2.5. Characteristics of the Laptev Sea ice conditions

2.5.1. Physic-geographical characteristics of sea

Boarders, depth. The Laptev Sea is free connected with Arctic water basin. Its northern boundary virtually runs from Cape Arctic to meridian point of northern extremity of Kotelniy Island (139° E) with edge of continental shallow district (79°N 139° E). Eastern boundary – from given point to Cape Anisiy, further to western coast of Kotelny Island, by western boarder of Sannikov Straight, round western coast of Islands Bolshoi and Maliy Lyakhovskie and then goes by eastern boundary of Laptev Straight. Western sea boundary goes from Cape Arctic by eastern coast of Severnaya Zemlya Islands, then by eastern boundary of Vilkitskogo Straight, and further by continental coast to Gulf of Khatanga peak. Southern boundary goes by continental coast from Cape Svyatoy Nos to Gulf of Khatanga peak (Fig. 2.5.1).

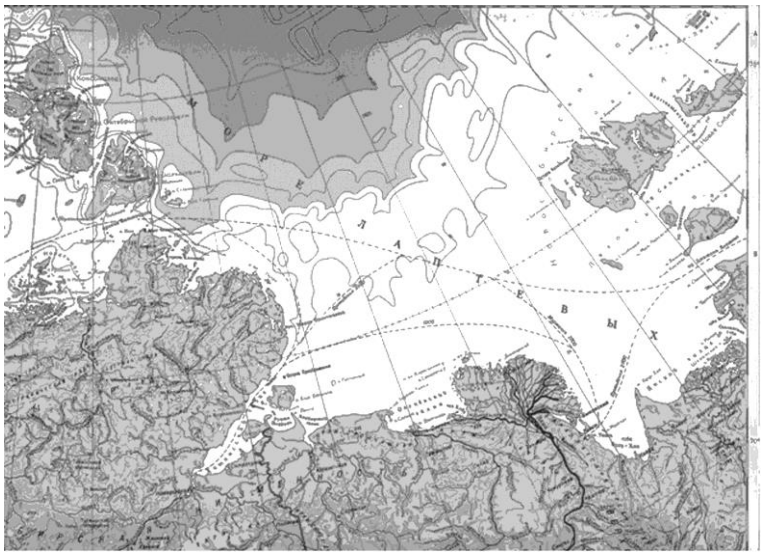

Fig. 2.5.1 – Geographical location of the Laptev Sea

Large variability of depth is seen in the Laptev Sea. In its southern region average depth is within limits 15-25 m. Sharp depth dump, beginning from 100 m and finishing about 3000 m, divides sea into northern and southern regions by parallel of Vilkitsky Straight. Depth less than 50 is observed on about 54% of sea basin (Fig. 2.5.1).

Beginning from time of active research in Arctic (30s XX century), ice observations were made in changed boundaries: northern boundary goes from Cape Berg in point 78°N 139° E. Sea area is 536000 km^2 (Gulf of Khatanga is not included). Western and eastern sea regions significantly differ by their ice-hydrologic characteristics, virtual boundary between them is in 125° E (Fig. 2.5.2). Area of western region is 249000 km^2, eastern - 287000 km^2.

Climate. Climate in The Laptev Sea is rather severe, because of its high latitude location (71–81° N) and atmospheric circulation features. From October to March the bigger part of basin is

influenced by narrow Icelandic depression. At the same time weather in south-eastern and eastern sea regions is defined by spur of powerful Siberian maximum and western periphery of Arctic anticyclone. Southern air flows prevail in winter.

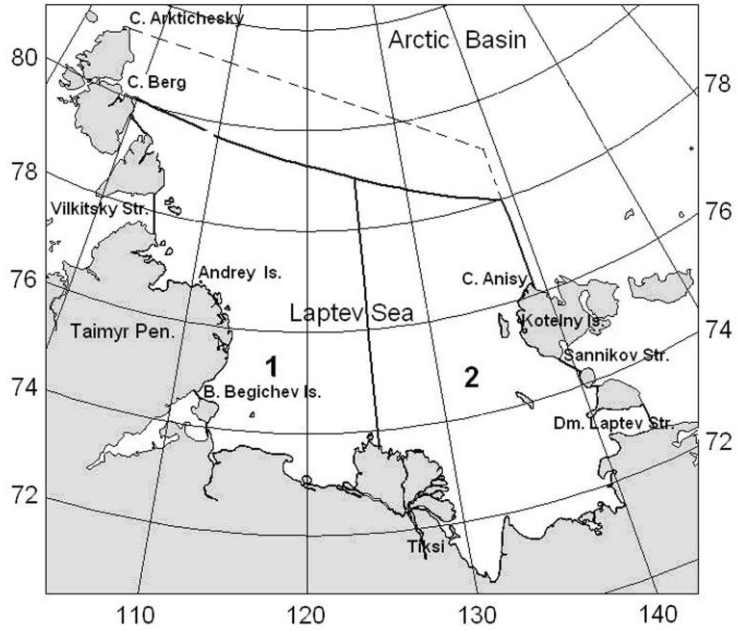

Fig. 2.5.2 – The Laptev Sea division into zones 1 –western and 2 –eastern regions

Reconstruction of atmospheric circulation starts in April, and in summer cyclonic processes dominate over the sea.

Abnormal character of air temperature propagation in winter – the warmest is northern sea part, the coolest – in southern, is main feature of thermal sea regime. In winter (January-February) air temperature along coast is –30÷–32°C, and in northern region is about–29°C. Air temperature under influence of radiation factor changes from –21÷–22°C to –19÷–20°C from north to south, beginning from April.

In summer period air temperature is close to zero over the bigger part of water area. In the south air temperature reaches 8°C near coasts, but in coastal district it rapidly decreases up to 2°C in July and August. The highest summer temperatures do not exceed 12–15°C in the north and 26–28°C in the south of sea basin.

Cyclonic water circulation is typical for the Laptev Sea. Near most northern Severnaya Zemlya Eastern-Taymyr current is separating from Transarctic current, which moves down along eastern coast of Severnaya Zemlya and Taymyr peninsula to the south. Along southern continent water is transported from west to east, where coastal flow is forced by Lensky current. Its bigger part inclines northwards and north-eastwards and as a Novosibirsky current comes out of sea limits, joining with Transarctic current, which moves north-westwards. The smallest water part goes through Sannikov Straight into the East-Siberian Sea.

2.5.2. Characteristics of sea ice cover in period of its growth

Almost nine months (October-June) the Laptev Sea is ultimately covered with ice.

Ice formation. Stable ice formation starts near northern boundaries of the Laptev Sea in first numbers of September and sequentially propagates to the south (Fig. 2.5.3). Western sea region covers with ice more intensive, than eastern, because ice formation here often starts among ice, survived after summer melting. In the first numbers of October ice formation processes propagate to southern coastal zones of western sea region, and on 5–7 of October zone, ice-free before, near delta of Lena river freezes up. Thus, sea freezes up on average during one month.

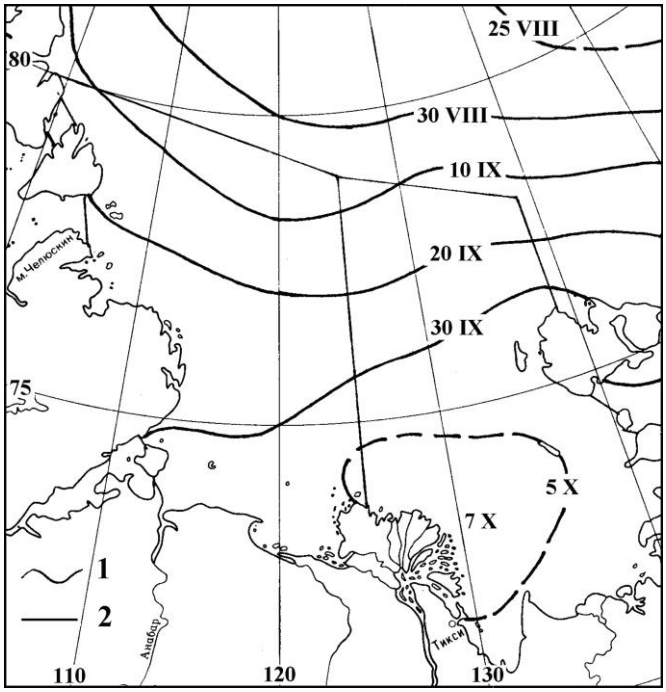

Fig. 2.5.3 – . Isochrones of Average terms of stable ice formation in the Laptev Sea. 1 – isochrones, 2 – sea and regions boundaries

Ice growth. When ice formation processes propagate to southern sea regions, intensive ice growth occurs in its northern and central parts, and to late October about 10% of drifting ice is thin first-year ice (30-70 cm) and approximately same percentage – medium first-year ice (70-120 cm). Ice, survived after summer melting, occupies up to 10% of western region area and about 5% of eastern region (Table 2.5.1). Some ice transforms into two-year ice stage, and some is transported out sea limits.

Ice cover thickness growth occurs rather intensive, and in the middle of winter period (February) about 60% of sea basin is occupied by thick first-year ice. To the end of ice cover growth period (May) thick first-year ice occupies about 86% of eastern sea region and 73% – of western.

Table 2.5.1 – Composition of ice age in the Laptev Sea regions in autumn-winter period, (% from region area)

Sea regions	Ice age														
	Young			Thin one-year			Medium one-year			Thick one-year			two-year, multiyear		
	months														
	X	II	V	X	II	V	X	II	V	X	II	V	X	II	V
Western	60	10	8	10	5	3	5	26	8	0	50	73	10	9	8
Eastern	74	3	7	8	5	3	3	20	4	0	71	86	3	1	0

In general, before melting (in May) thick first-year ice prevails in sea (thickness more than 120 cm), occupying 80% of sea water basin, young (thickness up to 30 cm) and thin ice (thickness 30-70 cm), formed mostly in polynyas, occupies about 10% (Fig. 2.5.4).

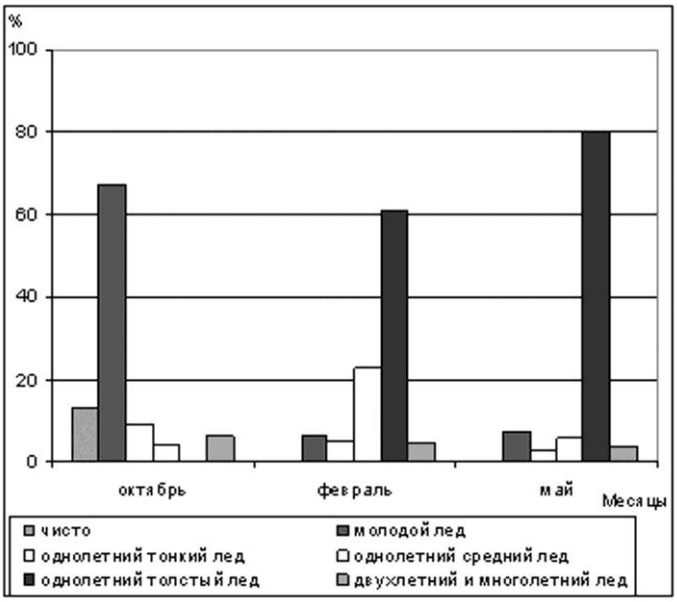

Fig. 2.5.4 – Distribution histogram of different ice age in the Laptev Sea in period of ice cover growth

Location of fast ice zones and drifting ice of different age in the Laptev Sea in the end of ice cover growth period (May) are shown on Fig. 2.5.5.

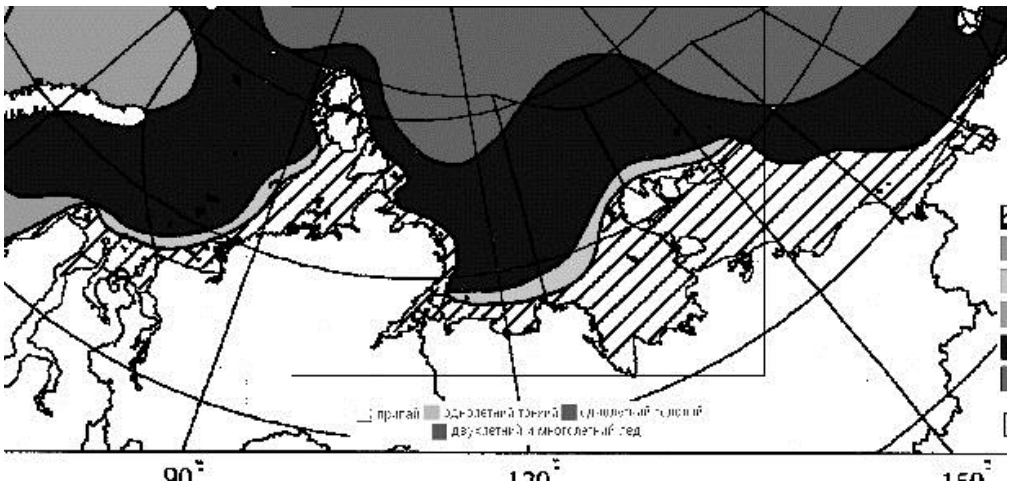

Fig. 2.5.5 – Average propagation of different ice age in the Laptev Sea in the end of ice growth period

Drifting ice mostly presented by large ice floes (extent up to 5000-10000 km, thickness up to 1,5-2,0 m) and their separate parts. Sea ice is little ridged, and ridging is 1–2 marks. Ridged ice ridge height is – 1,0–2,0 m, but hummock ridges are observed with maximum height up to 5-6 m (Table 2.5.2).

Table 2.5.2 – Characteristics of drifting ice in the Laptev Sea regions

Characteristic	Minimum and maximum values	
	Sea west	Sea east
Length of ice floes, m	10000-15000	5000-10000
Thickness of ice floes, m	1.4-1.6	1.6-1.8
Ridging, marks	3	2-3
Month with the most ridging	April-May	April-May
Average sail of hummocks, m	1.0-1.5	2.5
Maximum sail of hummocks, m	1.5-2.0	5.0-6.0
Hummock ridges width, m	5.0-7.5	7.5-10.0
Thickness of two-year ice floes, m	2.4-2.8	2.8-3.2

Drifting ice is transported to Arctic basin during entire period as a result of atmospheric circulation. In winter half year (October-May) on average about 280000 km^2 of ice is transported from sea to Arctic basin, which can be compared with area of eastern sea region.

Fast ice. Fast ice in the Laptev Sea is one of two largest and most solid (by ice thickness) in the Siberian Arctic shelf seas. The largest fast ice is in the East-Siberian Sea. Sea fast ice is formed in 10–15 days after stable ice formation along continental and island coast line. By this time ice thickness reaches 10-20 cm. From 60 to 100 % of cases fast ice formation occurs in October. However, 7 regions can be separated, if consider them by time range of probable fast ice formation terms (Table 2.5.3). In most regions fast ice formation is most probable (45-55%) in third decade of October.

Table 2.5.3 – Probability of stable fast ice formation terms in the Laptev Sea regions from the satellite data for the period 1980-2005, %

Regions	Months						
	X	X			XI		
	Decades						
	3	1	2	3	1	2	3
Severozemelskoye and Taymyr coast	12	13	21	46	8		
Entrance from Gulf of Khatanga			12	50	35	4	
Anabaro-Olenekskoye coast		15	13	51	20		
Lenskoye coast		37	41	22			
Gulf of Buor-Khaya		15	37	35	8	6	
Gulf of Yansk		18	37	45			
Novosibirskiye and Lyakhovskiye Islands		17	15	55	9	4	

The earliest fast ice development is observed in third decade of September along Severnaya Zemlya and Taymyr coast. Later, than in other sea regions, fast ice can be formed in the approach to Gulf of Khatanga (Severny Straight, Preobrazgeniya Island) in the second decade of October. But fast ice formation can be delayed to the second decade of November in the same region, as in Gulf of Buor-Khay and along eastern island coast (Table 2.5.3). Multiyear variability in terms of fast ice formation is observed on Lensky coastal waters and in Gulf of Yansk – three decades, and in other regions it is stretched for 4-5 decades (Table 2.5.3).

On average almost 80% of fast ice in the Laptev Sea is formed in its shallow eastern region and only 20% – in western region.

Fig. 2.5.6 – Seasonal changes of fast ice width in the eastern Laptev Sea.

Fast ice width in eastern sea region (north-western direction from coast of Gulf of Yansk) reaches on average 400 km (Fig. 2.5.6). As it is seen from Fig. 2.5.6, intensive fast ice development occurs till January, then it slows down and finishes in March-April, when fast ice propagation reaches its maximum.

Considering location fast ice boundaries (Fig. 2.5.7), in western sea region fast ice formation occurs significantly slower, and its width in the widest part from the north of Gulf of Oleneksky to the end of growth period is on average 170 km.

If fast ice boundaries move - its area changes. Intensive increasing of fast ice area occurs to January - early February in both sea regions (Fig. 2.5.8). By this time about 80% of fast ice area is formed in the western Laptev Sea and 90% – in the eastern.

Fast ice is rather resistant to interannual changes of hydro meteorological conditions in eastern sea region. From satellite data for 1980-2005, fast ice minimum area in the end of its ice cover growth period is 88% from its maximum area, ever observed.

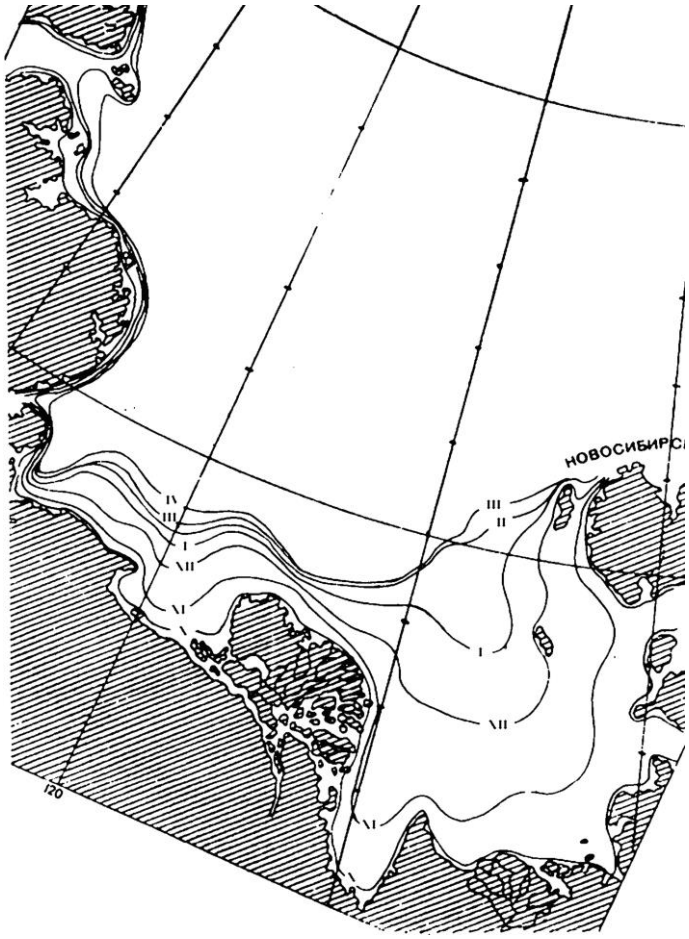

Fig. 2.5.7 – Average location of fast ice boundaries in period of its formation in the Laptev Sea from satellite data for 1980-2005

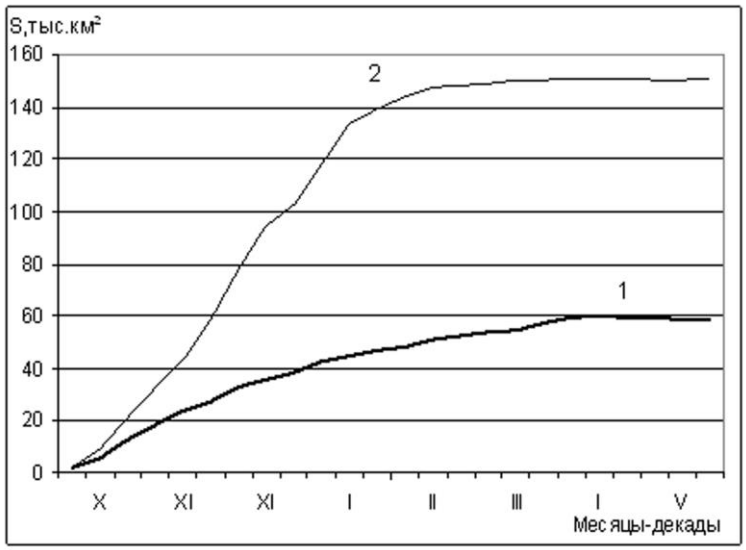

Fig. 2.5.8 – Seasonal changes of fast ice area in the western (1) and eastern (2) Laptev Sea

Range of interannual variability in fast ice area is 9% from region area or about 20 000 km^2 (Table 2.5.4). Fast ice area can significantly change in western sea region. Range of interannual changes in fast ice area is 19% from region area or about 47 000 km^2 (Table 2.5.4).

Table 2.5.4 – Average and maximum fast ice areas in the Laptev Sea regions, %

Regions	Fast ice area		
	average	maximum	minimum
Sea west	24	37	18
Sea east	53	57	48
Entire sea	40	47	35

As mentioned, Icelandic cyclones mostly influence on western sea regions, which make conditional softer winter conditions, resulting in less fast ice thickness, than in eastern sea region (Table 2.5.5). Fats ice thickness in eastern sea region exceeds 2 m.

Table 2.5.5 – Average fast ice thickness in the Laptev Sea regions in the end of month, cm

Regions	Months							
	X	XI	XII	I	II	III	IV	V
Sea west	24	61	98	128	148	170	184	192
Sea east	32	73	110	145	175	195	208	215

Flaw polynyas. Areas with open water and young ice with thickness up to 30 cm are formed under permanent ice transportation from the Laptev Sea – flaw polynyas. They are called by place of formation: Eastern Severozemelskaya, Eastern Taymyrskaya, Anabaro-Lenskaya and Western Novosibirskaya (Fig. 2.5.9).

Two of five polynyas of the Laptev Sea, Anabaro-Lenskaya and Western Novosibirskaya, are stationary, their average frequency of occurrence is more than 75% (Table 2.5.6).

Table 2.5.6 – Average frequency of occurrence (P, %) and size of the Laptev Sea flaw polynyas in November-June from satellite data for the period 1980-2005.

Polynya name	P, %	Characteristic					
		Length, km		Width, km		Area, km^2	
		average	range	average	range	average	range
Eastern Novozemelskaya	64	323	50-540	26	5-75	9,1	0,4-53,3
North-western Taymyrskaya	70	180	50-350	36	5-165	6,4	0,3-36,3
Eastern Taymyrskaya	57	209	30-430	26	5-165	5,5	0,4-35,8
Anabaro-Lenskaya	84	371	60-750	40	5-200	14,7	0,4-71,1
Western Novosibirskaya	80	381	70-1170	42	6-235	16,6	0,8-82,2

These polynyas have continuity northwards from Novosibirskiye Islands - Northern Novosibirskaya polynyas, which are stationary most winter. Analyses of satellite data shows, that in 80% of cases all three stationary polynyas exist simultaneously and in years, which are favorable for development, can form pass-through behind fast ice with length more than 2000 km. These polynyas form “Great Siberian polynya”.

Size and area of polynyas significantly change. Polynyas, well-developed by their size, occur ten times more than polynyas, formed in periods unfavorable for their development. (Table 2.5.6).

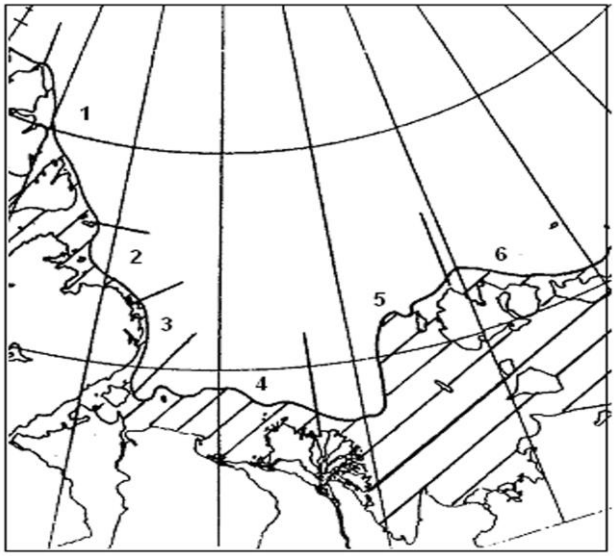

Fig. 2.5.9 – Areas of flaw polynyas formation in the Laptev Sea
Eastern Severozemelskaya (1), North-eastern Taymyrskaya (2), Eastern Taymyrskaya (3), Anabaro-Lenskaya (4), Western Novosibirskaya (5), Northern Novosibirskaya (6)

Polynyas area depends on seasonal alterations of atmosphere circulation over the sea. Total area of the Laptev Sea flaw polynyas on average is close to 50 000 km^2 during their occurrence in period of ice cover growth, when polynyas are involved in process of sea ice productivity. It is about 10% of sea area.

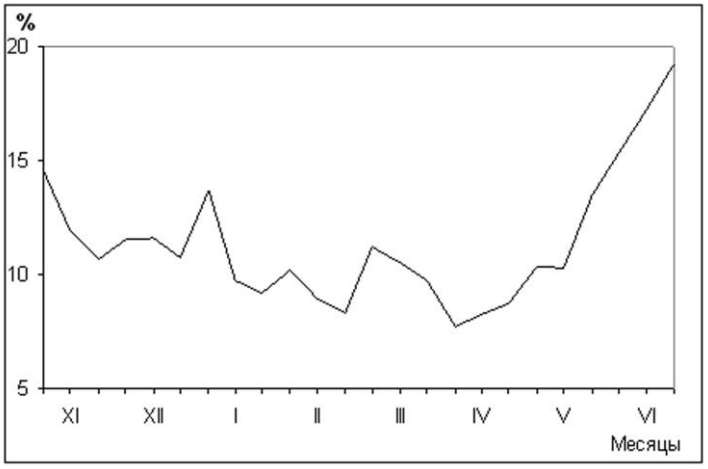

Fig. 2.5.10 – Seasonal changes of total flaw polynyas area in the Laptev Sea, %

In winter period, when polynyas are involved in process of sea ice productivity, and, despite of rather small total area, almost half ice, transported from sea, is reproduced due to polynyas.

Sharp increase of polynya area (20% of sea area) is observed in June (Fig. 2.5.10). However, ice cover starts melting in this time, and ice in polynyas stops its formation. Polynyas in this period are heat accumulators, and, consequently, ice-free areas in sea.

Correlation of polynya, fast ice and drifting ice area in the Laptev Sea is presented on Fig. 2.5.11. Drifting ice occupies 60% of sea area in the beginning of winter season and to 50% – in late May and in June.

2.5.3. Characteristics of ice cover during its melting period

Melting and sea clearing from ice. Ice cover melting starts in southern sea regions and on average occur on 5-10 of June. Ice formation stops in polynyas by this time, and they become heat accumulators and ice-free areas in sea. Clearing of southern sea regions starts under influence of warm advection in the middle of June.

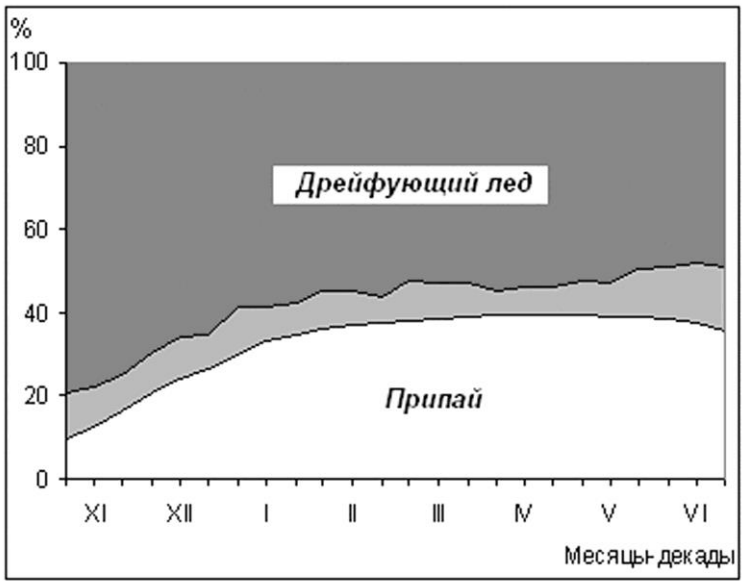

Fig. 2.5.11 – Seasonal changes of fast ice area, total polynyas area and drifting ice in the Laptev Sea

The Laptev Sea clearing from ice. About 10% of sea basin is free from ice to late June. Ice melting and clearing from ice of eastern sea region occurs more intensive during whole summer season, than in western sea region, and more than 80% of region is free from ice (Table 2.5.7).

Fast ice break up occurs in the Laptev Sea on average in late June. Gradual fast ice break up occurs during month, and fast ice completely disappears in late July, rarely in late August. On Fig. 2.5.12. average location of fast ice boundaries is presented (isochrones) in period of ice melting.

Table 2.5.7 – Area of the Laptev Sea ice-free regions in the melting period, %

Sea region	June			July			August			September		
	1	2	3	1	2	3	1	2	3	1	2	3
Sea west	6	9	11	13	16	23	32	41	46	49	50	48
Sea east	7	10	12	16	21	31	47	64	74	79	83	84

Clearing velocity increases in July after complete fast ice break up and change into drift ice of different size.

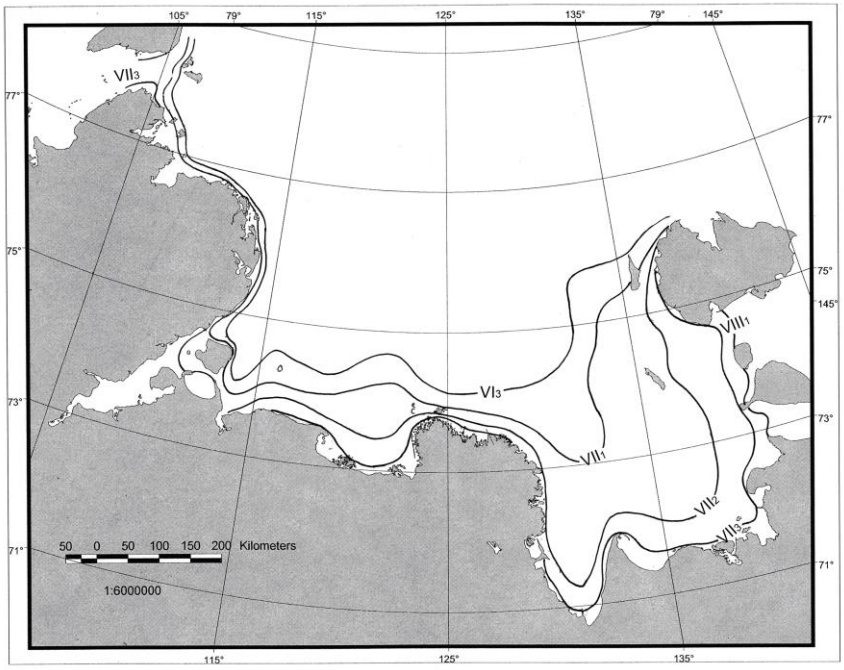

Fig. 2.5.12 – . Isochrones of average terms of fast ice melting in the Laptev Sea from satellite data for 1980-2005

On average fast ice break up occurs in eastern sea region several days earlier, than in western region. Multiyear range of ultimate fast ice break up is about month and a half in western sea region, and about two moths - in eastern region (Table 2.5.8).

Table 2.5.8 – Terms of ultimate fast ice melting in the Laptev Sea

Terms	Regions	
	Sea west	Sea east
Average	21.07	18.07
Early	4.07	29.06
Late	16.08	25.08

Ultimate fast ice melting occurs in both sea regions in the second decade of July most often. In general, about 90% of total fast ice break up cases occur in July (Table 2.5.9).

Character of fast ice break up differs in sea. As it is seen from Fig. 2.5.13, fast ice area sequentially decreases from May till ultimate melting in early August in western sea region.

Table 2.5.9 – Terms of ultimate fast ice melting frequency of occurrence in the Laptev Sea, %

Sea region	June			August		
	1	2	3	1	2	3
Sea west	11	43	38	7	2	
Sea east	19	53	23	3	2	1

Small changes occur in fast ice area practically till late June in eastern region, and fast ice ultimately disappears during July.

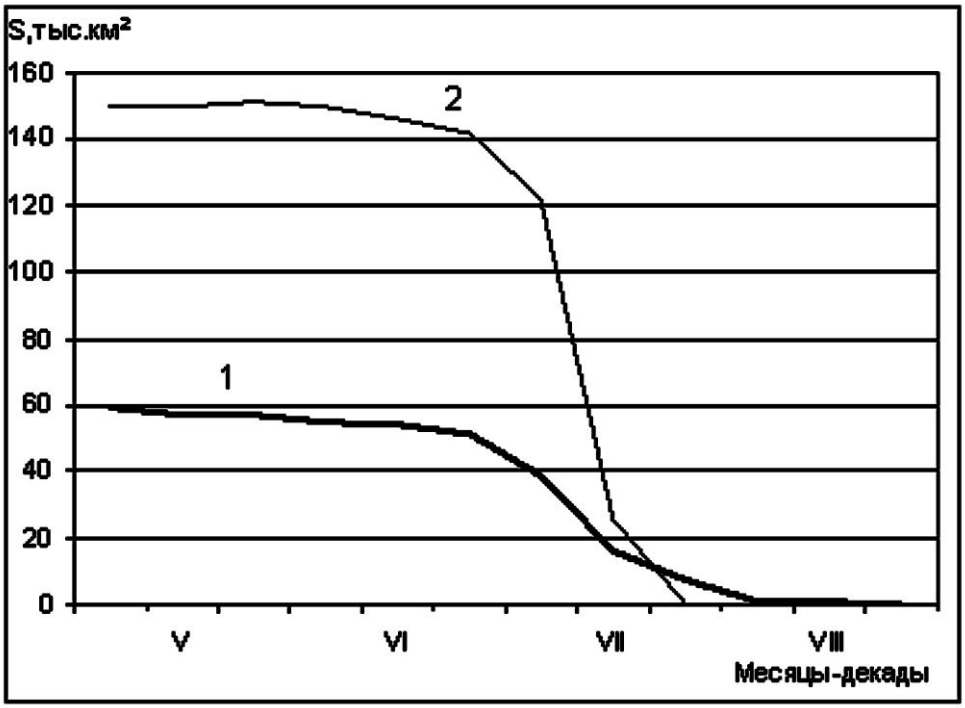

Fig. 2.5.13 – Changes of fast ice area in the western (1) and eastern (2) Laptev Sea in its melting period

Process of sea clearing occurs near fast ice more intensive. About half of western sea region and ¾ – of eastern on average are free from ice in late August (Table 2.5.7). Totally about 70% of sea water basin is free from ice to late September (Table 2.5.7). Ice edge in eastern sea region is located northwards Novosibirskiye Islands during this time and moves down south-westwards to eastern coast of Taymyr peninsula. In September melting processes slow down, ice edge moves northwards and locates in western sea region on latitude of Vilkitsky Straight (Fig. 2.5.14).

Amount of compact ice (7-10) decreases and amount of open ice and very open ice (1-6) increases during processes of melting and ice cover decay (Fig. 2.5.15).

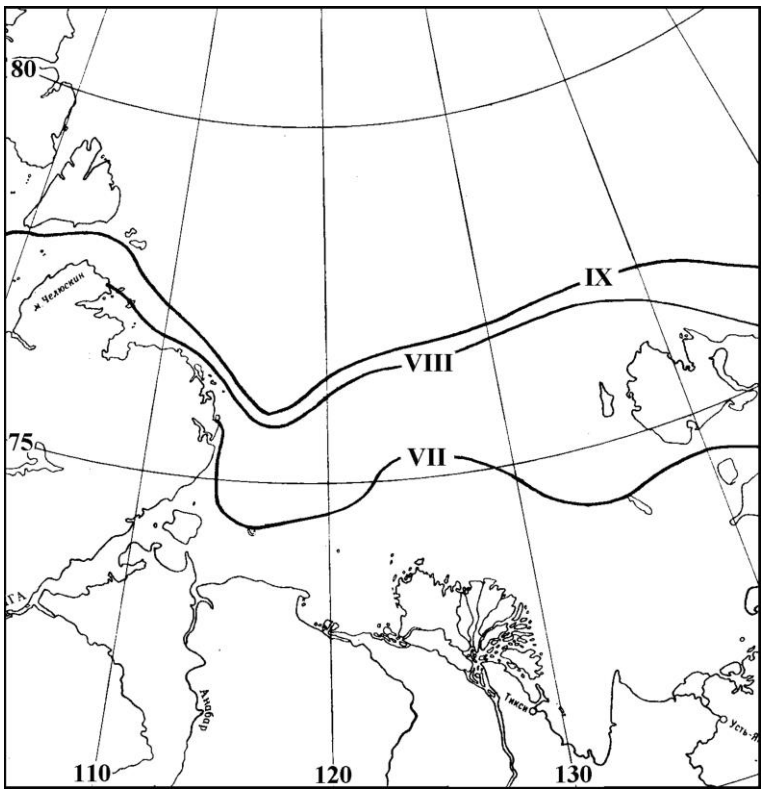

Fig. 2.5.14 – Location of ice edge in late June-September in the Laptev Sea

Amount of very open ice stays within limits of 17-19% beginning from late July, when area of compact sea decreases on average to 15% (Table 2.5.10).

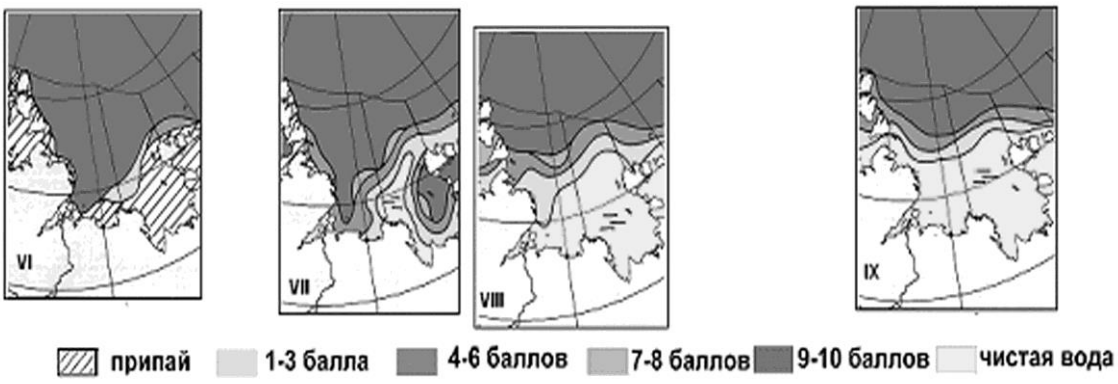

Fig. 2.5.15 – Propagation of ice with different concentration in the Laptev Sea in June-September (probability 50%)

Table 2.5.10 – Amount of compact (7-10), open and very open ice (1-6) and open water in the Laptev Sea in melting period

Ice compactness, marks	June			July			August			September		
	1	2	3	1	2	3	1	2	3	1	2	3
7-10	92	90	88	79	67	54	41	29	20	18	17	15
1-6	1	1	1	7	14	19	19	17	19	17	16	18
No ice	7	9	11	15	19	27	40	53	61	65	67	67

Ice massifs. Compact ice (7-10) is located in two ice massifs – Yansk and Taymyr in period of melting and ice cover decay (Fig. 2.5.16).

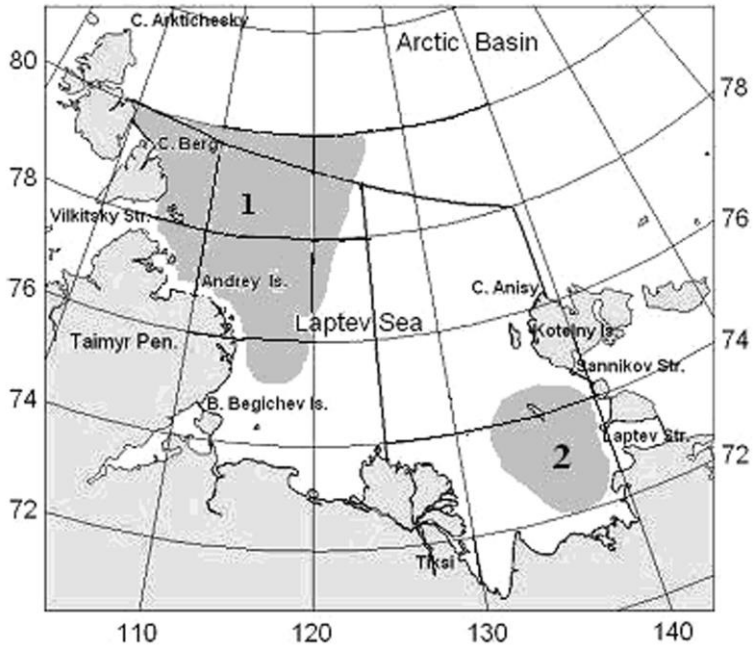

Fig. 2.5.16 – Location of ice massifs in the Laptev Sea. 1 – Taymyr and 2 – Yansk ice massifs

Yansk ice massif is formed from broken fast ice. It is located in Gulf of Yansk and near Straights Sannikov and Dmitriy Laptev. Yansk ice massif ice disappears during August-September for observational period (1938-2007) in more than 80% of cases (Fig. 2.5.17). At that, frequency of occurrence for such cases is same for August and September (41 and 43%, respectively). In some years this ice massif doesn't disappear till late summer. It hardens navigation in Gulf of Yansk and blocks Novosibirsky gulfs from western side.

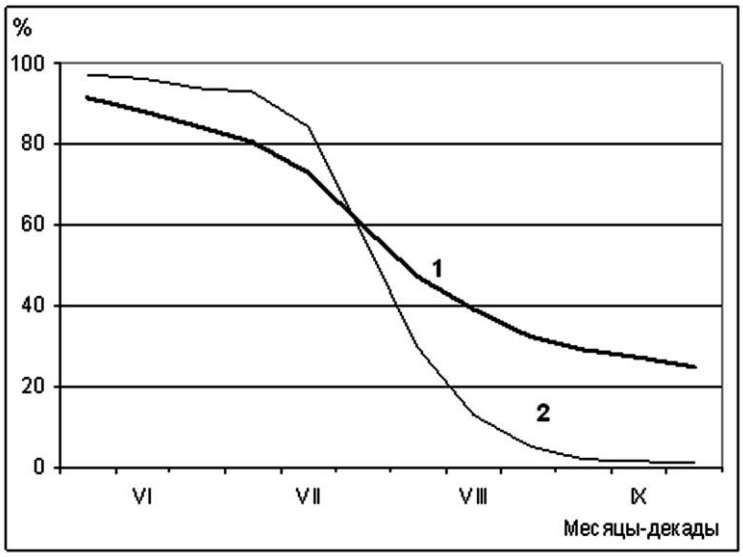

Fig. 2.5.17 – Area changes of Taymyr (1) and Yansk (2) ice massifs in of June-September, %

Taymyr ice massif is formed from compact ice of western sea region, which in summer period is supplied by ice, transported from Arctic basin with Eastern-Taymyr current. Taymyr massif is one of the most significant spur oceanic massifs with large area. On average Taymyr massif in the middle of July occupies about 60% of the western Laptev Sea, and in late September – 25% (Fig.2.5.17). However, in 10% of cases 50-70% of massif compact ice doesn't melt till the beginning of ice formation. Taymyr massif often blocks Vilkitsky Straight from eastern side and hardens ship navigation.

Taymyr ice massif rarely disappears completely to the end of melting period. From data for 1938-2007 it happened in 15% of cases, at that 5% of cases were in August.

Grounded hummocks. Grounded hummocks are observed in summer near coast on depth 10 m and less or in shoals in open sea. Grounded hummocks are rest of fast ice or strongly ridged drifting ice floes, settled on the ground. Their draft changes from 1,6 to 22,0 m. Grounded hummocks normally disappears to late August. The biggest propagation of fast ice boundary is shown on Fig. 2.5.18.

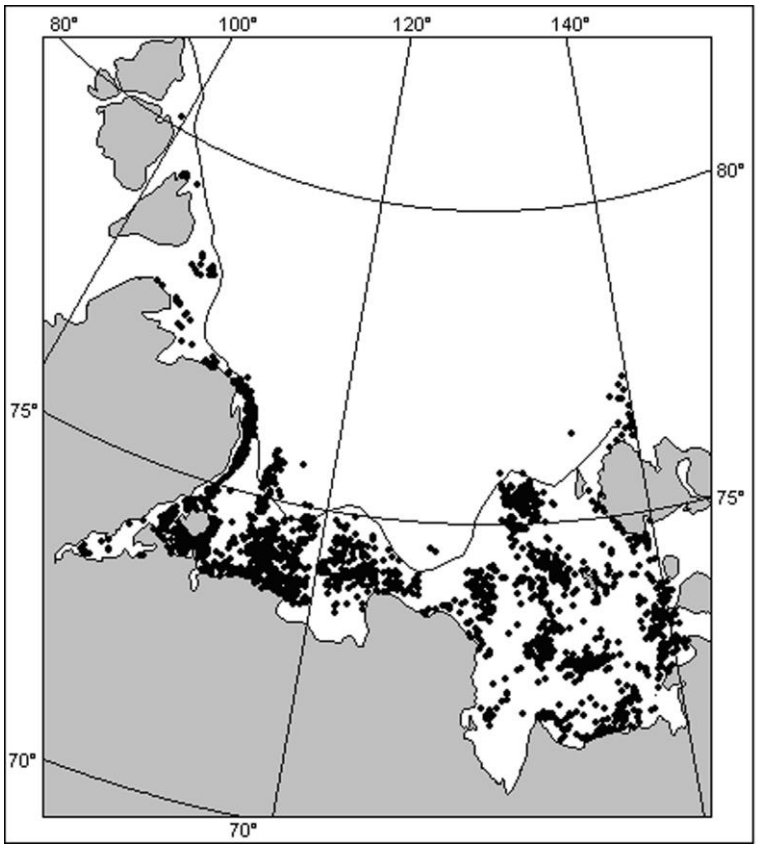

Fig. 2.5.18 – Location of grounded hummocks and their largest propagation boundary from air reconnaissance data for 1962-1991

Icebergs. Small amount of icebergs is produced to the sea from islands of Severnaya Zemlya. The biggest amount is observed near northern island among archipelago islands. They propagate

southwards along Taymyr coast under influence of winds and Eastern-Taymyr current. Separate icebergs were found near Island Preobragzeniya in some cases. Mostly icebergs propagate to western sea region, and only in separate cases small icebergs were observed in eastern sea regions.