A Practical Method for the Prediction of the Surface Currents of the Ocean[1,2]

By LOUIS A. POST, Oceanographer U.S. Navy Hydrographic Office

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Abstract

A method is advanced for the prediction of surface currents based on the stability of computed dynamic currents. Wherever the latter are known and simultaneously the measured (geomagnetic) current and local wind direction, speed, and duration are known, the vector difference between the measured and the computed currents is assumed to be the portion of the current induced by the wind.

The hypothesis is demonstrated empirically by a correlation of the above factors based on data obtained during a recent oceanographic survey. The predicted surface current vector is shown to be the resultant between a forecast wind-current and a permanent dynamic current.

A new type of survey is proposed to make feasible the complete correlation of these factors.

Introduction

The principal obstacle to the investigation and interpretation of many of the observed properties of the ocean is ignorance of the limits of a "normal" condition as a frame of reference to which the observed properties are related.

Techniques for establishing the normal condition of ocean currents have so far been limited to methods for obtaining the average of conditions from a large number of observations. This average is by no means adequate to define a normal or fixed condition upon which we may superimpose predictable variables, for it already includes the average of all possible variables.

A frame of reference: It is important to consider to what extent an adequately fixed condition, unaffected by such surface variables as wind, is afforded by the dynamic topography of the sea surface. It is generally conceded by oceanographers that the oceanic circulation derived from dynamic sections results purely from the distribution of mass within the ocean. Disturbances in the equilibrium of water masses give rise to "density" currents varying in direction and velocity, and it would appear that the currents so produced can reflect only forces of sufficient permanence to create and maintain the disturbances. Such forces apparently do not include the transitory local, or even seasonal variables of wind although these do alter the actual, observed current velocity and direction.

[1] The writer wishes to thank Dr C. O'D. Iselin for reading this paper and suggesting several important improvements.

The opinions expressed in this paper are solely those of the author and do not necessarily reflect the opinions of the Hydrographic Office or U.S. Navy.

[2] 1. Normal: basic, as "a basic condition", exclusive of superimposed variables — not an average.

2. Dynamic current: The component of ocean currents derived from the dynamic topography and resulting from the distribution of mass within the ocean; also "permanent current".

3. Stability: state of being unaffected by external influences, as the stability of dynamic current with respect to wind.

Thus, STOMMEL (1951), writes that "although fluctuations of the global wind system of periods of a week or longer can induce measurable changes in both the velocity and surface levels of the ocean, an adjustment of the density distribution over the whole ocean cannot occur for periods of less than 30 years." And further, "seasonal fluctuations of oceanic circulation cannot be discovered by the usual methods of dynamic computation."

The permanent effect of wind upon dynamic topography would thus appear to be cumulative for long periods over the ocean as a whole; locally, wind would not seem to be detectable in the dynamic topography.[1] Although there are certain known conditions under which great fluctuations in dynamic topography occur, PARR (1938), these do not appear to depend upon the wind, locally or seasonally.

The present study makes an attempt to answer two questions: (1) What evidence exists that ocean currents, dynamically computed, provide a nearly fixed frame of reference, a constant integrant of surface flow though not always identical with it, a sort of "ecliptic" of oceanography upon which we may superimpose the other variables? A question which naturally follows is (2) Can these variables be accurately predicted? The writer suggests that such changes as the result of fluctuations in the wind system, superimposed upon relatively established (dynamic) surface currents of the oceans, are both measurable and predictable.

To demonstrate this concept, the following method is advanced to determine (a) the stability of dynamic currents with relation to observed (electromagnetically measured) and wind-driven currents, and (b) the amounts of wind-driven currents induced by different velocities of wind.

The Method

Stability of dynamic currents with relation to observed and wind-driven currents: This method may be used wherever three factors have been determined simultaneously for a series of stations; (1) the dynamic or density current speed and direction, (2) the observed (geo-

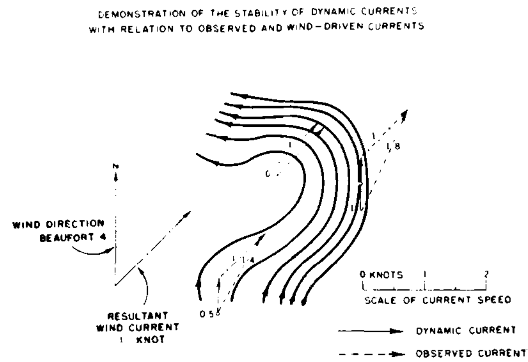

FIGURE I

Fig. 1.

magnetic) current speed and direction, and (3) the wind speed, direction and duration.

Contours of dynamic height anomalies are drawn for the sea surface over a practically level isobaric surface. Dynamic current velocities and directions may be thus determined for a number of adjacent oceanographic stations. Vectors are drawn as in figure 1 (hypothetical). Similarly, vectors are drawn to represent currents measured by the Geomagnetic Electrokinetograph, VON ARX (1950), just before or after the stations. The third factor is the wind speed, direction and duration at each station.

When the dynamic currents are subtracted vectorially from simultaneous observed currents, the resultant wind-driven currents should be to the right of the wind (in the Northern Hemisphere), EKMAN (1928) and should be proportional to the observed wind if indeed dynamic currents, as defined above, remain unaffected by local wind.

It can be seen from figure 1 that the observed current includes the same component of wind-current (1 knot) at every station at which the same wind speed and direction prevail, even where the dynamic current indicated is nil. At the same time the dynamic current component remains unaffected by the wind.

Example

The hypothetical relationship shown in figure (1) cannot at present be fully utilized to determine wind-currents for all the forces of wind on the basis of observed data. There is a scarcity of synoptic material necessary to

[1] The fact that icebergs more often follow the computed currents than the winds has been frequently noted.

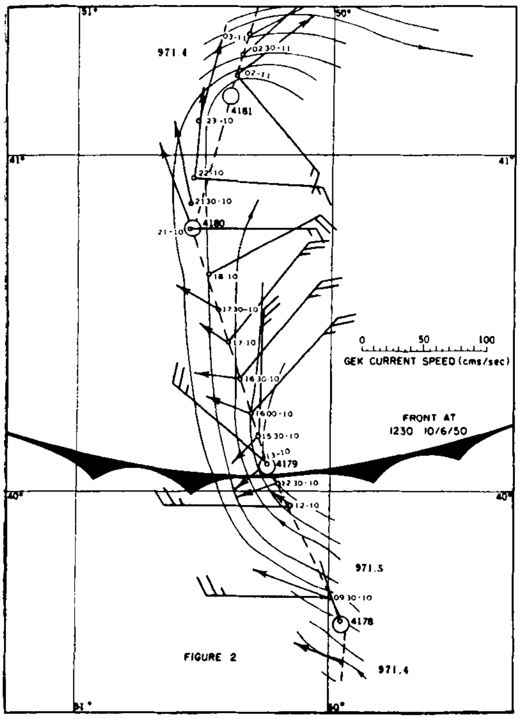

Fig. 2.

prepare a complete correlation of the three factors, dynamic current; observed current; and wind direction, speed and duration.

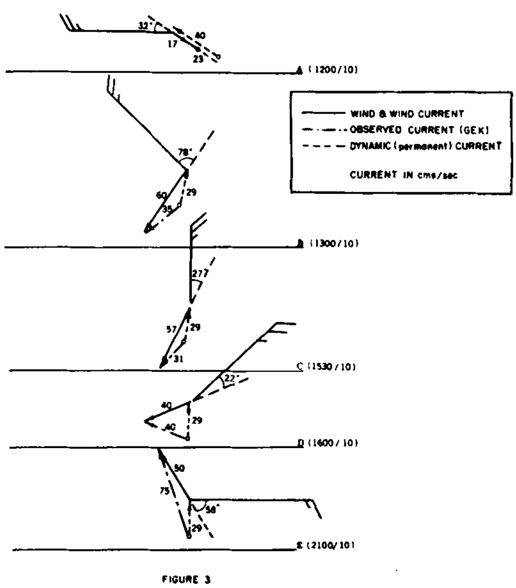

Fig. 3.

The dynamic current at 1200/10 (40 cms/sec.) is an average value derived from the difference in dynamic height between stations 4178 and 4179. The value from 1300/10 to 2100/10 (29 cms/sec.) is derived from the dynamic height difference between stations 4179 and 4180. This value was necessarily used at all points between stations, since a somewhat different spacing of lines than in figure 2 would have been equally valid. (The topography is drawn in figure 2 as it appears in figure 18, Bulletin 36, International Ice Patrol.)

Figure 2 is not an ideal example from the standpoint of the location and spacing of the stations, but it was the best one available to the writer having the necessary simultaneous observations and during which a significant change transpired in the local wind.

However, a sufficient quantity of simultaneous wind and surface current measurements, together with dynamic topography, is now available to demonstrate the hypothesis empirically.

Figure (2) represents the dynamic topography from oceanographic data obtained by the U.S.C.G.C. EVERGREEN on June 9—10, 1950. Simultaneous surface current vectors, measured between the stations at half-hourly intervals with the GEK[1], VON ARX, (1950) have been superimposed on the topography.

The occurrence of deviations between currents measured by the GEK and the dynamic currents is clearly coincident with the location and time of change in wind force and direction following frontal passage as indicated, while the dynamic currents appear to have remained constant.[2] As assumed previously, the amount of this deviation (the wind current vector) should be proportional in both direction and speed to that of the observed wind.

In figure (3), showing the effect of wind change during the frontal passage in figure (2), the wind current vectors, though only roughly proportional, demonstrate the rapid responsiveness in the surface current to short period changes in the wind.

Evidence of the Ekman Spiral appears in the deflection of the wind current to the

[1] GEK data used in figure 2 have been furnished by W. S. von Arx, Woods Hole Oceanographic Institution. Wind data and the dynamic topography were supplied by Floyd Soule, Woods Hole Oceanographic Institution.

[2] At least the net transport of the relative surface current indicated between stations 4179 and 4180 is in a northerly to easterly direction while the currents measured by the GEK are in a southwesterly to northwesterly direction.

right of the wind. It is probable that some inconsistency in the amount of this deflection results from inexactness in the permanent currents prepared from the dearth of dynamic data available for synopsis. Detailed information as to the depth of change in the observed current is also lacking.

These inaccuracies can be overcome only by the conduct of controlled oceanographic surveys, involving at least three, closely spaced survey vessels, operating simultaneously preferably at anchor station in areas of generally weak permanent currents, for sufficient time to experience and record the effect on the current of any force and duration of wind. Continuous oceanographic stations will establish closely the permanent current topography between the vessels and will also readily expose the effects of internal wave or other related phenomena. Simultaneous observed currents measured with the GEK together with area weather patterns and accurate wind observations will complete the necessary data.

The present study is offered in support of this proposal. Despite discrepancies in existing data that are too large for statistical analysis, the present study at least qualitatively supports the method and illustrates the responsiveness of the observational techniques employed.

Methods in present use for the prediction of wind-current from observed wind speed have been based on averages of drift observations where permanent currents were supposed to have been weak or non-existent, and where the sole drift experienced was attributed to wind.

An accurate prediction table for wind current will become possible when sufficient numbers of wind-current vectors for each force interval of wind have been determined as in figures (1) and (2) and tabulated. Current vectors, so determined for an observed or predicted wind, may be directly superimposed on specially prepared surface dynamic current charts at any point.

The resultant will be the predicted current at that point and should prove invaluable to the solution of problems of precise navigation, including those of rescue operations for which the area of search will be measurable reduced.

The proposed type of survey will provide a truly synoptic basis for the analysis of wind current versus wind force and duration. It will provide the basis for prediction tables for ocean currents, subsurface as well as surface, and will utilize empirical knowledge beyond the reach of any existing data, which are too widely spread in space and time to determine the interrelationship of wind and currents.

Conclusion:

1. Averages of ocean current data are considered to be unsuitable as a basis for the prediction of currents, because they include, together with the permanent current, all of the variables on which prediction depends.

2. A method is advanced for testing the stability of the surface dynamic topography. Where this is constant, the difference between the measured (geomagnetic) current and the dynamic current should be proportional to the local wind speed, direction and duration.

3) An empirical check on the above relationships, based on data from a recent oceanographic survey, supports the thesis that dynamic topography is unaffected by fluctuations of local wind, whereas the measured (GEK) surface current is observed to depart from the topography by amounts approximately proportional to observed short period changes in the wind.

4. A new type of survey is proposed by which the rising stage of wind-driven currents can be studied comprehensively from the simultaneous and continuous measurement of dynamic current, observed current, and wind velocity and duration.

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