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Anticyclonic Warm Core Gulf Stream Rings off the Northeastern United States during 1987

by

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Abstract

For the fourteenth year, interpretations of patterns in sea surface temperatures from satellite infrared data are used to determine the formation, movements and life history of warm core rings in the slope water off the northeastern United States. In 1987, 14 rings were present in the slope water, of which 10 were new rings forming in 1987 and the remaining 4 had formed in 1986 and survived into the current year. Life spans of individual rings ranged from 10 to 247 days. Based on records for 1974–1986, the number of rings and longevity in 1987 were about typical. At least 2 rings were present in the slope water for each month of the year and 3 were present during 7 months. All of the 10 rings which developed in 1987 formed in the waters east of 68°W longitude. With generally westward and southwestward movement of the rings, numerous instances of dynamic interactions with shelf water were noted. Three of the rings which formed in 1987 survived into 1988.

Introduction

This report summarizes for the fourteenth year, 1987, the movements of anticyclonic warm core Gulf Stream rings in the slope water region off the coast of the northeastern United States, primarily from Cape Hatteras, North Carolina, to Georges Bank and south of Nova Scotia. Similar yearly analyses have been prepared for each of the preceding thirteen years, beginning with and generally following the methods described by Bisagni (1976) for rings in 1974–75.

Information Sources and Analysis Methods

This analysis is based primarily on data collected by the Advanced Very High Resolution Radiometer (AVHRR), a sensor onboard NOAA-9, one of the National Oceanic and Atmospheric Administration (NOAA) polar-orbiting satellites. Two satellite passes covering the study area are potentially available each day, depending on the extent of cloud cover present. Using the processing facilities of the Oceanographic Remote Sensing Laboratory, University of Rhode Island, the high resolution (1km) digital data are atmospherically and geometrically corrected and enhanced to clearly identify thermal features. Data from the geostationary satellites (GOES) are used in conjunction with the AVHRR data to help differentiate between clouds, fog and sea surface thermal features. Oceanographic Analysis Charts prepared jointly by the NOAA National Weather Service and National Environmental Satellite, Data and Information Service (NESDIS), issued three times a week, are utilized to help interpret the relative positions of thermal features. Opportunistic shipboard data received from scientists and fishermen are also integrated when available.

A base map showing submarine canyon locations and zones used in the zonal analysis is provided in Figure 1. Ring center positions are plotted on the respective tracklines (Figs. 2-5, 7-11 and 14-18). Formation and destruction locations plus periodic positions are dated. At any time of the year, but especially in summer, rings may not be visible in satellite imagery because of lack of thermal contrast at the surface. When rings in close proximity to one another are not visible , or are hidden by clouds for a number of weeks there may be uncertainty in distinguishing between the rings when they reappear. In such cases, the simplest interpretation of movements have been accepted.

Surface boundaries of rings are shown for the estimated date of formation and at representative stages in the life of the ring. The location of these boundaries involves errors of unknown magnitude, though every effort has been made to use various enhancement techniques to reduce these errors.

Only rings which occurred west of 60°W longitude during some portion of their lifetime are considered in this analysis. Rings are labelled with the year in which they formed or crossed 60°W, and alphabetically in the order of formation. This report includes only warm core rings formed when the Gulf Stream meanders to the north, then closes back on itself, trapping warm

Sargasso Sea water in its core, and then breaks away from the Stream. Additional warm patches of water with apparent circulation appear periodically in the slope water region, however since their formation is not in the above described manner, these are not labelled as warm core rings. These warm eddies are therefore, not included in this report.

Ring Histories

A total of fourteen warm core Gulf Stream rings occurred in the slope water region between Cape Hatteras, North Carolina and 60°W longitude during 1987. Four of these rings were formed in 1986 and the rest were formed in 1987. Three of the rings formed in 1987 persisted into 1988. Estimated formation and destruction dates as well as lifespans for each ring are listed in Table 1.

Ring 86-E (Fig. 2) formed from a large Gulf Stream meander on 7 August 1986 and was centered at 39.2°N, 67.5°W. After interacting with the Gulf Stream in September and early October, the ring moved westward until early December when it again came in contact with the Gulf Stream. On 30 December 1986, the ring was centered at 37.6°N, 73.6°W. During January, 1987 ring 86-E remained relatively stationary and continued interacting with the Gulf Stream, which diminished the ring's size and ultimately led to the ring's destruction on 2 February near 37.2°N, 74.0°W.

Ring 86-F (Fig. 3) formed from a Gulf Stream meander on 12 August, centered at 39.6°N, 64.1°W. During much of August and September this ring interacted with Gulf Stream meanders. Ring 86-F separated from the Gulf Stream in mid-September and continued moving westward and southwestward throughout the remainder of the year. The last center position recorded for ring 86-F was 38.4°N, 72.6°W on 30 December 1986. This ring was absorbed by the Gulf Stream on about 5 January 1987.

Ring 86-H (Fig. 4) formed on about 20 October 1986 from a Gulf Stream meander. The center location of 41.1°N, 62.5°W and the formation date have been estimated due to persistent cloud cover throughout this period. In November and December this ring interacted with ring 86-G and ring 86-I. The latter ring formed south of ring 86-H and forced it to the east. Ring 86-H was centered at 41.4°N, 62.2°W on 30 December 1986.

Ring 86-H moved southwestward, diminishing in surface diameter throughout January and February. By mid-February this ring showed a significantly weakened surface expression. By mid-March, ring 86-H had weakened further and began interacting with a westward extending meander of the Gulf Stream. Ring 86-H was resorbed by that meander on about 31 March near 40.0°N, 68.4°W. The same meander later formed ring 87-B.

Ring 86-I (Fig. 5) formed on 4 December 1986 from a Gulf Stream meander and was centered near 40.0°N, 63.9°W. The ring briefly interacted with ring 86-H as it began moving westward. Throughout January ring 86-I moved southwestward, maintaining fairly constant size. In mid-February this ring began interacting with the Gulf Stream meander. In late February the ring started entraining shelf water around its eastern and southern boundaries. In early March the ring broke away from the Gulf Stream and continued moving southwestward. During the next several weeks ring 86-I occasionally interacted with Gulf Stream meanders which strengthened its surface expression.

The movement of ring 86-I slowed considerably from mid-April through June. During this time, entrainment of shelf water was visible along the ring's eastern and southern boundaries. On 8 May, the M/V Oleander crossed the northeast corner of ring 86-I. The imagery during this period was poor due to scattered clouds, however the oceanographic conditions recorded in the XBT survey (Fig. 6) correlate well with the chart for 5 May 1987. The hydrographic vertical section showed the 12°C isotherm deepening to 300m within the ring. The surface salinity increased from 34.5 ppt to 35.8 ppt as the ship entered the ring. In mid-June this ring was again interacting with the Gulf Stream. Throughout July clouds obscured the area, however the ring apparently continued interacting with the Gulf Stream while moving southwestward and was finally resorbed on about 7 August near 36.4°N, 74.2°W.

Ring 87-A (Fig. 7) was formed by a westward extension of a Gulf Stream meander on about 19 January and was centered at 40.4°N, 62.1°W. The ring interacted briefly with the Gulf Stream and was pushed slightly northward before completely detaching from the Stream in mid-February. As ring 87-A moved westward, it began entraining shelf water and by the end of March it had entrained shelf water along three-quarters of its outer boundary.

In April, ring 87-A interacted with a Gulf Stream meander and later with ring 87-B. Ring 87-A apparently split in two, forming ring 87-C and diminishing ring 87-A's size significantly. On 10 May ring 87-A was resorbed by a large Gulf Stream Meander near 40.2°N, 66.7°W.

Ring 87-B (Fig. 8) was formed on or about 28 March by a very large Gulf Stream meander that brought warm Gulf Stream waters and strong currents to within 15 km of the continental shelf break near Georges Bank. The resultant large ring was centered at 38.7°N, 67.7°W. By late April the ring was entraining mixed shelf and slope water along its eastern and southern boundaries. This short-lived ring was resorbed on 7 May near 39.2°N, 68.2°W by a large Gulf Stream meander which was also in the process of resorbing ring 87-A.

Ring 87-C, centered near 40.6°N, 65.1°W, was formed on or about 20 April when ring 87-A split in two during an interaction with a very large meander that formed ring 87-B. The formation date and center location are estimated due to extensive cloud cover during formation. Ring 87-C progressed slowly southwestward and actively entrained both shelf and Gulf Stream water. During mid-May another Gulf Stream meander, responsible for the destruction of rings 87-A and 87-B, pushed the ring southeastward and disconnected it from its entrainment features. Following this interaction, the ring seemed to be displaced to the north and west by the advancing meander and, in late May, the now-strengthened ring 87-C could be seen clearly much further west. During this period the ring moved rapidly west averaging 17 km per day. In early June, ring 87-C was pushed due east and its surface area was reduced by interactions with another meander that formed ring 87-E, although there were still indications of substantial shelf water entrainment along its eastern edge.

Throughout June, ring 87-C continued to weaken and was difficult to see in the satellite imagery. Consequently, no positions are given from 10 June to 29 June on Fig. 9. By late June, ring 87-C was more easily discernable and could be seen entraining both shelf and Gulf Stream/slope water. During early July the ring was observed to be moving southwest until it began interacting with the Gulf Stream and, by late July, was strongly entraining Gulf Stream water.

Lack of thermal contrast and persistent cloud cover throughout August and into September made it nearly impossible to follow ring 87-C. The ring remained as a small weak eddy throughout August with very little southwestward movement due to the close proximity of ring 87-E to the west. As noted in Fig. 9, no center positions are shown throughout September although a trackline has been illustrated. At this point an error was discovered in the labelling of rings 87-E and 87-C on the Modified Oceanographic Analysis Charts. A warm patch of slope water determined later to be a remnant of ring 86-I was mistakenly labelled as 87-E, and what was actually 87-E was mislabelled as 87-C.

Ring 87-C was finally observed on 24 September as a small eddy with a surface diameter of approximately 88 km, centered at 38.4°N, 72.5°W. The ring was observed to be entraining Gulf Stream water along its southern side and shortly thereafter, on September 28, the ring was resorbed by the Gulf Stream at approximately 38.3°N, 72.3°W. The Modified Oceanographic Analysis Charts indicate the ring's presence until 20 October, however it was later determined that the feature was a combination of warm slope water and remnants of ring 87-C that had been pushed north by the Gulf Stream.

Ring 87-D (Fig. 10) was a short-lived ring that was formed on 30 May from the same Gulf Stream meander that resorbed rings 87-A and 87-B. It was formed near 39.9°N, 64.3°W and had a surface diameter of approximately 208 km. The ring existed for 11 days and was centered near 40.0°N, 64.0°W when it was resorbed by another eastward propagating Gulf stream meander on 9 June. Due to its short life the ring had no westward movement, instead, the ring moved slightly northeastward as it was being resorbed.

Ring 87-E was formed from a Gulf Stream meander on 9 June and was initially centered near 39.3°N, 67.9°W. In late June, once the ring was fully detached from the Gulf Stream, it moved rapidly westward (approximately 12.5 km/day) probably due to the influence of the newly-strengthened ring 87-C to its east.

On 15 July, the M/V OLEANDER crossed the southwestern corner of ring 87-E during an XBT survey. Poor satellite imagery during this time precludes illustrating the ship's trackline on an image although the hydrographic vertical section from the OLEANDER confirmed the presence of ring 87-E. Within the ring, the 15°C isotherm extends to a depth of over 200 m and the 11°C isotherm to over 300 m (Fig. 12). A salinity maximum of 35.5 ppt, indicative of some influence from Gulf Stream water, was observed in the vicinity of the ring (Fig. 12).

There are no positions for ring 87-E between 17 July to 21 August because of clouds and poor thermal contrast, however the ring seems to have moved very little during this time. Another vertical section from the OLEANDER XBT cruise through the northeast corner of ring 87-E on 19 August showed some indications of the ring's presence below 100m by a deepening of the isotherms (Fig. 13). The weak surface parameters also seem to coincide with the isothermal satellite imagery conditions (Fig. 13). In late August an U.S. Environmental Protection Agency (EPA) cruise in the vicinity of ring 87-E observed ENE currents of approximately 1.5 knots at 39.1°N, 71.9°W.* Unfortunately, clouds and lack of thermal contrast continued to make it difficult to observe the ring.

The final position in Fig. 11 dated 10 September is the last available clear position in which the ring was observed. On 24 September a developing meander was observed to be in the area where ring 87-E had been and it is therefore assumed that the ring was resorbed sometime about 17 September near 38.1°N, 72.9°W.

Ring 87-F (Fig. 14) formed from a Gulf Stream meander on about 27 July and was centered at 41.4°N, 63.1°W. Clouds and fog obscured the area during this period so the formation date is estimated. The ring began moving southwestward and started entraining shelf water soon after its formation. By 31 August, the ring was entraining shelf water along three-quarters of its outer boundary.

In September ring 87-F moved westward and grew significantly in surface diameter from 79 km at the end of July to 120 km. There were several periods of cloudiness during September, however the ring apparently continued moving southwestward and entraining shelf water throughout the month.

At the beginning of October, ring 87-F began interacting with the Gulf Stream. In mid-October this ring was on the eastern slope of a forming meander. The meander extended to the northwest and pushed the ring northward briefly. As the ring continued its southwestward movement, it moved along the western slope of the meander. By the beginning of November, the ring was located between two meanders and its surface diameter had decreased significantly. Ring 87-F was finally resorbed by the Gulf Stream on 16 November near 38.9°N, 69.8°W.

Ring 87-G (Fig. 15) formed from a Gulf Stream meander on or about 11 August and was centered at 42.4°N, 61.2°W. This ring moved slowly westward, and entrained shelf water along its eastern and southern boundaries. The ring did not completely separate from the Gulf Stream until mid- September. Its westward progression remained slow throughout the month.

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* Pers. Comm. Scott McDowell, Battelle Ocean Sciences, Duxbury, MA

In October, ring 87-G remained almost stationary. During this time the ring's northern boundary was within 40 km of the shelf break. The ring's presence influenced the position of the shelf/slope thermal front east of the ring by drawing the front as much as 60km seaward of the shelf break. This seaward movement of the front was also influenced by ring 87-H.

At the end of October, a Gulf Stream meander extended to the northwest and began interacting with ring 87-G. The meander pushed further northwestward which prevented ring 87-G from moving in the usual southwest direction. Again, cloud cover obscured the area in November but it appears that ring 87-G continued interacting with the meander until approximately 23 November when the ring detached from the Gulf Stream and moved northward. At this point the ring was considerably weaker and had very little surface expression. On or about 30 November the ring, centered near 41.2°N, 62.9°W, was absorbed by a Gulf Stream meander which had also formed ring 87-I.

Ring 87-H (Fig. 16) was generated from a Gulf Stream meander near 41.5°N, 59.2°W on about 4 October and began moving northwestward. This ring was not named until it crossed 60°W about 20 October and was centered at 41.5°N, 61.6° W. As it crossed 60°W ring 87-H apparently absorbed a warm patch of water to the west of it, which increased the ring's surface diameter.

At the end of October ring 87-H began interacting with the Gulf Stream and started diminishing in size. Cloud cover obscured the area during November but the ring apparently broke off from the Gulf Stream early in the month and moved northward. Then the ring began moving slowly southwestward.

Cloud cover persisted in the area making it difficult to follow the ring's movements. In mid-December a Gulf Stream meander located just south of 87-H extended to the northwest and halted the ring's southwestward movement. The ring travelled northeastward and on 30 December was located at 41.3°N, 60.5°W. This ring continued into 1988.

Ring 87-I (Fig. 17) was formed on about 24 November near 39.8°N, 64.3°W from the same Gulf Stream meander that resorbed 87-G. By mid-December, the ring which had begun moving westward, started interacting with a Gulf Stream meander. On 30 December, the ring was located at 39.7°N, 64.4°W and was still interacting with a meander.

Ring 87-J (Fig. 18) was formed on 30 December, centered at 38.5°N, 67.5° W. However, it was not named until the first week in January, 1988 because persistent cloud cover made it difficult to confirm its location until then. A full history of this ring will be included in next year's report.

Zonal Analysis

A generalized summary of the movements of rings during 1987 is presented in Table 2. This summary shows the rings' mid-month positions with respect to the zones diagrammed in Fig. 1. There were 31 total zone-month occurrences. During the years 1975-1986, the total zone-month occurrences ranged from a low of 24 in 1974 to a high of 51 in 1982 and 1983, with a mean of 38. Two rings occupied the same zone at mid-month only once in 1987. This is the fourth consecutive year that no rings have occupied Zone 8.

Composite Tracklines of Ring Center Positions and Envelope of Surface Boundaries

A composite of tracklines of all ring center positions, and an envelope of ring surface boundaries appear in Fig. 19. The envelope was developed from boundary positions digitized from satellite data and from weekly analysis charts. Of the ten rings which formed in 1987, three formed east of 63°W (87-A, 87-G, 87-H);three formed between 63°W and 65°W (87-D, 87-F, 87-I); and the remaining four formed west of 66°W. Of the total fourteen rings which occurred in 1987, four never moved west of 65°W (87-D, 87-G, 87-H, 87-I); five others never moved west of 70°W (86-H, 87-A,87-B, 87-F, 87-J); and the remaining five travelled at least as far west as 71°W.

Number of Rings, Times of Formation, and Longevity

Ten warm core Gulf Stream rings formed during 1987 off the northeast coast of North America. During 1974-1986, ring formation averaged nine per year, ranging from a minimum of five in 1974 to a maximum of eleven in 1979 and 1982. Four rings that formed in 1986 survived into 1987; one of which (86-I) was long-lived (247 days). Of the ten rings that formed in 1987, three had formed by the end of April, one formed each month from May through August and the remaining three formed after late September. Longevity of the rings formed in 1987 ranged from 10 to 161 days.

Acknowledgements

We would like to thank Robert Benway of Marine Climatology Investigation (MCI) for providing the hydrographic vertical sections from the XBT surveys. A special thanks goes to Glenn Strout of MCI for his work in digitizing the ring boundaries and especially for developing the new trackline figure format.

REFERENCE

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 pp.

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

Ring	Dates[1]			Life Span (days)
86-E	8/7/86	-	2/2/87	179
86-F	8/12/86	-	(1/5/87)	146
86-H	(10/20/86)	-	3/31/87	161
86-I	12/4/86	-	8/7/87	247
87-A	1/19/87	-	5/10/87	112
87-B	3/28/87	-	5/7/87	39
87-C	(4/20/87	-	(9/28/87)	161
87-D	5/30/87	-	6/9/87	10
87-E	6/9/87	-	(9/17/87)	101
87-F	(7/27/87)	-	11/16/87	113
87-G	(8/11/87)	-	(11/30/87)[2]	112
87-H	(10/4/87)	-	INTO 1988	>89
87-I	11/24/87	-	INTO 1988	>36
87-J	12/30/8	-	INTO 1988	>2

[1] Dates not in parentheses are accurate to within two days. Dates in parentheses could be off by greater than one week, as clouds obscured the sea surface.

[2] This ring was not labelled until it completely crossed west of 60 W on about 10/20/87.

Table 2. Ring positions at mid-month with respect to zone during 1987.

Zone	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1											87-H	87-H
2	86-H	87-A						87-F	87-G	87-G	87-G	
3		86-H	87-A	87-A	87-C				87-F			87-I
4	86-I		86-H	87-B		87-C 87-E				87-F		
5		86-I	86-I				87-C	87-C				
6				86-I	86-I		87-E	87-E	87-C			
7	86-E					86-I			87-C			
8												

NOTE: RING 87-J FORMED ON 30 DECEMBER 1987 IN ZONE 4.

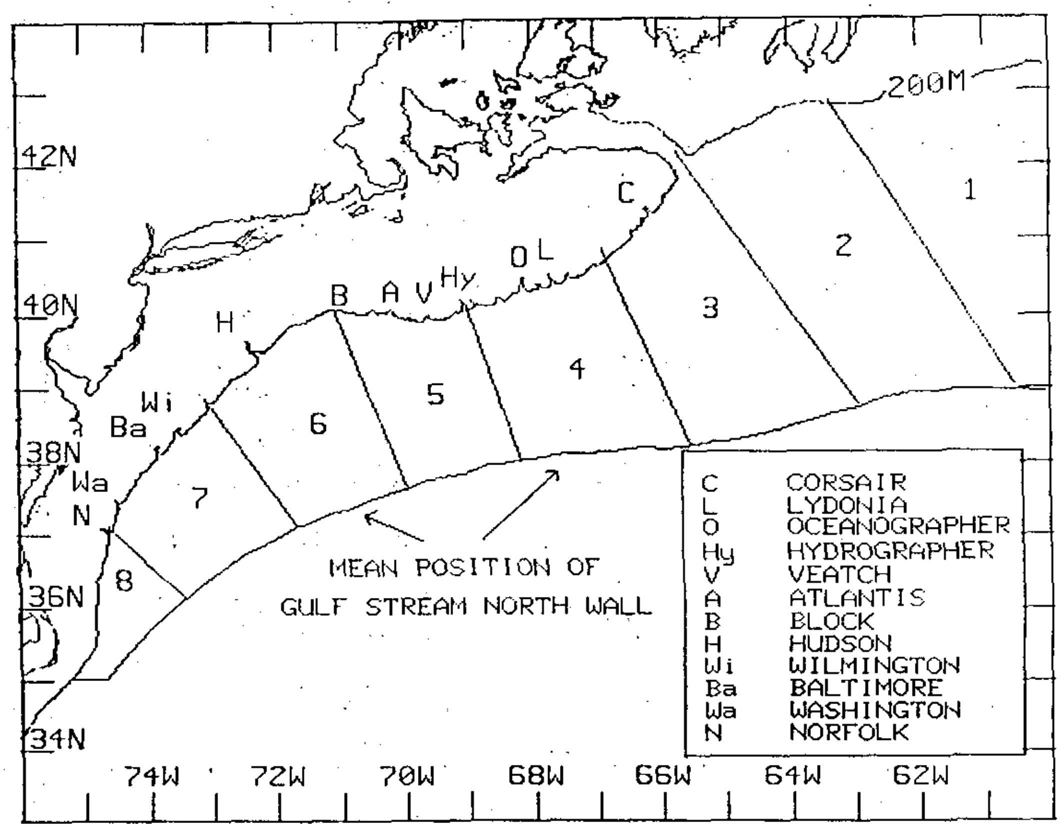


Figure 1. Base map for ring tracklines, showing canyon names and zones used in Table 2.

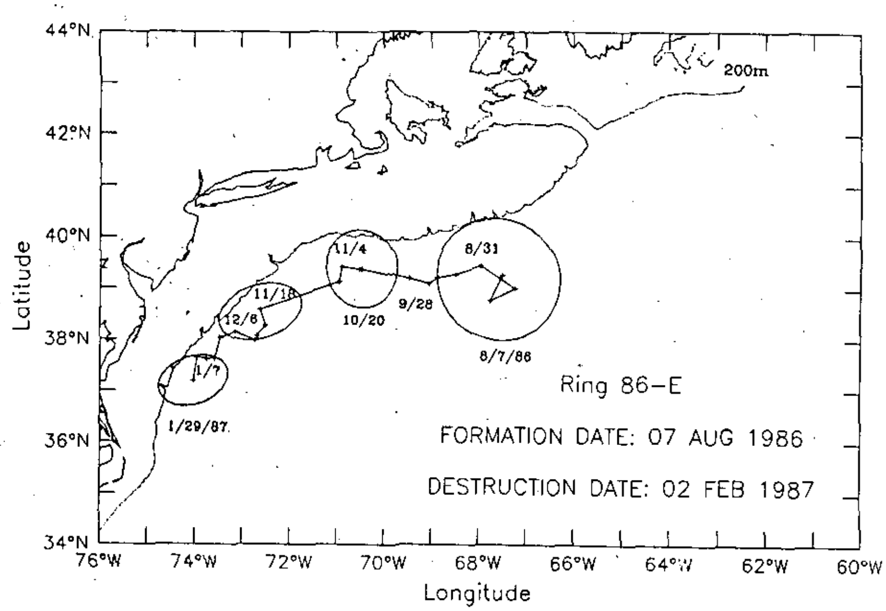


Figure 2. Trackline for ring 86-E.

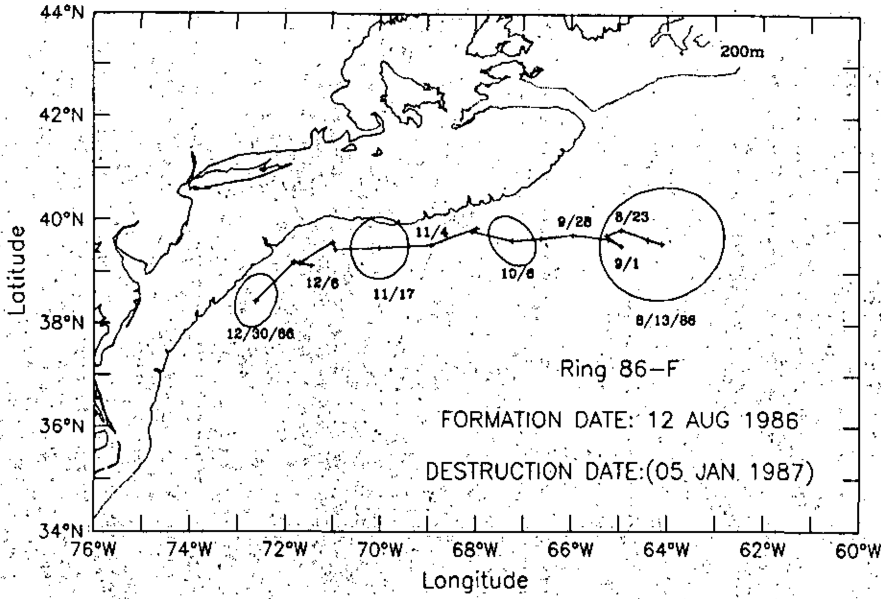


Figure 3. Trackline for ring 86-F.

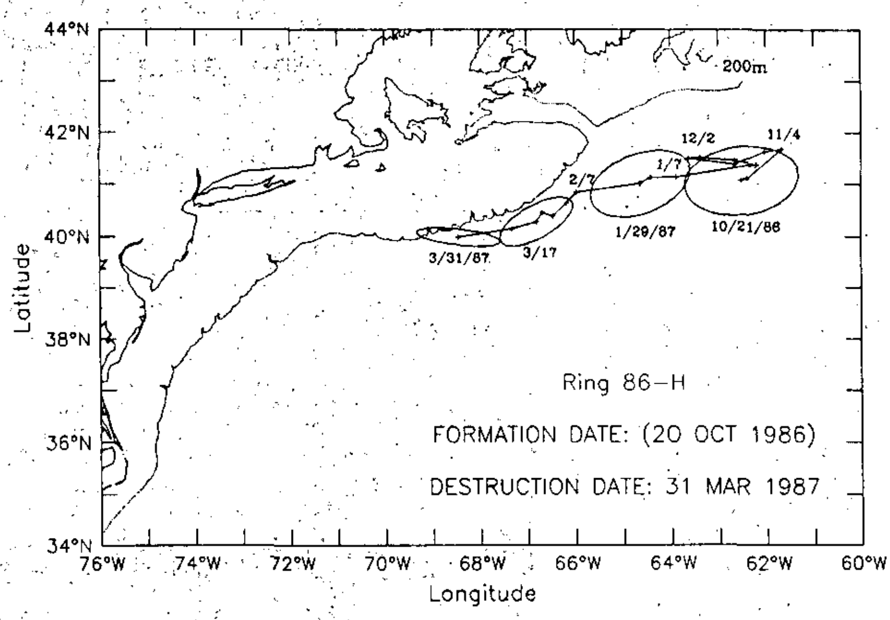


Figure 4. Trackline for ring 86-H.

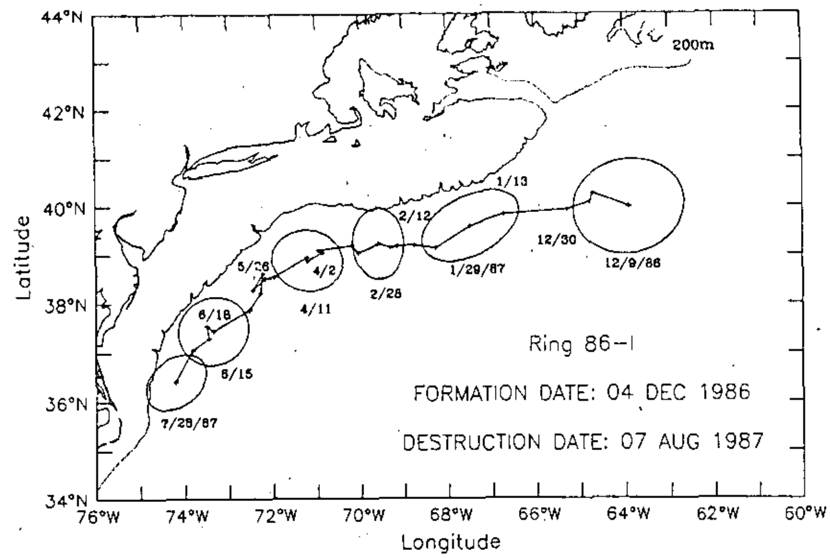


Figure 5. Trackline for ring 86-I.

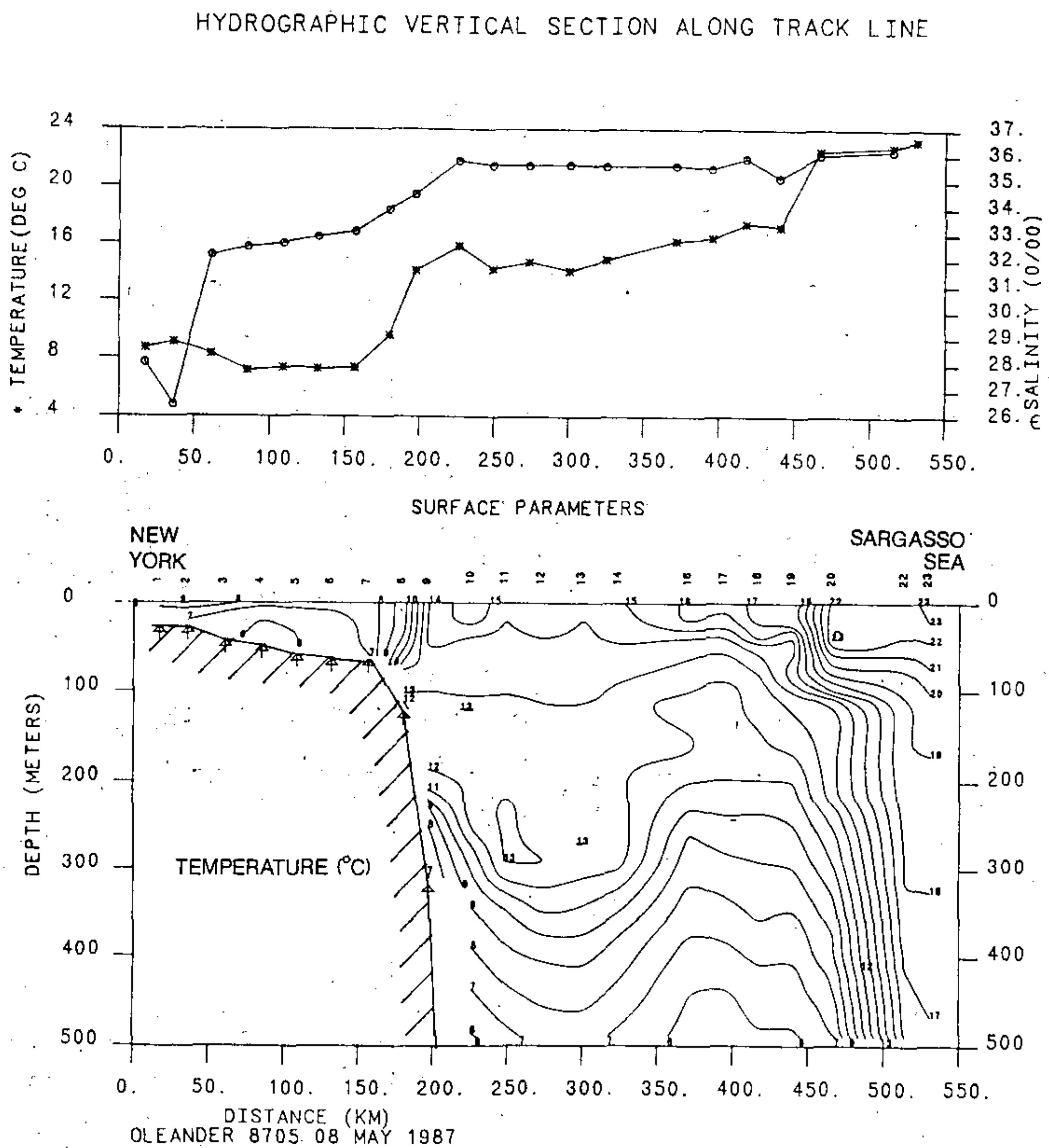


Figure 6. Hydrographic data from M/V Oleander XBT Survey 5/8/87.

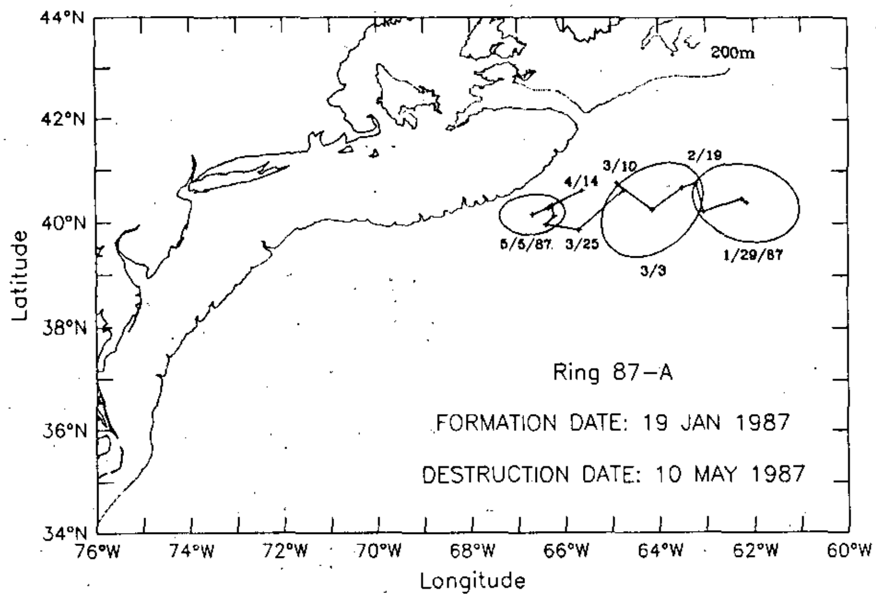


Figure 7. Trackline for ring 87–A.

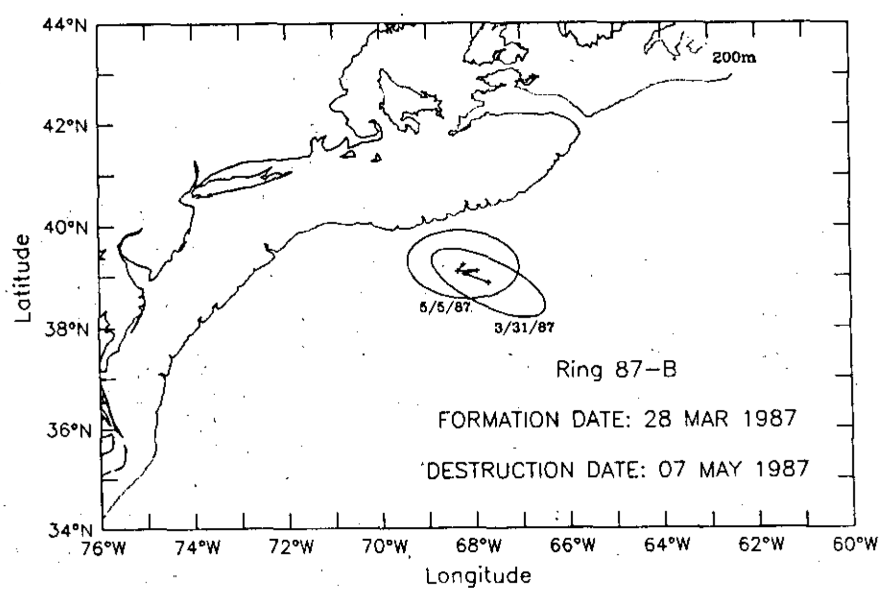


Figure 8. Trackline for ring 87–B.

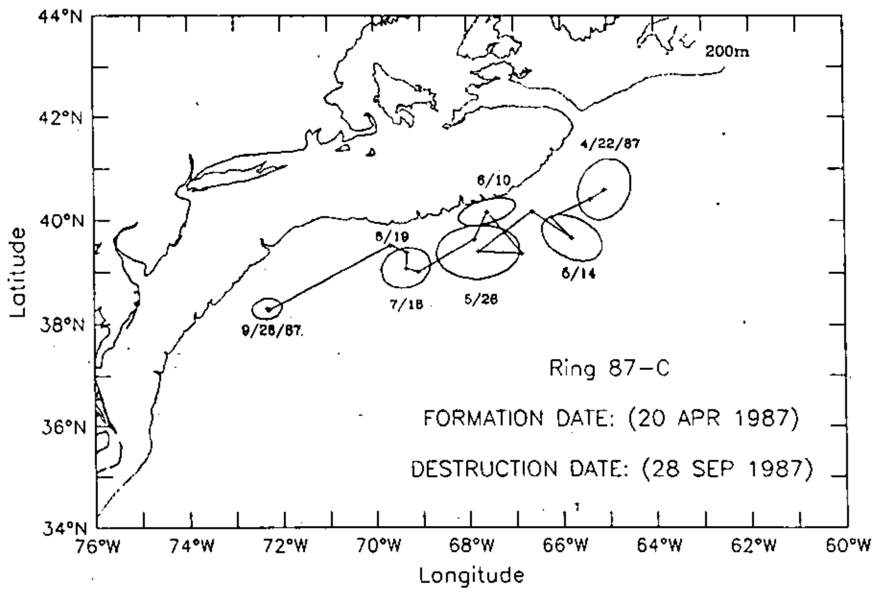


Figure 9. Trackline for ring 87-C.

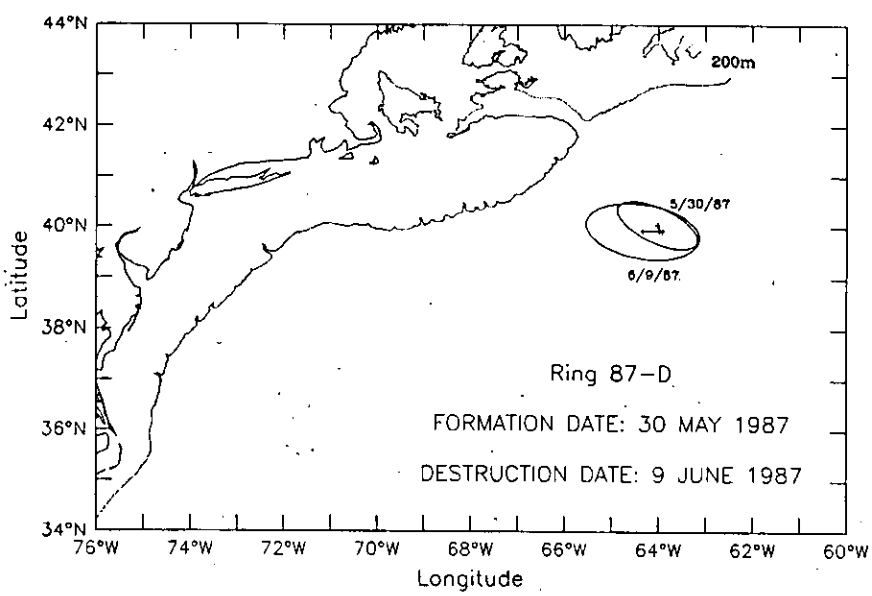


Figure 10. Trackline for ring 87-D.

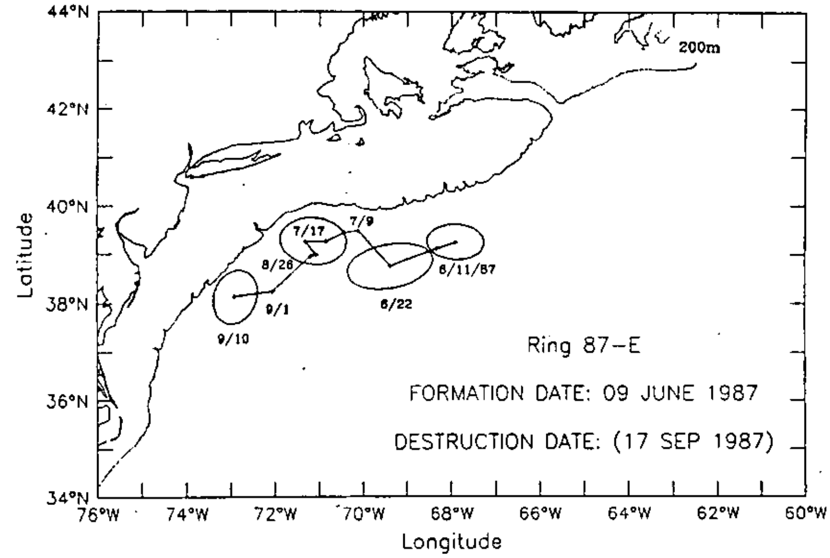


Figure 11. Trackline for ring 87-E

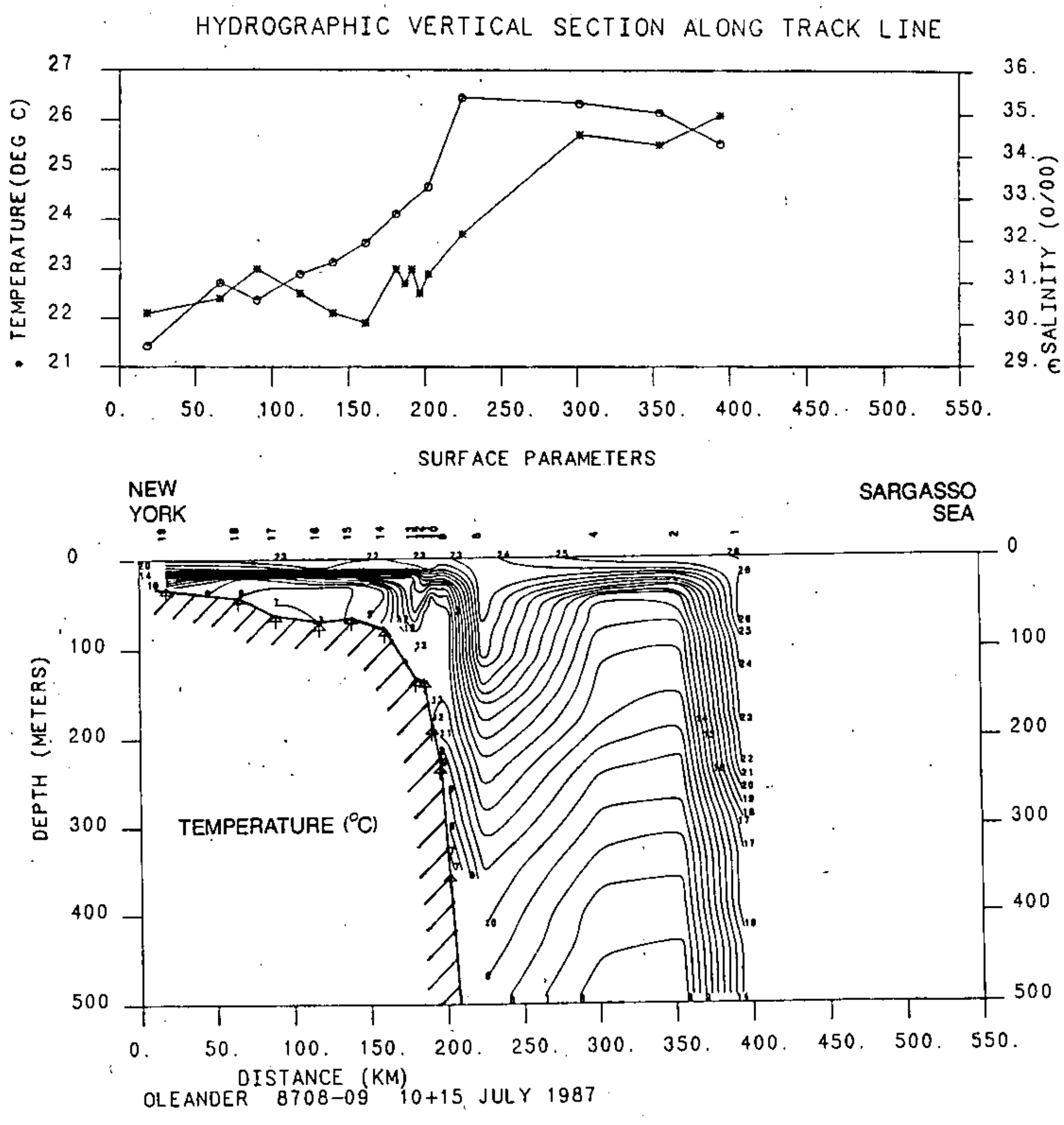
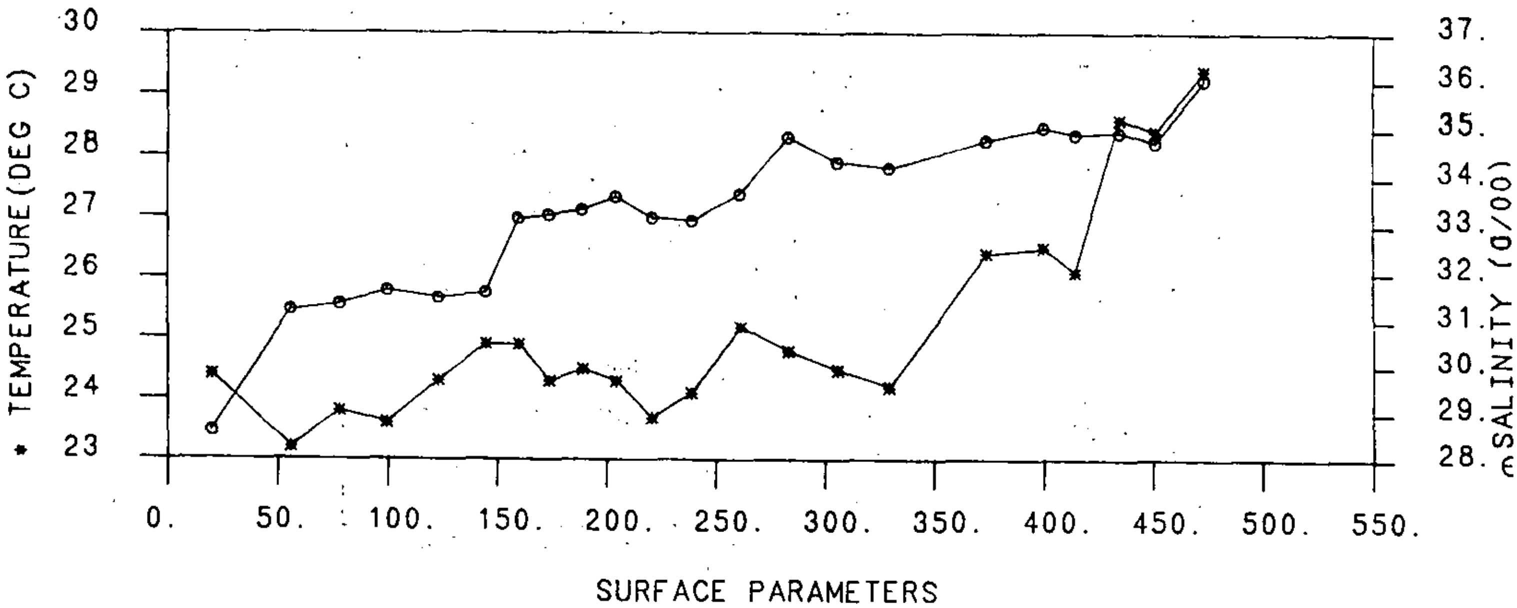


Figure 12. Hydrographic data from M/V Oleander XBT Survey 7/15/87.

HYDROGRAPHIC VERTICAL SECTION ALONG TRACK LINE



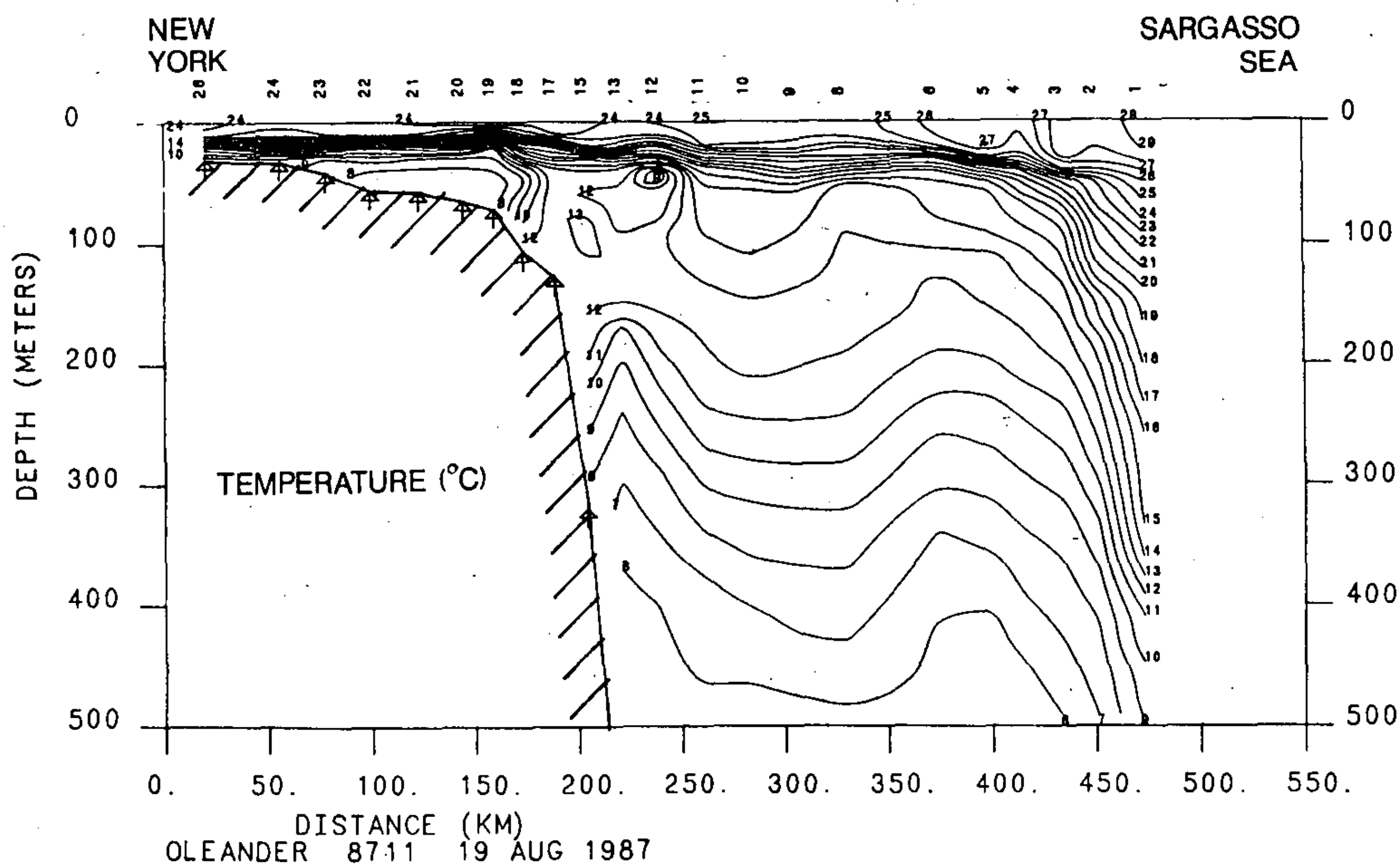


Figure 13. Hydrographic data from M/V Oleander XBT Survey 8/19/87.

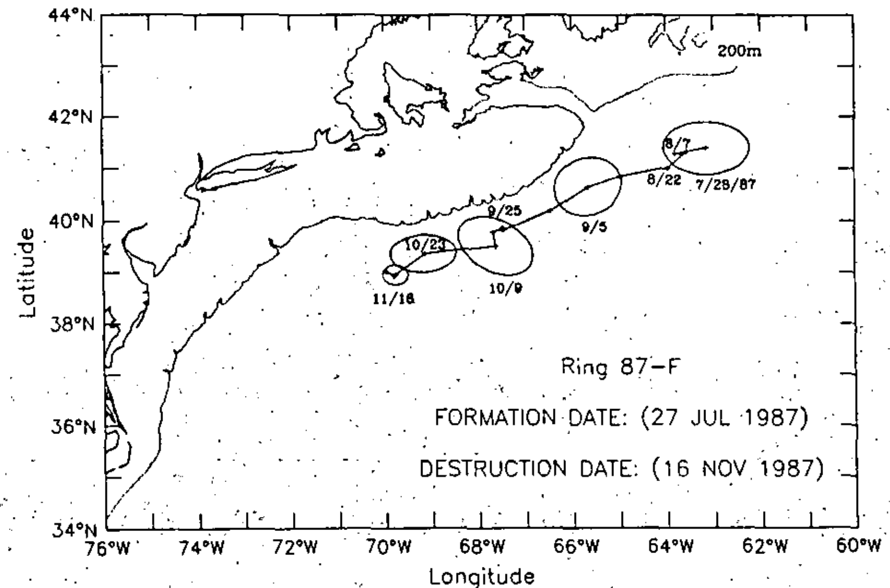


Figure 14. Trackline for ring 87-F.

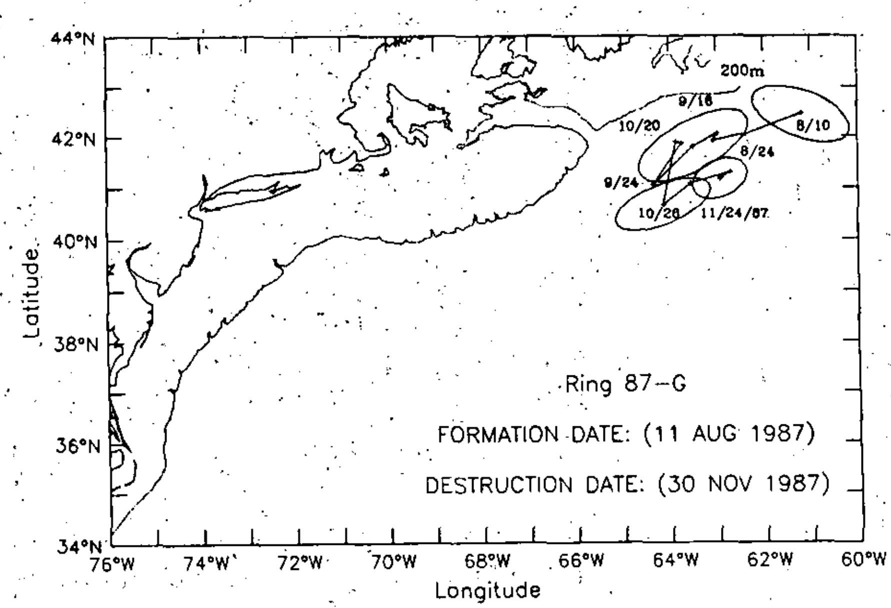


Figure 15. Trackline for ring 87-G.

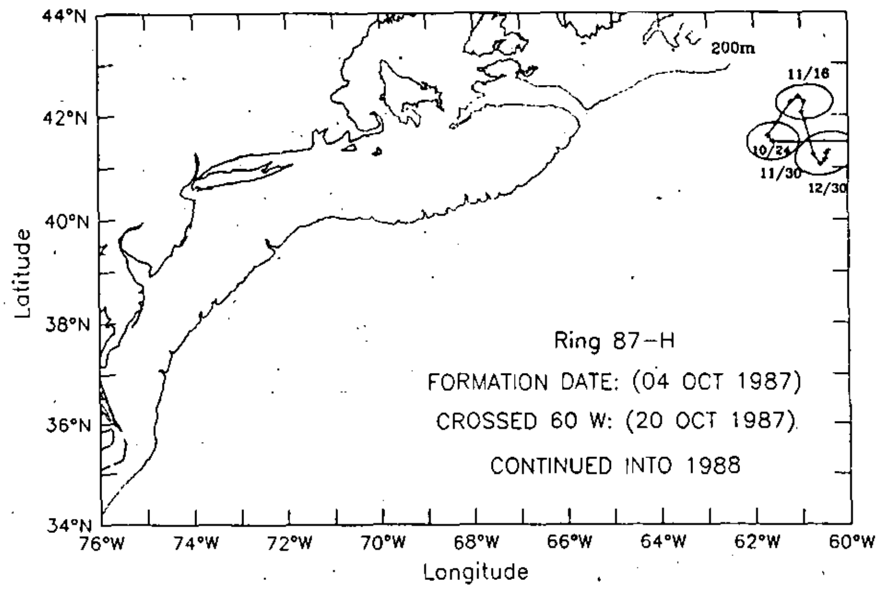


Figure 16. Trackline for ring 87–H.

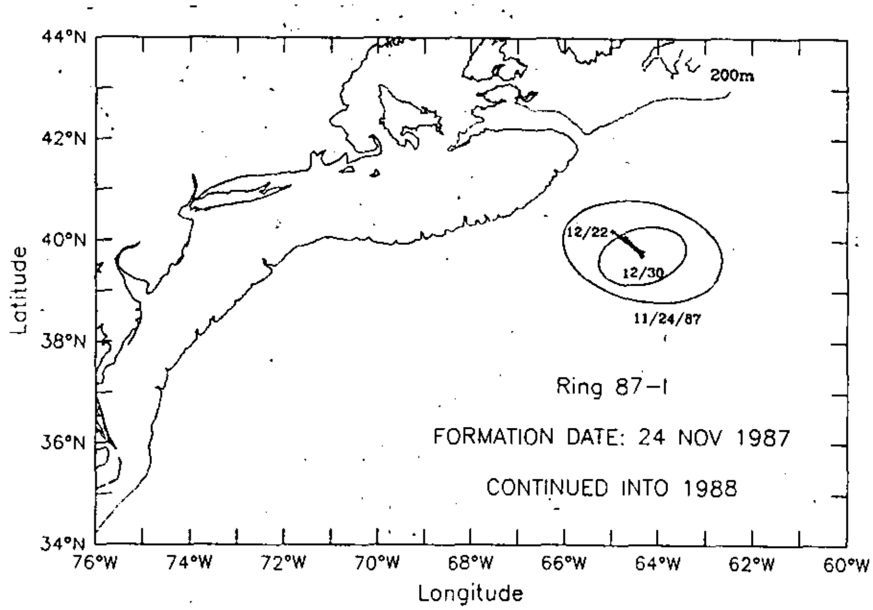


Figure 17. Trackline for ring 87–I.

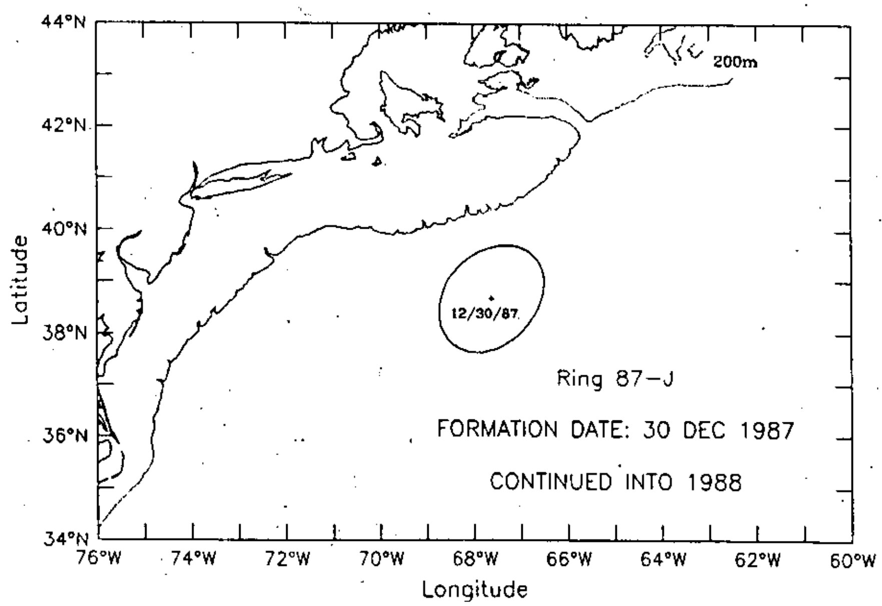


Figure 18. Trackline for ring 87–J.

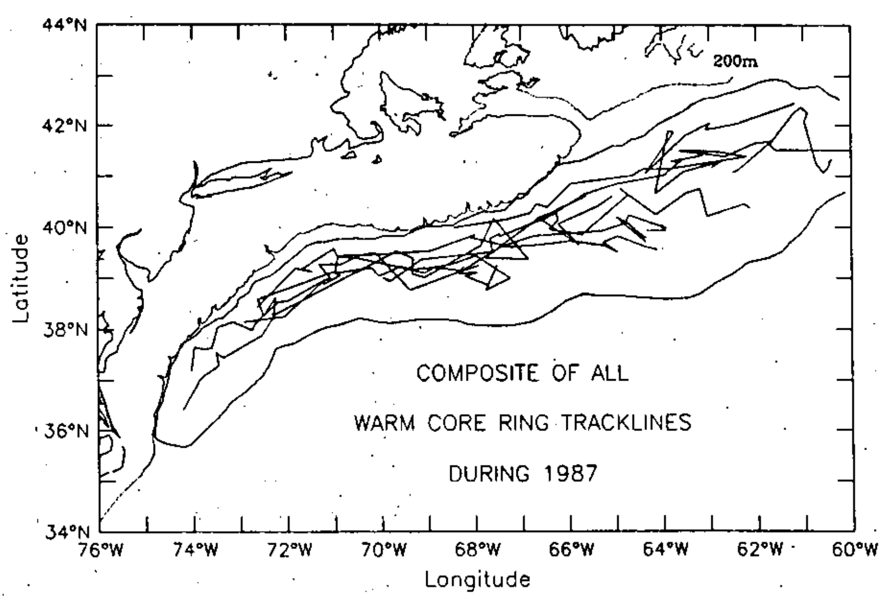


Figure 19. Composition of ring tracklines and envelope of ring surface boundaries.