DETERMINATION OF THE VELOCITY FIELD OF A QUASI-STATIONARY FLOW IN THE OCEAN

GEOPHYSICS

1966

SovietRxiv

Abstract

Full Text

UDC 551.465.55

GEOPHYSICS

K. A. CHEKOTILLO

DETERMINATION OF THE VELOCITY FIELD OF A QUASI-STATIONARY FLOW IN THE OCEAN

(Presented by Academician E. K. Fedorov, 29 X 1965)

The methods most widely used at present for calculating marine currents proceed from the assumption that the current velocity (or one of its components) at some depth or other becomes zero. However, in the light of recent achievements in the study of marine currents, the hypothesis that the current velocity decays with depth appears untenable.

Since one of the main features of motion in the ocean is its multiscale character, let us first establish the scale of the model of ocean circulation that will be investigated. It seems that, in order to construct a scheme that would characterize currents in the ocean in detail, the horizontal length scale should be taken as a distance of 100 km. It can be shown that in a model with this scale, currents in regions remote from coasts and from the equator are described by the so-called Ekman system of equations:

$$-f\rho v = -\partial p/\partial x + \partial T_{zx}/\partial z, \tag{1}$$

$$f\rho u = -\partial p/\partial y + \partial T_{zy}/\partial z, \tag{2}$$

$$g\rho = \partial p/\partial z, \tag{3}$$

$$\partial u/\partial x + \partial v/\partial y + \partial w/\partial z = 0, \tag{4}$$

where u, v, w are the components of the velocity of the averaged turbulent motion along the axes x, y, z, which are directed eastward, northward, and vertically downward, respectively; $T_{zx} = -\rho\overline{w'u'}$, $T_{zy} = -\rho\overline{w'v'}$; u', v', w' are the components of the fluctuating velocity; f is the Coriolis parameter; the meanings of the other symbols are generally known. System (1)–(4) shows that the motion consists of currents of two types: a current caused by the horizontal pressure gradient in the field of the Coriolis force, and a current produced by the vertical gradient of Reynolds stress in the field of the Coriolis force. The current of the first type (gradient-convective), by its nature, is ordered and encompasses the entire thickness of the ocean waters. The current of the second type has a turbulent nature and is created in relatively thin layers adjacent to the ocean surface and to the bottom (we shall call it a T_z-current). Thus, in layers of ocean water considerably removed both from the surface and from the bottom, the transport of water is effected by ordered motion. It must be assumed that the transport of properties at these depths also occurs as a result of ordered, eddy-free motion. Under stationary conditions the equation of isopycnicity has the form

$$u\,\partial\rho/\partial x + v\,\partial\rho/\partial y + w\,\partial\rho/\partial z = 0. \tag{5}$$

On the basis of system (1)–(4), the components of the current velocity can be expressed as follows:

$$u = u_g + u_{T_z} = u_\gamma + \frac{1}{f}\frac{\partial Q}{\partial y} + u_{T_z}, \tag{6}$$

$$v = v_g + v_{T_z} = v_\gamma - \frac{1}{f}\frac{\partial Q}{\partial x} + v_{T_z}, \tag{7}$$

$$w = w_g + w_{T_z} = F\left(v_\gamma z - \frac{1}{f}\int_0^z \frac{\partial Q}{\partial x}\,dz\right) - \frac{\partial}{\partial x}\int_0^z u_{T_z}\,dz - \frac{\partial}{\partial y}\int_0^z v_{T_z}\,dz, \tag{8}$$

where the indices g and T_z denote the gradient-convective current and the current caused by the vertical gradient of the Reynolds stress, respectively; γ indicates the current caused by the slope of the sea surface; $F = \beta/f$, β is the Rossby parameter; $Q = \int_{p_a}^{p_z} \alpha\,dp$; p_a is atmospheric pressure; α is the specific volume of sea water.

It has already been noted that the horizontal T_z-current occurs only in relatively thin surface and bottom layers (we shall denote their thicknesses by h and h_H, respectively). In a first approximation these currents may be determined on the basis of the theory of C. G. Rossby (1), obtained for a homogeneous sea. In the surface layer the velocity of the T_z-current will be a function of the wind velocity, and in the bottom layer a function of the velocity of the gradient-convective current. In turn, the wind velocity at the sea surface can be determined from the field of atmospheric pressure at sea level.

The quantities Q entering into (6)–(8) can be found from the known density field of the water. Thus, according to the system (6)–(8), the problem of determining the components of the current velocity reduces to finding the values u_γ and v_γ.

In the main body of ocean waters, outside the layers covered by the horizontal T_z-current, the vertical component of velocity is described by the expression

$$w|_{H-h_H>z>h} = F\left(v_\gamma z - \frac{1}{f}\int_0^z \frac{\partial Q}{\partial x}\,dz - \frac{\mathrm{rot}_z\,\mathbf{T}_a}{\bar{\rho}\beta} - \frac{T_{ax}}{\bar{\rho}f}\right), \qquad (9)$$

where H is the ocean depth; $\bar{\rho}$ is the mean value of water density in the interval between the sea surface and the horizon z; $\mathbf{T}_a$ is the vector of the tangential wind stress at the sea surface; T_{ax} is the component of the wind stress along the x-axis.

Taking into account (6), (7), (9), equation (5) for the interval from $z = h$ to $z = H - h_H$ can be represented in the form

$$\left(u_\gamma + \frac{1}{f}\frac{\partial Q}{\partial y}\right)\frac{\partial \rho}{\partial x} + \left(v_\gamma - \frac{1}{f}\frac{\partial Q}{\partial x}\right)\frac{\partial \rho}{\partial y} +$$

$$+F\left(v_\gamma z - \frac{1}{f}\int_0^z \frac{\partial Q}{\partial x}\,dz - \frac{\mathrm{rot}_z\,\mathbf{T}_a}{\bar{\rho}\beta} - \frac{T_{ax}}{\bar{\rho}f}\right)\frac{\partial \rho}{\partial z} = 0. \qquad (10)$$

If in equation (10) one substitutes the values of Q and ρ determined on any two horizons of the indicated interval, then, regarding the field of tangential wind stress as known, we obtain two equations with the unknowns u_γ and v_γ. The algebraic solution of the system leads to finding the required unknowns, which means determining the entire field of current velocity.

The field of tangential wind stress at the sea surface is determined from the wind-velocity field, which, as indicated, can be obtained from data on the distribution of atmospheric pressure at sea level. Consequently, the components of the current velocity can be found by the described method if the field of atmospheric pressure at sea level and the water-density field are known.

To test the proposed method in the northwestern part of the Pacific Ocean (the square 30—40° N, 145—155° E), horizontal currents at the ocean surface and at the 1000 and 1500 m horizons were calculated from mean multiyear data for August. In addition, all velocity components were computed on a section along 148° E (Figs. 1 and 2). The value h was determined by Rossby's formula; for the greatest value of the velocity of the resultant wind in the area under study, $h = 288$ m. In connection with this, the characteristics of the density field, determined at the 600 and 1000 m horizons, were substituted into equation (10). Data on the density field were taken from the *Catalog of Deep-Water Observations of the Pacific Ocean* (Institute of Oceanology, Academy of Sciences of the USSR, 1960). Data on atmospheric pressure at sea level were taken from (2).

Fig. 1. Vectors of current velocity at the ocean surface (a) and at a depth of 1500 m (b), calculated from mean multiyear data for August. Different arrow

Fig. 1

Figure 1: Fig. 1

Fig. 2

Figure 2: Fig. 2

thicknesses correspond to the following four gradations of velocity (in cm/sec): 1—5; 6—10; 11—30; greater than 30 (a thicker arrow denotes a greater velocity).

Fig. 2. Three-dimensional representation of the calculated current velocities on the section along 148° E. Isolines drawn every 5 cm/sec denote the zonal velocity. Hatched regions correspond to motion directed westward. The arrows give the directions of the velocity vectors in the yz plane (taking into account the ratio of the horizontal and vertical scales of the drawing).

Fig. 3. Vectors of current velocity at the ocean surface, determined from ship drift for August (2). The notation is the same as in Fig. 1.

On the ocean surface, the currents have the same character as the currents determined as a result of instrumental observations (Fig. 3); the predominant current velocities are grouped around 10 cm/sec. At the horizons of 1000 and 1500 m, the direction of the currents is generally opposite to the direction of the surface currents. The current velocity at 1000 m mainly ranges from 1 to 5 cm/sec; at 1500 m, from 1 to 10 cm/sec.

Institute of Oceanology
Academy of Sciences of the USSR

Received
22 X 1965

REFERENCES

[1] C.-G. Rossby, Massachusetts Inst. Technology Meteorolog. Pap., 1, No. 4 (1932).
[2] U. S. Navy Marine Climatic Atlas of the World, II, North Pacific Ocean, Direction of the Chief of Naval Operations, 1956.
[3] Atlas of Surface Currents Northwestern Pacific Ocean, Hydrographic Office U. S. Navy, Washington, 1950.

Note: Figure translations are in progress. See original paper for figures.

Fig. 3

Figure 3: Fig. 3