2.1. Baltic Sea Ice Condition Characteristics

2.1.1. General aspects

The Baltic Sea (beginning from ancient times and till XVII century was known in Russia as "Varangian sea") – is an inland marginal sea. The Baltic Sea is located in Northern Europe and belongs to the Arctic Ocean water basin (Fig. 2.1.1.).

The northernmost point of the Baltic Sea is located near Polar circle (65°40' N, and the southernmost – near Vismar (53°45' N). The westernmost point is situated in the Flensbourg area (9°10' E), and the easternmost – in the Saint-Petersburg area (30°15' E). The Sea area is 415 000 км², its average depth is 52 m, and maximum depth is 459 m.

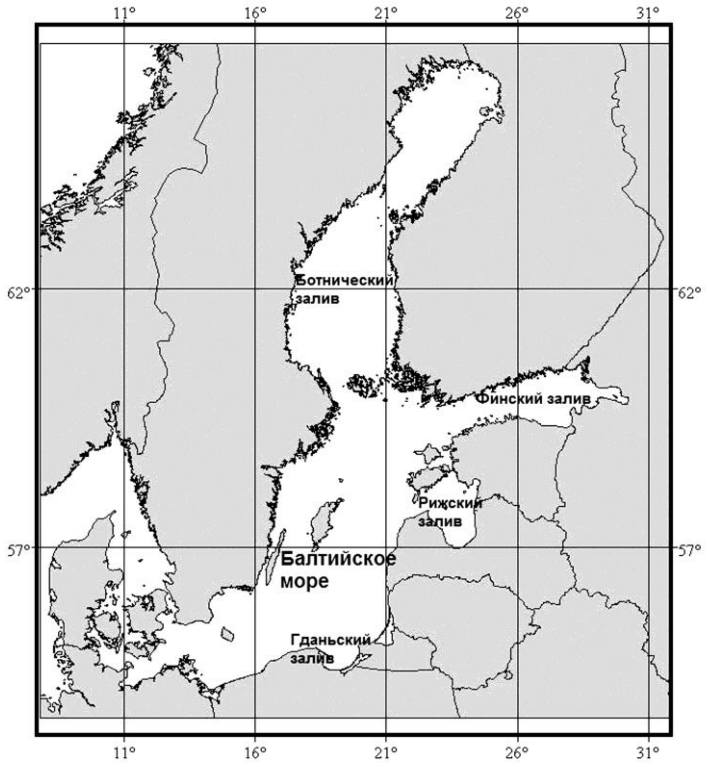


Fig. 2.1.1 The Baltic Sea division into zones

Significant variability and variety of ice conditions is the characteristic feature of the Gulf of Finland and the whole Baltic Sea. More unfavorable conditions are observed in its northern part, comparing to the southern and central Baltic.

The Baltic Sea ice regime is determined by geographical location and climatic conditions, water desalination under influence of coastal discharge, heat exchange intensity of open sea with its gulfs and with the Northern Sea.

2.1.2. Ice formation

On average, ice appears in the northernmost part of the Gulf of Bothnia in late November. Then, in late November – early December ice appears in the Gulf of Finland upper part and in the Gulf of Vyborg (Fig. 2.1.2).

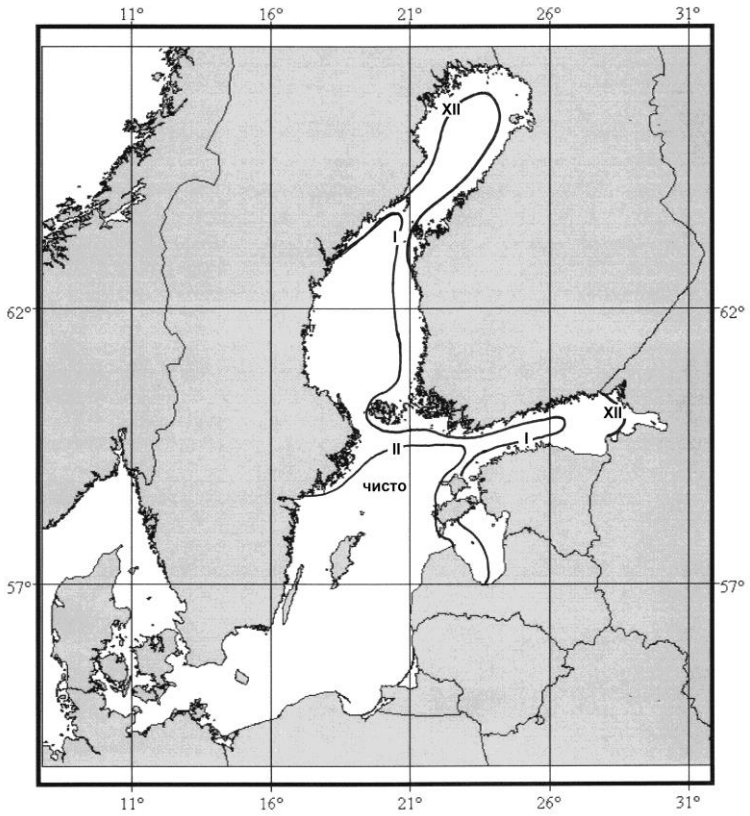


Fig. 2.1.2 Annual mean ice distribution in early December

Under unfavorable development of ice conditions, ice formation in the northern part of the Gulf of Bothnia starts in late October. In November ice formation involves the whole Gulf of Bothnia northern part and can be seen along the whole northern sea shore. In the middle of December new and young ice are observed in the whole water basin of the Gulf of Bothnia and the Gulf of Finland (Fig. 2.1.3 a, b, c).

2.1.3. Ice cover

The ice area in the Baltic Sea changes in wide range from 50 to 420 000 км^2, when the whole sea is covered with ice. Ice cover of the Baltic Sea and it's large regions is closely connected with the sums of freezing degree-days, with correlation coefficients of 0.9 and higher.

Repetition of mild, moderate and severe winters in different sea areas doesn't always coincide. The most characteristic example of disagreement of winter type in the open Baltic, Gulf of Finland and German coast is considered to be winter of 2002/2003. It was very severe in the Gulf of Finland, moderate, a bit less than norm in the Gulf of Bothnia, and mild along the German coast.

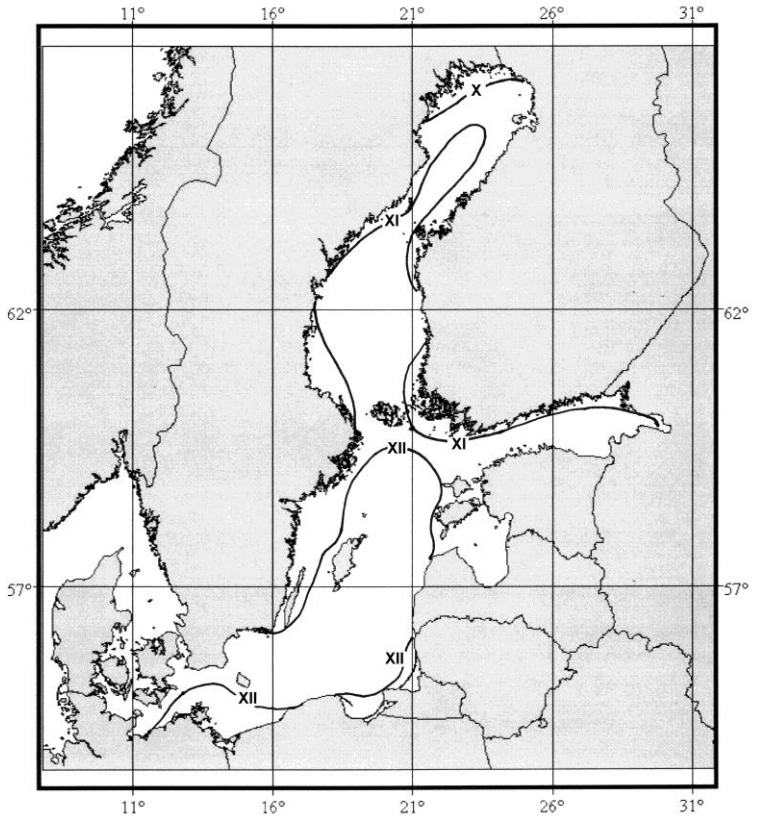


Fig. 2.1.3 Stable ice formation processes development in unfavorable years

Ice cover develops to its maximum in the period between late February and the middle of March. The most difficult ice conditions are observed in the northern part of the Gulf of Bothnia and in the eastern part of the Gulf of Finland. The most significant difficulty criterion for the Gulf of Bothnia and the Gulf of Finland is not ice area but ice volume, which allows taking into consideration both ice area and ice thickness.

In severe years ice thickness reaches 80-100 cm in the northern part of the Gulf of Bothnia, and 90cm in the Gulf of Finland in period of maximum ice cover growth.

Fast ice is formed along the Baltic Sea eastern coast with the width reaching 20 km in the north, up to 10 km in the south; drifting ice consists mostly from grey and grey-white ice. According to eastern sea coast hydro meteorological stations data maximum ice thickness varies from 10-30 cm in mild winters up to maximum of 40-60 cm in severe winters. In very severe winter 1941/42 ice, frozen up together, formed hummocked ice zone along coast with thickness 50—60 cm. Cleansing from ice takes place in the 3rd decade of April, and in northern part, in the area of

Saaremaa and Hijumaa islands, separate ice strips and ice patches can be observed in the 1st decade of May. In very mild winters ice along Baltic Sea eastern coast is absent.

Southern parts of the Baltic Sea don't usually freeze in mild winters. Floating ice of small capacity is formed along Polish, German and Denmark coasts in mild and severe winters. Thus, near an eastern Germany coast even in severe winters sea is covered with ice only for 30-45 days, and usual ice thickness is 30-40 cm.

In southern coastal areas of Baltic the largest amount of ice is observed in late January – February. Ice cake and small floe are predominant ice forms. On average the ice thickness doesn't exceed 20-30 cm, the maximum thickness is 50-60 cm. Ultimate clearing from ice takes place in mild winters in the middle of February, in severe winters – in early March.

Fast ice melting and destruction usually starts in the second half of March – early April. In the Gulf of Finland in its first half the first wave of ice fracturing sequentially reaches areas of Gogland, Moshchniy, Seskar Islands. In the second half of April fast ice fracturing occurs southward of Moshchniy and Seskar Islands, and in Luzhskaya Bay. In late April – early May complete ice cleansing is noticed in the Sestroretsk shallow areas and in the Gulf of Vyborg. However, during winter season and in some months terms and boundaries of ice distribution can significantly differ from the conditions, described above.

In the Gulf of Bothnia ice disappears in late April – early May. Ice cover distribution in years with average ice conditions is shown in Fig. 2.1.4.

2.1.4. Typical ice conditions

Under average multiyear conditions ice cover in the Gulf of Finland in December is about 10%, but in February-March it reaches 80% of Gulf area (Fig. 2.1.5.). In April ice cover decrease to 49%, and in May is just about 4%. Fast ice thickness under normal conditions in the area of hydro meteorological station Ozerki in December is equal to 10 cm, in March reaches 50 cm, and decrease in April to 40 cm (Fig. 2.1.6.). Air temperature annual variation is characterized by stable transition to negative values in the middle of November, decrease in January – February up to -7.5 – -8,5˚C and stable transition to positive values in early April.

Increasing of ice cover in December to 24%, in February, March and April – to 100%, and reducing in May – to 13% are characteristic for unfavorable conditions. Fast ice thickness on its seasonal maximum under unfavorable conditions reaches 75 cm.

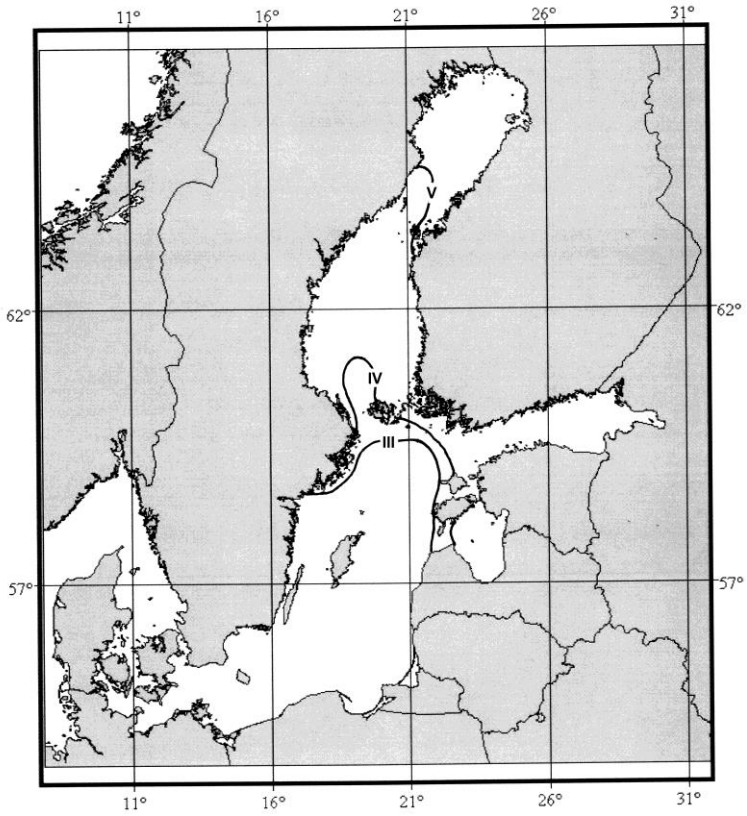


Fig. 2.1.4. Ice cover development in years with average ice conditions

Autumn transition of air temperature to negative values was noticed in the first decade of November, the most negative temperature values, about -19 ─ -20˚C, were observed in January, and spring transition to it's positive values occurred in the first decade of April.

For favorable conditions small ice quantity in December and April, insignificant ice cover – in February are typical. Ice thickness under the same conditions in March normally doesn't exceed 30 cm. Accordingly air temperature transition to negative values in Saint-Petersburg occurs with delay to the third decade of November, and respectively it's transition to positive values is observed earlier, in the third decade of March

2.1.5. Ice drift

Wind has a determinative effect on ice drift in the Gulf of Finland due to its limited size. Under stable southern winds ice accumulates near its northern coast. Spring ice melting in this area and in adjoining route areas slows down. With the change of wind direction to northern ice is moved to the central and southern parts of gulf, where it melts rapidly in spring.

The average ice drift speed is not big, about 15 cm/s. Depending on wind speed, ice concentration, size and shape of ice floes this speed varies in wide range from 2-5 to 90 cm/s, and

even more during severe storms. Steady ice motion is established in 1-2 hours after beginning of the wind. An angle of ice drift deviation from wind direction is 1-7º on average.

2.1.6. Ice conditions multiyear variability

Studies of ice cover seasonal changes in the Gulf of Finland showed, that water basin area covered by ice can rapidly reach 100% by the middle of winter. Therefore, if considering multiyear variability, it's more reasonable to use the largest seasonal area of the Baltic Sea ice, which from year to year varies in very wide range from 50000 to 420000 km^2, when the whole sea area is covered by ice (Fig. 2.1.7.).

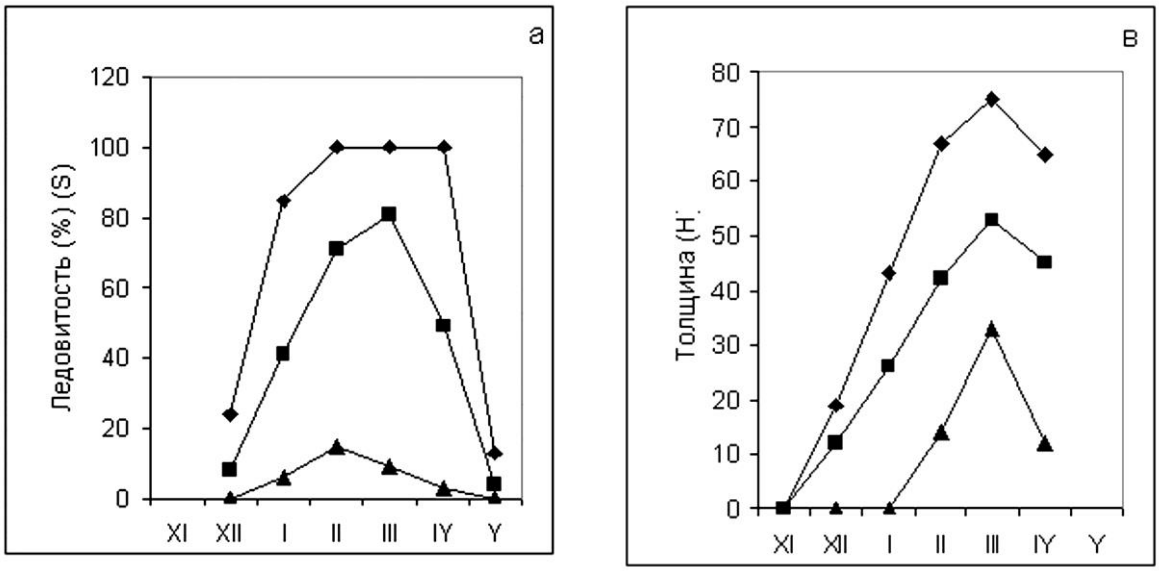
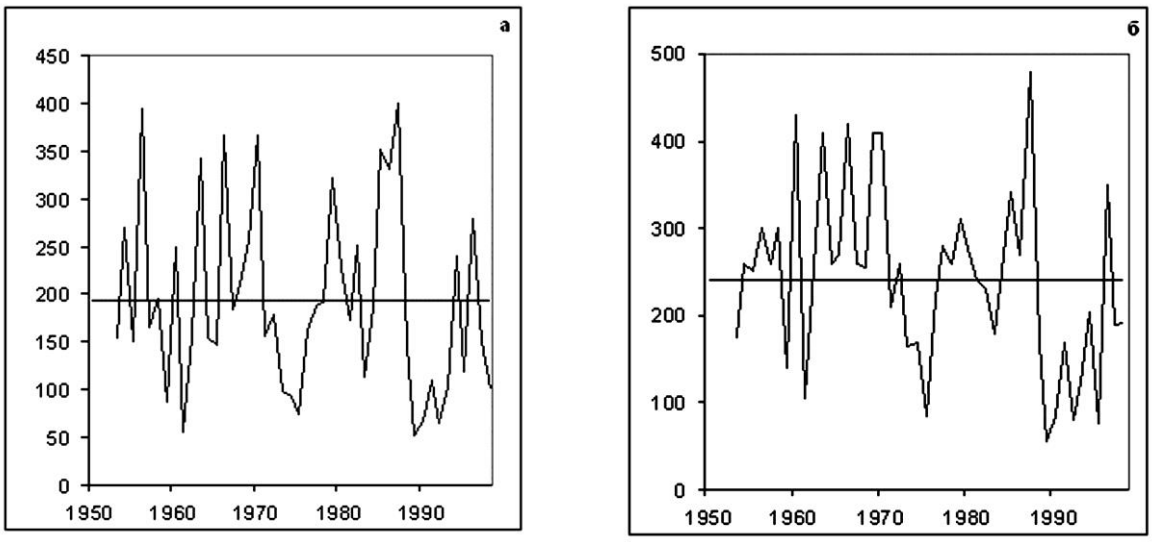


Fig. 2.1.5–Typical ice distribution in March in years with easy (a) and heavy (b) ice conditions



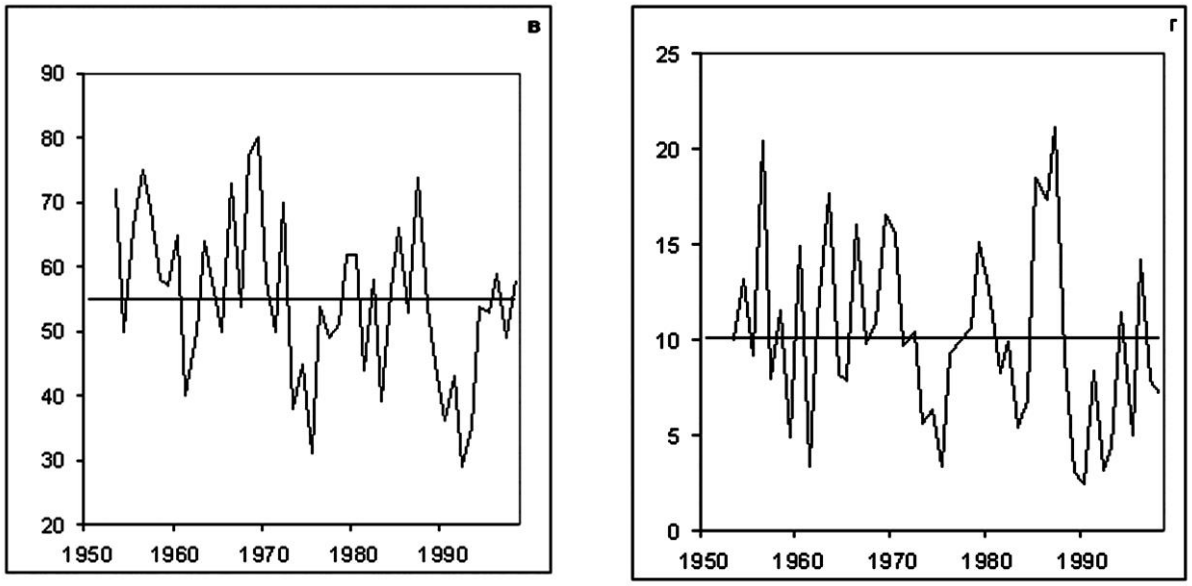


Fig. 2.1.6– Seasonal variability of ice cover and ice thickness in the Gulf of Finland (a – the Gulf of Finland ice cover (%); b – ice thickness (cm) in Ozerki)

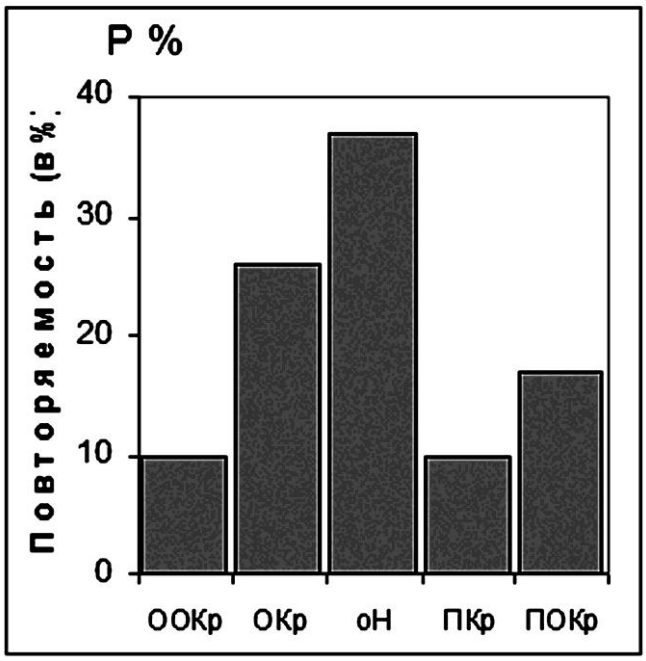


Fig. 2.1.7.– Interannual changes of ice cover, ice route length and ice thickness for the period 1953 - 1998 (a – the Baltic Sea ice cover (103 km 2) on it's seasonal maximum; b – the longest route length (n.m.) in ice along fairway; c - maximum ice thickness (cm) in Ozerki; d – ice volume (km 3) in the Gulf of Finland).

On Picture 2.1.7 it is noticeable, that largest by size and single-valued relative to norm deviations are repeated for different characteristics, mostly in the same years. And really in the most unfavorable years, which are 1956, 1963, 1966, 1969 and 1987, the Baltic Sea ice cover on it's

seasonal maximum exceeded 300000 km^2 and the largest route length in ice was more than 370 miles. In the same years ice thicknesses on its seasonal maximum were more than 70 cm and the largest ice volume in gulf exceeded 16 км^3. It's interesting, that according to all chosen indicators, unfavorable 1987 year is the most extreme for the considered time period.

To the most favorable winters by the match of single-valued norm deviations were referred winters of 1961, 1975, 1989, 1990, 1992 with the Baltic sea ice cover less than 60 000 km^2 and route length in ice on seasonal maximum less than 85 miles. Ice thickness in Ozerki and ice volume in the Gulf were less than 40 cm and 3,2 km^3, respectively.

Maximum position of ice edge and fast ice boundaries are normally connected with severe and very severe winters. In the period from 1901 to 2000 the most severe sea ice conditions in the Baltic, with the Baltic Sea ice area changed from 350000 to 420000 km^2, were observed 13 times, i.e. the most severe winters in XX century occurred once in 7-8 years.

During seasonal maximum, which normally is in the late February – early March, ice distribution area in Baltic Sea can vary in very wide limits from 50000 to 420000 km^2. Under the most favorable conditions ice processes develop mainly in eastern part of the Gulf of Finland, as well as in central and northern parts of the Gulf of Bothnia. However, under very unfavorable conditions almost all Baltic Sea including its gulfs are covered by ice in very severe winters.

Main ice cover statistical characteristics are shown in Table 2.1.1. Some insignificant reduction of values from more long-term to more short-term periods is characteristic for them. The given result indicates certain temporal stability of main statistical parameters of used Baltic Sea ice area data sets.

Table 2.1.1 – Statistical characteristics of the Baltic Sea ice area variability (10^3 km^2) on its seasonal maximum for the different periods

Period, characteristic	1900-1999	1950-2005
Average	190	188
Standard deviation (δ)	104	96
Maximum	420	402 (1987)
Minimum	52 (1989)	52 (1989)
Range	368	350

For general characteristics of the Baltic ice conditions it is important to estimate severe winter types repeatability (Table 2.1.2.) and repeatability probability, %, of particular winter type N years in succession (Table 2.1.3.).

Table 2.1.2 –Frequency of occurrence of winter severity type (%) based on three gradations of Baltic Sea ice area (km^2) for the period from 1900 to 2005.

№	Type of winter severity	Sea ice area, km^2	Number of cases, N	Repeatability, %
1	Mild	60-180	144	50,9
2	Moderate	181-300	62	21,9
3	Severe	301-420	77	27,2
TOTAL		60-420	283	100,0

Severe winters repeatability was shown to be significant and is about 27,2 %. From the Table 2.1.3 it is seen, that probability of severe winter occurrence during two successive years is not big (5%), which confirms the harmonic nature of ice cover changes with a period of 2-3 years.

Table 2.1.3 – Typification of winter severity types and particular winter type repeatability (%) in the Baltic Sea and Gulf of Finland during N successive years for the period from 1719/1720 to 2004/2005

Winter type	Ice area gradation, km^2	N years				
		1	2	3	4	5
Mild	60 - 180	50,9	30,4	2,1	1,4	1,1
Moderate	181 - 300	21,9	0,7	-	-	-
Severe	301 - 420	27,2	5,0	1.8	1,1	-
TOTAL		100,0	-	-	-	-

Tendency of the Baltic Sea ice area reduction in 30s and 50s of the last century is probably connected with earlier climatic warming in the Arctic and subarctic (the Barents and Greenland Seas). Ice area enlargement in 1953-1988 reflected modern climate cooling, and finally, short-term but intensive tendency of ice area reduction in 1988-1998 was accompanied by flash of new climate warming. As a whole, all studied 100-year period was characterized by ice area reduction tendency and general climate warming.