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INFORMAL REPORT

AIRCRAFT OBSERVATIONS OF A CYCLONIC EDDY SOUTH OF THE GULF STREAM

APRIL 1969

NAVAL OCEANOGRAPHIC OFFICE
WASHINGTON, D. C. 20390

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ABSTRACT

A series of aircraft observations of sea surface temperature in March 1967 revealed the formation of a cyclonic eddy south of the Gulf Stream. These observations were made with an airborne radiation thermometer from an altitude of 300 meters. A meander in the Gulf Stream, appearing as a tongue of cold water and extending 150 km southward into the Sargasso Sea, was located on 1 March near 37°N,66°W. By 16 March an elliptical-shaped eddy had formed from the meander, with its major axis oriented northeast-southwest. Surface temperatures in the eddy averaged 10°C, whereas the temperature of the water surrounding the eddy averaged 20°C. During the next 21 days, the eddy shrank in size at the surface and migrated about 5 km/day southeastward. The surface temperature contrast at the boundary of the eddy also decreased from 10° to 5°C. Aircraft bathythermograms showed the eddy to be a dome of cold water extending to a depth of at least 300 meters.

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DIVISION DIRECTOR

TABLE OF CONTENTS

FIGURES

FIGURES (CONTINUED)

INTRODUCTION

This paper is based on six aerial surveys conducted over the Gulf Stream during March and April 1967. These surveys are significant, because they provided the first aerial remote sensor data showing the formation and movement of a cyclonic eddy. Sea temperatures were measured with an airborne radiation thermometer (ART) and expendable bathythermographs (AXBT).

The survey technique using an airborne radiation thermometer to chart meanders in the Gulf Stream was first demonstrated by Stommel et al. (1953). The aircraft was flown along the northern boundary of the Stream, guided by abrupt sea surface temperature changes which often produce gradients of 10°C within several hundred meters. According to Strack (1953), these surface temperature gradients are good indicators of the position of the Gulf Stream during the coldest seasons of the year.

Adopting this technique, the Naval Oceanographic Office began an aerial observation program to determine more rapidly and on short notice the position of the Gulf Stream's northern boundary for use in forecasts of ocean temperature for the Navy's Antisubmarine Warfare Environmental Prediction Services (ASWEPS), Pickett and Wilkerson (1966). The instrument used in this program is a Barnes Model 14-320 ART flown in the ASWEPS oceanographic aircraft, an NC-121K, Lockheed Super Constellation.

CYCLONIC EDDY FORMATION

Eddy formation along the edge of the Gulf Stream has been of particular interest to oceanographers for many years. Spilhaus (1940) and Iselin and Fuglister (1948) described two general classes of eddies associated with the Gulf Stream -- one to the north and another to the south of the stream.

Eddies formed to the north are frictionally driven or shear-zone rotating water masses with diameters ranging from about 7 to 30 km. These warm bodies of water drift through cold Slope Water with anticyclonic rotation. Eddies formed on the south side of the Gulf Stream rotate in the opposite direction and, according to Iselin and Fuglister, are considerably larger. These cyclonic eddies appear to form when meanders in the Gulf Stream are cut off and set adrift in the Sargasso Sea. Cyclonic eddy formation begins with a Gulf Stream meander which develops into a long narrow loop projecting toward the south. As the trough in the loop deepens, the loop closes and entraps cold Slope Water in its central portion. The closed loop then breaks away and drifts into the warm Sargasso Sea.

Iselin and Fuglister circumnavigated a cyclonic eddy near 66°W. It extended 360 km east-west and 100 km north-south. Later, Fuglister and Worthington (1951) observed two cyclonic eddies north of Bermuda during OPERATION CABOT, a multiple-ship survey of the Gulf Stream conducted in June 1950. They observed in detail the breaking off of one of these eddies, thus confirming the theory that large cyclonic eddies south of the Gulf Stream are formed in the manner described above. They also estimated that meanders cannot become large enough to form eddies west of 70°W and probably only reach critical size in regions where bottom ridges affect the course of the stream.

More recently, Fuglister (1966) has undertaken an investigation of the movement and decay of cyclonic eddies originating from the Gulf Stream in order to answer questions raised during OPERATION CABOT as to how frequently and at what points cyclonic eddies originate and to what extent their shapes, paths of motion, and life span can be considered typical. Fuglister determined the answers to many of these questions during cruises of the ATLANTIS II and CRAWFORD from early September 1965 to February 1966 when two cyclonic eddies were observed and tracked north of Bermuda. During 1967, Fuglister made sustained and detailed observations of a cyclonic eddy (believed to be the one discussed in this paper) using techniques for physically tagging the eddy once it separated from the Gulf Stream.

An example of what appears to be cyclonic eddy formation is shown in Figure 1. This overview of the North Atlantic was taken from NASA's meteorological satellite NIMBUS II. The photofacsimile film from the spacecraft's high resolution infrared scanning radiometer shows the Gulf Stream moving diagonally through the picture and forming a meander at about 68°W in the shape of a long loop projecting southward. The loop appears to have closed upon itself as though it were in the last stages of cyclonic eddy formation (Wilkerson 1967).

INSTRUMENTATION

The airborne infrared radiation thermometer operates in the 8- to 13-micron region of the electromagnetic spectrum and uses a thermistor bolometer detector. The equipment is described by Peloquin and Weiss (1962). Briefly, the thermistor bolometer is exposed alternately to the sea surface and to a temperature-controlled reference black body in the instrument. The resultant signal, which is proportional to the difference between the incoming and the reference black body radiation, is amplified and converted to a d.c. signal driving the pen of a strip-chart recorder.

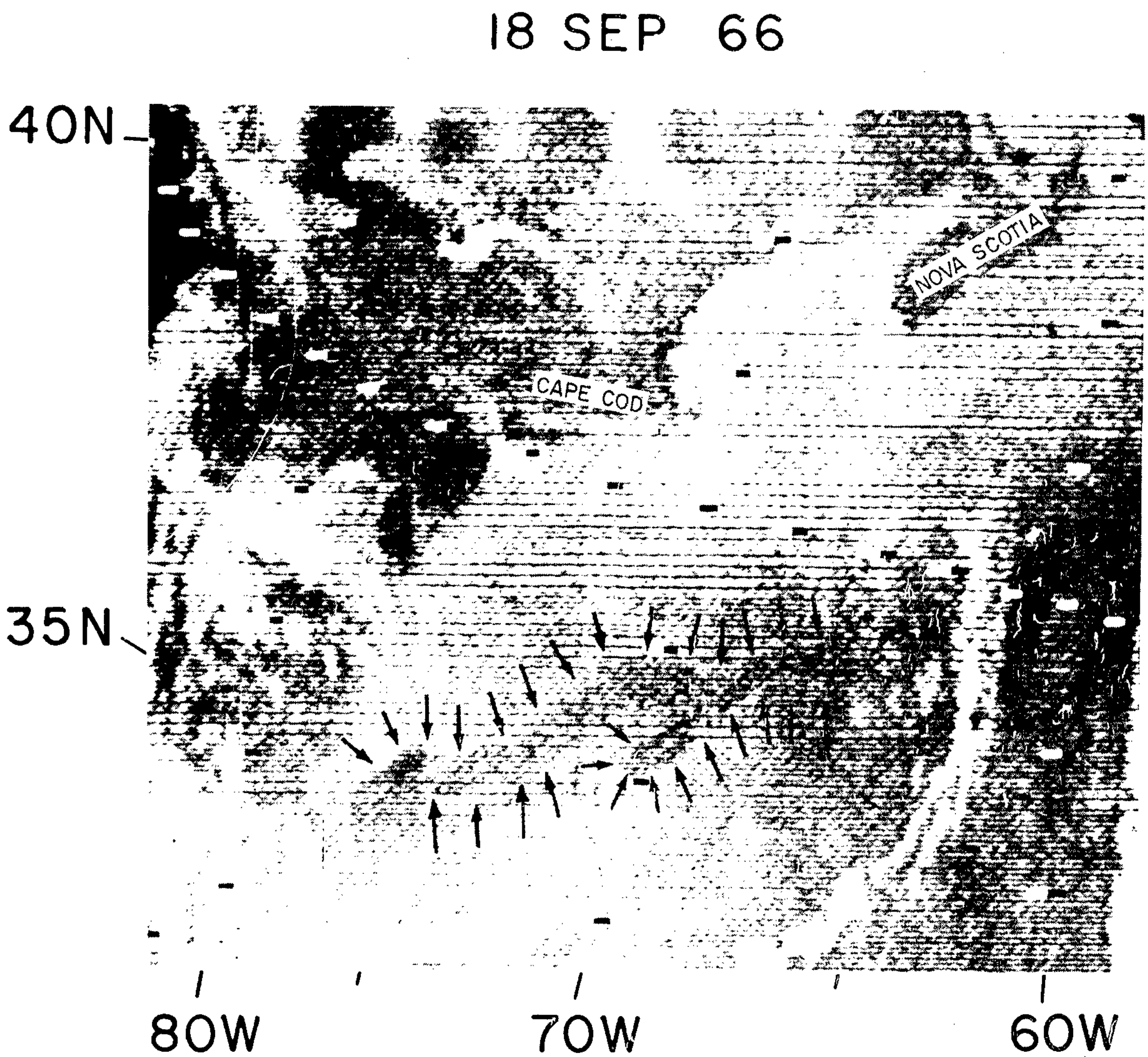

FIGURE 1. NIMBUS II SATELLITE VIEW OF THE GULF STREAM FROM HIGH RESOLUTION INFRARED RADIOMETER DATA.

From an altitude of 300 meters, the instrument views a 12 x 12 meter spot along the flight path beneath the aircraft. The geometry of measurement is shown in figure 2. The instrument is calibrated over the range of -2° to +35°C to an accuracy of ±0.2°C. However, atmospheric conditions can lead to errors of as much as several degrees Celsius in recorded temperatures (Clark 1967). To correct errors due to atmospheric effects, Pickett (1966) derived corrections for the Model 14-320 radiation thermometer using data gathered from a variety of altitudes and locations for which simultaneous surface measurements were available. These empirical corrections give the instrument a field accuracy of ±0.4°C 95 per cent of the time. The corrections, which are a function of altitude and flight-level air temperatures, have been applied to the airborne radiation thermometer data described in this paper.

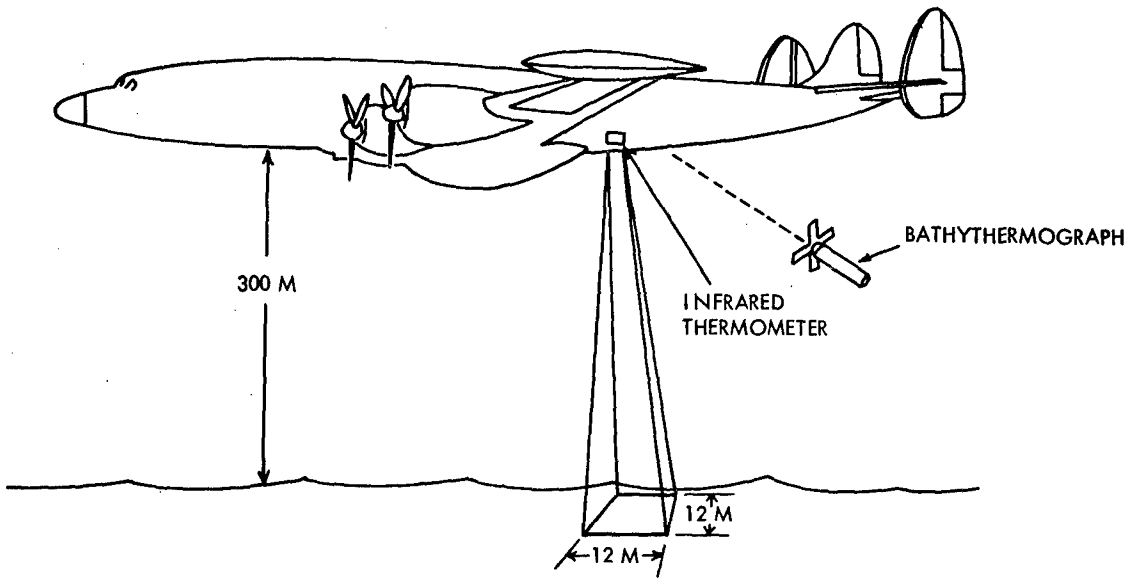

FIGURE 2. MEASUREMENT GEOMETRY OF THE AIRBORNE RADIATION THERMOMETER.

RESULTS

The first in the series of aerial surveys needed for this study was flown 1 March 1967. The position of the northern boundary of the Gulf Stream as determined from the flight data is shown in Figure 3. The position of the thermal boundary was charted from Cape Hatteras to 62°W. The narrow meander centered at 66°W suggested that a cyclonic eddy was about to form.

Surface temperatures in the warm core of the Gulf Stream were between 21° and 22°C, while Slope Water temperatures north of the stream ranged from 8° to 14°C. In most instances, the surface temperature profile across the interface between Slope Water and the Gulf Stream showed a gradient of 10°C in 3 km. The surface temperature profile recorded at 66°W as the aircraft flew southward is shown in the inset of Figure 3.

On 3 March 1967, a portion of the meander was resurveyed to determine its change in position. The resurvey showed that the trough had deepened slightly and was displaced eastward about 18 km. Also, the neck of the loop appeared to have narrowed.

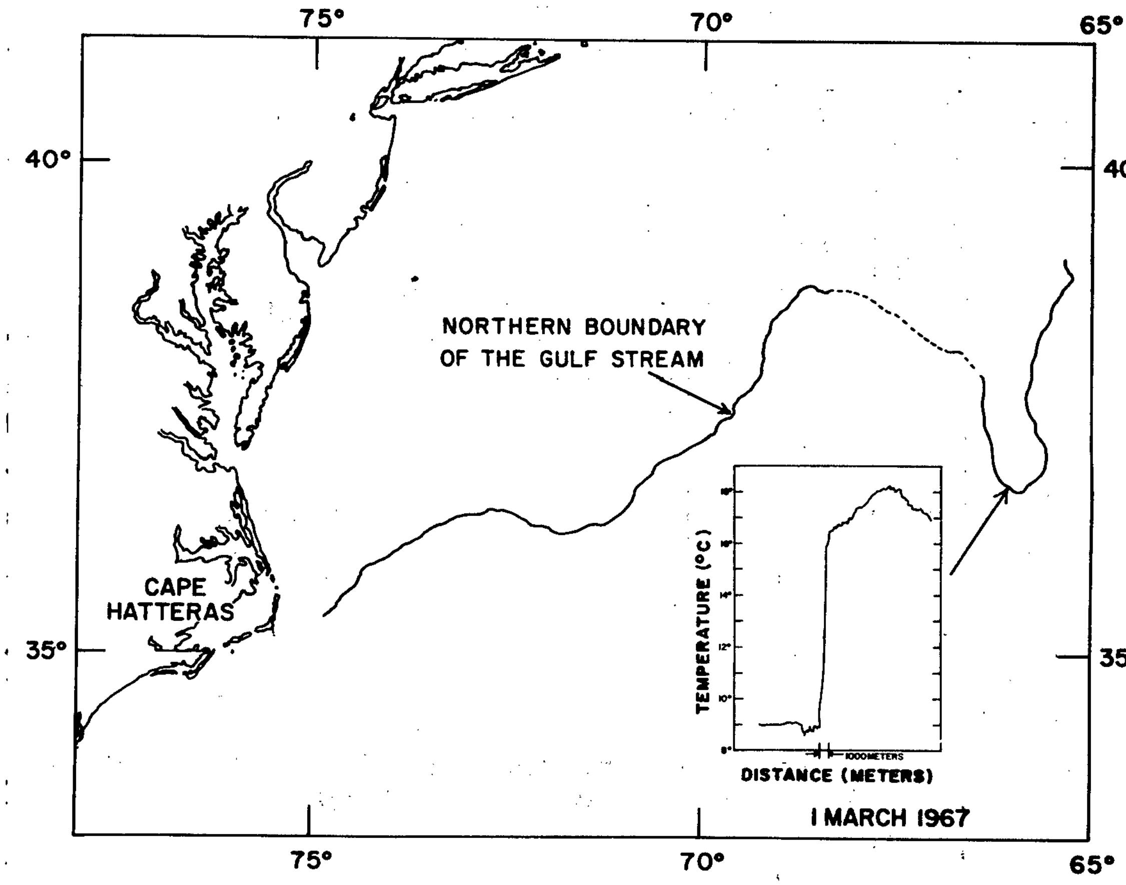

FIGURE 3. POSITION OF THE GULF STREAM NORTHERN BOUNDARY.

The next survey conducted 10 March, 7 days later, again traced the Gulf Stream boundary starting at Cape Hatteras. This survey positioned the Gulf Stream's northern boundary at 40°N near 66°W, some 200 km further north than it was a week earlier. Change of position relative to the 1 March position is shown in Figure 4. The aircraft was directed southward toward the last known position of the trough at 37°N. Sea surface temperatures near this location revealed cold water (11°C) in the central portion of the eddy. It is significant that during the flight on 10 March between the northern boundary and the eddy as indicated by the dashed lines in Figure 4, sea surface temperatures were uniformly warm and ranged between 18° and 21°C. No connecting link between the cold water of the eddy and the Slope Water north of the Gulf Stream was evident. Because of the limited flight time remaining, the boundary of the eddy was only partially circumnavigated; but the survey of the western boundary of the eddy indicated the surface diameter of the eddy to be about 100 km as shown in Figure 5. This surface boundary, visible during most of the flight through a contrast in water color, represents the inner edge of the current ringing the eddy.

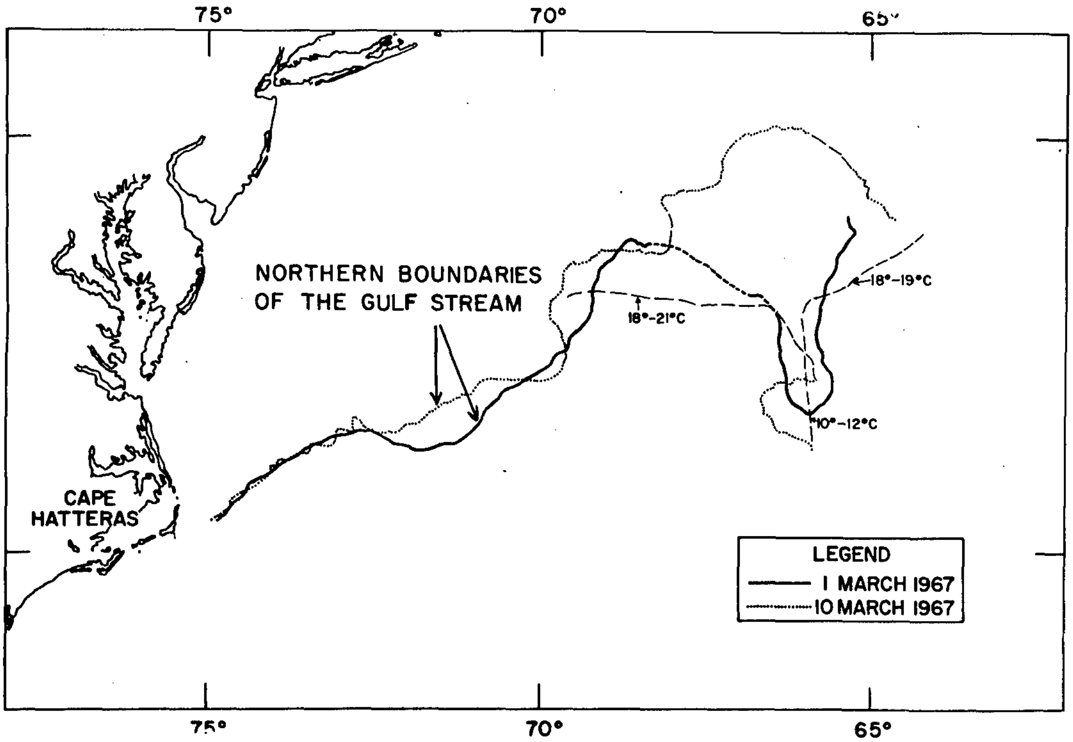

FIGURE 4. A COMPARISON OF THE NORTHERN BOUNDARY POSITIONS OF THE GULF STREAM FROM FLIGHT DATA OF 1 MARCH AND 10 MARCH 1967.

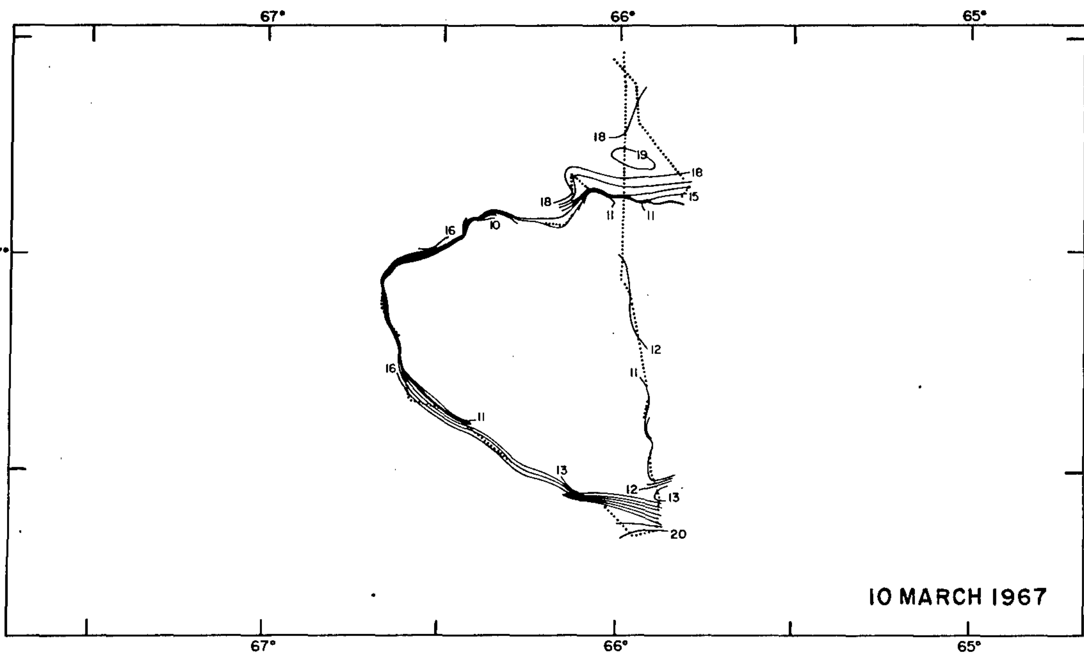

FIGURE 5. SEA SURFACE TEMPERATURE ANALYSIS AND THE FLIGHT TRACK OF 10 MARCH 1967.

According to Fuglister, the boundary at depth extends approximately 50 km beyond the surface boundary.

On 16 March 1967, the eddy was circumnavigated. The results are shown in Figure 6. Surface temperatures across the central portion of the eddy averaged about 13°C, while surrounding surface temperatures were between 19° and 20°C. The surface shape and orientation of the eddy could now be determined. It was elliptical, its major axis extended 200 km southwest-northeast, and its width was about 80 km. This information and data from previous flights were forwarded to Mr. Fuglister at Woods Hole Oceanographic Institution. As a result, he requested the research vessel CRAWFORD, which had been operating south of Bermuda, to take temperature-depth profiles through the eddy during her return to Woods Hole on 20 and 21 March. The ship's track (dashed line) is shown also in Figure 6. Figure 7 shows a comparison of surface temperatures recorded by aircraft and ship through the central portion of the eddy. Surface temperature observations taken from the ship between points A and B have been plotted along the temperature profile taken from the aircraft between A' and B' to show the general agreement in the two sets of data which were recorded along the similar headings across the eddy but separated in time by 4.5 days.

The temperature cross section taken by the CRAWFORD is shown in Figure 8. These data from shipboard expendable bathythermographs provided the first observations of the subsurface temperature structure of the eddy. The 300-meter-depth temperatures of 10°C are characteristic of Slope Water and were in sharp contrast to 300-meter-level temperatures of the surrounding water in the Sargasso Sea, which during that season of the year, were greater than 15°C everywhere.

Aerial survey of the eddy was continued on 28 and 30 March. The results of the more extensive survey on 30 March are shown in Figure 9. Although there was some question about the shape of the eastern portion, owing to lack of data, the eddy appeared to have retained its elliptical shape. It had migrated south-eastward with an average speed of about 5 km per day. Its surface dimensions, especially its width, were reduced considerably. At its narrowest point the eddy measured 15 km.

The final aerial survey made on 6 April 1967 (Figure 10) indicated that the eddy had migrated about 12 km further southeastward and that its major axis had rotated counterclockwise about 30°. Its shape at the surface remained elliptical, but its major axis of 160 km was oriented northeast-southwest. During the final survey flight, airborne expendable bathythermographs were dropped across the width of the eddy at the locations shown in Figure 10 to obtain nine

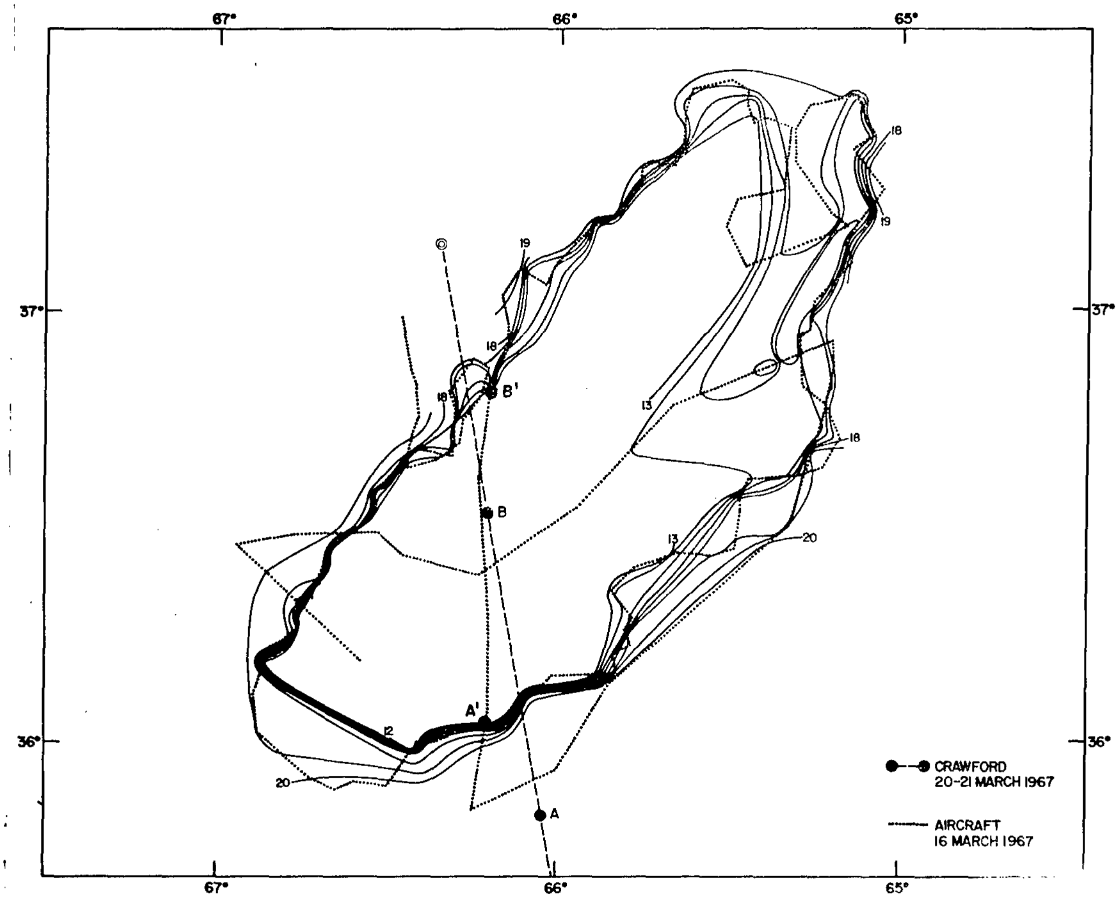

FIGURE 6. SEA SURFACE TEMPERATURE ANALYSIS AND FLIGHT TRACK FOR 16 MARCH 1967. DASHED LINE INDICATES THE COURSE OF THE R/V CRAWFORD ON 20-21 MARCH 1967.

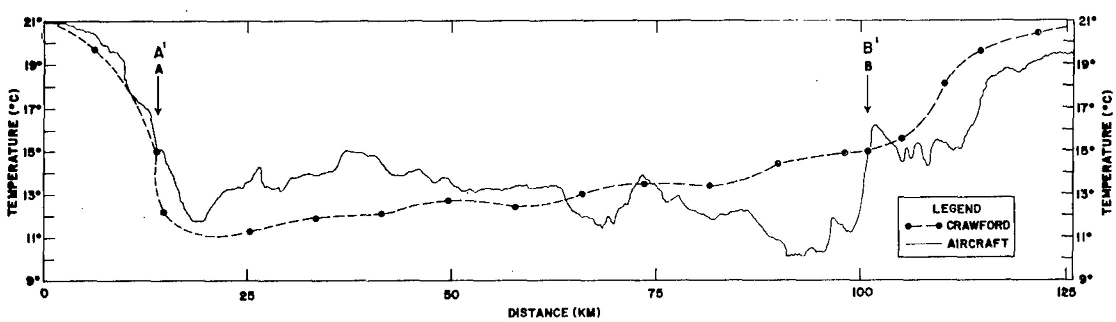

FIGURE 7. A COMPARISON OF SURFACE TEMPERATURE PROFILES ACROSS THE EDDY TAKEN FROM FLIGHT DATA OF 16 MARCH 1967 AND FROM SHIP DATA OF 20-21 MARCH 1967.

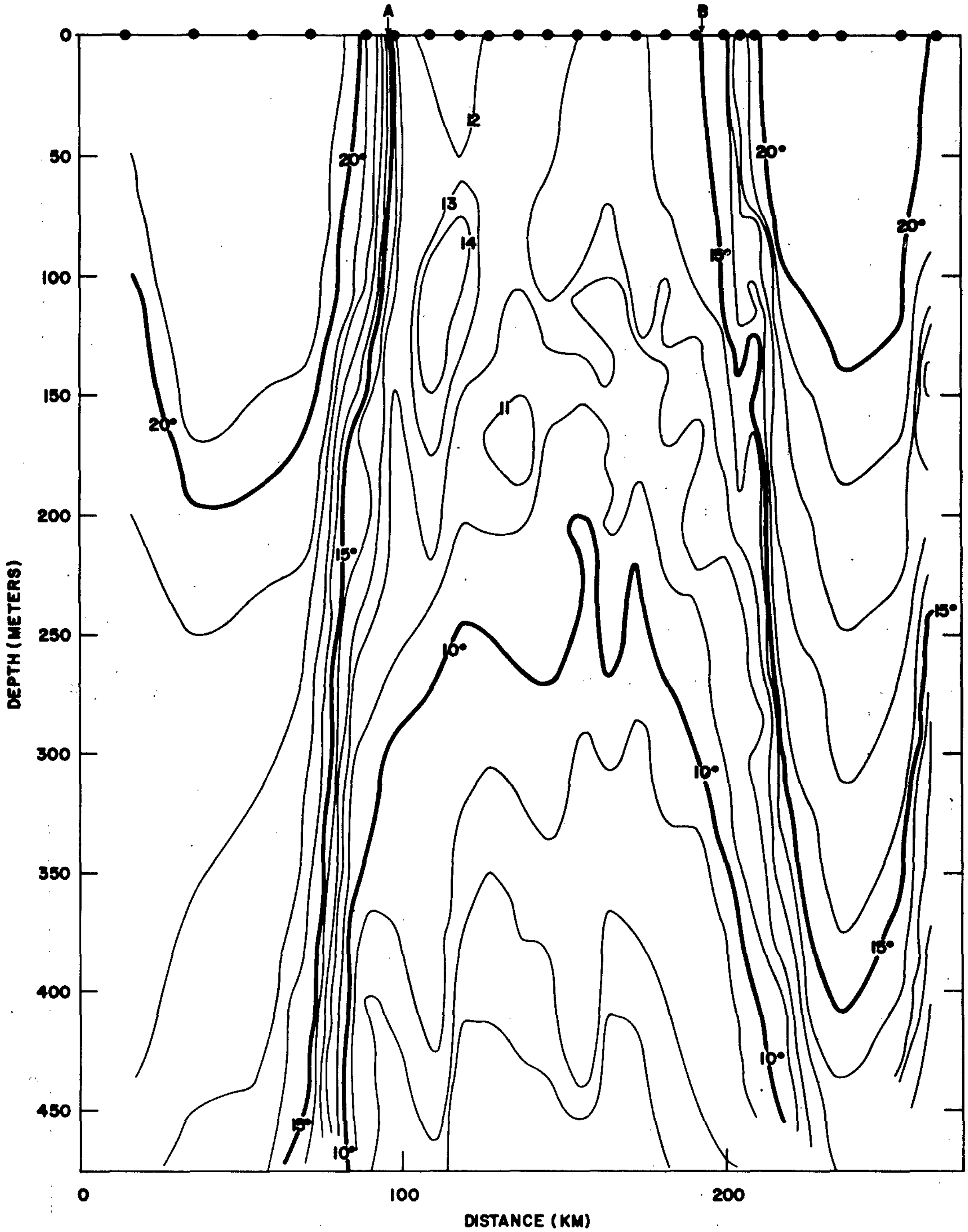

FIGURE 8. TEMPERATURE-DEPTH ANALYSIS FROM R/V CRAWFORD DATA*, 20-21 MARCH 1967.

* Used with the kind permission of Mr. F. Fuglister, Woods Hole Oceanographic Institution.

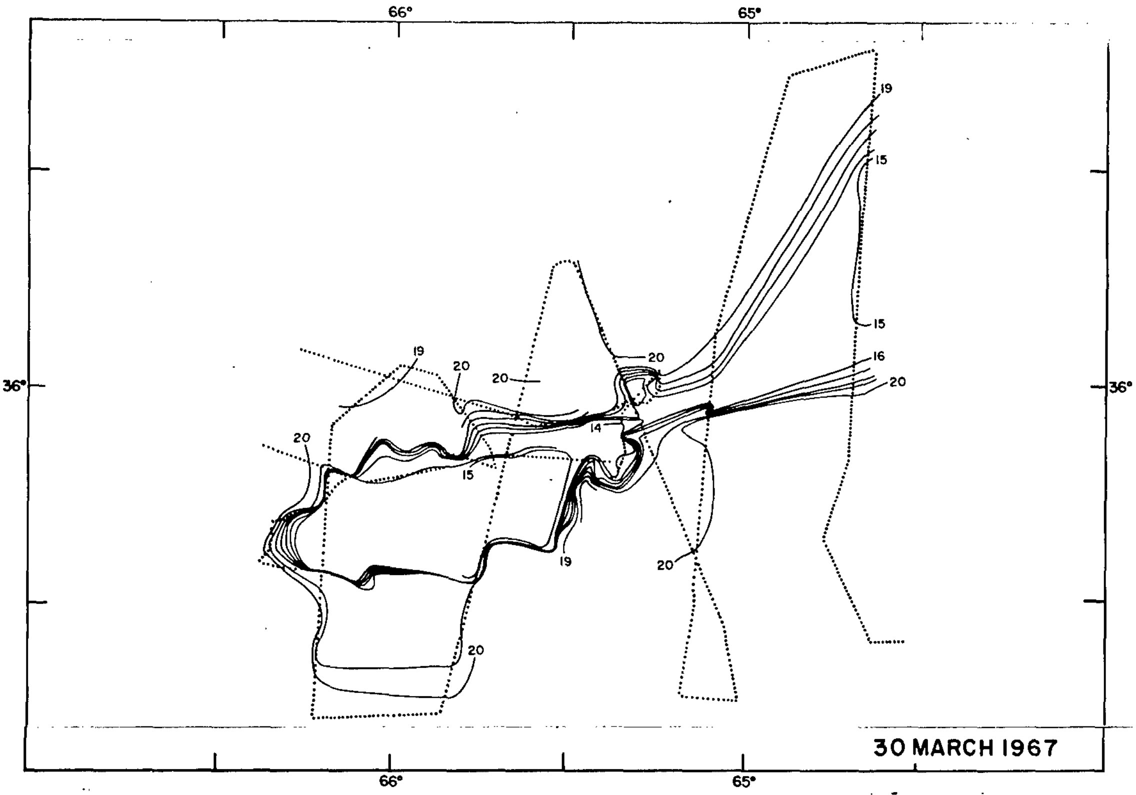

FIGURE 9. SEA SURFACE TEMPERATURE ANALYSIS AND FLIGHT TRACK FOR 30 MARCH 1967.

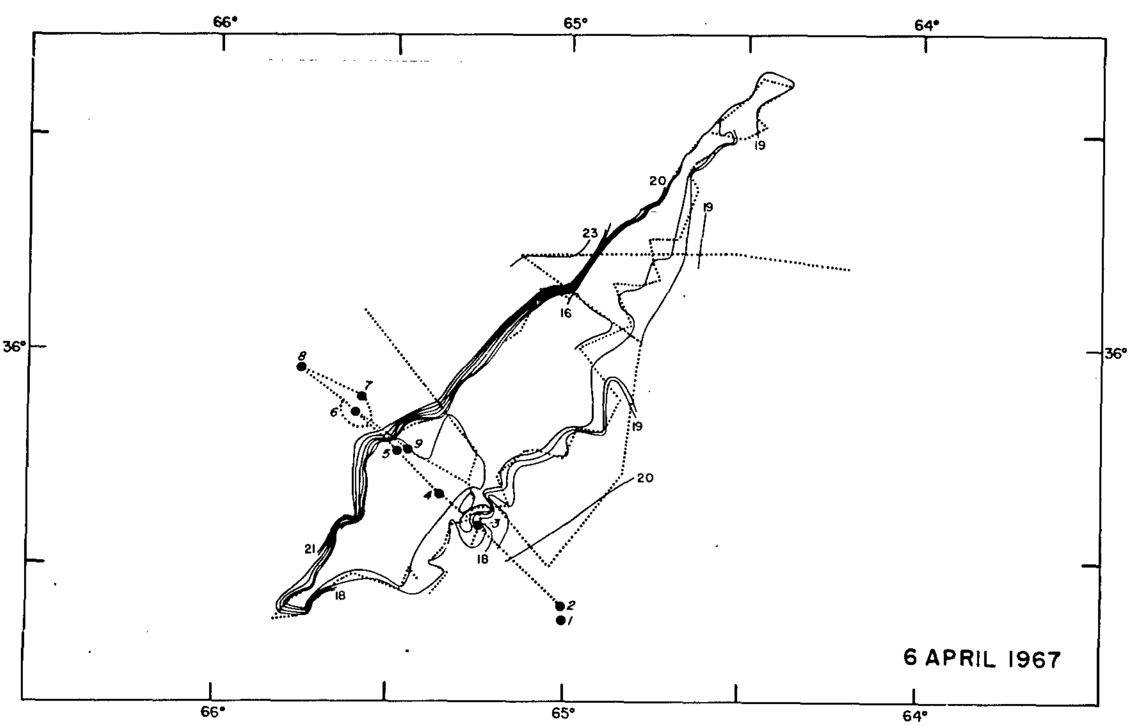

FIGURE 10. SEA SURFACE TEMPERATURE ANALYSIS AND FLIGHT TRACK OF 6 APRIL 1967. CIRCLES NUMBERED 1 THRU 9 INDICATE LOCATIONS OF THE TEMPERATURE DEPTH SOUNDINGS WITH AIRBORNE EXPENDABLE BATHYTHERMOGRAPHS.

temperature-depth profiles. As shown in Figure 11, these measurements again revealed the characteristic dome of cold water extending to at least 300 meters and showed that temperatures at the 300-meter level remained 10°C. Figure 12 shows the relative positions of the eddy formation as they were determined from the aerial surveys during the course of 5 weeks.

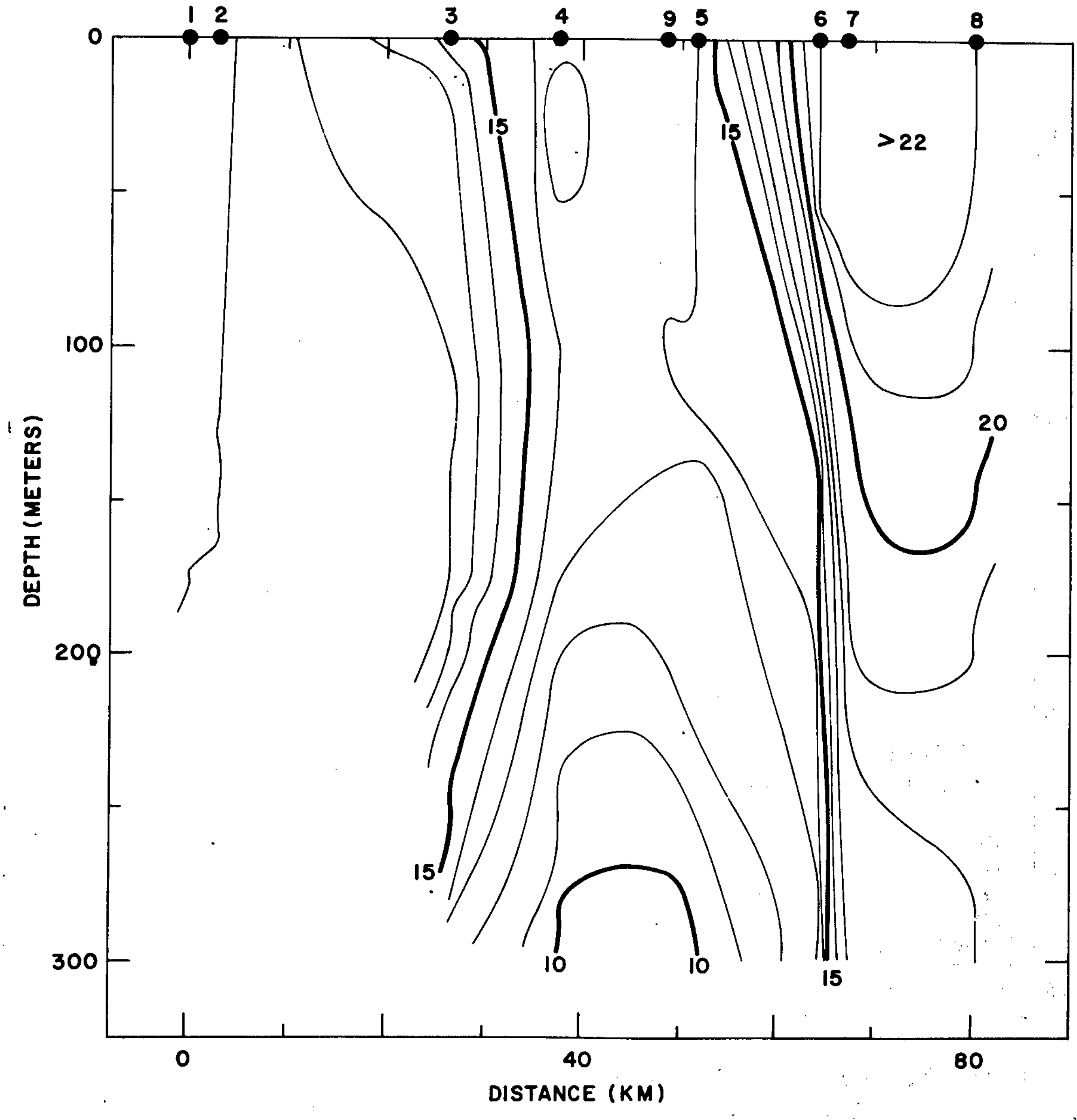

FIGURE 11. TEMPERATURE-DEPTH ANALYSIS FROM FLIGHT DATA OF 6 APRIL 1967.

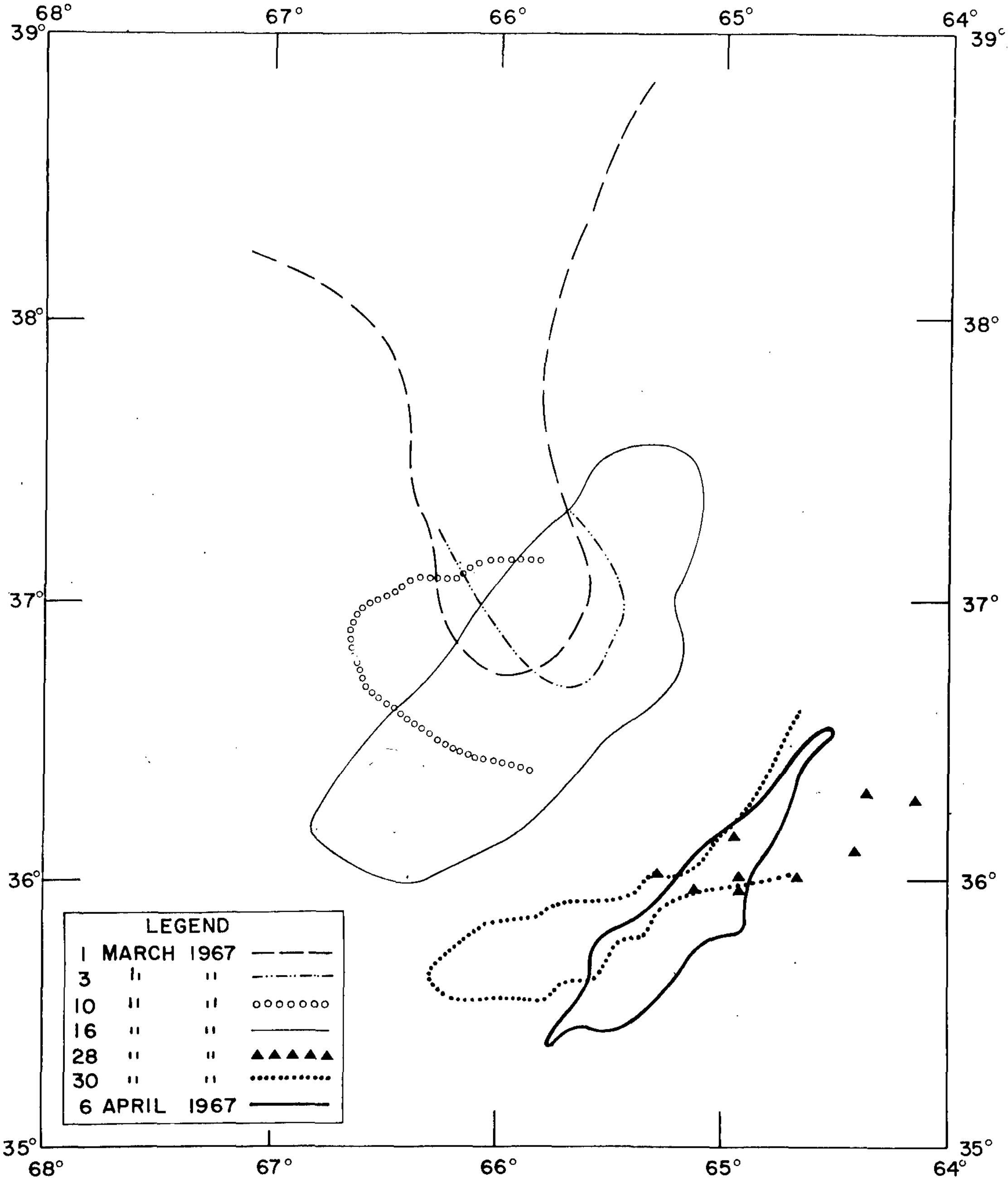

FIGURE 12. RELATIVE POSITIONS OF THE EDDY FORMATION AS DETERMINED FROM AERIAL OBSERVATIONS DURING THE PERIOD 1 MARCH to 6 APRIL 1967.

SUMMARY

Aerial survey of a meander in the Gulf Stream north of Bermuda revealed the formation of a large cyclonic eddy. The development and subsequent drift of the eddy was documented with sea surface temperature data obtained with an airborne radiation thermometer during six flights between 1 March and 6 April 1967.

The eddy formed between 1 and 10 March. Its elliptic shape at the surface remained oriented in general southwest-northeast, but in the course of 5 weeks, it shrank in size at the surface from 200 to 160 km in length and from 80 to 30 km in width. During this period, the eddy drifted southeastward at an average rate of 5 km per day.

Surface temperatures within the eddy warmed from about 11°C to about 16°C but remained sufficiently colder than the surrounding Sargasso Sea water to maintain a well-defined surface temperature boundary. From temperature cross sections taken with both shipboard and airborne expendable bathythermographs, the eddy appeared as a dome of cold Slope Water with a high gradient boundary. At a depth of 300 meters, temperatures of 10°C inside the eddy were in sharp contrast to the temperatures of the surrounding water in the Sargasso Sea which were greater than 15°C everywhere.

Cyclonic eddy data collected during this study are consistent with ship observations of this phenomenon. These data represent an addition to the sparse documentation of the formation of cyclonic eddies south of the Gulf Stream and demonstrate the feasibility of airborne surveys as a means of detecting and tracking such phenomena during formation and initial development.

REFERENCES

CLARK, H. L. (1967), Some Problems Associated with Airborne Radiometry of the Sea. Applied Optics, 6:2151.

FUGLISTER, F. C. (1966), Cyclonic Eddies Formed by the Gulf Stream Atlantic Oceanography, Woods Hole Oceanographic Institution Reference No. 67-36: 1-2.

FUGLISTER, F. C. and WORTHINGTON, L. V. (1951), Some Results of a Multiple-Ship Survey of the Gulf Stream. Tellus, 3(1).

ISELIN, C. O'D. and FUGLISTER, F. C. (1948), Some Recent Developments on the Study of the Gulf Stream. Journal of Marine Research, 7(3).

PELOQUIN, R. A. and WEISS, M. (1962), Airborne Instrument for Precision Measurement of Sea Surface Temperature Using Infrared Radiation Emitted by the Sea. ISA Symposium on Marine Instrumentation.

PICKETT, R. L. (1966), Environmental Correction for an Airborne Radiation Thermometer. Proc. of the Fourth Symposium on Remote Sensing of the Environment.

PICKETT, R. L. and WILKERSON, J. C. (1966), Airborne IR Tracking of Gulf Stream. Geo-Marine Technology 2(5): 8-11.

SPILHAUS, A. F. (1940), A detailed Study of the Surface Layers of the Ocean in the Neighborhood of the Gulf Stream with the Aid of Rapid Measuring Hydrographic Instruments. Journal of Marine Research, 3(1).

STOMMEL, H. et al. (1953), Rapid Aerial Survey of the Gulf Stream with Camera and Radiation Thermometer. Science, 117(3043).

STRACK, S. L. (1953), Surface Temperature Gradients as Indicators of the Position of the Gulf Stream. Woods Hole Oceanographic Institution Reference No. 53-53.

WILKERSON, J. C. (1967), The Gulf Stream from Space. OCEANUS, June 1967, 2-8.

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13. ABSTRACT

A series of aircraft observations of sea surface temperature in March 1967 revealed the formation of a cyclonic eddy south of the Gulf Stream. These observations were made with an airborne radiation thermometer from an altitude of 300 meters. A meander in the Gulf Stream, appearing as a tongue of cold water and extending 150 km southward into the Sargasso Sea, was located on 1 March near 37°N,66°W. By 16 March an elliptical-shaped eddy had formed from the meander, with its major axis oriented northeast-southwest. Surface temperatures in the eddy averaged 10°C, whereas the temperature of the water surrounding the eddy averaged 20°C. During the next 21 days, the eddy shrank in size at the surface and migrated about 5 km/day southeastward. The surface temperature contrast at the boundary of the eddy also decreased from 10° to 5°C. Aircraft bathythermograms showed the eddy to be a dome of cold water extending to a depth of at least 300 meters.

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