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Correlation of Movements in the Western North Atlantic

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Correlation of Movements in the Western North Atlantic

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Donald V. Hansen

A search was made for correlation of current meter records, movement of geostrophic eddies, and Swallow float measurements with Gulf Stream meandering. Data of all these kinds are too few to permit strong conclusions, but some evidence is found indicating that passage of Gulf Stream meanders is accompanied by fluctuations of meridional flow extending an indeterminate distance outside the stream.

1. INTRODUCTION

The path of the Gulf Stream between Cape Hatteras and the Grand Banks of Newfoundland was delineated at approximately monthly intervals between September 1965 and April 1967. The position of the stream was delineated by following the position of the 15°C isotherm at 200 meters depth. Most of the operation was accomplished by the U.S.C.&G.S. ship *Explorer* using temperature and pressure sensors mounted on a ballasted fiberglass depressor, produced by the Braincon Corporation of Marion, Massachusetts, and sold as the V-Fin NAVITHERM system. Bathythermograph observations were made on return tracklines to confirm the basic observations and to obtain further information on thermal conditions on either side of the main thermal front.

Figures 1 and 2 show typical pathlines from this set of observations.

The major wavelike features of this sequence of pathlines have been interpreted (Hansen, 1970) as quasi-geostrophic waves on the order of 320 km wavelength propagated or advected eastward at net speeds of 5 to 15 cm/s. Figures 3 and 4, taken from that report show the propagation of phase inferred for these waves. The horizontal axis in these figures is the rhumb line through 37°30'N, 70°W; 40°N, 60°W. The question of possible influence of these translations of the stream position on currents outside the stream itself is of considerable observational and theoretical interest, so an attempt was made to correlate these translations with the few other pertinent measures of water movements available from the North Atlantic. Although the data are too few and of too disparate types to yield firm conclusions, some interesting correspondence has been found, and these findings are summarized here.

2. RELATION TO CURRENT METER RECORDS

The best available direct measures of transient currents in the Western North Atlantic during the period of pathline observations are from current meter buoys maintained near the stream by Woods Hole Oceanographic Institution (Fofonoff, 1968). The greatest number of useful records have been

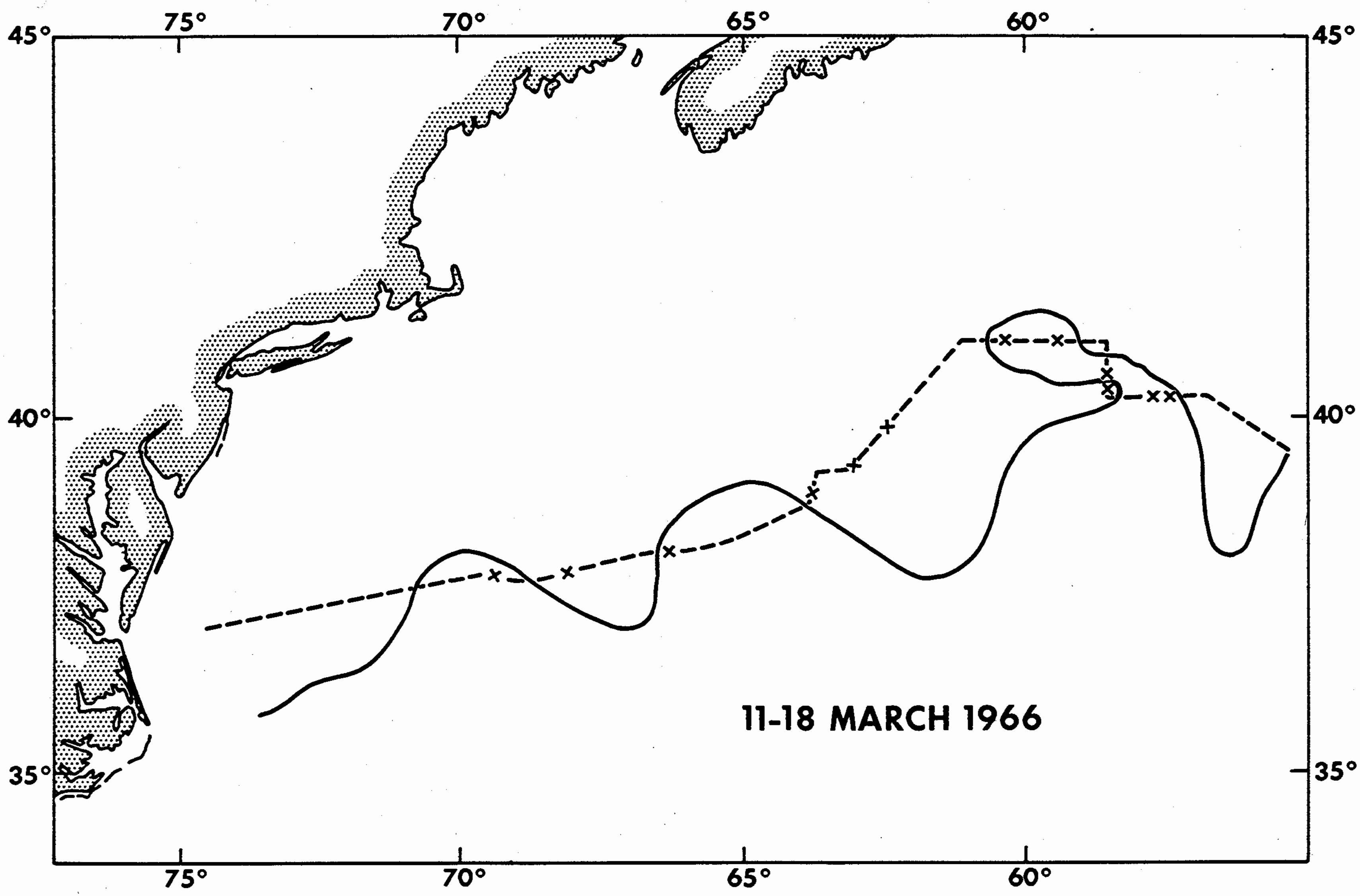

Figure 1. Position of 15°C isotherm at 200 m depth and return track for March 1966 cruise of Explorer. Points shown as x denote recrossing of indicator isotherm on return track.

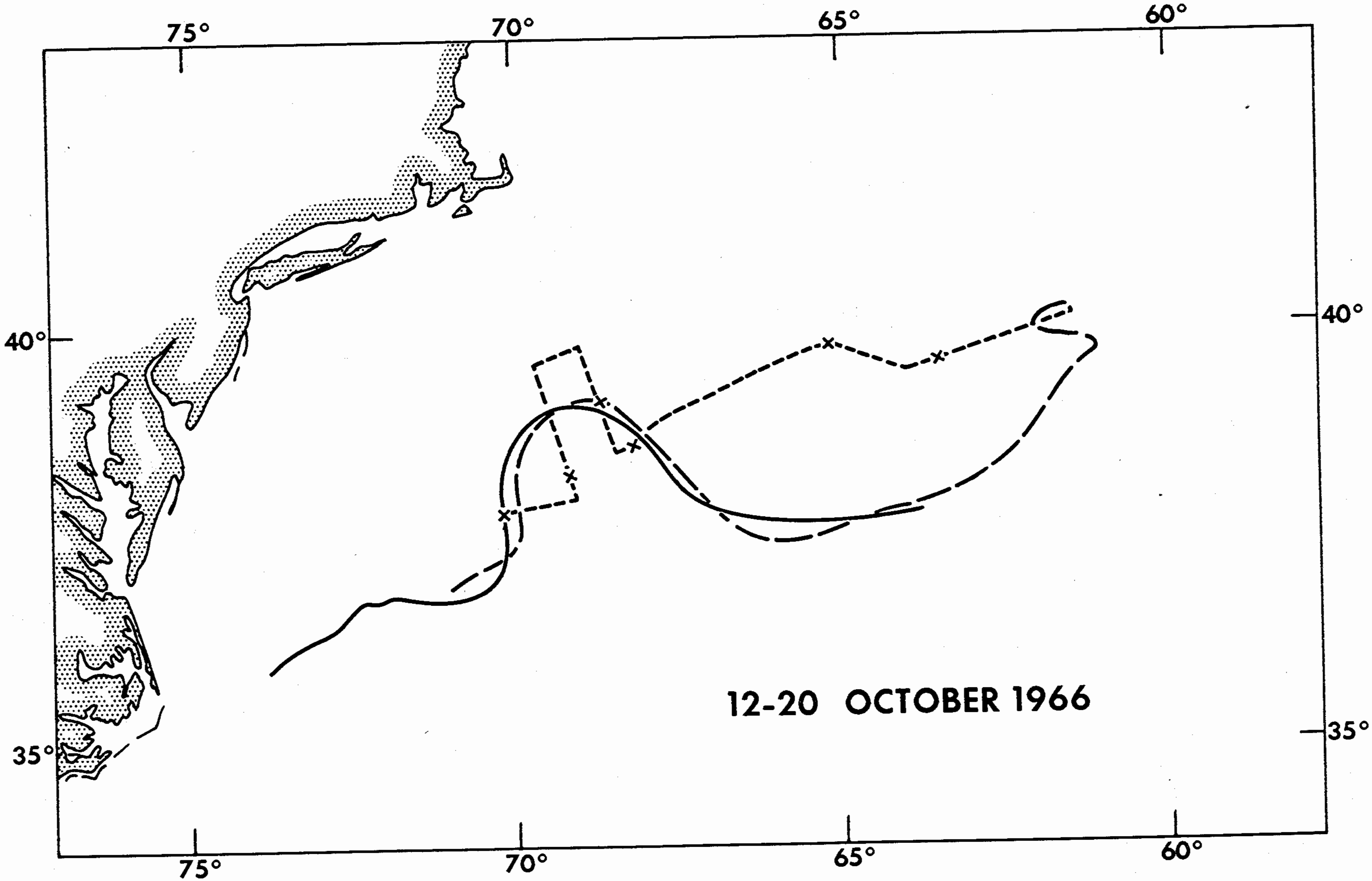

Figure 2. Two positions of 15°C isotherm delineated in rapid succession in October 1966. Points shown as x denote recrossing of indicator isotherm on second return track.

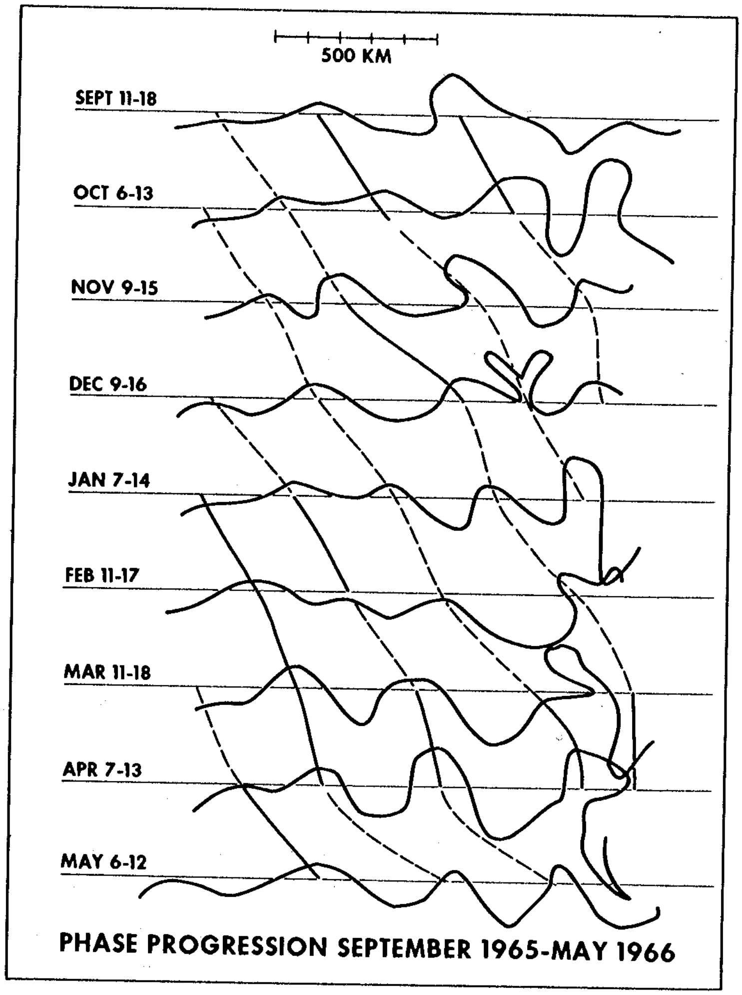

Figure 3. Interpretation of evolution of Gulf Stream meanders, September 1965 - May 1966. Dashed lines denote postulated phase progression, solid lines denote phase progression supported by other evidence.

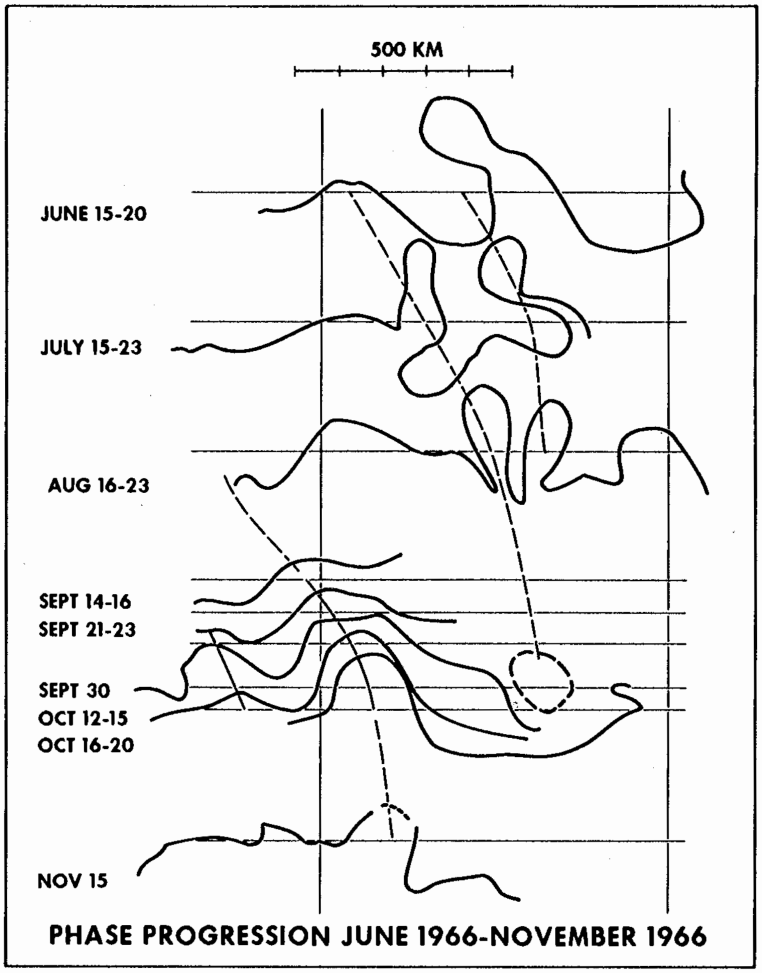

Figure 4. Interpretation of evolution of Gulf Stream meanders, June-November 1966.

obtained from Site D. This site (39°20'N, 70°00'W) is generally 100-200 km north of the near surface core of the Gulf Stream, and low frequency fluctuations of the north current component above 200 m are shown by Thompson (1969) to have significantly greater kinetic energy density than fluctuations of the east component. At this level the north and east components are only poorly correlated, but the principal axis of the low frequency fluctuations lies about north-south as would be the case for a Rossby wave with wave number lying nearly east-west like the Gulf Stream meanders. Possible relationships between these energetic north-south current fluctuations and the fluctuating position of the nearby Gulf Stream are of particular interest here.

Observed and inferred meridional positions of the thermal front associated with the Gulf Stream on 70°W during the Explorer cruises is compared (fig. 5) with the integral of the daily mean of the north component of current metered in the upper 200 m at Site D (Webster, 1968*). Each segment of the integrated current meter record has been adjusted meridionally for the best visual fit to the temperature data. Only the gravest mode of the major meander

* These and other data from the buoy project were presented in a seminar given by Dr. Webster during the Geophysical Fluid Dynamics Program, Woods Hole Oceanographic Institution, Summer, 1968.

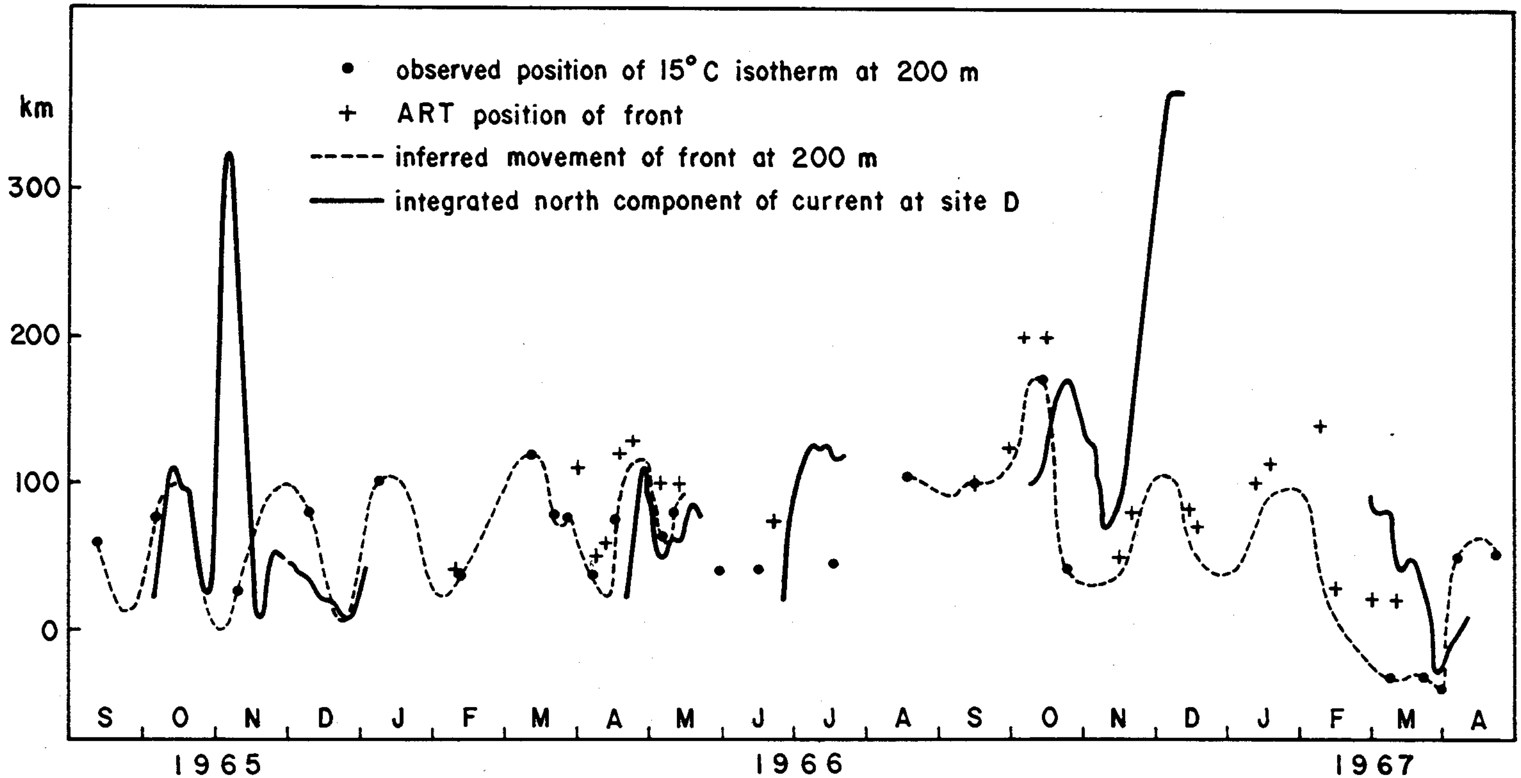

Figure 5. Comparison of integrated meridional component of current at Site D with meridional movement of Gulf Stream on 70°W inferred from *Explorer* data and airborne radiation thermometer (ART) data obtained by Navy aircraft.

features can be inferred from the temperature data; even for this the amplitude of north-south movement can only be estimated in most months, and no estimate has been attempted for the midsummer period due to the difficulty of interpreting evolution of the complicated thermal structures shown in figure 4. However, aside from large transients in November of 1965 and 1966, the sense and magnitude of the north component of current appears to reflect meridional movements of the Gulf Stream. There is some indication that movement of the thermal front on 70°W may lead the current meter data in phase, most notably during the autumn of 1966. This phase shift is suggestive of the meander structure described by Webster (1961) from observations off Onslow Bay and reproduced in a mathematical model by Orlanski (1969). On the other hand a phase lead on the order of 6 to 10 days is to be expected if the perturbation structure is essentially normal to the mean path of the stream rather than strictly north-south, but the data are insufficient to warrant further speculation about cross stream variation of phase.

The mean of all current observations at this site has a negligible meridional component, which is of course also true of movement of the thermal front.

A set of simultaneous current measurements was obtained from opposite sides of the Gulf Stream, at sites D and J (36°N, 70°W) in the spring of 1966. At 10 m depth, fluctuation of currents with a north component on the order of 10 cm/s and a gross periodicity of about two weeks occurred essentially in phase at the two sites, and, as shown in figure 5, in phase with lateral movement of the Gulf Stream.

3. RELATION TO MOVEMENT OF CURRENT EDDIES

At the outset of the stream path monitoring project, two cyclonic current rings or geostrophic eddies were discovered freshly separated on the south side of the Gulf Stream and were observed (Fuglister, 1967) for the next several months. Figure 6 shows the meridional movement of these eddies 200 to 300 km to the south compared with the local meridional movement of the 15°C isotherm inferred from figure 3. Observations of the eddy position suffer from the same lack of resolution in time as the sequence of pathlines, and the already imprecise indication of possible relationships between their positions is further obscured by zonal movement of the eddies. Particularly at 66°W, it can be argued that the sequence of eddy latitudes is just as well represented by a random distribution about a linear trend. On the other hand, there is indication of a systematic relation to meridional movement of the nearby Gulf Stream, in that although meridional movements of the eddies are small, in every case where a clear judgment can be made, they are in

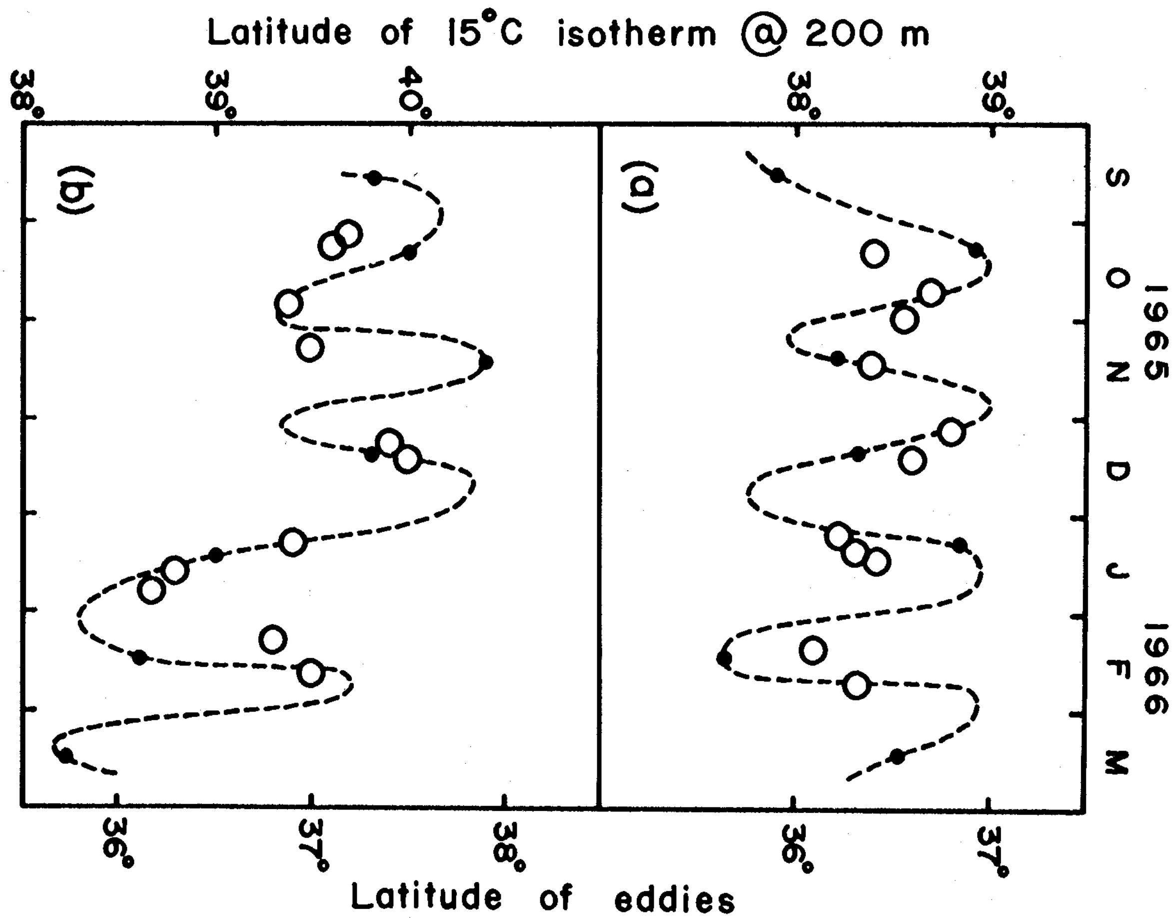

Figure 6 Meridional movement of detached eddies (open circles), and observed (dark points) and inferred (dashed lines) meridional movement of Gulf Stream at (a) 66°W and (b) 63°W.

the same direction as the inferred frontal movement. At 63°W both the sense and magnitude of the eddy movements are in reasonable agreement with those of the stream movements.

4. RELATION TO SWALLOW FLOAT MEASUREMENTS

If the positions of the thermal front summarized in figure 3 are approximated by

$$\phi_T = \phi_m(x)+\phi_p(x)\cos k(x-ct) , \tag{1}$$

where ϕ_T denotes the latitude of an isotherm in the main front as a function of eastward distance x, and time t, ϕ_m is the time average latitude, and ϕ_p is the amplitude of a progressive wave disturbance of the mean, the few suitable observations suggest the existence of an identifiable meridional flow that, aside from a possible ambiguity of phase, behaves as

$$u = \frac{\partial}{\partial t}\phi_T = ck\phi_p \sin k(x-ct) . \tag{2}$$

While no direct evidence is available to indicate how far from the stream this disturbance may be felt, Iselin (1961) has suggested an association with transient currents revealed by the well known Swallow float measurements near Bermuda. As summarized by Crease (1962), these were a predominantly meridional motion with an apparent time scale of 10 to 100 days and an rms amplitude of approximately 6 cm/s. Between 65°W and 70°W, the longitude of the float measurements, meander amplitudes are on the order of 100 km. The period and rms amplitude of the meridional movement described by (2) are therefore $\frac{2\pi}{ck} \approx 46$ days, and $\frac{ck\phi_p}{\sqrt{2}} \approx 11$ cm/s, both in order of magnitude agreement with values cited by Crease.

Crease also computed a current structure function, $\overline{[u(x)-u(x+\ell)]^2}$, for simultaneous float measurements separated a distance ℓ, the overbar denoting time or ensemble average. For the flow specified by equation (2) the normalized form of this function is,

$$S_\ell = 2[1-\overline{\cos(k\ell\cos\theta)}]. \qquad (3)$$

If ℓ is taken normal to the current structure, then S_ℓ is simply,

$$S = 2[1-\cos k\ell]. \qquad (4)$$

I judge however from Crease's figure 1 that the separation of his float pairs was more or less randomly oriented, in which case (3) becomes,

$$S = 2[1-J_0(k\ell)], \qquad (5)$$

where J_0 is the conventional notation for Bessel's function.

His values normalized by the mean square velocity fluctuation and a mean meander wave-length of 320 km, are plotted for comparison with these estimates (figure 7).

The small amount of data available from the float measurements as well as the meander observations prohibits confidence, but it is clear that the float measurements are quantitatively suggestive of an attenuated effect of Gulf Stream meanders.

5. DISCUSSION

The evidence offered here is for the existence of meander scale current structures outside the stream proper, rather like the radiated geostrophic wave obtained in a mathematical model of Gulf Stream meanders by Robinson and Niiler (1967). They estimate cross stream current components on the order of 10 cm/s for a stationary meander pattern, but differing by 180° from the phase relation between meridional currents and frontal movement suggested by figures 5 and 6.

An alternative interpretation is that Gulf Stream meanders may in fact be a manifestation of quasi-geostrophic oscillations arising in mid-ocean independently of the stream, as has been suggested by Phillips (1966), as a result of fluctuating wind stress. The amplitudes of both the meridional movements of the Gulf Stream and the transients sampled by the Swallow floats are well above those computed by Phillips

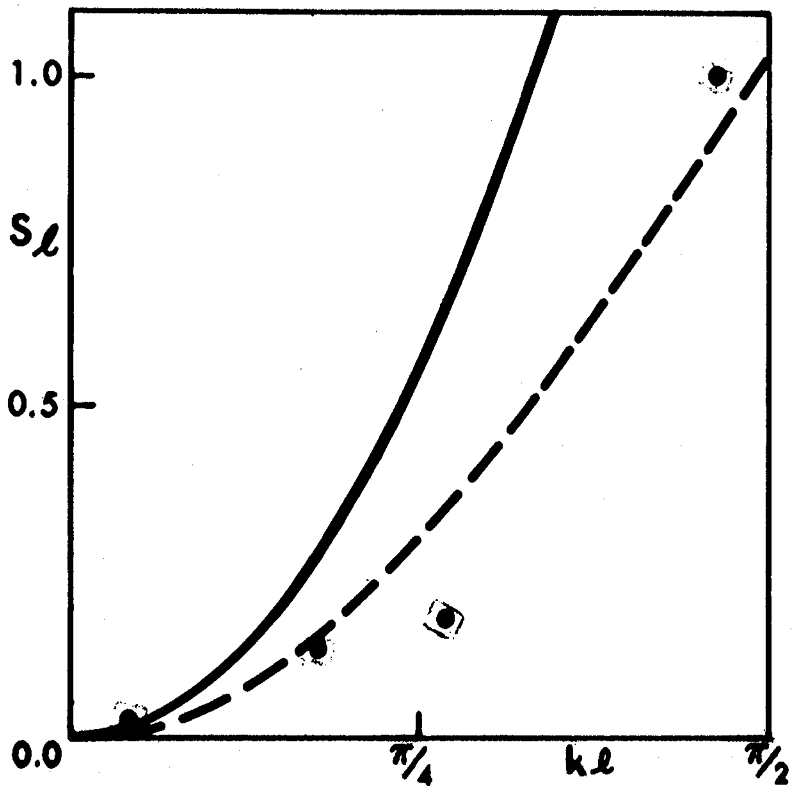

Figure 7. Structure function computed from (4) (solid line), (5) (dashed line), and float measurements (dark points).

from wind stress of plausible magnitude. Phillips suggests that the oscillations generated by fluctuating wind stress interact with and extract energy from the Gulf Stream as part of the Gulf Stream meander inducing mechanism. It is difficult to reconcile the westward phase speed of about 8 cm/s expected of the mid-ocean oscillations with the eastward phase speed of the same magnitude observed in the meanders. Unfortunately, there are no observations to indicate phase speeds of the fluctuations in the float measurements.

It appears feasible to test the existence of the suggested relation of currents outside the stream to Gulf Stream meandering by means of shallow Swallow floats or parachute drogue observations while monitoring the position of the Gulf Stream. One such experiment using a single parachute drogue was attempted near 71°W on 30 March 1967. Figure 5 shows that the currents at Site D changed from southerly to northerly at about this time.

Unfortunately the anticyclonic section of meander whose leading (eastern) edge was selected for the experiment site did not develop sufficient amplitude to provide a useful result. The drogue, set initially in slope water, moved south across the edge of the stream becoming entrained in the stream, and thereafter acquiring a predominantly eastward motion. The drogue must have been influenced to some extent by northerly winds of 25 knots. In view of the relatively weak (~10 cm/s) expected of the systematic flow, it is to be expected that a number of such experiments would be required for a clear result to show above the random variations.

6. ACKNOWLEDGMENTS

The correlations attempted in this note have drawn upon the efforts of a considerable number of people. I particularly wish to acknowledge the contributions of Dr. Ferris Webster and Mr. Frederick Fuglister of Woods Hole Oceanographic Institution who kindly provided the current meter and eddy position data, and Mr. R. L. Pickett and Mr. J. C. Wilkerson of the U. S. Naval Oceanographic Office whose special efforts to obtain ART data along the stream were most helpful in interpreting some of the month to month variations of the stream path. Finally, the labors and long days at sea required of the officers and men of the U. S. Coast and Geodetic Survey vessels _Explorer_, _Pierce_, and _Whiting_ to obtain the Gulf Stream paths is acknowledged.

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