Study of intra-day dynamics of currents in the area of the navigable strait of Baltiysk to adjust the movement of water transport

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Abstract. The aim of this work is to determine the characteristics and dynamics of flows navigable waters of the Vistula lagoon, strait of Baltiysk and coastal areas of the Baltic sea. The research was conducted by employees of the Russian State University together with employees of Shirshov Institute of Oceanology of the Russian Academy of Sciences (IO RAS) at release of drifters on the water area of the sea strait with the subsequent processing of the received GPS data with visualization in the MapSource program. The study in the Baltic sea canal was the regularities of traffic flow, identified certain intra-day dynamics of a course, significantly dependent on wind conditions over the water area. In the course of the work performed, an almost complete intra-day analysis of currents in the Baltic shipping strait area was carried out.

1. Introduction

Under the influence of various causes in the surface, deep and bottom layers of the seas and oceans there are different in the nature of the movement of water masses-sea currents. A moving mass of water is hundreds of times denser than air and can generate forces of enormous magnitude. Currents are mainly characterized by direction and speed, and has an effect on the moving vessel [1]. A vessel caught in the current will have a drift from the line of the intended course, with a decrease or increase in speed. An important condition of marine navigation is the knowledge of the speed and direction of the current by the skipper and his account when maneuvering. Despite the difficulty of navigating and maneuvering in the presence of a current, such as when the current is directed across the pier, it can be used to improve the handling of the vessel at low speed and to give the vessel a downforce.

The Baltic sea is of great importance for Maritime transport in Russia. Some of the most important ports of the Baltic sea in Russia are located in the Kaliningrad region, which are of great economic and transport importance for the Russian Federation.

One of such port cities of the Kaliningrad region is the city of Baltiysk, in the area of which the Strait of Baltiysk was studied.

The study of water dynamics, structure, intensity and repeatability of currents in the area of this navigable strait is an actual study, as currently there is a need:

1. in determining the most dangerous situations threatening navigation and development of recommendations for their prevention;
2. in management of the natural risks in the conditions of climate change [2];
3. in clarifying the mechanism of formation of the diffusion basin between the ends of the entrance moles with recommendations for maintaining this basin in a stable state, since its steep slopes pose a threat to the construction of moles together with navigation beacons;
4. in clarifying the value of water exchange between the Vislin Bay and the Baltic sea;
5. in the development of information technologies for the collection and storage of such data [3].

The article deals with the approach of studying the main characteristics of currents in the shipping strait and its possible impact on the maneuverability of the vessel.

2. Methods and materials

Shelf and coastal areas of oceans and seas have complex and diverse natural conditions, which are characterized by intense spatial and temporal variability. Currents in such areas are one of the most complex and dynamic phenomena. In the area of the Baltic canal is one of the main ports of the Kaliningrad region, which in turn makes it relevant to study the nature of currents in the area of the shipping strait [4].

Recently, the circulation studies based on satellite altimetry have become widespread. This method is promising for this area of research, but at the moment satellite altimetry data have rough spatial and temporal resolution and are poorly suited for the study of coastal currents. In addition to the above, there is a problem in comparing the received satellite data with subsatellite information, which is usually absent.

One of the methods of studying surface currents is the method of floats [5]. It is implemented on the Lagrange approach in the framework of classical hydromechanics and observation of the movement of each individual particle. The location of the particle is fixed at regular intervals, which allows you to restore the trajectory and speed of the particle and make schemes of surface water circulation. In practice, a drifting buoy-drifter is used as an observed particle. Global navigation satellite systems are used to position drifters.

In the study, the drifter consists of a float, an underwater sail and a cargo. For cost-effectiveness of the design, data on the location of the drifter were taken from GPS when the drifter was directly detected. The underwater sail represents metal blades, the float from foam plastic for detection of a drifter on water area is fixed, a place for fastening of cargo for a drifter deepening on the necessary horizon of research. The work used deep and surface drifters, due to the different buoyancy, which is achieved by different types of dredgers. On the surface is a buoy to determine the location of the drifter. Visualization of the trajectory of the drifters was performed using MapSource software based on GPS data [6].

There is also another approach in the form of the Euler method. The method is based on the study of the velocity field and wind direction at each point of space occupied by a moving liquid. With the help of Ekman's theory (1) of wave (drift) flows, it is possible to calculate the velocity and direction of the flow from the data of the wind field:

\[
\begin{align*}
  u &= U_0 e^{-\alpha z} \cos(45^\circ - \alpha z), \\
  v &= U_0 e^{-\alpha z} \sin(45^\circ - \alpha z).
\end{align*}
\]  

As a result, the coordinates of the movement of drifters were obtained. Visualization of the trajectory of the drifters was performed using MapSource software based on GPS data.

Studies of the dynamics of currents were carried out for two days (12 and 13 July). When working on July 12, 3 deep and 4 surface drifters were released into the water area, one of them (4M) with a track. July 13 released 3 deep and 3 surface drifters.

At the beginning of the research in the water area, drifters are released to the pre-planned points and remain in free drift for the planned time [7]. Location is determined visually when inspecting the water area and determining the location of foam buoys fixed to drifters with GPS coordinates fixation. One of the most actual problem is a drifters monitoring, because drifters can walking on a long distance (about 300m) from ship boards. Therefore, the output points is a complex task. To eliminate
this problem, it is advisable to equip each buoy with a receiver with a possible transmission of coordinates.

The MapSource mapping program allows you to visualize the resulting tracks of the drifter system according to the tracks of each drifter stored by GPS.

3. Results and Discussion
Initially, the boundaries of the area of work were defined — the Baltic canal and the adjacent sections of the Vistlín’s gulf and the Baltic sea (figure 1). A characteristic feature of this water area is the change of directions of currents depending on the time of day, noted during the observation of buoys, which can be used for navigation in this area [8].

![Figure 1. Area of work.](image)

July 12 work was carried out from 18-20 to 20-15 was launched 4 surface and 3 depth drifter. The results are shown in figure 2 and table 1.

July 13 work was carried out from 14-10 to 16-20 was launched 3 surface and 3 depth drifter. The results are shown in figure 3 and table 2.

To analyze the results of the flow characteristics, measurements of meteorological characteristics in the area of work were carried out along the way. A summary table of meteorological characteristics for 12 and 13 July is presented in table 3.

Comparison of the obtained data on the characteristics of the currents with the data of the weather report is presented in figure 4 and figure 5.
Figure 2. Trajectories of drifters in the strait of Baltiysk 12.07.

Table 1. Characteristics of the strait of Baltiysk current 12.07.

| № drifter's | average speed cm / sec | direction ° |
|-------------|------------------------|-------------|
| surface     |                        |             |
| 4M          | 7.4                    | 315         |
| 4G          | 15.56                  | 311         |
| 8           | 17.32                  | 312         |
| 7           | 24.03                  | 317         |
| deep        |                        |             |
| 21          | 9.07                   | 317         |
| 22          | 10                     | 310         |
| 26          | 16.11                  | 309         |
Figure 3. Trajectories of drifters in the strait of Baltiysk 13.07.

Table 2. Characteristics of the strait of Baltiysk current 13.07.

| № drifter's | surface average speed cm / sec | direction° |
|-------------|---------------------------------|------------|
| 1           | 7.36                            | 333        |
| 7           | 3.94                            | 347        |
| 8           | 17.58                           | 339        |

| deep        |                                 |            |
|-------------|---------------------------------|------------|
| 22          | 8.47                            | 325        |
| 26          | 15.28                           | 330        |

Table 3. Meteorological characteristics in the area of the strait of Baltiysk 13.07 on 12.07 and 13.07.

| Wind        | date | time  | direction° | speed cm / sec |
|-------------|------|--------|------------|----------------|
|             | 12.07| 18:00  | 90         | 87             |
|             | 13.07| 15:00  | 202        | 83             |
|             | 13.07| 18:00  | 225        | 77             |
Buoys located in the study area Baltic canal were observed the patterns of traffic flow in the strait that it was decided to explore with drifters. Since intraday changes were observed-in the morning the current is directed to the strait, in the evening from the strait, it was decided to conduct studies at different times of the day: morning, afternoon and evening. It was not possible to obtain morning data due to bad weather conditions, so the analysis of the results was carried out on the received day and evening observations. From figure 2 (evening measurements) it can be seen that the current is directed from the strait, since the direction of the arrows showing the movement of water in the sea strait in figure 2 has a direction from the Vislin Bay to the Baltic sea. The speed of surface and deep drifters does not differ significantly, is about 15 cm/s. in figure 3 (daytime), the direction of the flow towards the strait is noted, as well as the turn of the current to the North, in consequence of which the current spreads across the strait. For this reason drifters at measurements on July 13 constantly washed ashore. The speeds of surface drifters slightly exceed the speeds of deep drifters. The surface velocities are approximately 7 cm/s, the flow velocities in the deep layers vary within 10 cm/s. from the studies
conducted, it follows that in this period the flow velocity in the evening is slightly higher than the value of the velocities obtained in the daytime. It is noted that the flow in the evening is more uniform, compared with the flow recorded in the daytime [9-10].

When comparing these characteristics of the currents with the data of the weather reports we can assume that the speed and direction of currents has a direct effect wind influence [11], as the data obtained from a weather station shows that the wind speed on 12 July was higher than July 13, that could increase the speed of the current on July 12, compared to the flow rate on July 13. In spite of the fact that currents have a big dependence on wind influence, they not always have absolutely direct dependence. In figure 4, it can be seen that the measured direction of the current on this day does not completely coincide with the direction of the classical wind flow. In figure 5, the calculated and obtained flow directions have a greater difference [12].

The obtained results of currents in the strait can be used for recommendations to skippers when passing the strait of Baltiysk. If the ship is late to put the rudder to the right, the stern will begin to attract to the shore, and the bow will deviate to the opposite side of the strait. A stream of water hitting the starboard side will deflect the bow even further to the left. In such a situation, it becomes difficult to straighten the ship with the help of the rudder. It will be necessary to stop the ship to reduce the impact of interaction between the shore and the ship. Otherwise, the vessel may crash into the opposite Bank and then turn against the current (figure 6).

![Figure 6. Influence of the counter current on the controllability of the vessel.](image)

In the case of a passing current, the speed relative to the water is less than the speed of the same vessel going against the current. If the ship belatedly put the rudder to the right, it will turn across the strait. The stern will most likely begin to attract to the right Bank. The flow of water will hit the port side and prevent the turn to the left. However, this phenomenon affects the vessel much less than the counter current (figure 7).

![Figure 7. The influence of the passing current on the management of the vessel.](image)
4. Conclusion

The result of this work is clearly seen that in the evening for directed out of the strait, and in the morning for sent to the strait, during the day there is a change of direction of flow. This rotation of the flow in the strait can be observed in figure 3, where the flow is directed across the strait. Having carried out almost complete day-to-day research, it can be assumed that the current in the strait of Baltiysk does have day-to-day variability, which was observed by buoys located in this strait.

The velocities of surface and deep currents differ slightly and vary within 10-15 cm / s.

The probable cause of intraday change of direction of the current in the wind regime, formed over this area, however, it is worth noting that the wind impact has no absolute influence on the formation of currents strait [12-13].

The obtained data on the nature of currents in the strait contribute to better awareness of skippers when passing this strait. Can be useful in making decisions maneuvering the vessel depending on the intraday dynamics of currents in the strait.

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