Chapter I. Fast ice conditions in the Kara Sea and possible reasons of interannual changes of fast ice area *(V.E. Borodachev, Z.M. Gudkovich, S.V. Klyachkin, V.M. Smolyanitsky)*

The characteristic feature of the ice cover in the Arctic seas is the presence of the immovable or fast ice. Fast ice makes the significant influence on the evolution and intensity of many hydrometeorological processes, particularly, on the dynamics and thermodynamics of sea water and ice in the region of the flaw polynyas, ice exchange between the neighbor basins and temperature regime of atmosphere.

The first reliable information about the fast ice formation in the Kara Sea can be found in Kolchak A.V (1909) and Lesgaft E.F (1913). Baskin et. al. (1998) presents the interesting information about fast ice in the investigated region, types of its formation and peculiarities of ice cover in the specific regions.

Fast ice in the Kara Sea usually starts to form as the young coastal ice near some coastal areas and islands after the beginning of stable ice formation, especially, in October (Borodachev, 1998; Borodachev & Smolyanitskiy, 1999; Karelin, 1998). It also consists of the ice cover in Minina skerries and Nordsheld archipelago. Then the fast ice boundary insignificantly displaces seaward within November-December. The location of fast ice boundary slightly changes near the steep-to coasts of Franz Josef Land, Novaya Zemlya, in Baydaratskaya Guba, near the western coasts of Yamal Peninsula, in the flaw area of Obskaya Guba and Yeniseisky gulf. However, in the northeastern sea region the area of fast ice significantly increases within the second half of December, in January and, particularly, in February. Its boundary is located along the line extended over the Sergey Kirov-Izvestiy-Arktichesky Institut islands in February-March. Only westerly from Severnaya Zemlya (except Bolshevik Island) the location of fast ice boundary at that time changes insignificantly. As a rule, it does not change within the sea by April-May. So, the rather steady fast ice is formed in the northeastern sea area to the north from Taimyr Peninsula.

Figure 1 presents the mean fast ice boundary in the Kara Sea in April, which was obtained on the basis of 10-day period sea ice charts archived at AARI for 1950-1992. The zone of fast ice expansion is shaded.

Comparison of the location of fast ice boundary in the Kara Sea with bathymetric map of this sea evidences that fast ice is developed weakly near the steep-to coasts. In the regions of Vilkitsky strait, its western areas and in the region located to the north from Taimyr Peninsula the location of fast ice boundary in late winter is governed by the nearness of islands. It is characteristic that the fast ice boundary is located near 10m isobath up to the mid December. Fast ice rapidly extends in these regions next month when the thickness of level ice increases up to 90-120 cm.

The other feature of fast ice boundary location in the Kara Sea in late winter is that it does not usually extend beyond the 10-m isobath to the north from the mouth area of Ob and Enisey rivers. But the shallow water area with depths up to 30m extends there significantly northerly up to 75 ^{o}N. The run and tidal currents (Voinov, 1999) are observed just in this region.

Spatial-temporal variability of fast ice boundary location is a significant feature according to data obtained within the specific years. Fast ice can occupy different areas in the sea and cover its different water areas due to conditions of its formation and development. The proposed typical fast ice location shows up this variability. Data of fast ice width obtained by means of 10-days period sea ice charts for five sections, the location of which is presented on Fig.1, were used as the initial ones. These data were put into a database and used as a base for the further calculations.

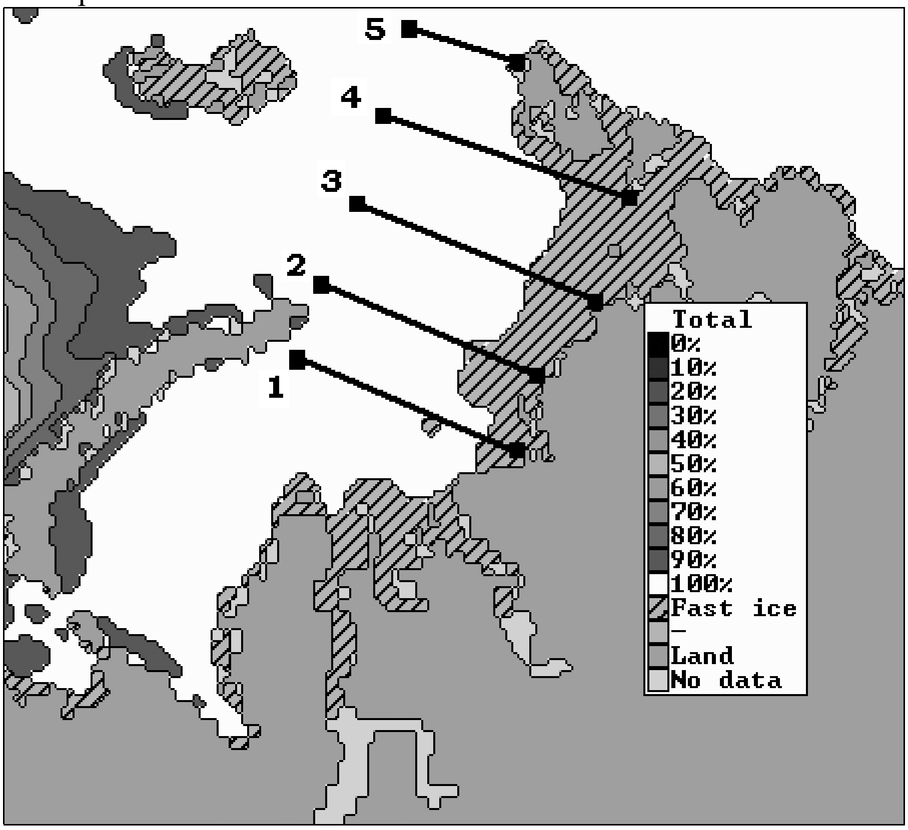


Figure 1. Mean fast ice boundaries and distribution of ice cover concentration. 1-5 - position of sections for estimation of fast ice width and typification of its boundaries.

A method of the selecting the typical fast ice boundary location can be described in the following way. The groups were defined by data of fast ice width for each of five sections using the method described in publications (Borodachev & Frolov, 1997; Borodachev, 1999). Then the types of geographical position of fast ice boundary for the end of each winter month were specified according to the defined analogous groups. Performed investigation allowed to specify and to describe the following six types of fast ice boundary location for the end of each month of the winter period (Figure 2 a-f).

Type I is characterized by small fast ice area, therewith, its boundary usually skirts near the continent coast, Nordsheld archipelago, Firnley, Geiberg and Severnaya Zemlya islands. Fast ice area, in the average, is equal to about 50 x 10^3 km^2 in February (It is less by 2 times than the mean one), a little bit more than 80 x 10^3 km^2 (It is less by 1.5 times than the norm one) in March, about 90 in April, 85 – in May. There is no second-year ice in fast ice, the hummocking exceeds 3 points in the marginal zone. The frequency of this type for 47-year observation period is equal to 10 %.

Type II differs from Type I in that the characteristic fast ice boundary is kept only up to late March. In April its area sharply increases up to the long-term average values to the east from meridian of Sterlegova Cape. In fast ice the thick first-year ice prevails with ice patches and strips of thin and medium first-year ice. The frequency of this type is equal to 13 %.

Type III is characterized by that fast ice is formed directly within long-term boundaries. Its frequency is the maximum one and equal to 26 %.

Type IV is characterized by sharp increase of fast ice area to the southwest from Isachenko Island within the period from March through April. Fast ice, in general, has the average long-term boundaries to the northeast from Isachenko Island. But in April-May fast ice can particularly break-up. The frequency of this type is equal to 21 %.

Type V. The fast ice boundary is close to the extreme one: it is formed directly within the whole region and is kept up to the moment of ice cover destruction. Therewith, in fast ice the high frequency of second-year ice is observed, especially, northerly of Isachenko Island-Russky Island – Firnley Island range. The frequency of this type is equal to 15 %.

Type VI is characterized by maximum fast ice development in the north-eastern Kara Sea and extremely western location of its boundary sometimes comprises Sverdrup Island. Its frequency is equal to 15 %, the probability of the second-year ice presence in fast ice is high.

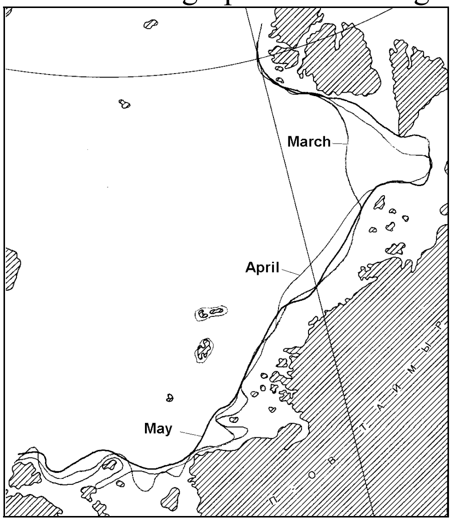
Tables 1-4 present the statistical characteristics of the dates of formation and complete break-up of fast ice in the region of polar stations, changes of the fast ice width within a year for five sections mentioned above, the data of fast ice hummocking and relative area of strainless ice cover in fast ice zone.

According to table 1 a conclusion can be made that the fast ice formation in the north-eastern Kara Sea, in the average, occurs within the first two 10-day periods of October, in the south-western sea area this process is drawn out up to November. If the development of hydrometeorological processes is unfavorable within the autumn period, the freezing occurs in early dates, which go before the mean ones by 1½-2 10-day periods. In other years it is delayed by 1 month relative to the mean dates.

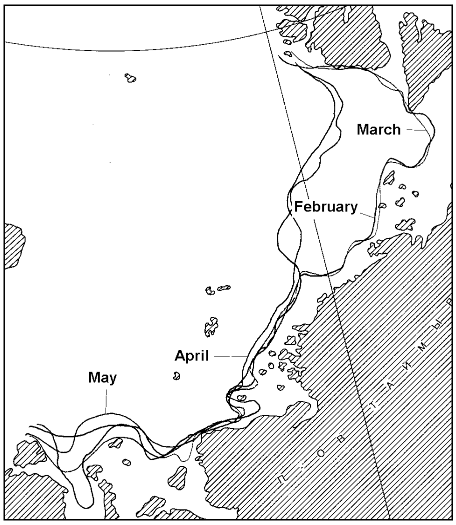
Ice thickness in fast ice depends on the dates of stable ice formation and temperature conditions of the autumn-winter period. Publication of Buzuev et.al. (1988) presents detail review of ice thickness variability.

The fast ice thickness depends on the dates of hard ice formation and temperature conditions in autumn-winter period. The ice thickness variability is described in publication of Buzuev et.al. (1988). In the northeastern sea area the fast ice thickness is equal to 70 cm in the 2nd 10-day period of November. In the southwestern sea area (the region of Bely Island) the fast ice of the same thickness is formed by the end of December, near Amderma- only in mid January. When the ice formation starts later and the air temperature is rather high in autumn, the minimum thickness is observed in the northeastern sea area within these dates. This thickness is characteristic for the young and first-year thin ice of the initial stage. In the southwestern sea area the ice thickness can correspond to the age of young ice with such hydrometerological conditions. Fast ice thickness is equal to 120 cm, that corresponds to the lower limit of the thickness of first-year thick ice, in the region of Zelaniya Cape-Amderma it occurs in the 2nd 10-day period of April, near Dikson Island – in the 2nd 10-day period of February, i.e. earlier by 5 10-day periods. In fast ice in the northeastern sea area the ice amounts to such thickness, in the average, by mid January.

As fast ice is formed from drifting ice of different age, its thickness is rather non-uniform. That is why, even in winter (February-April) the ice areas of thickness not more than 60-90 cm can be found among thick first-year ice in fast ice. Observation data show up that fast ice in the Kara Sea even in winter period is not absolutely compact. As a result of thermal deformation, sometimes cracks with a width up to several meters are formed in it (Evans, Untersteiner, 1971; Nelson, 1975; Cooper, Cooperstown, 1975; Kulakov, Legen'kov, 1981; Kalesnik, 1981; Spedding, 1981). These cracks, as a rule, take off near the protruding seaward capes, sea-bottom elevations, near islands and also between the islands. Their width changes, sometimes the cracks interlock, and small hummock ridges are formed on their place. Tidal cracks are formed near ice-foot beside the thermal cracks. Frequency of cracks in fast ice increases from winter to spring amounting to the maximum within a month before fast ice breaking-up in the investigated region.



a) Type I



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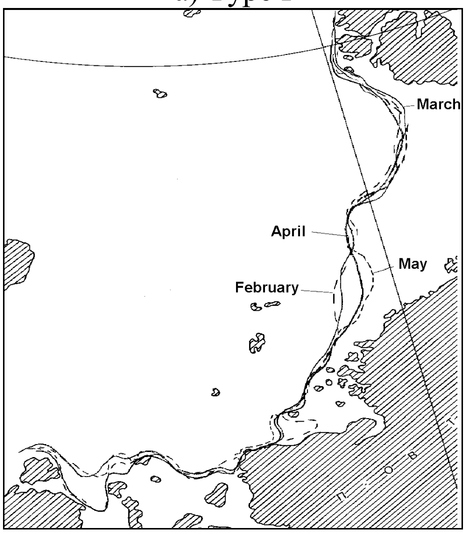
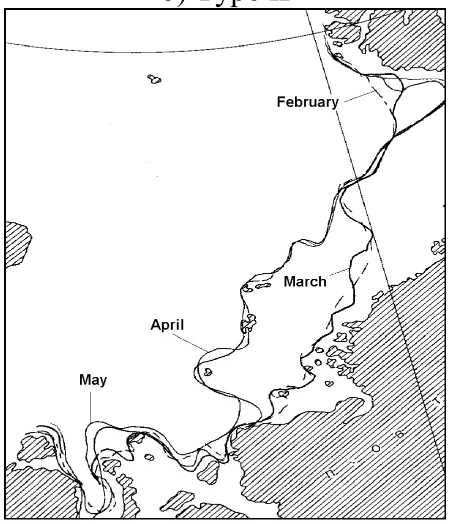
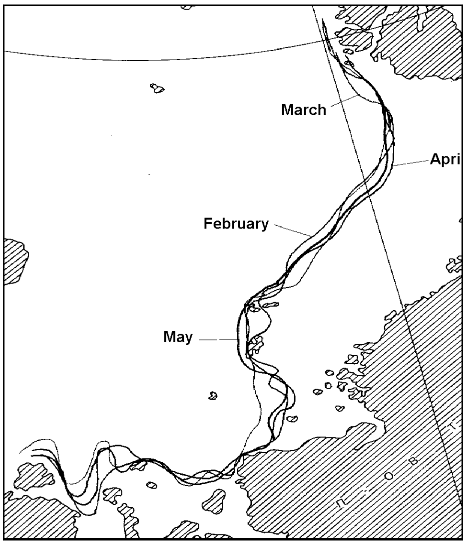


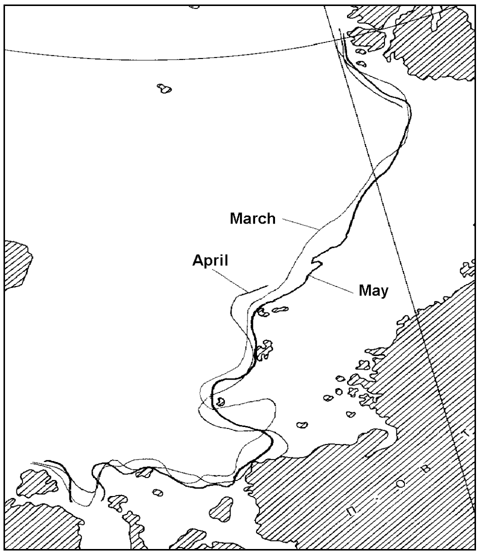
c) Type III



d) Type IV



e) Type V



f) Type VI

Figure 2. Typical location of fast ice boundary in February-May (Types I-IV)

According to Table 1, the complete fast ice break-up in the north-eastern Kara Sea occurs, in the average, in the second half of July-first half of August. However, within the concrete years the dates of fast ice break-up can two-way differ by 15-30 days and more from the mean ones. Fast ice break-up usually occurs there when ice thickness is equal to 80-100 cm (Voevodin, Kuznetsov, 1984).

Fast ice in the Kara Sea consists of, mostly, ice cover of the autumn formation, i.e. first-year ice. Only within some years in the straits of Severnaya Zemlya archipelago in its western areas, in the Vilkitsky Strait the concretions of second-year and even multi-year ice can be kept in fast ice. Sometimes fast ice does not break-up within the period longer than 1 year transforming into second-year and multiyear ice around Vize, Ushakov, Schmidt and Sedov islands.

In dependence on the character of the fast ice formation, the relief of its above surface can be different. It can be defined by stable process of fast ice formation and its duration. Within some years the fast ice hummocking is equal to 1-2 points (Table 3). It increases up to 3 points near the external fast ice boundary. Within some years the fast ice hummocking can be increased up to 3-4 points, therewith, the zones with increased hummocking are distributed on fast ice areas chaotically.

Table 1

Statistic characteristics of the complete formation and destruction of fast ice

Statistics	Meteorological station								
	Isvestiy Island	Isachenko Island	Dikson Island	Sterlegova Cape	Pravdy Island	Russky Island	Geiberg Island	Chelyuskin Cape	Golomyanny Island
Statistical characteristics of the complete fast ice formation									
N	31	31	34	34	34	33	30	34	30
Mean	21.10	04.10	09.10	21.10	07.10	19.10	03.10	01.10	06.10
Min	19.09	03.09	25.09	21.09	31.08	17.09	05.09	27.08	26.08
Max	28.11	01.11	30.10	21.11	01.11	06.12	01.11	29.10	02.12
rms	17.0	16.0	8.0	16.0	15.0	18.0	14.0	16.0	23.0
Statistical characteristics of the complete fast ice break-up									
n			33	33	33	33	29	33	26
Mean			19.07	30.07	14.08	18.08	14.08	06.08	09.08
Min			04.07	04.07	07.07	11.07	23.07	15.07	18.07
Max			06.08	23.08	09.09	28.09	16.09	10.09	HB
rms			8.0	11.0	13.0	17.0	13.0	15.0	17.0

Table 2.

Statistic characteristics of fast ice width for sections #1-#5, km

Statistic	Section					Statistic	Section				
	#1	#2	#3	#4	#5		#1	#2	#3	#4	#5
January						June					
Mean	98	26	129	139	29	Mean	131	92	212	252	30
Min	85	0	60	0	17	Min	90	20	194	97	0
Max	113	41	207	304	64	Max	269	189	229	302	66
rms	12	19	80	158	23	rms	60	72	8	43	26
February						July					
Mean	109	64	160	195	38	Mean	46	19	136	152	21
Min	98	21	29	40	13	Min	0	0	0	0	0
Max	155	178	218	273	70	Max	113	43	220	324	64
rms	16	54	75	87	22	Rms	48	17	85	108	22
March						August					
Mean	128	93	211	260	36	Mean	0	1	9	4	11
Min	62	28	190	162	0	Min	0	0	0	0	0
Max	251	190	229	331	65	Max	0	34	61	106	60
rms	53	70	10	39	25	rms	0	6	17	19	19
April						September					
Mean	141	105	210	232	35	Mean	0	0	0	2	8
Min	101	32	195	31	6	Min	0	0	0	0	0
Max	250	189	228	323	63	Max	0	0	0	15	33
rms	54	71	7	72	21	Rms	0	0	0	6	12
May						October-December					
Mean	132	84	210	255	37	Mean	74	15	70	119	22
Min	96	31	199	138	8	Min	0	0	0	0	0
Max	267	185	219	300	66	Max	109	35	205	258	62
Rms	53	63	7	48	22	rms	40	13	73	102	24

Table 3

Statistic characteristics of fast ice hummocking, points and area of strainless fast ice areas $S_{\tau0}$, %

Month	Statistic parameter				$S_{\tau0}$(%)	S_{nd}(%)
	Mean	Min	Max	Mode		
February	2,0	0,6	3,4	2,1	1,6	40,3
March	1,9	0,2	3,4	1,7	1,9	39,9
April	2,0	0,1	3,7	2,2	2,0	71,0
June	1,6	0,3	2,9	3,5	3,2	44,0
July	1,6	0,2	3,1	1,6	16,1	18,2
August	2,5	1,8	2,9	2,6	3,1	27,7

Note: S_{nd} - area, in % to the total, uncovered but observations (no-data)

Table 4 presents the information about the annual variability of average fast ice area in the north-eastern Kara Sea and its interannual variability obtained by the same data.

Table 4

Statistic characteristics of fast ice area in the north-eastern Kara Sea

Month	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII
Area, 10^3km^2	6	14	5	81	75	105	126	126	128	120	76	12
rms	3	6	4	27	23	26	15	18	16	19	28	7
N cases	5	3	3	4	4	11	14	18	12	11	16	15

Despite the amount of observations, which these data were based on, are distributed within a year non-uniformly, the annual variability of fast ice area is clearly shown up. It slowly increases from the beginning of ice formation to March, slightly changes within the March-May period and rapidly decreases from June by September.

To investigate the interannual variability of fast ice area in the northeastern Kara Sea the results of fast ice planimetry for this region, which were obtained by I.D.Karelin by satellite data and these of visual aerial reconnaissance for May within 1949-1997, were used. They show up that fast ice area in this region, in the average, is equal to 110 x 10^3 km^2 (it is equal to 22 % of the region area) changing from 46 x 10^3 km^2 to 142 x 10^3 km^2. So, the range of interannual changes amounts to 87 % of the average value. Analysis of frequency of different values of fast ice area (Figure 3) shows up that the histogram of frequency distribution has clearly defined the bimodal character. Fast ice area most often changes in the range 85-95 x 10^3 km^2 (in 25 % of all cases) and 115-125 x 10^3 km^2 (27 % of all cases). The range of 95-115 x 10^3 km^2 is accounted for only 18 % of all cases.

The study of the main reasons of fast ice formation and destruction were called for due to the different fast ice width on the various areas of the Arctic seas and the significant interannual variability of fast ice area in some regions. In publication of N.N. Zubov (1945) it was shown up that the most favorable conditions for formation of extensive fast ice are the coastal line, islands and shallow water area, in which the stamukhas are formed (the ice structures, which are formed on the bottom). N.N. Zubov pointed out that the main reasons, which impede the fast ice expansion and bring to its break-up, are frequent currents, tidal phenomena and wind. P.A. Gordienko (1963) attached much importance to a role of stamukhas among these factors.

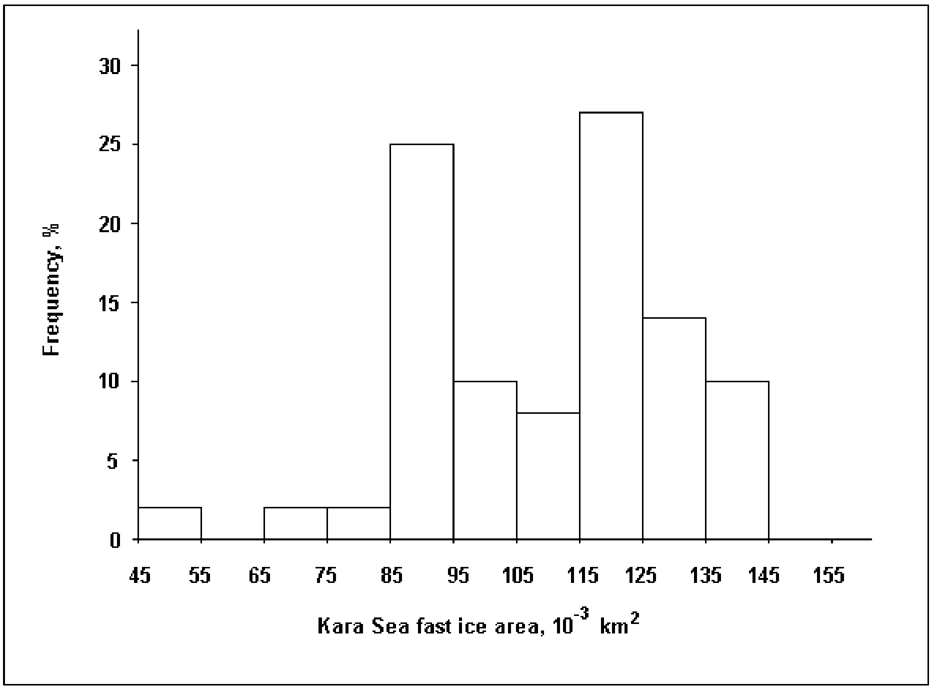


Figure 3. Histogram of fast ice area in the northeastern Kara Sea in May for the period 1949-1996

On opinion of many researchers the interannual variability of fast ice width, essentially, depends on the interrelation between offshore wind fluxes and the coastward ones within winter season. When offshore winds prevail, fast ice width decreases. The coastward winds cause the seaward fast ice expansion (Tarbeev, 1960; Lepparanta, 1981; Skokov, 1985; Batskih et.al., 1987; Yulin, 1997; Karelin [in print]).

In some publications a prompt was made to estimate fast ice width quantitatively in dependence on the offshore wind speed, thickness and solidity of ice cover. Fast ice width is defined by the balance between the integral forces of wind pressure and forces of internal resistance of ice floe accounting the expanding and shearing stress (Gudkovich, 1974; Tarbeev, 1960). As a result, the actual values of fast ice width near the rectangular coast and the minimum ice thickness necessary for fast ice formation in dependence on sizes and form of sea basin were obtained. Considering the forces connected with tangential stresses on below surface of ice cover, which are caused by tidal currents, made it possible to explain the aspect that the edge of developed fast ice in the Arctic shallow seas usually occurs approximately along the 25 km isobath. Near the steep-to coast the fast ice is formed only in narrow bays and straits or is limited by the zone of stamukhas expansion.

The described above ideas were amplified later in the publication of Gudkovich & Klyachkin (in print). The main attention was attached to parameterization of the influence of "fixation" of ice floe near the coast on its resistibility to the destruction caused by external force. The empirical values of the parameters, by which the degree of the influence of different types of "fixation" on the ice floe solidity in dependence on the distance from the coast can be accounted, were obtained. These results were used, when the numerical method for calculation and forecast of ice conditions in Gulf of Finland was developed (Klyachkin, 1998). One of the tasks of this method is to calculate and forecast the position of fast ice boundaries.

An interesting hypothesis about the reasons limiting the fast ice development in the Arctic seas was described in the publication of Dmitrenko et. al. (1998). Considering the possible mechanisms of the formation of warm water layer in seasonal picnocline layer within autumn-winter period (Gudkovich & Kudryashov, 1985), the authors made a conclusion that the main mechanism of heat penetration into the picnocline layer within the summer period is the intrusion relative to warm water from the side of lens edge of water, which was desalinated by river discharge ("baroclinic front"). Within next autumn and winter this heat gradually displaces toward the baroclinic front and then propagates onto the surface impeding the ice accretion and fast ice expansion seaward.

The calculations of the corresponding heat fluxes performed by the authors of this article showed up that this heat amount is sufficiently to decrease the thickness of ice of natural accretion by 129 cm. On their opinion, this is the difference between the thickness of fast ice and the drift one. Therewith, an aspect is ignored that flaw polynyas, which include the young ice areas in winter, are formed, mostly, under the influence of coastward winds (Zakharov, 1996). So, flaw polynyas are, especially, of the dynamic origin but not of the thermal one.

According to the authors' hypothesis, the condition limiting the fast ice area is the presence of freshened water lens, along the external boundary of which the fast ice is formed. So, fast ice is to be developed less within the years, when the waters freshened by river discharge are in the eastern Kara Sea, than within these, when the waters displace westward. In the publication of Dmitrenko et.al. (1999) a conclusion was made that river discharge within the flood period makes influence on the fast ice expansion within next winter period. On the authors' opinion, this is proved by the maximums of mutually spectral function and coherence coefficients corresponding to 2-3-year cycle in river discharge. The increase of river discharge should bring to the decrease of fast ice width and backward. This conclusion, as it will be described below, does not be proved by observation data of river discharge and fast ice area in the Kara Sea.

The mechanisms connected with vertical oscillations of ice cover under the influence of various wave types were not described in the above brief review of investigations of possible factors making influence on the processes of formation and break-up of fast ice (Timokhov & Kheisin, 1987; Smirnov, 1996; Lavrenov & Alekseev, 2000 etc.). May be the influence of these mechanisms in the Arctic seas is the local one.

To show up the features of wind fields making influence on the fast ice formation in the north-eastern Kara Sea and its interannual variability, the 10 years, within which the fast ice area in May in this region was decreased (it was equal to less than $95 \cdot 10^3$ km^2) and 10 years, when it significantly exceeded the norm (it was equal to more than $130 \cdot 10^3$ km^2) were specified. The first group consisted of the following years: 1949, 1953, 1954, 1956, 1963, 1968, 1972, 1985, 1995, 1996; the second one: 1959, 1969, 1971, 1979, 1981, 1989, 1991, 1992, 1994, 1997. The mean charts of atmospheric pressure for the months preceding the observation period (from July through April) were developed for each group.

Figure 4 presents the pressure charts, which were averaged for September-April period for two groups of years. Within the years, when fast ice is weakly developed, the atmospheric pressure trough extended from the Barents Sea to the northeast. Within the years, when the fast ice area is extended, an axis of this trough is directed to the southeast. It provides the conditions, which are characterized in the first case by the increase of zonal West-East air transfers over the sea in comparison with the second case. Such differences, probably, are caused by displacement of Atlantic cyclone tracks in connection with the development of blocking Siberian or Arctic anticyclones.

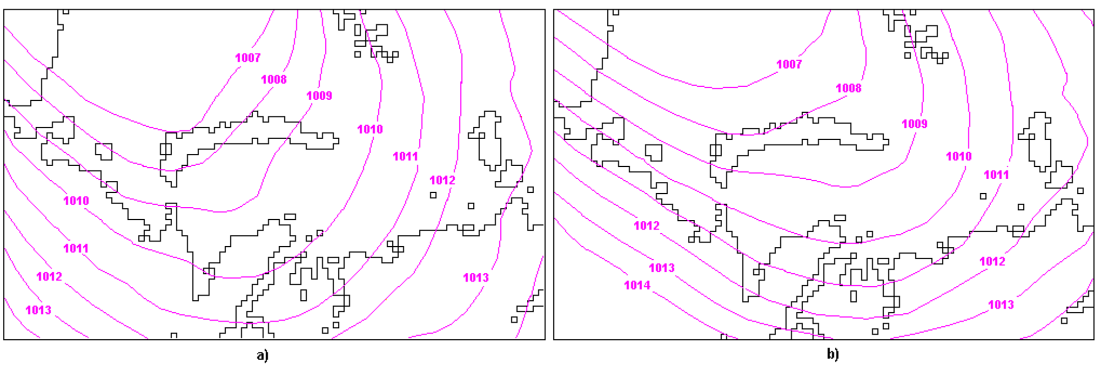


Figure 4. Average atmospheric pressure for the September-April period within the years with increased (a) and decreased (b) fast ice area

Figure 5 presents the mean differences of atmospheric pressure between 70^o N and 80^o N calculated for the 50 ^{o}, 60 ^{o}, 70 ^{o}, 80 ^{o} and 90 ^{o} E for each month for two specified groups of years, which characterize the zonal air transfers over the sea.

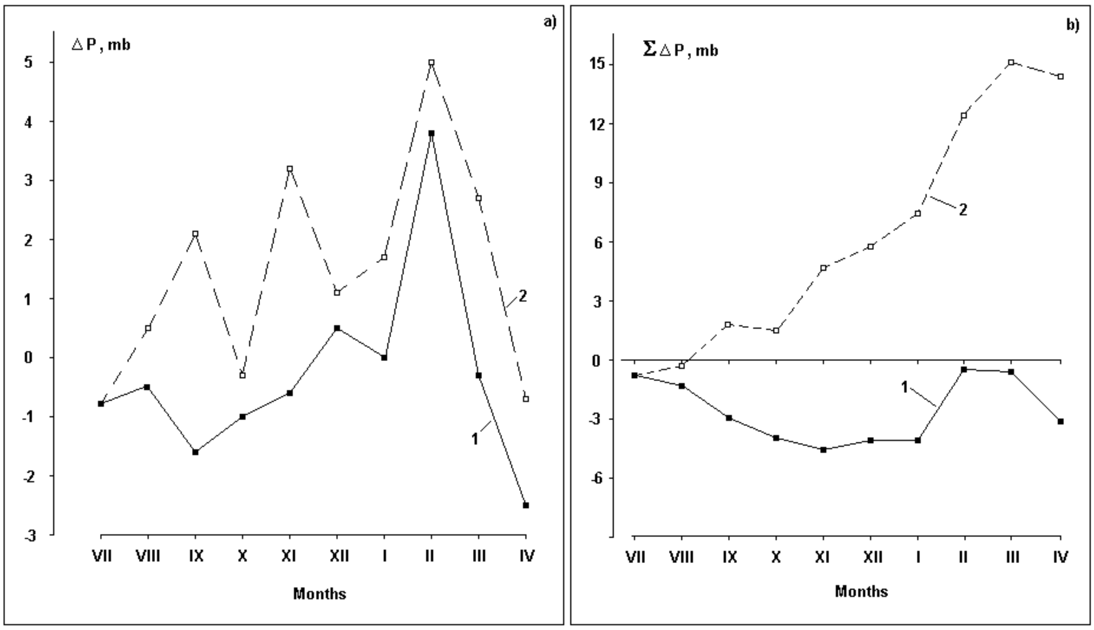


Figure 5. Mean difference of atmospheric pressure (ΔP, GPa) between 70^0 N and 80^0 N in the Kara Sea (a) and the value of the accumulated pressure difference (b): 1- years with the extended fast ice area, 2- years with the decreased fast ice area.

When fast ice area is decreased within the whole winter, in the average, the component of air transfer, which is directed from west to east, prevails. When it is the increased one, the zonal component of air transfer directed from east to west prevails.

The characteristic differences are observed in mean pressure fields for preceding summer months (July-August) for the investigated groups of years. Within the years preceding the group of years with increased fast ice area, the northeastern air transfers are increased over the sea in comparison with the years with weakly developed fast ice (Figure 6).

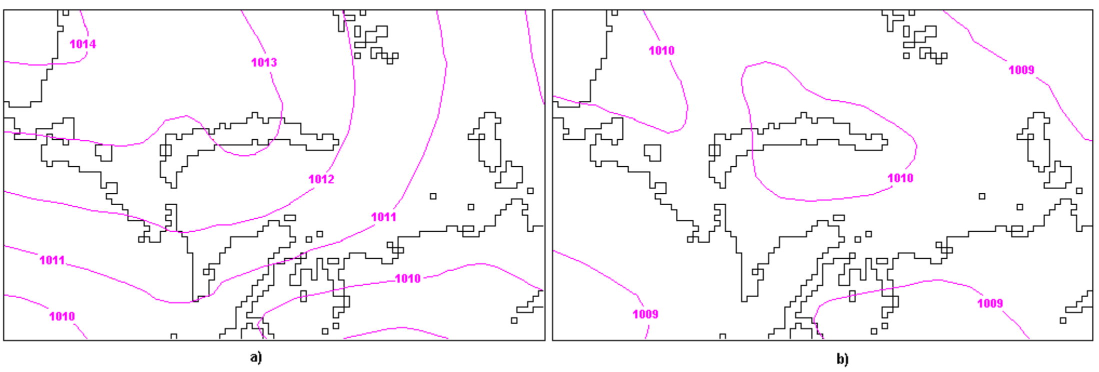


Figure 6. Mean atmospheric pressure for the July-August period within the years preceding the years with the increased (from above) and decreased (from below) fast ice area.

So, a conclusion can be made that the increase of West and South-West winds and the decrease of East and North- East winds over the Kara Sea limit the fast ice development in the north-eastern sea area. Fast ice area extends, when winds of the opposite directions are prevailing. This conclusion does not seem contrary to the hypothesis about the influence of river discharge if its influence is connected not with the volume of river discharge, but with the position of zone of freshened water, which obviously depends on air transfer.

According to data of the Ob and Enisey rivers discharge into the Kara Sea for May-August period (They are archived at the Department of water resources and estuaries' hydrology), the mean river discharge within years preceding these with significantly developed fast ice (646 km^3) does not practically differ from its average area within the years preceding the years with decreased fast ice area (645 km^3). Within the years with weakly developed fast ice in the Kara Sea (less than 50 $\cdot 10^3$ km), the volume of river discharge for the preceding May-August was close to the norm. Two such cases were observed within the period 1936-1996 (1945, 1995). A conclusion is made that the volume of river discharge, practically, does not make influence on the fast ice formation in the Kara Sea.

The hypotheses about the possible mechanisms defining the interannual variability of fast ice area in the Kara Sea

1. Redistribution of water density under the influence of zonal winds

It is known that the increase of western air transfer over the Kara Sea is accompanied not only by displace of water freshened by river discharge into the eastern sea area, but by the increasing of penetration of more salty water into this sea from the Barents Sea as well. Therewith, the horizontal gradients of the surface water density are increased, that brings to speed increase of current directed to the north-east and north to the Arctic basin. These phenomena were experimentally observed during the shipboard expedition at "Otto Schmidt" icebreaker in October-November, 1979 (Gudkovich &Kudryashov, 1985). The increase of this current, which the translation stresses in ice cover are connected with, has to impede the fast ice expanding. Such situation is characteristic for the eastern type of complete destruction of ice cover in the Kara Sea, and favourable ice conditions for navigation are formed (Nikiforov et.al., 1980) The relationship of fast ice area in the north-eastern Kara Sea in May and the ice concentration in this region in August is characterized by small but essential positive correlation coefficient 0.36. It is equal to 0.45-0.50 for the East Siberian Sea (Yulin, 1998).

2. Barothropic low- and high-level of the surge near the fast ice edge

The field of tangential stresses on sea surface caused by wind ice drift is not expanded to the water area covered by fast ice. That is why the conditions are formed for sea level rising near the fast ice edge or its lowering (in dependence on the direction of the complete flow of drift current relative to fast ice edge). As this flow has the component directed in the northern hemisphere to the right from the direction of wind drift (Belyakov, 1974), a conclusion can be made, that, if the wind ice drift is directed along the fast ice edge located right-hand, the sea level rises, and the corresponding inclination of the level seaward occurs near it. If the wind drift has the backward direction, the rising and lowering of sea level occurs toward fast ice.

The results of the simulation of the rising and lowering of sea level with presence of ice cover prove this factor (Gudkovich & Proshutinskiy, 1988). The results of the simulation of the level distribution and currents from this publication show up that high-level of the surge occurs in the region of the fast ice edge and is connected with significant current increase along this fast ice edge for corresponding wind direction. The shears, which appear under their influence in the ice cover, are complemented by stress of expansion connected with the influence of sea level gradient from the fast ice boundary seaward (Gudkovich & Zakharov, 1998).

The barothropic effects of sea level rising near the fast ice boundary under the influence of the South-West winds in the Kara Sea are added to baroclinic current increase, which is specified by the above mentioned inflow more salty water from the west. The phenomena of sea level lowering with wind speed increase of the opposite directions cause the current components directed toward the “constant” currents of, especially, baroclinic origin, which are characteristic for these regions. So, the horizontal shear in the field of drift speed in this case is weakened, the coastward speed component specified by the level gradient will be interchanged by the offshore component. The conditions for fast ice expansion are formed.

The sea level rising caused by West winds near the access to the Vilkitskiy strait increases the eastward current through this strait. It impedes the fast ice formation in it. When the sea level lowers, current speed decreases and brings to the fast ice formation.

<u>3. Differences in the thickness of ice cover defined by thermal anomalies (in the atmosphere and ocean).</u>

Air temperature anomalies are connected with these of air transfer in the Arctic. Air temperature usually increases in the Kara Sea, when the West wind speed increases in winter. The East winds cause the contrary effect. Ice thickness and ice solidity both depend on air temperature. Therefore, the potential resistivity of ice cover to the ice break-up depends on air temperature also. The average air temperature within winter period for the years with the decreased fast ice area was higher by 2.3^{o}C than for these with the increased one. However, the corresponding difference of calculated ice thickness is equal to 11 cm (it is equal to 6 % of the mean thickness).

The proposed hypothesis solves the contradiction between the relationship of fast ice area and the prevailing wind direction in two regions: the northeastern Kara Sea and western East Siberian Sea. In the first region the prevailing coastward West winds are accompanied by the decrease of fast ice area, the offshore East winds are accompanied by its increase. In the second region the coastward North-East winds cause the increase of fast ice area, the offshore West winds cause its decrease (Yulin, 1998). In the considered hypothesis it is important to account not only wind direction (coastward-offshore) relative to fast ice boundary but the processes of sea level change also, which are connected with the direction of drift currents in the sea layer under ice. Accounting the variation to the right of wind ice drift from wind and the variation of drift current from ice drift, a conclusion is made, that the East winds cause the decrease of sea level near the fast ice boundary in the East Siberian Sea. West winds cause its decrease. In the first case (as in the Kara Sea) there are the conditions for the fast ice expanding, in the second one – for its decrease.

The shown up relationship makes it possible to develop the mathematics model of formation and destruction of fast ice in the Arctic seas.

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