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Meteo

COMPUTER PRODUCED SYNOPTIC ANALYSES OF SURFACE CURRENTS AND THEIR APPLICATION FOR NAVIGATION

by

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ABSTRACT

The available methods for estimation of wind currents, mass transport velocity by waves and permanent flow (thermohaline gradient current) are briefly summarized and a simplified computer approach is outlined.

The computed synoptic surface currents are compared with monthly mean current charts and with surface wind conditions. This analysis indicates that the surface currents are greatly wind-driven. A detailed verification procedure which will use the observed changes in sea surface temperature is outlined.

The use of the synoptic current fields for computation of divergence and convergence and the resulting changes in subsurface thermal structure is described. The relative importance of the synoptic surface currents in ship routing, rescue operations and other practices is reviewed.

1. INTRODUCTION

A number of naval, fisheries and other maritime operations require a knowledge of the direction and speed of surface currents, as well as their past and near future behavior. The Fleet Numerical Weather Facility (FNWF) at Monterey, California, became interested in ocean currents primarily because of their importance in Anti-Submarine (ASW) applications.

Large variations have been observed in thermocline depth which cannot be explained by mechanical or convective mixing. These changes exhibit cycles which correspond closely to the evolution of synoptic weather patterns over the ocean. It is quite clear that current atlases cannot be used to predict thermocline depth when considerable change can occur in a period of a few days. What is needed for this particular problem are daily current analyses and prognoses.

Navigators also undoubtedly find that atlases, monthly mean charts and the like frequently do not give an exact enough answer to the question: what is the current at a given point in space and time? The purpose of this paper is to report on an attempt to compute surface current flow on a quasi-synoptic schedule and to show some preliminary results. If these results appear to be of use to navigation, means will be found to accomplish dissemination.

2. BACKGROUND

Before selecting and justifying an approach which would be simple but still give some hope of yielding useful results, it was necessary to screen and evaluate a voluminous amount of literature on the subject. Fortunately, a great part of this review had been done recently by Laevastu (1962).

Most theoretical approaches have been mainly concerned with explaining the general, more permanent features of the horizontal circulation patterns (see, e.g., Robinson 1963). The Russians have recently applied correlation theory in an attempt to forecast detailed current changes from a known field; however, our knowledge of the initial state (and particularly its derivatives) is often rather sketchy. Actually, the ocean responds quite rapidly to hourly and daily changes in driving forces, and currents are known to be variable in space and time (Knauss 1960).

These considerations dictated use of a method which would account for fairly rapid response and would stand up to daily verification. Many attempts at current prediction have been disappointments because of oversimplifications resulting from the assumptions made. It seems logical to separate the total current into its elementary components to see which should be neglected, which can be simplified, etc. This is the attack which has been followed in this investigation.

3. COMPONENTS OF SURFACE CURRENTS

Surface currents are caused and influenced simultaneously by a number of forces which vary independently from each other in space and time. If one neglects the special effects due to variation in depth, coastal configuration, runoff, etc., the current vector at a given location, time and depth below the surface $(\mathbb{V}_{xyzt})$ can be given as the resultant of the following components:

$$\mathbb{V}_{xyzt} = \mathbb{V}_c + \mathbb{V}_w + \mathbb{V}_i + \mathbb{V}_t \qquad (1)$$

where $\mathbb{V}_c$ is the permanent flow (thermo-haline gradient current or "characteristic current" as used by Palmén (1930) and Hela (1952)), $\mathbb{V}_w$ is the current due to transport by wind and waves, $\mathbb{V}_i$ is the periodic part of the inertia current and $\mathbb{V}_t$ is the periodic part of the tidal current.

The computations which will be described here cover a period of 24 hours, and it will be assumed that semidiurnal and diurnal tidal components will equal out and can be neglected. In addition, inertial eddies will not be considered because the available quantitative information about their behavior does not warrant their inclusion in this simple technique. The two components which this study will attempt to evaluate are thus the "characteristic " or permanent transport and the transport due to wind and waves.

3. CHARACTERISTICS OF SURFACE CURRENTS

Surface currents are caused and influenced simultaneously by a number of factors which vary independently from each other in space and time. If one neglects the special effects due to variation in depth, coastal configuration, runoff, etc., the current vector at a given location, time and depth below the surface (V_{surf}) can be given as the resultant of the following components:

$$V_{surf} = V_c + V_w + V_i + V_t \qquad (1)$$

where V_c is the permanent flow (thermo-haline gradient current or "characteristic current" as used by Palmén (1930) and Hela (1952)), V_w is the current due to transport by wind and waves, V_i is the periodic part of the inertia current and V_t is the periodic part of the tidal current.

The computations which will be described here cover a period of 24 hours, and it will be assumed that semidiurnal and diurnal tidal components will cancel out and can be neglected. In addition, inertial motion will not be considered because the available quantitative information about their behavior does not warrant their inclusion in this simple technique. The two components which this study will attempt to evaluate are thus the "characteristic" or permanent current and the transport due to wind and waves.

4. THE CHARACTERISTIC COMPONENT

The characteristic component is directly related to density gradients caused by areal differences in heating-cooling and evaporation-precipitation. Although what we usually call "the permanent flow" is strongly controlled by the large-scale, more-or-less stationary wind systems, only the thermo-haline influences are included in that component here. Wind and wave effects will be lumped into one computation to be discussed later.

Several workers have found (e.g. Yasui 1957) that there is a close correlation between ocean temperature distribution and dynamic depth anomalies. Neglecting salinity, one can apply the well-known meteorological thermal wind relationship in the ocean if one knows the mean temperature of the layer between the surface and some level of zero current velocity. The characteristic current is then given by:

$$\mathbb{V}_c = - \frac{g \Delta z}{f \bar{T}} \nabla \bar{T} \times \mathbb{K} \tag{2}$$

where g is gravitational acceleration, f is the Coriolis parameter, $\bar{T}$ is the mean temperature above the level of zero current, Δz is the depth to zero current, and $\mathbb{K}$ is the unit vertical sector.

The determination of a representative mean temperature ($\overline{T}$) is, of course, the critical factor in this part of the problem. The temperature structure of the ocean is certainly not constant, particularly closer to the surface; therefore, semi-synoptic temperature fields should be used if possible. The only place where sufficient data is available for reliable analysis on a daily basis is at the surface so it was decided to use the FNWF Sea Surface Temperature (SST) analyses based on 84 hours of reported ship engine injection temperatures at the top of the layer. In order to include a part of the deeper temperature structure, the SST field is presently combined with a climatological field at 200 meters depth to obtain

$$\overline{T} = K_1 T_{sfc} + K_2 T_{200} \tag{3}$$

Finally, this field is modified empirically in areas where salinity considerations are known to be important (Oyashio, Greenland, Labrador currents). This in effect corrects the ocean temperatures for salinity much as the meteorologist corrects atmospheric temperatures for moisture content when he uses the concept of 'virtual temperature."

5. THE WIND COMPONENT

According to Ekman (1905), the direction of the wind current at the surface is 45° to the right of the wind in the Northern Hemisphere and this angle increases with depth. Recent investigations reveal that the deflection is more nearly 12-20 degrees, being larger and more irregular at the lower wind speeds (possibly because of the increased importance of other components) and smaller at higher wind speeds. As the surface wind is about the same angle to the left of the geostrophic wind, it is assumed herein that the direction of the wind current is the direction of the geostrophic wind.

Numerous empirical studies have indicated use of a single factor to relate surface current speed to wind speed. The formula of Witting (1909) appears to agree well with available data and further allows approximate incorporation of mass transport by waves in a simple expression:

$$W_w = K_3 \sqrt{\overline{W}_g} \qquad (4)$$

where W_g is the mean geostrophic wind speed for a 24-hour period.

In the present work it is assumed that the current is relatively uniform and unidirectional in the turbulent mixed layer down to the thermocline (or about 200 meters). The mass transport of the waves, however, would modify this picture as it decreases exponentially with depth (Masch 1962). Therefore, if $\overline{W}_g$ is in meters/sec and

W_w in cm/sec, K_3 is taken to be 3.3 for surface currents (ship routing and drift computations) and 2.2 for the average current down to the thermocline (convergence/divergence computations). Obviously, there is a time lag between the change of the wind and response of the sea. This lag seems to be shorter than previously believed, however, and is partially minimized by the 24-hour averaging.

Since all computations are carried out in the standard FNWF grid system, u and v current components are determined at approximately 200 nautical mile intervals for all Northern Hemisphere ocean areas. From these components, direction and total transport (nm/day) fields are determined and stored on magnetic tape for later output in chart form or as special messages giving the currents at specified latitude/longitude intersections.

6. RESULTS

Figure 1 is a hand analysis of one of the first current computations made on a synoptic schedule (18 GMT 16 November 1964). The contours represent total current transport in nautical miles per day; direction arrows have been plotted in the most significant current systems. One can clearly distinguish such well-known features as the Gulf Stream, Sargasso Sea, Labrador Current, Kuroshio and Cyashio. The low-latitude, westerly return flow which results primarily from the "wind component" term is well defined in both the Atlantic and Pacific. A narrow equatorial countercurrent was obtained as a result

of the 200-meter temperature structure used in the characteristic component.

Figures 2a and b are synoptic current charts for the Pacific and Atlantic, respectively, which have been drawn automatically on an incremental x-y curveplotter. Each chart requires approximately one minute to complete and is of sufficient quality that it can be used immediately for radio-facsimile transmission.

Figure 3 is a climatological current chart for winter. It can be seen that many of the most important features are correctly depicted in this approach both in location and intensity.

The problem of automatic plotting of direction arrows on these charts has not yet been solved. However, a possible substitute has been found and is now being programmed for numerical testing. Since u and v current components are available in field form at all grid points, it is believed a stream function field can be determined by a relaxation solution of the Poisson equation

$$\nabla^2 \psi = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \qquad (5)$$

This would permit plotting of a second set of lines (ψ) which would everywhere parallel the direction of flow.

7. VERIFICATION

A synoptic current chart would be of little value if it could not be verified and the computational scheme tuned as required. Direct

current measurements in the open ocean are too few and drift calculations made from navigational fixes are frequently inaccurate in weak current areas, so it is difficult to make a direct evaluation. It has been necessary, therefore, to resort to indirect means which are susceptible to verification on a synoptic basis.

Sea surface temperature (SST) is the only oceanographic element which permits a reasonable complete synoptic analysis on a hemispheric scale. Such analyses are made twice daily at FNWF Monterey (Wolff 1964), and their resolution is such that SST temperature changes can be determined for periods of 24, 48 hours, etc. From these changes will be subtracted the local changes computed from air/sea heat exchange equations. If the remainder correlates well with the advective change indicated by $W_{xyzt} \cdot \nabla SST$, the computed currents can be assumed to be reasonably correct.

This method of verification is now being programmed and numerical results are not yet available. Subjective study of SST change charts and corresponding current charts does, however, indicate that the approach described here is useful. It is evident that the wind component term predominates in many areas, and that it is this term which is mainly responsible for the rapid response of sea surface temperature changes in the ocean.

There are a number of modifications which must undoubtedly be made to this program; it is hoped these will be uncovered during the verification period. One obvious question is - what

effect does thermocline depth itself have upon the surface current speeds above the thermocline?

8. APPLICATIONS

The surface current program was initiated primarily to determine divergence and convergence and the accompanying up and down movement of thermocline depth. Furthermore, the results will be used for forecasting the advective part of sea surface temperature changes.

Over large parts of the oceans the currents have little direct effect on navigation. In some areas, however, they should be taken into consideration in Optimum Ship Routing. Charts of this type should also prove useful in the prediction of ice movement and in any rescue operations.

It is planned to make these computations on a daily synoptic schedule (probably at 06 and 18 GMT), and they could be transmitted from Fleet Weather Centrals in either facsimile or special message format if such is desired. Groups such as the Institute of Navigation may determine that there are applications in navigation which could make use of these products.

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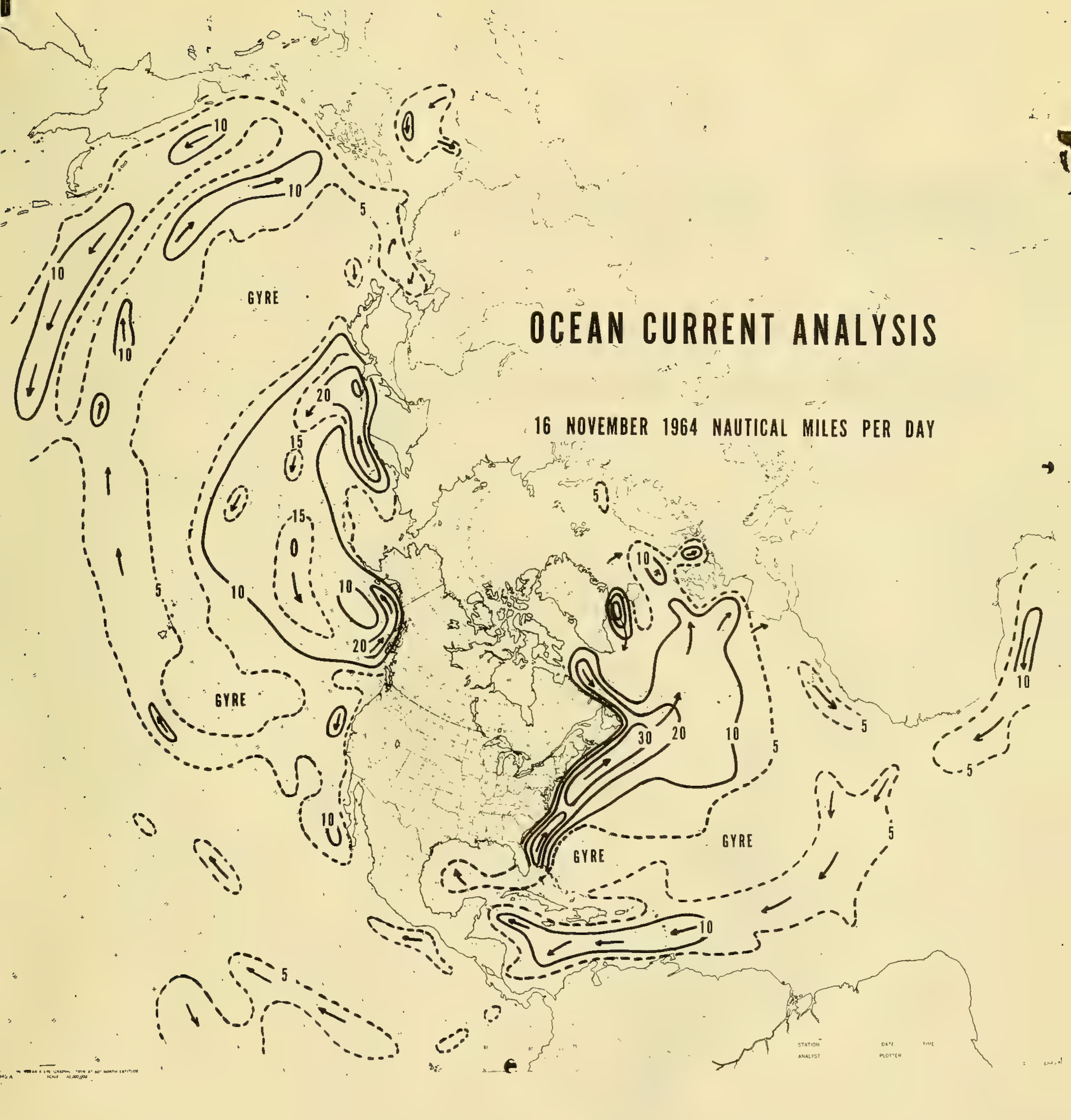
LIST OF FIGURE TITLES



OCEAN CURRENT ANALYSIS
16 NOVEMBER 1964 NAUTICAL MILES PER DAY
GYRE
GYRE
GYRE
GYRE
10
20
30
15
5
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AUTOPLOT OF CURRENT TRANSPORT

24 NOVEMBER 1964 NAUTICAL MILES PER DAY

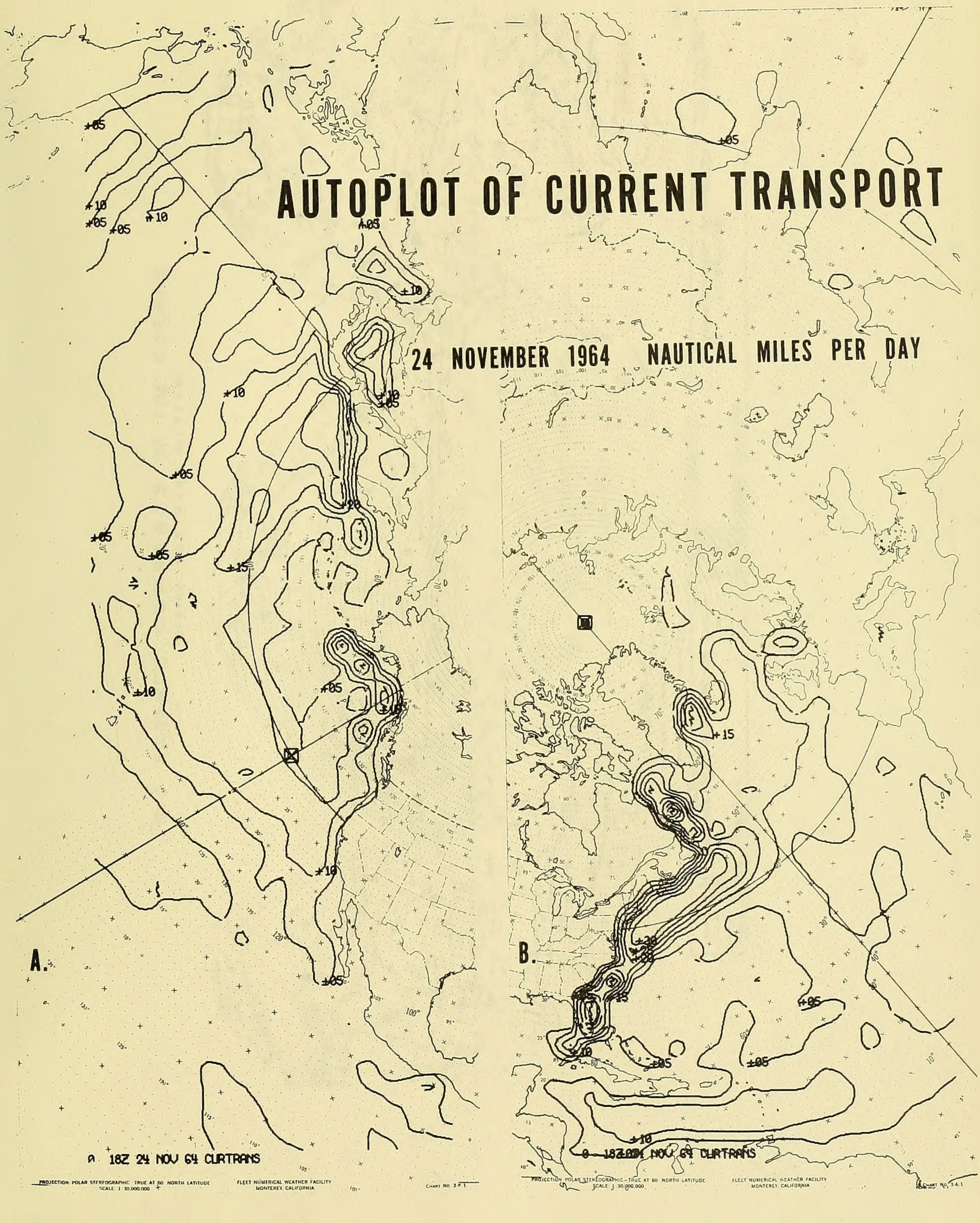
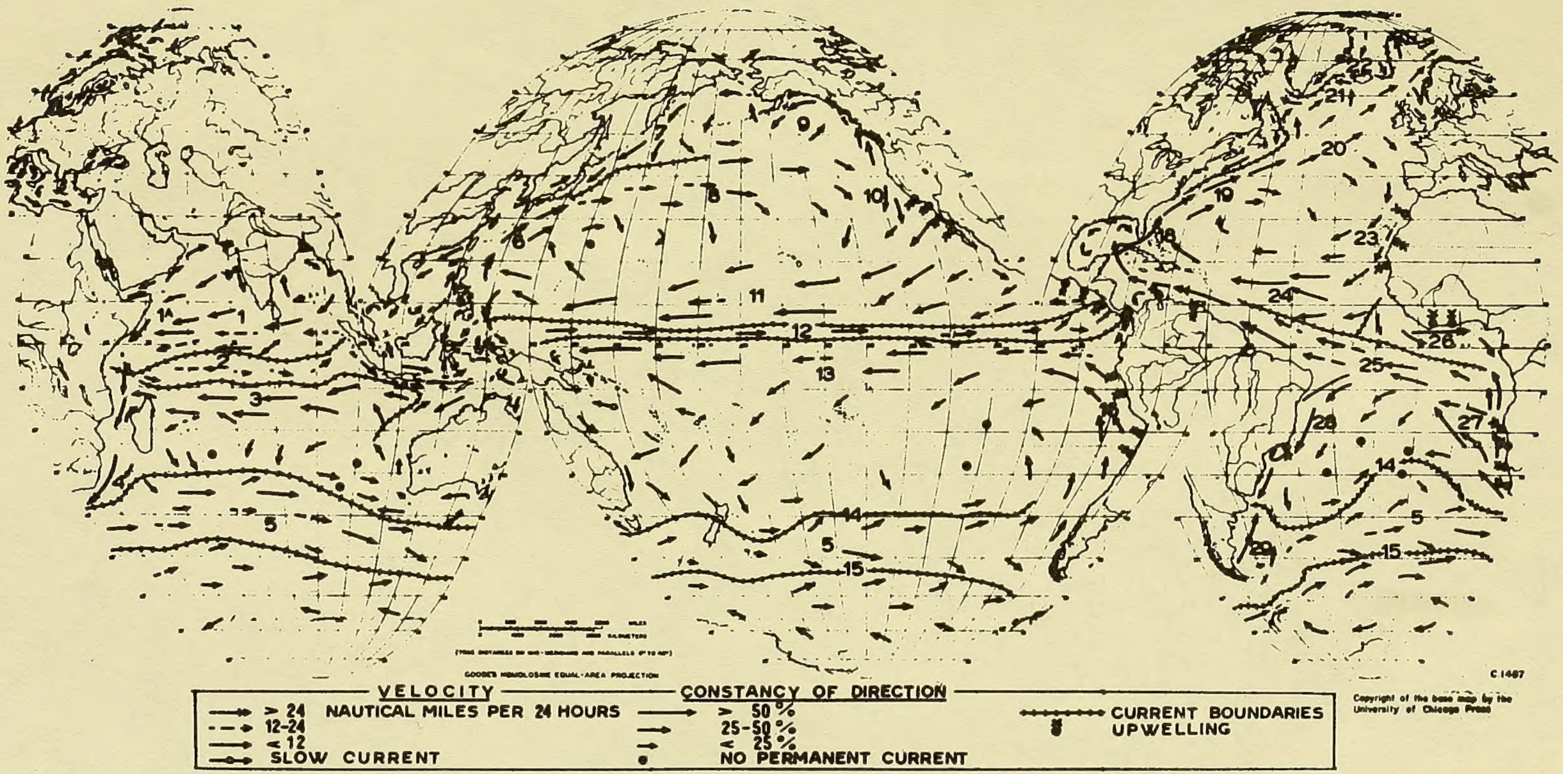


Fig. 3 SURFACE CURRENTS OF THE OCEANS
(DURING NORTHERN WINTER)



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