POAC'15
Trondheim, Norway

Proceedings of the 23rd International Conference on
Port and Ocean Engineering under Arctic Conditions
June 14-18, 2015
Trondheim, Norway

HYDROMETEOROLOGICAL AND ICE CONDITIONS IN THE PECHORA SEA DURING THE CONDUCT OF THE EXPERIMENT IN 2001-2003 (PART 1)

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ABSTRACT

Pechora Sea, situated in the South-Eastern Barents Sea is a shallow water area rich with hydrocarbons. The proximity to the land and major ports (like Naryan-Mar, Arkhangel'sk or Murmansk) and huge proven hydrocarbon reserves make this area one of the most promising from the point of view of future exploration. Though this water area is characterized by the rather harsh metocean and ice regimes. In September 2001, the Arctic and Antarctic Research Institute (AARI, Russia) with the help of ASL Environmental Sciences Inc. (Canada) had installed two submerged autonomous buoy stations equipped with the ADCP and IPS for two years for measuring current and ice drift parameters. The analysis of the obtained data let to specify the earlier estimations of ice and metocean regimes. This article is dealing with analysis of ice and synoptic conditions in 2001-2003 in the Pechora Sea that allowing more detailed estimation of the background of two years of ice and current measurements.

INTRODUCTION

This study is based on the materials obtained during the 2-year observations performed for LUKOIL and ConocoPhillips companies. The main purpose of these observations was to obtain data on the dynamics of water and ice for designing of the oil terminal in the south-eastern part of the Pechora Sea. Experimental data of 2001-2003 were used as a basis.

Previously the data of this experiment had been used only in a fragmentary manner (Nesterov, 2005a,b). No thorough analysis of the ice conditions and comparison to long-term observations and available estimations has been made before.

The present study consists of two parts.

The first one is experiment setting, physical-geographical particularities of the region, assessment of obtained instrumental data, description of hydrometeorological and ice conditions during the period of experiment conduct and recommendations related to the use of materials in the analysis of results.

The second part is devoted to the assessment of experiment results for various seasons (open water/presence of ice), analysis of element variability – speeds of wind, currents and ice drift and their contingence in complex geographical conditions (Zubakin et al, 2015).

Form earlier studies (Zubakin, 1987; Dmitriev et al, 2004; Zubakin et al, 2004; Nesterov, 2005) it is known that wind and tides are the main forces applied to the ice coverage and water masses in the area of the Pechora Sea, where instruments are installed. Besides, the tidal component is rather significant and reaches about 50% of the dispersion. Most of the year – from 7 to 9 months – the Pechora Sea is covered with ice. Because of this unevenness of the sea surface introduces its own specifics in the dynamics of sea currents under the ice cover.

First of all, it is worth noting physical-geographical particulars which complicate the process of accentuation of associations between the winds and the ice drift on the one hand and the ice drift and the currents on the other hand. They include:

- orography of the researched area, proximity to the coast, islands which impact in a certain way the circulation of water and ice;
- shallow water – sea depth in places of instrument setup is 21 and 26 m; firstly, there are difficulties in revealing tides; secondly, hummock keels of about 10-15 m create preconditions for disruption of water stream integrity;
- the Pechora River runoff the impact of which is noticeable during the spring high water (May-July);
- fast ice, immobile by its nature, fastened by stamukha ice keels to the shallow sea bottom, sometimes (February-June 2003) extends for tens of miles along the coast – from the Varandey Peninsula to the islands of Dolgy and Matveev; together with hummock and stamukha keels windrow ice is observed in the area of fast ice; it moves the shallow water boundary (solid boundary) from its natural position to a significant distance, i.e. establishes situations when the ice drift and water streams bear against the ice wall and deviate from wind directions based on absolutely different principles.

MATERIALS USED

Thus, in 2001-2003 the experiment was carried out (Nesterov, 2005a,b) in order to perform a comprehensive study of water and ice dynamics in the Pechora Sea (the south-eastern part of the Barents Sea, Figure 1) using autonomous subsurface buoy stations (ASBS). In September 2001 the team of specialists of the Arctic and Antarctic Research Institute (AARI, Russia) and ASL Environmental Inc. (Canada) set up two autonomous sea bottom stations for a 2-year period (till the end of October 2003). Setting depth was 26 m and 21 m (ASBS Gorelka and ASBS Varandey correspondingly). Stations were equipped with acoustic doppler current profilers (ADCP) Workhorse Sentinel 600 kHz (manufactured by RD Instruments, USA) and upward-looking sonars (hydroacoustic ice profilers) IPS-4 manufactured by ASL. ASBS positions are shown in Figure 1.

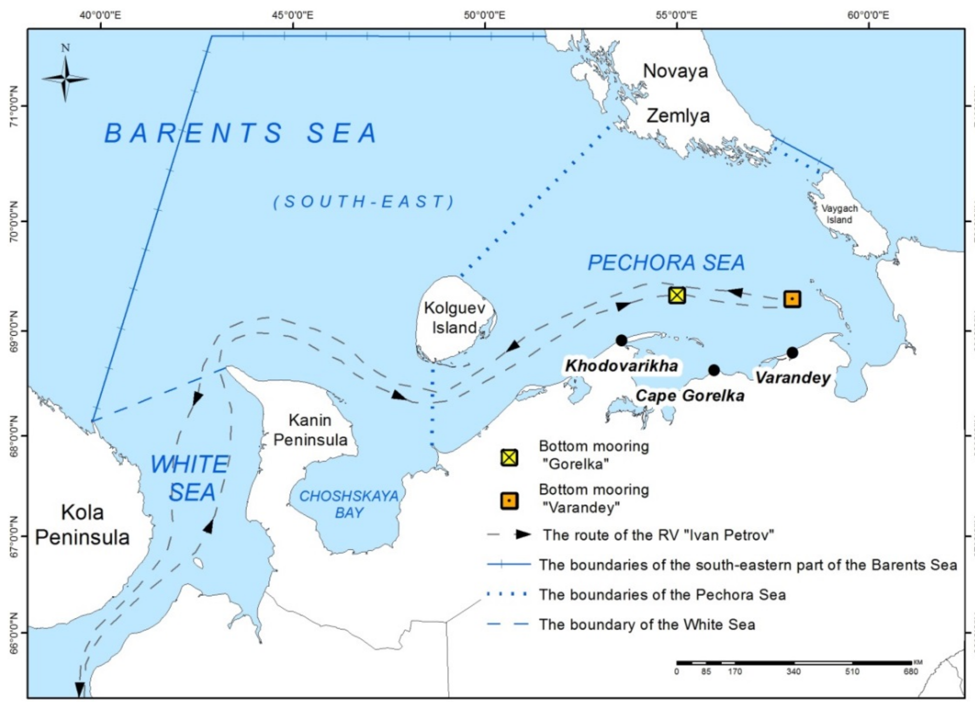

Figure 1. ASBS positions in the Pechora Sea in 2001-2003.

Autonomous Doppler Current Profiler (ADCP) Workhorse Sentinel was installed for registration of currents. It is characterized by high measurement accuracy in shallow water and low power consumption. It allows using this instrument for continuous year-round measurements. Besides, using ADCP it is possible to obtain the parameters of ice drift (Bottom Track function).

In parallel with ADCP the upward-looking sonar (ULS) was installed which is intended for the registration of sea ice draft parameters. Technical characteristics of ULS allow using it in the autonomous mode during a long period of time and obtaining accurate data on hummock keels, the topography of the bottom surface of ice floes. It is also possible to register changes of the level and near-bottom temperature.

In August 2002 the instruments were recovered, readings downloaded, and the instruments were reinstalled. Finally ASBS instruments were removed in October 2003. During the ice period of 2002-2003 ASBS Varandey was shifted by 1.3 miles to the south-east from its installation position. Information about the performed observations is provided in Table 1.

Table 1. Observation period and scope of obtained information.

ASBS	Observation period		Observed parameters	Increment, min	Duration, days	Note
	Beginning	End				
Gorelka (depth 26 m)	16/09/2001	25/10/2003	Current	10	768	21 horizons
	16/09/2001	02/10/2002	Level	60	380	
	01/02/2002	31/05/2002	Ice drift	60	120	
	01/02/2003	18/05/2003	Ice drift	60	107	
	01/04/2003	15/06/2003	Ice draft	0.03	75	
Varan dey (depth 21 m)	17/09/2001	31/10/2003	Current	10	774	16 horizons
	16/09/2001	10/09/2003	Level	60	724	
	01/02/2002	31/05/2002	Ice drift	10	120	
	25/12/2001	10/06/2002	Ice draft	0.03	163	

It is necessary to comment on the data of Table 1. Data on currents and level are obtained for the whole period of both stations setting. Ice drift based on the data of ASBS Gorelka is provided for the winter-spring period of 2002 and 2003. During the pre-winter period (November, December and January 2001/2003 and 2002/2003), when young ice up to 30 cm thick were observed, the results of measurements are characterized by significant measurement errors, and the registration of real speed started from February of both years (2002 and 2003). Also, during the spring-summer period (the second half of May, June-July of 2002 and 2003) the instruments were not functioning in a stable manner due to ice diverging and reduction of its concentration.

Draft of hammock keels at ASBS Gorelka was noted only from April to mid-June 2003. In 2002 ULS at ASBS Gorelka did not work (due to instrument wicking), thus, when the instruments were recovered in August 2002 the instruments were swapped with the ones from ASBS Varandey.

At ASBS Varandey currents and levels were recorded during the whole observation period, the ice drift was recorded only during the winter-spring period (from February through May 2002). The draft was also recorded in 2001/2002 (from December 25 through June 10), and in 2003 due to its malfunctioning the ULS at ASBS Varandey provided no data.

HYDROMETEOROLOGICAL CONDITIONS

Further let us review hydrometeorological and ice conditions during the period of the experiment and distinguish homogeneous periods when the manifestation of the desired contingence of processes should be observed a priori. In the annual cycle of variability of hydrometeorological processes for the Pechora Sea one can distinguish 4 main seasons. All of them are expressly associated with the condition of the ice coverage. The following can be emphasized from the analysis of the processes which took place in 2001-2003:

1. Pre-winter period (November – mid-January) – autumn-winter period when ice formation and establishment of young ice up to thin one-year one (30 cm thick) take place, and ice coverage reaches 50% of its magnitude in the south-eastern part of the Barents Sea (Fig. 1), i.e. practically the whole Pechora Sea is covered with ice.

2. Winter (the second half of January – mid-May) – winter-spring period when the development of ice coverage, increase of ridge intensity, formation of stamukhas and development of the fast ice are observed. Drifting ice reaches the age of medium one-year ice (70-120 cm) and the fast ice – of thick one-year ice.

3. Spring (second half of May – July) – spring-summer period when thawing of ice coverage, diverging of ice, reduction of ice concentration, breakage of fast ice and complete clearing of the sea take place.

4. Summer (August-October) or “free water”, summer-autumn period which is characterized by the absence of the ice coverage.

Based on the distinguished period of the year in 2001-2003 9 seasons were observed with meteorological characteristics provided in Table 2.

Table 2. Main characteristics of unidirectional circulation periods.

Period No.	Period duration	Wind streams	Wind speed (m/s)		Air temperature, °C			Note
			Av.	Max	Av.	Min	Max	
1	02.09.2001 30.10.2001	SW, W	4.7	23.0	1.75	-12.5	16.6	Numerous winds of various directions
2	31.10.2001 29.12.2001	SW	8.3	23.1	-11.5	-27.0	-0.5	Beginning of ice formation, development of ice coverage
3	30.12.2001 08.05.2002	SE, W	6.2	25.0	-14.2	-34.7	7.1	In January passing by ice coverage the 50% mark
4	09.05.2002 03.08.2002	N, W	4.9	19.0	4.1	-8.6	23.9	In beginning of May passing by ice coverage the 50% mark, in end-July complete clearance
5	04.08.2002 15.10.2002	N, NW, W	4.8	24.4	3.25	-5.5	12.1	In mid-period wind of varying directions
6	16.10.2002 23.12.2002	W, SW	7.0	25.8	-10.1	-30.6	0.75	In November beginning of ice formation
7	24.12.2002 01.05.2003	NE, W, SW	9.2	34.2	-16.8	-31.9	1.80	In January and by mid-April passing of ice the 50% mark
8	02.05.2003 09.08.2003	N, S, NW	4.9	25.5	3.0	-19.8	21.7	In the beginning of August complete clearance of the sea from ice
9	10.08.2003 01.11.2003	NW, SW, NE	6.2	20.7	5.1	-11.8	18.6	Strengthening of Iceland minimum at the end of August

We will assess the meteorological conditions by developing the previous studies (Scientific-and-Technical Report, 2004; Ivanov and Lebedev, 2004). The whole diversity of synoptic situation may be conditionally divided into elemental synoptic processes (ESP). According to AARI archives during the period from September 2001 through October 2003 207 ESPs were observed. After the analysis all the ESPs were divided into 48 homogeneous circulation periods (HCP). In the process of ESPs splitting the prevailing direction of wind above the Pechora Sea basin during each period was used as the main parameter.

Air temperature in the area of instruments setup varied from -34.7°C in winter to 23.9°C in summer. In 50% of cases air temperature did not drop below -13.6C and did not rise above 4.7°C. In time variation of the temperature daily and seasonal fluctuations are clearly traced. More than half of the time (57%) wind speed was within the range of 2-9 m/s, maximum wind speed was 34 m/s. In 22% of cases weak winds (<2 m/s) were observed. During the whole observation period the average speed of wind was 6 m/s. Besides, a selection of winds with the speed of at least 15 m/s (75 cases in total) was made. The total duration of time with high-speed winds was 8.8% of the total observation period. Wind speeds of 30 m/s and above were recorded in case of western rhumbs (WNW, W, SW). The following months of the ice season are distinguished by the number of cases when wind speed exceeded the selected level (15 m/s): December (11 cases), January (9 cases), February (9 cases), March (11 cases). During 2 years in summer (July-August) 4 cases of strong winds were registered.

DATA ANALYSIS AND DISCUSSION

Thus, periods 2, 6 from Table 2 should be associated with the pre-winter season; periods 3, 7 - to season 2 (winter); periods 4, 8 – to season 3 (spring); periods 1, 5, 9 - to season four (summer, "open water"). In future the selections made will allow, together with the analysis of Table 1, updating the goals and objectives of the second part of work related to the variability and contingence of wind fields, ice drift and currents.

Hereinafter we will assess the above mentioned characteristics of the hydrological conditions, such as tides and river runoff. Using the methodology (Voinov, 1999) the tidal component of the process dispersion was calculated (Scientific-and-Technical Report, 2004). For the currents at ASBS Gorelka 54% of the process energy is concentrated in the surface horizon and 48% - in the near-bottom horizon. At ASBS Varandey the values are as following: 66% - at the surface and 55% in the near-bottom horizon. Tidal currents in the surface layer and the tidal ice drift practically coincide in direction and magnitude (Scientific-and-Technical Report, 2004).

The Pechora Bay, where the Pechora River flows in, represents a vast gulf of the Pechora Sea. The sea boundary of the bay passes from the Russky Zavorot Peninsula, across the Guliaevskie Koshki (system of shoals and small islands), to the northern extremity of the Pesiakov Island. The area of the Pechora Bay is 6,400 km^2, and the volume of water – about 35 km^3 (Polonsky et al, 2007). 70% of the river runoff is carried over the strait near the Pesiakov Island (ASBS Varandey area, the rest – through the straits of the Guliaevskie Koshki in particular by the deep-water strait between the 3rd and 4th Guliaevskie Koshki islands (in the range of ASBS Gorelka). The annual runoff of the Pechora River is 135 km^3. During the period of May-June-July 65-70% of the annual runoff passes through (May – 22.1%, June – 34.8%, July – 10%). The irregularity of the runoff and its concentration during the mentioned period are caused by predominantly snow-related nourishment of the river. Rain-related high water often happens in August-October, due to this the water volume of the river is higher than in winter. Salinity values at the stations of Khodovarikha (ASBS Gorelka) and Varandey (ASBS Varandey) serve as the indicator of river water expansion in the area of experiments. In the period of high water (May-July) the salinity near the HMS Varandey reaches zero values and near the HMS Khodovarikha - 7‰, although in summer, autumn-winter and winter-spring periods it varies within 30-33‰.

Hence, in the spring-summer period a complex picture of waters with different nature is observed in the area of experiments: wind-induced, tidal, inertial, runoff, gradient currents, as well as currents caused by changes of density due to the inflow of river water and convective streams from thawing ice. At the same time the interaction between the above motions is non-linear.

During this period it is obviously impossible to obtain reliable values of contingence between the fields of wind, ice drift and currents. It is also not easy to segregate the tidal component from the summarized currents. Due to the above mentioned in the second part of the study there should be quite reasonable doubts in the results of the desired contingence assessment. It is not recommended to consider the spring-summer period (the second half of May-July) as the high priority in the analysis of observation materials.

Let us review ice conditions during the experimental period. Ice coverage of the sea, ice age, concentration and ridging intensity are the key parameters used in the express analysis of ice conditions. Ice coverage of the sea is the integral characteristic of the ice coverage conditions and expressed in percentage of the sea area covered with the ice. In this case it means the coverage of the south-eastern part of the Barents Sea. In its absolute values and anomalies (Table 3) the ice coverage represents macro-circulation (climatic) processes taking into account meteorological and hydrological particulars of the selected area. The monthly ice coverage and its anomaly were calculated for the period of 1934-2010.

Table 3. Monthly ice coverage (L in %) and its anomalies (ΔL in %) in the south-eastern part of the Barents Sea during 2001-2003.

Year/ month	L/ ΔL	Months								
		XI	XII	I	II	III	IV	V	VI	VII
2001/ 2002	L	26	36	57	82	73	62	42	16	1
	ΔL	19	10	13	22	7	-4	-10	-4	-1
2002/ 2003	L	22	41	59	53	56	40	34	16	0
	ΔL	15	15	15	-7	-10	-26	-18	-4	-2

While analyzing Table 3 one should note a significant unevenness of ice process developments which adequately demonstrate synoptic conditions of the region. There is a general tendency of abnormal deviations – positive anomalies of ice coverage during the first half of the ice period. This tendency in all the parts of the Barents Sea, and in the whole sea, was initially researched in the PhD thesis of I.V. Buzin (Buzin, 2008). During 2002/2003 positive anomalies remained till February, and during 2001/2002 till April. At the same time during this winter ice coverage was above the norm, and from April a minor negative anomaly close to the norm was observed. The season of 2002/2003 is noticeable exactly due to a very significant negative anomaly which was observed from February through July and most vividly expressed in April-May. The origin of this anomaly (its nature) is clearly implied from Figure 2.

In cases of western, north-western and northern wind streams (with the maximum wind speeds up to 25-30 m/s) packing of ice coverage took place (reduction of ice coverage by 30% during two weeks of April). In January, February, March and July four intrusions in the Pechora Sea of one-year thin (30-70 cm) and medium (70-120 cm) ice of the Kara Sea origin happened. Later this Kara Sea ice participated in the processes of packing and hummocking.

During this period (March-May) ice concentration was 9-10 points, strong packing was observed (Scientific-and-Technical Report, 2004), and hummocking reached 4-5 points, i.e. 80-100% of the Pechora Sea basin was covered by hummocks of various magnitude.

Based on the data of installed instruments a very important characteristic of hummocky formations - draft of keels – was analyzed (Scientific-and-Technical Report, 2004). In

2001/2002 the average draft of hummock keels at ASBS Varandey (Table 1) was increasing from December through May from 3.7 m to 7.1 m, the minimum draft threshold of the measured hummock keels was 0.30-0.5 m. In April and May the average draft reached its maximum and then reduced in June (hummocks were thawing, destroying and disappearing). The number of recorded hummocks (out of the total number) was about 3% in December, 17% - in February, 20% - in March, 26% - in April. In May the number of hammocks started decreasing down to 19%, and in June it amounted to 3% only. In April on average once a week a hummock with a keel larger than 15 m passed, three times a day keel draft exceeded 12 m, 11 times a day this value exceeded 10 m. In May 2 hummocks a day had a draft of more than 12 m, and twice a month it was possible to expect a hummock with a draft above 15 m. In April-May hammock density obtained using the data on the ice drift averaged at 9.2 hummocks per 1 km. It accords well with the data of aerial photography (Gudoshnikov et al, 1998) for this area.

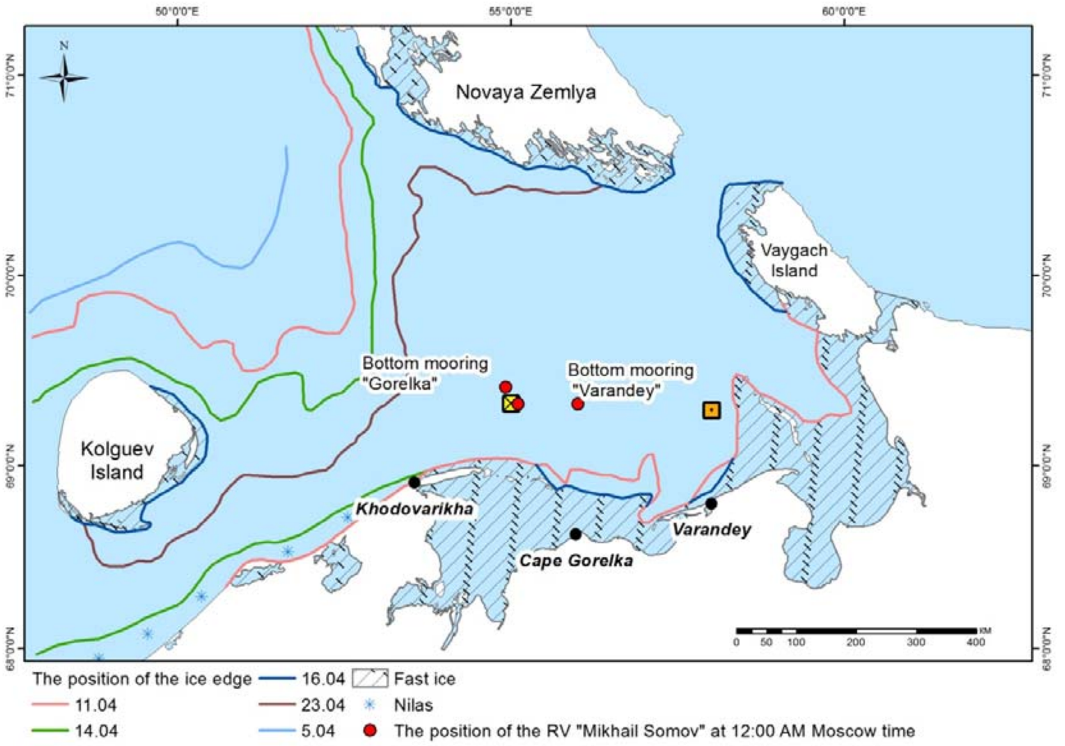

Figure 2. Map of ice edge and fast ice location during April 5-23, 2003.

Unfortunately, nothing is known about the dimensions of hummock keels for 2003 in the area of Varandey (the instrument malfunctioned), but it is possible to judge about their approximate or even larger size based on the data of the instrument at ASBS Gorelka. Besides, in the process of search for the instruments and Varandey station in October 2003 it turned out that it was displaced by 1.3 miles in the south-eastern direction. The depth of the mooring was 21 m. One may suppose that the station was displaced by the hummock with the depth of the keel exactly about 20-21 m. Tracks of hummock keels in this area at the depths of 19-20 m were observed earlier in the process of bottom sonar surveying for the site of the Prirazlomnaya oil platform.

In 2003 (April-May) the increased average value of the ice keel draft of 6.2 m and the maximum one of 18 m were observed at ASBS Gorelka. It is more than in the area of ASBS Varandey in 2002. In April hummocks with the keel draft above 10 m passed through this point four times a day, in May – 13 times a day. In April hummocks exceeding 12 m occurred once in 3 days, in May – five times a day. The number of keels with a deeper draft in May significantly exceeds the numbers of April.

The extreme development of fast ice in 2003 in the area of the Varandey Peninsula draws one's attention (Figure 2). The fast ice was formed in the end of February and existed till June having its beginning from HMS Varandey and covering islands of Dolgy and Matveev. In May the thickness of level fast ice was 120-170 cm. The fast ice contained stamukhas, i.e. the keels of drifting hummocks touched the sea bottom and became converted into stamukhas which formed the motionless zone.

Besides, windrow ice is often observed in the fast ice zone near the Varandey Peninsula. It goes under the fast ice edge. This phenomenon can reach significant magnitudes and expand to the sea bottom at the depth of 10-12 m freezing with hammock keels. Apparently, such situation was observed in the summer-spring period of 2003 (Figure 2).

Thus, projecting the edge of the fast ice on the bottom of the Pechora Sea one may suppose that it represents a solid (temporary) boundary shifted to the basin of the area. Therefore an obstacle is formed in the way of ice and water streams, and a left turn of drift and current vectors is inevitable. It represents a departure from classic notions of deep water drift theory, i.e. a right turn of drift and current vectors from the direction of wind vectors.

A similar picture was observed in this area in 1982 (Zubakin, 1987) when a 4-month experiment was conducted aimed at the research of ice coverage dynamics using an aircraft-based radar station. As it is demonstrated by the results of analysis of mass ice drift materials (Figure 3) the "neutral" line of drift deviation angles from the direction of wind streams passes exactly in the area of Varandey. The left turn of the drift vector is observed to the north of it – i.e. "negative" deviation angles.

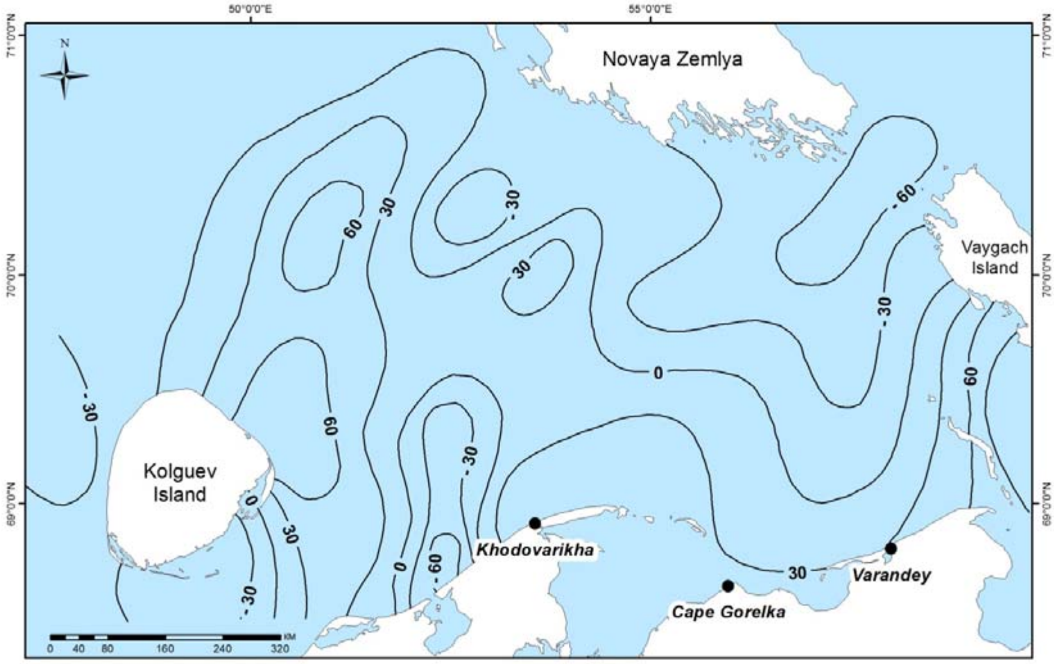

Figure 3. Distribution of ice drift deviation angles (degrees) from wind direction (Zubakin, 1987).

SUMMARY

The work performed has let us to obtain the estimations of hydrological and ice conditions during the experiment in qualitative manner, to distinguish the homogeneous periods and seasons of development of various factors and make a preliminary filtration of the initial information according to these criterions. The filtered information is suitable for further statistic and probabilistic analysis of the ice drift and currents and estimation of their conjugation with the wind field.

In order to summarize and provide recommendations for further studies (part 2) we will use the results described in Tables 1, 2 and 3:

1. Table 1, which is the main one, contains a list of observation materials and periods when they were obtained (operation of instruments). Table 2 emphasizes homogeneous seasons of hydrometeorological and ice conditions, supplements the data with the assessments of the river runoff. Table 3 updates the characteristics of the areal ice coverage during two ice seasons of 2001/2002 and 2002/2003.
2. September-October 2001, August-October 2002 and August-October 2003 are the homogeneous ice-free seasons ("open water" periods). Here it is possible to fulfill several tasks related to wind and current variability and their contingence with various additional variants (for instance, wind shift by 3, 6 hours, correlation between current horizons and the average stream in general, contingence of current vectors between two stations. It is possible to review the results of analysis for individual seasons and for combined groups of summarized non-periodical currents.
3. There are no data on ice drift (instruments did not record them) for pre-winter of 2001 and 2002, i.e. November-December and the 1st half of January (2002 and 2003) may be considered as the period suitable for the calculation of contingence between wind and current vectors with a critical assessment of the results related to the upper layer of water (here there are discontinuities, because during these periods ice was still present, as it is shown in Table 3).
4. The winter season, or the winter-spring period, should be split into 2 parts using the data of Table 3 related to ice coverage and its monthly anomalies. Data on positive anomalies of 2002 will compose one period of contingence calculations, and on negative anomalies (till mid-May) – the second.
   In 2003 the 1st part of the winter season with a small positive anomaly is suitable for a "classic" research. It is possible to combine vector groups of this period with the first half of 2002 to form one homogeneous group. The second part of 2003 is characterized by the extreme displacement of ice edge under the impact of W, NW and N winds, strong packing of ice coverage, strong compactions and increased ridging, because extreme negative anomalies of ice coverage were observed, which were caused by synoptic conditions. This period may be assessed from the point of process variability as a deviation from certain average values.
5. There are no data on ice drift for the second half of May, June and July (thawing period). During this period simultaneously with ice thawing the role of river runoff increases dramatically. As demonstrated by the data (Polonsky et al., 2007) the salinity in the region changes sharply from 33 ‰ in winter to 0-7‰ during the period of high water (May-July). It creates certain, and sometimes unsolvable problems related to the segregation of the dynamic components from the general process, even more so in case of linear formulation of certain tasks. Due to the above this period should not be reviewed so far and postponed for further studies.

The periods listed above allow limiting the scope of work related to the assessment of variability and contingency of wind fields, ice and current drifts (part 2).

ACKNOWLEDGEMENTS

The authors are grateful for Dr. Igor V. Buzin (AARI) for assistance in preparation and editing of the final version of this article.

REFERENCES

Buzin, I.V., 2008. "Estimation of the ice cover state and conditions of formation of the heavy ice seasons in the Barents Sea". PhD Thesis (Geography), AARI funds, 202 pp. *(in Russian)*

Dmitriev, N.E., Zubakin, G.K., Bokov, V.N., Voinov, G.N., 2004. Diurnal variability of ice and current drift in the Pechora Sea. Proc. AARI, v. 449, p. 24-42. *(in Russian)*

Gudoshnikov, Y.P., Kolesov, S.A., Naumov, A.K., 1998. Statistical modeling of hummock height distribution. Meteorology and Hydrology, No. 56, p. 80-86. *(in Russian)*

Zubakin, G.K, Gudoshnikov, Y.P., Ivanov, N.E., Nesterov, A.V., Sukhikh, N.A., 2015. Contingence of winds field, currents and ice drift in the Pechora Sea in 2001-2003 (part 2) ROAS-15, this digest.

Ivanov V.V., Lebedev A.A., 2004. Key regularities of perennial and seasonal variability of atmospheric macro-circulation, meteorological and ice conditions in the south-eastern part of the Barents Sea at the end of the 20^{th} – beginning of the 21^{st} century. Proc. AARI, v. 449, p. 8-23. *(in Russian)*

Nesterov, A.V., 2005(a). Dynamics of water and ice in the south-eastern part of the Barents Sea according to the data of autonomous bottom stations. Proc. of RAO-05, SPb, September 13-15, p. 128-131. *(in Russian)*

Nesterov, A.V., 2005(b). Study of water and ice dynamics in the Southeastern Barents Sea by means of self-contained moorings. Proc. of the POAC'05, vol 2., (The 18^{th} Intern. Conf. Port and Ocean. Eng. Under Arctic conditions June 26-30 Potsdam, NY, USA), p. 735-744.

Polonsky, V.F., Lunachev, Y.V., Ostroumova, L.P., 2007. Key features of the hydrological conditions of the Pechora estuary area. GOIN Proc., issue 210, p. 265-284. *(in Russian)*

Scientific-and-technical report "Processing of observations of currents, sea level and drifting ice performed during the period of 2001-2003 by the acoustic doppler profilers of currents (ADPT) and upward-looking sonars (UPS) in the Barents Sea in the areas of the Varandey Peninsula and the Cape of Gorelka. Summary of available data on ice conditions. SPb, AARI funds, 243 pp. / Edited by Zubakin, G.K., 2004. *(in Russian)*

Zubakin, G.K., 1987. Large-scale variability of ice coverage conditions in the seas of the North-European Basin. L., Gidrometizdat Publishing House, 160 pp. *(in Russian)*

Zubakin, G.K., Voinov, G.N., Dmitriev, N.E., Nesterov, A.V., Vinogradov, R.A., Borisov, R.A., 2004. Ice dynamics in the Kara Strait based on the natural data. Proc. AARI, v. 449, p. 43-52. *(in Russian)*

Voinov, G.N., 1999. Tidal phenomena in the Kara Sea. SPb, Russian Geographical Society 110 pp. *(in Russian)*.