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Monitoring effects of gulf stream meanders and warm core eddies on the fishing grounds of the continental shelf and slope

by

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Introduction

The National Marine Fisheries Service (NMFS) has started a program to monitor the effects of large Gulf Stream eddies and meanders on environmental conditions in ICNAF Subareas 5 and 6. Specifically, the monitoring is directed to meanders on the left (shoreward) side of the stream and to the warm core eddies that sometimes form from these meanders. Although meanders and eddies occur on both sides of the stream, it is only those on the left that sometimes move into the proximity of the fishing grounds of the continental shelf and slope.

These oceanographic features are of interest because they apparently cause the strongest subsurface currents and non-seasonal (aperiodic) variations in water mass properties found in the Slope Water region adjacent to the outer continental shelf. Although both meanders and eddies are of common occurrence in this region (about 6 warm core eddies per year during 1974 and 1975 [Bisagni, 1976]), they characteristically remain in deep water, with apparently little direct effect on environmental conditions in the waters of the continental shelf and slope (Figure 1). The infrequent meander or eddy, however, which moves close along the continental slope, can have considerable effect on these waters (Iselin, 1939; Chamberlin, 1976) (Figures 6 and 7). Furthermore, large eddies that remain in deep water can apparently have significant effects by offshore entrainment of shelf water.

Monitoring Program Components

There are two principal components of the monitoring program: (1) Utilizing interpretations of infrared-radiometer imagery from NOAA satellites to observe the locations, movements, size, and other characteristics of meanders and eddies as they appear at the sea surface, and (2) Obtaining direct observations in these features from vessel cruises. Interpretations of the satellite imagery and copies of some of the imagery, itself, are obtained through the cooperation of oceanographers of the U. S. Naval Oceanographic Office and the NOAA National Environmental Satellite Service (see acknowledgments for specific sources). Because the meanders and eddies change position slowly--usually no more than a few miles per day--, the weekly interpretations produced are a more than satisfactory basis for the monitoring, despite the fact that cloudy weather obscures the satellite imagery a majority of the time.

Shipboard observations will be needed intermittently, rather than on a regular schedule such as that of the satellite interpretations. These observations become essential; only when satellite imagery indicates that a particular eddy or meander is having or soon will have, a significant effect on the fishing grounds. Because satellites reveal only the sea-surface temperature expression of meanders and eddies, the depths and boundary slopes of these features can be reliably determined only from shipboard observations, and to some degree by instrument drops from low flying aircraft.

Satellites often give an inaccurate measure of both the size and location of meanders and eddies when these features are overridden at the surface by surrounding waters or chilled at the surface by cold winds at the surface. Eddies sometimes seem to entirely disappear in the satellite imagery, for days and perhaps weeks, and then often reappear many miles from where last seen. Following prolonged periods of cloudy weather, the relocation of an eddy may be difficult. A large shallow patch of Gulf Stream water that has overridden the Slope Water, can readily be mistaken for the eddy.

Adequate measurement of the effects of meanders and eddies on the fishing grounds is probably feasible at present only with combined observations from ships and satellites. Shipboard observations are paramount to reveal such effects as upwelling adjacent to meanders or eddies, subsurface injection of warm Gulf Stream or Eddy water onto the shelf, and subsurface entrainment of shelf water off the shelf. Combined observations should be particularly advantageous for measuring the volume of surface entrainment of shelf water. The areal extent of entrainment can be estimated from satellite imagery and the depth of the entrainment layer from shipboard.

Making observations in meanders and eddies will be a continuing difficult management problem, because these oceanographic phenomena are at present unpredictable regarding their magnitudes, places of origin, and speeds and directions of travel, whereas, vessel cruises are ordinarily planned well in advance of operations.

An initial effort to use both satellite imagery interpretations and research vessels in monitoring is described in the following section.

Observations Relating to a Large Warm Core Eddy Southeast of Georges Bank in March and April 1976

NOAA Satellite Imagery

Infrared imagery of the NOAA satellites, GOES 1 and NOAA 4, revealed an unusually large warm core eddy, southeast of Georges Bank, at the end of February, when it was estimated to have detached from the Gulf Stream, with its center at 39°45'N latitude, 63°15'W longitude (Figure 2). By March 20, it had moved westward about 90 nautical miles (170 kilometers), at an average speed of about 1.4 knots (7 cm./sec.), and its center was at about 39°30'N latitude, 65°15'W longitude.

Early in the life of the eddy, on February 28, unusually clear satellite imagery showed it to have an oval surface configuration, with dimensions of about 140 x 120 nautical miles (260 x 220 kilometers); the surface area was about 17,500 square miles (45,500 square kilometers), which is about 21 percent larger than the combined area of the Southern New England states (about 25 percent larger than Georges Bank). The area appeared to decrease moderately during the following month.

Recognition that this eddy, because of size, could have marked effects on Georges Bank, led the Northeast Fisheries Center, NMFS, in mid March, to initiate requests for observations by research vessels of other ICNAF member nations.

Observations from "Ernst Haeckel"

On March 20, the German Democratic Republic's Research Vessel "Ernst Haeckel," made a temperature and salinity section, with Nansen bottles, across most of the eddy's diameter in a nearly north-south direction, from south of the center to the northern margin. The data were radioed to NEFC on March 22. Although weather and strong subsurface currents were an obstacle to the "Haeckel," data were obtained to depths of over 400 meters. The temperature section revealed a core of 18°C water about 75 miles across and over 300 meters maximum depth near the eddy center. (We are aware of only one previous report of an eddy with an 18° core reaching a comparable depth [U. S. Naval Oceanographic Office, October 1974].) Salinity values of over 36.5°/°° in the core show it to have been composed of Gulf Stream or Sargasso Sea water. The maximum depths of the observations possible with the length of wire aboard the "Haeckel" were not sufficient for accurate calculations of geostrophic flow as an estimate of the eddy's speed of rotation. The section clearly shows the entrainment of cold shelf water (9°C) at the northern margin of the eddy.

Initially the eddy entrained cold surface water from the continental shelf off western Nova Scotia. During the third week in March the satellites showed it was entraining shelf water from the direction of eastern Georges Bank. At its westernmost position on March 24, the eddy had come close to a large meander that was building up on its west side and was entraining Gulf Stream water northward from this feature.

By March 28, the eddy ceased entraining Gulf Stream water, and appeared to have retreated some distance to the east and to be losing water to the Gulf Stream from its southwest margin. At the same time, the Gulf Stream meander to the west of the eddy had thrust far to the northward, bringing surface water warmer than 17°C to the southern margin of Georges Bank (Figure 3). The meander was also entraining Georges Bank water southward while the eddy picking up some of this at its western margin, entraining it back northward again.

Observations from "Albatross IV"

On April 2-3, the NOAA Research Vessel "Albatross IV" was diverted by the Northeast Fisheries Center from Georges Bank, southwestward into the northern part of the meander west of the eddy. XBT observations and neuston net samples were obtained in this large warm water incursion.

Observations from "Wieczno"

On April 4-7, the Polish Research Vessel "Wieczno" made an east to west section with Nansen bottles across the area of both the eddy and the meander at about 38°N. This 260 mile (480 kilometer) section, although impeded by bad weather, and limited to 450 meters maximum depth, was fully executed. Dramatic change corroborated by satellite imagery (Figure 4), was revealed. The meander had broken eastward, from its northern extremity, into the northern part of the eddy. As a result, instead of an eddy and a meander, a very wide meander had formed, reincorporating the eddy into the Gulf Stream. Satellite imagery subsequently revealed the persistence of this broad meander for about 2 weeks.

Observations from "Belogorsk"

The Soviet Research Vessel "Belogorsk" made a long Nansen bottle section, on April 16 to 19, in a southwestward direction through the meander in the area where the large eddy had been, and then northwestward to Georges Bank. At the time of writing this report, data has not been received from the "Belogorsk."

Satellite imagery up to April 20 presents a complex situation indicating that at the time of the "Belogorsk" observations the Gulf Stream changed direction toward the southeast at about 39°N latitude 67°W longitude, releasing a major part of the large eddy in the form of a reconstituted large eddy. Additional observations from research vessels may be obtained in the area of this apparent eddy, if they appear warranted by the evidence of subsequent satellite imagery.

Formation and Characteristics of Warm Core Eddies

Warm core eddies form in the Slope Water region off the continental shelf by detachment of meanders on the left side of the Gulf Stream (Figure 5). The detached meander maintains continuity of flow by closing into a "ring" at the area of detachment. The rotational flow, in a clock-wise (anticyclonic) direction, continues by inertia, at speeds from as low as 0.6 - 1.0 knots (30 - 50 cm./sec.) (Saunders, 1971) to more than 1.8 knots (90 cm./sec.) (Thompson and Gotthardt, 1971). The eddies have a warm core because they enclose Sargasso water that has crossed the Gulf Stream within the originating meander. (Eddies also form from meanders on the right side of the Stream. These eddies, which move off into the warm Sargasso Sea, rotate counterclockwise and contain a cold core of Slope Water). The warm core eddies seen off New England mostly form in the slope water region southeast of Georges Bank, where meandering of the Gulf Stream becomes extensive.

Unlike Gulf Stream meanders which move slowly eastward like waves, warm core eddies typically move west and southwest in the Slope Water region at varying rates up to about 0.2 knots (10 cm./sec.), but often halt or move in irregular directions for periods of days or even a few months (Bisagni, 1976). Some eddies recontact the Gulf Stream soon after their formation and are resorbed. However, those which continue to move to the west and southwest may continue to exist for over 6 months, but are eventually trapped and resorbed by the Gulf Stream at about the latitude of Virginia, where the Stream runs close to the continental slope. As an example, Figure 8 shows the trajectory for a warm core eddy which traveled from just southeast of Georges Bank on January 20, 1975 to near Cape Hatteras on October 29, 1975 is shown. Bisagni (1976) found that the warm core eddies were present about one-fifth of the time off the New York Bight during 1974-75.

Effects of Meanders and Eddies on the Fishing Grounds of the Continental Shelf and Slope

Direct effects of Gulf Stream meanders and warm core eddies on the environmental variability on the fishing grounds have probably been reasonably well observed, but the influence of this variability on the fishery resources is largely conjectural. Five kinds of environmental effects and their possible influences on the fishery resources and on fishing can be identified:

1) Warming of the upper continental slope and outer shelf by direct contact of a meander or eddy (Figure 6). This may influence the timing of seasonal migrations of fish as well as the timing and location of their spawning.

2) Injection of warm, saline water into the colder less saline waters of the shelf, by turbulent mixing at the inshore boundary of a meander or eddy (Figure 7). This may have influences on the fishery resource similar to that of direct warming, and also cause mortality of fish eggs and larvae on the shelf, when the cold water in which they live is warmed beyond their tolerance by the mixing-in of warm Slope Water.

3) Entrainment of shelf water off the shelf--an effect that is frequently seen in satellite imagery (Figure 2 and 3). Mortality of Georges Bank fish larvae is known to occur, presumably because of temperature elevation, when shelf water in which they occur is carried into the Slope Water (Colton, 1959). The most profound effects of the entrainment on the fishing grounds may be changes in circulation and water masses resulting from the replacement of the waters lost from the shelf.

4) Upwelling along the continental slope, which may result in nutrient enrichment near the surface and increased primary biological productivity.

5) Strong currents on the outer shelf and upper slope. Prolonged submergence of the surface floats of lobster pots and even losses of gear is a possible result that warrants investigation.

Acknowledgments

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References

Applications Research Division, U. S. Naval Oceanographic Office. 1974. An unusual anticyclonic eddy. Gulf Stream Monthly Summary v. 9, n. 6 June 1974.

Bisagni, J. J. 1976. The passage of anticyclonic Gulf Stream eddies through Deepwater Dumpsite 106, 1974-1975. NOAA Dumpsite Evaluation Report 76-1, U. S. Dept. of Commerce.

Chamberlin, J. L. 1976. Bottom temperatures on the continental shelf and slope, south of New England during 1974. MARMAP Contrib. No. 104 NOAA, National Marine Fisheries Service, U. S. Dept. of Commerce pp. 18-1 to 18-13 (duplicated).

Colton, John B., Jr. 1959. A field observation of mortality of marine fish larvae due to warming. Limnol. and Oceanog. v. 4, n. 2, p. 219-222.

Iselin, C. O'D., 1939. Some physical factors which may influence the productivity of New England's coastal waters. Jour. Mar. Res. v. 2, pp. 74-85.

Gotthardt, G. A. 1973. Gulf Stream eddies in the western North Atlantic. NAVOCEANO Tech. Note 6150-16-73. 42 pp.

Saunders, P. M. 1971. Anticyclonic eddies formed from shoreward meanders of the Gulf Stream. Deep-Sea Res. v. 18. pp. 1207-1219.

Thompson, B. and G. Gotthardt, U. S. Naval Oceanographic Office. 1971. Movement of a Gulf Stream eddy. Gulf Stream Monthly Summary. v. 6, n. 1 January 1971.

U. S. Naval Oceanographic Office. 1974. Gulf Stream Monthly Summary. v. 9, n. 11 November 1974.

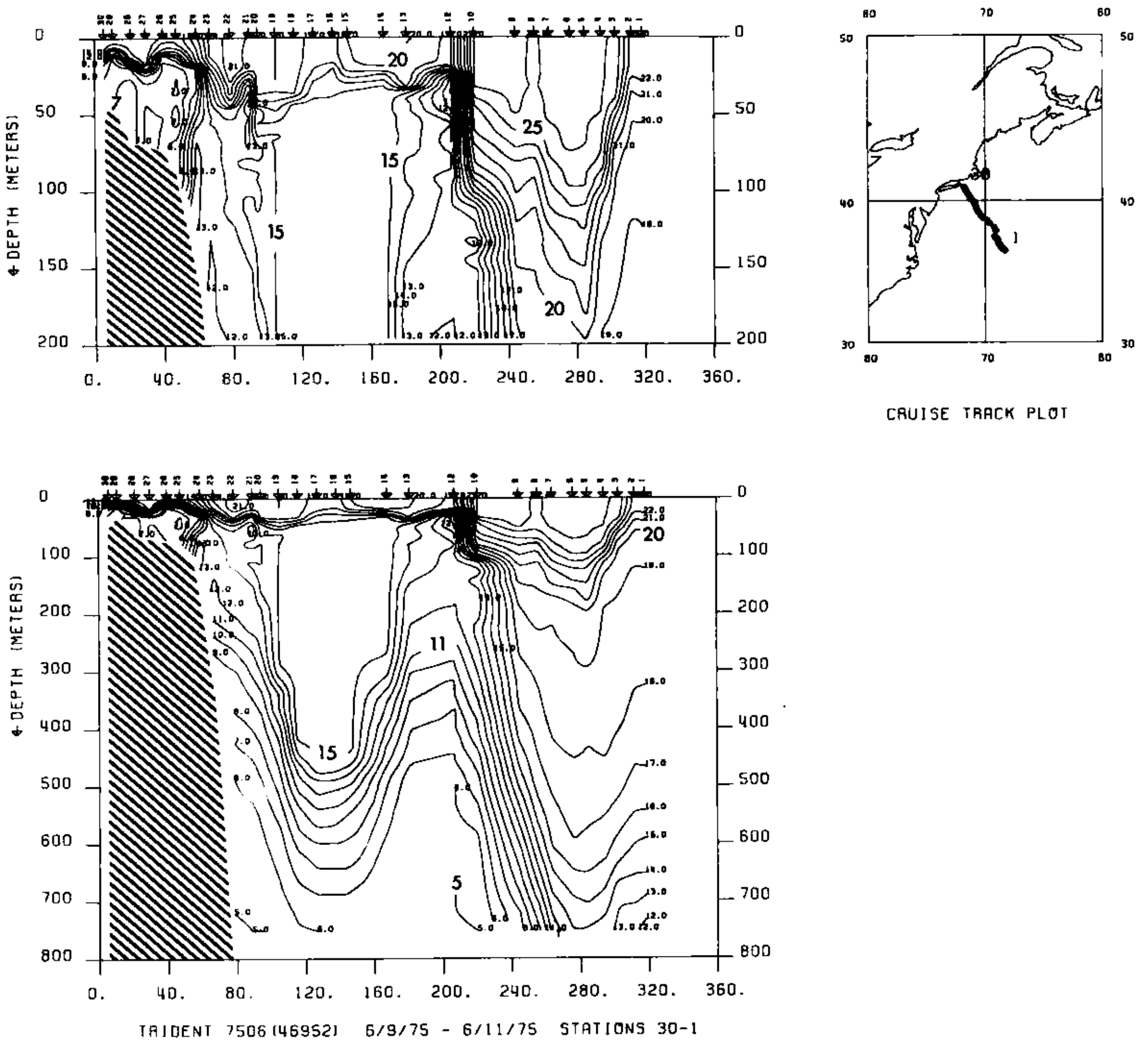

Figure 1. Vertical temperature section illustrating a large warm core eddy in the Slope Water region between the continental slope and Gulf Stream. This eddy is apparently having little effect on continental slope bottom temperatures.

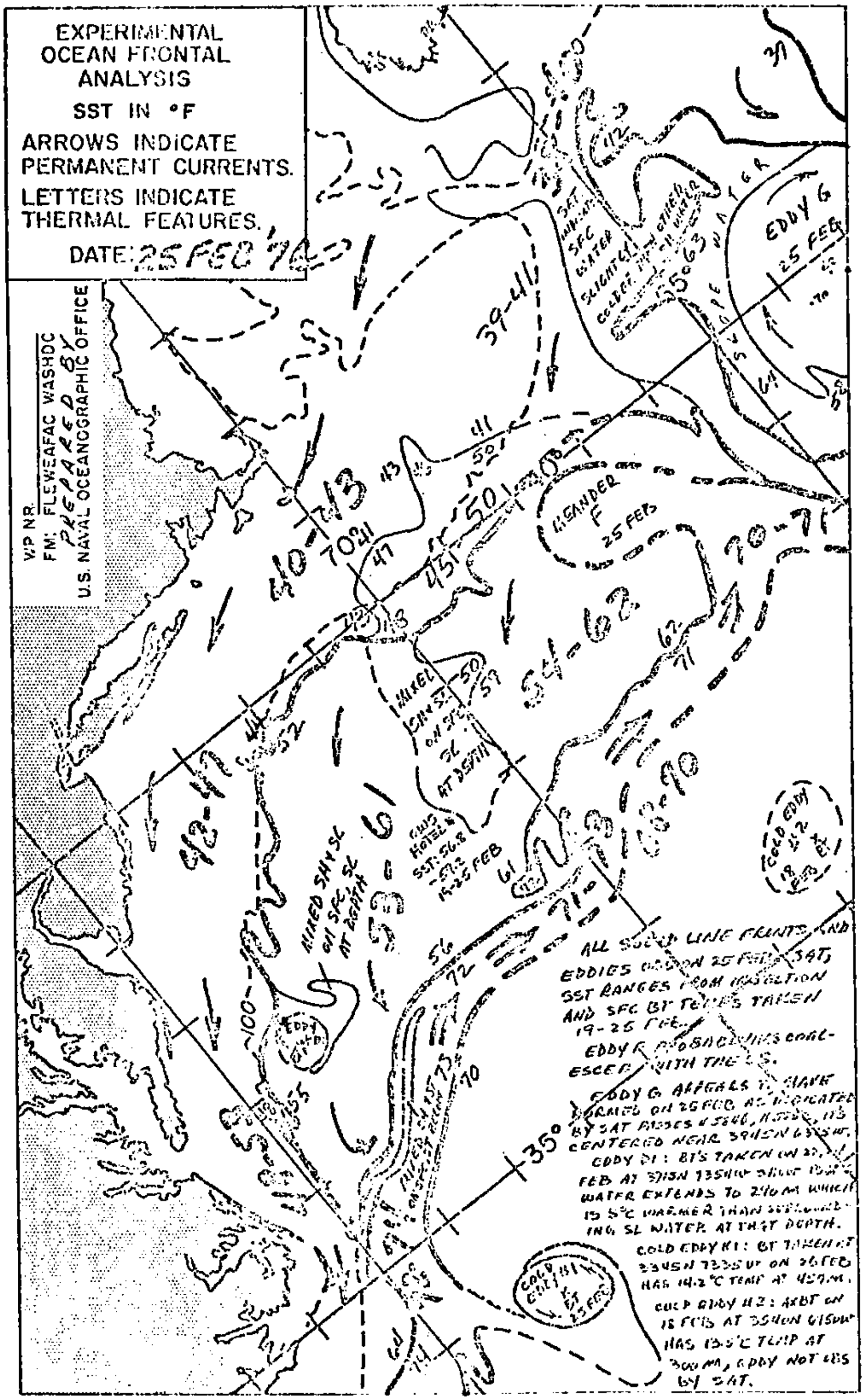

Figure 2. U. S. Naval Oceanographic interpretation of satellite imagery for February 25, 1976. The large warm core eddy (labelled "Eddy G") discussed in the text is at the upper right margin.

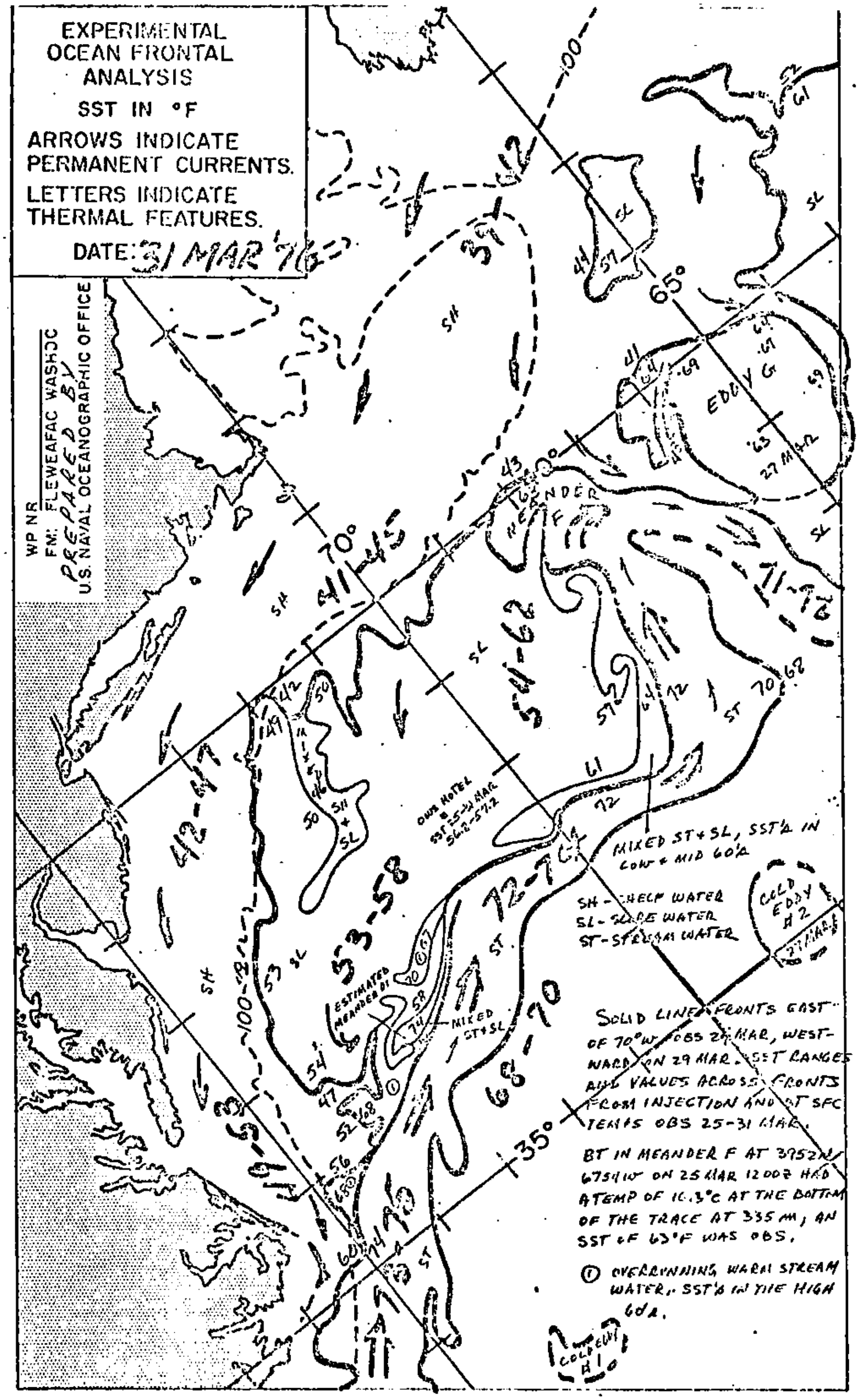

Figure 3. Same as Figure 2 for March 31, 1976. The large eddy (labelled Eddy "G) and the large meander to the west of the eddy are discussed in the text.

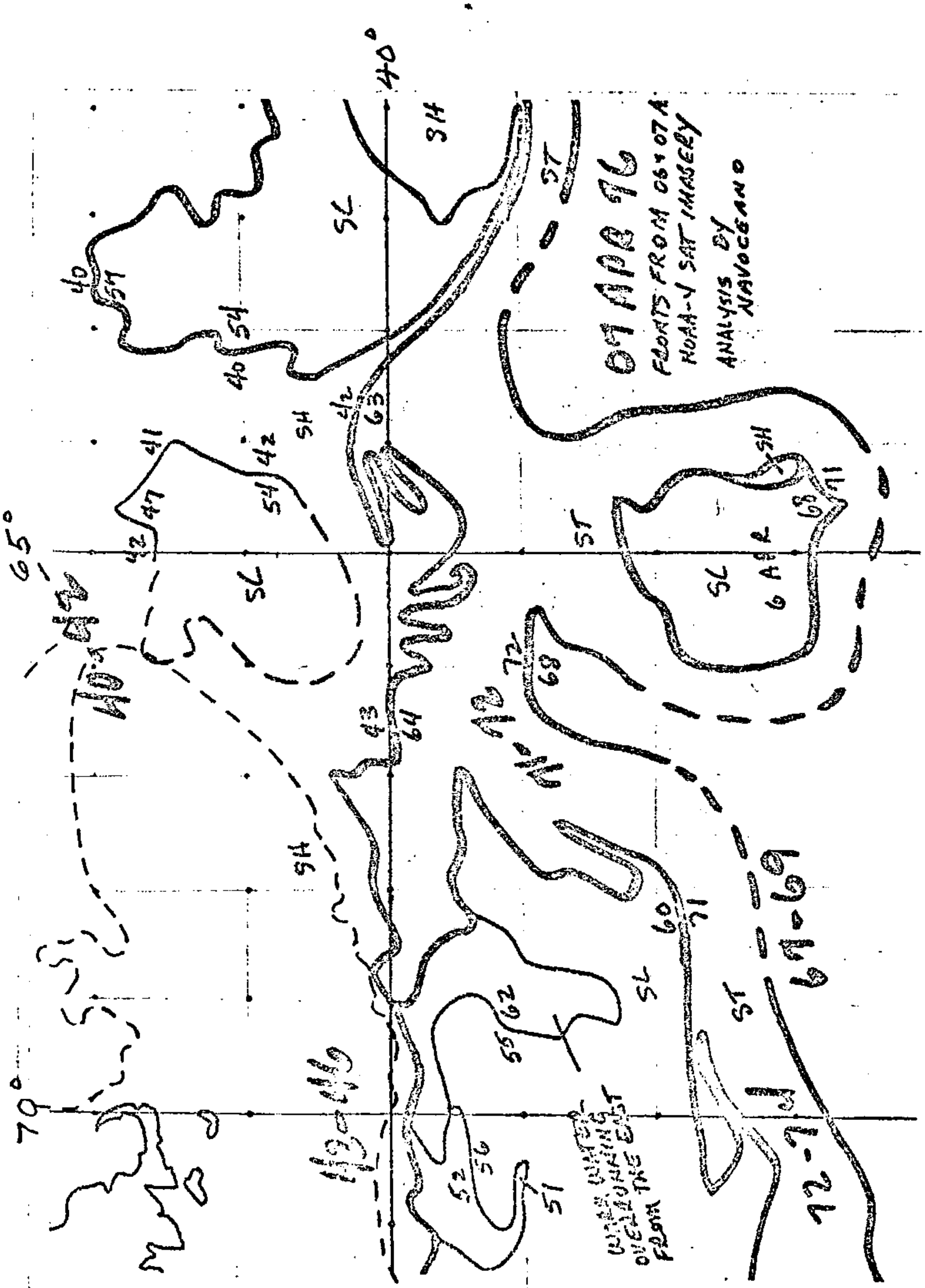

Figure 4. Same as Figure 2 and 3 for April 7, 1976. This is an enlarged portion of the Naval Oceanographic Office interpretation provided by telephone facsimile.

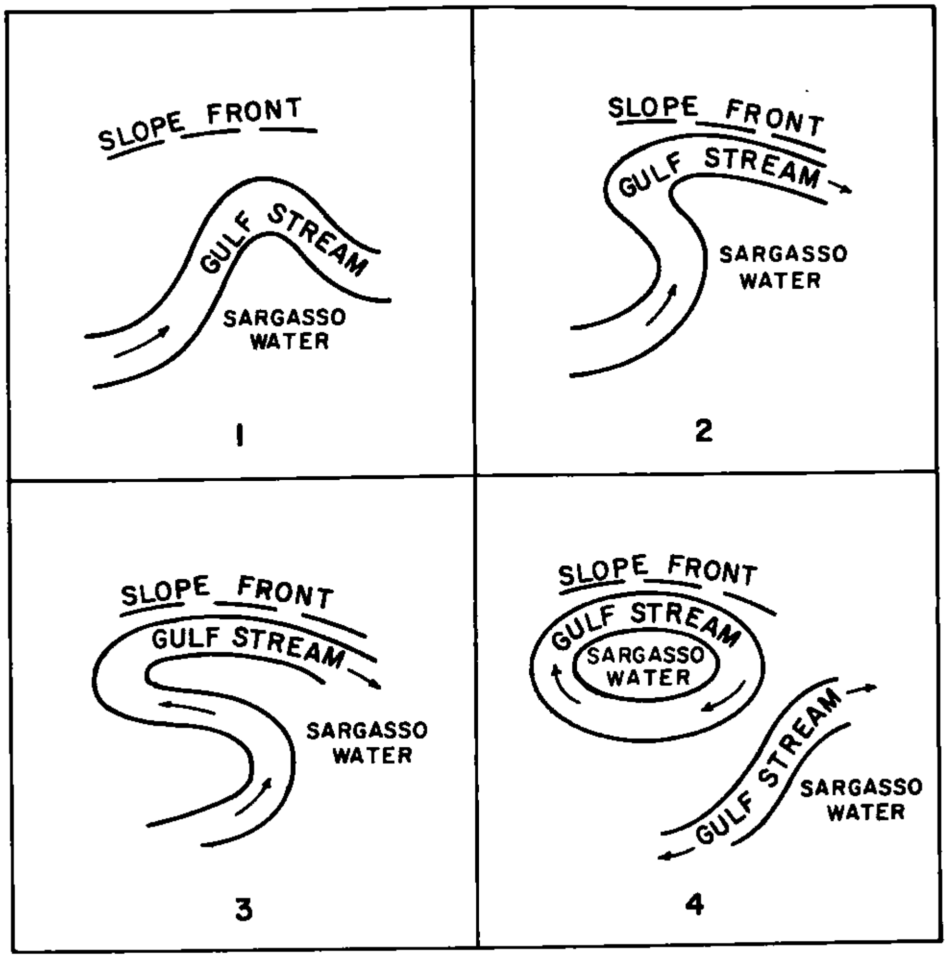

Figure 5. Schematic of warm core Gulf Stream eddy formation (after Gotthardt, 1973).

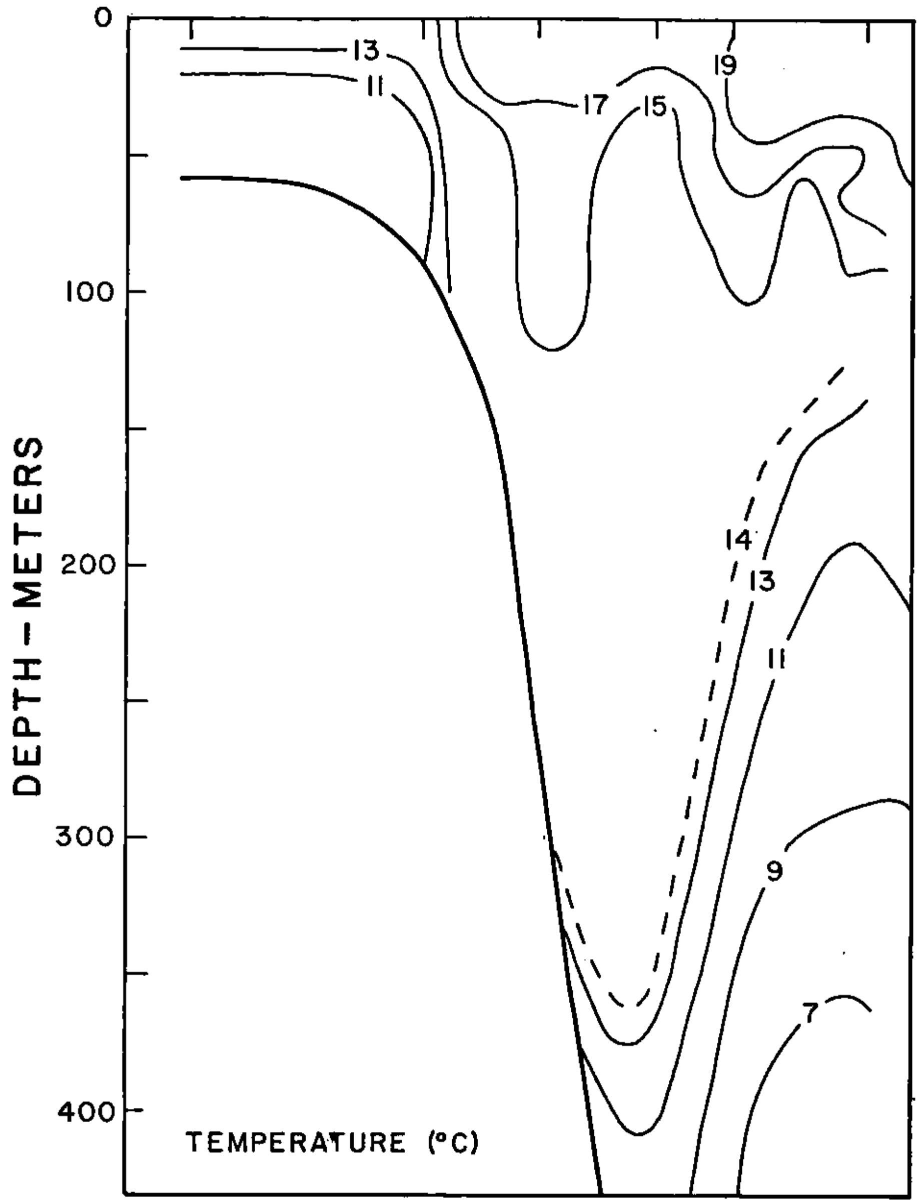

Figure 6. Vertical temperature section illustrating a warm core eddy contacting the outer continental shelf and upper slope near the Hudson Canyon (From Applications Research Division, NavOceanO, 1974).

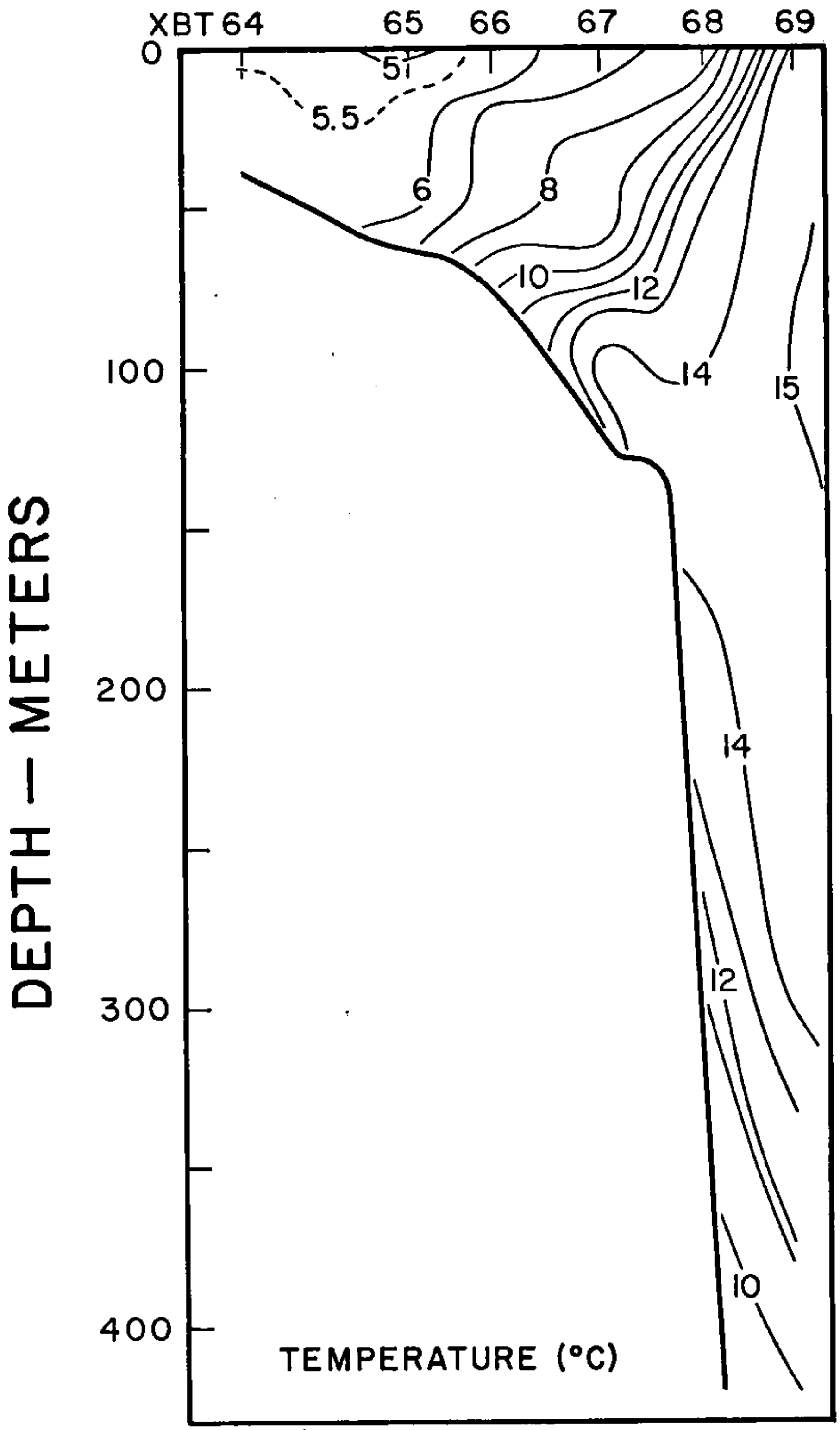

Figure 7. Vertical temperature section illustrating injection of warm water onto the continental shelf from a warm core eddy. Only the inshore margin of the eddy appears in the section. Data from NOAA R/V "Albatross IV", March 28-29, 1974 (After Chamberlin, 1976).

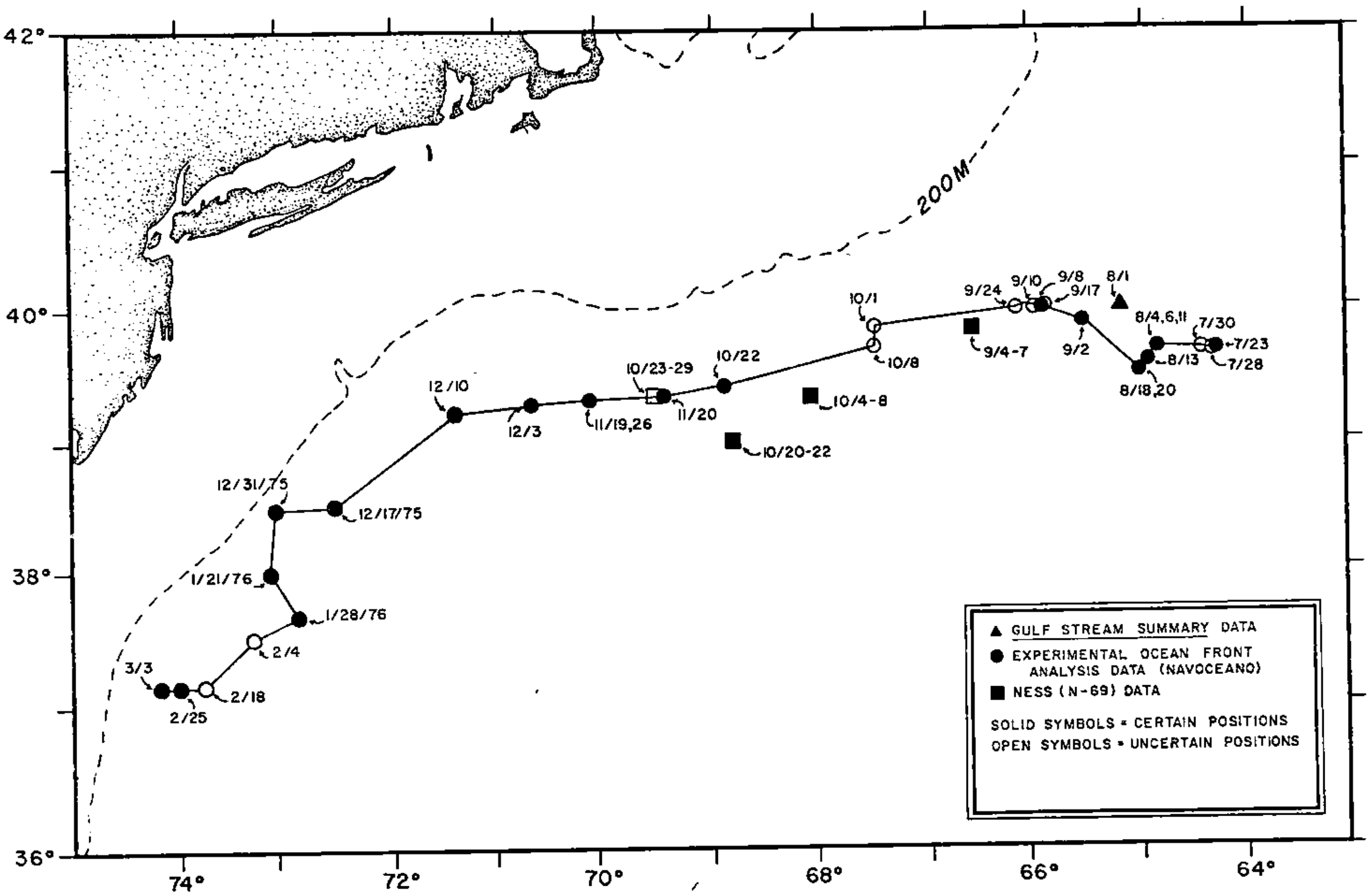

Figure 8. Example of the pathway of a long lived warm core eddy in the slope water. Successive positions of the center of the eddy are plotted. Data from NavOceanO and NESS interpretations of NOAA 3 satellite imagery (After Bisagni, 1976).