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Anticyclonic Warm Core Gulf Stream Eddies off the Northeastern United States During 1979

by

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This report summarizes for the sixth year, 1979, the movements of anticyclonic, warm core, Gulf Stream eddies in the slope water region off the New England and Mid-Atlantic coasts. Previous reports have been developed by Bisagni (1976) for the year 1974-75, Mizenko and Chamberlin (1979a and b) for 1976 and 1977, and Celone and Chamberlin (in press) for 1978.

Information Sources and Analysis Methods

Our eddy tracking analysis is based principally on the eddy positions shown in the weekly satellite derived Gulf Stream Analysis charts issued each Wednesday by the NOAA National Environmental Satellite Service (NESS). Four infrared images per day from the NOAA Geostationary Operational Environmental Satellite (GOES-4) were also used throughout the year, as well as infrared imagery from the TIROS-N satellite and NOAA-6 satellites for selected dates. The satellite imagery is used to produce a single warm core eddy analysis for each week, by modifying the NESS Gulf Stream Analysis charts. In weeks for which there is no clear satellite imagery, eddy positions are interpolated and then adjusted in the end-of-year analysis.

Eddy positions, estimated by eye, are plotted and dated on the trackline charts. When eddy positions are clearly seen as a result of (1) thermal contrast with surrounding slope water or (2) encircling bands of entrained colder shelf water or warmer Gulf Stream water, their center positions are plotted as a closed circle (●) and dated with the day of

observation. The GOES-4 imagery was the main basis for determining these dates. Less certain eddy positions which are estimated from unclear imagery or uncertain entrainment features are plotted as triangles (▲) and dated with the last day of the weekly compilation chart, a Wednesday. Center positions estimated entirely by interpolation are plotted as open circles (o) and dated the same way as for the less certain positions.

At any time of the year, some eddies may be invisible in satellite imagery because of a lack of surface thermal contrast. When eddies in close proximity to one another are invisible or hidden by clouds for a number of weeks there may be uncertainty regarding which is which, when they finally reappear. In such cases, the simplest interpretation of their movements is accepted. The invisibility of eddy 78-I for nine weeks, from 17 January to 20 March (Fig. 1) is an extreme example. During this period of invisibility, however, the northern edge of the Gulf Stream was visible often enough to assure that 78-I was not reabsorbed by the Stream and that no other eddy was generated in its vicinity.

Surface boundaries of eddies are shown for the date of eddy formation and at representative stages within the life of the eddy. These boundaries, interpreted directly from the satellite imagery and encompassing any entrainment features around the eddy, involve unknown degrees of error. Surface thermal expressions of eddies often have a distorted pattern, and shipboard observations have shown that the surface pattern may coincide imperfectly in both location and size with the boundary of the eddy below the surface.

Only eddies which moved west of 60°W during some portion of their lifetime are considered in this analysis. Eddies are labeled with the year when they formed, and alphabetically in the order of their formation.

Simultaneous observation in eddies from aboard two vessels provided subsurface information of unusual interest on two occasions during the year. The first of these observations, during mid-August in eddy 79-B south of Hudson Canyon, defined the eddy location beneath the surface at a time when it had been invisible (or faintly visible) in satellite imagery for over a month, because it lacked surface thermal contrast with surrounding waters. A record set of observations, on 11 October in eddy 79-I south of Georges Bank, provided definition of a large eddy either while it was separating from the Gulf Stream or just after separation. Details on these observations appear below in the discussions of the respective eddies.

Eddy Histories

During 1979, twelve warm core Gulf Stream eddies occurred off the northeastern United States. One, 78-I, formed in 1978 and was tracked during that year by Celone and Chamberlin (MS). Of the eleven 1979 eddies, five were still in existence at the beginning of 1980. The dates of eddy formation and destruction, as well as lifetimes, are listed in Table 1.

Eddy 78-I (Fig. 1) was first observed on 25 October 1978 off the eastern Scotian Shelf, centered at 58.0°W with a 150 km surface diameter (Celone and Chamberlin MS). By 3 January 1979, it was centered at 41.2°N 61.3°W, off the central Scotian Shelf, with a surface diameter of about 210 km. Because of clouds during the first three months of 1979, it was not seen again until 28 March, about 140 km farther to the west. During April and May, 78-I traveled in an irregular, somewhat clockwise pattern within an area southeast of Georges Bank. During the summer and fall it moved generally westward and then southwestward, retaining a relatively constant diameter of about 140 km. During October 78-I moved south and became elongated along the continental slope south of Hudson Canyon. During November it was gradually incorporated by the Gulf Stream east of Virginia; the final remnants being seen on 28 November at 36.5°N 74.4°W.

Eddy 79-A (Fig. 2) formed about 23 February south of Georges Bank, centered at 67.5°W with a surface diameter of about 140 km. The eddy moved relatively steadily to the west and then southwest throughout its lifetime until resorbed by the Gulf Stream about 10 August at 36.8°N 73.9°W.

Eddy 79-B (Fig. 3) separated from the Gulf Stream about 1 April south of eastern Georges Bank, centered at 66°40'W with surface diameter of 155 km. Initial westward movement was followed by irregular movement south of central Georges Bank during May and June. During the summer and fall it travelled generally west and then southwest until reabsorbed by the Gulf Stream about 16 October off southern Virginia, centered at 36.2°N 74.2°W.

Eddy 79-B lacked thermal contrast with the surrounding slope water in July and August, but XBTs from the fishing vessel "Clearview IV" and RV "Endeavor" cruise 041 clearly located it south of Hudson Canyon in mid-August (Figs. 4,5).

The "Clearview IV" was fishing for deep sea red crab, Geryon quinquedans, on the continental slope south of the Canyon. A series of XBT stations were

made from this vessel following observation of easterly currents in the area of the crab traps. On the successive nights of 17-18 August, the XBTs showed the eddy to be approaching the area of the traps. During the same time period, the easterly flow so increased in strength that it was necessary to move some of the fishing gear into the Hudson Canyon.

Eddy 79-C (Fig. 6) formed far to the south of the usual location of warm core eddies, because the Gulf Stream was south of its mean path. The eddy formed about 9 May, centered at 38.0°N 66.7°W, with a surface diameter of about 210 km. As the Gulf Stream began to return to its mean position, 79-C was pushed north to 38.3°N 66.3°W where it was destroyed by a meander about 26 May.

Eddy 79-D (Fig. 7) originated at 40.5°N 60.8°W about 20 May. After formation the 140 km diameter eddy traveled west until late June when it was pushed northeast by a large meander to a position centered at 40.7°N 63.4°W, where it was completely resorbed by 3 July. This meander produced eddy 79-E after incorporating 79-D.

Eddy 79-E (Fig. 8) formed about 10 July from the meander which had absorbed 79-E. It was first observed at 39.5°N 64.3°W, with a surface diameter of 175 km. After moving west during July and then northwest during August, toward the continental slope, 79-E traveled west and then south during the balance of 1979. On 3 January 1980, it had a surface diameter of about 95 km and an estimated location east of the Atlantic coast of Maryland, centered at 38.25°N 72.7°W. After July, it was never clearly apparent in satellite imagery.

Eddy 79-F (Fig. 9) was large and short-lived, forming about 8 August east of Georges Bank, centered at 41.0°N 62.5°W, with a surface diameter of about 200 km. Forced northward by a meander, it was resorbed about 28 August, when centered at about 41.7°N 62.8°W.

Eddy 79-G (Fig. 10) first appeared in satellite imagery east of Georges Bank on 21 September, after apparently forming by detachment of a small portion of a large Gulf Stream meander about 18 September. The eddy was centered at 41.6°N 64.9°W, with a surface diameter of 135 km. During September-November, 79-G remained near the entrance to the Gulf of Maine with little change in location or surface diameter. Late in November, it moved south, and during December west toward the southeast boundary of Georges Bank. Its estimated location on 3 January 1980 was centered at 41.0°N 65.3°W.

Eddy 79-H (Fig. 11) apparently formed about 19 September from another small portion of the same meander that produced 79-G. Centered east of 79-G at 41.8°N 63.0°W, it had a surface diameter of about 125 km. Like 79-G, 79-H was essentially stagnant south of the Scotian Shelf throughout the fall, although showing a net eastward movement of about 95 km. During late December, however, it moved west toward southeastern Georges Bank, and on 3 January 1980 had an estimated center position at 41.3°N 63.5°W.

Eddy 79-I (Fig. 12) was first seen in satellite imagery south of Georges Bank on 16 October with a large surface diameter of 190 km and centered at 39.5°N 67.3°W. Its formation from a westward extending Gulf Stream meander, although hidden by clouds in satellite imagery, is estimated to have been at about 39.5°N 66.75°W on 11 October, on the basis of two XBT sections obtained on that date aboard the RV "Wieczno" and the fishing vessel "Clearwater IV" (Figs. 13, 14, 15). On the previous day, strong eastward currents, presumably from the eddy had caused loss of surface floats on deep sea crab traps deployed from "Clearview IV". Following its formation, 79-I moved west along the southern margin of Georges Bank. In late November a Gulf Stream meander collided with the southern half of the eddy and greatly reduced its surface diameter. The smaller 79-I, remaining distinct in satellite imagery, continued to travel west, and on 3 January 1980, had a 108 km surface diameter and was centered at 39.6°N 69.4°W southeast of Nantucket Shoals.

79-J (Fig. 16) was another short-lived eddy. After forming on 23 November at 39.9°N 65.0°W, the 155 km diameter eddy moved about 75 km southwest until enveloped by a Gulf Stream meander during the second week of December at 39.5°N 65.1°W.

79-K (Fig. 17) formed about 20 December from the west side of the meander which resorbed 79-J. This large (203 km) eddy was originally centered at 39.9°N 65.7°W. It moved northwest toward southern Georges Bank and was centered at 39.8°N 67.3°W on 3 January 1980.

Zonal Analysis

The relative movements of all the 1979 eddies are presented in Table 2, which shows the mid-month position of each eddy with respect to the zone diagrammed in Figure 18. During 1979, the total eddy occurrence for all

zones combined was 43, compared to 24 in 1974, 35 in 1975, 29 in 1976, 45 in 1977, and 32 in 1978. An above average number of zonal occurrences reflects that more eddies formed in 1979 than recorded for any of the previous five years. The greater number of occurrences in 1977, however, is largely explained by the fact that so many of the 1979 eddies formed in the last half of the year (7 of 11), whereas in 1977 (Mizenko and Chamberlin 1979b) 8 of the total 9 formed in the first four months.

Composite Track Lines of Eddy Center Positions and Envelope of Surface Boundaries

The tracklines of eddy center positions and an envelope of eddy surface boundaries appear in Figure 19. Tracklines were compiled from the individual eddy paths presented in Figures 1-17. The envelope was composited from weekly charts of the eddy surface boundaries. Most eddy center positions are found between 38°50'N and 39°50'N although many eddies fall outside of this area, including 79-C, 79-D, 79-F, 79-G and 79-H. Other erratic positions and movements of the eddy centers are responsible for the irregular envelope through which the eddies moved.

Number of Eddies, Times of Formation, and Longevity

During 1979, eleven warm core Gulf Stream eddies formed off the northeast coast of North America. In the previous five years, eddy production has been consistently less: four in 1974, eight in 1975, seven in 1976, nine in 1977, and nine in 1978 (Mizenko and Chamberlin 1979b, Celone and Chamberlin 1980). Four eddies were formed in the first six months of 1979, a continuation of the low production rate in late 1978 (two eddies in the last 5 months). Seven eddies were generated in the second half of 1979, at the rate of one each month (with two forming in September from one meander). This predominance of eddy formation during the second half of 1979 is a distinct departure from the pattern in the previous five years when the number was always greater in the first half except in 1975 when there was equality (4 and 4). Of the total 36 eddies formed during those years, 25 formed in the first half (69%). Although only one 1978 eddy survived into 1979, as of January 1980, there were five 1979 eddies still in existence.

Although careful analysis has not yet been made, it appears that strong

Gulf Stream meandering was responsible for the high rate of eddy production in 1979. The consistent formation of one eddy per month in July-December indicates that the strong meandering was chronic, rather than during shorter time periods as in previous years (Celone and Chamberlin 1980). Strong meandering also accounted for the short lifespan of four of the eddies. Warm core eddies 79-C and 79-F were both formed from a large meander and were quickly engulfed by a subsequent meander. On two occasions, one eddy was absorbed at meander's leading edge and another formed from its trailing edge.

The longevity of 1979 eddies cannot yet be assessed, because five survived into 1980. Excluding those five, the eddies which formed in the beginning of the year were longer-lived. Eddies 78-I, 79-A and 79-B had travelled into the Mid-Atlantic Bight region by mid-July, before the strongest meandering and eddy production was initiated farther to the northeast. Eddies 79-G and 79-H avoided the rapidly meandering Gulf Stream by stagnating near the mouth of the Gulf of Maine. By January 1980 the meandering had declined; therefore, the eddies formed in the latter part of 1979 were able to travel unimpeded southwest into the Mid-Atlantic Bight. Eddy 78-I survived until November of 1979, a total of 401 days. This is the longest-lived eddy during the six years of our analysis.

References

Bisagni, J. J. 1976. Passage of anticyclonic Gulf Stream eddies through Deepwater Dumpsite 106 during 1974 and 1975. NOAA Dumpsite Evaluation Report 76-1, 39 p.

Mizenko, D. and J. L. Chamberlin. 1979a. Anticyclonic Gulf Stream eddies off the northeastern United States during 1976. In: Goulet, J. R. and E. D. Haynes (eds.) Ocean Variability - 1976. NOAA Tech. Rep. NMFS Circ. 427:259-280.

Mizenko, D. and J. L. Chamberlin. 1979b. Gulf Stream anticyclonic eddies (warm core rings) off the northeastern United States during 1977. Annal. Biol. 34:39-44.

Celone, P. J. and J. L. Chamberlin. 1980. Anticyclonic warm core Gulf Stream eddies off the northeastern United States during 1978. Annal. Biol. (in press).

Table 1. Eddy Formation, Destruction Dates, and Life Spans

Eddy	Dates*	Life Span (Days)
78-I	10/25/78 - 11/28/79	401
79-A	2/23/79 - 8/10/79	169
79-B	4/1/79 - 10/16/79	199
79-C	5/9/79 - 5/26/79	18
79-D	5/20/79 - 7/3/79	45
79-G	7/10/79 - into 1980	>175
79-F	8/8/79 - 8/28/79	21
79-G	(9/18/79)- into 1980	>105
79-H	(9/18/79) - into 1980	>105
79-I	(10/11/79) - into 1980	> 82
79-J	11/23/79 - 12/14/79	22
79-K	12/20/79 - into 1980	> 12

* Dates in parentheses could be off by greater than one week. Dates not in parentheses are accurate to within one week, and generally are accurate to within several days.

Table 2. Eddy Positions at Mid-month with respect to Zone during 1979

	J	F	M	A	M	J	J	A	S	O	N	D
1.	78-I							79-F		79-H	79-H	79-H
2.		78-I				79-D				79-G	79-G	
3.			78-I	78-I	78-I		79-E	79-E			79-J	79-G
4.				79-B	79-C	78-I	78-I		79-E	79-I	79-I	79-K
5.			79-A	79-A	79-B	79-B	79-B	78-I	78-I	79-E		79-I
6.					79-A	79-A		79-B		78-I	79-E	79-E
7.							79-A		79-B		78-I	
8.										79-B		

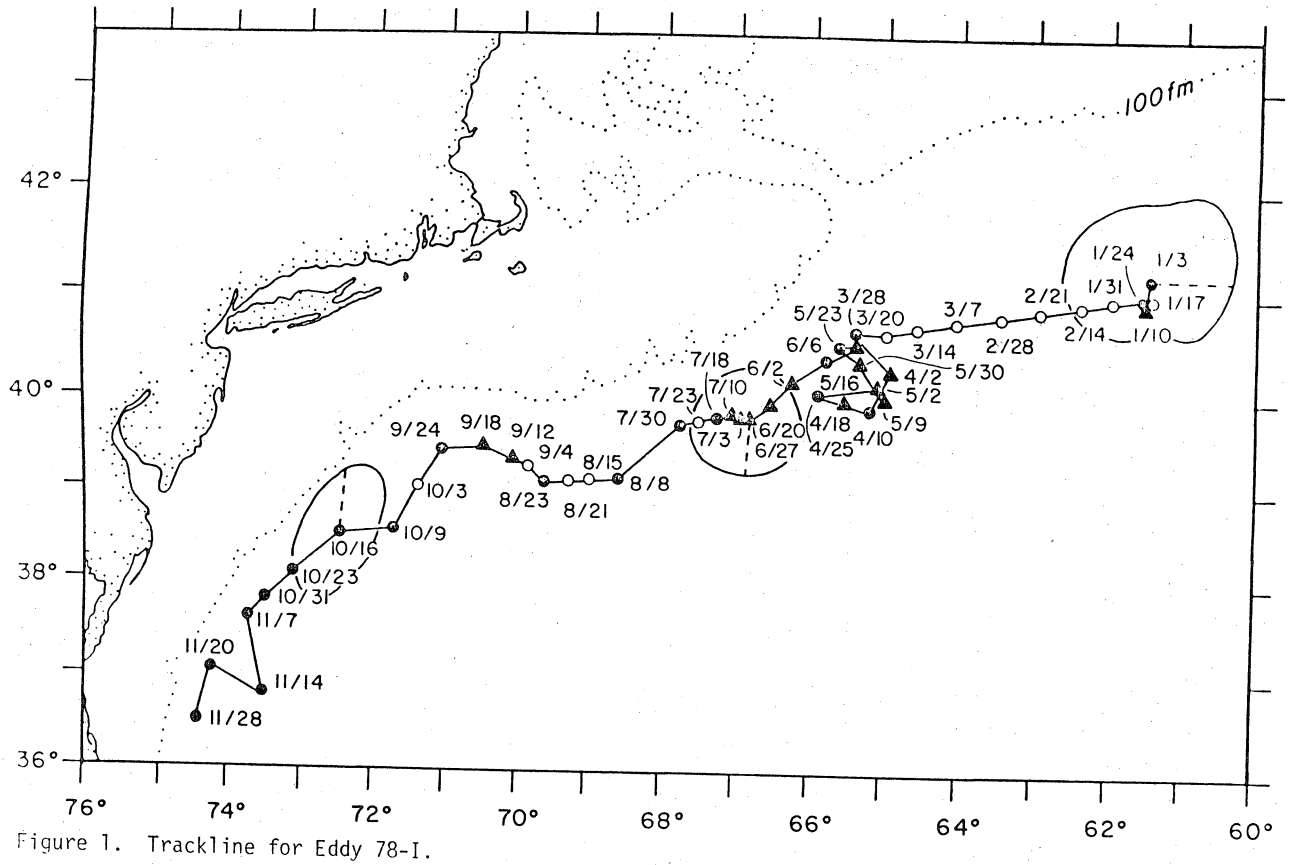

Figure 1. Trackline for Eddy 78-I.

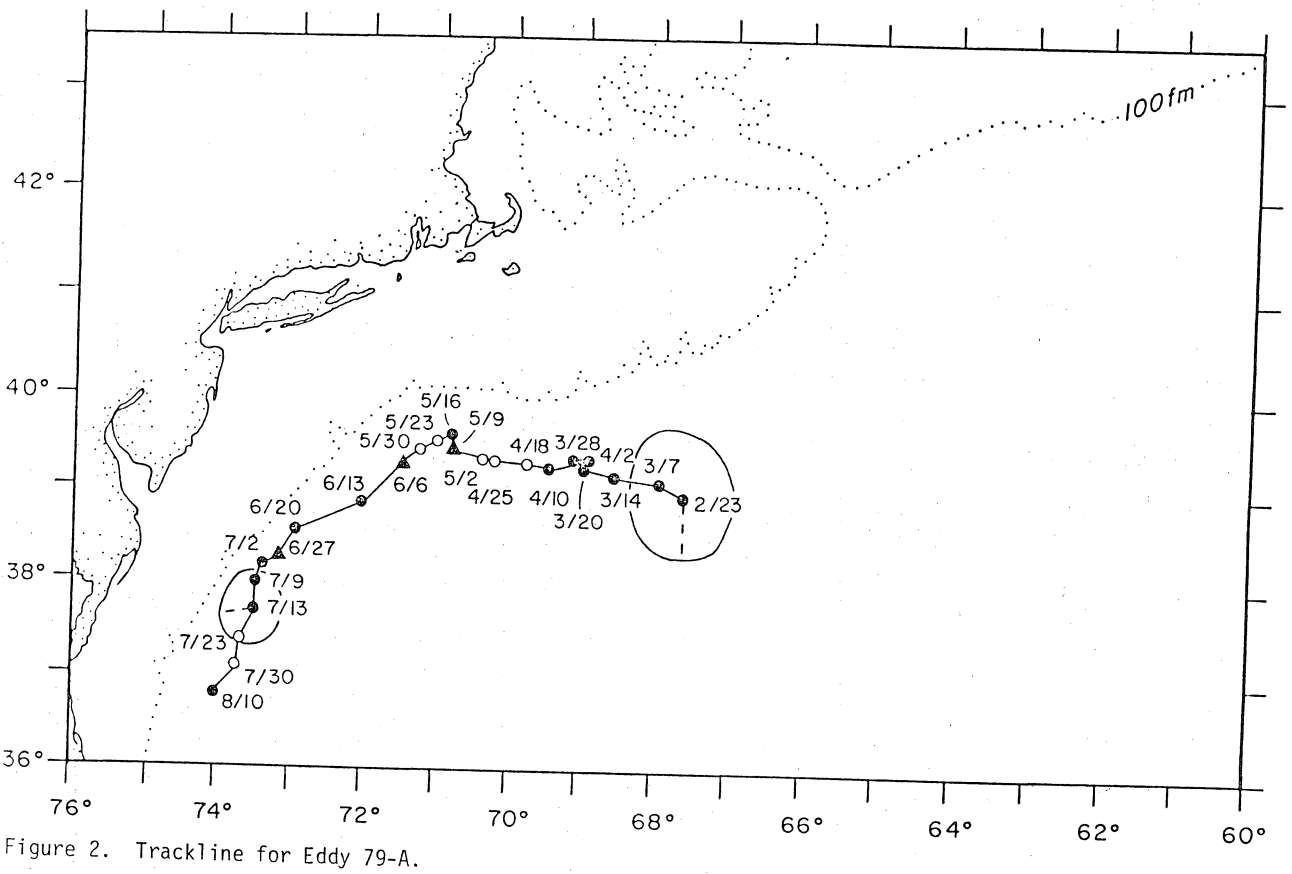

Figure 2. Trackline for Eddy 79-A.

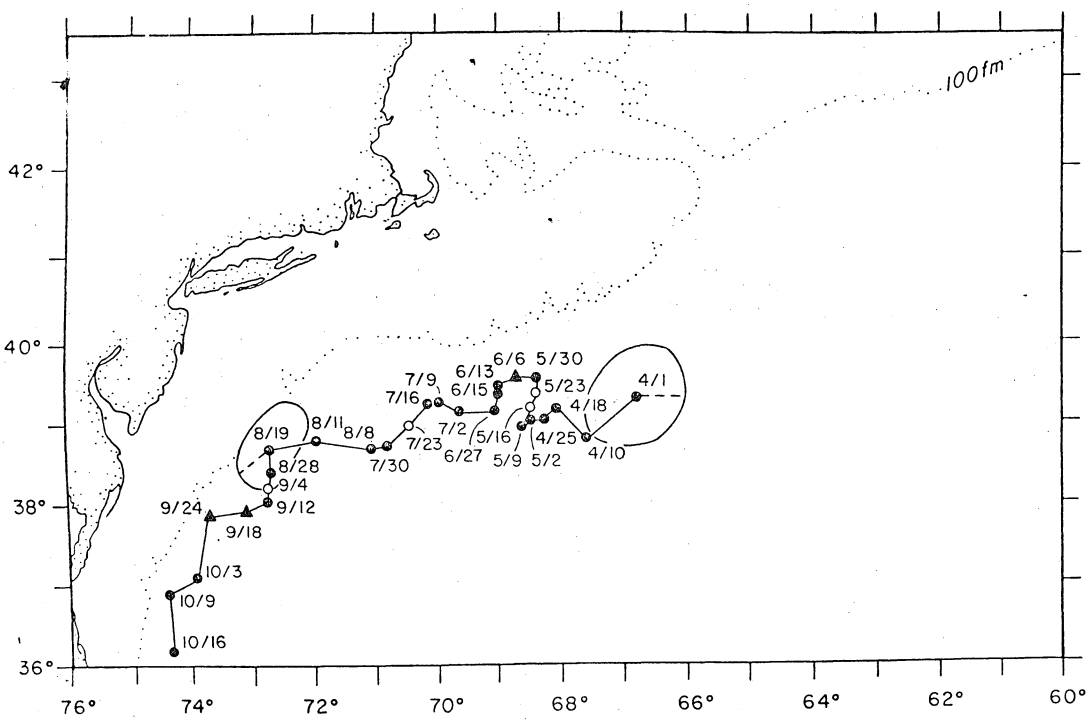

Figure 3. Trackline for Eddy 79-B.

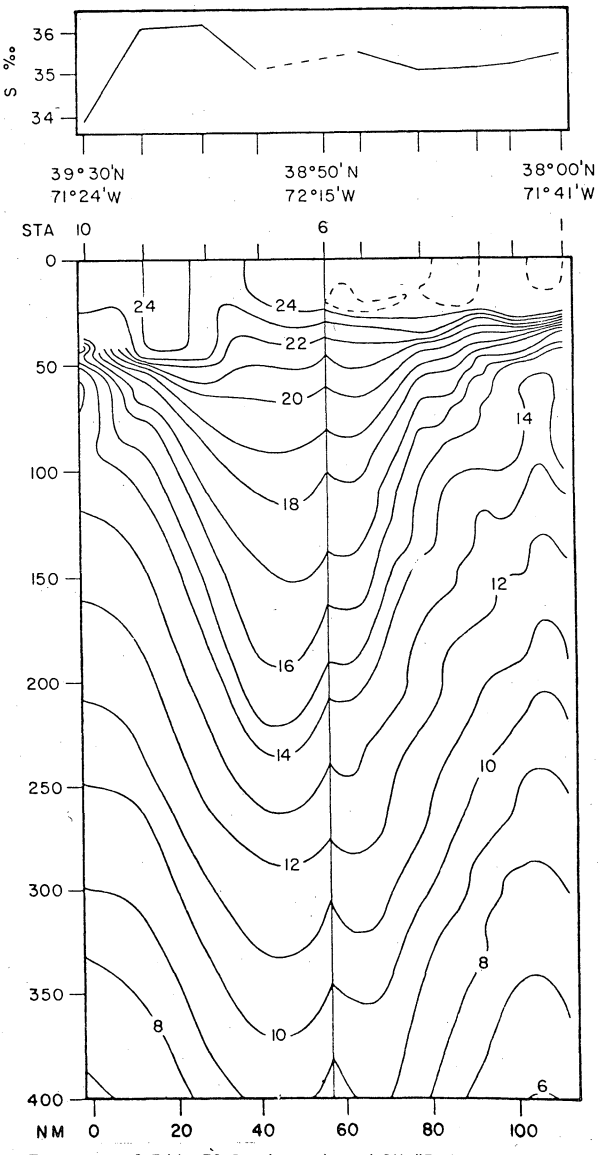

Figure 4. Transect of Eddy 79-B, done aboard RV "Endeavor" on 18-19 August, east of Cape May. Station locations appear on Figure 5.

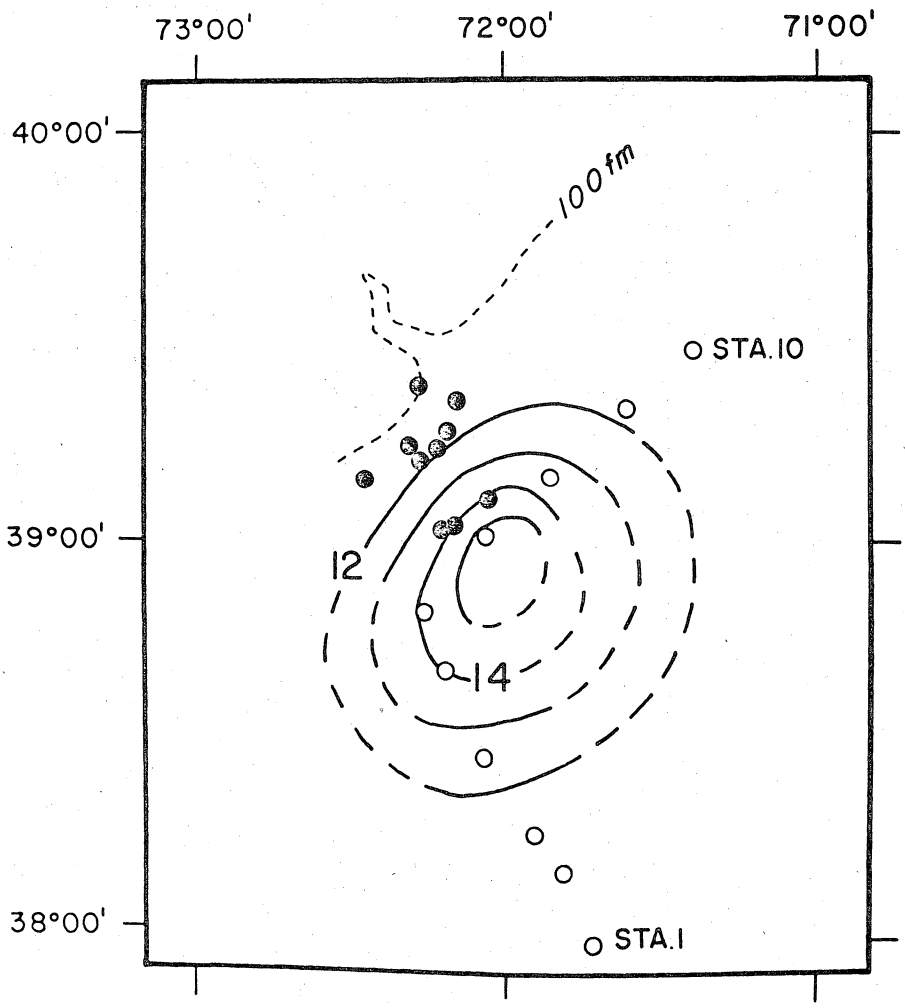

Figure 5. Eddy 79-B temperatures (°C) at 200 m, collected by RV "Endeavor" (o) on 18-19 August and "Clearview IV" (●) on 17-18 August.

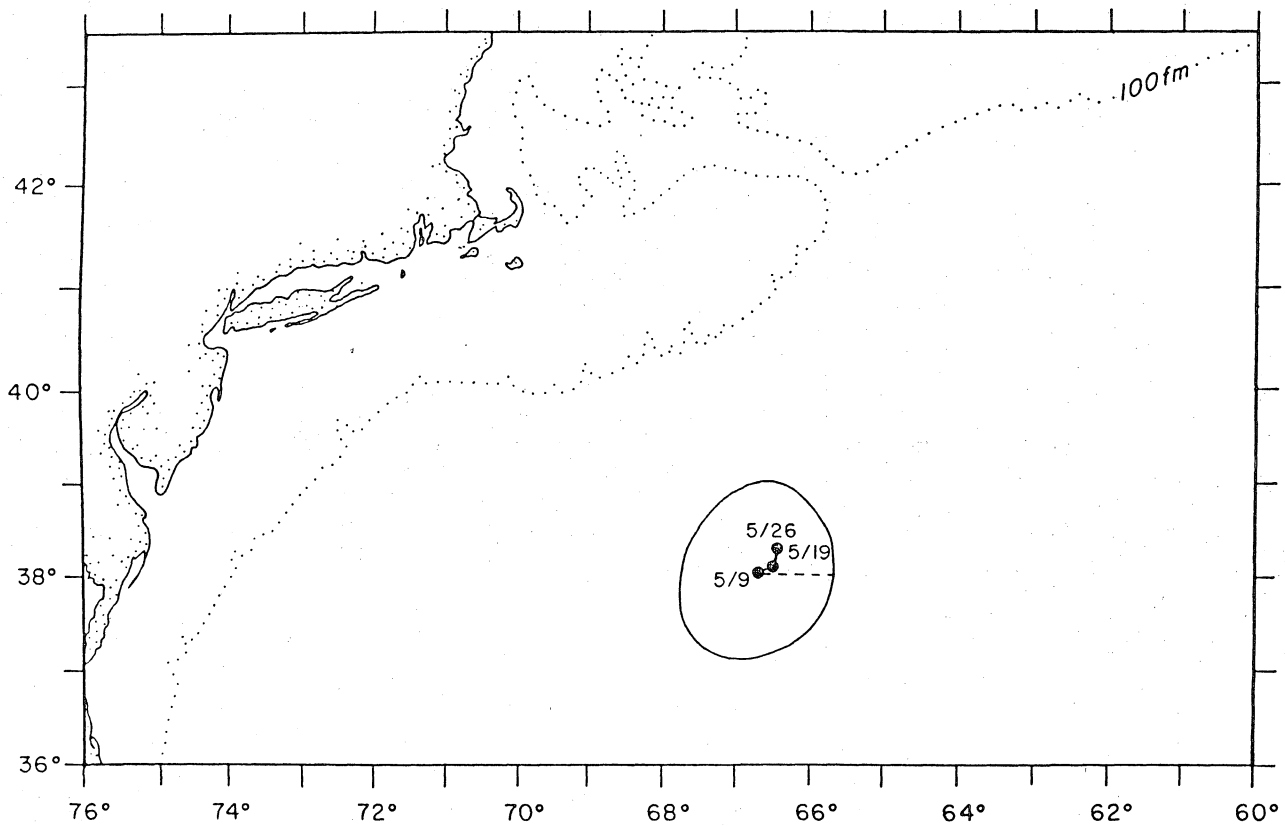

Figure 6. Trackline for Eddy 79-C.

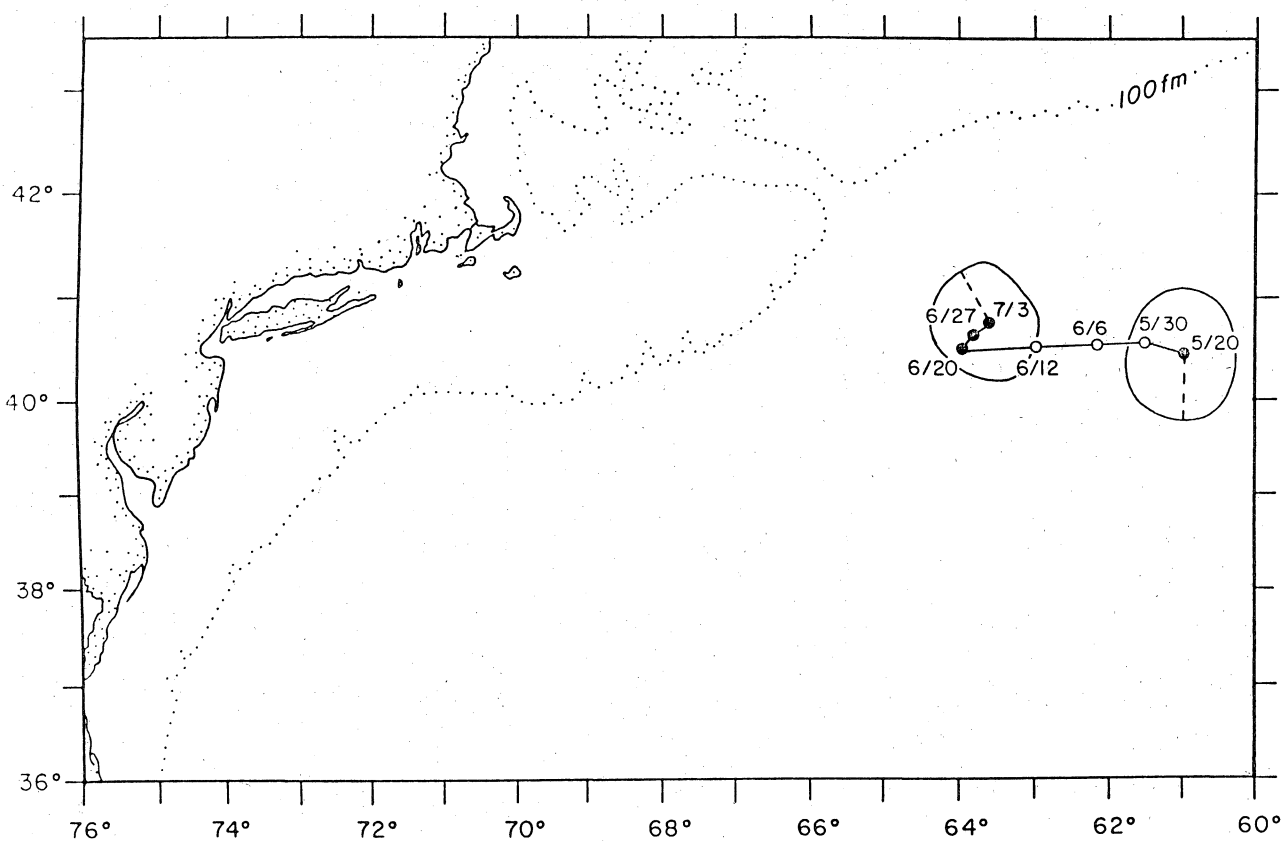

Figure 7. Trackline for Eddy 79-D.

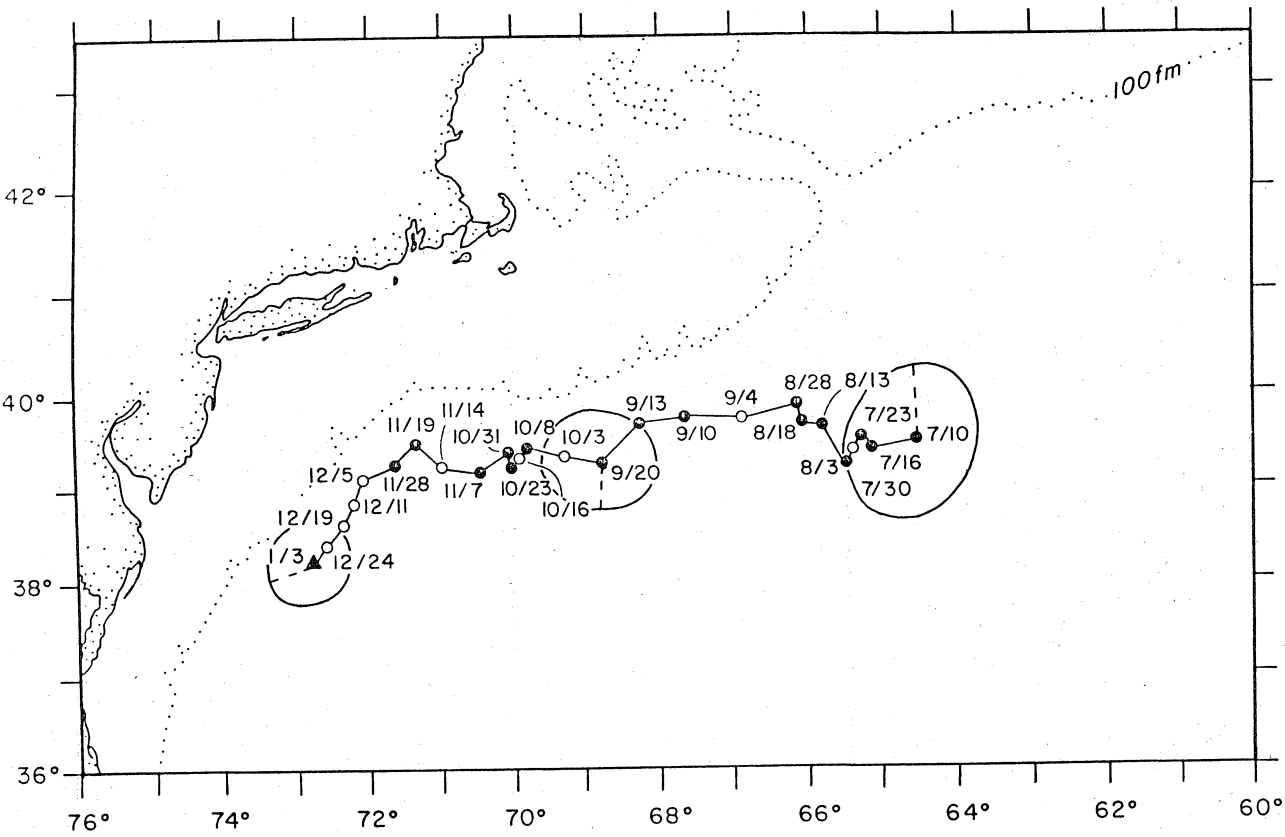

Figure 8. Trackline for Eddy 79-E.

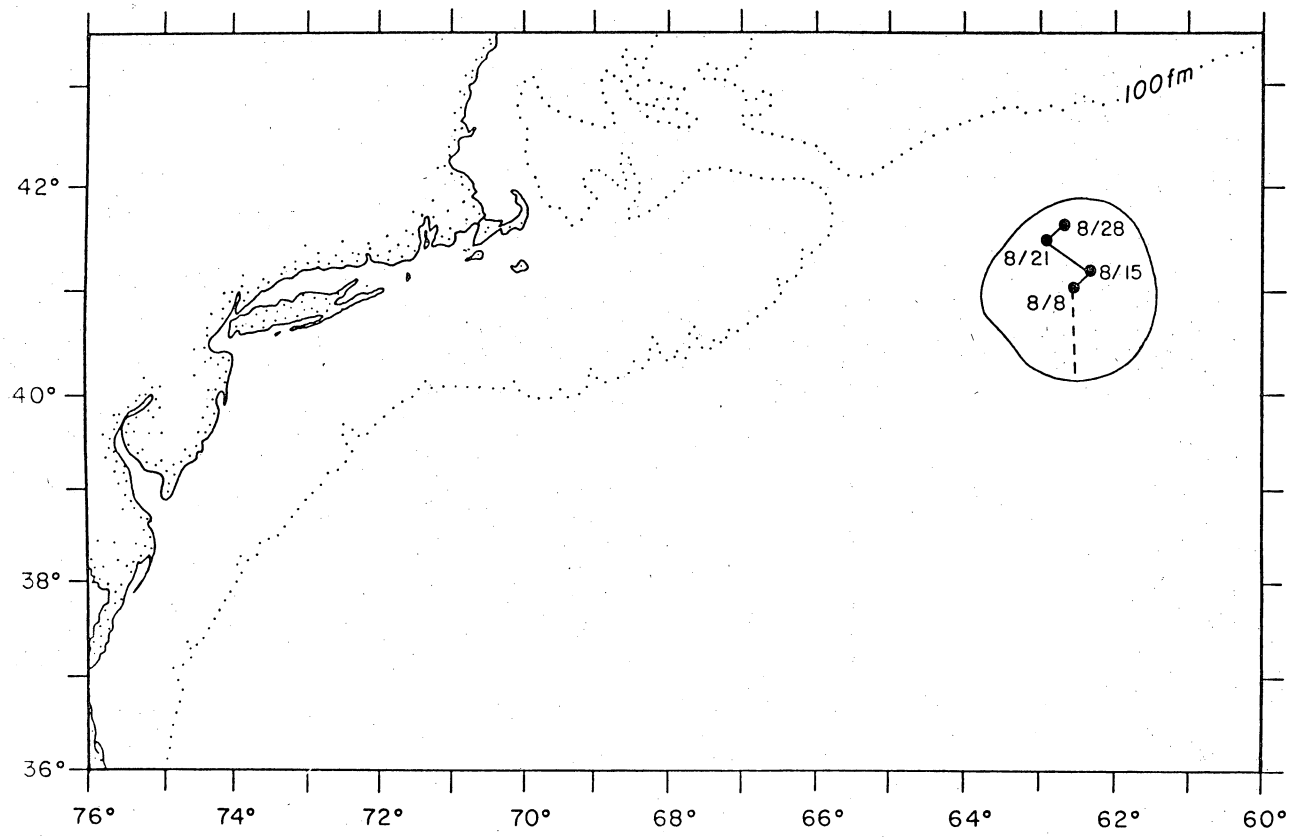

Figure 9. Trackline for Eddy 79-F.

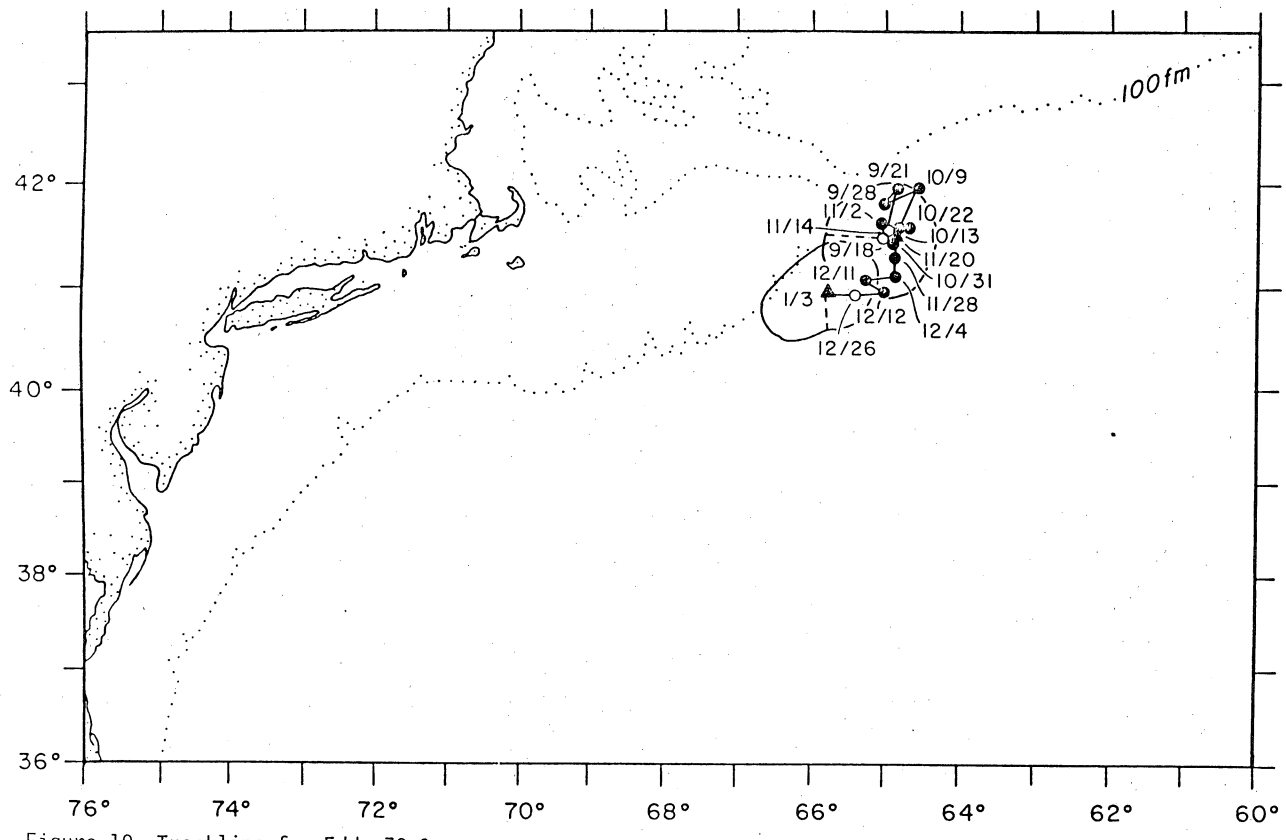

Figure 10. Trackline for Eddy 79-G.

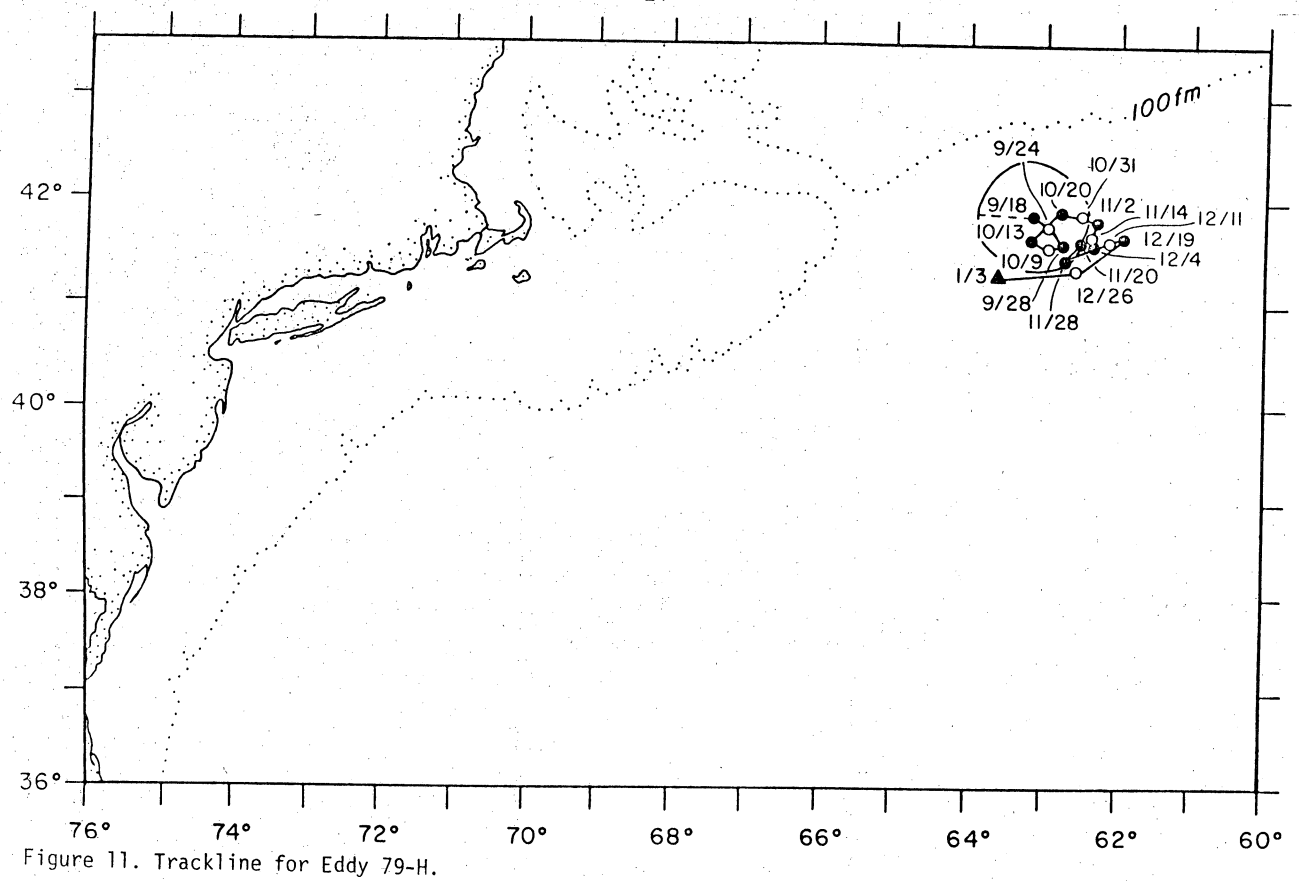

Figure 11. Trackline for Eddy 79-H.

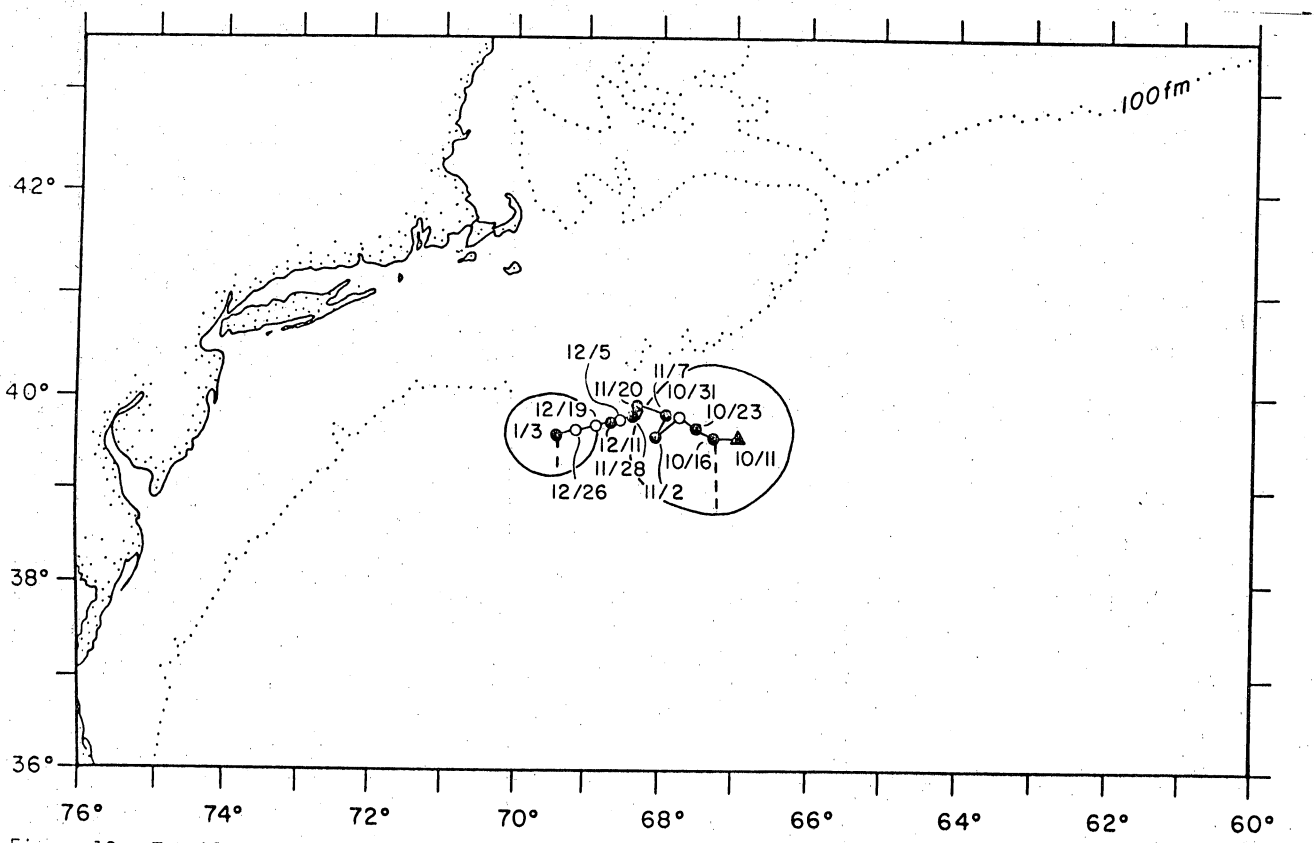

Figure 12. Trackline for Eddy 79-I.

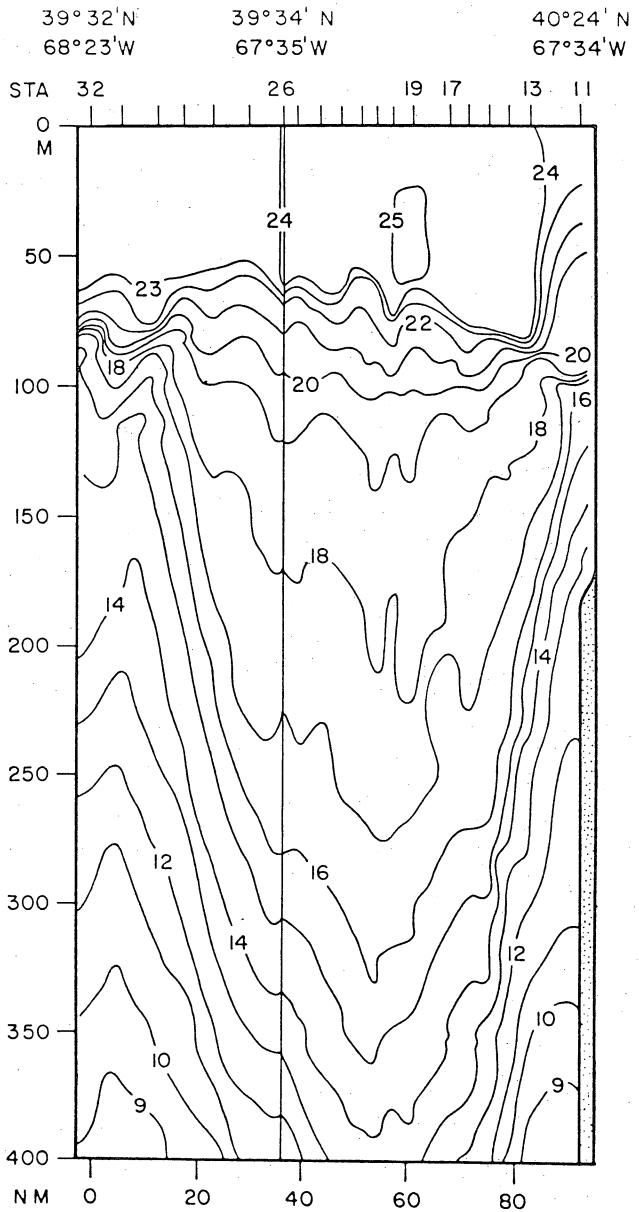

Figure 13. Transect of Eddy 79-I, done aboard RV "Wieczno" on 11 October, south of New England. Station locations appear on Figure 15.

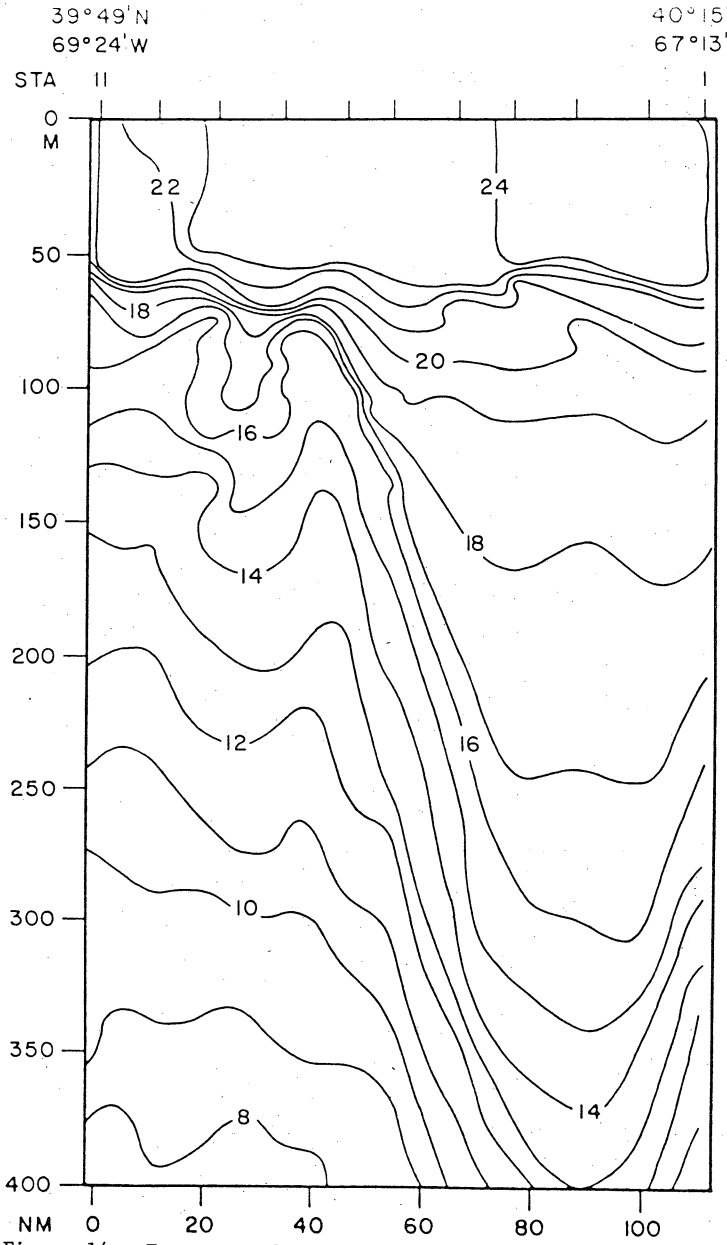

Figure 14. Transect of Eddy 79-I, done aboard "Clearview IV" on 11 October, south of New England. Station locations appear on Figure 15.

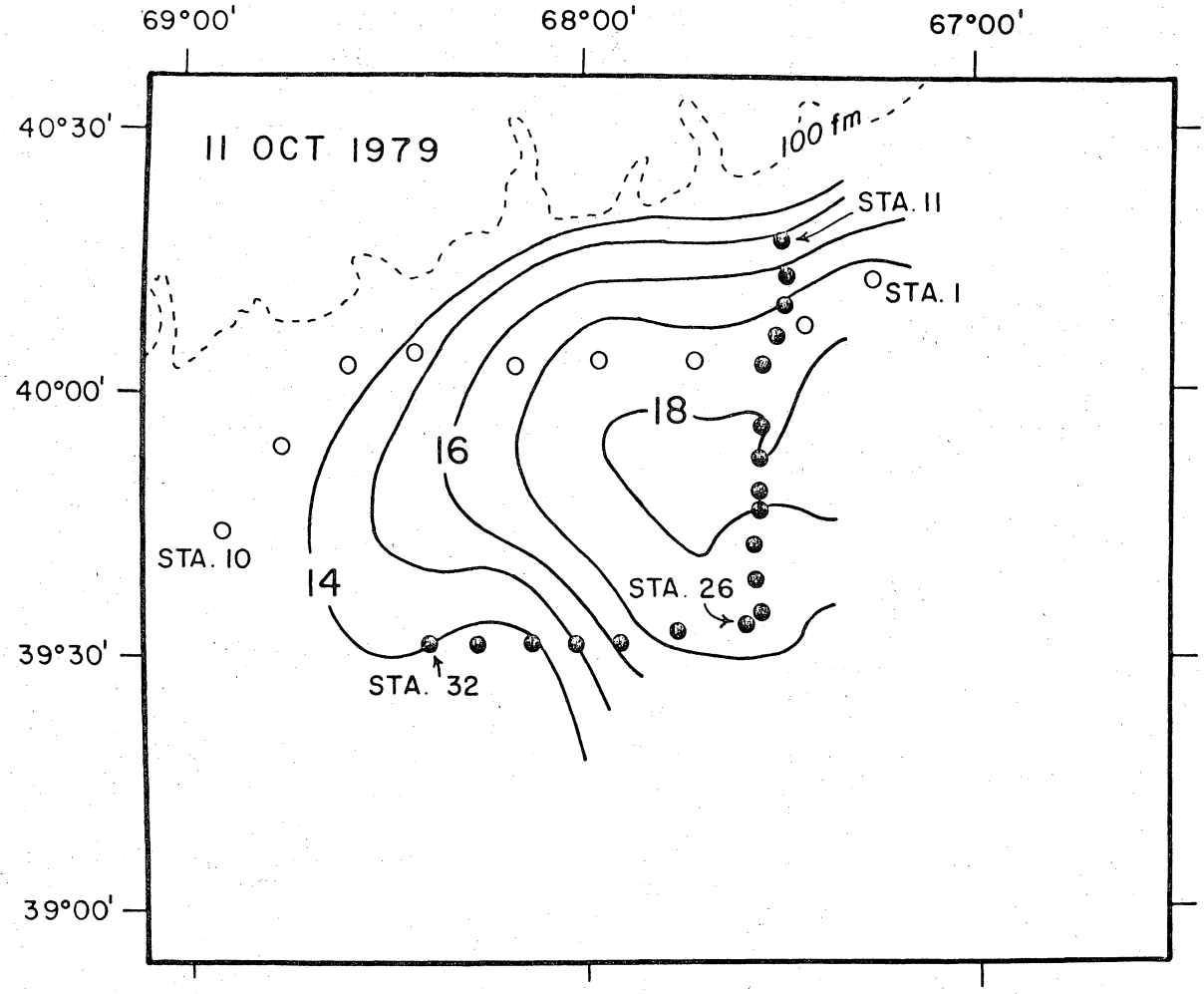

Figure 15. Eddy 79-I temperatures (°C) at 200 m, collected by RV "Wieczno" (●) and "Clearview IV" (o).

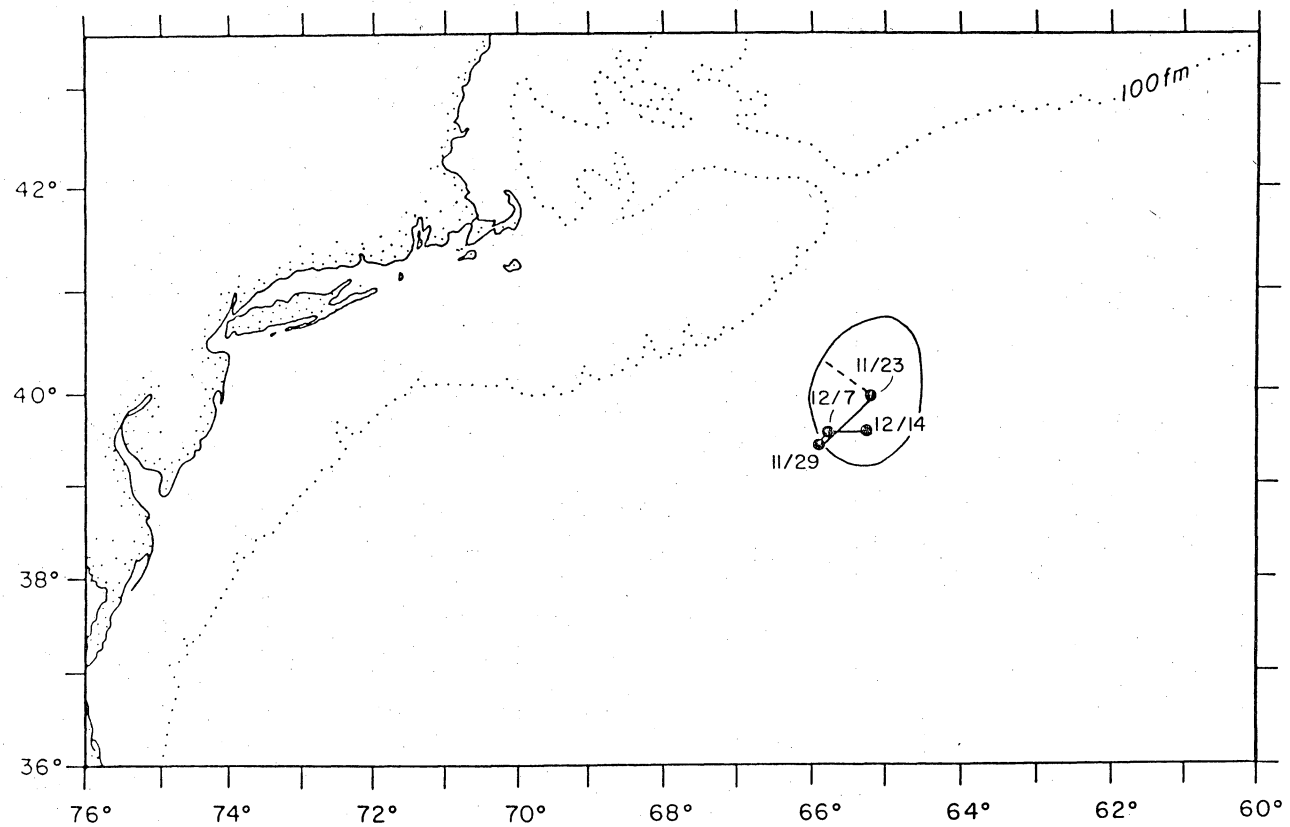

Figure 16. Trackline for Eddy 79-J.

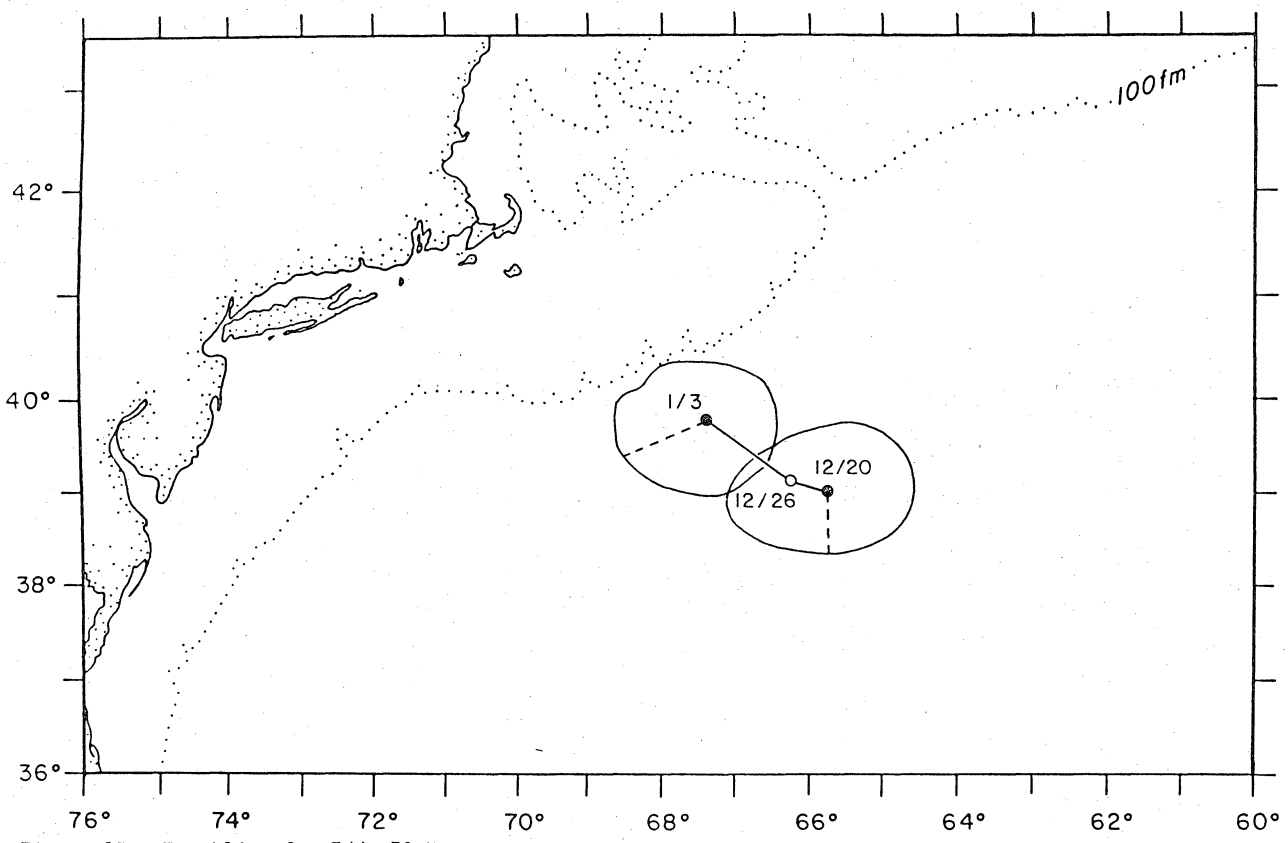

Figure 17. Trackline for Eddy 79-K.

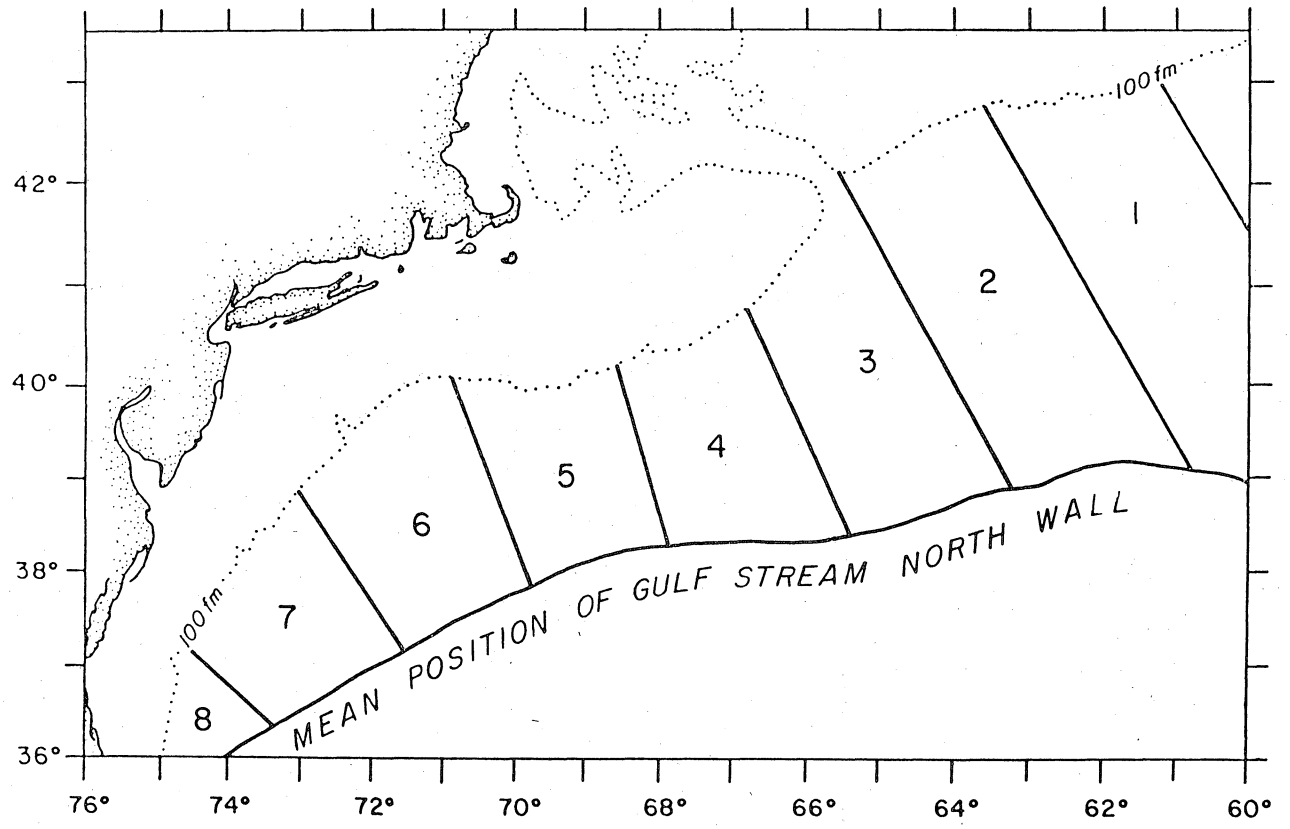

Figure 18. Zones used for Table 2.

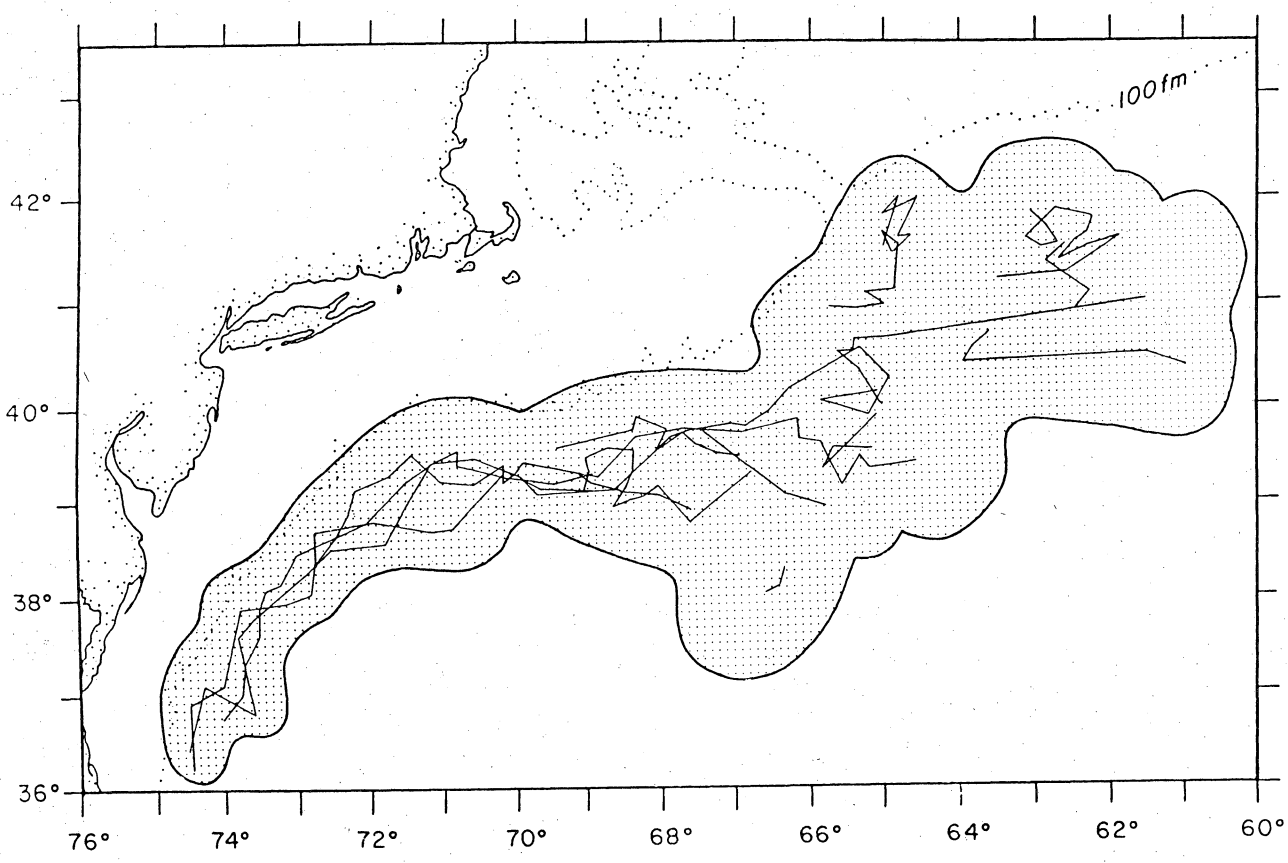

Figure 19. Tracklines of eddy center positions and envelope of eddy surface boundaries for eddies during 1979.