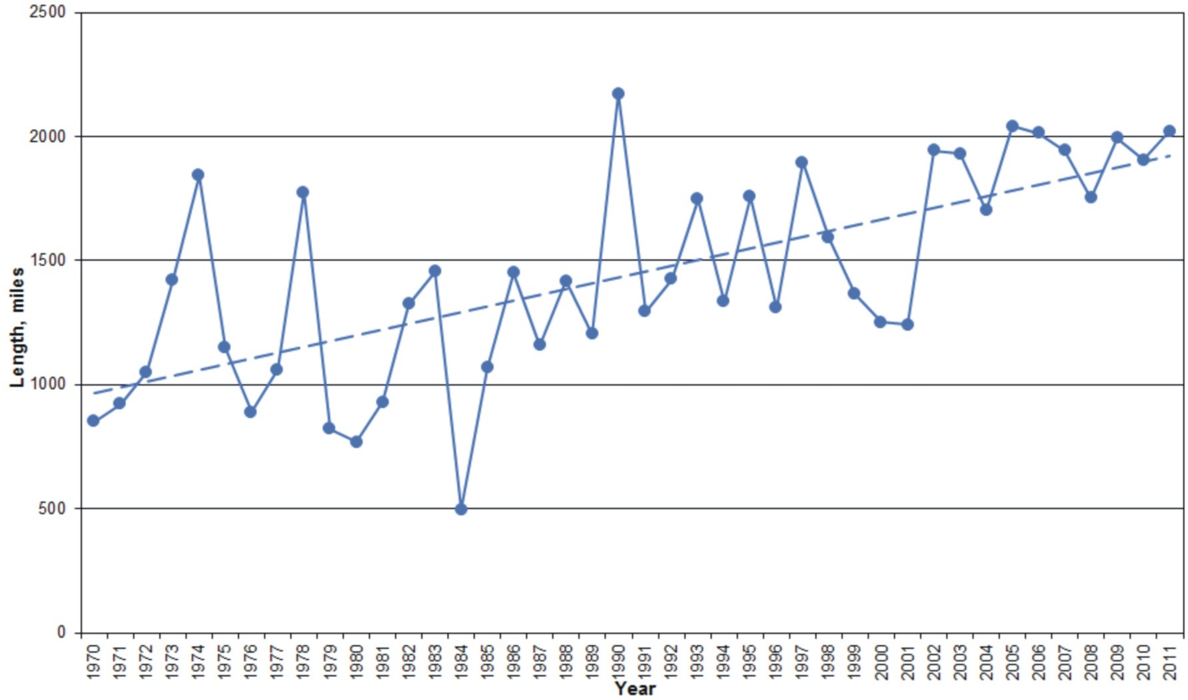


Figure 15. Length of the navigation route through the open water in August

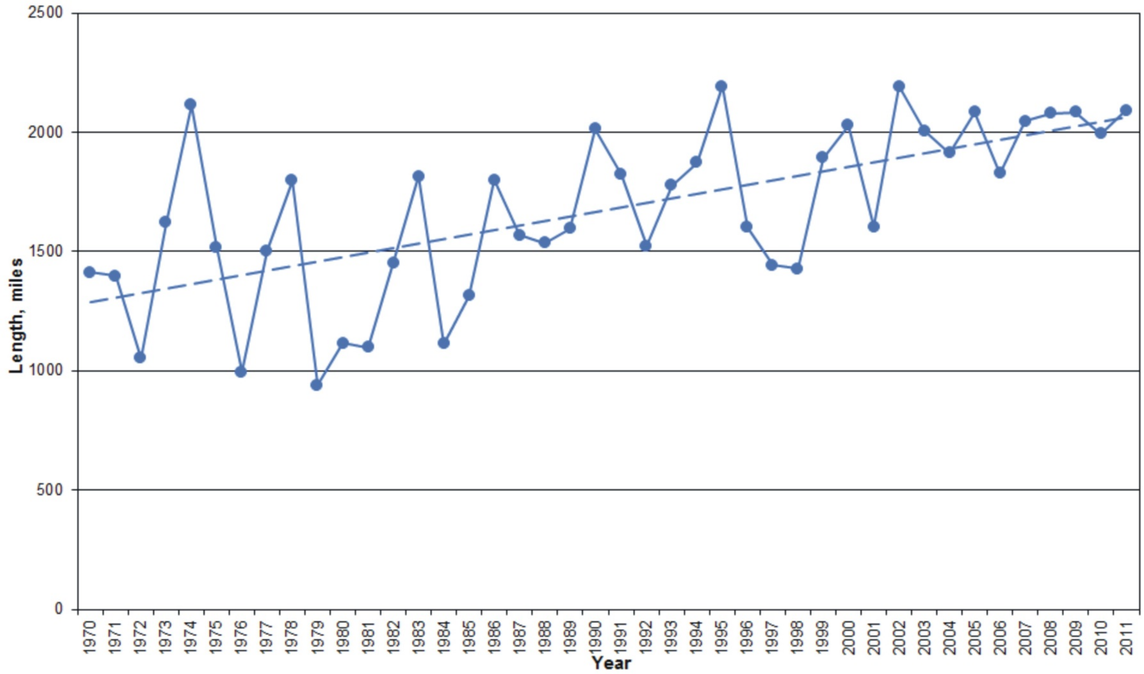


Figure 16. Length of the navigation route through the open water in September

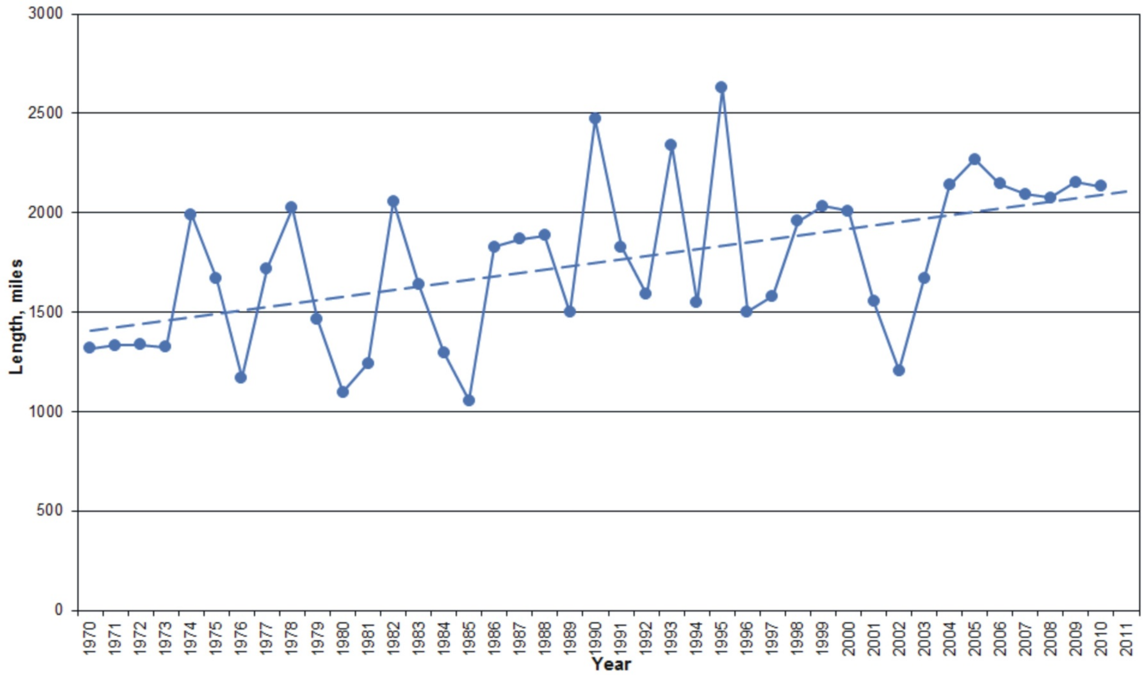


Figure 17. Length of the navigation route through the open water in October

Consequently:

1. The improvement of sea ice conditions along the NSR is observed in summer period 1970-2011: length of navigational route in compact and fast ice is reducing; length of navigational route through the open water is increasing (including new and young ice in autumn period).

2. In spite of improving of sea ice conditions in summer period, repeatability of difficult ice conditions formation along some parts of the NSR is generally persisting.

2 The historical data set of sea-ice parameters that affect navigation in the Arctic Seas (ice thickness, fast ice)

2.1 Data and methods

Tables A7-A8 (attachments). The important source of data about sea ice is observations on the polar stations. These observations are including following measurements: terms of freezing, formation of the fast ice, sea ice thickness, terms of melting, breaking of the fast ice etc.

A lack of information about fast ice distribution, obtained from the polar stations had been complemented with the air reconnaissance data. In the AARI the ice charts with a scale of 1:5000000 are plotting based on satellite data every 7-10 days since 1979. The area of fast ice is determined with the help of these ice charts.

The mostly developed fast ice zones are situated in the north-eastern part of the Kara Sea (to the east from the longitude of the Dikson), in the eastern part of the Laptev Sea (to the east from 125ºE) and to the west from 160ºE in the western part of the East-Siberian Sea (Figure 18).

The fast ice areas are determining within the boundaries of regions of the NSR shown in Figure 2. Tables A8 and A9 (attachments) present areas of the fast ice and ice thickness on the polar stations in three regions of the mostly developed fast ice: the north-eastern Kara Sea, the eastern Laptev Sea and the western East-Siberian Sea. The data are presented for the period of maximal fast ice development – end of May.

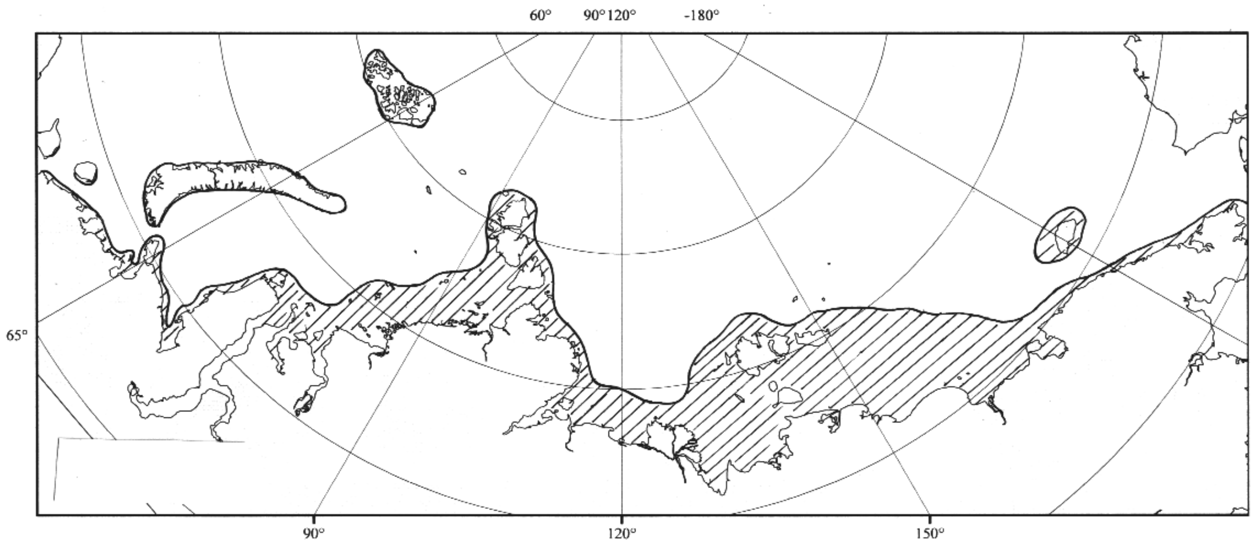
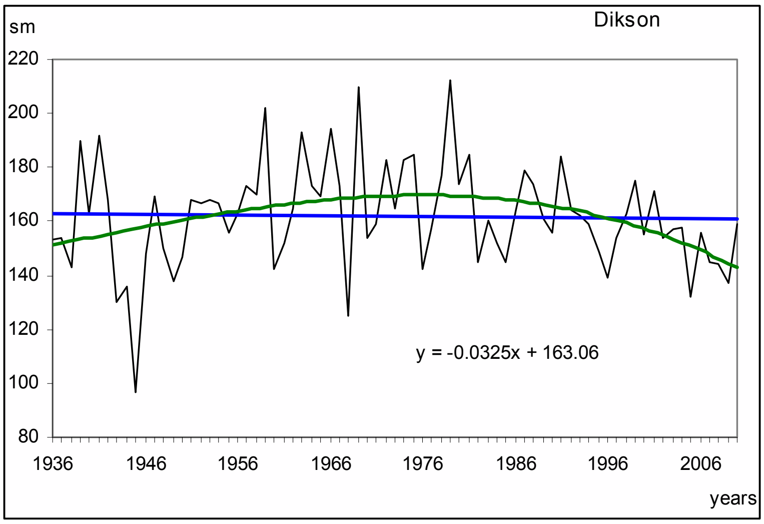


Figure 18. Maximal distribution of the fast ice in the Siberian Arctic.

2.2 Results

In May, during the period of maximal fast ice development, there is no regular navigation in the western East-Siberian Sea. Therefore the data analysis for the first two regions – the north-eastern Kara Sea and the eastern Laptev Sea – is important for the navigational tasks and is presented in the report (Figures 19-20).



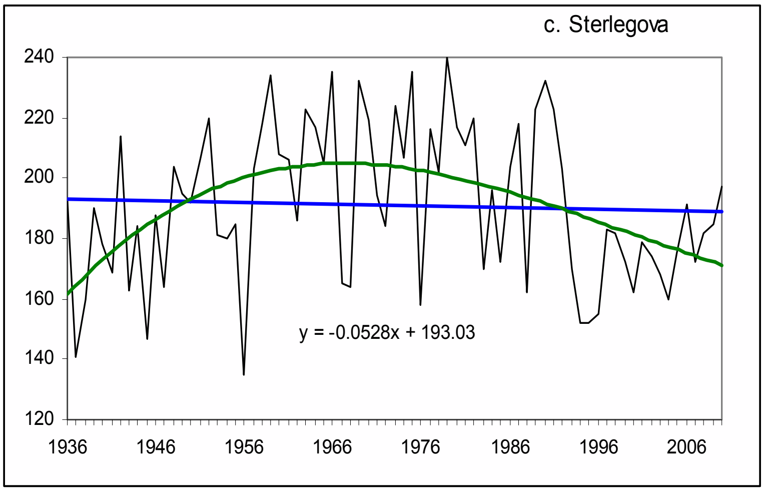


Figure 19. Variability of the fast ice thickness on the polar stations in the north-eastern Kara Sea (Dikson and Sterlegova polar stations). Blue line – linear trend, green line – cubic polynom.

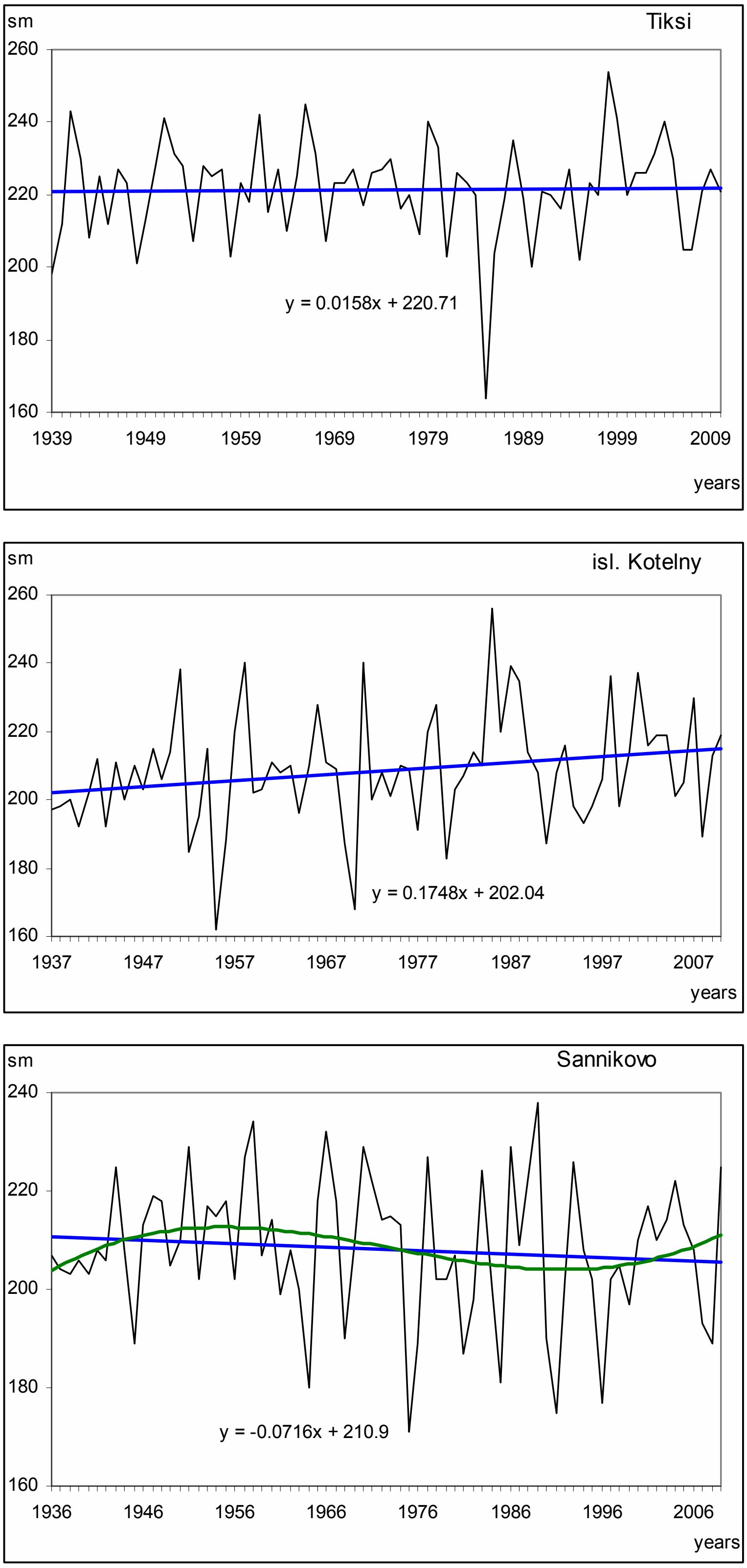


Figure 20. Variability of the fast ice thickness on the polar stations of the eastern Laptev Sea (Tiksi, Kotelny and Sannikova polar stations). Blue line – linear trend, green line – cubic polynom

Climatic changes in the Arctic during the XX-beginning XXI centuries are characterized by long term periodical fluctuations with the warming and cooling periods in the course of these fluctuations. The first warming period in the Arctic was observed in 20-40th years of the XX century. Positive anomalies of the air temperature prevailed during 1922-1953, caused by the first warming in the Arctic. The cooling period followed after the first warming period in 1960-1980. During 1954-1983 negative anomalies of the air temperature had been prevailing. The last warming period, started in the middle of 80th and continued in present time, had not finished yet.

Ice cover of the Arctic Seas is very sensitive (especially in summer) to climate changes. The most significant changes of the ice cover are observed in the western Arctic Seas (Barents and Kara), where sea ice in summer is almost completely melting.

Figure 19 shows that fast ice thickness in the north-eastern Kara Sea has strong interannual variability. Negative linear trend in 1936-2010 is not significant. However, according to the polynomial trend, the variability of the fast ice thickness on the both polar stations shows some tendencies related to the warming and cooling climate periods. Prevalence of more thick ice was fixed from a middle of 1950th to a middle of 1980th – beginning of 1990th. Lower thicknesses were fixed from the end of 1930th to beginning of 1940th and since a middle of 1990th.

Relation of the fast ice variability to the climate changes in the eastern Laptev Sea is not the same definite as in the Kara Sea. Slight positive trend is observed in the fast ice thickness variability on the Tiksi and Kotelny polar stations. Interannual fluctuations of the thickness were around the average value. Slight negative trend is observed in the fast ice thickness on the Sannikovo polar station. Polynomial trend shows some prevalence of the thicker ice in the cooling period and thinner ice in the warming period.

Table 4 shows average fast ice thickness on the polar stations during the cooling and warming periods. Thickness on the Kara Sea polar stations was in average significantly higher during the cooling period than during the warming period.

Slight increase of the fast ice thickness in the Tiksi polar station was observed during the cooling period. At the same time on the other Laptev Sea stations the thickness have been changed independently on the climate periods changes.

Table 4. Average ice thickness on the polar stations during the various climate periods

Periods	Polar stations				
	Dikson	c. Sterlegova	Tiksi	Sannikovo	i. Kotelny
1936-1957	156	181	219	211	202
1958-1983	171	207	223	208	206
1984-2010	157	183	220	206	214

Therefore, the presented data shows that fast ice thickness variability is changing in dependence on local conditions of the climate changes.

References:

Guide of the sea ice air reconnaissance. 1981. Leningrad. 230 p.

Buzuev A. Ya. Dubovtsev V.F., Zakharov V.F, Smirnov V.N. Conditions of ice navigation in Seas of the Northern Hemisphere. Moscow. 1988.

Attachments (the file in the .xls format is attached to the present report)

Table A1. Sea ice parameters along the NSR in 1949-1979: total ice concentration, fast ice, part of the NSR covered by old ice, part of the NSR without ice cover, sea ice thickness, hummocks concentration, ice melting stage

Tables A2-A6. Sea ice parameters along the Northern Sea Route in 1970-2011 in June-October: total ice concentration, fast ice

Table A7. Area of the fast ice based on the satellite data, thousands sq. km

Table A8. Maximal thickness of the fast ice in the area around the shore polar stations (cm)