Northwest Atlantic Fisheries Organization

Serial No. N1294

NAFO SCR Doc. 87/14

SCIENTIFIC COUNCIL MEETING - JUNE 1987

Anticyclonic Warm Core Gulf Stream Rings off the Northeastern United States During 1986

by

Carol A. Price and Kenneth W. Barton

Physical Oceanography Branch, Northeast Fisheries Center, NMFS/NOAA
South Ferry Road, Narragansett, RI 02882, USA

This report summarizes for the thirteenth year, 1986, 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 preceeding twelve years, by Bisagni (1976) for 1974-75; Mizenko and Chamberlin (1979) for 1976-1977; Celone and Chamberlin (1980) for 1978; Fitzgerald and Chamberlin (1982, 1983, 1984) for 1979-81; Celone and Price (1985) for 1982, and Price and Celone (MS 1984) for 1983, and Price (MS 1985) for 1984, and Price and Barton (MS 1986) for 1985.

Information Sources and Analysis Methods

This analysis is based primarily on data collected by the Advanced Very High Resolution Radiometer (AVHRR), a sensor onboard National Oceanic and Atmospheric Administration (NOAA) polar-orbiting satellites, specifically NOAA-6, NOAA-9 and NOAA-10. Six 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 is 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 also 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 the zones used in the zonal analysis is provided in Figure 1. Ring center positions are plotted on the respective trackline charts (Figs 2-7,9 and 11-13). Formation and destruction locations plus bi-monthly positions are dated. At any time of the year, but especially in summer, rings may not be visible in satellite imagery because of the 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 uncertainity in distinguishing between the rings when they reappear. In such cases, the simplest interpretation of movements has 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 west of 60°W, and alphabetically in the order of formation. This report also 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 also periodically appear in the slope water region, though their formation is not in the above described manner and thus are not labelled as warm-core rings. These warm eddies are, therefore, not included in this report.

Ring Histories

A total of ten warm core Gulf Stream rings occurred in the slope water region between Cape Hatteras, North Carolina and 60°W longitude during 1986, all of which were formed in 1986. Estimated formation and destruction dates as well as lifespans for each ring are listed in Table 1.

Ring 86-A (Fig. 2), the longest-lived ring in 1986, formed from a Gulf Stream meander on about 3 January 1986 centered at 40.0°N, 62.2°W. Clouds obscured the sea surface from mid-January through early

March. In early March this ring appeared to be larger in surface area than previously observed, and was interacting with the Gulf Stream. By the end of March, the surface area of the ring was very large (322 km in east-west diameter), as it began moving west-northwest away from the Gulf Stream. During early to mid-April entrainment of shelf water around the eastern border of the ring was very evident in the satellite imagery. In early May, a Gulf Stream interaction took place, which greatly reduced the surface diameter of the ring to 168 km.

Several large patches of warm water broke off from the western edge of ring 86-A from mid-May to early June, without affecting the observed surface circulation of the ring. The surface expression of these patches indicated a westward flow associated with the features, though an oceanographic cruise through the area in early June revealed no obvious current or subsurface structure in one of these warm patches.

In mid-June, shelf water entrainment was again pronounced along the eastern side of ring 86-A. The position of this ring remained in the same general area from the end of April through late June. Brief contacts with the Gulf Stream were observed from July to September as the ring moved westward. By the end of September, these interactions had increased in intensity, as the southwestward moving ring began entraining Gulf Stream water around itself, and into its core. The surface expression of the ring became less defined as this interaction continued into late October. The ring was eventually absorbed by the Gulf Stream on 31 October, centered near 36.7°N, 74.1°W.

Ring 86-B (Fig. 3) formed on or about 14 January 1986, from a Gulf Stream meander, and was centered near 41.7°N, 59.8°W. Clouds generally obscured the area until early March. This southwestward moving ring was estimated to have completely crossed west of 60°W on about 10 February. In early April, as the persistent clouds began to break up, ring 86-B was observed to be entraining slope water along its eastern and southern borders. By late April, the ring moved to the south interacting with several features, which included 1) shelf water entrained along the eastern edge of the ring, 2) Gulf Stream water entrained along the southern edge of the ring and 3) a warm patch of water which had broken off ring 86-A being entrained along its northwestern border, so that by late May, the surface area of ring 86-B had been greatly reduced, while continuing to move west.

In early June, this ring came in contact with a warm patch of water which had broken off ring 86-A. This warm patch of water was confined between ring 86-A to its west and ring 86-B to its east, and appeared to have a counterclockwise circulation, which may have been induced as a result of the close contact with these two rings. By the middle to end of June, this warm patch had dissipated, and ring 86-B was again seen as a well defined ring, though it now was wedged between ring 86-A to its west and a newly formed ring 86-C to its east. As its movement became more constricted in late June, ring 86-B weakened and began being absorbed by ring 86-C. By 28 June, only a small patch of warm water with no detectable circulation was observed where ring 86-B had been, and this date was taken to be the date of absorption of this ring by ring 86-C. The last position of the ring was centered near 40.1°N, 66.9°W. (Note: In the Modified Weekly Oceanographic Analysis Charts, this ring was incorrectly continued after this destruction date. See ring 86-C for an explanation.)

Ring 86-C (Fig. 4), a very short-lived ring, formed from a westward extending meander on 14 June, centered at 39.9°N, 64.1°W. By late June, this ring began interacting with another ring to its east, ring 86-C1, which had recently detached from the same meander which spawned ring 86-C. This interaction apparently forced ring 86-C to southwest at a relatively fast average speed of 14.3 km/day throughout middle to late June. In mid-July, ring 86-C and 86-C1 began to separate with ring 86-C moving to the west, approaching ring 86-A. Ring 86-C was soon wedged between ring 86-A to its west, ring 86-C1 to its east, and a Gulf Stream meander to its south. Due to this constricted movement, ring 86-C began rapidly interacting with the meander, and two days later on 17 July it was completely absorbed by the Stream. Ring 86-C's last position was centered at 39.7°N, 67.4°W. (Note: In the Modified Weekly Oceanographic Analysis Charts, this ring was incorrectly labelled as Possible 86-B and 86-B Remnants during early July, due to a confusion regarding the dynamic interactions occurring in this geographic area at the time.)

Ring 86-C1 (Fig. 5) was another short-lived ring which formed from the same meander, and within a couple of weeks of ring 86-C. Some confusion arose as to the interactions of the existing rings and meanders during this time period, and this ring was mislabelled in the Modified Weekly Oceanographic Analysis charts as described below. Ring

86-C1 formed from a westward extending Gulf Stream meander on 26 June, centered near 40.1°N, 64.2°W. Immediately after its formation, this ring moved to the south and began interacting with ring 86-C, located to its southwest. In early July, confusion arose as to which rings were actually involved in this interaction, due to periodic cloud cover in available imagery. We now confirm that ring 86-C and 86-C1 were involved in this interaction, and were mislabelled in the charts as Remnant 86-B and 86-C, respectively. (This mislabelling of ring 86-C1 continued throughout July). A meander formed to the southwest of 86-C1, and continued to build in amplitude. As the southwestward movement of ring 86-C1 became constricted by this meander, the ring became elongate in a north-south direction and began interacting with the Stream. This interaction continued as the Gulf Stream began to absorb ring 86-C, completely destroying the ring on 25 July. Its last position was centered near 39.3°N, 65.2°W.

Ring 86-D (Fig. 6), also a short-lived ring, formed from a Gulf Stream meander on 17 July, centered near 41.0°N, 61.7°W. Ring 86-D moved to the north-northeast probably in response to a Gulf Stream meander forming southwest of the ring. Ring 86-D was a relatively small (average surface diameter of 100 km), weak ring throughout its life. Due to the lack of thermal contrast associated with this ring, it was primarily identified by the expression of slope water entrainment around its eastern border. This ring apparently dissipated by 26 August, as no entrainment or thermal contrast was visible after this time in the cloud free imagery, nor was there any indication of the Gulf Stream or any other warm-core rings in the vicinity of ring 86-D which may have absorbed this ring. The last center position for this short-lived ring was near 41.9°N, 64.1°W.

Ring 86-E (Fig. 7) formed from a large Gulf Stream meander on 7 August, and was centered at 39.2°N, 67.5°W, having formed further to the west than the area where rings generally form. This ring was extremely large when it was formed, with a surface diameter of 223 km. By the end of August, ring 86-E became wedged between ring 86-F to its east and ring 86-A to its west, resulting in the transformation into an elongated ring. A warm patch of water broke off the southwestern border of this ring in late August, with no apparent affect on its large surface diameter. In early September, ring 86-E began moving westward away from the Gulf Stream, though interaction with the Stream was evidenced by

several warm streamers. In late September, a Gulf Stream meander formed south of the ring, causing it to elongate temporarily due to constriction. Soon after, the ring began interacting with the Gulf Stream, entraining Gulf Stream water around the western and northern borders of the ring. In early October the meander moved to the east and the interaction subsided. Throughout October and November the ring continued to move to the west until early December when it again came in contact with the Gulf Stream, possibly influencing the formation of a meander west of the ring.

On 12 and 13 November the M/V OLEANDER crossed ring 86-E during an XBT survey. Unfortunately, no satellite imagery was available during this period to illustrate the trackline. A hydrographic vertical section from the OLEANDER confirmed the presence of ring 86-E. Within the ring the 15°C isotherm extends to a depth of nearly 300 m and the 10°C isotherm to over 500 m (Fig 8A). Surface salinities of over 36 ppt, indicative of water of Gulf Stream origin, were observed in the vicinity of the ring (Fig.8B).

By mid-December, ring 86-E, had entrained Gulf Stream water along its western border, apparently strengthening the ring and increasing its surface diameter. By 30 December, the ring, still interacting with the Gulf Stream, was centered at 37.6°N, 73.6°W.

Ring 86-F (Fig. 9) formed from a westward extending Gulf Stream meander on 12 August, centered at 39.5°N, 64.1°W. During 17-23 August, this ring's surface diameter was reduced by half to 103 km by an interaction with the Gulf Stream. By the end of August, the ring was still communicating with the Gulf Stream as evidenced by several warm streamers observed along its southern border. In early September, this ring began interacting with a Gulf Stream meander to its west. This meander began to quickly absorb ring 86-F as it propagated downstream, greatly reducing the ring's surface diameter to 44 km. This ring was almost completely absorbed by the meander, though by mid-September ring 86-F separated from the northern protion of this meander as a well developed ring. This ring continued moving to the southwest from October to December.

On 10 and 11 December, the OLEANDER crossed through ring 86-F on an XBT survey. While the surface expression of the ring was weak, the hydrographic vertical section shows indications of the presence of the

ring. The 15°C isotherm extends to nearly 140 m and the 10°C isotherm extends to nearly 320m (Fig. 10A). Surface salinities are close to 36 ppt and reach a maximum in the vicinity of the ring (Fig. 10B). No satellite images are available during this time but indications are that the OLEANDER passed through the northeast section of the ring. The center position recorded for ring 86-F on 30 December 1986 was at 38.4°N, 72.6°W.

Ring 86-G (Fig.11) broke off from a large, newly formed warm-core ring, which was not labelled, as it never crossed west of 60°W. In early August, a portion along the northwest border of this unnamed ring began to split off, and by 9 August appeared to have its own circulation, entraining shelf water along its eastern border. Ring 86-G was thus recorded to have formed on this date, centered at 42.7°N, 58.17°W. This ring was not clearly seen again until late August, when it was still associated with the larger ring which had spawned it. Ring 86-G continued to move slowly westward, under the indirect influence of the larger ring. By mid-September, the ring had doubled its surface area to nearly 128 km and exhibited strong circulation. In early October, a Gulf Stream meander which eventually formed ring 86-H began interacting with and absorbing the larger ring to the south of ring 86-G, and prevented ring 86-G's movement to the west. By early November, ring 86-C began interacting with, and being absorbed by newly formed ring 86-H located to its south. By early December, only a remnant of ring 86-G, with little circulation, was visible along the northern portion of ring 86-H. Ring 86-G apparently was absorbed by ring 86-H on about 9 December, centered near 42.7°N, 62.7°W.

Ring 86-H (Fig. 12) formed on about 20 October from a Gulf Stream meander. The formation date and center location of 41.0°N, 62.5°W are estimated due to persistent cloud cover during this time period. Throughout late October, November, and early December, this ring was interacting with a smaller ring, 86-G, located northeast of ring 86-H. In middle and late November, ring 86-H came into brief contact with the Gulf Stream. In early December, a new ring, 86-I, formed south of ring 86-H, and forced the latter ring to the east. By early January 1987, ring 86-I had moved to the west, allowing ring 86-H to begin moving to the west. Ring 86-H's position on 30 December 1986 was centered at 41.3°N, 62.6°W.

Ring 86-I (Fig. 13) formed on 4 December, centered at 39.9°N, 63.9°W, from a westward extending Gulf Stream meander. This ring formed directly south of rings 86-H and 86-G, which were interacting with one another. Ring 86-I briefly interacted with ring 86-H to its northeast, as it began moving to the west. Its position on 30 December 1986 was centered at 40.1°N, 65.3°W.

Zonal Analysis

A generalized summary of the movements of rings during 1986 is presented in Table 2, which shows their mid-month positions with respect to the zones diagrammed in Figure 1. Total zone-month occurrence is 37. During the years 1974-1985, 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 once during 1986. For the third year in a row, zone 8 was not occupied by any warm-core rings.

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 Figure 14. The envelope was developed from boundary positions digitized from satellite data and from the weekly analysis charts. Nine of the ten rings occurring in 1986 formed very near or east of 64°W; the remaining, ring 86-E, formed near 67°W. Two of the ten rings never moved west of the 63°W meridian while seven rings (86-B, 86-C, 86-C1 86-D, 86-G and 86-H and 86-I - as of 12/30/86) never moved west of the 68°W meridian. The remaining three rings (86-A, 86-E and 86-F) travelled at least to approximately the 73°W meridian.

Number of Rings, Times of Formation, and Longevity

Ten warm core Gulf Stream rings formed during 1986 off the northeast coast of North America. During 1974-1985, ring formation averaged eight per year, ranging from a minimum of five in 1974 to a maximum of eleven in 1979 and 1982. No rings that formed in 1985 survived into 1986. Of the ten rings that formed or crossed west of 60°W longitude in 1986, two formed by mid-January, two formed in June, one formed in July, three formed in early to mid-August, one formed in October, and one formed in early December. Longevity of the rings

ranged from 30 to 302 days. Four of these rings (86-E, 86-F, 86-H and 86-I) continued into 1987.

Acknowledgements

We would like to thank Robert Benway of Marine Climatology Investigation (MCI) for providing the hydrographic vertical sections (Figs. 8 and 10) and special thanks go to Glenn Strout of MCI for his work in digitizing the ring boundaries.

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 pp.

Celone, P. J., and J. L. Chamberlin. 1980. Anticyclonic warm-core Gulf Stream eddies off the northeastern United States in 1978. ICES Annales Biol., 35: 50-55

Celone, P. J. and C. A. Price. 1985. Anticyclonic warm-core Gulf Stream rings off the northeastern United States during 1982. ICES Annales Biol., 39 : 19-23.

Fitzgerald, J. L., and J. L. Chamberlin. 1982. Anticyclonic warm-core Gulf Stream rings off the northeastern United States in 1979. ICES Annales Biol., 36: 44-51.

1983. Anticyclonic warm-core Gulf Stream rings off the northeastern United States in 1980. ICES Annales Biol., 37: 41-47.

1984. Anticyclonic warm-core Gulf Stream rings off the northeastern United States in 1981. ICES Annales Biol., 38: 29-33.

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

Price, C. A. and K. W. Barton. MS 1986. Anticyclonic warm-core Gulf Stream rings off the northeastern United States during 1985. NAFO SCR Doc., No 86/77, Serial No. N1197, 17p.

Price, C. A. MS 1985. Anticyclonic warm-core Gulf Stream rings off the northeastern United States during 1984. NAFO SCR Doc., No. 85/19, Serial No. N960, 12 p.

Price, C. A., and P. J. Celone, MS 1984. Anticyclonic warm-core Gulf Stream rings off the northeastern United States during 1983. NAFO SCR Doc., No. 84/18, Serial No. N796, 18 p.

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

ring	Dates[1]	Life Span (Days)
86-A	(01/03/86) - 10/31/86	302
86-B	(01/14/86) - 06/28/86[2]	166
86-C	06/14/86 - 07/17/86	33
86-C1	06/26/86 - 07/25/86	30
86-D	07/17/86 - (08/26/86)	41
86-E	08/07/86 - into 1987	>147
86-F	08/12/86 - into 1987	>142
86-G	08/09/86 - (12/09/86)[3]	123
86-H	(10/20/86) - into 1987	>83
86-I	12/04/86 - into 1987	>28

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 02/10/86.

3 This ring was not labelled until it completely crossed west of 60°W on 10/15/86.

Table 2. Ring positions at mid-month with respect to zone during 1986.

Zone	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	86-B	86-B				86-D				86-G	86-G	
2	86-A	86-A	86-B	86-B			86-D	86-D			86-H	86-H
3			86-A		86-B	86-C	86-C1	86-F	86-F			86-I
4				86-A	86-A	86-A 86-B	86-C	86-E		86-F		
5							86-A		86-E	86-E	86-F	
6								86-A			86-E	86-F
7									86-A	86-A		86-E
8												

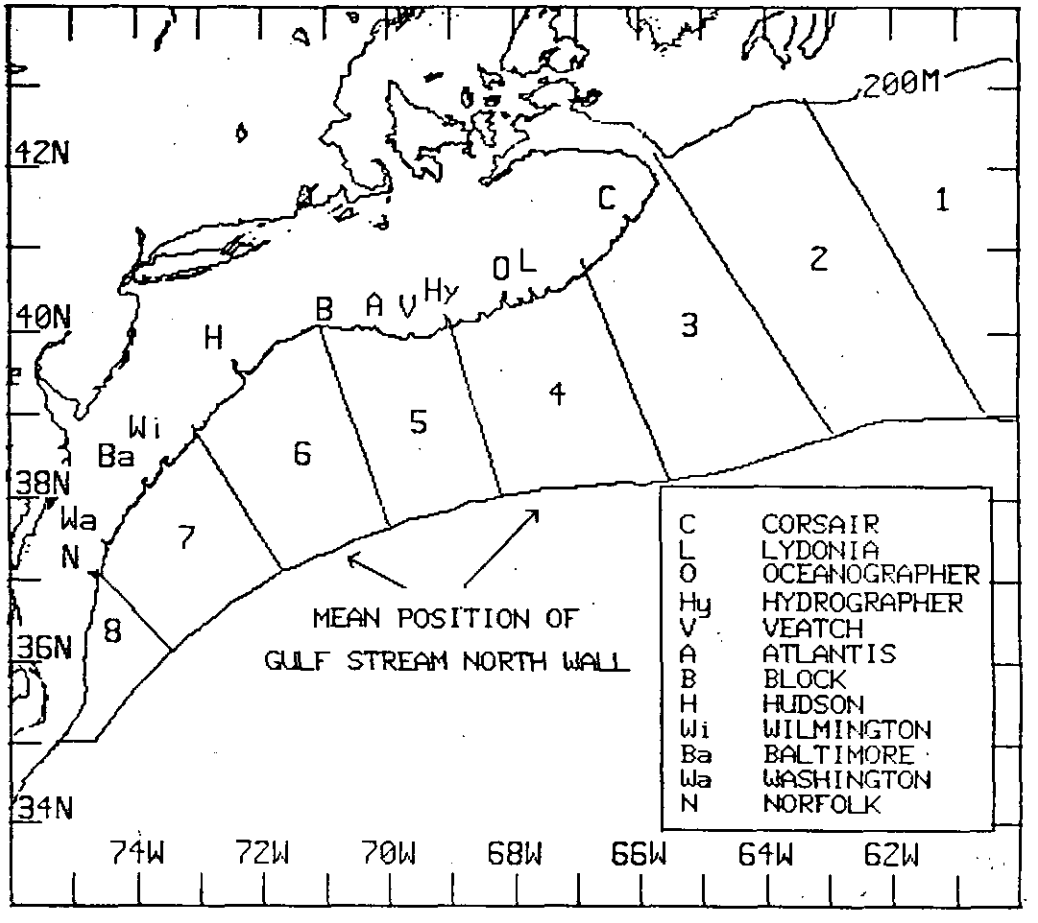


Figure 1. Base map for ring tracklines, showing canyon names and zones used in Table 2.

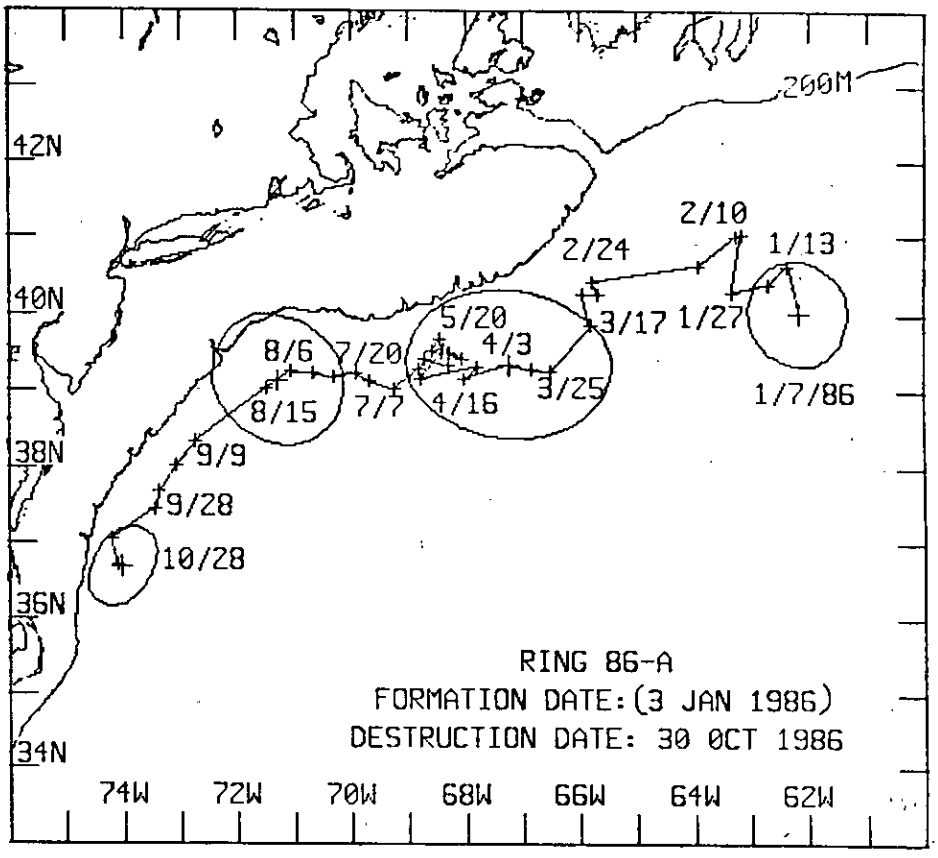


Figure 2. Trackline for ring 86-A

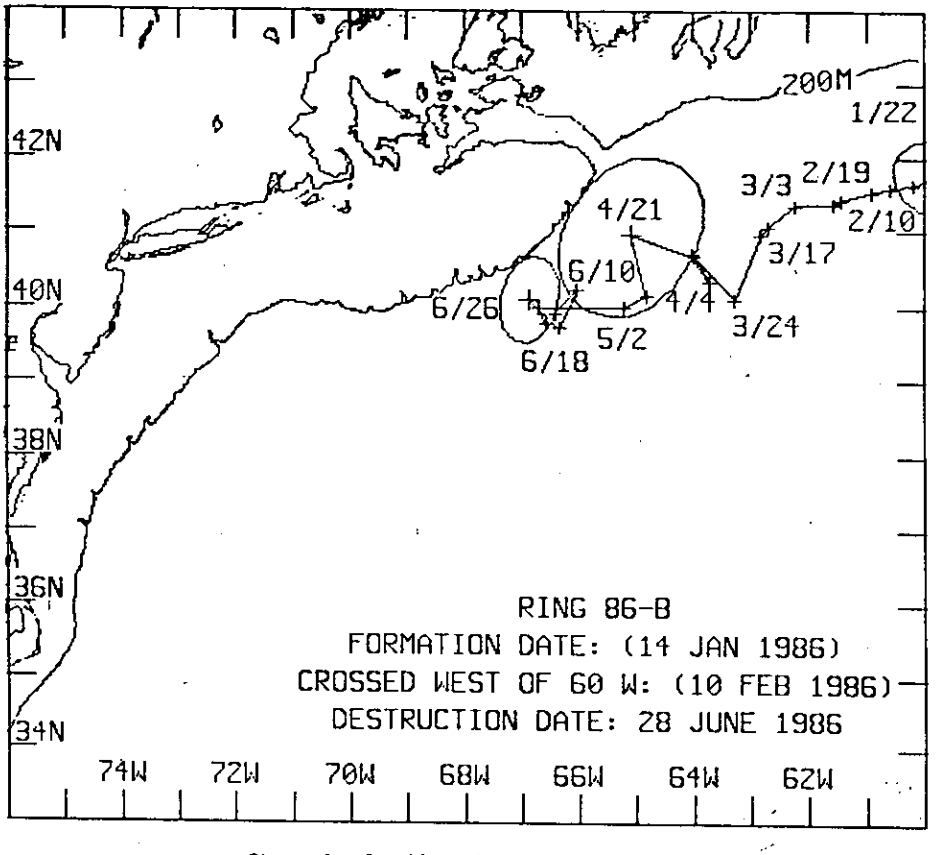


Figure 3. Trackline for ring 86-B.

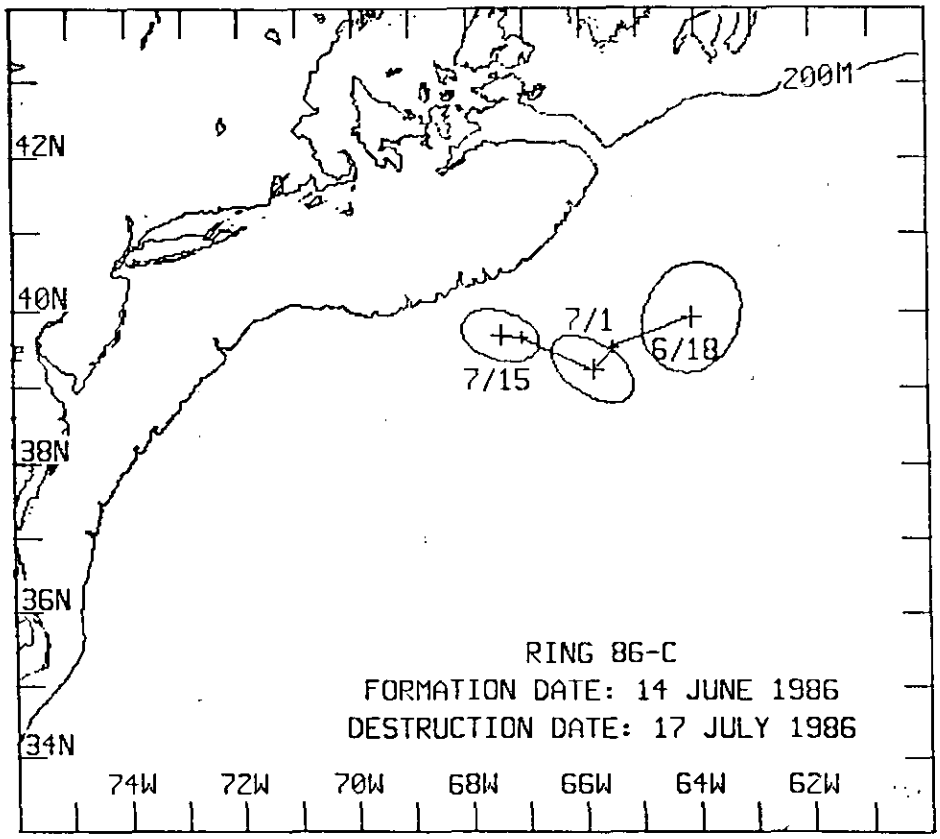


Figure 4. Trackline for ring 86-C.

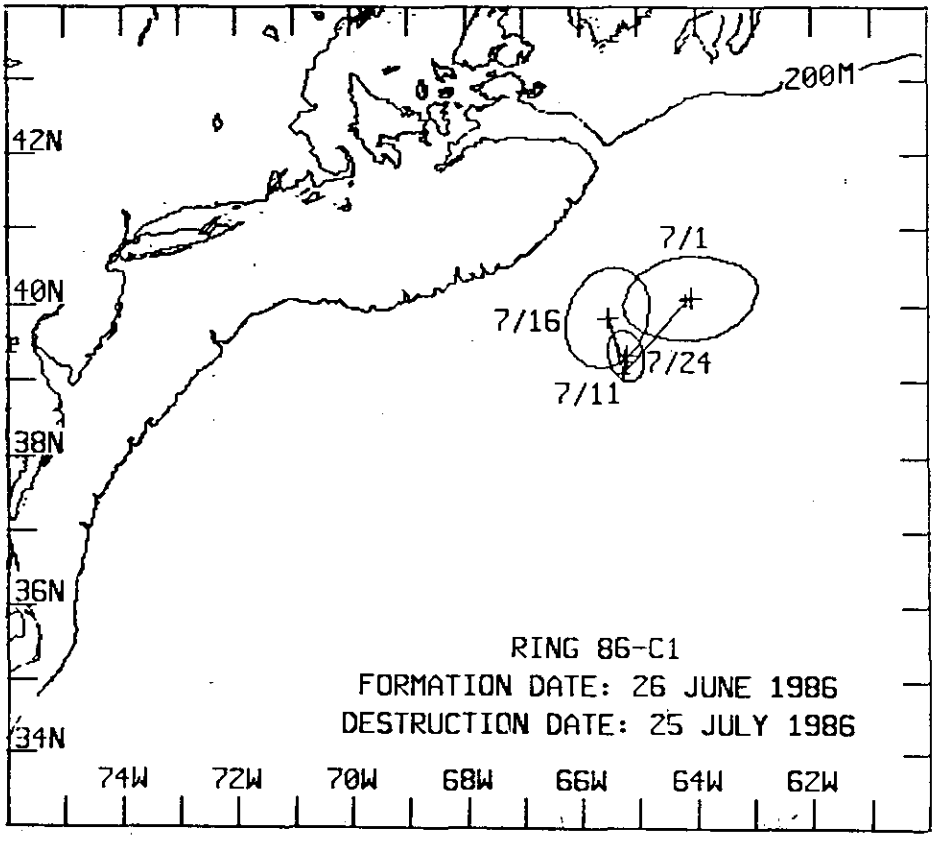


Figure 5. Trackline for ring 86-C1.

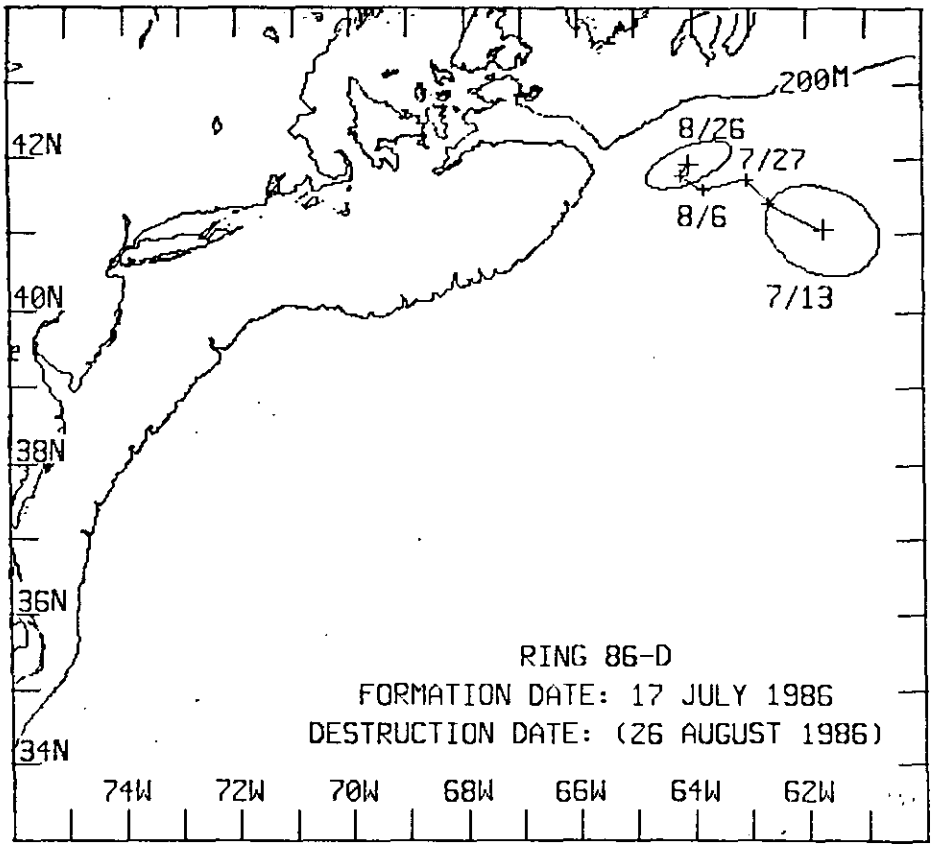


Figure 6. Trackline for ring 86-D

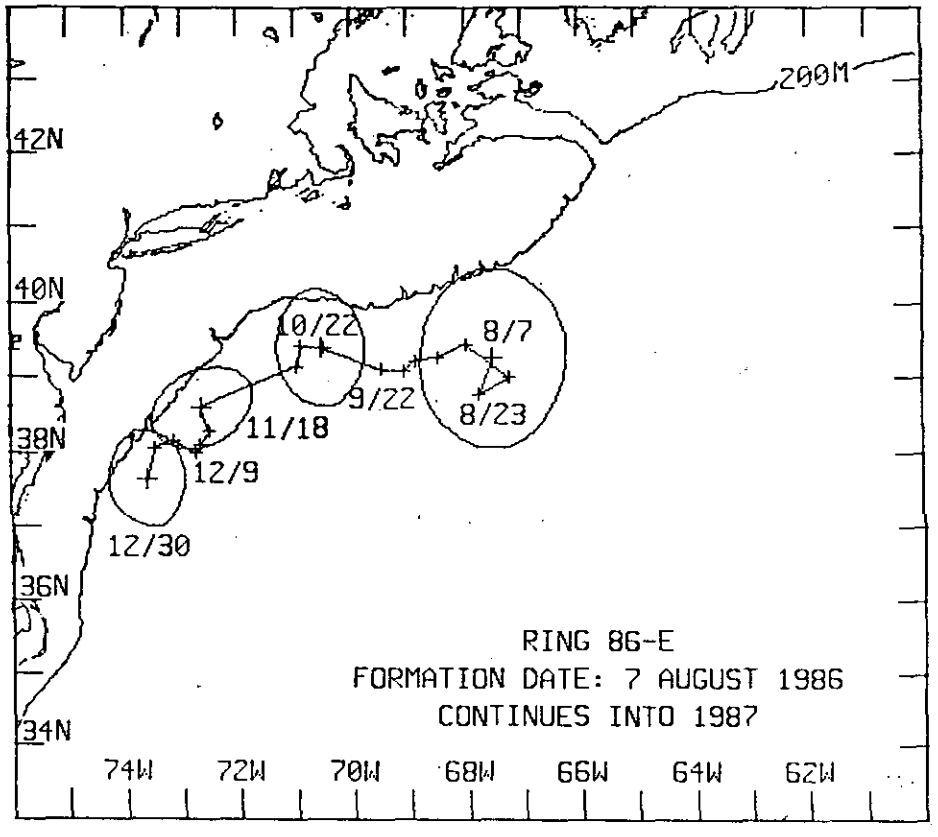
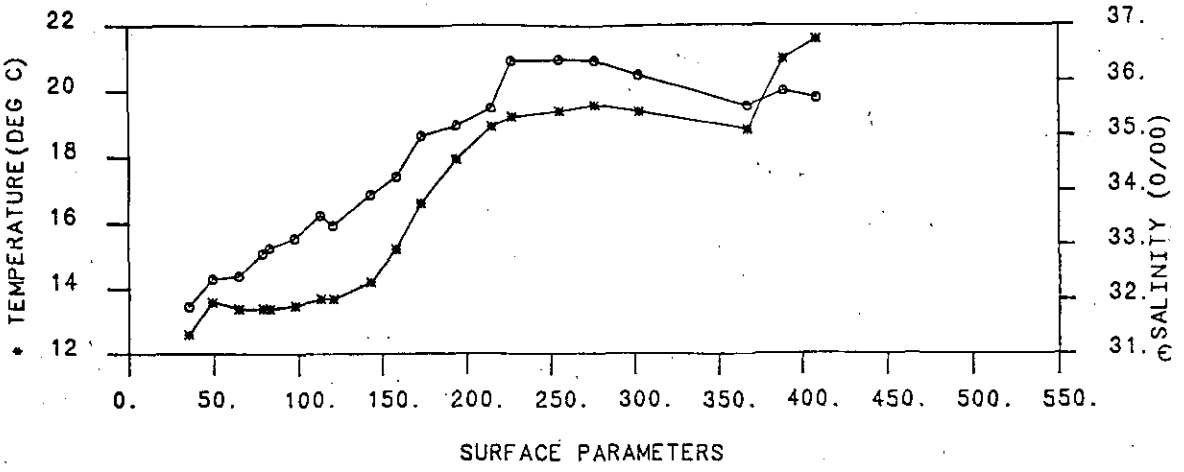


Figure 7. Trackline for ring 86-E.



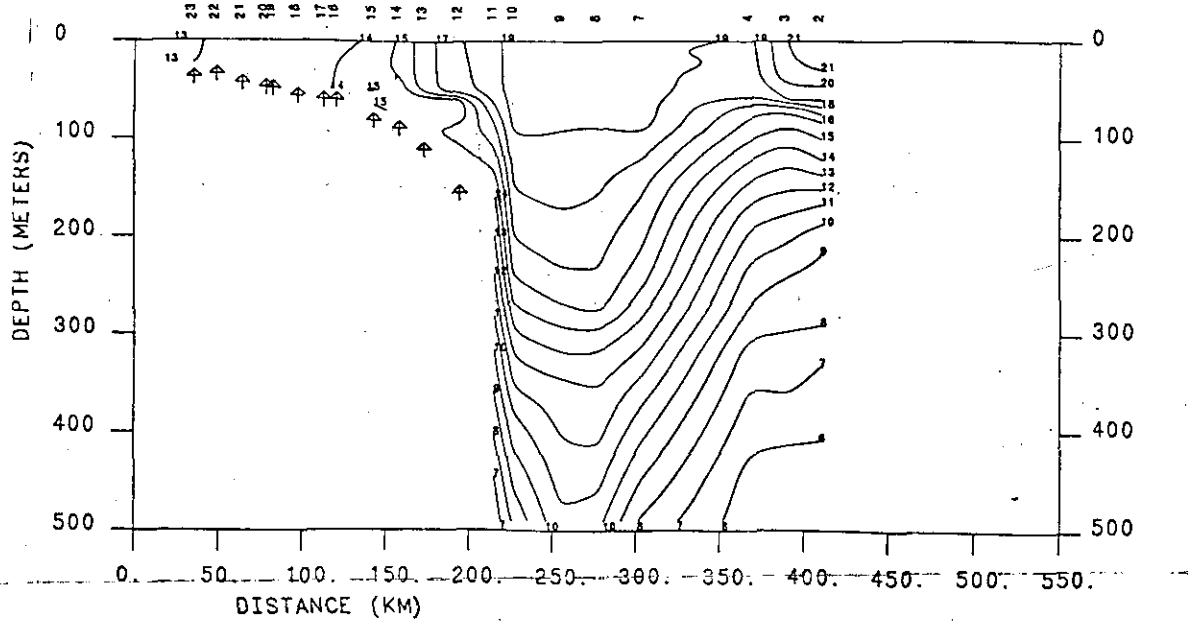


Figure 8. Hydrographic measurements obtained in the vicinity of ring 86-E, by the M/V Oleander on 12-13 November 1986. (A) vertical section showing 86-E, and (B) sea surface salinity.

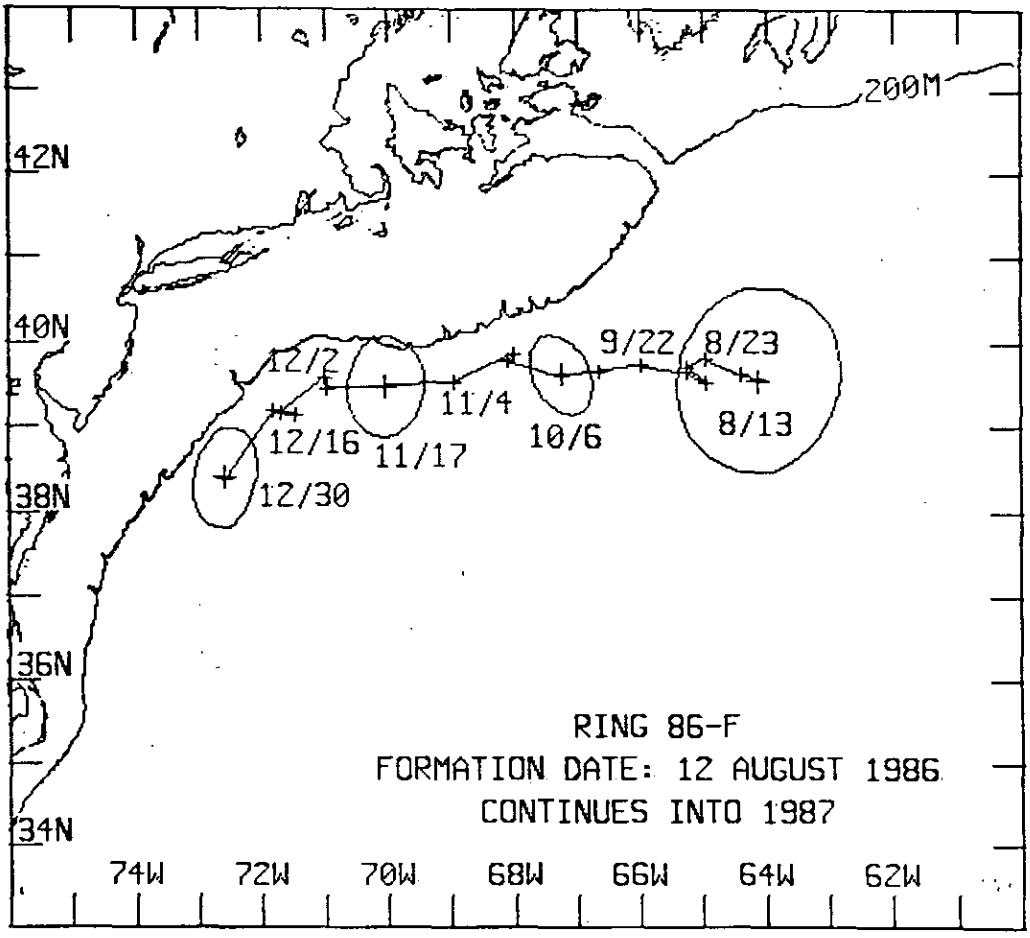


Figure 9. Trackline for ring 86-F.

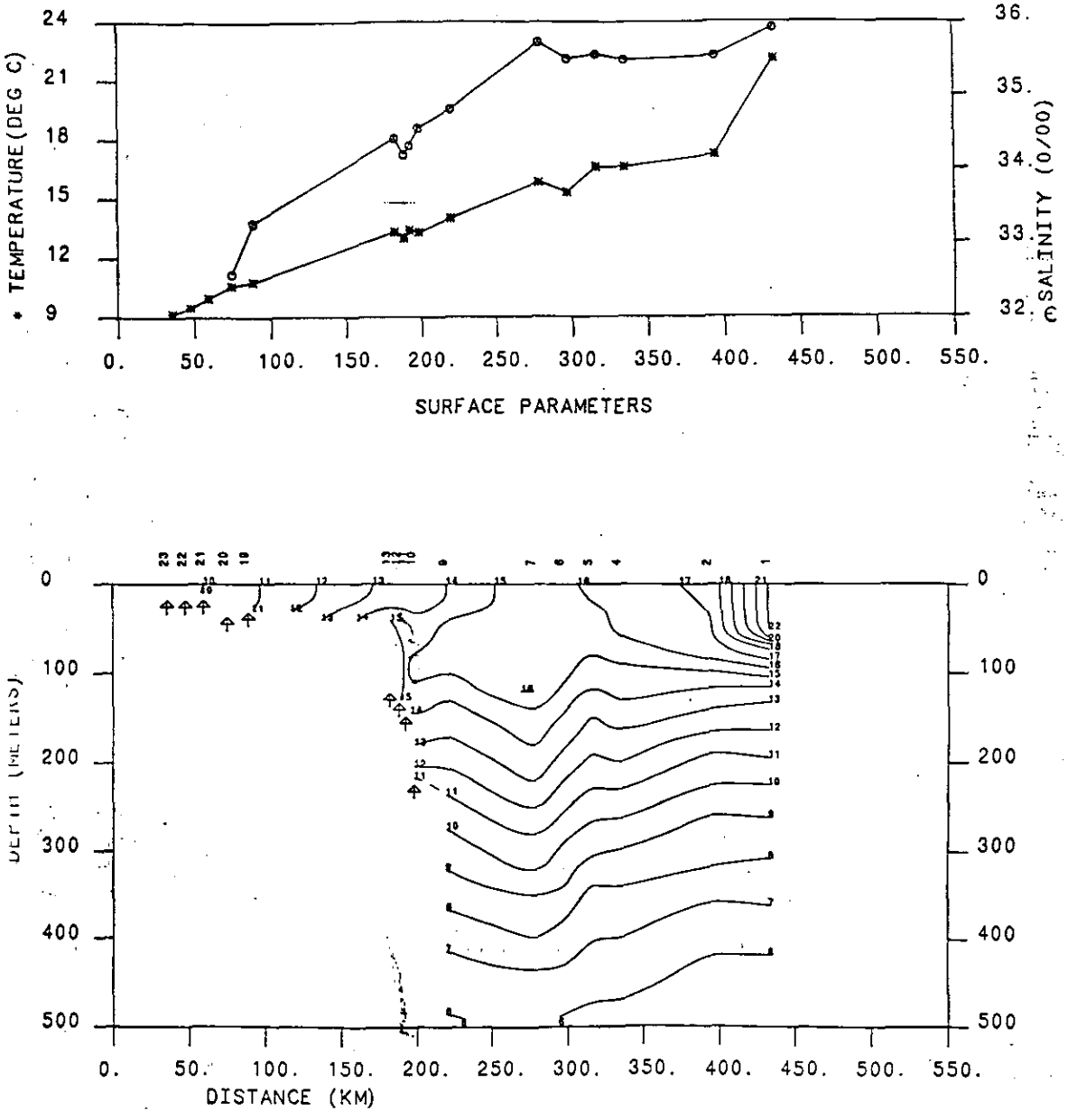


Figure 10. Hydrographic measurements obtained in the vicinity of ring 86-F, by the M/V Oleander on 10-11 December 1986. (A) vertical section showing ring 86-F, and (B) sea surface salinities.

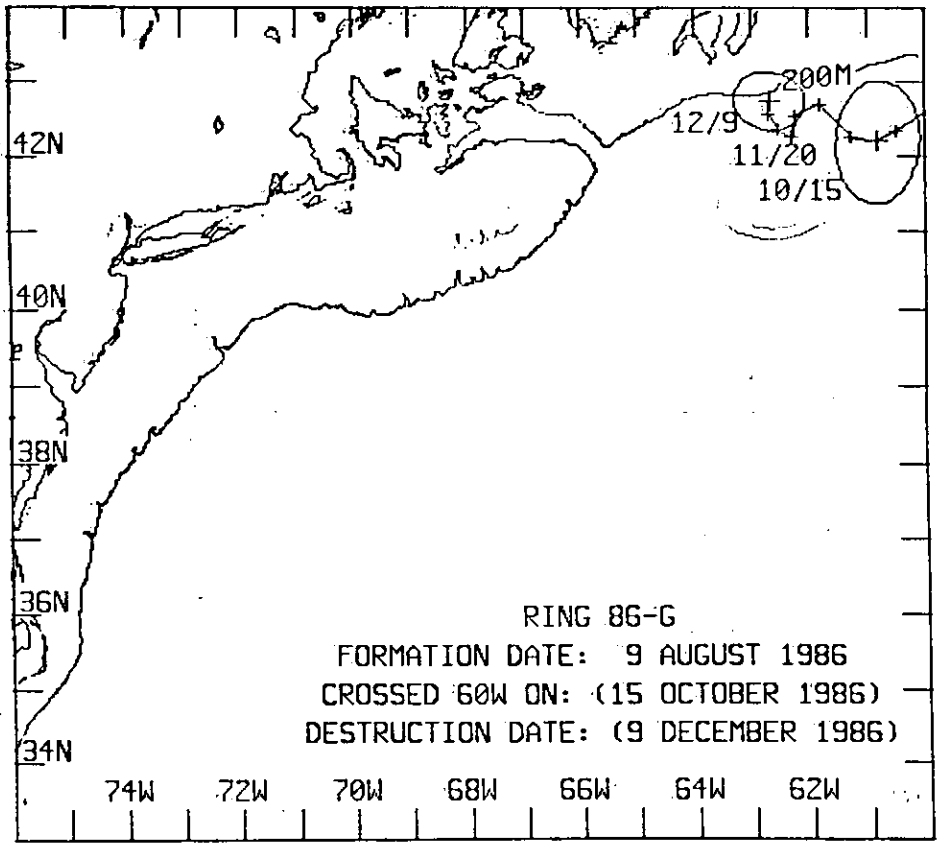


Figure 11. Trackline for ring 86-G.

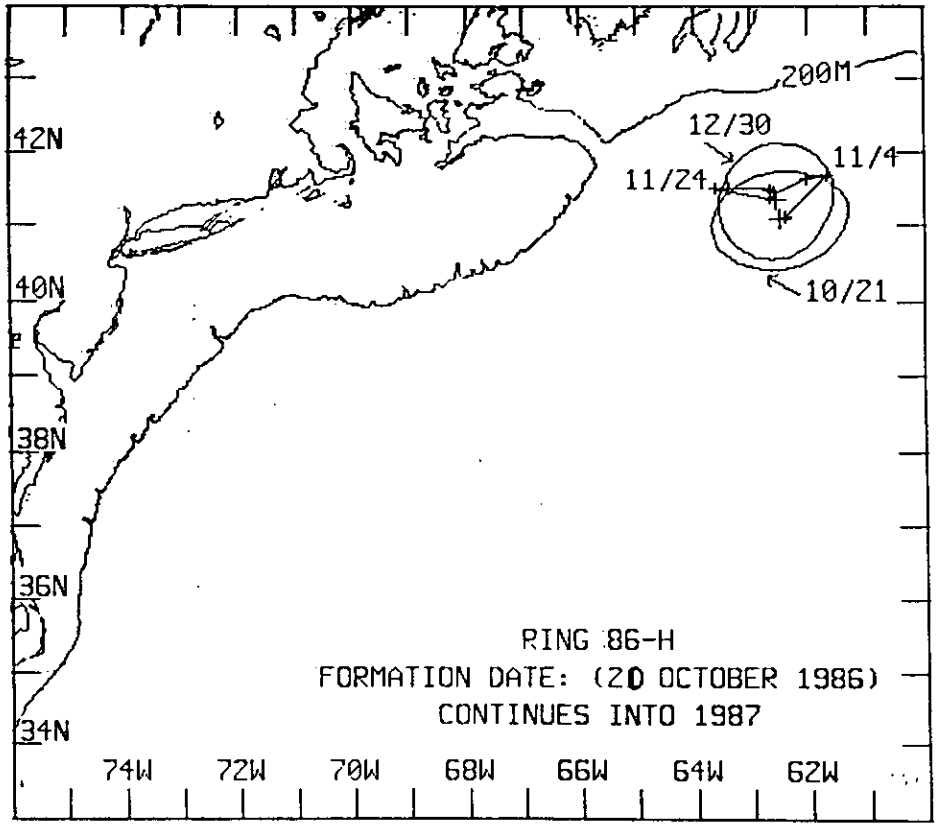


Figure 12. Trackline for ring 86-H.

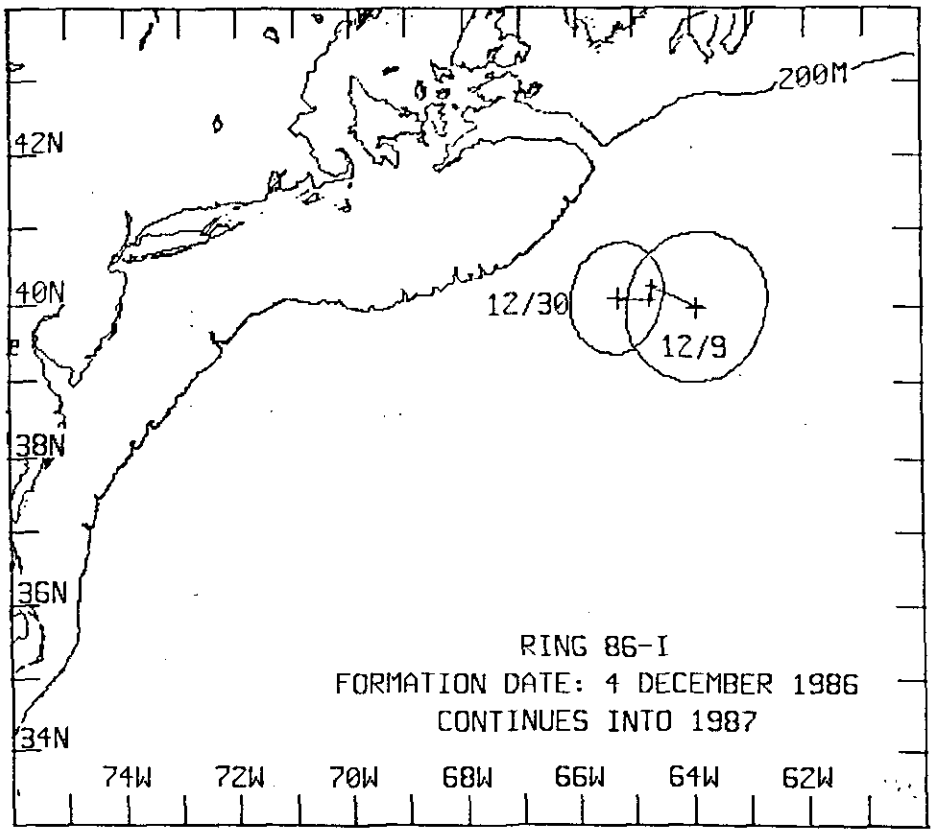


Figure 13. Trackline for ring 86-I.

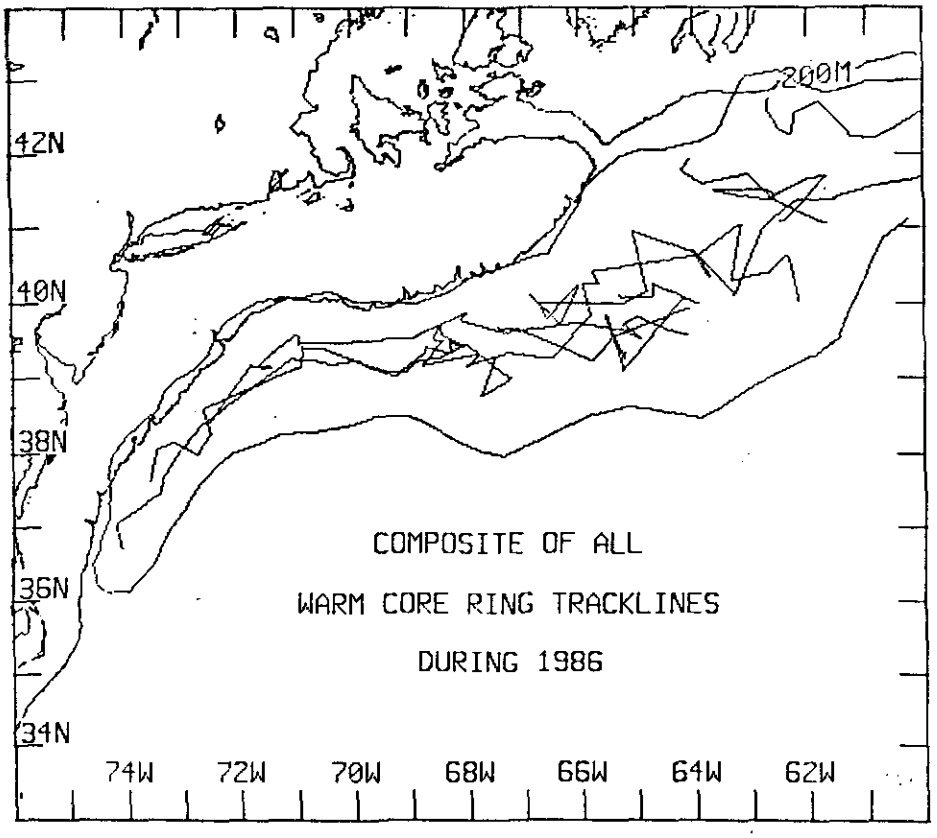


Figure 14. Composition of ring tracklines and envelope of ring surface boundaries.