AN APPLICATION OF AN ICE DRIFT HYDRODYNAMIC MODEL FOR A SHORT-TERM FORECAST OF THE ICE SHEET BEHAVIOR IN THE TATAR STRAIT

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Introduction

The development of all-the-year-round navigation in the Tatar Strait, related to the projects of exploitation of the resources of the Sakhalin continental shelf, requires the development and perfection of metocean forecasts (including ice ones). Papers of Aldoshina (1960), Yakunin (1979), Petrov (1999) and other authors are devoted to the study of the ice conditions in the Tatar Strait. However, majority of these works are based on a phenomenological approach, when the general properties of the ice sheet and its year and seasonal variations were studied. They considered many properties of ice cover that were typical for the region and found out certain regularities. In the (Petrov, 1999) an attempt of zoning of the ice conditions was made. Papers of Plotnikov (1996), Aldoshina (1960) are devoted to the problem of long-term forecasts of the ice conditions in the concerning region. In the current paper we consider some results of numerical modeling of the ice drifting and an attempt of seeking for the possibility of short-term and medium-term forecasts of the redistribution of the ice cover on the base of these results.

Setting up of the Problem

The model of the ice drifting in the Tatar Strait was constructed on the base of the equations of motion of a viscous liquid at the quasi-stationary approximation. The general scheme of the equations of motion of the ice, integrated over all thickness of the ice, at the scales typical for the region, will look like the following ones:

$$\rho h\frac{\partial u}{\partial t} = \rho hfv + T_x + D_x + \rho h\left(\frac{\partial}{\partial x_i}A\frac{\partial u}{\partial x_i}\right) - h\frac{\partial P}{\partial x},$$

$$\rho h\frac{\partial v}{\partial t} = -\rho hfv + T_y + D_y + \rho h\left(\frac{\partial}{\partial x_i}A\frac{\partial v}{\partial x_i}\right) - h\frac{\partial P}{\partial y}, \tag{1}$$

where, ρ stands for the density of the ice,
h is the thickness of the ice,
f is the Coriolis parameter,
t is the time,
$T_{x,y}$ are the tangential tensions of the wind friction at the “ice-air” boundary,
$D_{x,y}$ are the tangential tensions of the wind friction at the “ice-water” boundary,
A denotes the factor of horizontal impulse exchange in the pack ice that is defined as a function of the concentration of the ice (Doronin & Sjitchev, 1977):

$$A = \alpha_c S(1 - \gamma S),$$

where, α_c and γ are constants,
S expresses the compactness, in the fraction of a unity.

To define the tangential tension of the friction at the “ice-air” and “water-ice” boundaries, we determined the corresponding empirical coefficients by numerical experiments.

At the first level of approximation we assumed the constant and tidal currents under the ice to be absent, although the solution scheme allows us to define both constant and time-dependent currents.

The complete simulation of the problem, as well as the boundary conditions and description of the solution method are given in (Pokrashenko & Molchanova, 1987).

In the current paper some results of modeling of the ice drift are discussed in details.

The Source Data for the Model Computations

The values of the compactness and thickness of the ice, that were necessary for the initial conditions, were taken from both maps of aircraft ice patrol (version 1), or maps of the distribution of the ice conditions in the strait typical for the period (version 2). These data were accumulated for every knot of the calculating grid. We used the weighted-mean values h_{ik} for ice thickness, that are defined as

$$h_{j,k} = \frac{\sum_i \bar{h}_i S_i}{\sum_i S_i},$$

$$i = 1,2,...N, \quad , \qquad (2)$$

where, N stands for the cumulative number of maturation ice gradations (1-3);

$\bar{h}_i$ is the average thickness of the ice of i[th] degree of maturation;

S_i is the compactness of the ice of i[th] age;

i, k are the indices of a knot of the calculating grid.

To estimate the speed of the wind, were used both the ten-day maps compiled in the Sakhalin Hydrometeocenter, and the maps of the typical wind fields compiled in the FERHRI under supervision of Yakunin (1979).

In the course of modeling of the cases of ice redistribution known for this region we will assign typical wind situations over the defined area and will consider the corresponding migrations of the ice. The obtained results could be used both to verify the model, and to investigate the influence of the wind, or wind together with the gradient current, or other processes on the drifting ice.

The Results and Discussion

The calculations for several wind directions were made. These directions are: northerly, northwesterly, northeasterly, southwesterly and southeasterly for winds. A wind blowing in a definite direction is known to be able to change the ice conditions considerably during a comparatively short period of time. As a rule, we took the averaged long-term characteristics of ice distributions as the initial conditions. The distribution of the compactness of the ice concentration after the action of the northerly winds is depicted in Fig. 1a, and that after the action of the northwesterly wind is depicted in Fig. 1b. We assumed the speed of the winds the same and equal to 10 m/s. The initial distributions of the ice conditions were the same for these winds.

According to these calculations, in the case of the northerly winds (Fig. 1a), the area of compacting of the ice sheet, as a rule, is situated at the medium part of the strait, while at the shores of the continent the ice is more rarefied. An ice polynya forms at the eastern shore and it ranges toward north almost reaching the Furuhelm Cape. At the western coast the ice gets more rarefied, but at capes the values of concentration reach 9-10 numbers. An intense convergence of the ice sheet takes place mainly in the middle part of the Tatar Strait and northwards of it. We must note that, according to the data of air reconnaissances, the northern winds make the ice rarefy.

If the northwesterly winds blow steadily at the speed of 10 m per sec or more, the area of solid ice displaces eastwards (Fig. 1b). The solid ices are observed right up to the edge. Along the entire western coast the ice sheet is observed to be driven back, and a narrow streak of water free from ice is formed. The convergence of the ice is noted in the middle part of the strait, as well as in the region of the capes at the western shore of the Sakhalin Island.

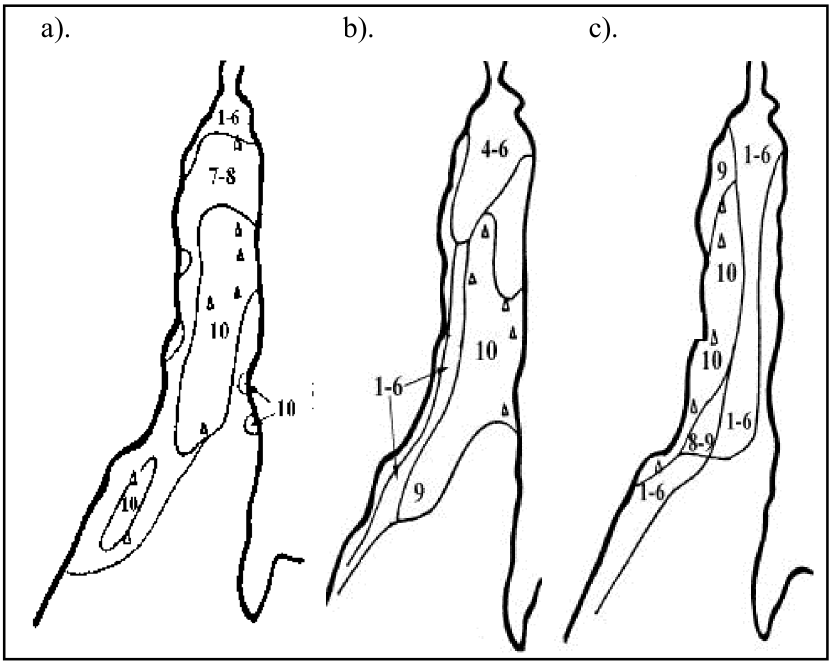

Fig.1. Distribution of the ice concentration after the action of the: (a) northern winds, (b) northwestern winds and (c) northeastern winds

If the northeasterly winds keep blowing longer than three days, the area of the solid ice adjoins tightly to the coast of the continent (See Fig. 1c). The ice sheet gets rarefied closely to the edge of the ice (the value of concentration varies from 1 to 6 tenths). In accordance with these results, at the eastern part of the strait a large ice polynya forms, that has minimal size in the region of the capes. At the coast of the continent the areas of convergence are observed. Far off the shore the areas of compression are observed in the middle of the top of the strait.

According to results, the southwesterly winds press the south extremity of the ice cover to the Primorye coast (Fig. 2a). This is probably related to the contour of the shoreline and its representation in the grid area, and the assumption of the adhesive conditions at the solid boundary. In the northern part of the coast of the continent an area of solid ice is composed (concentration about 8-10 tenth). The solidest ice is formed in the western part of the upper half of the strait. The southwesterly winds form several areas of the convergence of the ice (these areas are selected by Δ in Figs. 1, 2.). Firstly, these are zones of the coast of the continent where local areas with the maximum compactness exist in the common zone of low ice concentration. Such areas stand out against a background the common zone of low ice concentration everywhere at the shore of the Sakhalin Island.

A long-term action of the southeasterly winds forms a definite type of distribution of the concentration and thickness of the ice, as well. One can spot a more intense deviation of the edge of the ice towards the shore of the continent. At the shore of the Sakhalin Island the edge of the ice is squashed out from the shore and closes to it at the upper third of the strait. An area of solid ices ranges from the Red Partisan Cape to the Sakhalin Island, and as one moves off the shore, the area turns to the extremely solid ice. An area of intense convergence of the ice sheet is seen at the western shore. As compared to the previous variant, the area of compression (*i.e.* the area of convergence of the ice) has displaced far more westwards.

As it can be noted, the calculations on the model situations are in a good agreement with some facts known earlier. The obtained results of the modeling allow one to select the optimum shipping routes along the navigable directions of the strait. Thus, according to the obtained data, in case of southwesterly winds ships have to move to De Castri, Vanino along the coast of the continent. In case of southeasterly winds the best route to the northern ports passes the western part of the strait, crossing the area of the solid ice sheet at the latitude of the ports.

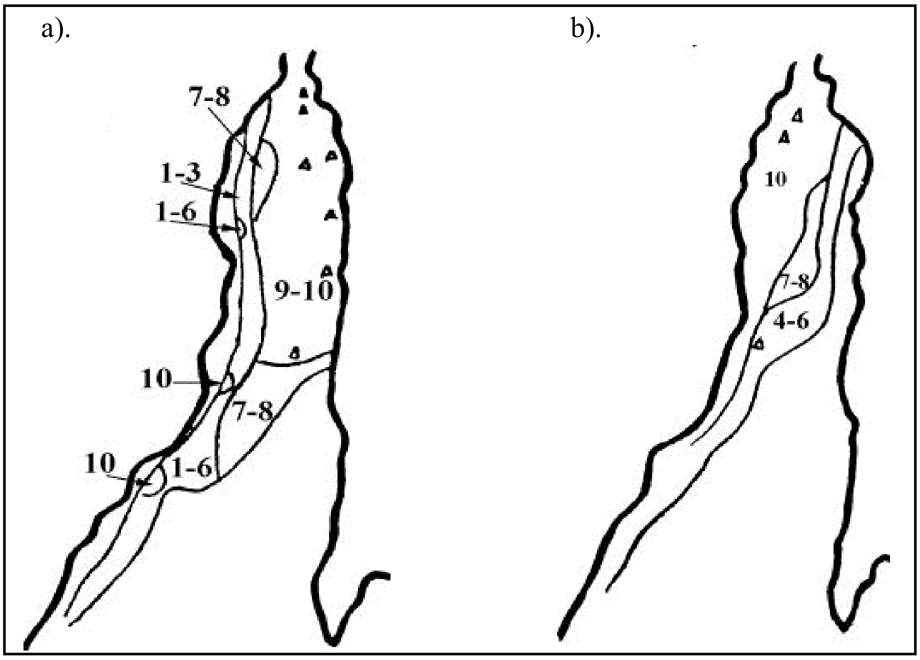

Fig.2. Distribution of the ice concentration after the action of the:
(a) southeastern winds, and (b) southwestern winds

These results show that the northerly winds make the ice conditions allow ships to travel to De Castri port by two routes. The first route goes along the coast of the Sakhalin Island crossing the area of solid ice cover at the latitude of 50-51°N, and after that, heading for 270°. The second way is to move along the coast of the continent in the area with the concentration of 7-9 numbers, far away from the shore. According to our preliminary calculations, the first way is more favorable.

In case of the northwesterly winds, it is better to move along the coast of the continent up to the latitude of the Grossevichi Cape, bypassing the area of solid ice sheet in the middle part of the strait.

In case of long duration of the northeasterly winds (not shorter than 5 days) one could reach De Castri port most readily moving along the route passing shores of the Sakhalin Island; in case Vanino port would be blocked up with the solid ice. In case of such winds the best route crosses the strait at the latitude of Kholmsk port nearly to the very coast of the continent. Later on, we would recommend to turn northward at the longitude of the Red Partisan Cape to cross over the area of the solid ice right at its bottleneck.

The recommendations advanced above may be certainly only of preliminary character. It is mainly because they are based only on the model calculations where we have not allowed for both the variations in the thickness of the ice and the distribution of the sizes of ice floes. Should we take them into account, the obtained results would change dramatically. Nevertheless, the confirmation of the obtained results with existing evidence allows us to recommend this direction to be developed further.

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