THE TIDAL EFFECTS IN THE NORTHERN OB BAY.

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ABSTRACT
In 2005, 2010-2012 AARI had performed a number of metocean research surveys in the northern part of Ob Bay for the aim of supporting the system of LNG transportation. These surveys were dealing with the hydrological and ice regimes of the water area. The parameters of tidal oscillations, tidal currents and tidal ice drift were estimated. The obtained data had determined a number of essential design solutions for Sabetta port.
The main results of the tidal harmonic analysis in the northern part of the Ob Bay are given in the article. The harmonic analysis of the field materials was performed on the basis of the least-squares method’s variant, developed in AARI. The results of this analysis describe completely the pattern of formation and propagation of the main tidal waves in the northern Ob Bay in the ice-free period. The values of mean spring and neap tidal levels and values of the tidal currents on the surface and bottom levels are calculated. For the local areas (uniform in the sense of tidal conditions) the values of mean spring and neap tidal current velocities are estimated.

INTRODUCTION
In order to study the patterns of the ice floe drift, in 2011 and 2012 ice buoys Argos with GPS receivers were deployed on the drifting ice in the northern part of the Gulf of Ob’ and on the fast ice in the region of the Sabetta port. Scheme of the buoys drift, deployed on the drifting ice in the northern part of the Gulf of Ob’ (*No* 77379, 77450, 77938, 77949), and on the fast ice in the region of Sabetta (*No* 54002, 54124, 76307, 76501) in 2011 is presented in Fig. 1. Here it should be mentioned that drift in the northern part of the Gulf of Ob’ was observed starting May 18, uniform time intervals is equal to 15 min. Group of buoys started to move as the fast ice broke up, June 19, ice drift within the Gulf of Ob’ continued till the middle of July. In this group of buoys uniform time intervals were 1 hour.
In 2012, as a result of abnormally easy ice conditions, observation period was shorter. Measurements on the drifting ice floes in the northern part (*No* 115057, 115060, 115061, 115066) began May 6 and continued till the middle of June. In the region of Sabetta ice drift began June 4-7, after the decay of fast ice (buoys *No* 115065, 115067, 115285, 76323), whereas observation period ended already June 11. In 2012 uniform time intervals were 1 hour.
Preliminary data of the drift coordinates were converted into format of [m] and [cm/s] by the known ratio between length of the degree of arc of meridian and that of parallel at different latitudes (Oceanographic tables, 1975). The uniform time intervals was checked on preliminary basis and in case of small gaps in data coordinates were defined by means of linear interpolation.
Temporal series of 2011 with uniform time intervals 15 min were smoothed by 15-minute filter (Pugh, 1987). At uniform time intervals of 1 hour background of noise is small and smoothing filters weren’t applied.

2011 year 2012 year

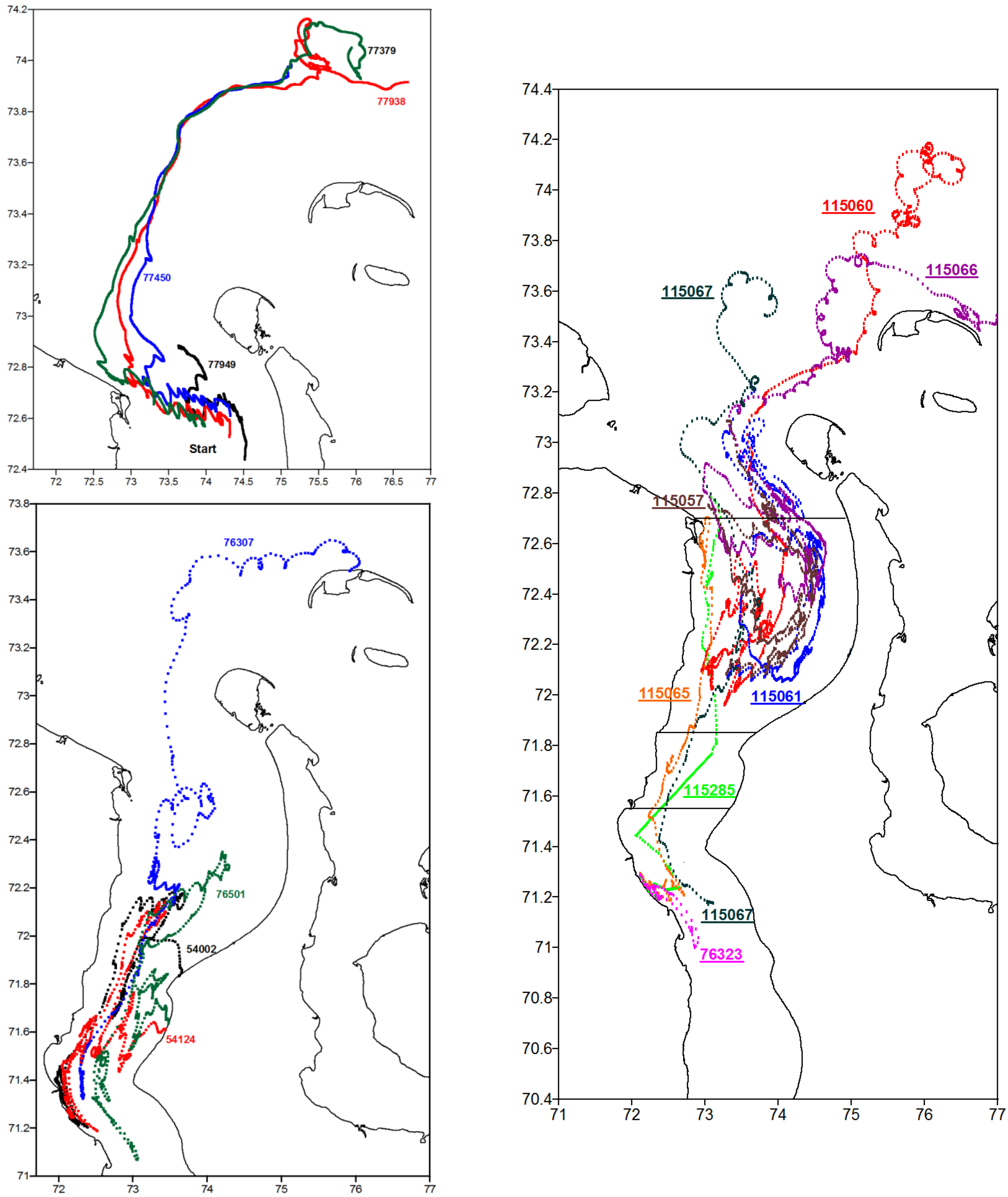

Figure 1. Area of drift of buoys in Ob bay.

HARMONIC ANALYSIS OF THE DRIFT VELOCITIES OF ICE FLOES BY DATA OF INDIVIDUAL BUOYS

As it can be seen from the Figure 1, during measurements on drifting ice in the northern part of the Gulf of Ob' trajectories of the ice floes drift were always represented by complicated circular-like trajectories with length of tens of kilometers. Judging by these trajectories ice floes moved mainly northward and finally ended up out of the Gulf of Ob'. In 2012, ice drift that began in the Sabetta region in half of the cases finished outside of the Gulf of Ob'.

Data of the synchronous measurements of currents and ice drift, obtained in different regions of Arctic using ADCP, allows us to conclude that tidal currents in the surface layer of the sea and tidal motions of the drifting ice correlate only roughly. However, in this case we consider point measurements that illustrate the so called Euler transport of water masses and drifting ice. Motion of the drifting ice is considered Lagrange transport. These two types of motion are not identical. Nevertheless, we can roughly refer the results of statistical processing of the ice floes drift to the center of coordinates of the ice motion within a chosen period of analysis, which allows us to compare results of point- and spatial motion

Before that, we hadn't had any information on the tidal drift of ice in the Gulf of Ob'. It can be said that the estimates of tidal component of the ice drift in the Gulf of Ob' obtained in 2011 were the first.

As determined in previous surveys (Kopteva, 1953, Voinov, 2003), the principal feature of tides and tidal currents in the freezing seas is the seasonal variability of their main parameters (amplitude value of constituents, their phases, tidal ranges etc). Parameters of tidal oscillations in the Gulf of Ob' vary considerably in winter (November-June) and during this period it is necessary to define them for each month. In summer (July-October) the seasonal variability isn't as significant as in winter period, but it also differs each month.

Also, there are individual seasonal variations of tidal oscillations of level and currents, that in the Gulf of Ob' depends on the time of formation and degree of the fast ice evolution, its thickness, lifetime of the fast ice and drifting ice, that is, there is from-year-to-year variability. The abovementioned is applied to tidal oscillations of level and currents, but it is possible to refer these conclusions to tidal motions of the drifting ice.

The first practical task was to determine the homogeneity of drift regions of individual buoys with regard to tidal regime. That is why it was necessary first of all to perform a sliding harmonic analysis of the time series for individual buoys for various periods and determine approximate time intervals for it was possible to obtain harmonic constants of principal tidal constituents with reliable resolution. There comes dilemma: on the one hand, it is necessary to define the longest of all possible period of analysis in order to distinguish the entire spectrum of major constituents; on the other, region, where ice floes are drifting in should be homogeneous by the tidal regime. Sometimes, the last requirement is neglected in order to comply with the first. It does not lead to serious mistakes, because in such cases we obtain averaged estimates of tidal drift for a large water area. Afterwards, as other observation data are obtained, it will be possible correct and refine such estimates.

Harmonic analysis was carried out by means of the least-square method in accordance with the version, elaborated in AARI (Voinov, 2003). The model of tide included major diurnal constituents O_1 and K_1, major semidiurnal constituents M_2 and S_2 (in rare cases N_2) and major 1/4 diurnal and 1/6 diurnal constituents. According to experiments, the window of 10-15 days is the minimal analysis period for resolving the mentioned constituents.

From the theory, on the basis of the Rayleigh criterion (not taking account of the ratio signal/noise), about 28 days are required to resolve constituent N_2 from the constituent M_2. That is why sometimes we had to exclude this constituent (N_2) from the model, although the estimates of the constituents M_2 and S_2 got less precise. Aside from that, reliability of the constituents estimates decreases at the attempts to include a range of other secondary constituents, namely Q_1, J_1, M_1, L_2, etc into the model of tide. In order to get reliable estimates of the range of the secondary (or related) constituents, it is required to increase the period of analysis (window), but sometimes it is impossible to do due to the fact that we need to comply with the criteria of homogeneity of the tidal region. Results (harmonic constants of components on meridian and parallel) by constituents K_1, S_2, N_2 in second approximation were corrected by means of theoretical ratios to exclude the influence of secondary (related) constituents, which are, respectively: π_1, S_1, ψ_1, φ_1, P_1 (from K_1); K_2, T_2, R_2 (from S_2); ν_2 (from N_2).

In general, it is possible to carry out harmonic analysis of diurnal cycles on the basis of Admiralty analysis of tides. But using this approach means we will be able to use only those observations that were made in syzygy and thus it will be impossible to part the influence of inertial fluctuations of ice drift from that of tidal and nonperiodic fluctuations (which is the crucial factor for accuracy of estimates of tidal constants). That is why results of analysis by Admiralty method are characterized by considerable range of amplitudes and phases of major tidal constituents.
The accuracy of estimates depends on influence of nonperiodic and inertial currents and, in some cases, influence of inertial fluctuations of tides lead to overrating amplitude of S_2 constituent. Theoretically determined inertial period at the latitude 72° is 12.57h.
Results of harmonic analysis of series of 8-15 days were referred to the circular region with radius of 5 miles with center defined as average coordinates of the temporal series of the period of analysis.
Tables 1 and 2 provide data on coordinates of centers of the series – average coordinates of individual series, period of harmonic analysis and duration of the period.

Table 1. Data on coordinates and the period of analysis of the temporal series of velocities of the ice drift in the Gulf of Ob' in 2011.

Buoy *No* (in order of deployment)	Latitude (N)	Longitude (E)	Period of analysis	Series length (hour)	Note
1. (77450)	72° 42.6'	73° 39.7'	18-24.05	144	Radius is 5 miles
2. (77379)	72° 42.1'	73° 13.2'	18-24.05	144	Radius is 5 miles
3. (77938)	72° 40.8'	73° 33.3'	18-24.05	144	Radius is 5 miles
4. (77949)	72° 39.3'	74° 08.0'	18-24.05	145	Radius is 5 miles
5. (76307)	72° 19.0'	73° 30.7'	24.06-03.07	229	Radius is 5 miles
6. (76307)	72° 04.2'	73° 11.3'	19.06-04.07	358	Radius is 5 miles
7. (76501)	71° 55.2'	73° 26.7'	04-19.07	363	Radius is 5 miles
8. (54002)	71° 52.2'	73° 01.5'	03-15.07	299	Radius is 5 miles
9. (76501)	71° 47.0'	73° 13.9'	28.06-13.07	359	Radius is 5 miles
10. (54124)	71° 45.3'	72° 55.5'	04-18.07	346	Radius is 5 miles
11. (54124)	71° 25.2'	72° 13.5'	19.06-04.07	361	Radius is 5 miles

Table 2. Data on coordinates and the period of analysis of the temporal series of velocities of the ice drift in the Gulf of Ob' in 2012.

Buoy *No* (in order of deployment)	Latitude (N)	Longitude (E)	Period of analysis	Series length (hour)	Note
1. (115066)	72° 41.0'	73° 22.0'	12-19.05	192	Radius is 5 miles
2. (115066)	72° 37.0'	74° 09.0'	12.05-10.06	720	Radius is 5 miles
3. (115061)	72° 30.1'	74° 13.0'	09-14.05	144	Radius is 5 miles
4. (115057)	72° 30.0'	73° 34.0'	12-18.05	168	Radius is 5 miles
5. (115060)	72° 16.1'	73° 33.0'	06-31.05	608	Radius is 5 miles
6. (115057)	72° 16.0'	74° 13.0'	19.05-02.06	360	Radius is 5 miles
7. (buoys in fast ice)	71° 14.5'	72° 22.5'	07-10.06	96	Radius is 5 miles
8. (115061)	72° 12.0'	74° 21.0'	16.05-04.06	480	Radius is 5 miles

On the base of values of harmonic constants of constituents M_2, S_2 and K_1, O_1 we calculated the following harmonic constants of ellipses of the tidal drift for components of the current speed by meridian and parallel: phase and direction of the maximal current speed, values of the maximal and the minimal current speed (semi-major and semi-minor axes of the ellipse), aspect ratio of the semi-axis ellipse (the ellipse compression) and sense of rotation of the velocity of current. These parameters of ellipses of the main semidiurnal constituent M_2 of tidal motions of ice for the abovementioned series are given in Table 3.

Table 3. Elements of ellipses of tidal ice drift of the constituent M_2 (maximum current speed) for series (Table 1 and 2)

Buoy *No*	Current speed, cm/s		Phase, deg.	Direction, deg.	The ellipse compression
	Semi-major	Semi-minor			
2011					
1.	24.24	3.05	110	148	–0.126
2.	22.85	6.23	126	156	0.273
3.	19.05	4.05	124	148	0.213
4.	20.84	3.85	109	159	0.185
5.	36.16	13.61	114	190	0.376
6.	25.70	6.96	138	195	0.271
7.	22.12	3.38	165	209	0.153
8.	28.17	1.68	166	207	–0.060
9.	15.71	7.14	2	200	–0.454
10.	29.56	2.66	8	202	0.090
11.	19.15	1.73	52	179	–0.090
2012					
1.	32.99	0.27	101	158	–0.008
2.	17.42	2.07	89	161	0.119
3.	34.14	9.97	133	182	0.292
4.	30.52	8.84	137	180	0.290
5.	27.05	6.14	139	197	0.227
6.	14.89	3.67	121	195	0.246
7.	28.15	1.27	65	138	–0.045
8.	9.94	1.61	116	192	0.162

From the data given in Table 3 and the data on amplitude of constituents S_2, K_1 and O_1, one may conclude that the tidal drift is of the regular semi-diurnal type, as the amplitude of the diurnal constituents is considerable less than that of semidiurnal ones (form factor < 0.25). Tidal motions of ice during the semidiurnal cycle are referred to reverse type; as for constituents M_2 и S_2, vector of the ice drift rotates mainly clockwise. Maximum current speeds of the semidiurnal drift evolve mainly in the direction from the south to north. As far as diurnal constituents are concerned, there's no regular pattern; difference between the value and the sign of the coefficient of the ellipse compression between the regions.

The closer it is to the coast of the Yamal peninsula, the higher gets mean syzygy speed of the tidal drift in the northern part of the Gulf of Ob'. At the Gydan's coast it comprises about 30 cm/s, whereas near the Yamal's coast it reaches 40-50 cm/s.

Here, it should be mentioned that all the obtained estimates of tidal characteristics of the drifting ice are related to May-June.

Reliability of the presented information is confirmed by comparison of the ellipse elements of the constituent M_2 with available data of 2011 and 2012 by stations situated close. For components, difference between phases by meridian and parallel don't exceed 3°, though difference between amplitudes by parallel is considerable. This can be caused by the influence of local conditions of observations, difference between the length of the series, etc. Though, difference between ice conditions in 2011 and 2012 may have effect. In 2012, ice conditions were abnormally easy during the whole period of observations.

CONCLUSION

Harmonic analysis of observations on the drift of ice floes by means of Argos buoys showed that it is possible to obtain stable estimates of the harmonic constants of the main constituents from these data. This conclusion was confirmed by comparison of results of observations gained in 2011 and 2012.

Obtained harmonic constants allows us to predict the pattern of the tidal drift of the ice floes in the northern and the middle parts of the Gulf of Ob' in May-June. These results can be used to calculate tidal deformations by the method of Legen'kov (1992).

Collection of data on the drift of ice floes allows us to study main regularities of the barothropic tidal motions of the main waves of tide in the surface layer of the sea.

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