Northwest Atlantic Fisheries Organization

Serial No. N1197

NAFO SCR Doc. 86/77

SCIENTIFIC COUNCIL MEETING - JUNE 1986

Anticyclonic Warm Core Gulf Stream Rings Off the Northeastern United States During 1985

by

Carol A. Price and Kenneth W. Barton

Environmental Processes Division, National Marine Fisheries Service (NOAA)
U.S. Department of Commerce, South Ferry Road, Narragansett, Rhode Island 02882, USA

This report summarizes for the twelfth year, 1985, 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 ten 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.

Information Sources and Analysis Methods

This analysis is based primarily on data collected by the Advanced Very High Resolution Radiometer (AVHRR), a sensor onboard the National Oceanic and Atmospheric Administration (NOAA) series of polar-orbiting satellites, specifically NOAA-6, NOAA-8 and NOAA-9. Six satellite passes covering the study area are potentially available each day, depending on the degree of cloud cover present. Using the processing facilities of the Oceanographic Remote Sensing Laboratory, University of Rhode Island, the high resolution ($\sim$ 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 for reference (Fig. 1). Ring center positions are plotted on the respective trackline charts (Figs 2-6, 9-14). 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 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.

Ring Histories

A total of eleven warm core Gulf Stream rings occurred in the slope water region between Cape Hatteras, North Carolina and 60°W longitude during 1985. Two rings, 84-G and 84-I, were formed in late 1984 and survived into 1985. Nine rings developed west of 60°W during 1985, though none of these rings persisted into 1986. Estimated formation and destruction dates as well as lifespans for each ring are listed in Table 1.

Ring 84-G (Fig. 2) formed from a Gulf Stream meander on 20 August 1984, centered near 40.6°N, 60.7°W. This ring began moving to the west, resulting in an interaction with a Gulf Stream meander in mid-September. Ring 84-G continued its movement to the northwest, interacting with meanders in late October, when its surface area was increased, and again in early December. In mid-January 1985, ring 84-G

approached the continental shelf break, and continued travelling southwestward along the break. This long-lived ring began interacting with the Gulf Stream in mid-April, and continued to do so until it was finally resorbed by the Stream on 17 August 1985 near 38.5°N, 72.6°W.

Ring 84-I (Fig. 3) is questionable in that it was never clearly seen as a feature with strong circulation. In late December 1984, a warm patch of water with some circulation was observed in the satellite imagery. It appears that this was formed from a Gulf Stream meander on about 12 December 1984 centered near 41.9°N, 61.4°W and was therefore labelled as a warm core ring. This ring was not clearly seen during January 1985 due to persistent cloud cover. A large Gulf Stream meander was observed in February in the vicinity of where Ring 84-I was thought to be. It appears that this meander, centered near 40.8°N, 63.5°W, resorbed ring 84-I on 20 February, 1985 and five days later formed ring 85-B (see below).

Ring 85-A (Fig. 4) formed on 17 December 1984 from a Gulf Stream meander centered near 41.5°N, 56.3°W. Though persistent cloud cover obscured the satellite imagery during much of January 1985, this ring appeared to travel northwestward, crossing west of 60°W longitude on about 20 February. Its westward movement was restricted by ring 85-B, which formed in late February. As a result, ring 85-A decreased in surface area as it interacted with the Gulf Stream during March and April. In early May, a new ring, 85-C, formed south of ring 85-A, forcing this ring further to the north. Its interactions from May through July with ring 85-C continued to weaken ring 85-A, as it slowly moved westward. In late July, another new ring, 85-G, formed to the west of ring 85-A, and began moving towards ring 85-A. It appears that ring 85-A was absorbed by ring 85-G near 40.6°N, 65.6°W on 13 August 1985.

Ring 85-B (Fig. 5) formed from a Gulf Stream meander centered near 40.8°N, 63.3°W on about 25 February 1985. This large ring travelled westward, approaching the continental shelf break in mid-March. In mid-April, this ring's surface area was greatly reduced during interactions with the Gulf Stream which continued until late May. This ring travelled westward until early July, when its westward movement was restricted by ring 84-G to its west. In early August, ring 85-F, which formed on 3 July, approached ring 85-B from the east, and began

entraining water from this ring. Ring 85-B was subsequently absorbed by ring 85-F on 11 August 1985 near 39.4°N, 71.6°W.

Ring 85-C (Fig. 6) formed from a Gulf Stream meander on about 29 April 1985 centered at 40.6°N, 62.9°W. It travelled westward during its first month and began to interact with ring 85-A on or about 25 May, continuing this interaction through 10 June at which time it came in contact with the continental shelf break southeast of Georges Bank. Its westward movement was impeded by the development of ring 85-F which was formed from a Gulf Stream meander on 3 July. Throughout the rest of the summer ring 85-C moved westward through the slope water occasionally interacting with both the Gulf Stream and the shelf water, although its size remained fairly constant. A large northward propagating meander reduced the size of ring 85-C in early November, weakening it and decreasing its thermal contrast.

On 16-17 October, the M/V Oleander crossed ring 85-C during an XBT survey, as is illustrated in an infrared NOAA-9 satellite image from 17 October over which the Oleander ship track has been plotted (Fig. 7). A hydrographic vertical section from the Oleander confirms the presence of ring 85-C. Within the ring, the 15°C isotherm extends to a depth of approximately 290m and the 10°C isotherm extends to approximately 460m (Fig. 8A). Surface salinities above 36 ppt, indicative of water of Gulf Stream origin, were observed in the vicinity of the ring (Fig. 8B). (XBT and salinity data supplied R. Benway, MCI, NMFS).

In late November the ring interacted with a tongue of Gulf Stream water reducing ring 85-C's surface area even more. Clouds obscured the region until 5 December at which time it was estimated that Ring 85-C had been resorbed by the Gulf Stream several days earlier on about 1 December 1985 in the area of 39.0°N, 72.4°W.

Ring 85-D (Fig. 9) formed on 23 May 1985 from a Gulf Stream meander centered near 39.8°N, 62.2°W. Its movement was restricted by ring 85-C to its west, ring 85-A to its northwest, and an unnamed ring to its east. This short-lived ring was absorbed by ring 85-C (and perhaps partially by the Gulf Stream) on 10 June 1985 near 39.5°N, 63.0°W.

Ring 85-E (Fig. 10), a short-lived ring, formed from a tongue of water that spiralled off the west side of ring 85-B. On about 24 May 1985, it was centered at 40.1°N, 68.4°W. Its movement was immediately restricted by a small unnamed eddy and ring 84-G to the west and ring

85-B to the east. Near the end of June ring 85-E became very confined between rings 85-B and 84-G. Ring 85-E dissipated rapidly at this point probably transferring most of its mass back to ring 85-B and was clearly dissipated on 25 June 1985 centered near 39.7°N, 69.8°W.

Ring 85-F (Fig. 11) was formed from a Gulf Stream meander on 3 July 1985 centered near 39.4°N, 67.2°W. It slowly moved westward along the continental shelf break impeded by ring 85-B to the west, and began to interact with the Gulf Stream in early August near 70°W longitude. This interaction continued through August and into September resulting in a large increase in its surface diameter. Ring 85-F's path turned southwestward near the end of September and began interacting with the Gulf Stream. It was dramatically reduced in surface size around 7 October when a large portion of its area was resorbed by the Gulf Stream. On 19 October the ring showed some circulation but very little thermal contrast. Clouds obscured the region until 27 October 1985 when clear imagery showed the ring had been completely resorbed by this date. The approximate final position was centered near 37.4°N, 74.1°W.

Ring 85-G (Fig. 12) was formed from a large Gulf Stream meander on 19 July 1985 centered at 40.3°N, 61.9°W. While forming, a small unnamed ring to the north was absorbed. During the first month of its life ring 85-G moved northwestward often interacting with the Gulf Stream and increasing its surface area. On 13 August ring 85-G absorbed ring 85-A to the northwest increasing its surface area even more. Near the end of August ring 85-G came in contact with the continental shelf break. Throughout the month of September, ring 85-G moved westward entraining both shelf and Gulf Stream water. A large Gulf Stream meander came in contact with the southwest side of this ring around 23 September. This interaction resulted in a reduction in surface area and pushed the ring to the southeast. The ring was last seen clearly on 15 October. Clouds obscured the region until 22 October 1985 when it was evident that the Gulf Stream had resorbed the ring near 40.0°N, 64.5°W.

Ring 85-H (Fig. 13) spent most of its life east of 60°W longitude and was formed from a Gulf Stream meander on 24 June 1985 centered at 41.6°N, 59.5°W. As it began to cross 60°W its western edge came in contact with the eastern edge of ring 85-G. It is likely that ring 85-G (a very strong ring) entrained much of ring 85-H at this point. Ring 85-H completely crossed 60°W on 1 August as a much smaller, weaker ring

than in its earlier life. Ring 85-H dissipated rapidly and was indiscernible on about 14 August 1985. Its last position was estimated to be centered at 41.4°N, 61.4°W.

Ring 85-I (Fig. 14), another short-lived ring, was formed from a Gulf Stream meander on 29 August 1985 centered at 40.1°N, 61.5°W. It immediately began to interact with another Gulf Stream meander and on 17 September 1985 was resorbed by this meander centered at 40.0°N, 62.3°W.

Zonal Analysis

A generalized summary of the movements of rings during 1985 is presented in Table 2, which shows their mid-month positions with respect to the zones diagrammed in Figure 15. Total zone-month occurrence is 43. During the years 1974-1984, 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 37. Two rings occupied the same zone at mid-month seven times during 1985.

Zone 7 was occupied only briefly by ring 85-F before it's resorbtion by the Gulf Stream. Zone 8 was not occupied by any rings for the second year in a row.

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 15. The envelope was developed from boundary positions digitized from satellite data and from the weekly analysis charts. Eight of the eleven rings occurring in 1985 formed very near or east of 64°W. Two of the eleven rings never moved west of the 63°W meridian while five rings (84-G, 85-B, 85-C, 85-E, 85-F) moved west of the 68°W meridian.

Number of Rings, Times of Formation, and Longevity

Eight warm core Gulf Stream rings formed during 1985 off the northeast coast of North America; one additional ring (85-A) formed in late 1984 but did not cross west of 60°W longitude until early 1985. During 1974-1984, ring formation averaged nine per year, ranging from a minimum of five in 1974 to a maximum of eleven in 1979 and 1982. Two rings that formed in 1984 survived into 1985; one of which (84-G) was long-lived (362 days). Of the nine rings that formed or crossed west of

60°W longitude in 1985, three had formed by the end of April, two formed during May, three formed between late June to mid-July, and one formed in late August. Longevity of the rings formed in 1985 ranged from 18 to 239 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 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. 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)
84-G	08/20/84 - 08/17/85	362
84-I	(12/12/84) - 02/20/85	70
85-A	12/17/84[2] - 08/13/85	239
85-B	(02/25/85) - 08/11/85	167
85-C	04/29/85 - (12/01/85)	216
85-D	05/23/85 - 06/10/85	18
85-E	(05/24/85) - 06/25/85	32
85-F	07/03/85 - (10/27/85)	116
85-G	07/19/85 - (10/22/85)	95
85-H	06/24/85[3] - 08/14/85	51
85-I	08/29/85 - 09/17/85	19

1 Dates not in parentheses are accurate to within two days Dates in parentheses could be off by greater than one week.

2 This ring was not labelled until it completely crossed west of 60°W on about 02/20/85.

3 This ring was not labelled until it completely crossed west of 60°W on 08/01/85.

Table 2. Ring positions at mid-month with respect to zone during 1985.

Zone	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	84-I	85-A						85-H				
2		84-I 85-B	85-A	85-A	85-A 85-C	85-A 85-D	85-G	85-G	85-I			
3	84-G		85-B	85-B	85-B	85-B 85-C	85-A	85-A	85-G	85-G		
4		84-G	86-G				85-F 85-C	85-C	85-C			
5				84-G	84-G	84-G 85-E	85-B	85-F		85-C		
6							84-G	85-B 84-G	85-F		85-C	
7										85-F		
8												

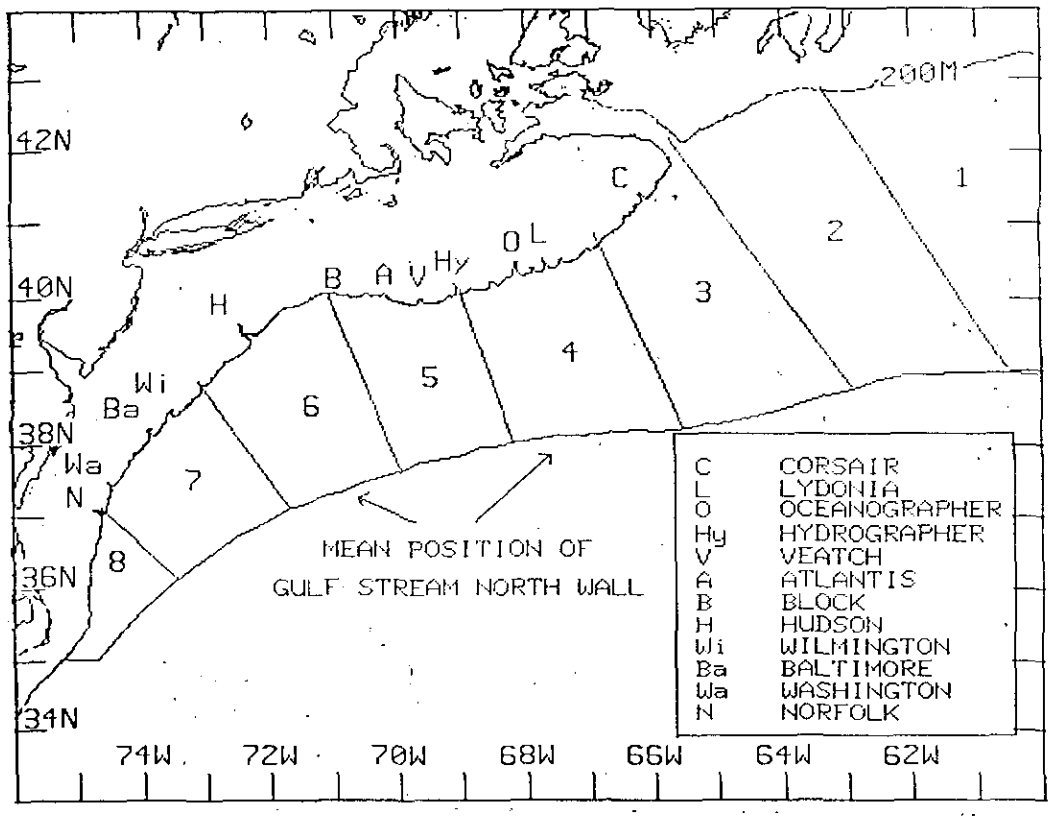


Figure 1. Base map for ring tracklines, showing canyon names and zones used in Table 2.

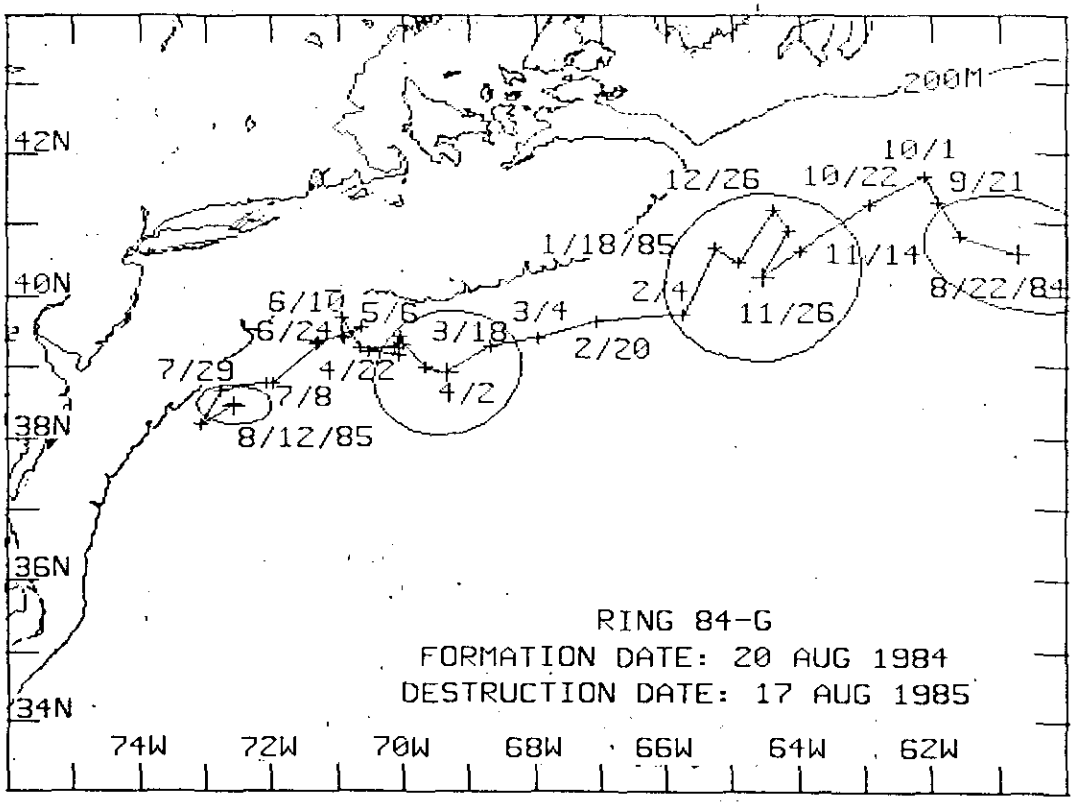


Figure 2. Trackline for ring 84-G.

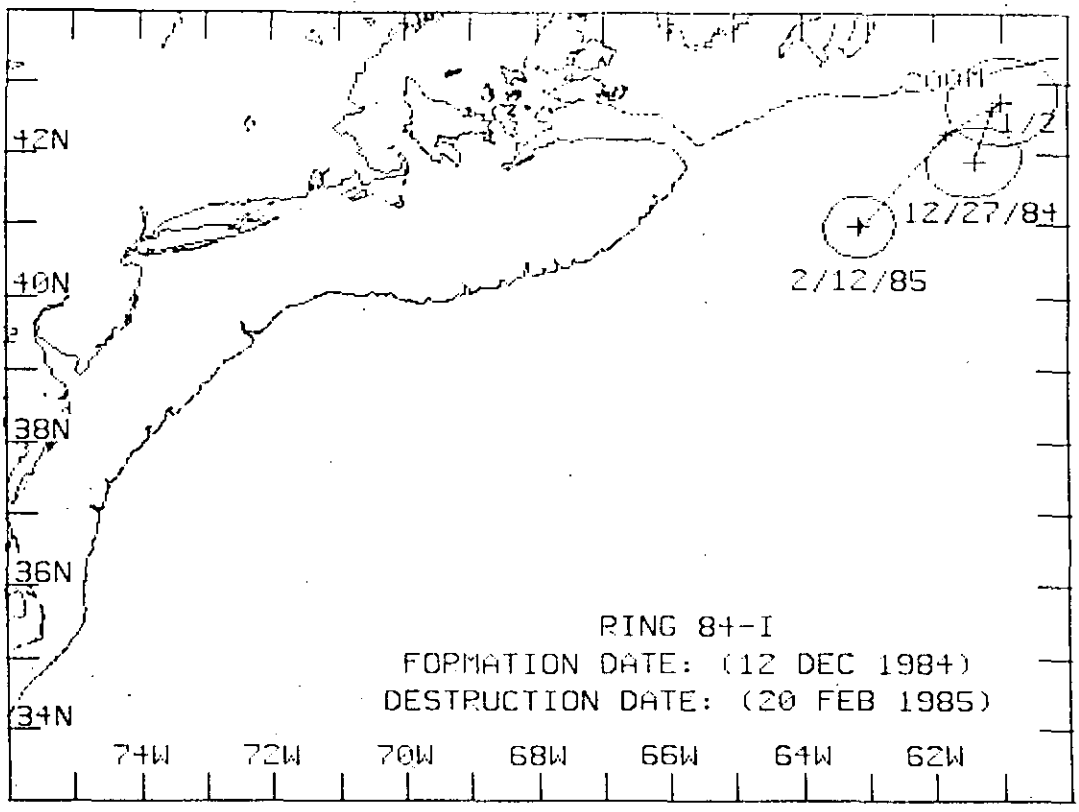


Figure 3. Trackline for ring 84-I.

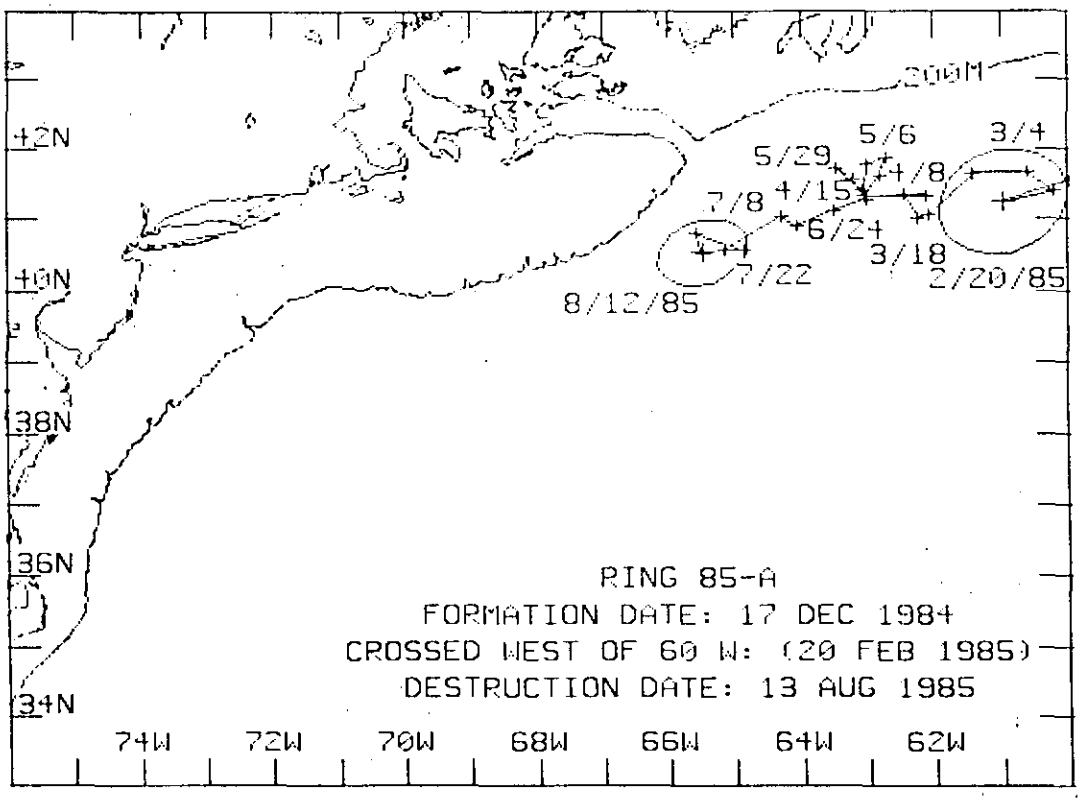


Figure 4. Trackline for ring 85-A.

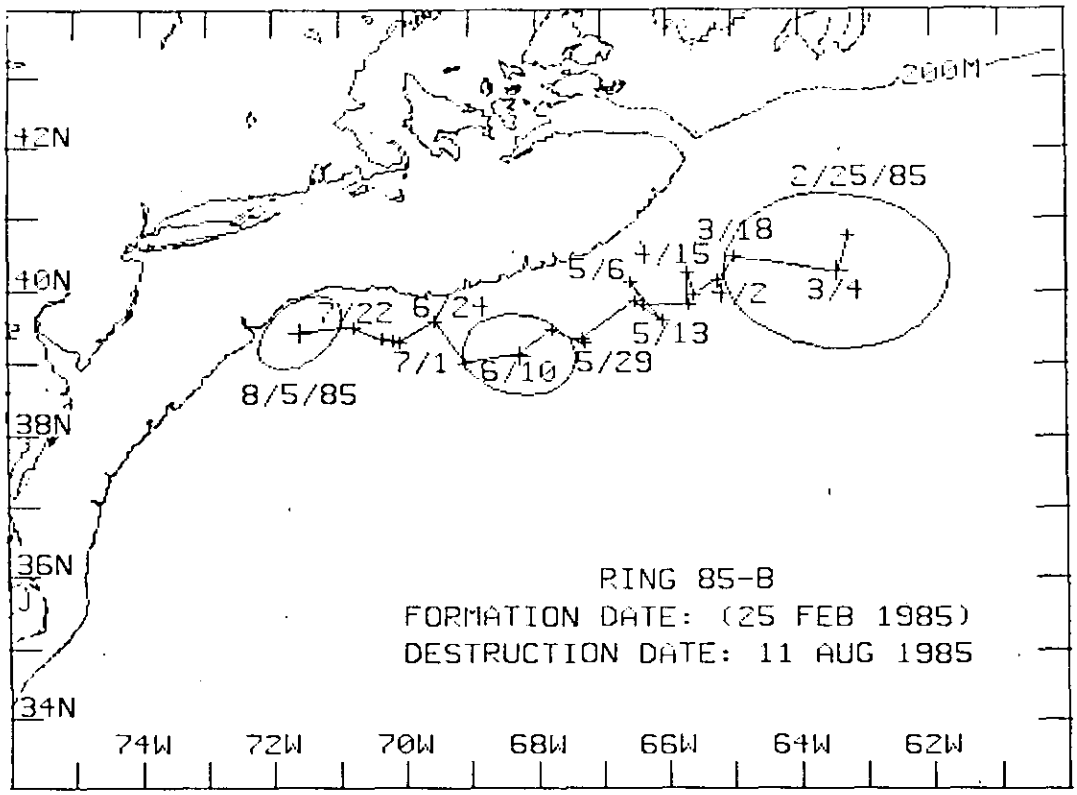


Figure 5. Trackline for ring 85-B.

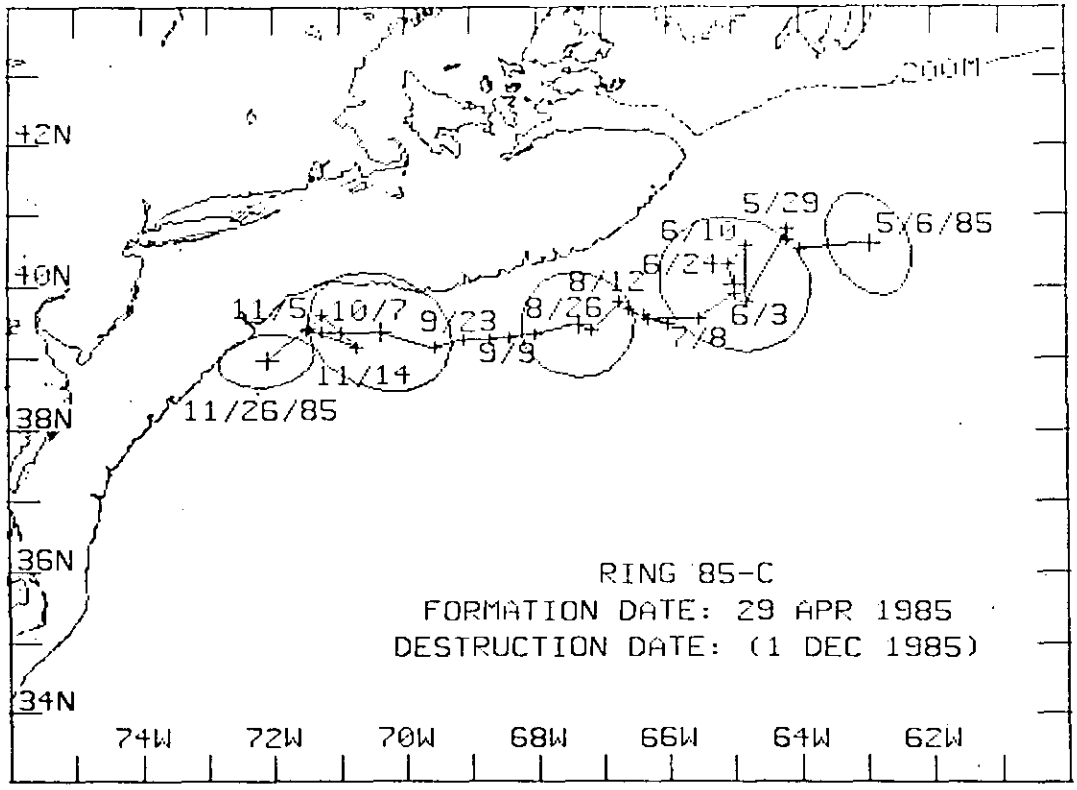


Figure 6. Trackline for ring 85-C.

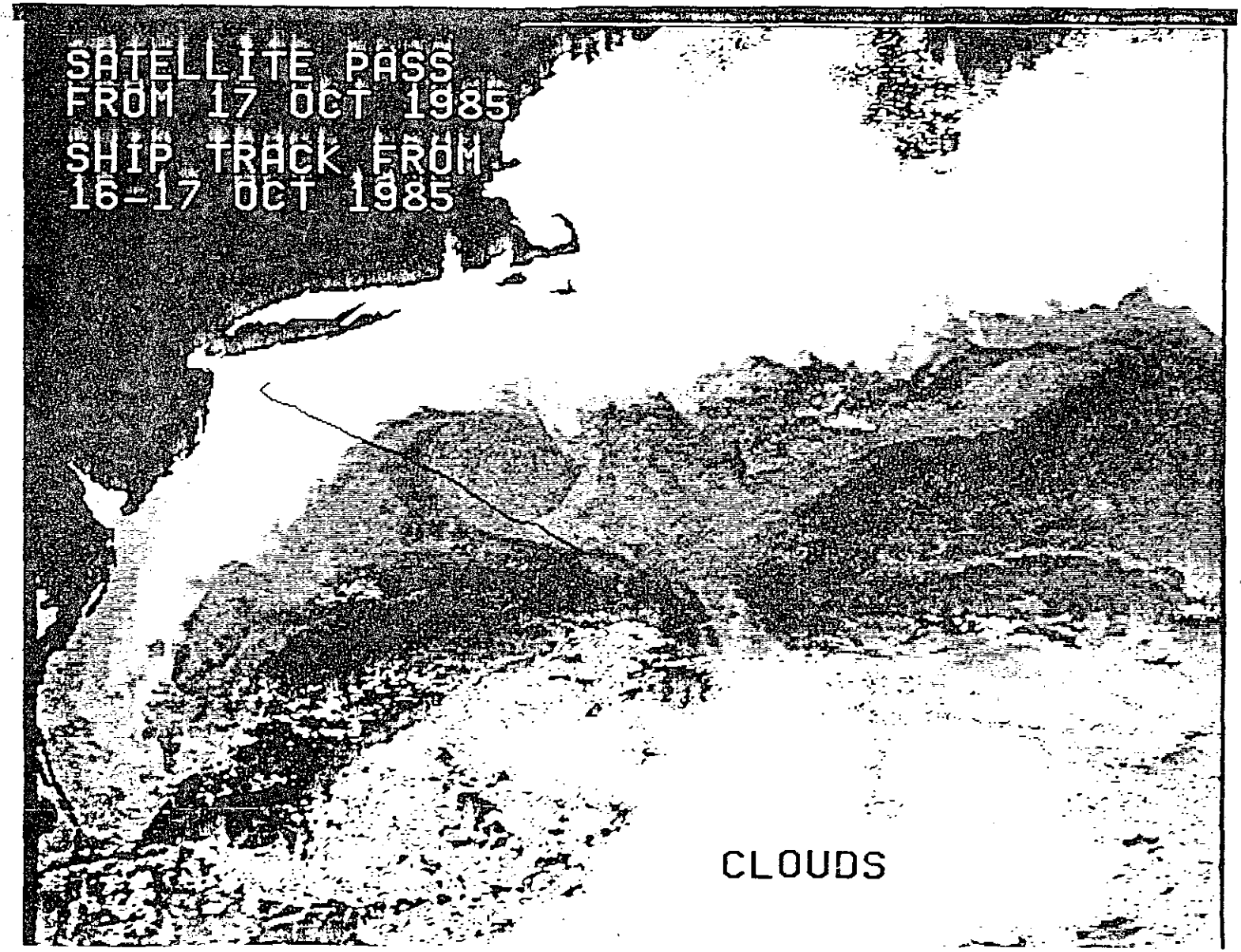
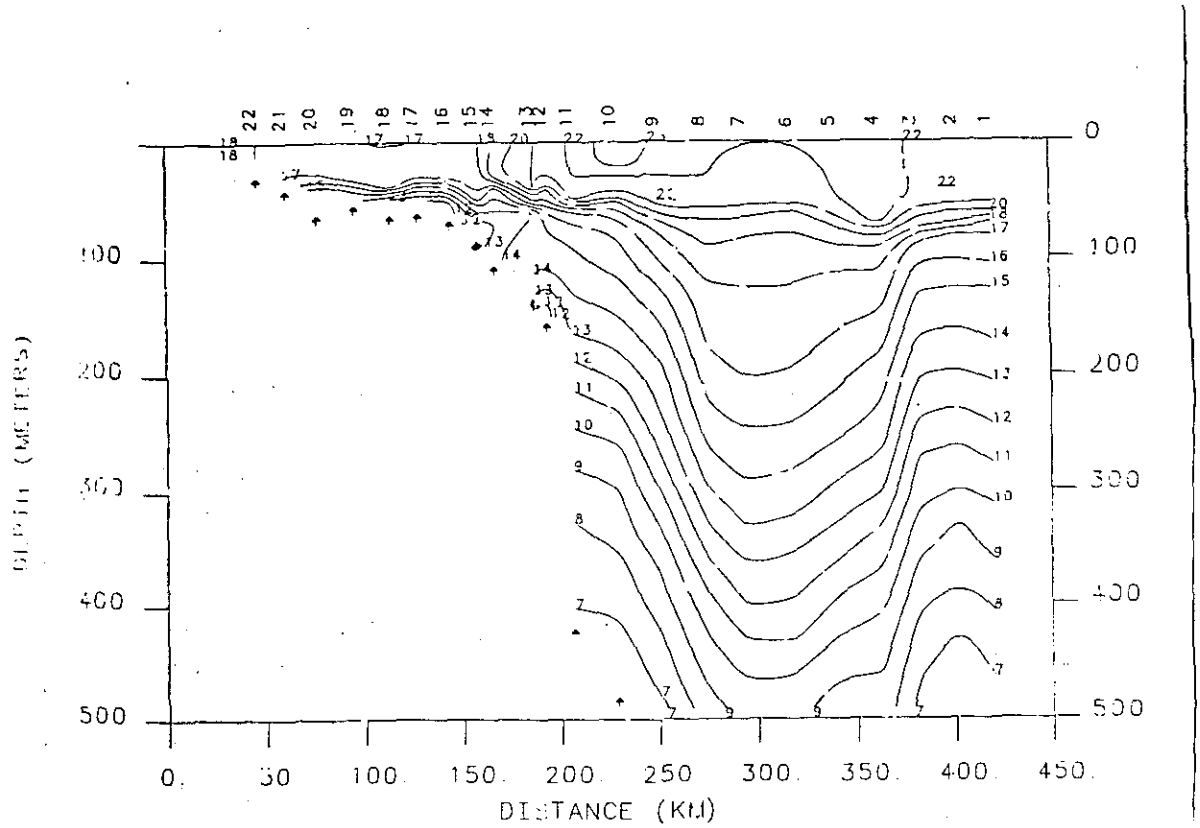


Figure 7. Infrared NOAA-9 satellite image from 17 October 1985 with M/V Oleander shiptrack from 16-17 October 1985 plotted in black. Warm gulf stream water appears black, slope water appears grey, shelf water appears light and clouds appear white. Ring 85-C has been labelled.



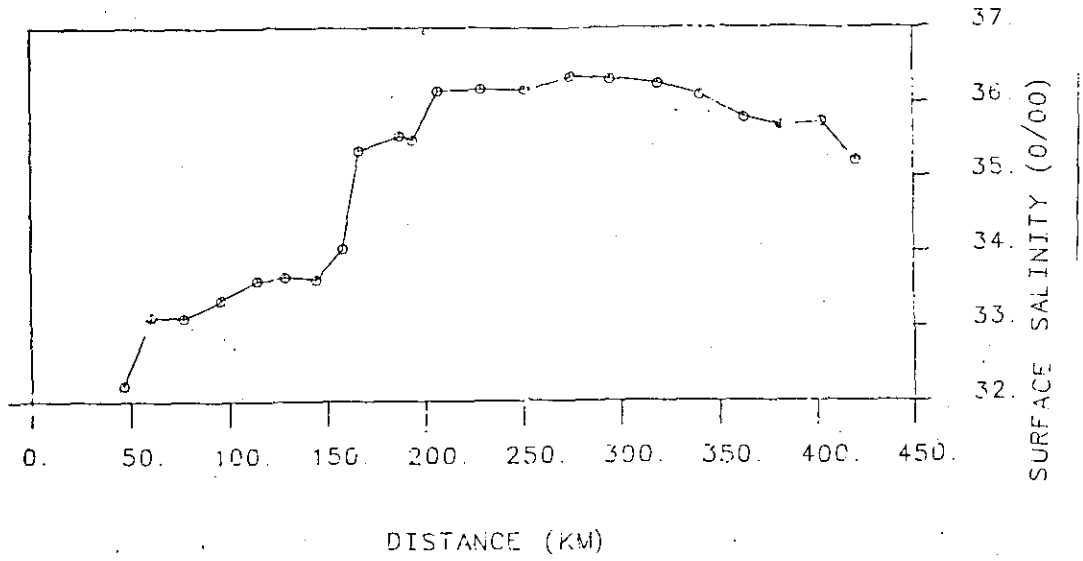


Figure 8. Hydrographic measurements obtained in the vicinity of ring 85-C, by the M/V Oleander on 16-17 October 1985. (A) Vertical section showing ring 85-C, and (B) sea surface salinities.

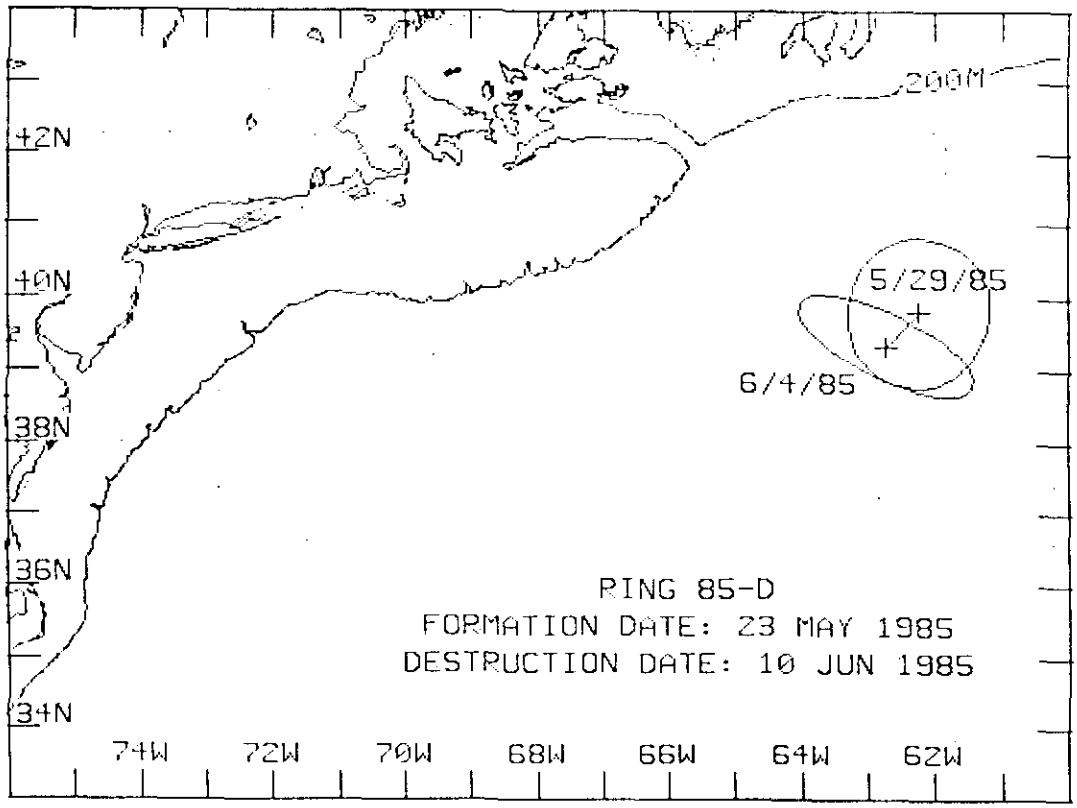


Figure 9. Trackline for ring 85-D.

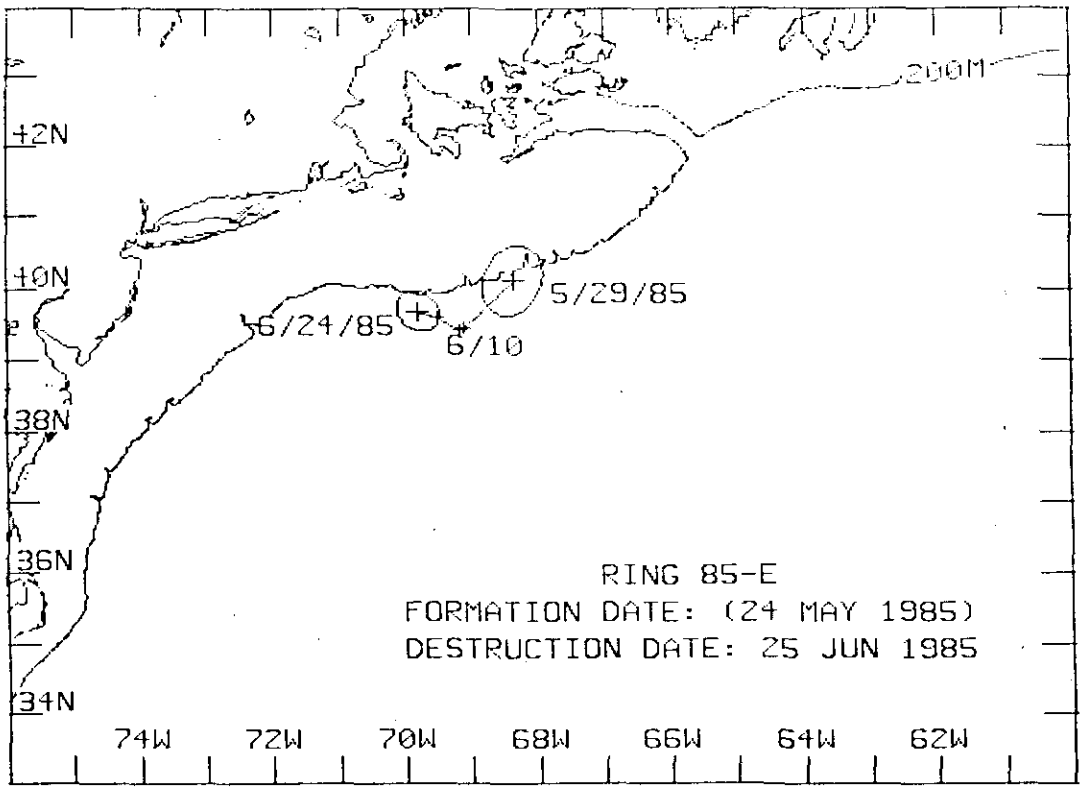


Figure 10. Trackline for ring 85-E.

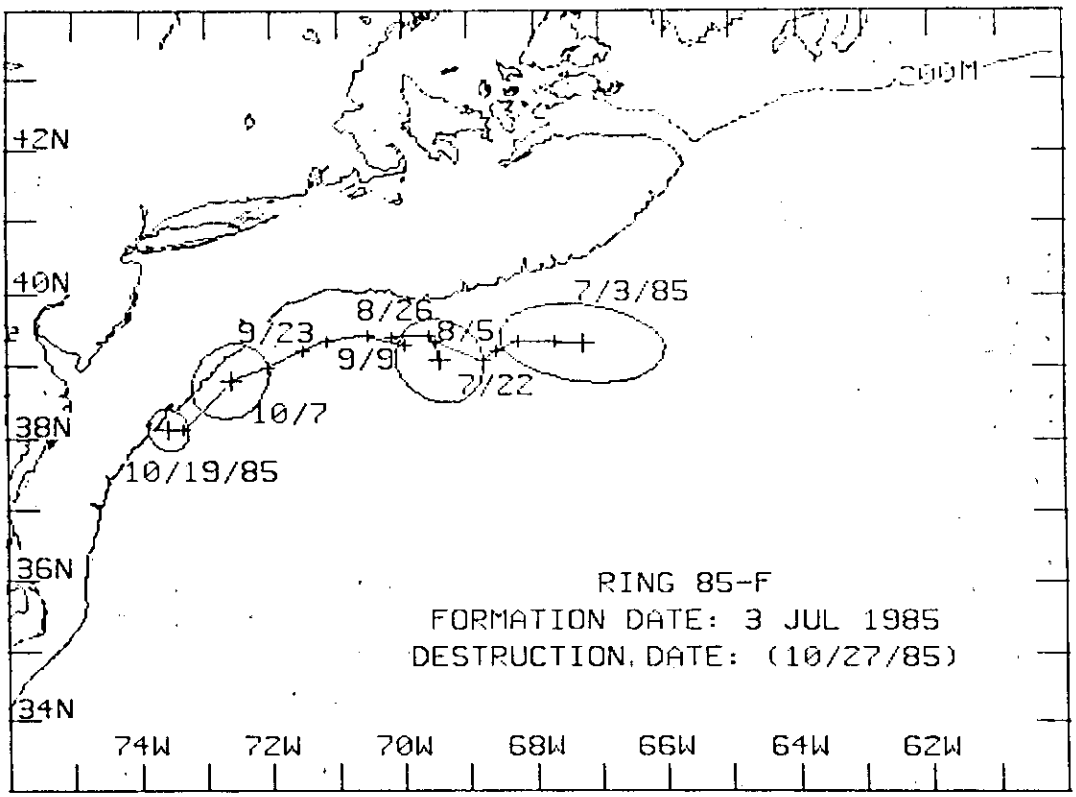


Figure 11. Trackline for ring 85-F.

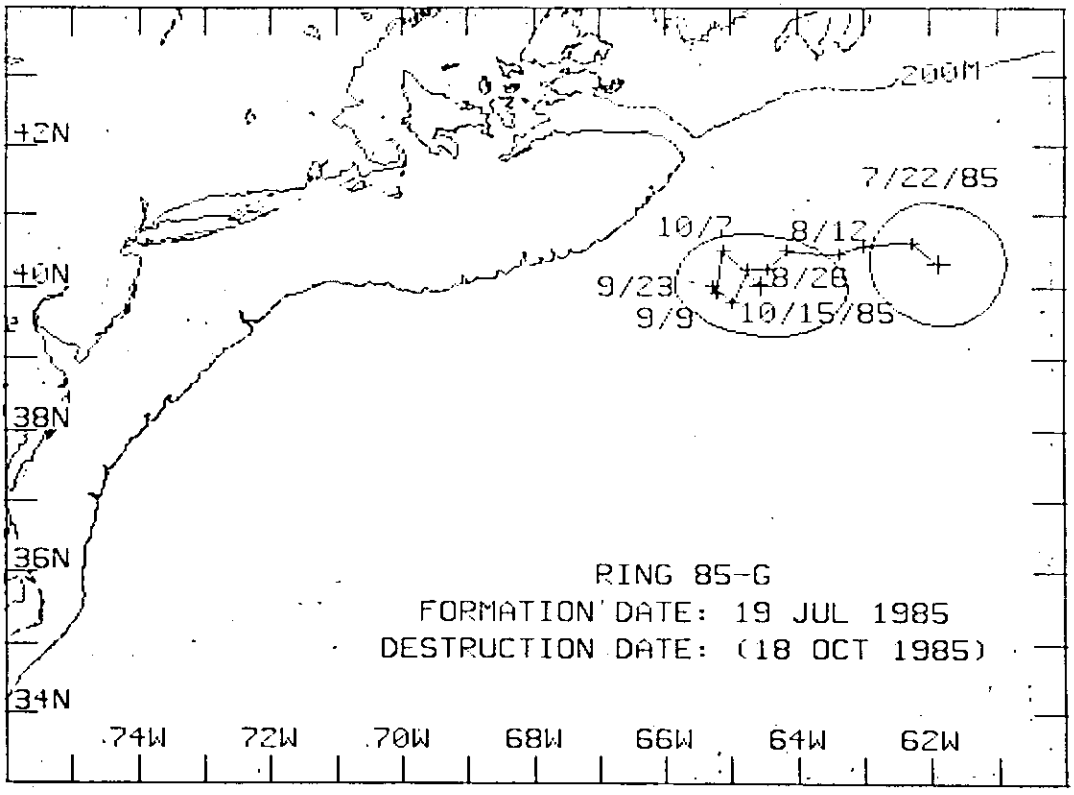


Figure 12. Trackline for ring 85-G.

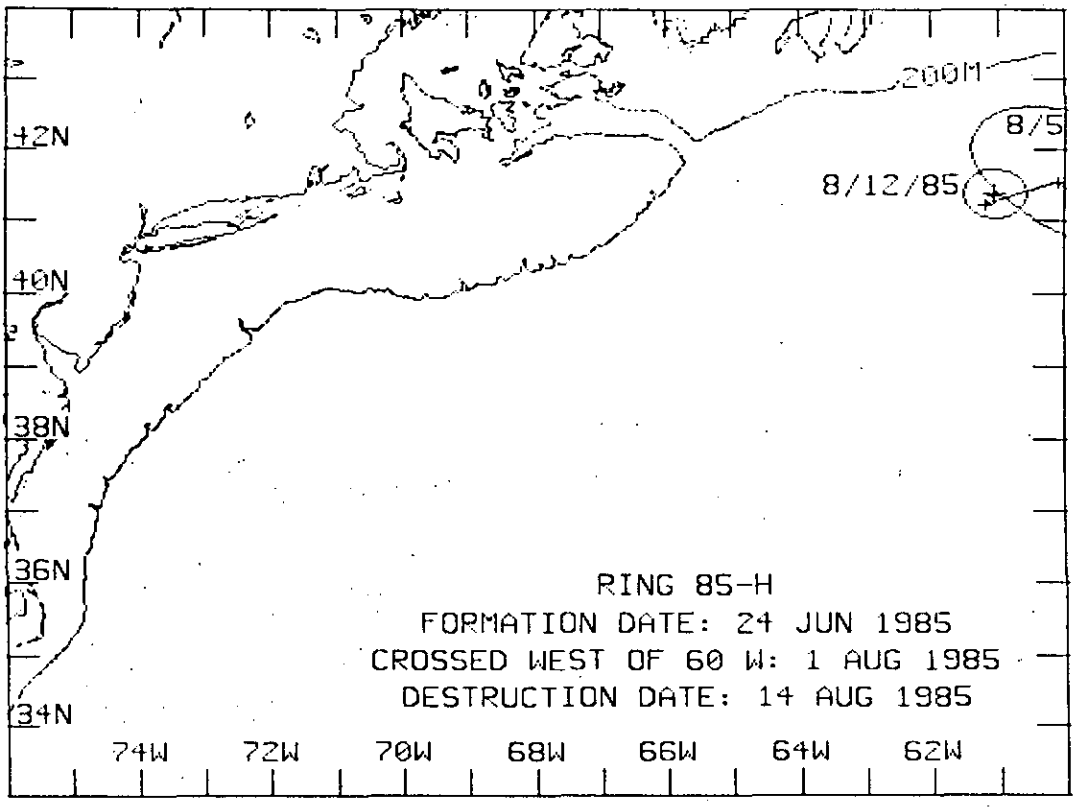


Figure 13. Trackline for ring 85-H.

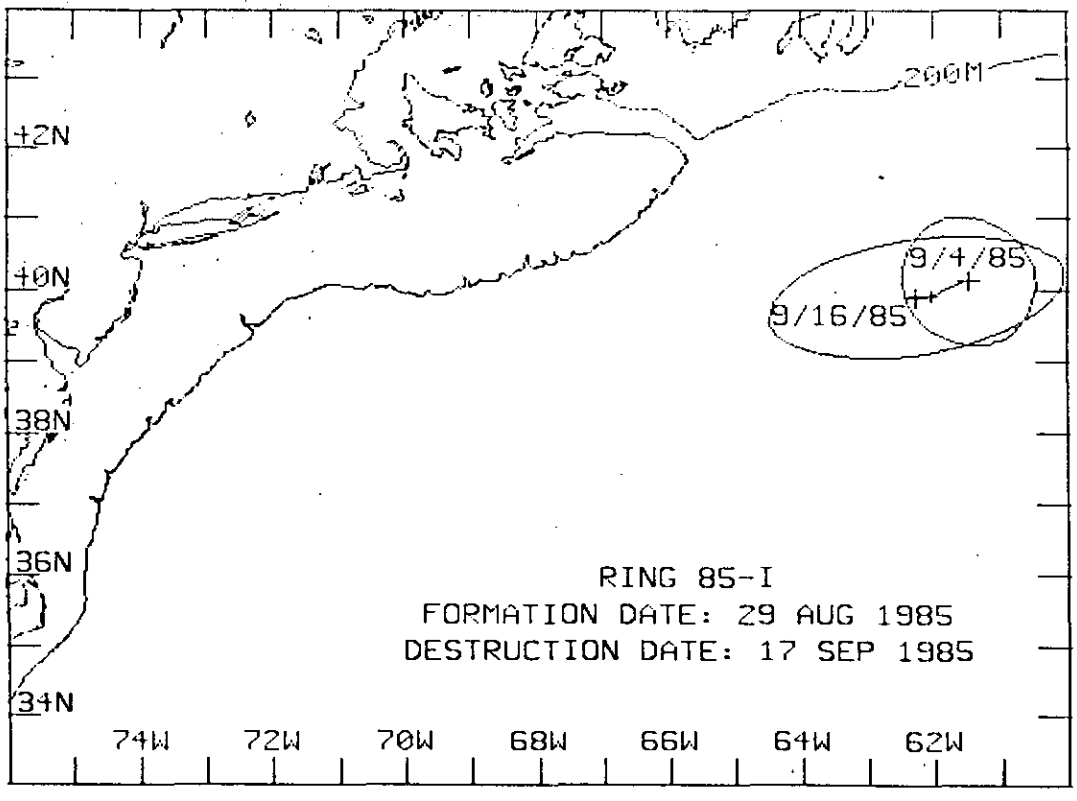


Figure 14. Trackline for ring 85-I.

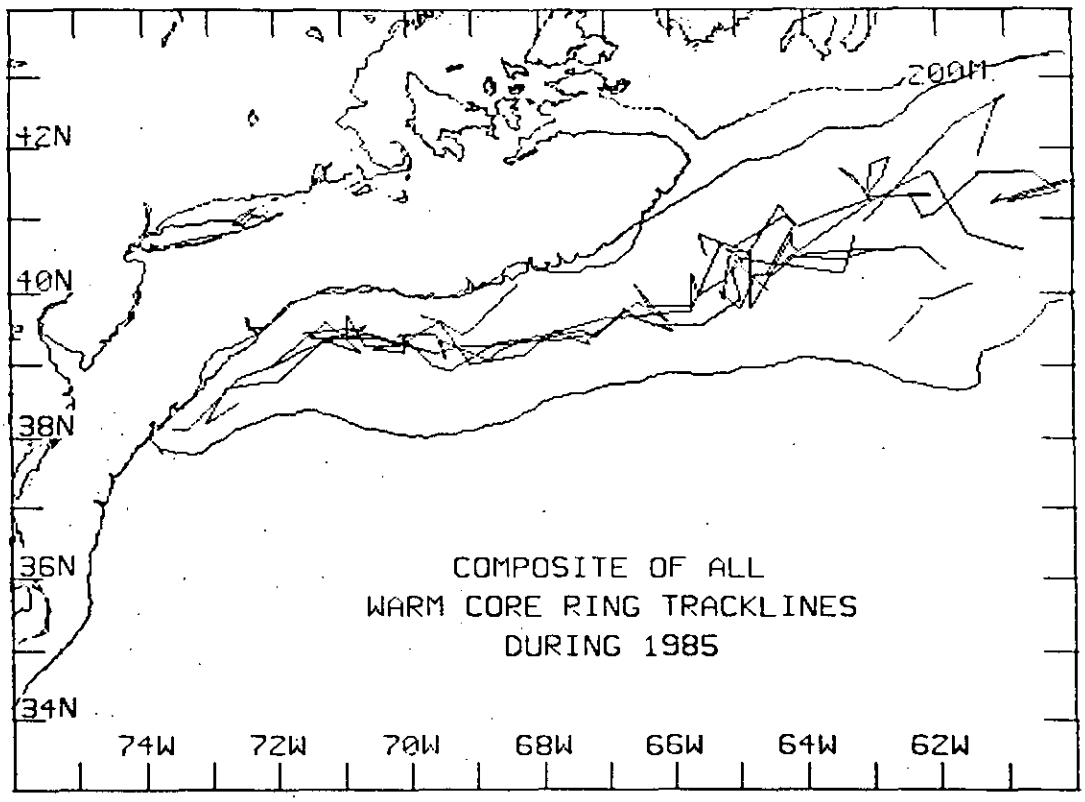


Figure 15. Composition of ring tracklines and envelope of ring surface boundaries.