SPREADING AND MORPHOMETRIC PECULIARITIES OF ICEBERGS IN THE BARENTS SEA

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ABSTRACT
In recent years there are active ice research activities in the Barents Sea area, connected with the development of oil-gas fields. The objective of estimating the iceberg danger occupies an important place in conducting the ice studies since icebergs present one of the most dangerous natural phenomena in the development of the fields and operation of offshore structures. Glaciers situated on their islands and archipelagos can produce icebergs of comparatively large mass-size characteristics. The questions of spreading and morphometric peculiarities of icebergs in the Barents Sea are consider in present paper.

KEY WORDS: Barents Sea; Iceberg; Shape of Iceberg; Size of Iceberg; Draft of Iceberg

INTRODUCTION
At the present time, the Arctic and Antarctic Research Institute (SI "AARI", St. Petersburg) has collected a set of observations of iceberg location in the Barents Sea area numbering about 17 000 records. The available data present two blocks. The first covers the period 1928 to 1991 and mainly contains information on the date of detection, number of icebergs and their location. The seconds block covers the period 1992, 2002 – 2005. In addition to data on the location, it contains data on the morphometry of icebergs obtained by means of modern methods in the course of the expedition studies and organization of monitoring observations. In total, the set of morphometric observations contains information on 270 icebergs and bergy bits that were investigated.

The paper presents a detailed analysis of these data. Evidence on the location of icebergs allows us to describe the boundaries of their spreading in the Barents Sea area and estimate the frequency of their appearance in the specific areas. Based on data of morphometric observations, estimates of the main statistical parameters of the length, width and height of icebergs, their volume and mass are calculated; the corresponding histograms are presented and theoretical distributions are chosen.

The available data of radar measurements, as well as the materials of the underwater photo- and video-survey allow us to estimate the draft of icebergs by the known freeboard parameters. In this study, the calculation of such estimate is based on the assumption that the shape of the iceberg underwater portion is close to the shape of specific geometric bodies (prism, sphere and cylinder).
Special attention is given to the results of ice surveys in the area of the Shtokman gas-condensate field (SGCF) in May 2003. The data of the expedition studies have changed significantly the understanding of the boundaries of spreading of icebergs and bergy bits, and also showed that appearance of large icebergs of a sufficiently large size is possible in the study area. The maximum horizontal and vertical sizes and the largest mass, noted in the expedition in 2003 are extremes among all available values, noted in the south part of Barents Sea (72°N – 74°N along 45°E).

1. ICEBERGS DISTRIBUTION IN THE BARENTS SEA

According to archive data and the recent materials of glaciological investigations (Atlas of the Arctic, 1985; Govorukha, 1989; Koryakin, 1964), the maximum calving with further iceberg propagation over the water area of the Barents Sea is typical for the glaciers of the Arctic Archipelagoes of Spitsbergen, Frantz Josef Land, Novaya Zemlya. However, the probability of transit icebergs drift from the Arctic water basin, the outlet glaciers of the Canadian Arctic archipelago and also from Severnaya Zemlya glaciers with their possible penetration in the Barents Sea area through deep-sea straits, must not be ruled out (Dementiev, 1997).

Statistical characteristics of iceberg and bergy bit propagation in the Barents Sea were obtained on the basis of air reconnaissance and vessel observations performed by Russia in the years 1928–1991, and for the results of special programs of the years 1988–1992 (IDAP, ICEBASE), as well as field research observations for the recent years (2002-2005) (Fig. 1).

Let us note that icebergs distribution in the Barents Sea water area is non-uniform. The maximal amount of icebergs is observed near the archipelagos and islands, i.e. the sources of their generation. With the distance, their concentration is reducing. Besides, we should note that the zone of 5 % probability of pack ice appearance is located southward off 74°N.

The data on icebergs location in the squares 2°N x 5°E are presented in Fig. 2. The numerator characterizing each of the squares is the maximal number of icebergs registered within one year period, while the denominator represents the total number of registrations made within the entire period of observations.
Figure 2. Distribution of the observed number of icebergs in the Barents Sea (by the data for the period 1928 – 1992, 2002 – 2005)

One more parameter characterizing the iceberg and bergy bit propagation is location of their southern boundary (minimum latitude value of iceberg location). The multiyear variability of position of the southern boundary of icebergs distribution for the period from 1928 to 2005 and the linear trend are represented in Fig. 3.

Figure 3. Multiyear variability of position of the southern boundary of icebergs distribution in the Barents Sea for the period 1928 to 2005

According to the data provided in the diagram (Fig. 4), within the period from 1928 to 2005 only in two cases the southern boundary of icebergs distribution was registered southwards of 70°N (1929 and 2003), in 4 cases no icebergs at all were registered southward of 79°N. (1937, 1938, 1941 and 1943). The inter-quartile location of the southern boundary is determined by the interval [74.25; 76.27]. Besides, within the period from 1945 to 2005 the displacement of the boundary of icebergs spread to the south has been observed. The linear regression equation for the above period takes the form (at confidence level 0.9):

\[
S(t) = -0.0369t + 147.5549, \quad t \text{ – годы. } t=1945,\ldots,2005.
\]

Among the observations of icebergs carried out within the period after 1991 we should specially note the year 2003 when an abnormal high amount of icebergs and bergy bits was observed in the area of SGCF.

109 icebergs and bergy bits were registered in the period 1–15 May 2003 during the field research work (air reconnaissance and observations on board of the research vessel "Mikhail..."
of the SI "AARI" in the region of the Stockman Gas-Condensate Field. It should be noted that 75 of them were observed southward off 74°N. The southernmost position of icebergs occurrence according to visual observations was registered to the north-east of Kolguev Island (69°37.5′N, 48°15.9′E) – a bergy bit was registered (Naumov et al., 2003). The dimensions of bergy bits and icebergs were, according to visual and instrumental assessments from 10-20 to 450 m and the height from 3 to 10 m above the sea level.

A prerequisite for registration of abnormal amount of icebergs in 2003 was probably the presence of favorable conditions in the area of the Barents sea for active iceberg formation process and the availability of the forces essential for further spreading of icebergs over the sea area in spring and summer season of 2003. The detailed analysis of surface and upper-air pressure fields allows making a conclusion that on the whole, the development of synoptic processes during the entire period (from 08.2002 to 05.2003) was going on in stable though abnormal condition. Due to special features of thermal and baric fields over the Barents Sea during the period of study, the predominance of northern and north-eastern air flows in the surface layer was observed. The above, in fact, determined the icebergs drift direction from the sources of their formation to the south.

Admittedly, the most important fact, as regards the extremely vast spreading of icebergs in 2003, is the fact that icebergs were registered in the area of SGCF. It is known that they were observed in the area of the field at later dates, as well. So, by information of "Sevmorneftegas" in July 2003, an arched (weathered) iceberg was seen from the vessel performing a geophysical survey. Later, in August and September 2003 separate icebergs were observed in the water area of the northern Barents Sea (Buzin, 2004).

2. DISTRIBUTION OF THE SHAPE, SIZE AND MASS OF ICEBERGS

Regular airborne reconnaissance flights and special programs devoted to investigating the iceberg problem (IDAP, ICEBASE) conducted during the period 1988 to 1992 showed that one can encounter eight varieties of the shapes of icebergs in the Barents Sea. These are bergy bit, tabular iceberg, growler, glacier berg, dome-shaped iceberg, rounded iceberg, sloping iceberg and aged iceberg (Zubakin et al., 2005). The distribution of the frequency of occurrence of the shapes of icebergs detected in the Barents Sea for the period 1928 to 1991 is presented in Fig. 4 (estimates are made using 3216 values).

Data show that bergy bits comprise 72.89% of the total number of observations where the iceberg shape was determined, tabular icebergs – 15.9%,growlers – 5.57%, glacier bergs – 4.07%, and the fraction of other shapes is 1.65%.
Morphometric measurements of iceberg parameters were performed in the course of the field research works of the SI “AARI”, as well as in the periods of the program performance IDAP, ICEBASE, using technical means (air reconnaissance of ice formations, etc.). The obtained data allow us to estimate mean and maximum values of such characteristics of their above-water part as height, length and width; as well as total volume and mass of an iceberg. The used data for these estimates encompass the period 1989, 1991, 1992, 2003-2005. Location of these icebergs is demonstrated in Fig. 5.

Data of direct measurements and photogrammetric processing of air reconnaissance materials allowed us to describe statistical characteristics of horizontal plain sizes and heights of these icebergs (Table 1).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Average</th>
<th>Bounds of average</th>
<th>Median</th>
<th>Min</th>
<th>Max</th>
<th>Quartiles</th>
<th>Stand. deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (m)</td>
<td>112.5</td>
<td>102.1-122.9</td>
<td>90.0</td>
<td>8.0</td>
<td>480.0</td>
<td>52.5-145.0</td>
<td>83.9</td>
</tr>
<tr>
<td>Width (m)</td>
<td>68.0</td>
<td>62.2-73.8</td>
<td>54.0</td>
<td>6.0</td>
<td>210.0</td>
<td>40.0-90.0</td>
<td>43.6</td>
</tr>
<tr>
<td>Height (m)</td>
<td>10.2</td>
<td>9.4-10.9</td>
<td>10.0</td>
<td>1.6</td>
<td>20.8</td>
<td>6.3-13.2</td>
<td>4.9</td>
</tr>
</tbody>
</table>

It was determined in the result of this analysis that geometrical sizes can be approximated by lognormally distribution with the following parameters $m=88.23; a=0.7$ (length, Fig. 6) and $m=55.37; a=0.68$ (width, Fig. 7).

Figure 5. Location of icebergs with measured morphometric characteristics

Figure 6. Distribution of iceberg length

Figure 7. Distribution of iceberg width
As can be seen from the figures, the icebergs mainly had the width of 40 to 80 m and the length of 50 to 100 m. The maximum recorded length was 480 m, width – 210 m. It should be noted that these values had been registered for a grounded iceberg. A drifting iceberg having maximum sizes of the above-water part was registered in the course of the field research work of the SI "AARI" in 2003 (Fig. 8, Zubakin et al., 2005). Length of this tabular iceberg was 430 m, its width – 190 m.

The correlation coefficient determining the degree of linear dependence between the iceberg length and width comprises 0.8. Scattering of values and the regression line corresponding to equation $y(x) = 1.583x + 8.473$, are presented in Fig. 9.

Information on iceberg heights obtained mainly in the results of aerial photography demonstrated that this value had been within the limits of 8–12 m (Fig. 10); their mean value equaled 10 m. Distribution of iceberg heights can be approximately described by the Weibull distribution with the scale parameter $a = 11.48$ and shape parameter $c = 2.24$ (Fig. 10).

Using the results of photogrammetric processing, one can construct the models of above water surfaces and estimate such characteristics as the iceberg height, freeboard volume and area by waterline. In the case where the hydrostatic equilibrium condition is fulfilled, one can assess the underwater part volume, mass of iceberg in general and its draft. Distribution of the mass of icebergs is presented in Fig. 11. Table 2 presents the statistical characteristics of the mass of icebergs.
Table 2. Statistical characteristics of the mass of icebergs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Average</th>
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<th>Median</th>
<th>Min</th>
<th>Max</th>
<th>Quartiles</th>
<th>Stand. deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (thous.t)</td>
<td>467.6</td>
<td>283.1</td>
<td>652.1</td>
<td>155.8</td>
<td>52.0</td>
<td>3670</td>
<td>155.8</td>
</tr>
</tbody>
</table>

The maximum mass (3.67 million tons) was also noted in 2003 (74°26.3’N; 41°31.8’E). The geometrical sizes of the iceberg that has such a mass were 330x160 m and the maximum height of 13.2 m.

3. DRAFT OF ICEBERGS

Among the observations of icebergs, the number of measurements of the freeboard parameters is much greater than the number of measurements of the underwater portion ( iceberg draft or its thickness).

Analysis of measurement data of iceberg draft demonstrated that this value had been located mostly within the ranges 40–80 m (mean value – 56.5 m). The draft exceeded 80 m in two cases. The statistical characteristics obtained as a result of measurements of the thickness and draft of the underwater part of icebergs, are given in Table 3.

Table 3. Statistical characteristics of the underwater part of icebergs from data of measurements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Average</th>
<th>Bounds of average</th>
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<th>Min</th>
<th>Max</th>
<th>Quartiles</th>
<th>Stand. dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draft of iceberg (m)</td>
<td>56.5</td>
<td>48.8</td>
<td>64.2</td>
<td>59.0</td>
<td>26.3</td>
<td>45.0</td>
<td>15.9</td>
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</table>

Based on the available data, one can estimate the draft of icebergs by the known freeboard parameters. As it has been mentioned above, the parameters of the above-water part of an iceberg can be determined on the basis of aerial photography: length, width, height above sea level, as well as the volume of its submerged part. If an iceberg is in hydrostatic equilibrium, these data allow us to estimate the volume of its under-water part, while knowing water and ice densities. Assuming then that the shape of the underwater part is close to the shape of the specific geometric bodies, one can calculate the iceberg draft. According to data of measurements, in order to describe the underwater iceberg portion, a prism, a spherical segment and a segment of the ellipsoid of revolution were chosen as geometrical bodies (Fig. 12).

Figure 12. Geometrical bodies used for description of the underwater portions of icebergs
The sizes of the enumerated bodies are determined by the volume of the underwater portion of iceberg and the sizes of its section by waterline: area by waterline – prism base area (Spr) and/or circle-section area (Sr); iceberg length and width in the section by waterline – ellipse large and small axes (El(l,b)), respectively.

Calculations show that for tabular bergs, the best is a description of the underwater portion using a prism, and for icebergs of irregular shape it is better to use a segment of the revolution ellipsoid. Table 4 presents the statistical characteristics of the underwater portion of icebergs obtained as a result of the keel draft assessment from the known parameters of the freeboard taking into account the iceberg shape.

Table 4. Statistical characteristics of the underwater part of icebergs from the results of keel draft assessment taking into account the iceberg shape

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Average</th>
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<th>Min</th>
<th>Max</th>
<th>Quartiles</th>
<th>Stand. dev.</th>
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</thead>
<tbody>
<tr>
<td>Draft of iceberg (m)</td>
<td>41.5</td>
<td>35.6</td>
<td>47.5</td>
<td>40.0</td>
<td>4.8</td>
<td>100.0</td>
<td>22.2</td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td>25%</td>
<td>75%</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>25%</td>
<td>75%</td>
</tr>
</tbody>
</table>

Fig. 13 presents the iceberg draft distribution based on the assessment results.

Thus according to the results of iceberg draft assessment, the most frequent value was within 20 to 40 m at an average value of about 41 m. The maximum keel draft of the surveyed icebergs can comprise 100 m. Such a draft was obtained from the hydrostatic equilibrium condition for a glacier berg (74°38.3’N; 41°54.2’E) with a maximum noted height (20.8 m), which had a sufficiently complicated configuration in the plan (Zubakin et al., 2005).

CONCLUSION

It should be noted in conclusion that this work was a continuation of investigations started in 2003 in the framework of ice surveying in the region of the Stockman gas-condensate field. Assessment of iceberg hazard in the region of this field and over the entire water area of the Barents Sea was one of the aims of these investigations actual for development and exploitation of shelf regions.

Investigation of morphometric properties of icebergs and bergy bits allows us to determine their parameters necessary for calculations by designing of hydrotechnical structures and organization of their protection. The presented results are generalization and analysis of the data on icebergs in the Barents Sea available at the SI "AARI". These data demonstrate that
appearance of dangerous icebergs of rather large sizes in the Barents Sea is possible in its different parts thus determining necessity of continuation of development and provision of special programs of iceberg study.

Moreover, study of glaciers as a source of calving is also very important. Performance of glaciological investigations is planned in further multidisciplinary investigations in the course of "International Polar Year" (2007-2009). These investigations will be oriented at study of outlet glaciers, their calving dynamics and assessment of iceberg transit into different parts of the sea and especially into oil and gas fields of primary development.

REFERENCES


