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DYNAMIC MODELLING PROCESS OF ENVIRONMENT ON VESSEL MOVE WITH USING RIS TECHNOLOGIES

МОДЕЛЮВАННЯ ДИНАМІЧНИХ ПРОЦЕСІВ ДОВКІЛЛЯ ПІД ЧАС РУХУ СУДНА З ВИКОРИСТАННЯМ РІС ТЕХНОЛОГІЙ

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ABSTRACT

Remote methods of Earth’s surface research have become widely used in the 21st century, as they allow for a larger and more comprehensive observation area. These methods can provide valuable information about various Earth objects and phenomena, such as the changes in bottom topography in shallow water under navigation conditions. This article presents a novel approach to forecasting these changes by using natural processes as indicators and developing programs that can track and display them on electronic devices.

The article introduces the concept of “scale factor” to determine the significance of different dynamic processes for the research, depending on their spatial and temporal dimensions. The article also proposes a dynamic map modelling method that can predict the siltation of the sea/river bottom for a given period of time and improve the model by comparing the forecast with the actual result. The article suggests that research should take into account the changes in the object over time and under the influence of various factors in a dynamic way.

Based on the research, we draw the following conclusions:

1. The “scale factor” should be applied in dynamic navigation map research and compilation using different-scale data of the water surface and bottom topography;

2. A dynamic component should be added to the information block of the navigation cartographic systems ECDIS and Inland ECDIS, enabling the navigator to see the position of the vessel, taking into account the wave height relative to the bottom in real time;

3. The methods of parallel bottom topography transferring rely only on the data of statistical observations using iterations. These methods usually work well on sandy and silty soils, where the relief has clear wave-like forms, as well as frequent external influences following the main general direction.

Keywords: *RIS, dynamic processes, "scale factor", "chart dynamic model", ECDIS.*

АНОТАЦІЯ

Досягнення науки і техніки в ХХ1 столітті якісно змінили традиційні способи і прийоми вивчення земної поверхні. На даний момент широко використовуються дистанційні методи, коли спостерігач або вимірювальний засіб знаходяться на деякій дистанції від об'єкта вивчення для того, щоб в кілька разів збільшити територію, охоплювану спостереженням. Ці матеріали збільшують кругозір дослідників, призводять до збільшення потоку отриманої цінної інформації про відомі об'єкти і явища Землі.

У представленому дослідженні наведені роз'яснення того, за допомогою яких механізмів можна використовувати природні процеси в напрямку складання прогнозу зміни рельєфу дна на мілководді в умовах судноплавства. Ключовим фактором є розробка програм, що *дозволяють відстежувати зміни природних процесів з відображенням і фіксацією їх на електронних носіях будь-яке дослідження переважно проводити з урахуванням зміни стану об'єкта в часі і під впливом різних факторів одночасно і динамічно. У статті динамічні процеси діляться на "значущі" і "несуттєві". Ця залежність визначається масштабом простору і часу, де і коли вони відбуваються. Поняття "масштабний фактор" вводиться з метою визначення ступеня значущості впливу динамічних процесів при проведенні досліджень. Наведений в роботі спосіб моделювання динамічної карти дає можливість складати прогноз замулювання морського / річкового дна на заданий період часу. Після порівняння прогнозу з фактичним результатом можна вводити поправки в підбирається функцію, т. ч. постійно вдосконалюючи модель.*

В результаті проведених досліджень прийшли до таких висновків:

1. У процесі досліджень і складання динамічної навігаційної карти при використанні різномасштабних даних водної поверхні і рельєфу дна, слід вводити ваговий коефіцієнт “scale factor”;

2. В інформаційний блок навігаційних картографічних систем ECDIS і Inland ECDIS рекомендується вводити динамічну складову, що дозволяє судноводію бачити положення судна з урахуванням висоти хвилі, щодо дна в реальному режимі часу;

3. Розглянуті методи паралельного перенесення рельєфу дна, засновані лише на даних статистичних повторюваних спостережень з використанням ітерацій. Ці методи дають достовірний результат, як правило на піщаних і мулистих ґрунтах, де рельєф має яскраво виражені хвилеподібні форми, а також при порівняно часто повторюваних зовнішніх впливах при дотриманні загального генерального напрямку.

Ключові слова: РІС, динамічні процеси, "коефіцієнт масштабу", "динамічна модель карти", ЕКНІС.

Defining the general matter and its connection to important scientific or practical objectives

We are all and everything that surrounds us is in constant motion i.e. in a dynamic state. Therefore, all considered and studied processes should be considered in dynamics. However, dynamic processes can be "significant" and "insignificant" depending on the scale of the space and time where and when they occur. We introduce the concept of "scale factor" to determine the degree of significance of the influence of dynamic processes in research. In order to explain why we needed to introduce this concept, let's try to answer a philosophical question. What is primary matter or consciousness? The answer is simple and both exist "always" (as for time) and "everywhere" (as for space) because both are "infinite". This leads to the assumption that those laws that work in the scale we feel may work differently or not work at all with the approach to (+) or (-) infinity.

Previous researches analysis and definition of new trends in problem solution

Currently, there is already a number of works [1,2,3], devoted to the modelling of the water surface in dynamics as well as changes in the seabed topography and vessel movement, taking into account this process. It should be noted that on all modern transport vessels paper navigation maps are used only as a backup, on electronic maps the skipper observes the movement of the vessel only in the plane of the monitor screen in the coordinate system x,y. A program allowing to watch the changes of processes of influence on nature with a reflection and fixing on electronic carriers development can become a key factor [5]. Modern technologies allow us to obtain an image of the vessel in dynamics in interaction with the environment, taking into account the selected parameter "scale factor".

The research objective

The purpose of this work is to conduct research in the field of modelling of dynamic processes of the environment during the movement of the vessel, as well as to determine the qualitative characteristics of "significance" when using the proposed 5th element of the spatial dimension "scale factor".

Presenting the main material of research with a full grounding of received scientific results

In determining the "significant" scale will be based on the parameters of the object of study, as well as the choice of "sufficient" amount of time required for this scale. These are the geometric dimensions of the vessel, sediment, deadweight, displacement, the area of interaction with the elements of the environment (wind, wave, current, depth, etc.) and the time interval at which you can set the characteristic patterns. In this paper, we analyze the existing models of the environment in dynamics and try to find patterns of influence on a moving ship in this environment.

According to the principle of construction mathematical models are divided into analytical and simulation. In analytical models, the processes occurring in the environment can be represented as functional dependencies, which are used:

– equations;
– approximation problems;
– optimization problem.

In the simulation by preliminary measurements, which are the initial data, it is possible to simulate the dynamics of the process at a certain period of time, but the prediction of the dynamics is very difficult.

Depending on the nature of the medium under study, the models can be deterministic and stochastic. Deterministic models suggest the absence of any random effects. Stochastic models take into account the random effects occurring in the studied environment.

According to the principle of measurements, the incoming data models can be continuous and discrete, as well as static and dynamic.

Due to the fact that our knowledge of the processes taking place in the environment cannot be comprehensive, we will not be able to simulate its state with a high degree of reliability. For example, tropical cyclones, which cause very significant damage to ships, are never repeated in their characteristics and trajectory. And therefore their movement is almost impossible to predict. This gives us grounds to develop a hypothetical model that can and should be tested on the basis of an experiment.

We will simulate the dynamic processes of the seabed topography. To do this, it is necessary to conduct repeated bottom measurements at the test site using a multibeam echo sounder (Fig.1).

On the dimensional tablet, we draw a grid of squares in the conventional coordinate system x,y,z (Fig.2) and at each vertex with coordinates XI, UI we define zi.

When choosing a "significant" scale guided by the requirements for the accuracy of the measured parameters. As a result, it was found that the time scale should be attributed to one month, and the scale of the grid of squares can be from one to ten meters depending on the nature of the terrain and the mobility of the soil. The dynamics of the relief will be displayed on ENC and IENC, taking into account the fact that Dynamic charts (sea and river) must ensure the safety of navigation and therefore they must accurately display the applied information, especially isobates.

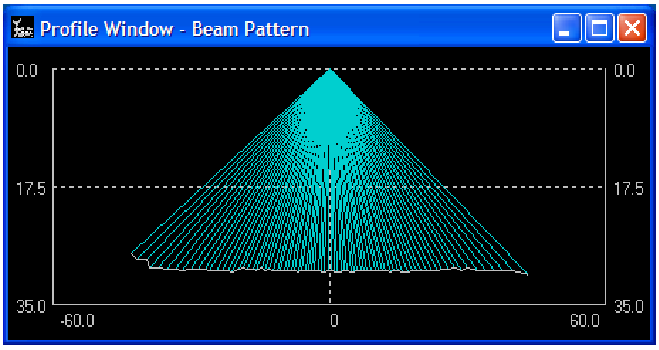
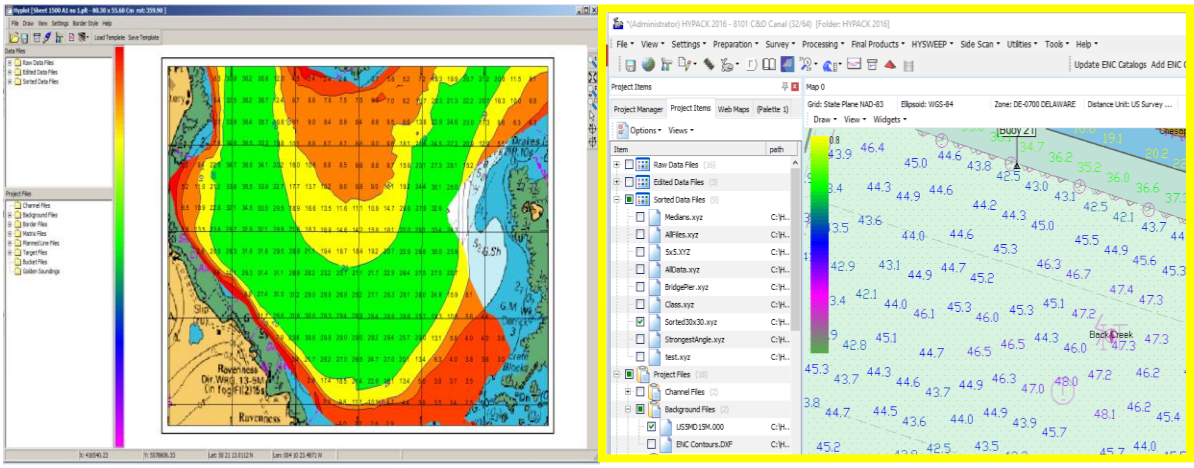


Fig. 1. Multibeam sonar in the work



A)   B)

Fig. 2. Sounding tablet with printed grid

As is known, the seabed relief is constantly changing, especially in the estuaries of rivers, on approach channels, in places of underwater currents and during prolonged storms. These changes can be significant (up to several meters), which in shallow water can lead to an emergency situation for the vessel.

As the 1st problem, we consider the problem of constructing a model of the dynamics of the seabed topography. The algorithm of this model assumes the presence of the following initial data):

– soil type;
– soil fluidity;
– physical characteristics of water (density, temperature in the bottom layer)
– sea depth;
– characteristics of sea waves (height and wavelength, wave direction, wind strength and direction), characteristics of the bottom current (speed, direction and vertical distribution).

To make a model, it is necessary to establish the patterns of movement (erosion, alluvium) of underwater soil by determining the functional dependencies of changes in the seabed topography on the dynamic parameters of the marine environment, i.e. it is necessary to determine the type of function $F(x;y;z)$.

For the estuarine section of the Danube, where the silting up of the fairway, chose the study site, where installed a hydro-meteorological buoy (Fig.3), which is continuously recorded all the characteristics that affect the movement of the underwater soil. Having accepted the hypothesis of parallel transport of a moving wave of underwater relief, we apply the Gauss-Seidel iterative method. Let us assume that the parallel transfer occurs at each point XI, yi along its own trajectory, which corresponds to the transfer of the height hi to the distance bi (in projections on the coordinate axes x and y, respectively) for the i-th point. It should be noted that hi refers to the time t0 and bi to the time t1. Then we can write the studied array as a system of equations.

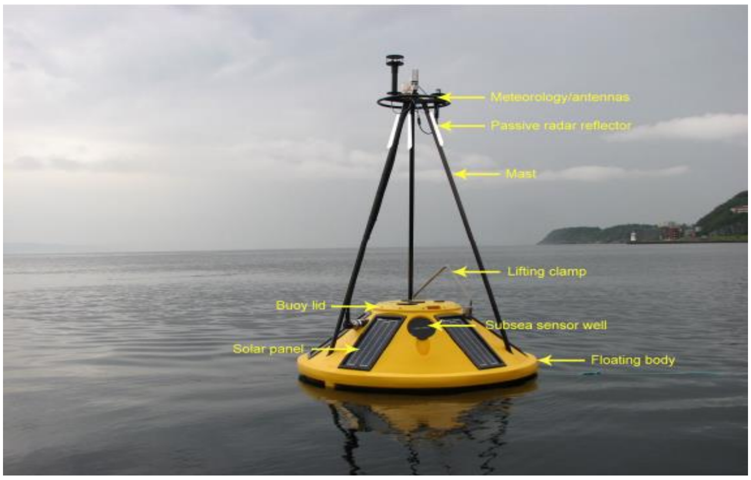


Fig. 3. Hydrometeorological buoy

Let's take equation (1) as an array of data on the bottom topography

$$\begin{cases} a_{11}x_1 + \ldots + a_{1n}x_n = b_1 \\ a_{n1}x_1 + \ldots + a_{nn}x_n = b_n \end{cases}, \qquad (1)$$

and imagine it in this form:

$$\begin{cases} a_{11}x_1 = a_{12}x_2 - a_{13}x_3 - \ldots - a_{1n}x_n + b_1 \\ a_{21}x_1 + a_{22}x_n = -a_{23}x_3 - \ldots - a_{2n}x_n + b_2 \\ \ldots \\ a_{(n-1)1}x_1 + a_{(n-1)2}x_2 + \ldots + a_{(n-1)(n-1)}x_n = -a_{(n-1)n}x_n + b_{n-1} \\ a_{(n-1)1}x_1 + a_{n2}x_2 + \ldots + a_{n(n-1)}x_{n-1} + a_{nn}x_n = b_n \end{cases}, \qquad (2)$$

where a_{ii} are the coefficients to be determined.

Here in the j-th equation we moved to the right part all the terms containing x_i, for i>j and wrote the system as follows:

$$(L + D)\vec{x} = -U\vec{x} + \vec{b},$$

where D denotes a matrix with the corresponding elements of matrix A on the main diagonal and all other zeros; whereas the matFigs U and L contain the upper and lower triangular parts A with zeros on the main diagonal.

After selecting the appropriate initial approximation, the iterative process is constructed according to the formula:

$$(L + D)\vec{x}^{(k+1)} = -U\vec{x}^{(k)} + \vec{b}, k = 0,1,2,3.....n. \qquad (3)$$

The values of x were successively calculated by the transformation of the system:

$$\begin{cases} x_1^{(k+1)} = c_{12}x_2^{(k)} + c_{13}x_3^{(k)} + \ldots + c_{1n}x_n^{(k)} + d_1 \\ x_2^{(k+1)} = c_{21}x_1^{(k+1)} + c_{23}x_3^{(k)} + \ldots + c_{2n}x_n^{(k)} + d_2 \\ \ldots \\ x_n^{(k+1)} = c_{n1}x_1^{(k+1)} + c_{n2}x_2^{(k+1)} + \ldots + c_{n(n-1)}x_{n-1}^{(k+1)} + d_n \end{cases},$$

where $c_{ij} = -\dfrac{a_{ij}}{a_{ii}}, d = \dfrac{b_i}{a_{ii}}, i = 1.....,n.$

Thus, the i-th component of the n-th approximation is calculated by the formula:

$$x_i^{(k+1)} = \sum_{j-1}^{i-1} c_{ij} x_j^{(k+1)} + \sum_{j=i+1}^{n} c_{ij} x_j^{(k)} + d_i, i = 1.....,n.$$

The condition for the end of the iterative process when the specified accuracy ε is achieved in a simplified form is as follows:

$$\left\| x^{(k+1)} - x^{(k)} \right\| \leq \varepsilon.$$

Convergence condition:

$$|a_{ii}| \rangle \sum |a_{ij}|.$$

Above we have considered a simplified model that shows only approximately how the underwater terrain will behave under the established load. To obtain a more realistic picture as a result of modelling, we will use systems of nonlinear equations.

We present a model of bottom relief in the form of a system of nonlinear equations

$$\begin{cases} f_1(x_1, x_2, x_3, \ldots.., x_n) = 0 \\ f_2(x_1, x_2, x_3, \ldots.., x_n) = 0 \\ \ldots \\ f_n(x_1, x_2, x_3, \ldots.., x_n) = 0 \end{cases},$$

or

$$X = |x_1, x_2, x_3, \ldots.., x_n|.$$

Solving this system, we find the vector

$$f_n(x_1, x_2, x_3, \ldots.., x_n) = 0, i = \overline{1 \ldots n},$$

satisfying the system with a given accuracy ε.

Iterative methods were used to solve this system.

$$\overline{X}^0 = \left[x_1^0, x_2^0, \ldots, x_n^0 \right].$$

Transforming the system of equations:

$$\begin{cases} f_1(x_1, x_2, x_3, \ldots.., x_n) = 0 \\ f_2(x_1, x_2, x_3, \ldots.., x_n) = 0 \\ \ldots \\ f_n(x_1, x_2, x_3, \ldots.., x_n) = 0 \end{cases},$$

to mind:

$$\begin{cases} x_1 = \varphi_1(x_1, x_2, x_3, \ldots.., x_n) \\ x_2 = \varphi_2(x_1, x_2, x_3, \ldots.., x_n) \\ \ldots \\ x_n = \varphi_n(x_1, x_2, x_3, \ldots.., x_n) \end{cases},$$

or

$$x_i = \varphi_i(x_1, x_2, x_3, \ldots\ldots, x_n), i = \overline{1, n}.$$

Select the initial approximation

$$\overline{X^0} = \left[x_1^0, x_2^0, \ldots, x_n^0\right].$$

Find approximate values of roots:

$$x_i^k = i(x_1^{k-1}, x_2^{k-1}, x_3^{k-1}, \ldots\ldots, x_n^{k-1}),$$

using the values of the variables obtained in step (k-1). The iterative process stops as soon as the condition is met (for all variables):

$$\left|x_j^k - x_j^{k-1}\right| \le \varepsilon, j = \overline{1, n}.$$

Under the condition of convergence of the iterative search process, namely:

$$\sum_{i=1}^{n} \left|\frac{\delta\varphi_i}{\delta x_j}\right| \langle 1, j = \overline{1, n}.$$

As a result of simple mathematical operations, we can find the function y(x) in the parallel transfer of geometric shapes of the bottom using the solution of the Cauchy problem. So, for example, consider Runge-Kutte Methods, which are based on the approximation of the desired function Y(x) within each step by a polynomial, which is obtained by decomposing the function Y(x) in the neighbourhood of the step h of each i–th point in the Taylor series

$$y(x_i + h) = y(x_i) + h \cdot y'(x_i) + \frac{h^2}{2!} y''(x_i) + \frac{h^3}{3!} y'''(x_i) + \frac{h^4}{4!} y^{(4)}(x_i) + \frac{h^5}{5!} y^{(5)}(x_i) + \ldots$$

The proposed model allows us in the information box IECDIS to give a graphical display of the dynamic process of isobaths on the part of the electronic map, as shown in Fig.4, as well as the image of the dynamics of the seabed topography in the 3-D image.

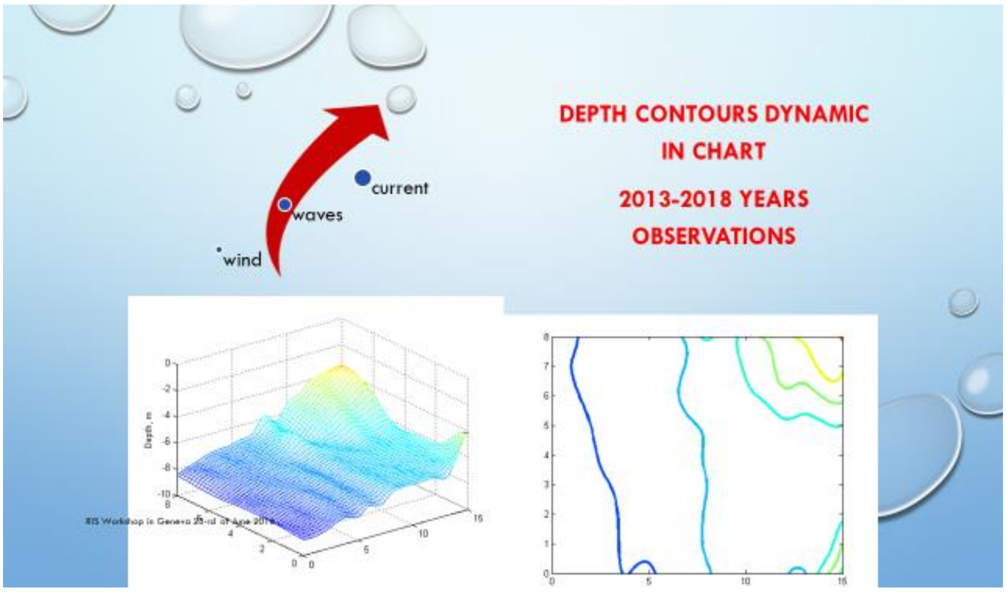


Fig. 4. The Image of the bottom topography in the dynamics (left) and the Isobar (right)

The proposed model can also be represented as a flowchart shown in Fig.5. This model involves constant monitoring of the environment, which used a hydrometeorological buoy, data from which were recorded in an electronic data Bank. This Bank stores and further processes such data as wind speed, duration and direction, data on the state of the wave (wave length and height, as well as the direction of its movement), the calculated speed of the bottom current, changes in the water surface level and depth. Using these data, by carrying out a multivariate analysis determine the weight characteristics of each of the elements of the environment. Then, using the iteration method, we select a function describing the water surface and the bottom surface. These functions are assigned to different time scales, so bringing them to the same scale, taking into account the dynamic components, we get a “chart dynamic model”. The above method of dynamic map modelling makes it possible to make a forecast of sea/river bottom silting for a specified period of time. After comparing the forecast with the actual result, we introduce corrections to the selected function, thus constantly improving the model.

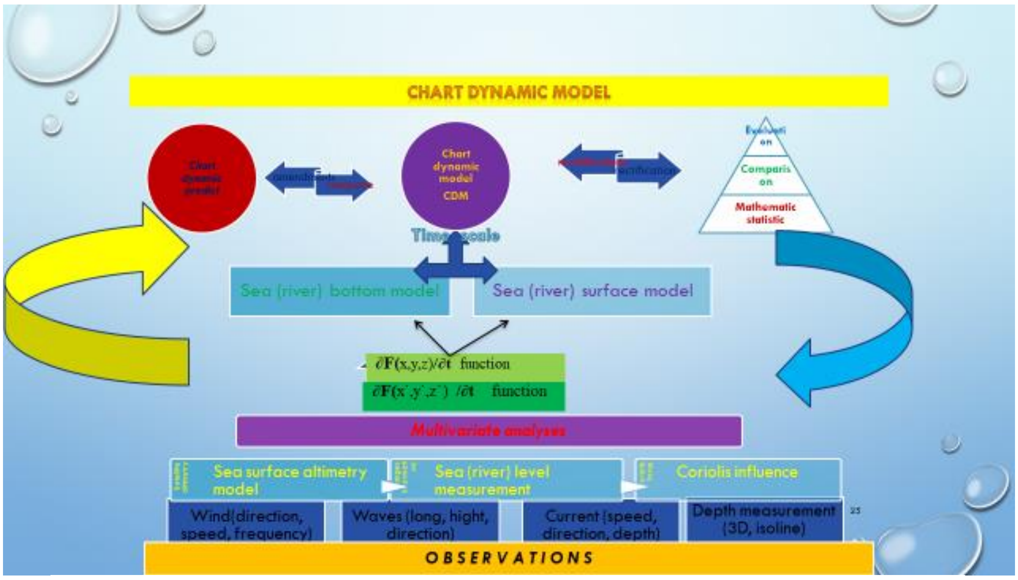


Fig. 5. Block diagram of the dynamic model of the navigation map

Fig. 6a. ENC in April 2013

The fragments of the dynamic map are shown in Fig.6(a,b,c,d,e,f), which shows an image of the depth contours in the study range in different time periods.

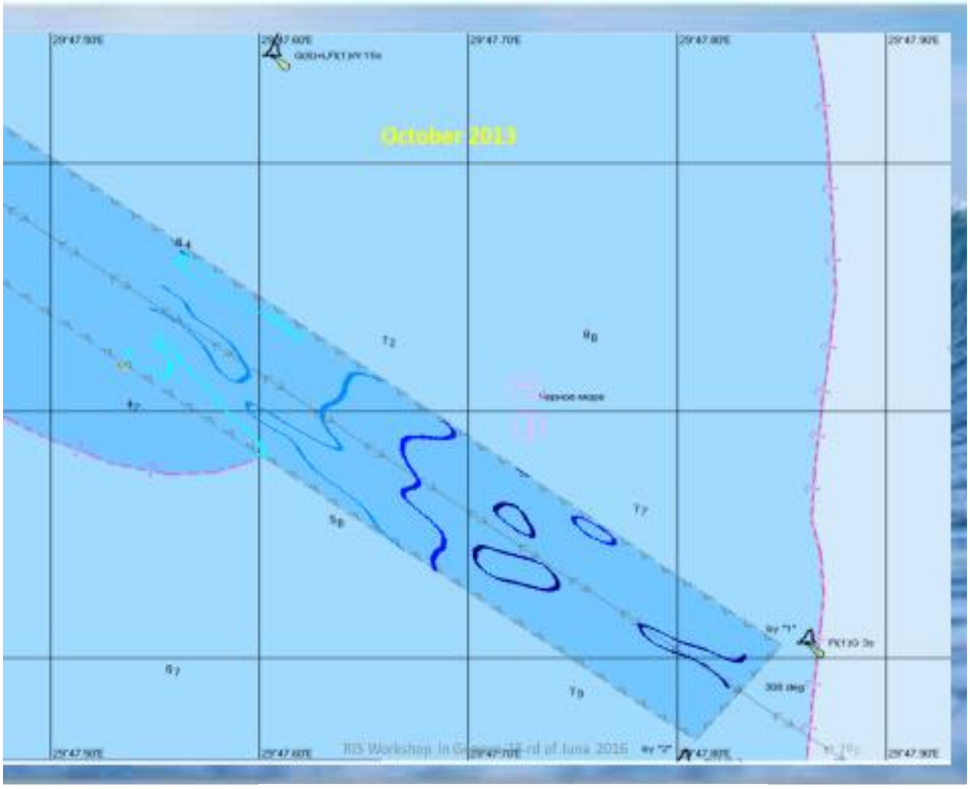


Fig. 6b. ENC in October 2013

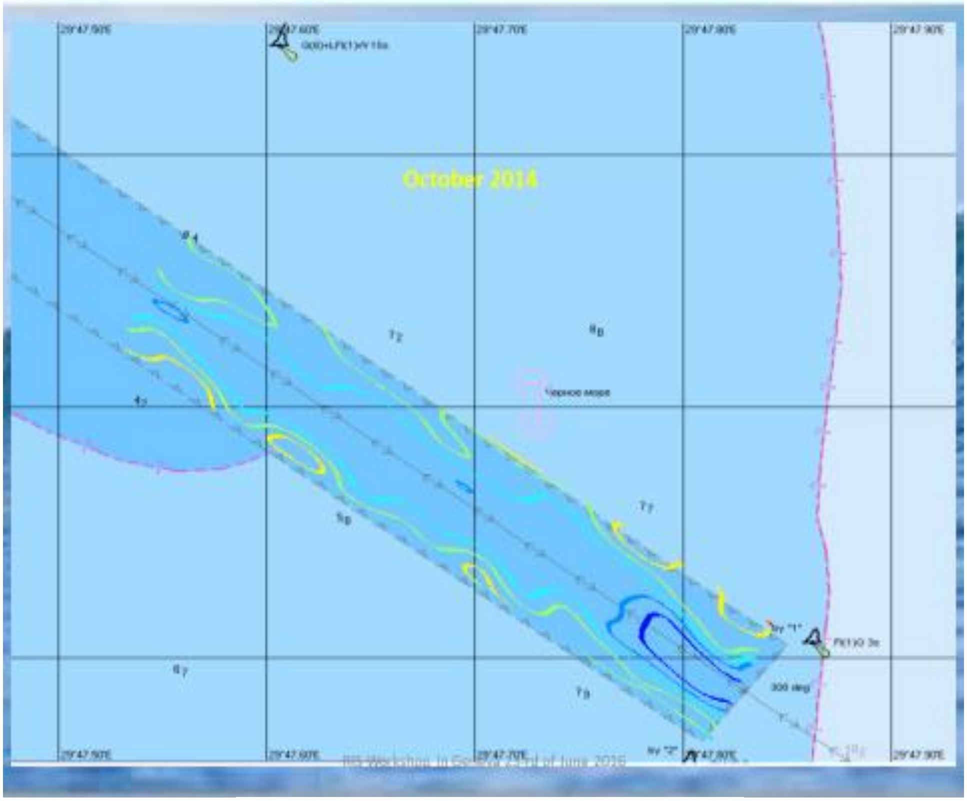


Fig. 6d. ENC in October 2014

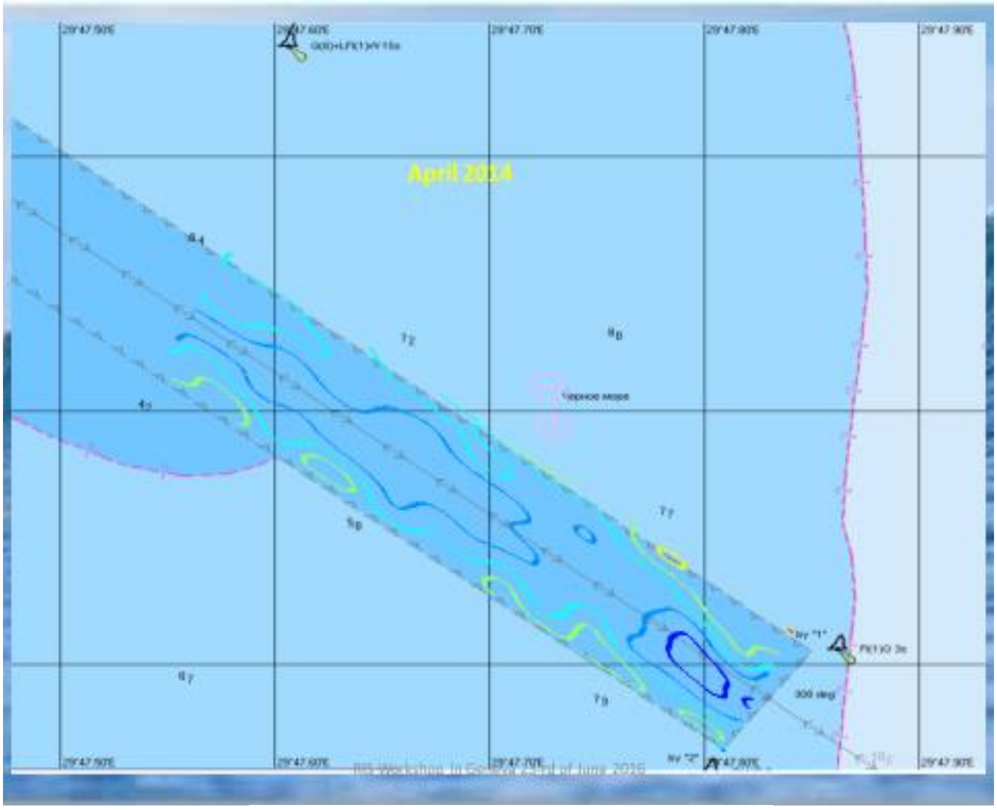


Fig. 6c. ENC in April 2014

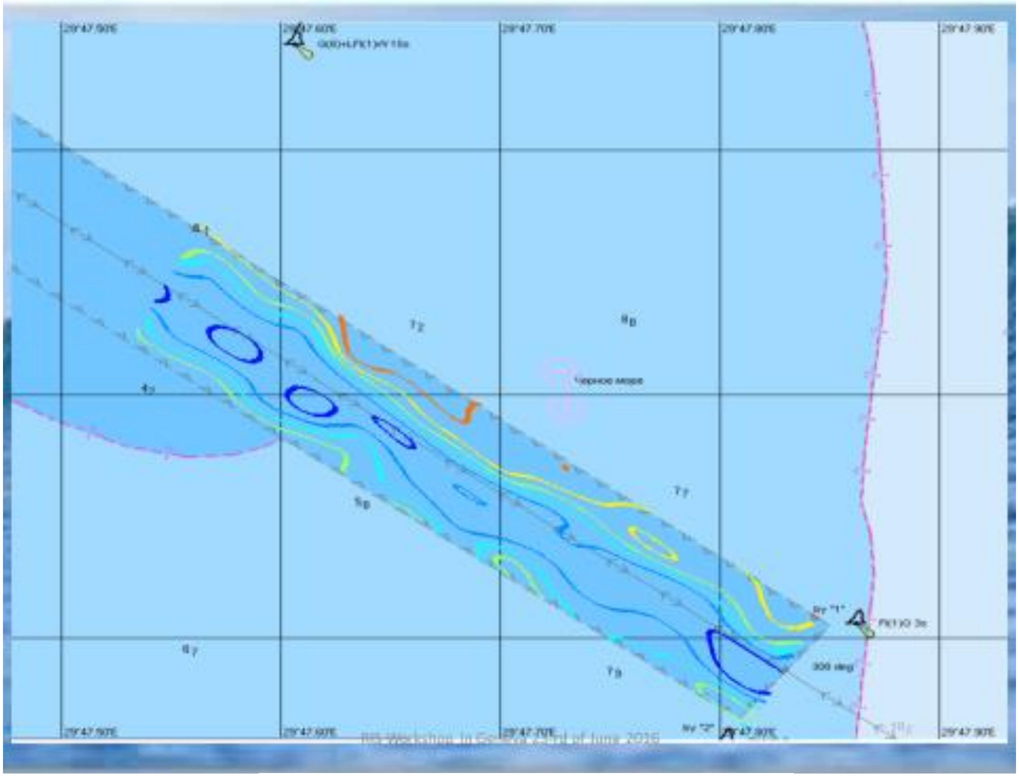


Fig. 6f. ENC in October 2015

Fig. 6e. ENC in April 2015

When considering the model of underwater terrain, ship and water surface movement, it should be taken into account that all these movements are of different scales in time. For example, consider the most commonly used models of ship motion.

The mathematical model of the vessel's motion as a controlled dynamic system in the General case can be represented as follows:

$$S(t) = F(t, C, S(0), U(t), L(t), E(t)), \qquad (4)$$

where F is the operator characterizing this particular mathematical model; C is the vector of constant parameters of the system that characterize this particular simulated vessel; S(t) is a set of variables describing the state of the system at the time t. If we consider the plane-parallel motion of the vessel, we can be limited by the three parameters of the coordinates x_0 and y_0 and the heading angle q:

$$S(t) = (x_0(t), y_0(t), q(t)); \qquad (5)$$

U(t) - control actions on the system at different times: steering angle δ R (t), speed n m (t) and the step ratio H/D(t) of the propeller, the position of the regulator of the thruster N TMG_{rel} (t), which sets its relative power as a percentage from the maximum possible:

$$U(t) = \delta(t), nm(t), H/D(t), NTMG_{rel}(t). \qquad (6)$$

L(t) – a function of the load on the system, in this case, the distribution of all cargo on the ship; E(t) – a function of external perturbing effects on the system: depth at all points of the water area, wind speed and direction and flow, amplitude and phase spectrum of the waves, as well as the spectrum of the directions of wave propagation at all frequencies for all points of the water area at all times.

Existing mathematical models of the plane-parallel motion of the vessel can be presented in the form, which in a more detailed form looks like this:

$$\begin{aligned}
&d_2x_0/dt_2 = i\sum Fx_{oi}(t,C,dx_0/dt,dy_0/dt,dq/dt,x_0(t),y_0(t),q(t),U(t),L(t),E(t))/m\\
&d_2y_0/dt_2 = i\sum Fy_{oi}(t,C,dx_0/dt,dy_0/dt,dq/dt,x_0(t),y_0(t),q(t),U(t),L(t),E(t))/m\\
&dq/dt = i\sum M_i(t,C,dx_0/dt,dy_0/dt,dq/dt,x_0(t),y_0(t),q(t),U(t),L(t),E(t))/I_z
\end{aligned} \tag{7}$$

However, most authors use the following more convenient equivalent structure of the mathematical model:

$$\begin{cases}
dx_0/dt = \nu\cos(q-\beta);\\
dy_0/dt = \nu\sin(q-\beta);\\
dq/dt = w;\\
\dfrac{d\nu}{dt} = -\nu w\sin\beta\cos\beta\left(\dfrac{1}{1+k_{11}} - \dfrac{1}{1+k_{22}}\right) - \dfrac{(i\sum F_{yi})\sin\beta}{(1+k_{22})\rho V} + \dfrac{(i\sum F_{xi})\cos\beta}{(1+k_{11})\rho V};\\
\dfrac{d\beta}{dt} = w\left(\dfrac{\sin^2\beta}{1+k_{11}} + \dfrac{\cos^2\beta}{1+k_{22}}\right) - \dfrac{(i\sum F_{xi})\sin\beta}{(1+k_{11})\rho V\nu} + \dfrac{(i\sum F_{yi})\cos\beta}{(1+k_{22})\rho V\nu};\\
\dfrac{dw}{dt} = \dfrac{i\sum M_i}{(1+k_{66})I_z};\\
i\sum F_{xi}(t,C,\nu(t),w(t),\beta(t),x_0(t),y_0(t),q(t),U(t),L(t),E(t)) = X_b + X_p + T_E + X_{\text{ext}};\\
i\sum F_{yi}(t,C,\nu(t),w(t),\beta(t),x_0(t),y_0(t),q(t),U(t),L(t),E(t)) = Y_b + Y_p + T_{TMG} + Y_{\text{ext}};\\
i\sum M_i(t,C,\nu(t),w(t),\beta(t),x_0(t),y_0(t),q(t),U(t),L(t),E(t)) = M_b + M_p + M_{TMG} + M_{\text{ext}}.
\end{cases} \tag{8}$$

Here v(t) and w(t) – linear and angular velocity of the vessel; β(t) – drift angle (measured clockwise from the direction of the velocity vector to the direction from the stern to the bow of the vessel); X_b , Y_b , M_b longitudinal and transverse force and moment of hydrodynamic resistance on the hull; X_p , Y_p , M_p forces created by conventional steering; T_E – effective propeller thrust; T_{TMG}, M_{TMG} – effective thrust thruster and created by it moment; X_{ext}, Y_{ext}, M_{ext} – forces, due to the external conditions of navigation: wind, current, waves, etc.; k_{11}, k_{22}, k_{66} – coefficients of longitudinal and transverse attached masses and attached moment. Each of the forces and moments, as well as a number of other variables in the system (6) depend on a combination of factors (t, C, v(t), w(t), β(t), x_0(t) y_0(t), q(t), U(t) L(t), E(t)), however, for simplicity, a recording mark such a functional dependence will be omitted.

The system (8) assumes that the components of damping (that is, depending on the angular velocity w) inertial forces associated with the attached masses are already included in the hydrodynamic drag forces ($X_в$, $Y_в$, $M_в$) and therefore are not explicitly prescribed in the system.

Any of the existing mathematical models involves the system of equations (8) to the full or simplified and crude form, supplemented by a set of formulas defines the relationship of all forces and moments (X_b, Y_b, M_b, X_p, Y_p, M_p, T_E, T_{TMG}, M_{TMG}, X_{ext}, Y_{ext}, M_{ext}) from the factors (t, C, v(t), w(t), β(t), x_0 (t) y_0 (t), q(t), U(t), L(t), E(t)). It is the type of these formulas that determines the specifics of each mathematical model.

Let us now consider the dynamics of the water surface on which the ship is moving. To do this, assume that the water surface is a steady flow of an ideal fluid moving without friction. As in the derivation of the differential equations of Euler equilibrium, an elementary parallelepiped is distinguished in the flow of moving fluid and the equilibrium of force projections on the coordinate axis is considered. According to the basic rule of dynamics, the sum of projections acting on the elementary volume is equal to the product of the mass of the liquid at its acceleration:

for the axis x

$$-\frac{\partial p}{\partial x}\cdot dx\cdot dy\cdot dz=\rho\frac{Dw_x}{D\tau}\cdot dx\cdot dy\cdot dz,$$

for the axis y

$$-\frac{\partial p}{\partial y}\cdot dx\cdot dy\cdot dz=\rho\frac{Dw_y}{D\tau}\cdot dx\cdot dy\cdot dz, \tag{9}$$

for the axis z

$$-(\rho\cdot q+\frac{\partial p}{\partial z})\cdot dx\cdot dy\cdot dz=\rho\frac{Dw_z}{D\tau}\cdot dx\cdot dy\cdot dz.$$

Solving these equations we obtain a dynamic model of the water surface.

Depending on the nature of the seabed, the type of vessel, and the depth and condition of the water surface, we choose models that describe the dynamics of the terrain, the movement of the vessel and the dynamics of the water surface in accordance with the reference to the location of the vessel. Time and distance scaling is achieved by interpolation. When it turns out that the map as it "breathes", ie, the contour is constantly moving, depending on altitude and wavelength as shown in Fig.6. At the same time, the vessel will be displayed in relation to the seabed on the monitor as shown in Fig.8. The algorithm for solving this problem is shown in Fig.5. For several years in the mouth of the Danube, namely at the exit from the Danube to the Black sea, repeated multiple observations of changes in the bottom topography were carried out, recording in the intervals between observations, such hydrometeorological parameters as wind strength and direction, wave height and length, as well as the speed and direction of flow. An example of the results obtained after the measurements can be presented in the form as shown in Fig.7(a,b).

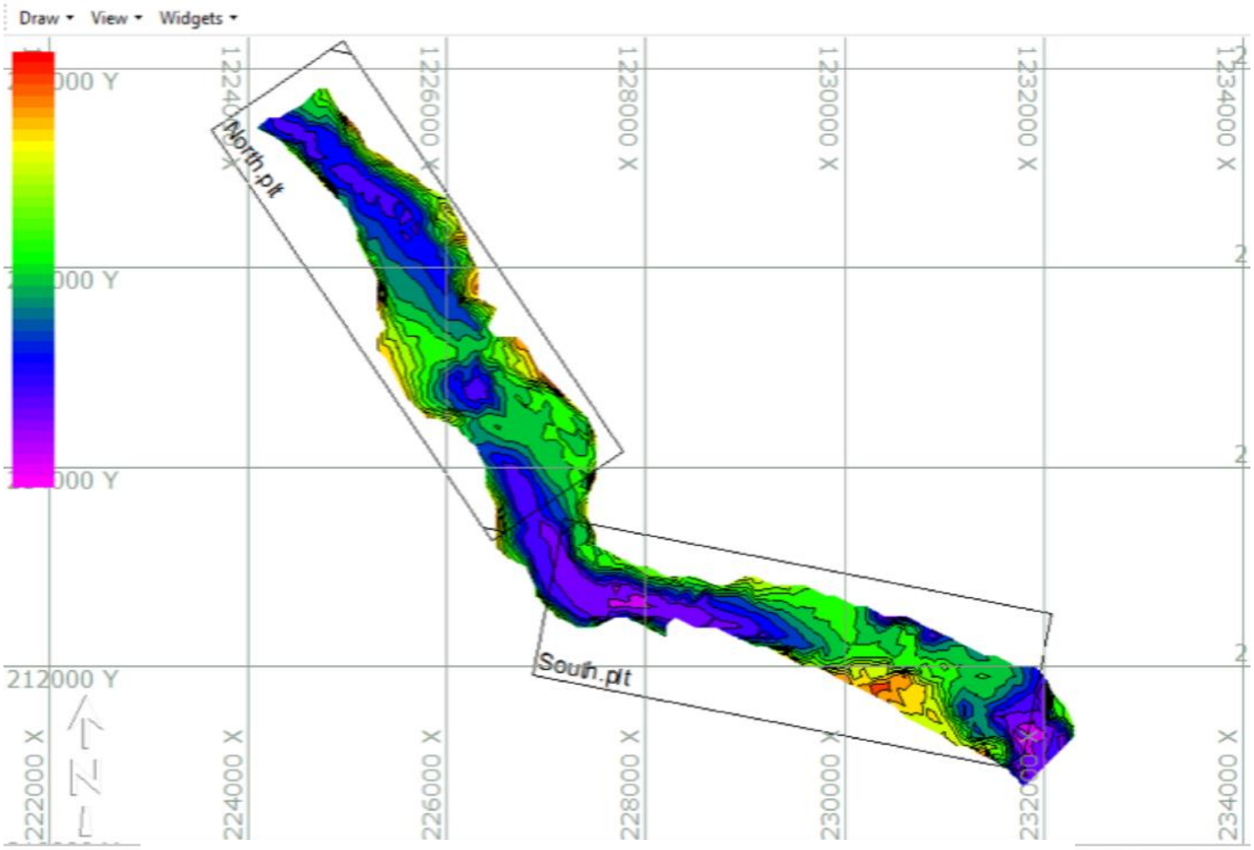


Fig. 7a. Results of measurement of the investigated area

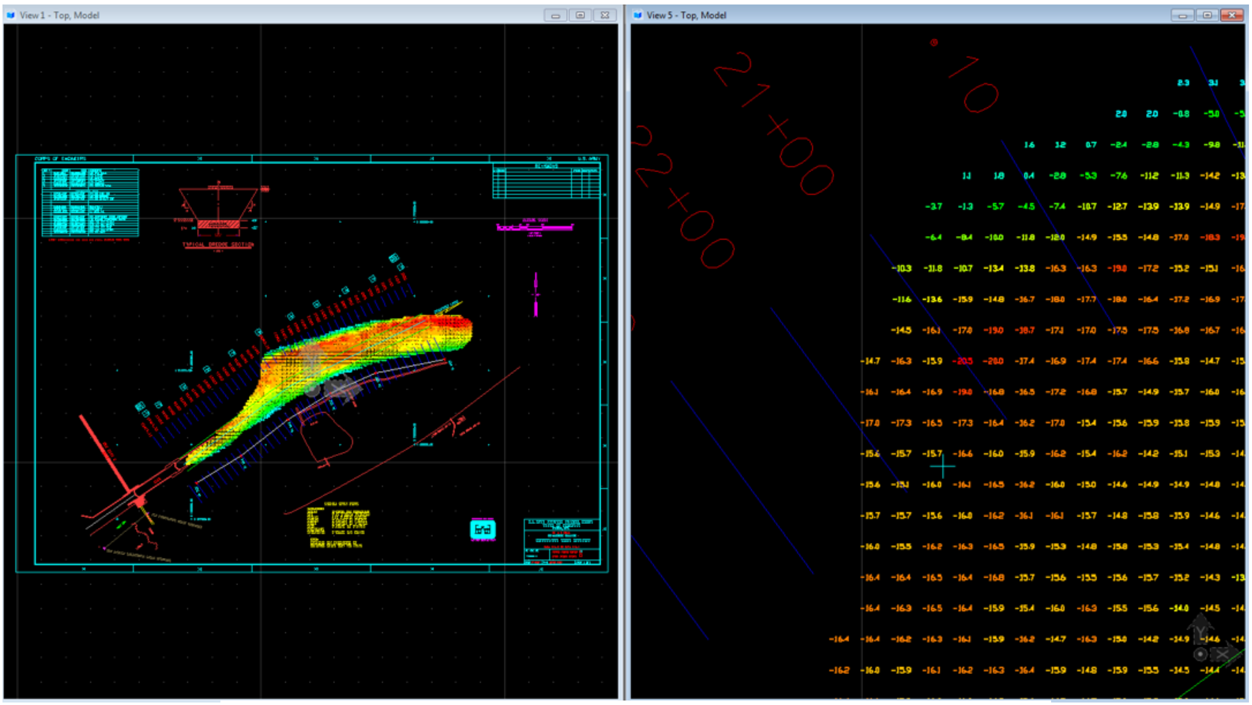
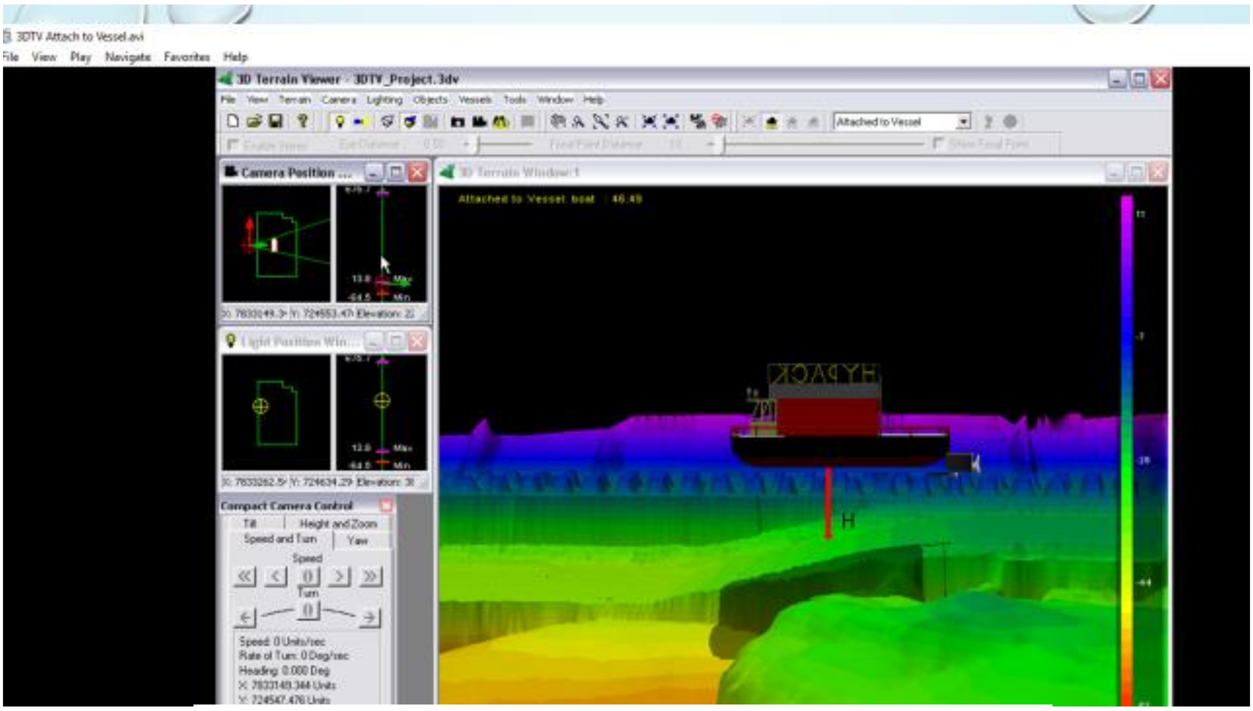


Fig. 7b. Results of measurement of the investigated area



Attached to Vessel boat 46.49

Speed: 0 Units/sec
Rate of Turn: 0 Deg/sec
Heading: 0.000 Deg
X: 7833149.344 Units
Y: 724547.476 Units

Fig. 8. Dynamics of the vessel with respect to the seabed

Writing the substantial derivative of the projections of the velocities along the axes of spatial coordinates:

$$\frac{Dw_x}{D\tau} = \rho\left(\frac{\partial w_x}{\partial \tau} + w_x \cdot \frac{\partial w_x}{\partial x} + w_y \cdot \frac{\partial w_x}{\partial y} + w_z \cdot \frac{\partial w_x}{\partial z}\right);$$

$$\frac{Dw_y}{D\tau} = \rho\left(\frac{\partial w_y}{\partial \tau} + w_x \cdot \frac{\partial w_y}{\partial x} + w_y \cdot \frac{\partial w_y}{\partial y} + w_z \cdot \frac{\partial w_y}{\partial z}\right); \qquad (10)$$

$$\frac{Dw_z}{D\tau} = \rho\left(\frac{\partial w_z}{\partial \tau} + w_x \cdot \frac{\partial w_z}{\partial x} + w_y \cdot \frac{\partial w_z}{\partial y} + w_z \cdot \frac{\partial w_z}{\partial z}\right);$$

and having contractions, get to the respective projections of the differential equations of unsteady fluid flow:

$$-\frac{\partial p}{\partial x} = \rho\left(\frac{\partial w_x}{\partial \tau} + w_x \cdot \frac{\partial w_x}{\partial x} + w_y \cdot \frac{\partial w_x}{\partial y} + w_z \cdot \frac{\partial w_x}{\partial z}\right);$$

$$-\frac{\partial p}{\partial y} = \rho\left(\frac{\partial w_y}{\partial \tau} + w_x \cdot \frac{\partial w_y}{\partial x} + w_y \cdot \frac{\partial w_y}{\partial y} + w_z \cdot \frac{\partial w_y}{\partial z}\right); \qquad (11)$$

$$-p \cdot q - \frac{\partial p}{\partial z} = \rho\left(\frac{\partial w_z}{\partial \tau} + w_x \cdot \frac{\partial w_z}{\partial x} + w_y \cdot \frac{\partial w_z}{\partial y} + w_z \cdot \frac{\partial w_z}{\partial z}\right).$$

For steady flow: $\frac{\partial w_x}{\partial \tau} = 0, \frac{\partial w_y}{\partial \tau} = 0, \frac{\partial w_z}{\partial \tau} = 0,$ then:

$$-\frac{\partial p}{\partial x} = \rho\left(w_x \frac{\partial w_x}{\partial x} + w_y \cdot \frac{\partial w_x}{\partial y} + w_z \cdot \frac{\partial w_x}{\partial z}\right);$$

$$-\frac{\partial p}{\partial y} = \rho\left(w_y \frac{\partial w_y}{\partial y} + w_x \cdot \frac{\partial w_y}{\partial x} + w_z \cdot \frac{\partial w_y}{\partial z}\right); \qquad (12)$$

$$-p \cdot q - \frac{\partial p}{\partial z} = \rho\left(w_z \frac{\partial w_z}{\partial z} + w_x \cdot \frac{\partial w_z}{\partial x} + w_y \cdot \frac{\partial w_z}{\partial y}\right).$$

Systems of equations are differential equations of motion of the ideal Euler fluid for unsteady and steady flows.

When moving a viscous fluid in the flow, in addition to the forces of pressure and gravity, friction forces also act. For a three-dimensional flow, the projection of the resultant friction forces on the x-axis has the form

$$\mu\left(\frac{\partial^2 w_x}{\partial x^2} + \frac{\partial^2 w_x}{\partial y^2} + \frac{\partial^2 w_x}{\partial z^2}\right) dxdydz = \mu \nabla^2 w_x dxdydz.$$

The sum of the projections of all forces on the coordinate axis should be equal to the product of the mass of the liquid enclosed in the parallelepiped on the projection of acceleration on the coordinate axis:

$$\left(-\frac{\partial p}{\partial x} + \mu \nabla^2 w_x\right) dxdydz = p \frac{Dw_x}{\partial \tau} dxdydz;$$

$$\left(-\frac{\partial p}{\partial y} + \mu \nabla^2 w_y\right) dxdydz = p \frac{Dw_y}{\partial \tau} dxdydz; \qquad (13)$$

$$\left(-p\cdot q-\frac{\partial p}{\partial z}+\mu\nabla^2 w_z\right)dxdydz=p\frac{Dw_z}{\partial\tau}dxdydz\,.$$

After the reduction, we obtain the Navier-Stokes differential equations describing the motion of a viscous drop liquid:

$$\begin{gathered}-\frac{\partial p}{\partial x}+\mu\nabla^2 w_x=p\frac{Dw_x}{\partial\tau};\\ -\frac{\partial p}{\partial y}+\mu\nabla^2 w_y=p\frac{Dw_y}{\partial\tau};\\ -p\cdot q-\frac{\partial p}{\partial z}+\mu\nabla^2 w_z=p\frac{Dw_z}{\partial\tau}\,.\end{gathered}\tag{14}$$

The corresponding substance derivatives in the equations can be expressed for both unsteady and steady-state fluid flow.

Conclusions and further research prospects

Solving equations (1)-(14) in the program structure "Mathlab" we obtain the required result.

To summarize our study, it should be noted that:

1. In further studies, the use of multi-scale data should introduce the so-called weighting factor for indexing “scale factor”;
2. In the information block of navigation cartographic systems ECDIS and Inland ECDIS it is recommended to introduce a dynamic component that allows the skipper to see the position of the vessel relative to the bottom in real-time;
3. Methods of parallel transport are recommended for use in the wavelike form of the surface of the sea (river) bottom;
4. In this article, we have considered only the methods of parallel transfer of the bottom topography, based only on the data of repeated observations using the methods of iterations. At the end of our experiment, we obtained a discrepancy between the predicted and measured values of the coordinates of the nodal points of the bottom relief of no more than 20%.

ЛІТЕРАТУРА

1. Юдин Ю.И., Сотников И.И., “Математические модели плоскопараллельного движения судна. Классификация и критический анализ,” *Вестник МГТУ*, том 9, No2, стр.200-208, 2016.
2. Самонов В. Е., “Математическое моделирование движения тонкого слоя жидкости под действием поверхностных сил,” дисс. к.т.н. СГУ, Ставрополь, 2013.
3. Гладких И.И., *Геодезические методы контроля динамики подводного рельефа на участках морских трубопроводов.* Одесса: ОГМА, 1997.
4. Учитель И.Л., Ярошенко В.Н., Гладких И.И., *Основы неогеодинамики*. Одесса: Астропринт, 2000.
5. Дворецкий В. А., “Автоматизация учета радиолокационной девиации,” *Судовождение: Сборник научных трудов,* Одесская национальная морская академия, № 2, с. 47–49, 2000.
6. Raynov A., Kulakov M., Medvedeva I., Oleynik J., “Develoment of a digital RIS index in Ukraine’s inland water-ways in process of implementing the information portal of the European

Union," Proc. Of 24th Internanional Scientific Conference Transport Means, Scopus, pp. 785-789, 2020.

7. Bulgarian National Committee of Geodesy and Geophysics, "National Report on Geodetical and Geophysical Activities in Bulgaria 2007 – 2011," Prepared for the XXVth IUGG General Assembly, Melbourne – Australia, 28 June – 7 July, 2011.
8. Romanian National Committee of Geodesy and Geophysics, "National Report on Geodetic and Geophysical Activities 2007-2010," XXVth IUGG General Assembly, Melbourne, Programme 2007-2013, 28 June -7 July, 2011.
9. Dragomir P., Rus T., Avramiuc N., Dumitru P., "EVRF2007 as Realization of the European Vertical Reference System (EVRS) in Romania," International Symposium GeoCAD08, Alba Iulia, Romania, 09-10 May, 2010.
10. Гладков Г.Л., Бекряшев В.А., Бродский Е.Л., *Содержание внутренних водных путей. Навигационно – гидрографическое обеспечение судоходства*. СПб.: Изд–во ГУМРФ им. адмирала С.О. Макарова, 2018.

REFERENCES

1. Udin U.I., Sotnikov I.I., "Matematichni modeli plosroparalelnogo dvigenya sudna. Klasifikatsya ikriticheski analiz," *Vestnik MGTU*, tom 9, No2, pp.200-208, 2016. [in Russian].
2. Samonov W.E., "Matematichne modelirovanie dvigenya tonkogo sloya gidkosti pod deystviem poverhnostnich sil," diss. k.t.n. SGU, Stavropol, 2013. [in Russian].
3. Gladkich I.I., *Geodezicheskie metodi kontrolya dinamiki podvodnogo relefa na uchastkach morskich truboprovodov*. Odessa: OGMA, 1997. [in Russian].
4. Uchitel I.L., Yaroshenko V.N., Gladkich I.I., *Osnovi geodinamiki*. Odessa: Astroprint, 2000. [in Russian].
5. Dvoretsky V.A., "Atomatizatsya ucheta radiolokatsionnoi deviatsii," *Sudovogdenie: Sbornik nauchnich trudov,* ONMA, № 2, pp. 47–49, 2000. [in Russian].
6. Raynov A., Kulakov M., Medvedeva I., Oleynik J., "Develoment of a digital RIS index in Ukraine's inland water-ways in process of implementing the information portal of the European Union," Proc. Of 24th Internanional Scientific Conference Transport Means, Scopus, pp. 785-789, 2020.
7. Bulgarian National Committee of Geodesy and Geophysics, "National Report on Geodetical and Geophysical Activities in Bulgaria 2007 – 2011," Prepared for the XXVth IUGG General Assembly, Melbourne – Australia, 28 June – 7 July, 2011.
8. Romanian National Committee of Geodesy and Geophysics, "National Report on Geodetic and Geophysical Activities 2007-2010," XXVth IUGG General Assembly, Melbourne, Programme 2007-2013, 28 June -7 July, 2011.
9. Dragomir P., Rus T., Avramiuc N., Dumitru P., "EVRF2007 as Realization of the European Vertical Reference System (EVRS) in Romania," International Symposium GeoCAD08, Alba Iulia, Romania, 09-10 May, 2010.
10. Gladkov G.L., Bekryashev V.A., Brodski E.L., *Soderganie vnutrennich vodnich putei. Navigatsionno – gidrograficheskoe obespechenie sudochodstva*. SPb.: Izd-vo GUMRF im. adm. S.O. Makarova, 2018. [in Russian].