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# Anticyclonic Warm Core Gulf Stream Rings off Northeastern United States During 1980

by

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This report summarizes for a seventh year, 1980, the movements of anticyclonic, warm core, Gulf Stream rings (eddies) in the slope water region off the New England and Mid-Atlantic coasts. Similar yearly analyses have been reported by Bisagni (1976) for the year 1974-75, Mizenko and Chamberlin (1979 a, b) for 1976 and 1977, Celone and Chamberlin (1980) for 1978, and Fitzgerald and Chamberlin (in press) for 1979.

## Information Sources and Analysis Methods

The analysis is based primarily on the ring positions shown in two series of frontal analysis charts: (1) Satellite Derived Oceanographic Analysis charts prepared each Wednesday by the NOAA National Environmental Satellite Service from January 2 - May 21, and (2) the succeeding Oceanographic Analysis charts prepared by the NOAA National Weather Service and National Environmental Satellite Service each Monday, Wednesday, and Friday, starting on May 28. In addition, AVHRR infrared satellite imagery from NOAA polar-orbitting satellites infrared imagery was used selectively for the first six months of the year, and received twice daily starting in July. Up to four infrared images per day were also received through the year from NOAA geo-stationary environmental satellites. The imagery was used to produce a single warm core ring analysis for each week, by modifying the above mentioned frontal analysis charts. In weeks for which there was no clear satellite imagery, ring positions were interpolated and then adjusted in the end-of-year analysis.

[1] Submitted for publication in ICES Annales Biologiques

Ring center positions, estimated by eye, are plotted and dated on the trackline charts. When ring positions were clearly seen in imagery 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, the center positions were plotted as closed circles (●) and dated with the day of observation. The GOES-4 imagery was the main basis for determining these dates during January to July, while the daily NOAA-6 imagery was used from August to December. Less certain ring positions, estimated from unclear imagery or questionable entrainment features, were plotted as triangles (▲) and dated with the last day of the weekly compilation chart. 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 rings may be invisible in satellite imagery because of a lack of surface thermal contrast. When rings 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 has been accepted.

Surface boundaries of rings are shown for the estimated date of ring formation and at representative stages in the life of the ring. These boundaries, interpreted directly from the satellite imagery and encompassing any entrainment features around the ring, involve unknown degrees of error. Surface thermal expressions of rings 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 ring below the surface.

Only rings which occurred west of 60°W during some portion of their lifetimes are considered in this analysis. Rings are labeled with the year when they formed, and alphabetically in the order of their formation.

In addition to the Gulf Stream rings, an anomalous ring-like feature is also described.

Ring Histories

A total of thirteen warm core, Gulf Stream rings occurred off the northeastern United States during 1980. Five of them (79-E, 79-G, 79-H, 79-I and 79-K) were formed during the last half of 1979 and survived into 1980. Three of the eight rings that formed during 1980 still existed at the end of the year.

Table 1 lists the dates of ring formation and destruction, as well as their longevity in days.

Ring 79-E (Fig. 1) formed about 10 July 1979 at about 39.5°N, 64.3°W, southeast of Georges Bank as reported by Fitzgerald and Chamberlin (1981). The last five ring positions reported in that paper have been revised; the new positions appear in Table 2. On 1 January 1980 Ring 79-E was positioned at 39.0°N, 71.5°W, southeast of the Hudson Canyon. The ring was hidden by clouds in satellite imagery during most of January, but reappeared east of the Delmarva Peninsula in February. Ring 79-E continued to travel southwest and was resorbed by the Gulf Stream about 5 March.

Ring 79-G (Fig. 2) formed from the northwest part of a large Gulf Stream meander about 18 September 1979, centered at 41.6°N, 64.9°W, close to the offing of the Northeast Channel of the Gulf of Maine. By the end of 1979, the ring was located off southeastern Georges Bank at 41.0°N, 65.8°W, (Fitzgerald and Chamberlin, 1981). The ring travelled west near the continental slope until mid-April, when it veered offshore and moved southwest through the mid-slope water region. The presence of Ring 79-G off the Hudson Canyon in mid-May was confirmed by a temperature section collected from the MORMAC "Rigel" on cruise 80-04 (section prepared by M. M. Hughes and S. K. Cook, on file at Atlantic Environmental Group). On 31 May the small (70 km) ring was absorbed into Gulf Stream water entrained by Ring 80-A.

Ring 79-H (Fig. 3) formed close to the Scotian Shelf about 18 September 1979 from the northeast part of the same meander which produced Ring 79-G. By 2 January the ring was centered at 41.2°N, 62.9°W. (Fitzgerald and Chamberlin, 1981). Although the ring was hidden by cloud cover in the satellite imagery during most of January and February, it was apparently resorbed about 5 March at 40.4°N, 65.8°W by the northern edge of a large Gulf Stream meander. Ring 80-A then formed from this meander.

Ring 79-I (Fig. 4) formed south of Georges Bank about 11 October 1979 centered at about 39.5°N, 67.3°W. It had reached 39.6°N, 69.4°W, southeast of Nantucket Shoals by the end of 1977 (Fitzgerald and Chamberlin, 1981). A vertical temperature section from USCGC "Gallatin" cruise 80-01, running southwest from the New York Bight apex on 24-25 January, traversed the southwest flank of 79-I, which was over-ridden at the surface by cold shelf water (section prepared by M. M. Hughes and S. K. Cook, on file at Atlantic Environmental

Group). The ring was resorbed by the Gulf Stream east of Cape Hatteras about 9 April, 1980.

Ring 79-K (Fig. 5) formed about 20 December, 1979, centered at 38.9°N, 65.7°W about 150 km southeast of Georges Bank, it had moved near the continental slope south of the Bank by year's end (Fitzgerald and Chamberlin, 1981).

During the spring of 1980, two vertical temperature sections were obtained which traversed 79-K in a NW to SE direction off Hudson Canyon. The first, on 6 April from MORMAC "Rigel" cruise 80-03, passed through the southwest flank of 79-K just before the ring travelled in a clockwise loop east of the Canyon during the following five weeks (section prepared by M. M. Hughes and S. K. Cook, on file at Atlantic Environmental Group). The second temperature section, on 16 May from NOAA R/V "Kelez" cruise 80-02, was apparently near the center of the ring (Hughes and Cook, 1982. Annls. biol., Copenh., 36; Fig [Fig. 3 in submitted MS]).

Ring 79-K was resorbed by the Gulf Stream east of Chesapeake Bay mouth about 14 July.

Ring 80-A (Fig. 6) formed about 10 March from the Gulf Stream meander which had resorbed Ring 79-H several days before. This large (154 km) ring was first located southeast of Georges Bank, centered at 39.8°N, 65.4°W. In some published reports, this ring has been labelled 79-H (Fitzgerald and Crist, 1980 and West, 1980); however, in our yearend analysis we have concluded that a Gulf Stream meander resorbed 79-H during March and formed 80-A. Ring 80-A frequently increased in diameter through contacts with the Gulf Stream. After entering the slope water region south of New England in late May, it became broader by extensive entrainment of shelf water from the north and Gulf Stream water from the south. In the process, it became the largest diameter warm core ring (179 km) even reported west of the 70° W meridian (Fitzgerald and Crist, 1980). The entrainment continued until early August, during which time the ring remained off Hudson Canyon.

While this large ring was off Hudson Canyon, a vertical temperature section passing through it, near the center, was obtained from MORMAC "Argo" on 1 July by Hughes and Cook (1982. Annls. biol. Copenh. 36; Fig. [Fig. 4 in submitted MS]). The section shows not only the great size of the ring, but also, at its offshore margin entrained shelf water below the surface to a depth of about 75 m.

By late August, the ring had decreased in diameter and moved to the east of the Delmarva Peninsula, but continued to show strong entrainment of shelf water at the surface. The ring was reduced to 69 km in diameter by October and resorbed by the Gulf Stream east of Cape Hatteras by mid-month.

Ring 80-B (Fig. 7) detached from the Gulf Stream on 9 April, centered about 200 km southeast of Georges Bank (40.3°N, 63.7°W). When the ring reached 70.0°W it turned southwest and moved through the mid-slope water thereby remaining far (>75 km) offshore of the 200 meter isobath during its entire lifetime. The ring was resorbed by a small Gulf Stream meander about 27 October at 36.8°N, 72.4°W east of the Chesapeake Bay mouth.

Ring 80-C (Fig. 8) originated south of Sable Island, Nova Scotia near 41.7°N, 60.3°W, on 22 May. Approximately two months later, on 19 July, it was resorbed by a Gulf Stream meander at 41.2°N, 62.8°W south of Emerald Bank.

Ring 80-D (Fig. 9) detached from the Gulf Stream on 10 June centered at 40.2°N, 62.9°W, south of the Scotian Shelf. This small ring (102 km) was resorbed only a month later by the large Gulf Stream meander which later formed 80-E. Ring 80-D was last seen in satellite imagery about 8 July, at 40.0°N, 63.6°W, 40 km west of where it formed.

Ring 80-E (Fig. 10) formed from the extended meander which had resorbed 80-D. It formed about 28 July at 40.9°N, 65.0°W, southeast of the Northeast Channel of the Gulf of Maine. During October, influenced by the Gulf Stream, the ring appeared to move erratically to the northeast and then to the southeast while decreasing in diameter from over 120 km to less than 70 km in two weeks. It was resorbed about 27 October at 39.7°N, 66.6°W, near the southeast side of Georges Bank.

Ring 80-F (Fig. 11) formed on 4 August at 40.2°N, 61.8°W about 250 km south of Western Bank on the Scotian Shelf. It moved northeastward over 200 km during August before turning to a more normal west-southwest direction in early September. At the end of 1980, it was south of Georges Bank (centered at 39.8°N, 66.9°W, on 5 January 1981).

Ring 80-G (Fig. 12) was a large ring (165 km) which originated south of Georges Bank (39.2°N, 68.6°W) on 11 October. At the end of 1980 it was south of Cape Cod (centered at 39.4°N, 70.3°W, on 5 January 1981).

Ring 80-H (Fig. 13) formed on about 14 November centered at 39.0°N, 65.9°W, about 180 km southeast of Georges Bank. By the end of 1980, the ring had moved west-northwest to within 10 km of Georges Bank (centered at 39.8°N, 68.5°W, on 5 January 1981.)

An Anomalous Anticyclonic Ring-Like Feature

During year-around research on Gulf Stream warm core rings since 1974, we have been unable to explain the origin of several small anticyclonic ring-like features visible in satellite imagery of the slope water region off the southern New England and middle Atlantic coasts. Ordinarily seen adjacent to the shelf-slope water front and visible less than a month, these features have usually resembled the streaks of entrained shelf water or warm slope water than often partly or fully surround Gulf Stream warm core rings. With surface diameters as large as 100 km, they have been similar in size to old eroded warm core rings occurring in this region. We have not, in fact, been able to distinguish them from such rings in the imagery.

In the last half of April, 1980, a rather different small anticyclonic feature appeared in infrared satellite imagery at a location near the Gulf Stream east of the lower Delmarva Peninsula (Figs. 14-15). Earlier in the month, immediately to the north of where the feature later appeared, an irregular band of warm slope water extended from the Gulf Stream westward across the slope water region, a distance of about 280 km, between 37°-38°N latitude (chartlet for April 12 in Fig. 14). By April 17, the feature had begun to appear and by April 23 had enlarged and resolved itself into a nearly circular body of warm water about 65 km in diameter. Temperature contrast with the surrounding water was sharp. Full resolution (8 km) digital infrared data (uncorrected to absolute sea surface temperature values) from the NOAA geostationary satellite, SMS-2, for April 22, showed the feature to be 3°C warmer than surrounding slope water and 4°C colder than the maximum in the adjacent Gulf Stream.

The surface thermal boundary (front) of the feature is diagrammed in Figure 14 for five dates from April 23 to May 17. By May 11, it had moved about 35 km WNW from its original location, decreased in thermal contrast with surrounding slope water, expanded to a diameter of about 100 km, and begun to entrain shelf and slope water in the pattern of Gulf Stream warm core rings. The feature was then larger in its surface expression than nearby warm core rings 79-G and 79-K (May 11 chartlet in Figure 14). Subsequently, it decreased in size while moving SW until absorbed by the Gulf

Stream east of the Chesapeake Bay mouth, about June 11. The trackline of the feature is charted in Figure 15.

Zonal Analysis

A generalized summary of the movements of rings relative to one another, during 1980, is presented in Table 3, which shows their mid-month positions with respect to the zones diagrammed in Figure 16. Total zone-month occurrences in this table is 50, the largest number in seven years of analysis (24, 35, 29, 45, 32, and 43, respectively for the years 1974-1979). Thirty-eight percent of the 1980 total, however, results from five rings which carried over from 1979. This unusual carry over stemmed from the large number of rings that formed during the last half of 1979 (7 of the 11 that formed during 1979). In the five years prior to 1979, ring formation predominated during the first half of the year (69%).

Two rings occupying the same zone at mid-month occurred four times in 1980, whereas this happened only once during the previous six years (May 1977). On inspection, however, the four occurrences do not appear remarkable. In February, 79-H was near the northeast channel of the Gulf of Maine and 79-G was south of H. In March, 79-G was immediately to the east of 79-K, having moved westward faster than K during the previous few weeks. Such close proximity of rings resulting from different rates of motion has often occurred, but in past years has not occurred when they were in the same zone at mid-month. In May, 79-G, reduced in size, had moved offshore in a SW direction to a position close to the SE of 79-K. In November, 80-G and H were respectively near the west and east side of zone 4.

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

A composite of the tracklines of ring center positions, derived from Figures 1-13, and an envelope of ring surface boundaries appear in Figure 17. The envelope was composited from surface boundaries in weekly modified frontal analysis charts. The envelope is fairly uniform in width over its entire length, not becoming distinctly narrower at the southwest end, as was the case during the previous six years when all rings stayed relatively close to the continental slope off the Middle Atlantic coast.

Number of Rings, Times of Formation and Longevity

During 1980, eight warm core Gulf Stream rings formed off the northeast coast of North America. In the previous six years, ring production has usually been higher: 4, 8, 7, 9, 9, and 11, respectively from 1974-79 (Mizenko and Chamberlin 1979b, Celone and Chamberlin 1980, Fitzgerald and Chamberlin 1981). The rate of formation was uniform compared to that of prior years; four formed during the first half of 1980 and four during the second half. The intervals between dates of formation varied from 7 to 80 days, with a mean of 43. Three rings survived into 1981, in contrast with the five surviving from 1979.

The 1979 rings that persisted into 1980 and the first two formed in 1980 were long-lived, all surviving more than 170 days. The rings which formed in mid-1980 were shorter lived, 28-94 days.

## 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.

Celone, P. J. and J. L. Chamberlin. 1980. Anticyclonic warm core Gulf Stream eddies off the northeastern United States during 1978. Annls biol., Copenh., 35:50-55.

Fitzgerald, J. L. and J. L. Chamberlin. 1981. Anticyclonic warm core Gulf Stream eddies off the northeastern United States during 1979. Annls biol., Copenh., (in press).

Fitzgerald, J. L. and R. W. Crist. 1981. Satellite shows record diameter warm core eddy off Hudson Canyon. Coastal Oceanography and Climatology News, 2(4):39.

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. Annls biol., Copenh., 34:39-44.

West, S. 1980. Ring Around the Gulf Stream. Science News, 118(21):330-332.

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

| Ring | Dates* | Life Span (Days) |
|---|---|---|
| 79-E | 7/10/79 - 3/5/80 | 240 |
| 79-G | (9/18/79) - 6/4/80 | 261 |
| 79-H | (9/18/79) - 3/7/80 | 172 |
| 79-I | (10/11/79) - (4/9/80) | 182 |
| 79-K | 12/20/79 - 7/14/80 | 208 |
| 80-A | 3/10/80 - 10/17/80 | 221 |
| 80-B | 4/9/80 - 10/27/80 | 201 |
| 80-C | 5/22/80 - 7/19/80 | 58 |
| 80-D | 6/10/80 - (7/8/80) | 28 |
| 80-E | 7/25/80 - (10/27/80) | 94 |
| 80-F | 8/1/80 - into 1981 | >152 |
| 80-G | 10/11/80 - into 1981 | > 81 |
| 80-H | 11/14/80 - into 1981 | > 47 |

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

Table 2. Revised Center Positions of Ring 79-E for 5 December 1979 to 3 January 1980, from those published by Fitzgerald and Chamberlin (1981).

| Date | Published | Revised |
|---|---|---|
| 12/5 | 39.1°N 72.0°W | 39.3°N 71.6°W |
| 12/11 | 38.8°N 72.2°W | 39.2°N 71.5°W |
| 12/19 | 38.6°N 72.4°W | 39.2°N 71.5°W |
| 12/24 | 38.4°N 72.6°W | 39.1°N 71.4°W |
| 1/3 | 38.2°N 72.8°W | 39.0°N 71.4°W |

Table 3. Ring Positions at mid-month with respect to zone during 1980 (locations of zones in Figure 16)

| | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | | | | | | 80-C | | | 80-F | | | |
| 2. | 79-H | | | 80-B | | 80-D | 80-C | 80-F | | 80-F | 80-F | |
| 3. | 79-G | 79-H<br>79-G | 80-A | | 80-B | | 80-B | 80-E | 80-E | | | 80-F |
| 4. | 79-K | | | 80-A | | 80-B | | | | 80-E | 80-H<br>80-G | 80-H |
| 5. | 79-I | 79-K | 79-G<br>79-K | 79-G | 80-A | 80-A | | 80-B | | 80-G | | 80-G |
| 6. | 79-E | 79-I | | 79-K | 79-G<br>79-K | | 80-A | | 80-B | | | |
| 7. | | 79-E | 79-I | | | 79-K | 79-K | 80-A | 80-A | 80-B | | |
| 8. | | | | | | | | | | 80-A | | |

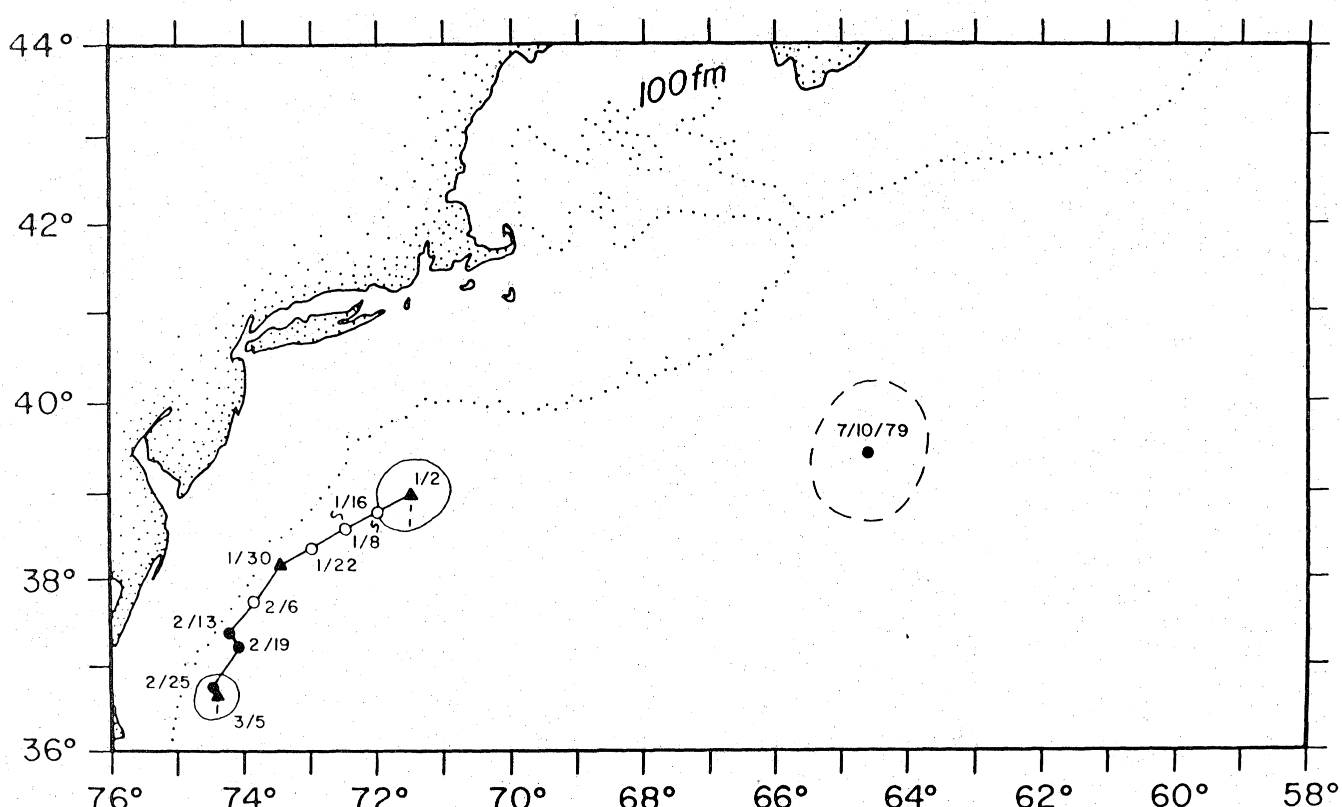


Figure 1. Trackline for Ring 79-E.

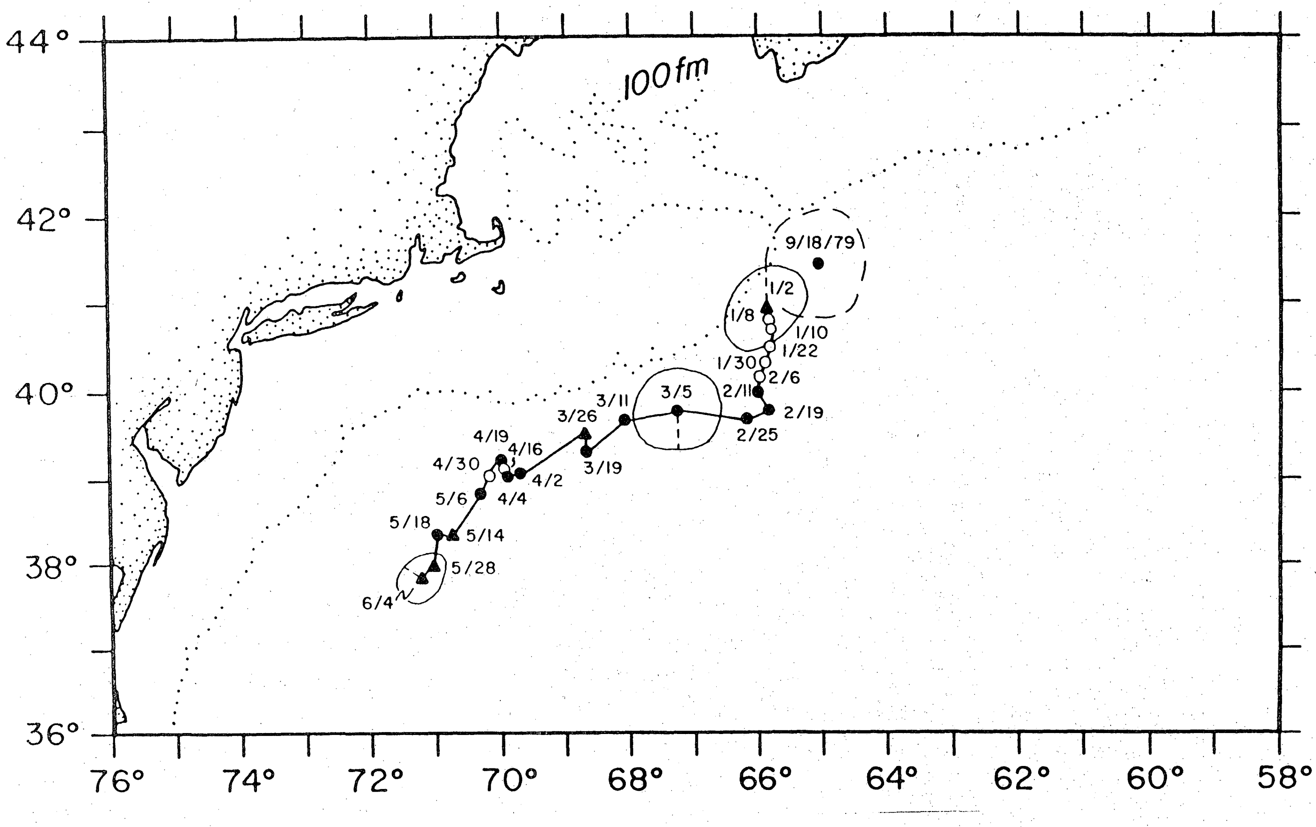


Figure 2. Trackline for Ring 79-G.

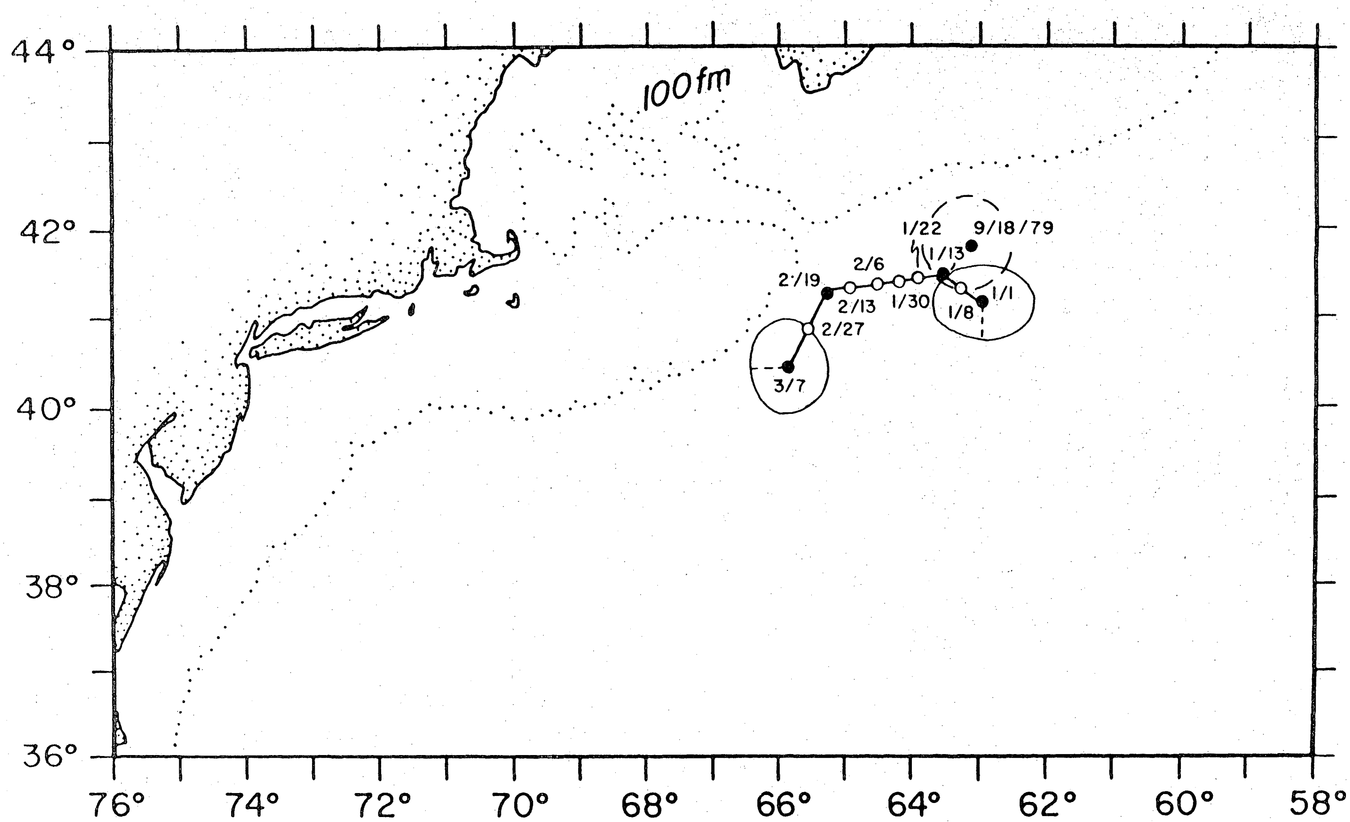


Figure 3. Trackline for Ring 79-H.

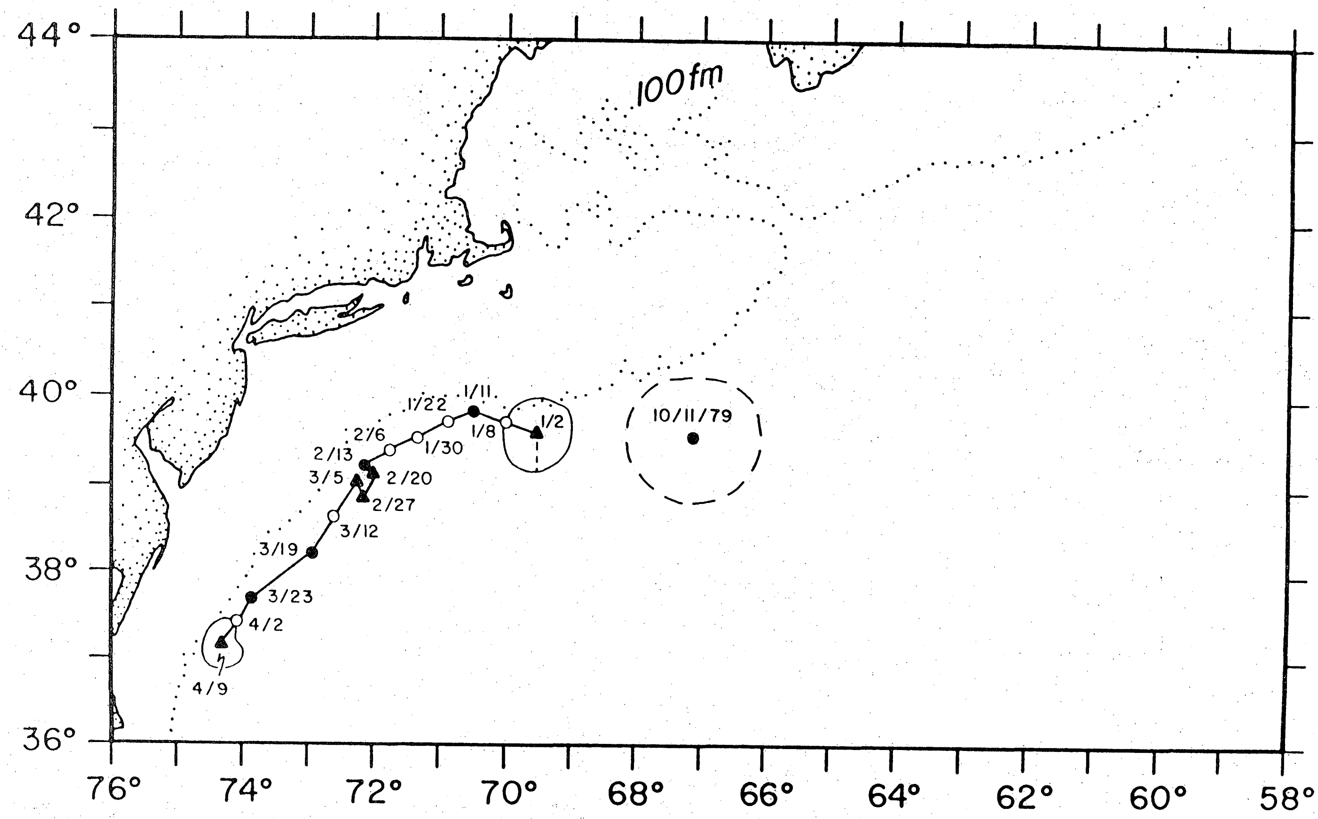


Figure 4. Trackline for Ring 79-I.

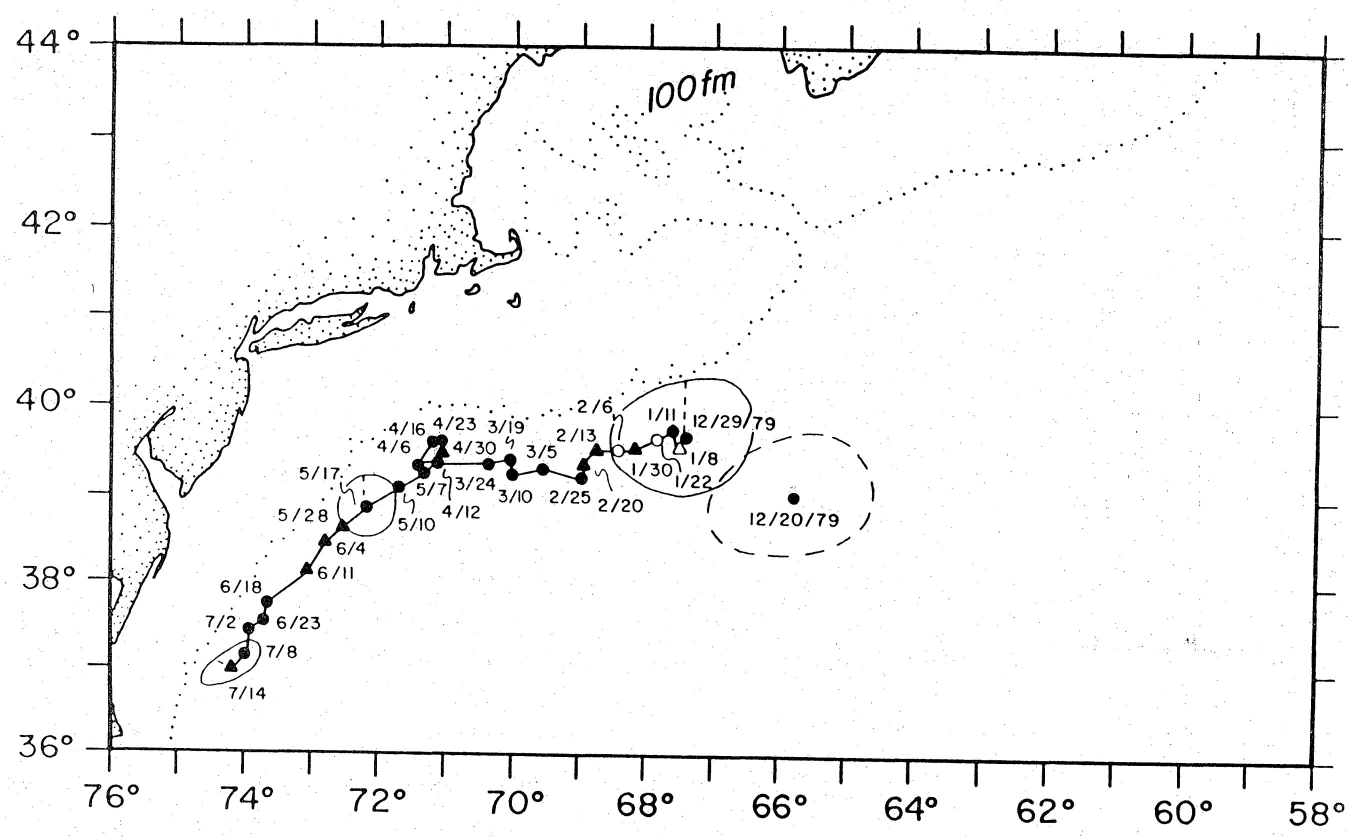


Figure 5. Trackline for Ring 79-K.

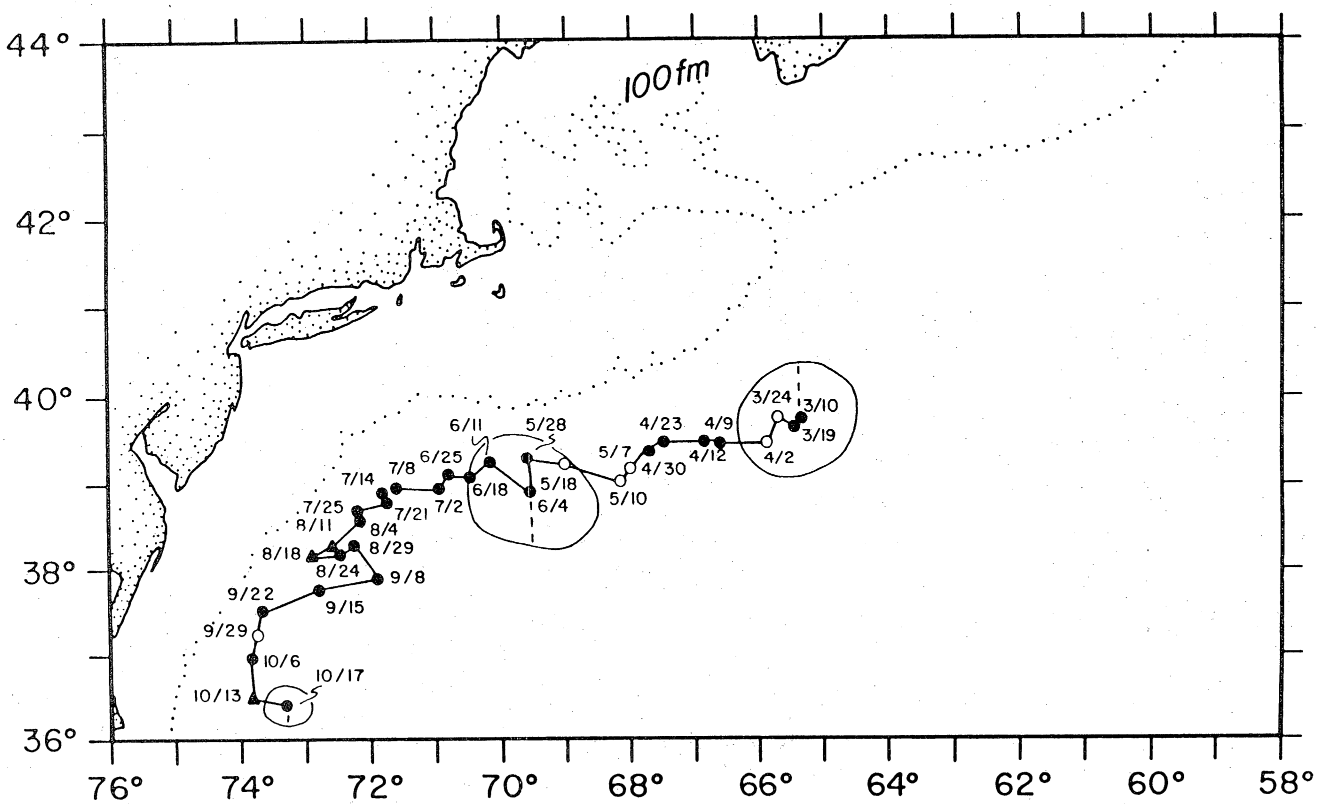


Figure 6. Trackline for Ring 80-A.

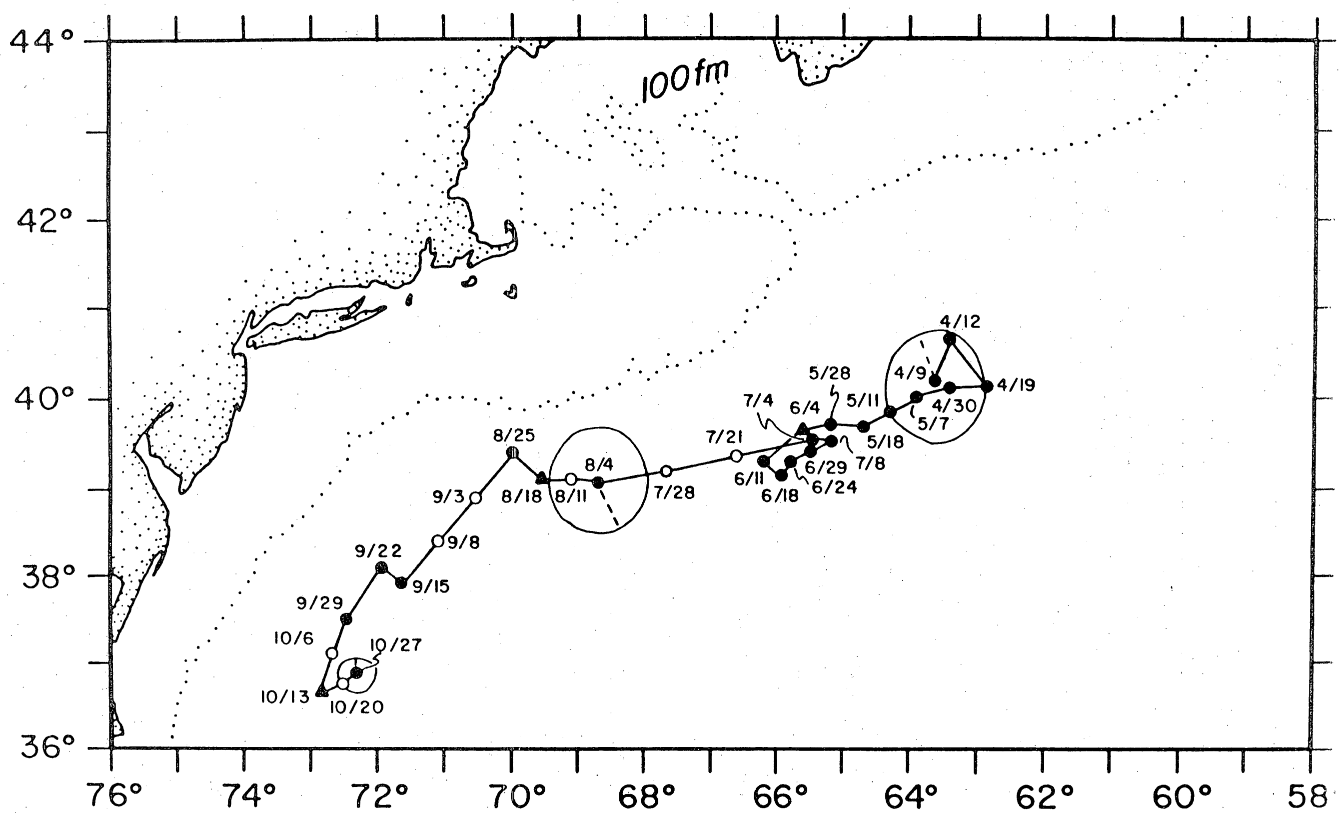


Figure 7. Trackline for Ring 80-B.

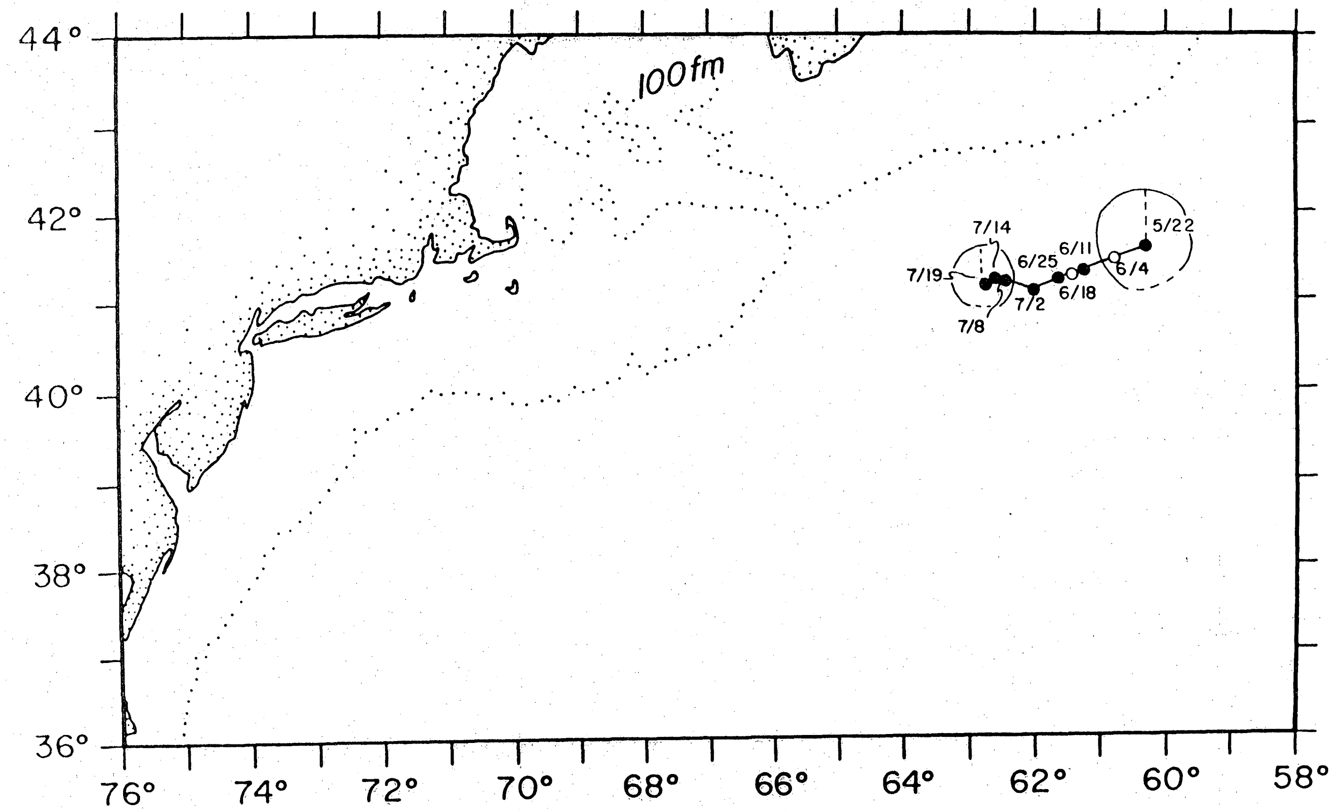


Figure 8. Trackline for Ring 80-C.

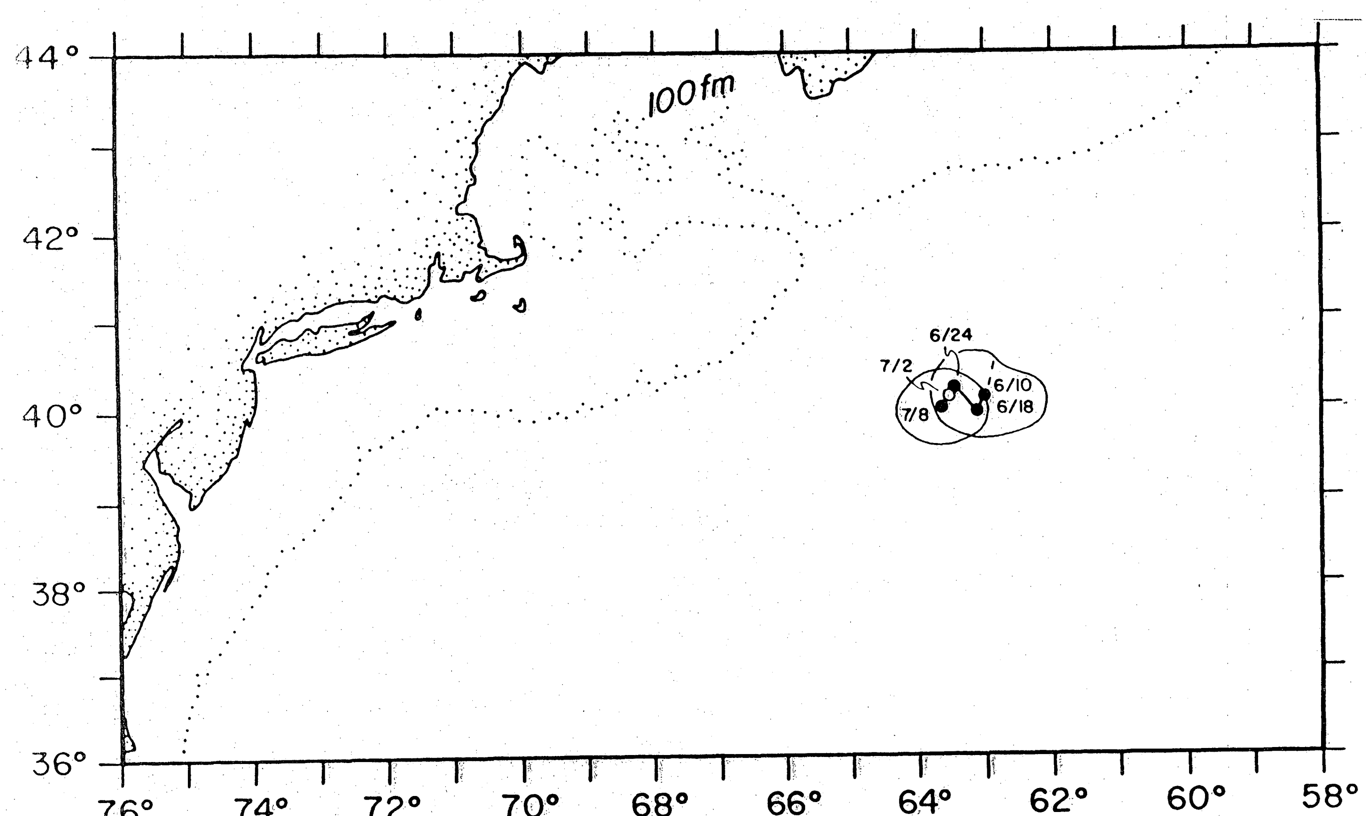


Figure 9. Trackline for Ring 80-D.

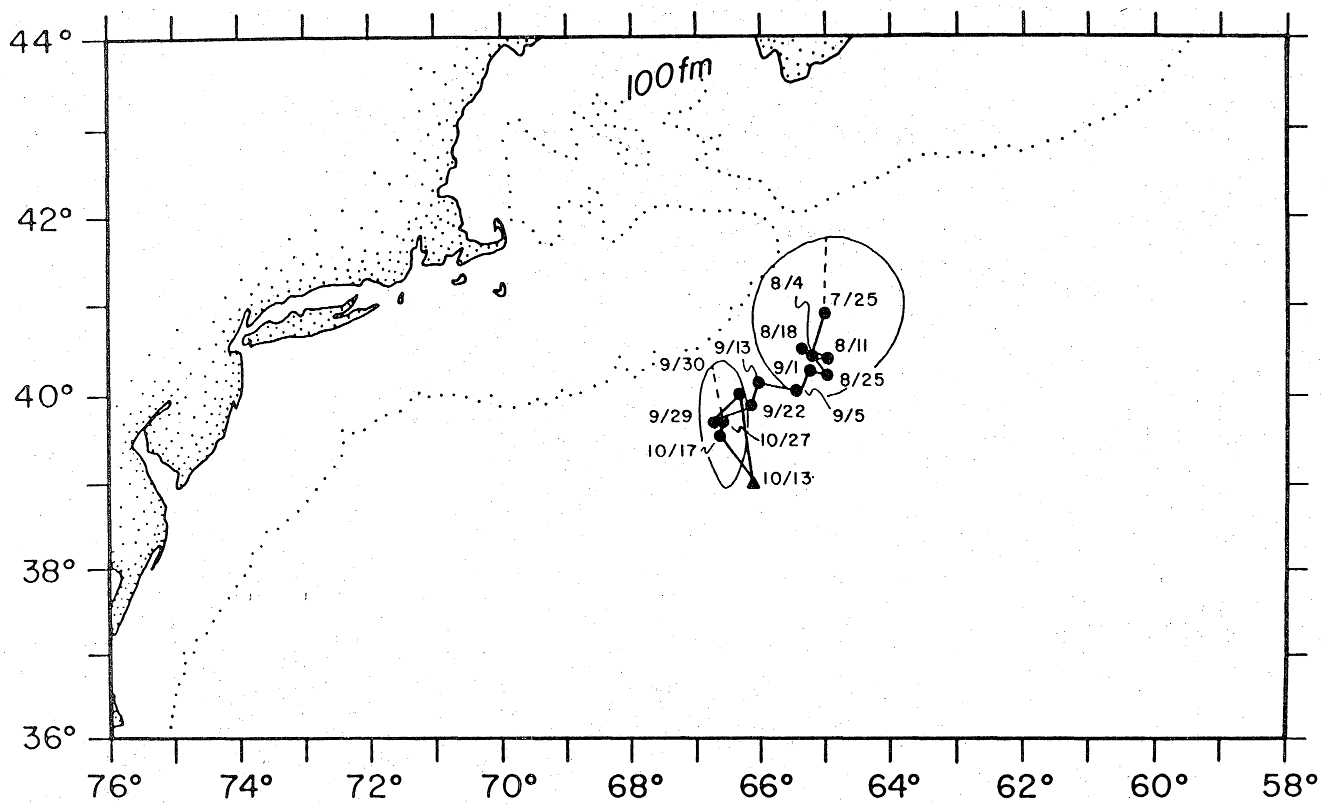


Figure 10. Trackline for Ring 80-E.

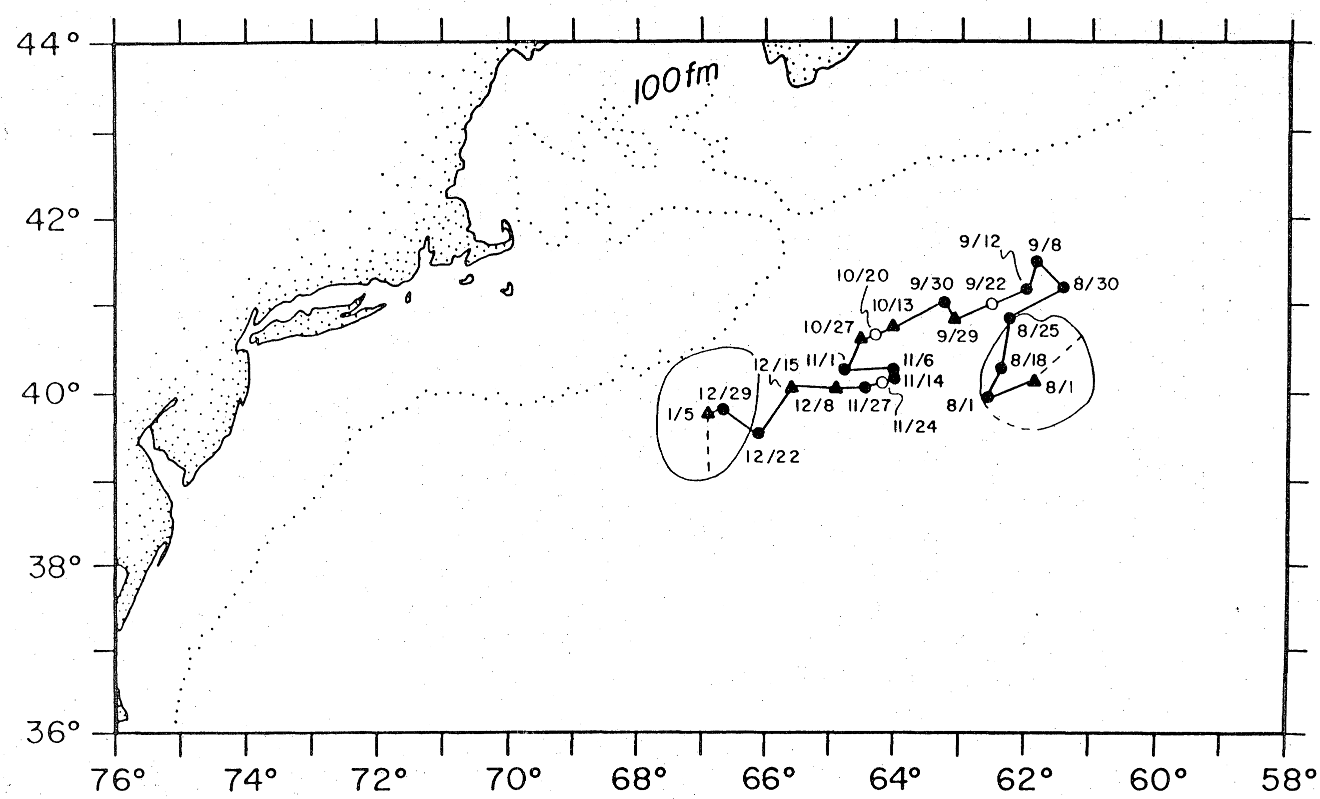


Figure 11. Trackline for Ring 80-F.

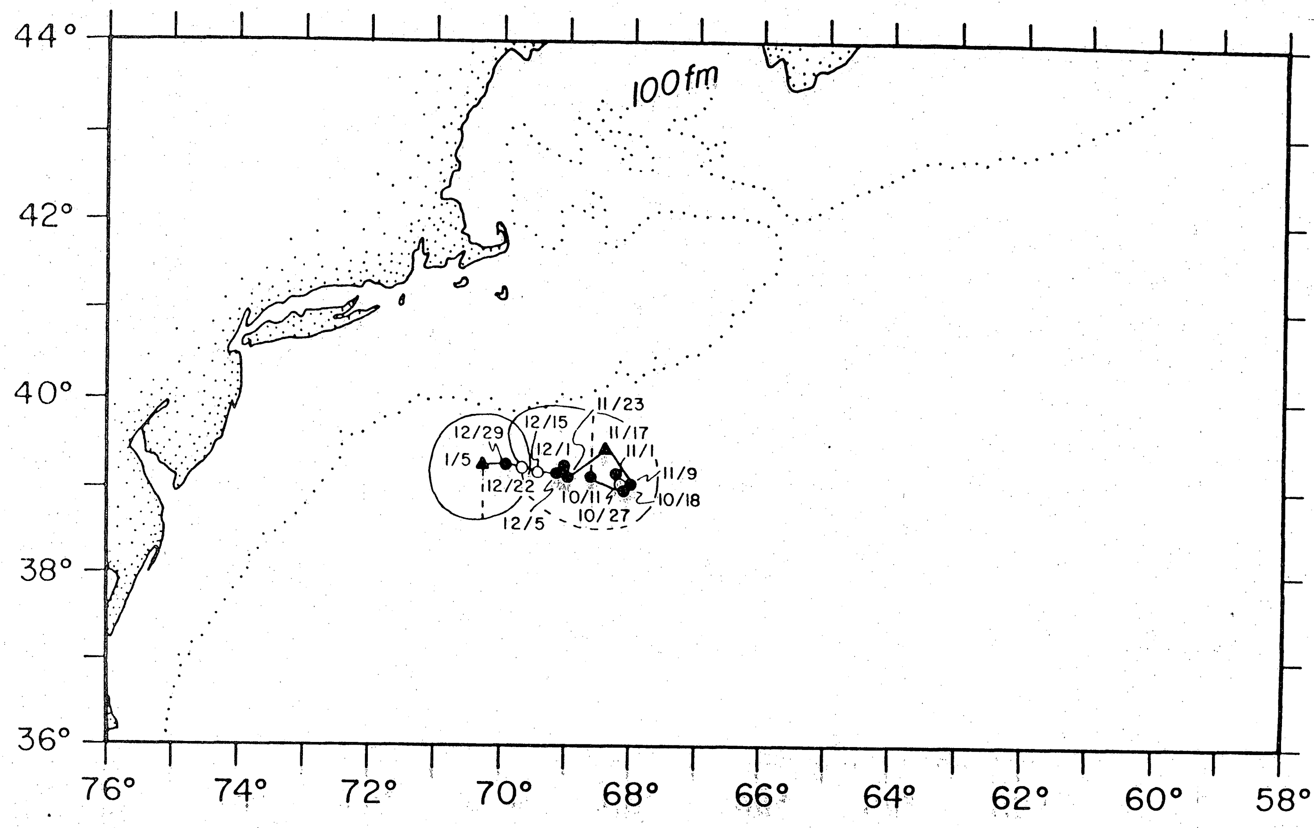


Figure 12. Trackline for Ring 80-G.

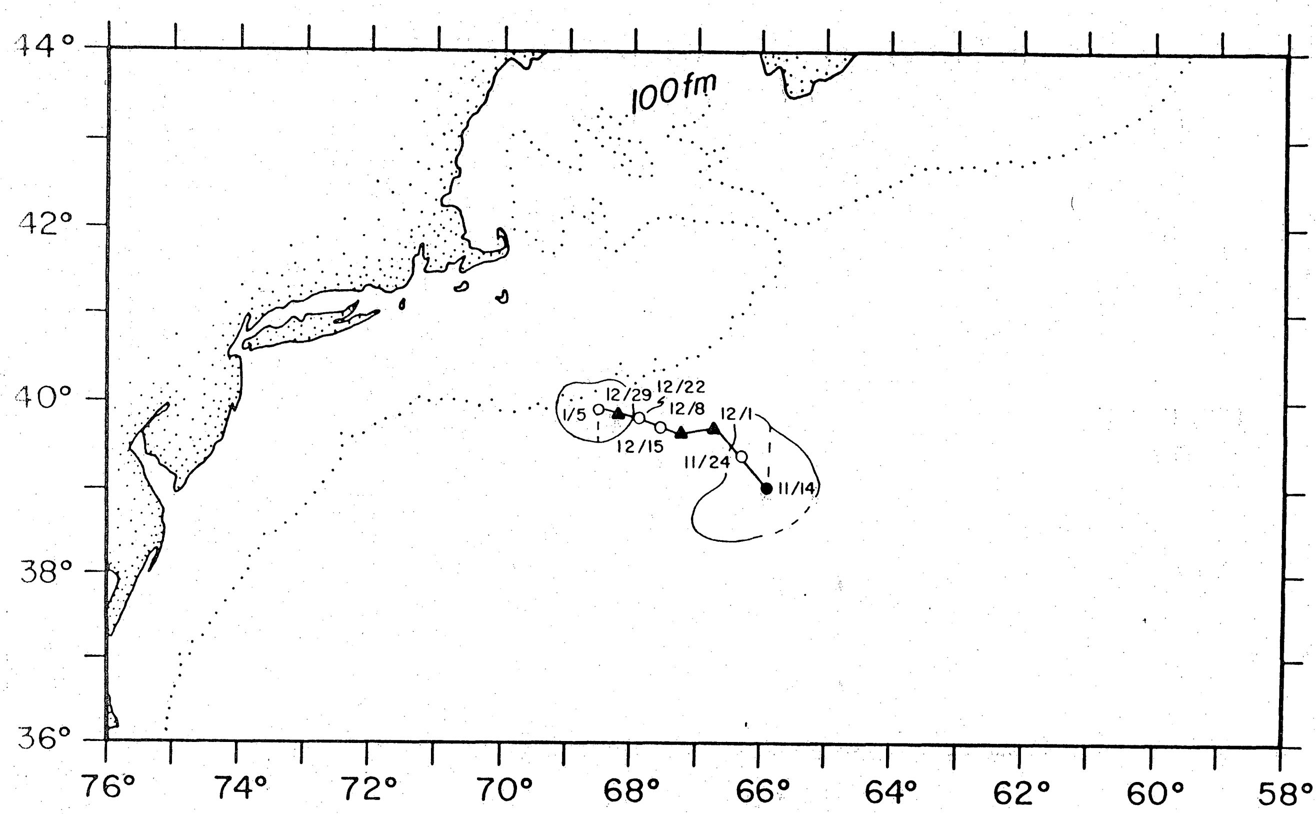


Figure 13. Trackline for Ring 80-H.

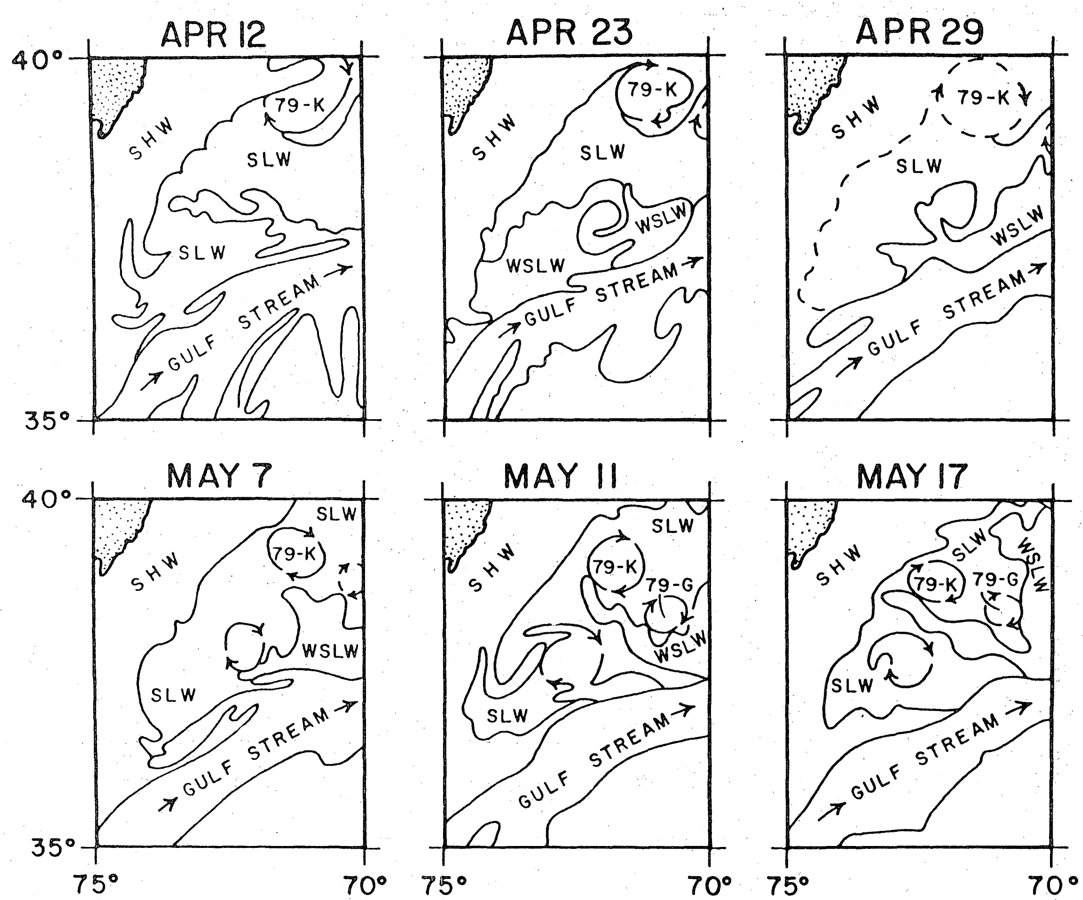


Fig. 14. Development of an anticyclonic ring-like feature as illustrated in frontal analysis chartlets from infrared satellite imagery. The April 12 chartlet is prior to development of the ring-like feature, which appears near the center of the remaining chartlets. See text for further explanation. Chartlets are modified from Weekly Satellite Derived Gulf Stream Analysis charts, NOAA National Environmental Satellite Service. (SHW - shelf water, SLW - slope water, WSLW - warm slope water, 79-G and 79-K - warm core rings.)

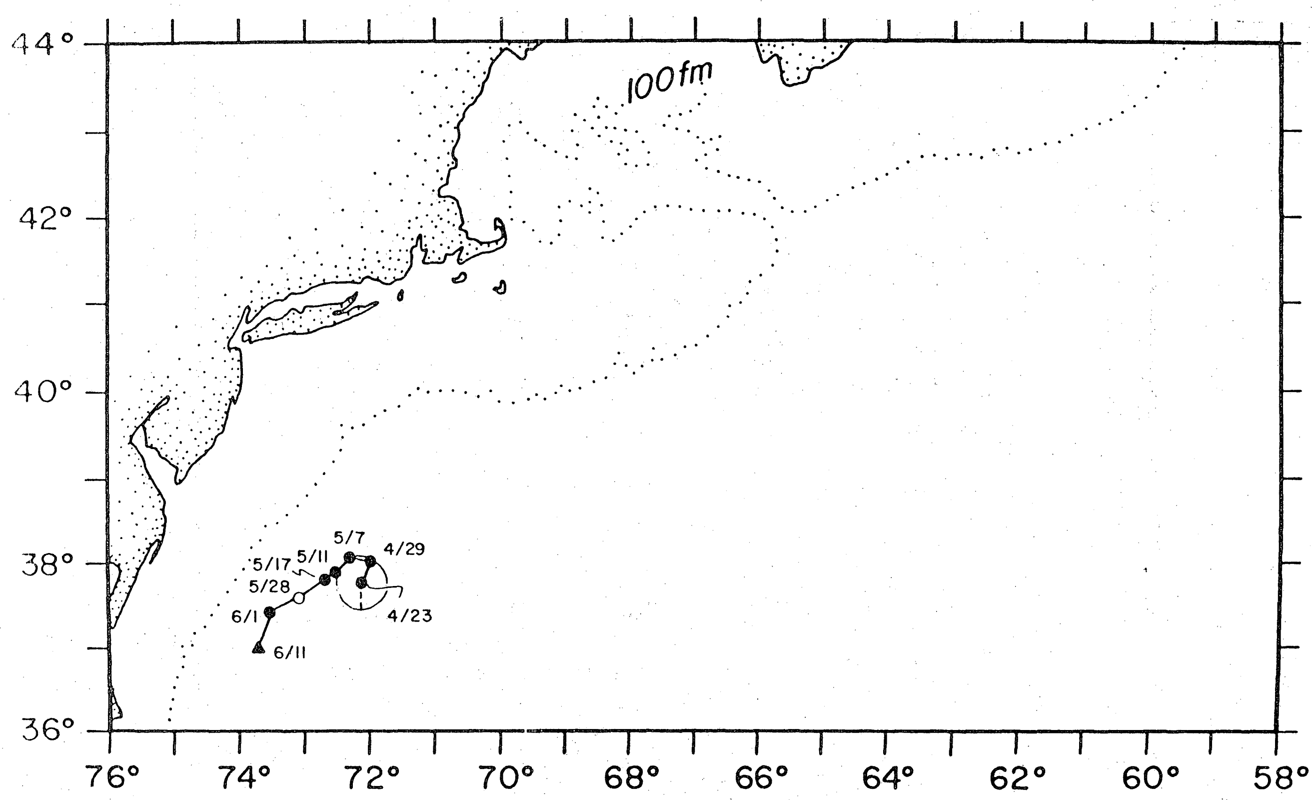


Fig. 15. Trackline of anticyclonic ring-like feature illustrated in Figure 14.

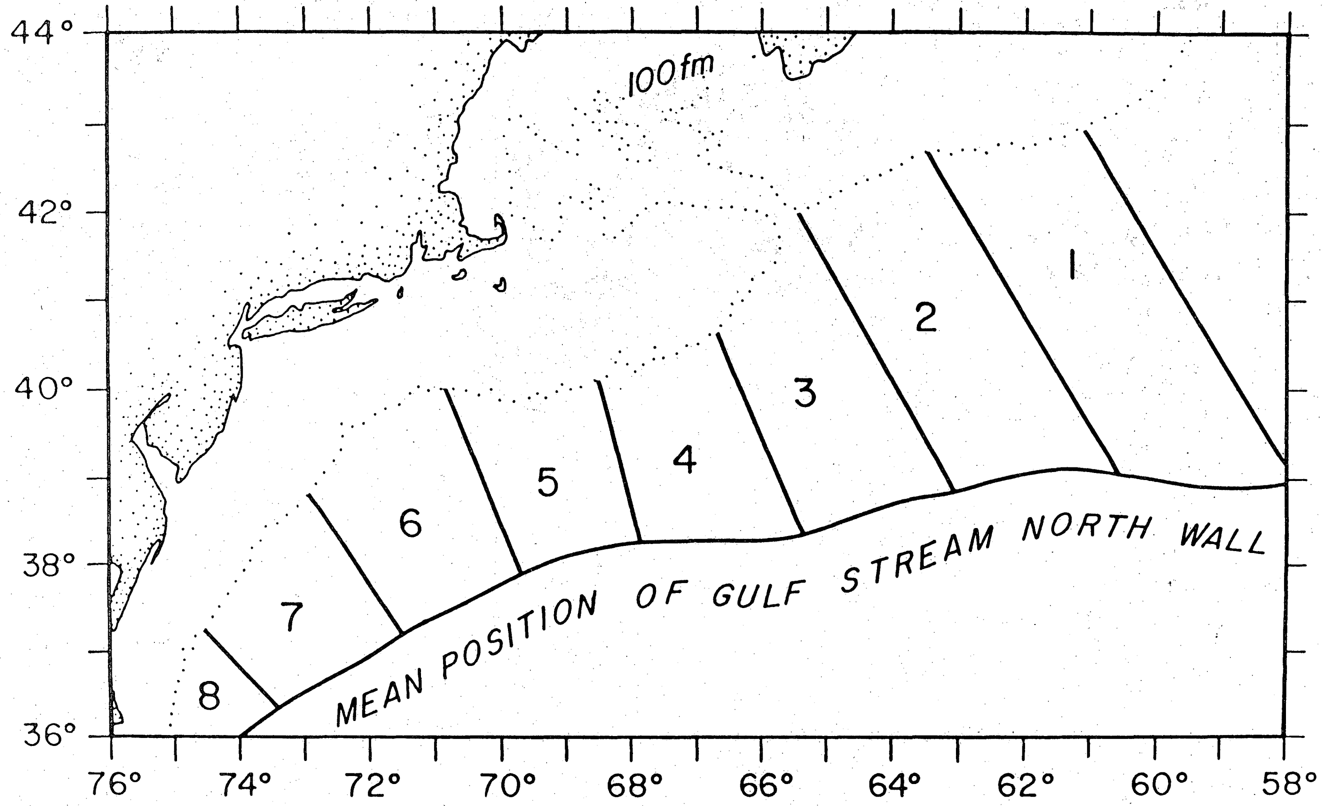


Figure 16. Zones used for Table 3.

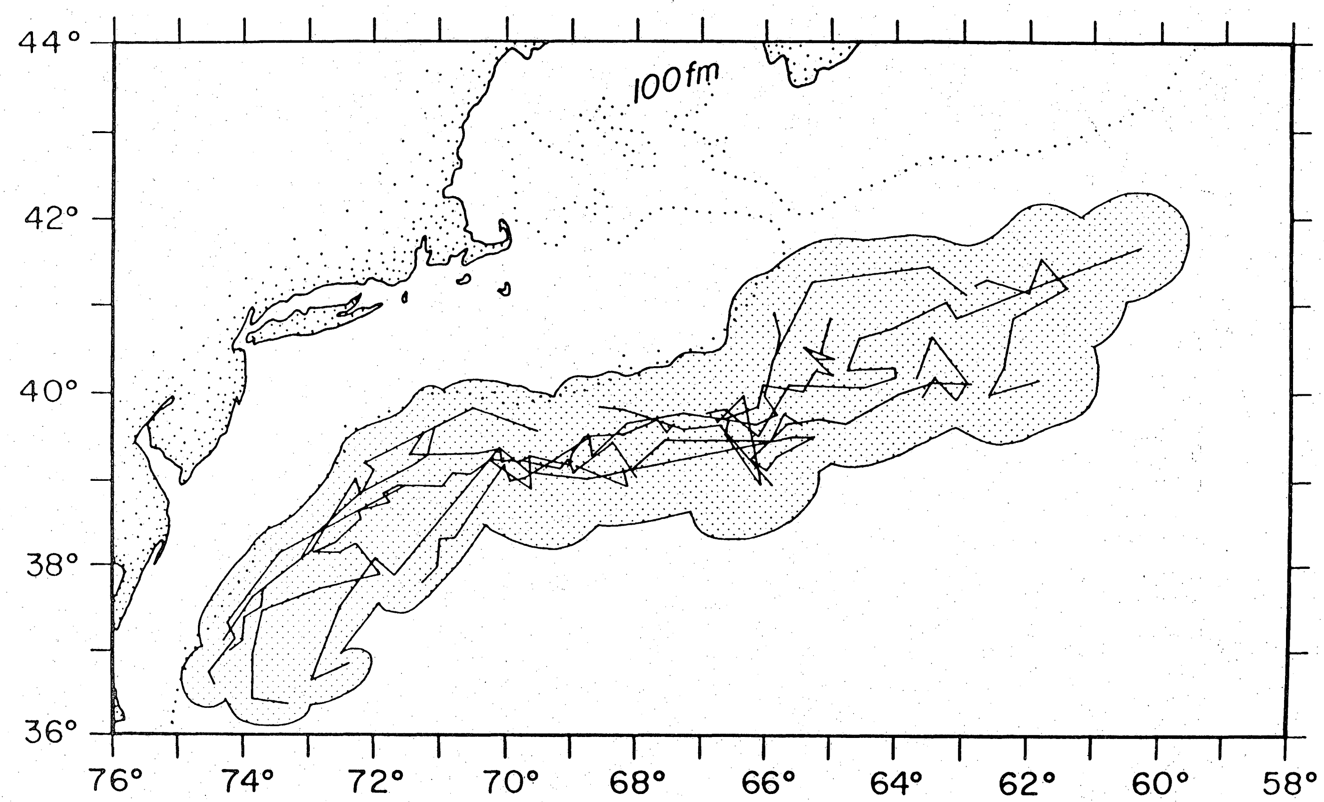


Fig. 17. Composite of ring tracklines and envelope of ring surface boundaries.