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GEOSTROPHIC CURRENTS AND REAL CIRCULATION ON THE ROMANIAN SHELF OF THE BLACK SEA

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ABSTRACT

The geostrophic currents on the 5 dbar surface have been computed for the hydrological cruises carried out in March, May and July 1973 and compared with the circulation patterns inferred from current measurements The particular problems arising from the use of the dynamic method on the Romanian continental shelf under the conditions of unstable current regime and of particular temperature and salinity structure - due to the significant freshwater inflow and to the specific features of thermic processes in this region - are also analysed.

1. INTRODUCTION

Marine currents - an effect of the complex air-sea interaction processes - reveal a permanent connection between these two media, with important impacts on the thermohaline structure of the World Ocean, as well as on the climatic conditions. Therefore the knowledge of the circulation systems characteristics is necessary in order to make it possible to answer multiple problems arising from the climatic studies, long-term meteorological and oceanographic forecasts required by the exploatation of biological resources of the sea.

In the same connection, this knowledge is indispensable in performing other human activities related to the marine environment: navigation harbour design and construction, beach protection, etc.

The insufficient understanding of the mechanisms responsible for the generation of marine currents, as well as the lack in the available information about space distribution and time evolution of their causes made it difficult to describe the regime of sea water circulation. The limited amount of direct measurements and the difficulties in enlarging it led to the use of some indirect computational methods for current velocity and direction.

One of these is the dynamic method used to evaluate the currents generated by horizontal pressure gradients, based on the distribution of sea water density. The method is particularly useful as the density calculation is based on temperature and salinity values which are more easily obtained than the direct observations on the currents. Moreover, the geostrophic currents computed by this method represent the synthetic result of all influences exerted on the sea (LACOMBE, 1965).

2. GEOSTROPHIC CURRENTS

Solving the basic equations of the hydrodynamics is possible only for a limited number of special cases, where the non-linear terms may be either replaced by linear approximations, either neglected.

One of the cases is that of stationary currents in the absence of external forces and friction, when the only forces acting on the fluid are due to the pressure gradients, Coriolis and gravitational accelerations (EGOROV, 1966; NEUMANN, 1968).

Since the isobaric surfaces are not horizontal, the fluid particles show the tendency to move down their slope, perpendicularly on the lines of equal depth. Because of the Earth rotation, the Coriolis force F_c produces the deviation of the velocity vector to the right (in the northern hemisphere), until it is balanced by the pressure force F_p (fig. 1). At this moment, the flow becomes stationary (permanent), the particles moving along the level lines of the isobaric surface with the velocity c. The reached equilibrium is called geostrophic equilibrium and is given by the equality of the two forces :

$$\frac{1}{\rho} \frac{\delta p}{\delta n} = 2\omega \ c \sin\varphi \qquad (1)$$

where $\delta p/\delta n$ is the slope of the isobaric surface, ω is the angular velocity of Earth rotation, φ is the geographic latitude, ρ - the water density

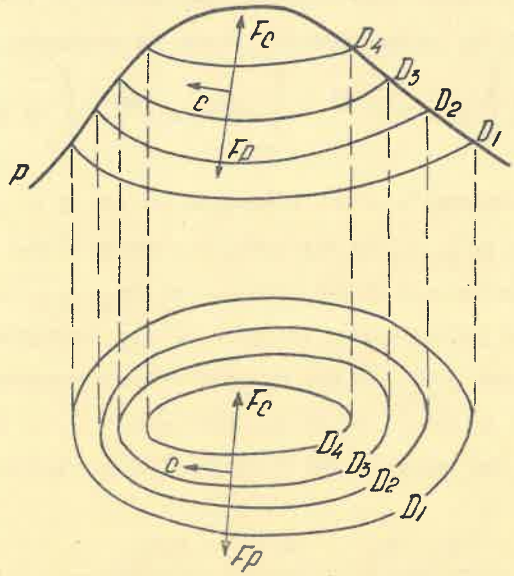

Fig. 1 - Equilibrium of forces in the geostrophic motion on an isobaric surface

and c - the current velocity. This current is called gradient current or geostrophic current.

Relation (1) allows the computation of the velocity c on the isobaric surface p. provided that its slope against a horizontal isobaric surface (on which the velocity is zero) is known :

$$c = \frac{1}{2\omega \sin\varphi} \frac{1}{\rho} \frac{\delta p}{\delta n} = \frac{1}{2\omega \sin\varphi} \alpha \frac{\delta p}{\delta n} \qquad (2)$$

where $\alpha = 1/\rho$ is the specific volume of sea water.

Using the concept of dynamic height D defined by :

$$\alpha p = \frac{1}{\rho} p = gh = 10\ D \tag{3}$$

the expression (2) can be written as :

$$c = \frac{1}{2\omega \sin\varphi} \quad \frac{\delta D}{\delta n} \tag{4}$$

where D is the dynamic height of the isobar p relative to a reference horizontal isobar.

If the vertical distribution of the density is known from the temperature and salinity measurements, D can be computed from:

$$D = \int_{p_o}^{p} \alpha_{S,T,P}\, dp = \int_{p_o}^{p} \alpha_{35,0,p}\, dp + \int_{p_o}^{p} \delta_{STP}\, dp = D_o + \Delta D \tag{5}$$

where p_o is the pressure of the reference isobar, p is the pressure of the given isobar, $\alpha_{S,T,P}$ is the specific volume of sea water with salinity S and temperature T at the pressure p, $\alpha_{35,0,P}$ is the specific volume of standard oceanic water (salinity $35^o/_{oo}$, temperatura 0^oC) at the same pressure and δ_{STP} is the specific volume anomaly of the water in the given station as comp[illegible]ed to standard water; D_o is the standard dynamic height of the isobar p and D is the dynamic height anomaly.

From (5) :

$$\frac{\delta D}{\delta n} = \frac{D_A - D_B}{L} = \frac{\Delta D_A - \Delta D_B}{L}$$

where subscripts A and B refer to two stations at a distance L. Thus, the current component normal to the line between them is given by :

$$c = \frac{1}{2\omega \sin\varphi} \cdot \frac{\Delta D_A - \Delta D_B}{L} \tag{6}$$

Therefore, the velocity c is computed taking a horizontal isobaric surface, on which there is no geostrophic motion, as the origin for the dynamic height; this is called reference surface or surface of no motion. Practice demonstrates that such an isobar can be found only at great depth - where the thermohaline structure is homogeneous and the current speed negligible.

When the water depth is smaller than the reference surface depth, e.g. in the oceanographic stations on the continental shelf, one resort to the operation of "oceanographic stations levelling" (TIMOFEEV and PANOV, 1962). The depth of the reference surface is taken as equal to the bottom depth measured in a station in the middle of the studied region, the value of which is close to the mean depth of all the stations. Then, corrections are added to the dynamic heights of the other stations :

$$\Delta = \frac{\alpha + \alpha_R}{2} (p_R - p) \qquad (7)$$

where α is the bottom specific volume in a given station, p is the bottom pressure in decibars (or the depth in meters), and α_R and p_R are the corresponding values for the reference station. This means that for the stations with smaller depths than that of the reference station, a water column with the height equal to the depth difference and the specific volume equal to the mean of the bottom specific volumes in the two stations, is conventionally added. In a similar manner, the height of water column is reduced for the stations deeper than the reference station.

Thus, the dynamic heights of a given isobaric surface, in relation to the reference isobar, are obtained and plotted on a map. The direction of the geostrophic currents on the isobar is given by the direction of the lines of equal dynamic height, so that the region of heigher dynamic heights is on the right of the current. The closer the lines, the greater the velocity of this current.

3. CIRCULATION ON THE ROMANIAN CONTINENTAL SHELF

All the general circulation patterns for the Black Sea, inferred from the analysis of the existing current measurements or from the mean distribution of the atmospheric pressure, or based on indirect indicators (temperature, salinity, spreading of the plancton species, dissolved oxygen and hydrogen sulphide), indicate the existence of a general north-south current off the Romanian coast.

This current is the result of the concurrent actions of manifold causes: the concentration of freshwater sources in the northwestern part of the sea and the excess outflow through Bosphorus, the prevailing northerly winds, etc.

As these causes show a great space variability, yet insufficiently known, the results of a particular observation cruise may present many characteristics very different from the mean circulation (MARINESCU, 1965).

Thus, in the schemes of water circulation on the Romanian continental shelf of the Black Sea drawn from the data gathered in the hydrological cruises carried out in March, May and July 1973 (fig. 2, 3, 4), the structure of the current field in the upper layer is very complex. Although for diminishing the effect of short-term changes in wind direction and speed, the current measurements at 5m depth have been processed, the existence of the general southward flow - the western branch of the Black Sea cyclonic gyre - is pointed out only by the general trend of the water flow. When analysed in details, these results show a lot of discrepancies from one season to another, as well as from the mean circulation. The most important discrepancy consists in the appearence of a northward current along the seashore in May and July.

For the same cruises, the dynamic topography of the 5 dbar surface have been computed. The station at 30 miles offshore Midia (bottom depth =50 m) has been taken as reference for levelling the other stations. The correction given by the formula (7) has been applied to the computed dynamic height. The results are given in fig. 5, 6 and 7.

The agreement between geostrophic and real, observed circulation is just approximate, yet preserving the general trend of the water drift. The discrepancies become more evident during the warm season.

From the comparative study of the presented situations, it may be noticed that actual currents are generally directed across the lines of equal dynamic height, and not along them, as predicted by the geostropic current theory. This may be explained by the fact that the internal

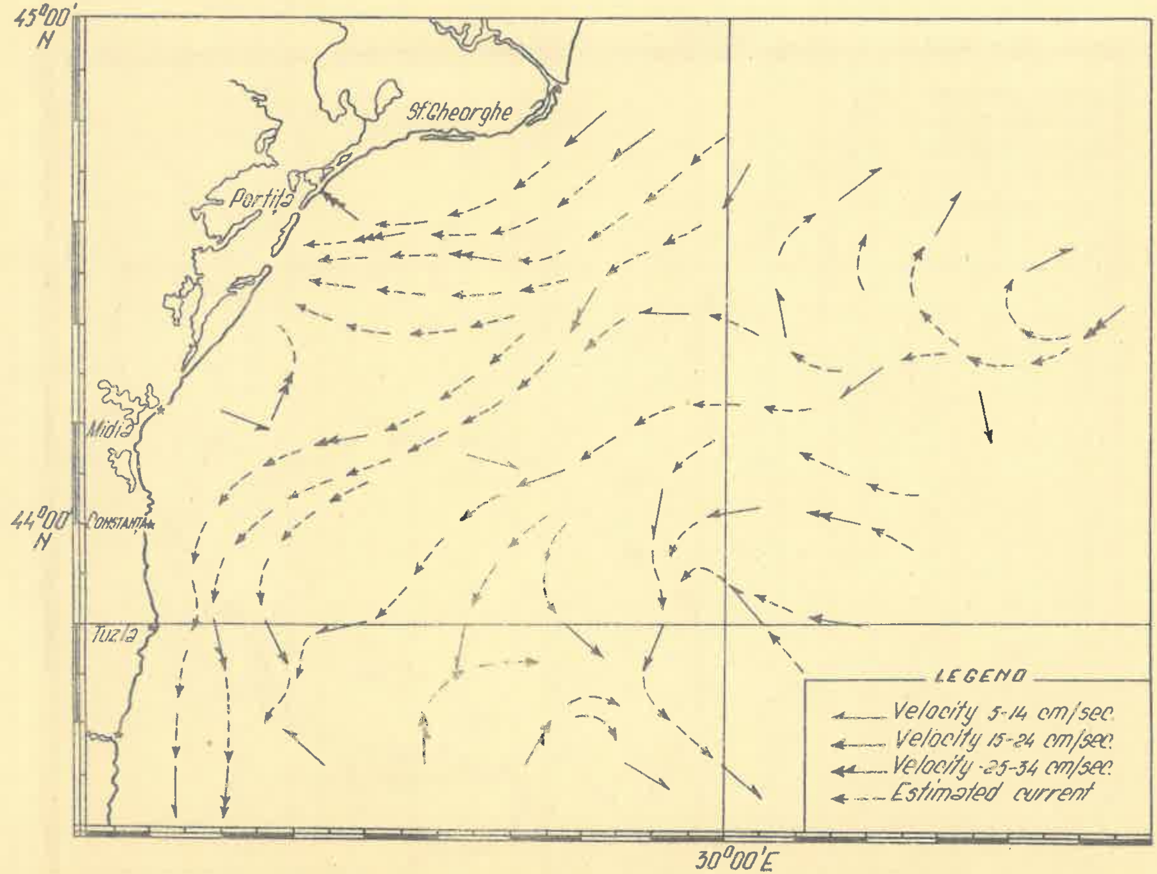

Fig. 2 - Circulation of surface waters (5 m depth) in March 1973

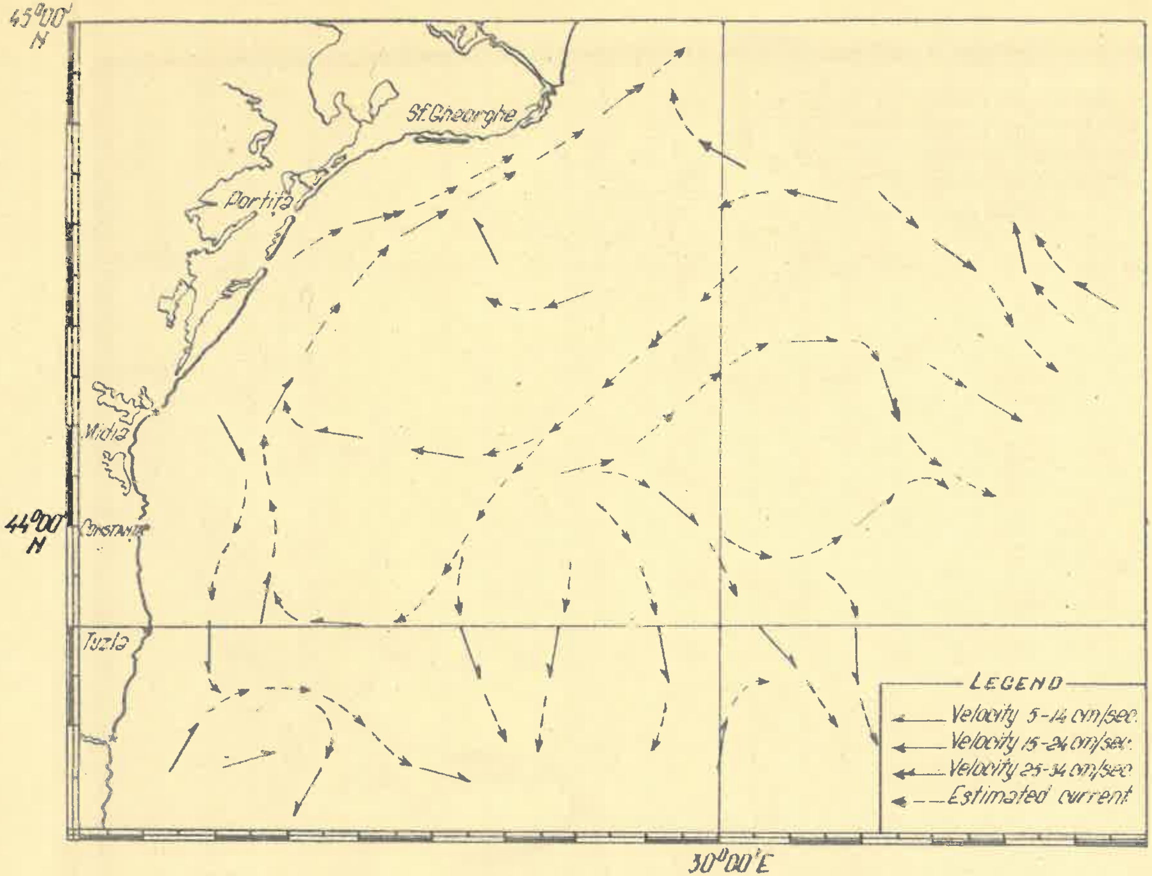

Fig. 3 - Circulation of surface waters (5 m depth) in May 1973

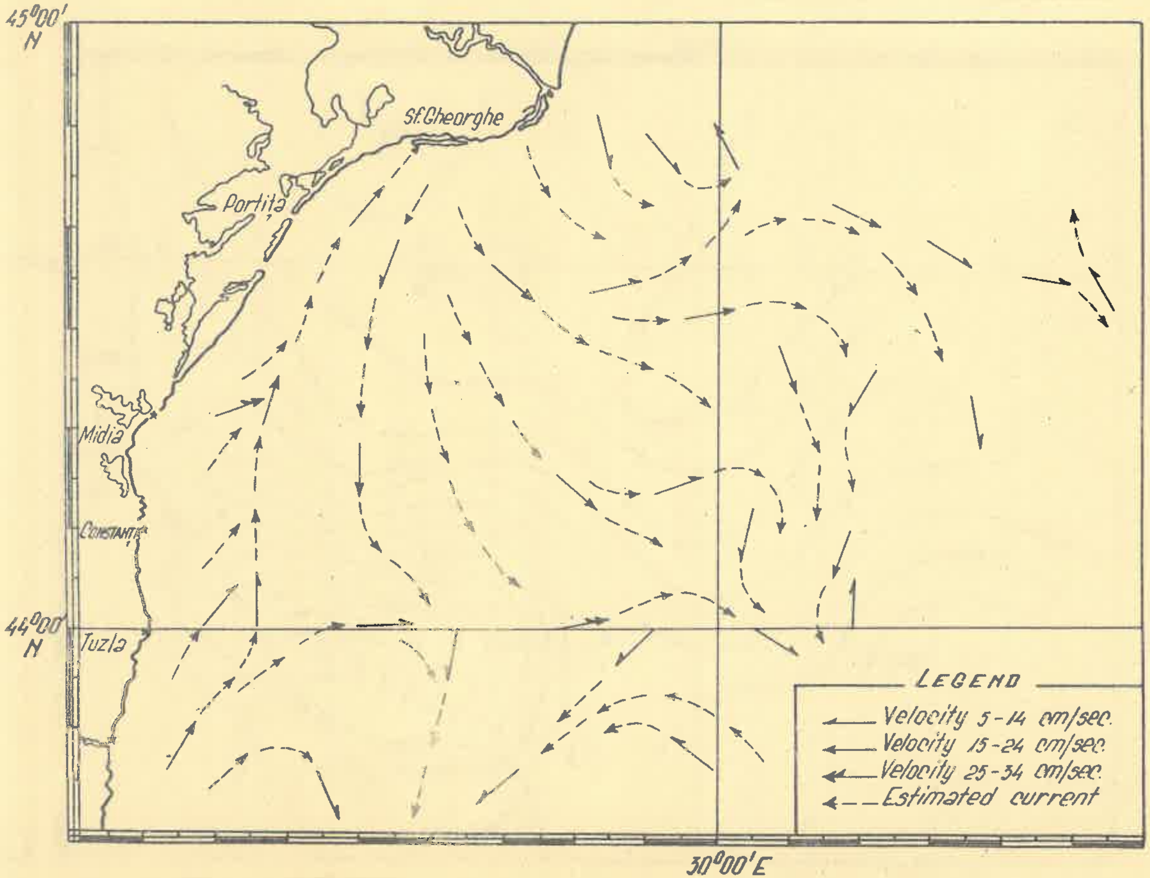

Fig.. 4 - Circulation of surface waters (5 m depth) in July 1973

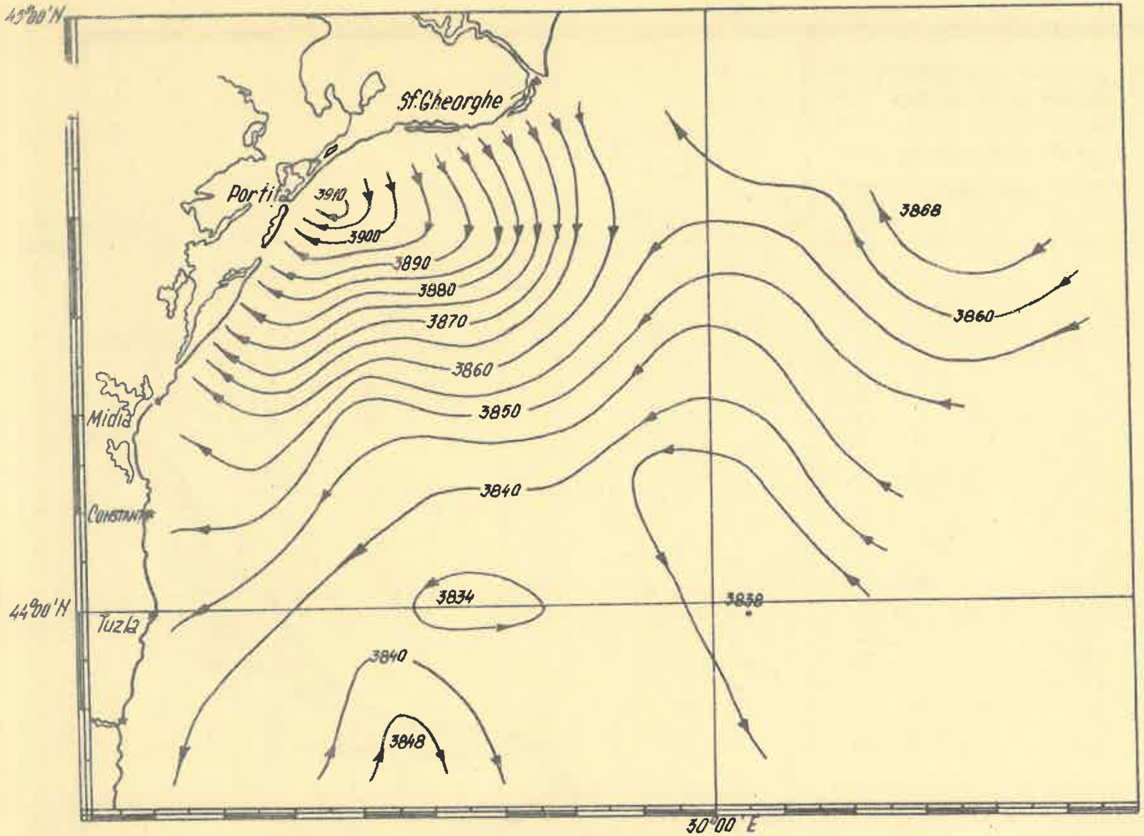

Fig. 5 - Dynamic topography of the 5 dbar surface in March 1973

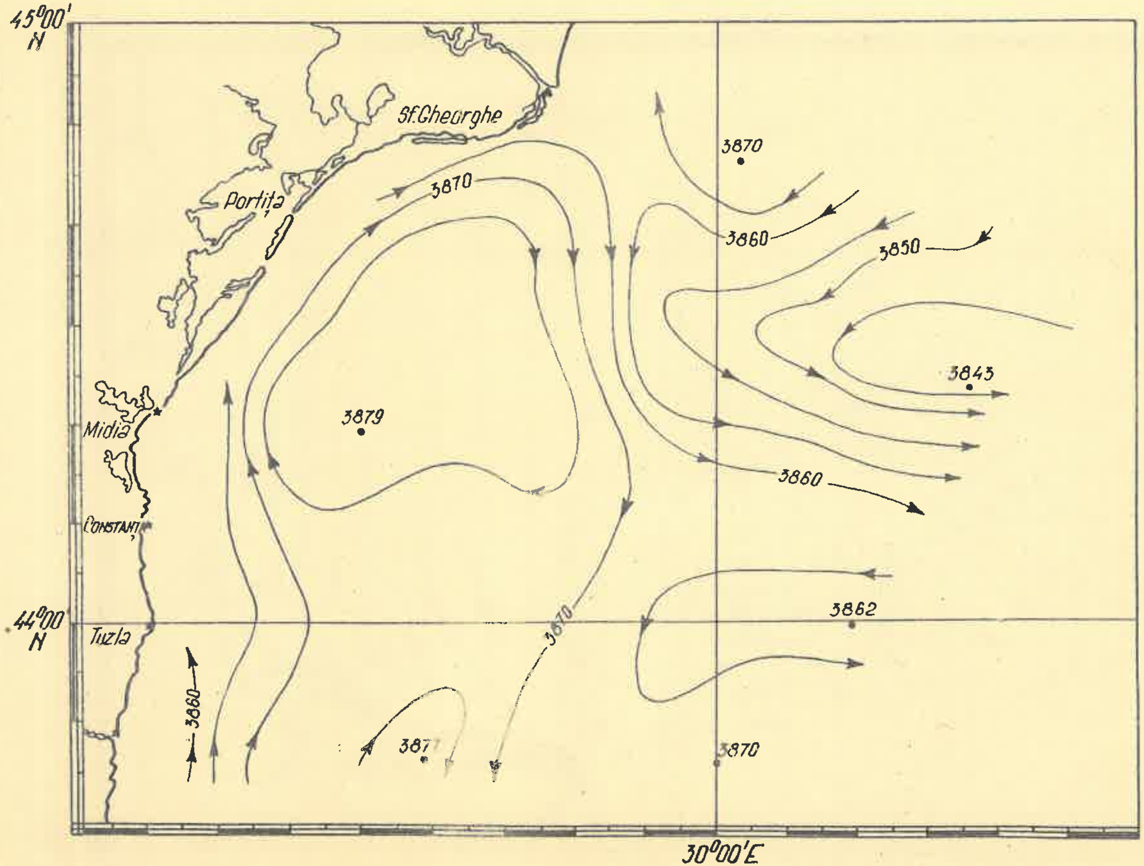

Fig. 6 - Dynamic topography of the 5 dbar surface in May 1973

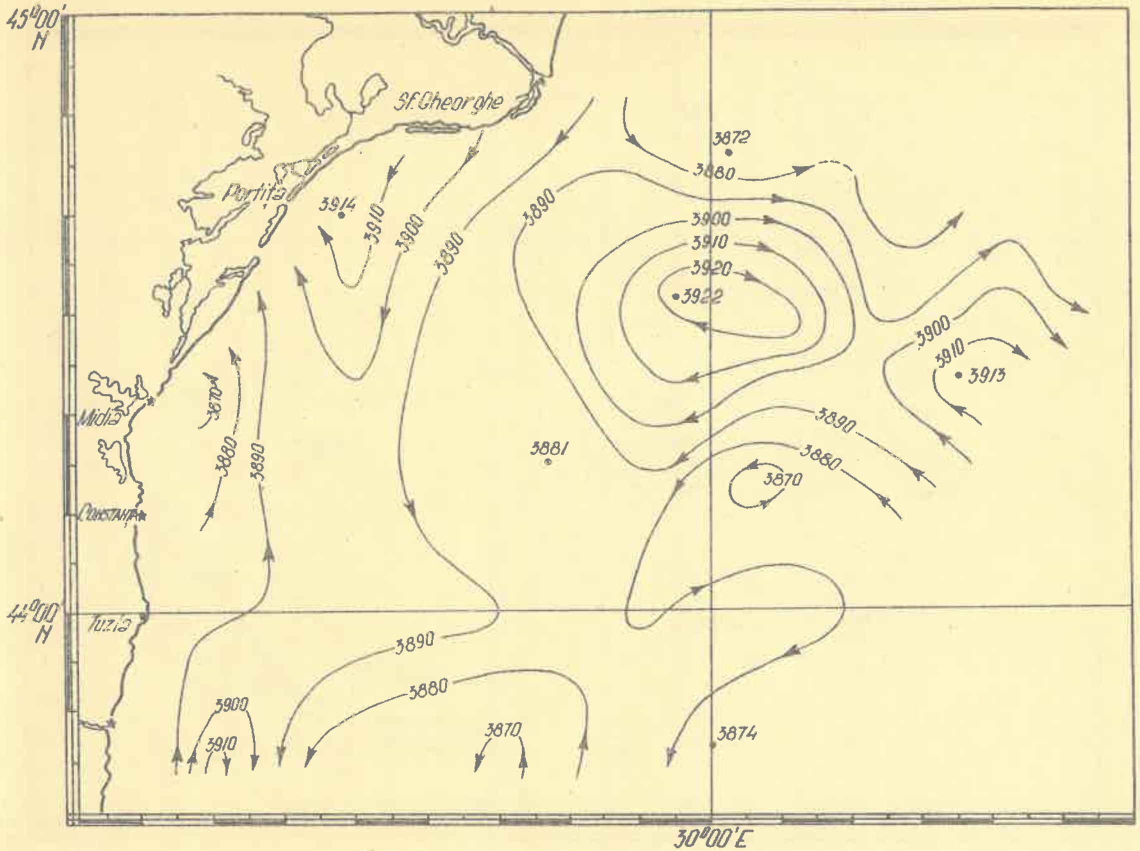

Fig. 7 --Dynamic topography of the 5 dbar surface in July 1973

and sea bed friction have been neglected in the theoretical approach. In fact, because of the sea water viscosity, the velocities of the currents due to the pressure gradients are smaller than the computed ones. Consequently, the Coriolis force, which is proportional to the speed, cannot exactly balance the pressure gradient force, and the flow is directed along this gradient, from zonas of heigher dynamic heights to lower dynamic heights. The same effect (in regions of shallow water) is due to the speed diminishing produced by the bottom friction.

On the other hand, one must take into account the fact that although the geostrophic currents have been computed from the density structure, this is not necessarily the cause of the movement. The wind driven currents produce a reorganization of this distribution, until the reach of the geostrophic equilibrium; using this distribution, the dynamic method gives the characteristics of the currents. They are the cause and not the effect of the nonhomogeneous space distribution of density. Therefore the currents computed by the dynamic method reflect more or less all the external actions exerted on the sea water.

Given the wind instability in the investigated area, the drift currents rarely reach the steady state and thus the condition (1) is not always fulfilled and the velocities computed by the dynamic method are different from the actual speeds.

This is more evident in the warm season when the wind action is limited within the relatively homogeneous water layer above the thermocline (20-30 m thick). In the cold period the currents are much more stable because of the greater intensity and stability of the winds. Therefore the agreement between geostrophic and real currents is better.

Finally, applying the correction (7) under the conditions of a salinity increase from the coast toward the open sea and of a very particular structure of the temperature field, resulting from the existence of the bottom cold water mass (BULGAR and DIACONU, 1973) may lead to considerable distortions in the real dynamic topography.

4. CONCLUSIONS

The dynamic height computation for different isobaric surfaces in order to determine the geostrophic current is a necessary step in processing the data gathered in classical hydrological stations.

This method is very useful when direct current measurements are missing (stations on a drifting ship). The obtained results agree quite well with the reality, especially for the regions of stable currents.

The application of the method under the specific conditions of the Romanian shelf - large temperature and salinity variations, unstable wind regime - provides an overall description of the water general flow, which is difficult to obtain from the instantaneous current speed and directions measurements. Thus, for the three observation cruises made in 1973, a general flow directed southward is evident especially during the period of thermal and saline homogeneity (fig. 5).

On the other hand, one must take into account the fact that the dynamic method gives only the possible currents, not real currents (as a result of the simplifying assumptions which have been made). This is more important when the method, is applied on the continental shelf, especially under the hydrological conditions of the northwestern part of the Black Sea.

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