(NASA-TM-82069) COMPARISON DATA FOR SEASAT N81-19529
ALTIMETRY IN THE WESTERN NORTH ATLANTIC
(NASA) 23 p HC A02/MF A01 CSCL 05B
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Technical Memorandum 82069

Comparison Data for Seasat Altimetry in the Western North Atlantic

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National Aeronautics and
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ABSTRACT

The radar altimeter flown on Seasat in 1978 collected approximately 1,000 orbits of high quality data (5–8 cm precision). In the western North Atlantic these data have been combined with a detailed gravimetric geoid in an attempt to produce profiles of dynamic topography (Cheney and Marsh, 1980). In order to provide a basis for evaluation of these profiles, available oceanographic observations in the Gulf Stream/Sargasso Sea region have been compiled into a series of bi-weekly maps. The data include XBT's, satellite infrared imagery, and selected trajectories of surface drifters and sub-surface SOFAR floats. The maps document the known locations of the Gulf Stream, cyclonic and anticyclonic rings, and mid-ocean eddies during the period July to October 1978.

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ILLUSTRATIONS

COMPARISON DATA FOR SEASAT ALTIMETRY IN THE WESTERN NORTH ATLANTIC

1. INTRODUCTION

Seasat altimeter data, together with a detailed gravimetric geoid, have been used to demonstrate the ability of satellite altimeters to detect sea surface height signatures associated with the Gulf Stream system (Cheney and Marsh, 1980). The presence of dynamic ocean features in the altimeter profiles was verified by comparison with standard oceanographic observations gathered from a variety of sources during the Seasat mission. This paper presents the full set of comparison data (or "surface truth") in a series of 7 bi-weekly maps. The purpose of these maps is to document known locations of the Gulf Stream, cyclonic rings, anticyclonic rings, and mid-ocean eddies as well as regions in which observations indicated the absence of dynamic features. Although dynamic heights computed relative to an arbitrary reference level are not strictly equivalent to dynamic topography derived from altimetry, these observations will provide a basis for interpretation as the Seasat data are investigated in more detail.

2. SEASAT ALTIMETER DATA

The Seasat mission extended from June 26 to October 10, 1978. Altimeter data were gathered during 3 principle periods (Table 1), accumulating the equivalent of approximately 70 days, or 1,000 orbits of continuous data around the world. The altimeter was turned off during the two intervening periods due to various hardware problems (Townsend, 1980). Figure 1 shows ground tracks of all data recorded in the western North Atlantic, which is typical of the coverage obtained globally at mid-latitudes. The evolution of the ground track pattern is described in Cheney and Marsh (1980). The grid spacing varies from a minimum of approximately 17 km to a maximum of 130 km. During the last 25 days of the mission the ground track was made to repeat at 3-day intervals, yielding a collinear data set with a grid spacing of approximately 800 km.

Table 1
Principal Seasat Altimeter Operating Periods

Orbit Number	1978 Date	Julian Day/GMT	Elapsed Time
145 – 295	July 7 – 17	188/0400 – 198/1700	10.5 days
416 – 891*	July 26 – Aug. 28	206/2000 – 240/0800	33.5 days
1145 – 1503	Sept. 15 – Oct. 10	258/0000 – 283/0200	25.1 days
			69.1 days

*Altimeter off for spacecraft maneuvers, orbits 701 – 707, 744 – 749, 820 – 823, 862 – 864.

3. OCEANOGRAPHIC DATA

The premature failure of Seasat occurred before any major coordinated Gulf Stream experiments could be carried out, and the existing oceanographic data are therefore somewhat haphazard. Some of the experiments conducted during this time included several Naval Oceanographic Office (NAVOCEANO) airborne surveys, a Naval Underwater Systems Center experiment, Gulf Stream sections by Woods Hole Oceanographic Institution, a cyclonic ring tracking program, POLYMODE, and the Local Dynamics Experiment. These experiments plus other observations obtained from NOAA/National Weather Service and Navy Fleet Weather Central yielded approximately 2,000 XBT's (expendable bathythermographs) in the Gulf Stream and Sargasso Sea during July to October 1978. Trajectories of satellite-tracked drifting buoys and SOFAR floats were also helpful in locating cyclonic Gulf Stream rings. Infrared imagery, while not *in situ*, has become an accepted oceanographic data source for the Gulf Stream and rings. Weekly summaries of NOAA-5 imagery produced by NAVOCEANO were therefore included in the comparison data set.

4. DYNAMIC HEIGHT CALCULATIONS

The XBT data were obtained in a variety of different forms: complete temperature profiles (to 350 m for airborne XBT's, 800 m for shipboard data), digitized profiles, 15°C or 17.5°C depth only, and maps of selected isotherm depths. In order to present these data in a common format, each observation was converted to a dynamic height using empirical relationships, as described below.

It is well known that dynamic height is largely a function of thermocline depth. To quantify this relationship, 163 STD (salinity/temperature/depth) and CTD (conductivity/temperature/depth) stations taken in numerous cyclonic rings during 1974–78 were used. These covered the full range of thermocline depths characteristic of the Gulf Stream cyclonic ring region. At each station the anomaly of dynamic height was calculated between the surface and 3,000 db. Relationships between this vertically integrated quantity and thermal parameters measurable with XBT's were investigated. Figure 2 shows the variation of dynamic height as a function of 15°C depth. The least squares linear fit has a standard deviation of 9 cm, surprisingly good considering that the data include seasonal variations. Thus, given 15°C depth, which can be obtained from most shipboard XBT's, the dynamic height can immediately be computed to within an accuracy of 9 cm, about the same accuracy as Seasat's altimeter. Similar linear relationships were derived for 17.5°C depth and 350 m temperature, each with a 9 cm standard deviation. In equation form, the relations are:

(a) $H = 0.15\ (D_{15}) + 167$

(b) $H = 0.21\ (D_{17.5}) + 174$

(c) $H = 341.1\ (T_{350}) - 351 \quad \text{for } T_{350} > 17.5°C;$

$H = 7.6\ (T_{350}) + 110 \quad \text{for } T_{350} \leq 17.5°C$

where H = anomaly of dynamic height in cm (0/3000 db), and the independent variables are 15°C depth in m, 17.5°C depth in m, and 350 m temperature in °C. Two lines are fitted to the 350 m temperature data above and below 17.5°C since there was an obvious slope change at the lower limit of the layer of "18 degree water" in the Sargasso Sea.

It is important to note that these relationships hold only for the western Sargasso Sea and cyclonic ring region. Although XBT's in the Gulf Stream could probably be converted to dynamic height with reasonable accuracy, relations involving parameters such as 200 m temperature are more appropriate for the cold slope water north of the Gulf Stream

5. BI-WEEKLY MAPS

Figures 3a thru 3g present the series of 7 bi-weekly maps compiled from the oceanographic data. Seasat ground tracks from which altimeter data were collected are superimposed. It is interesting to note the changing ground track pattern during August 17–30 when the orbit was being altered to the 3-day repeat mode. Infrared frontal positions are indicated by heavy lines: dashed representing observations during the first week, and solid representing the second week. The Gulf Stream is sometimes visible only along part of its length due to the presence of clouds and the lack of strong sea surface temperature gradient in late summer.

The warm rings, designated by letters, can be followed quite readily from week to week as they move generally westward. Three warm rings were present in July with a fourth appearing in August. Even though many hundreds of XBT's were available north of the Gulf Stream, it was not necessary to include these in the maps since satellite infrared imagery provided sufficient coverage of the warm rings. Occasional interaction between the warm rings and the Gulf Stream is apparent. Ring "S" coalesced briefly during a period of intense Gulf Stream meandering.

XBT's, indicated by dots, are the primary means of detection for the cold rings and other features south of the Gulf Stream. Where sufficient data are available, dynamic heights are contoured at intervals of 10 cm. Identification of "highs" and "lows" in the Sargasso Sea, as indicated by different shading, is based on surrounding observations or by referring to a map of the mean dynamic height for this region (Figure 4). This mean surface was derived from a map of the average 15°C surface (Richardson, Cheney, and Worthington, 1978) and is a compilation of 50,000 XBT's taken during 1970–76 from which cold ring observations were deleted. Isotherm depths were converted to dynamic heights (0/3000 db) with the empirical relation described earlier. The mean Gulf Stream is apparent, and the surface of the Sargasso Sea slopes gently away from a maximum just south of the Gulf Stream.

A total of five cold rings were observed during this time. Details of these observations are given in Table 2. The best tracking data were from cold rings 1 and 4, which were followed throughout the Seasat mission. Ring 2 was tracked for the first 2 months, and rings 3 and 5 were each followed for only one month. Ring 3 was the largest feature, having a diameter of approximately 350 km.

Several XBT sections were obtained through the Gulf Stream between Florida and Cape Hatteras. Dynamic height contours reflect the sharp 1 m step. Mid-ocean eddies with magnitudes of 10–15 cm can be seen near 30N–70W. In the August 3–16 map there is an interesting high just south of the Gulf Stream which is elevated 30 cm with respect to the Sargasso Sea. This may be a pocket of newly formed 18 degree water where the thermocline is bent downward (Leetmaa, 1977). A similar region is suggested on the September 14–27 map.

6. SUMMARY

The series of maps presented here summarize known locations of dynamic features in the Gulf Stream/Sargasso Sea region as determined from standard oceanographic data during the Seasat time frame, July to October 1978. The data include XBT's, satellite infrared imagery, and trajectories of surface drifters and sub-surface SOFAR floats. These observations provide a basis for interpretations of sea surface topography data collected by the Seasat radar altimeter in this area. The maps are expressed in terms of dynamic heights to facilitate this comparison.

The Gulf Stream and four warm rings were observed clearly throughout this period by IR imagery, while XBT data and buoy trajectories were used to delineate cold rings and other features south of the Gulf Stream in the Sargasso Sea. Although five cold rings were identified, this is only a fraction of the 10–15 rings that are believed to exist at any one time (Richardson, Cheney, and Worthington, 1978; Lai and Richardson, 1977). One of the potential applications of the altimeter data will therefore be to determine the entire ring population.

Table 2
Observations of Cold Rings, July – October 1978

Date (1978)	Position °N °W	Source or Platform[1]	Data[2]
Ring 1			
July 2	36.5 – 67.0	EOFA	NOAA-5 IR
July 13	36.5 – 65.2	EOFA, NAVOCEANO aircraft	NOAA-5 IR, 6 AXBT's
August 1	36.4 – 64.8	NAVOCEANO aircraft	9 AXBT's
August 9	36.0 – 65.2	EOFA	NOAA-5 IR
September 18	34.5 – 66.0	NAVOCEANO aircraft	14 AXBT's
September 28–30	35.0 – 66.7	URS Kurchatov	35 XBT's
September 22 to October 1	34.5 – 66.0 to 35.0 – 66.7	Satellite-tracked drifter continuous track	
Ring 2			
June 30	34.2 – 72.3	NOAA "Gulfstream"	NOAA-5 IR
July 16 to August 23	34.7 – 72.8 to 33.8 – 72.4	Sofar float continuous track (see POLYMODE NEWS No. 75)	
Ring 3			
July 2	35.5 – 61.0	EOFA	NOAA-5 IR
July 1–26	36.0 – 60.0	NOAA/NWS	14 XBT's
Ring 4			
July 13	33.5 – 65.7	NAVOCEANO aircraft	8 AXBT's
August 18	33.5 – 67.7	NOAA/NWS	12 XBT's
September 7	33.5 – 68.6	NOSC Red Seal	8 XBT's
September 19	33.5 – 69.0	NAVOCEANO aircraft	16 AXBT's
September 22 to January 14	33.5 – 69.0 to 33.6 – 72.7	Satellite-tracked drifter continuous track	
Ring 5			
July 13–19	32.2 – 56.4	NUSC, USNS Lynch	13 XBT's
July 20–31	32.5 – 56.5	NUSC, USNC Lynch	19 XBT's
August 1–13	32.7 – 56.7	NUSC, USNC Lynch	10 XBT's

[1]EOFA: Experimental Ocean Frontal Analysis (NAVOCEANO)
NAVOCEANO: Naval Oceanographic Office
NOAA/NWS: National Oceanic and Atmospheric Administration/National Weather Service
NOSC: Naval Ocean Systems Center
NUSC: Naval Underwater Systems Center

[2]NOAA-5 IR: NOAA-5 satellite infrared imagery
XBT: Expendable bathythermograph
AXBT: Airborne XBT

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Townsend, W. F. (1980) An initial assessment of the performance achieved by Seasat-1 radar altimeter. *IEEE J. Oceanic Engin.*, OE–5, 80–92.

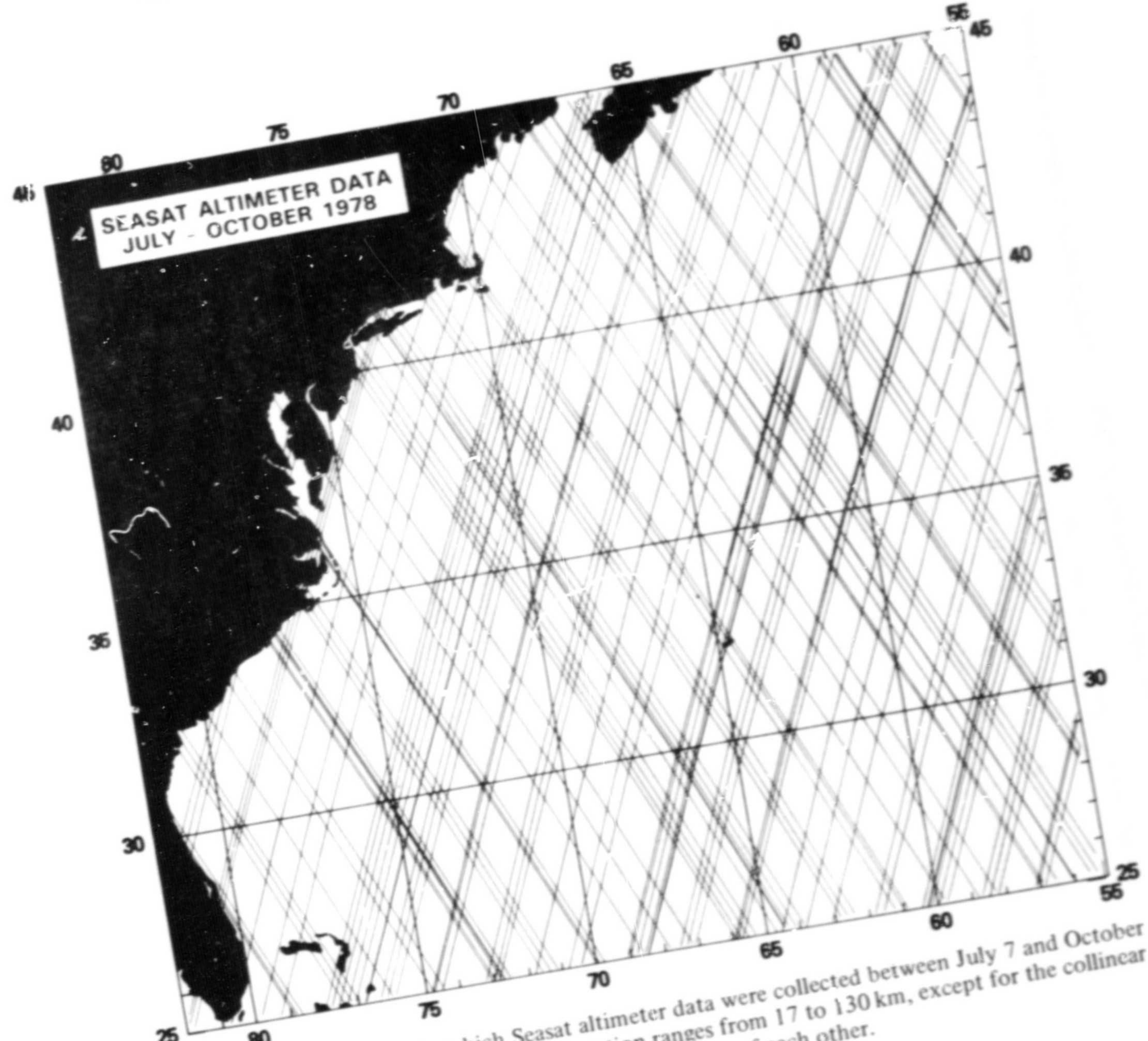

Figure 1. Ground tracks for which Seasat altimeter data were collected between July 7 and October 10, 1980 (see Table 1). The east west separation ranges from 17 to 130 km, except for the collinear data set, which consists of 8–9 tracks spaced within 3 km of each other.

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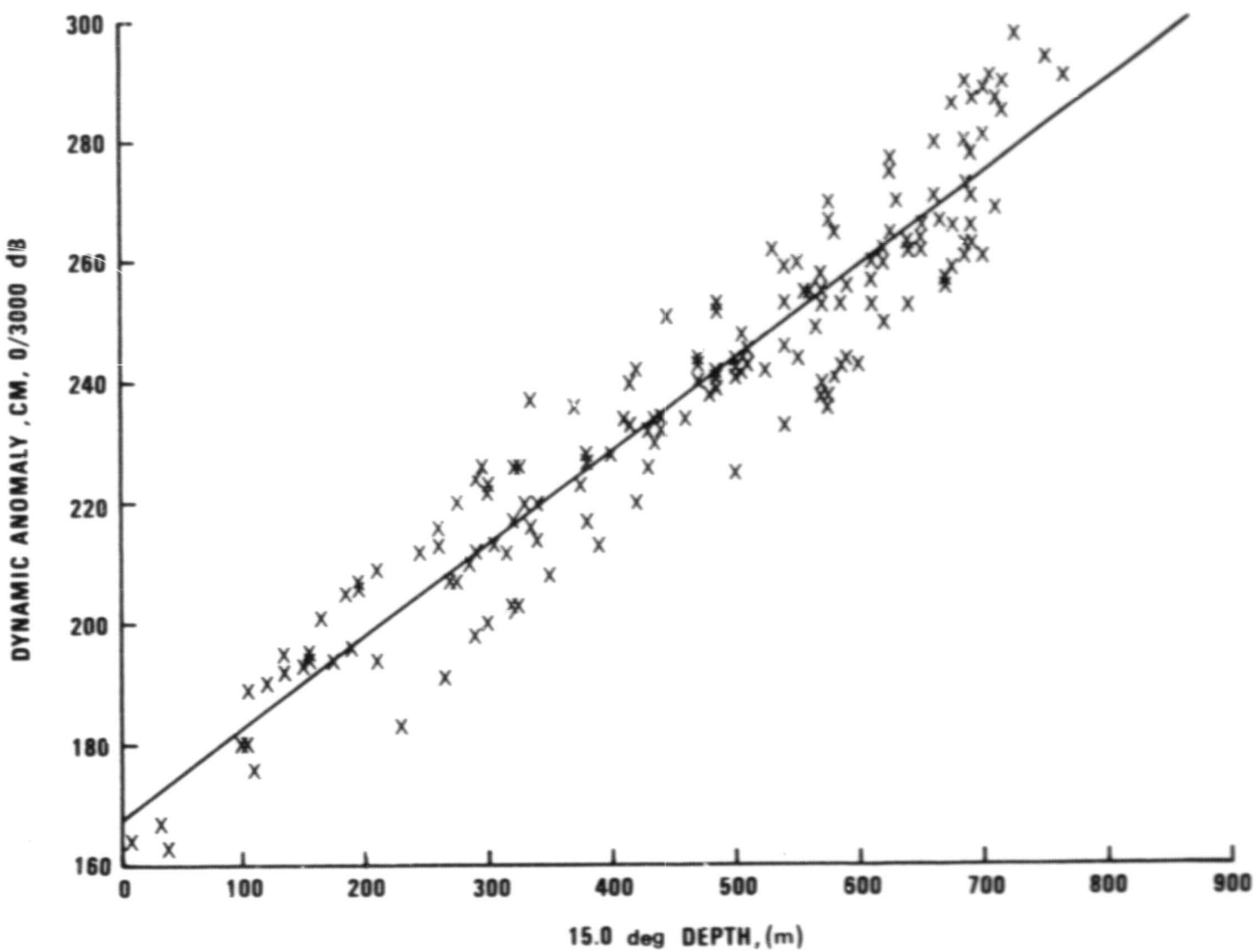


Figure 2. Relationship between surface dynamic height (relative to 3,000 db) and 15°C depth. Linear, least squares fit has a standard deviation of 9 cm. Data points represent 163 STD or CTD stations taken across cyclonic rings during 1974–78.

Figures 3a thru 3g. Comparison oceanographic data during the Seasat period, condensed into seven bi-weekly charts. Ground tracks and orbit numbers of Seasat altimeter data collected during this time are superimposed. Heavy lines are Gulf Stream and ring boundaries determined from NOAA-5 infrared imagery: dashed is first week, solid is second week. Dots are XBT's, converted to dynamic height anomalies (0/3,000 db) expressed in cm. Dynamic heights are contoured at 10 cm intervals where sufficient data exist. Different shadings indicate relative highs and lows.

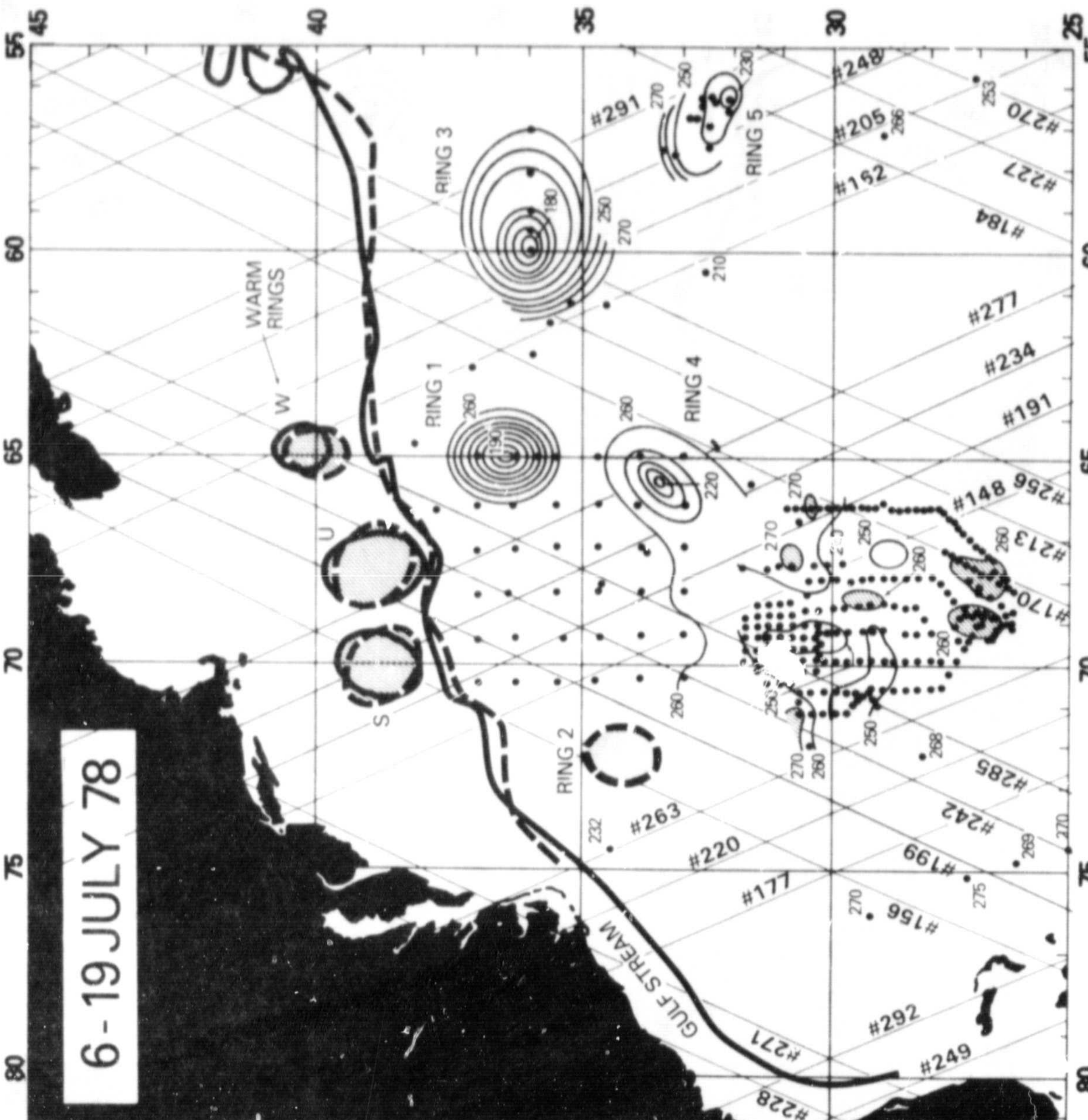

6 - 19 JULY 78
WARM RINGS
W
U
S
RING 1
RING 2
RING 3
RING 4
RING 5
GULF STREAM
#291
#248
#205
#162
#270
#227
#184
#277
#234
#191
#148
#256
#213
#170
#285
#242
#199
#156
#263
#220
#177
#292
#249
#271
#228
45
40
35
30
25
80
75
70
65
60
55

Figure 3a

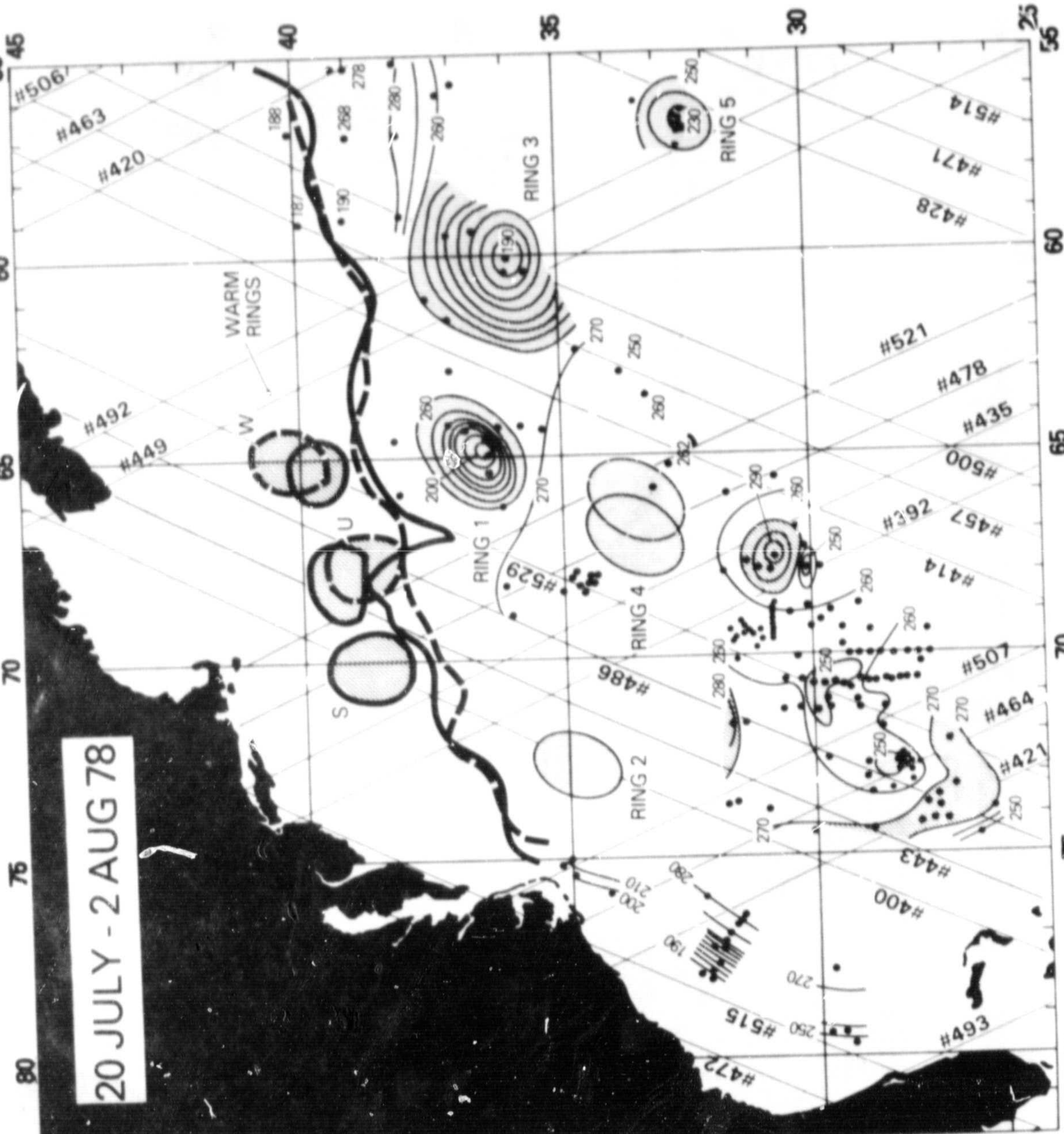


Figure 3b

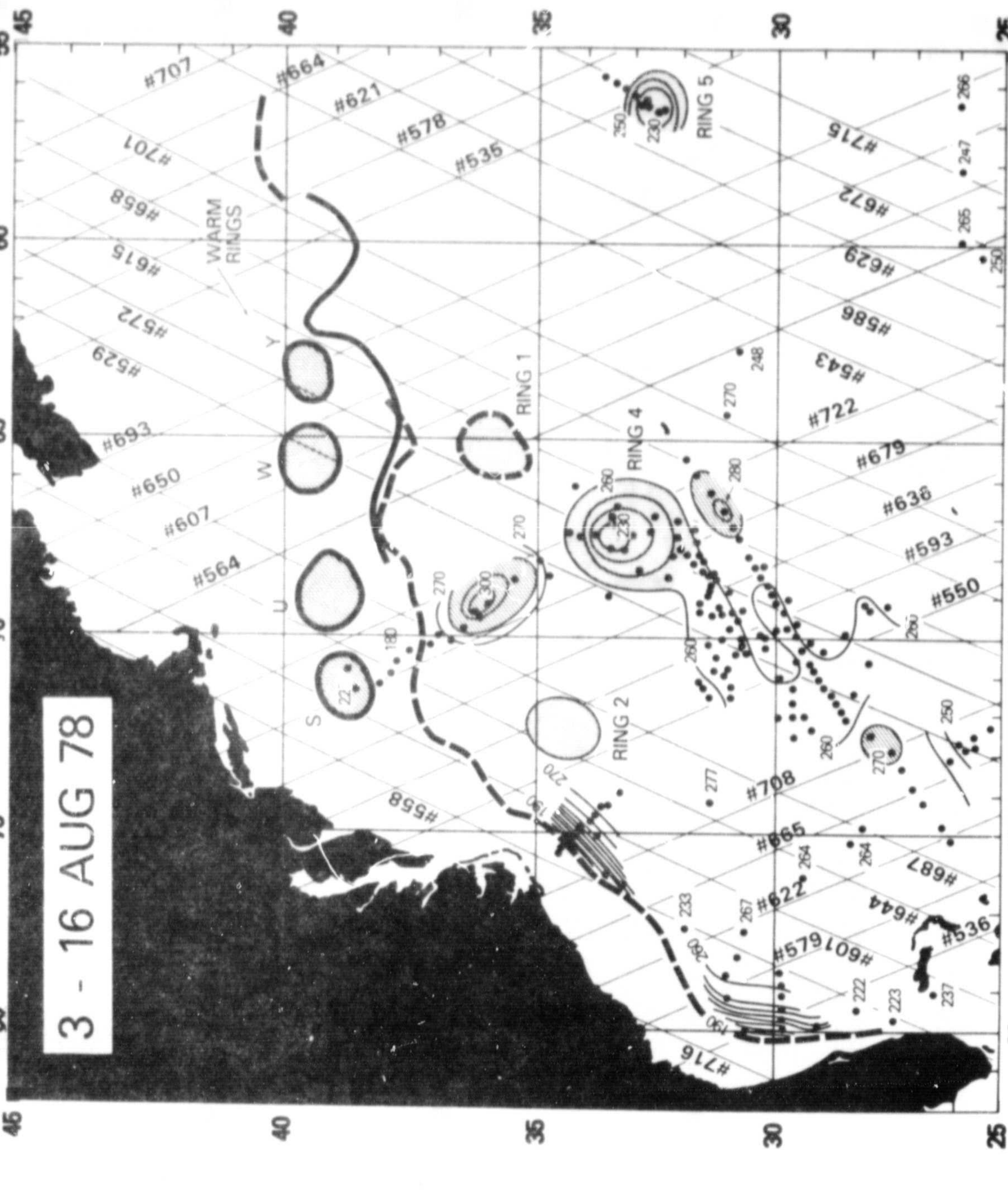


Figure 3c

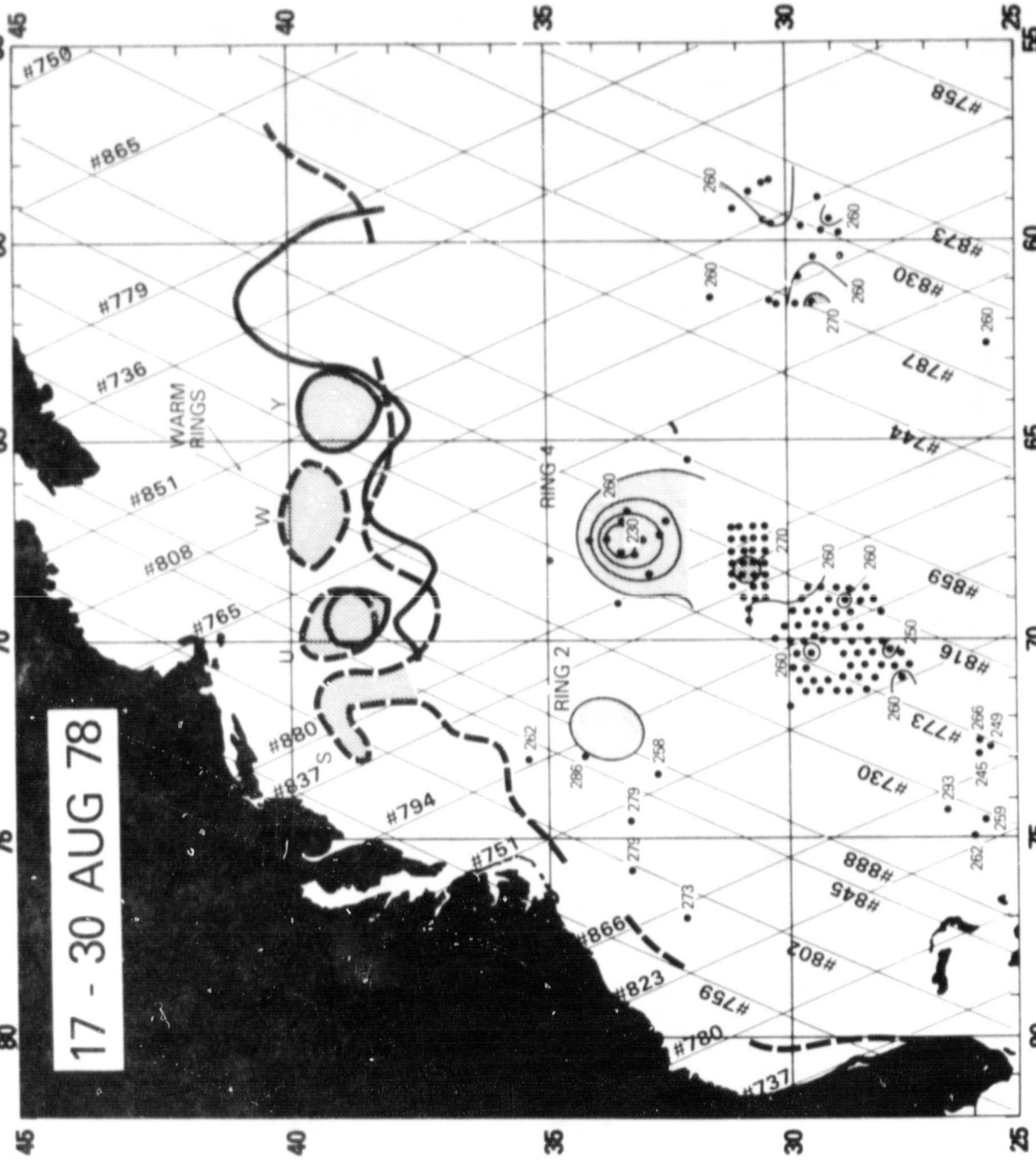


Figure 3d

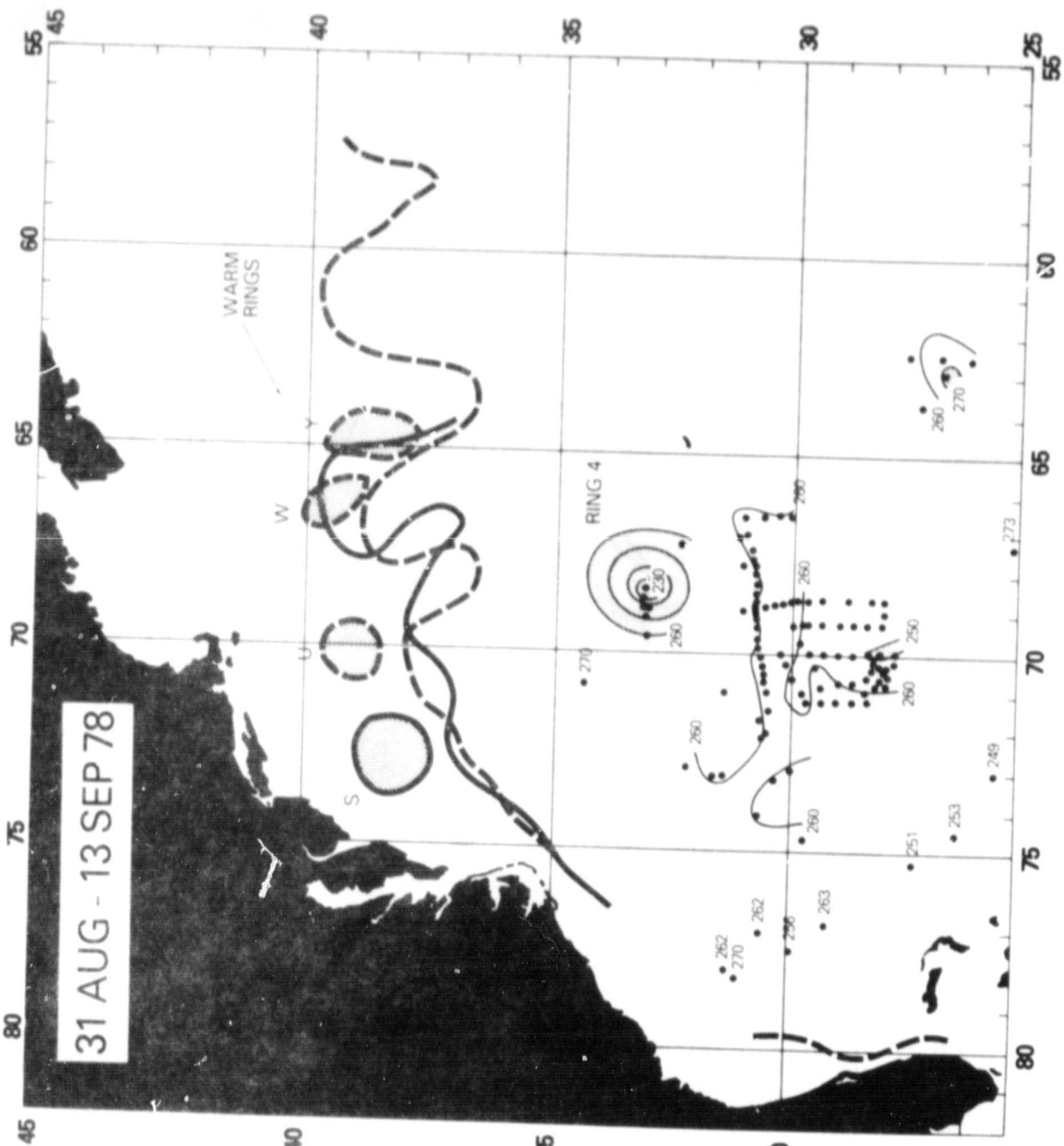
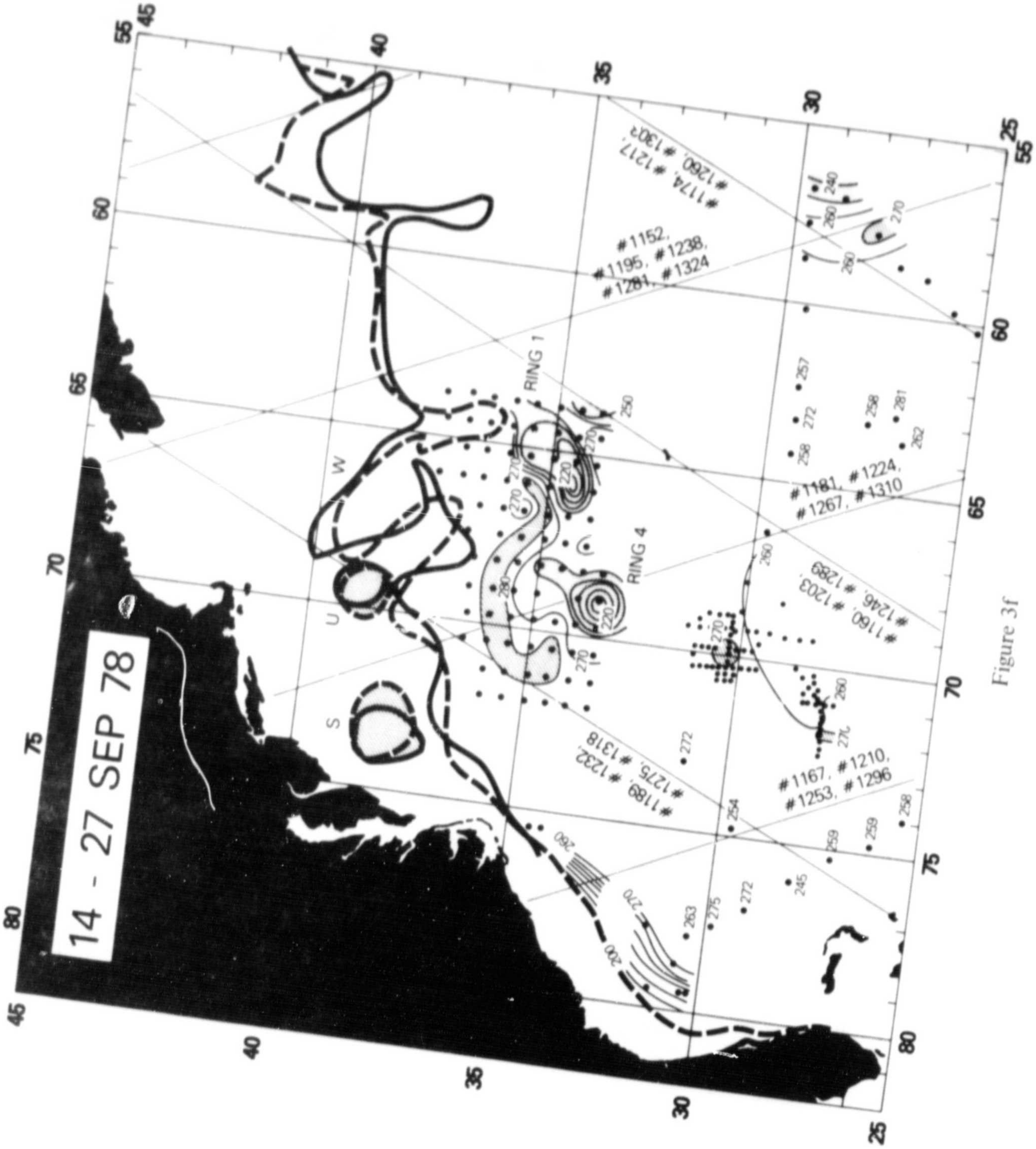

31 AUG - 13 SEP 78
WARM RINGS
RING 4
S
U
W
Y
45
40
35
30
25
80
75
70
65
60
55
230
260
270
250
249
251
253
262
263
273

Figure 3e



14 - 27 SEP 78
RING 1
RING 4
#1152, #1195, #1238, #1281, #1324
#1174, #1217, #1260, #1303
#1181, #1224, #1267, #1310
#1160, #1203, #1246, #1289
#1167, #1210, #1253, #1296
#1189, #1232, #1275, #1318
S
U
W

Figure 3f

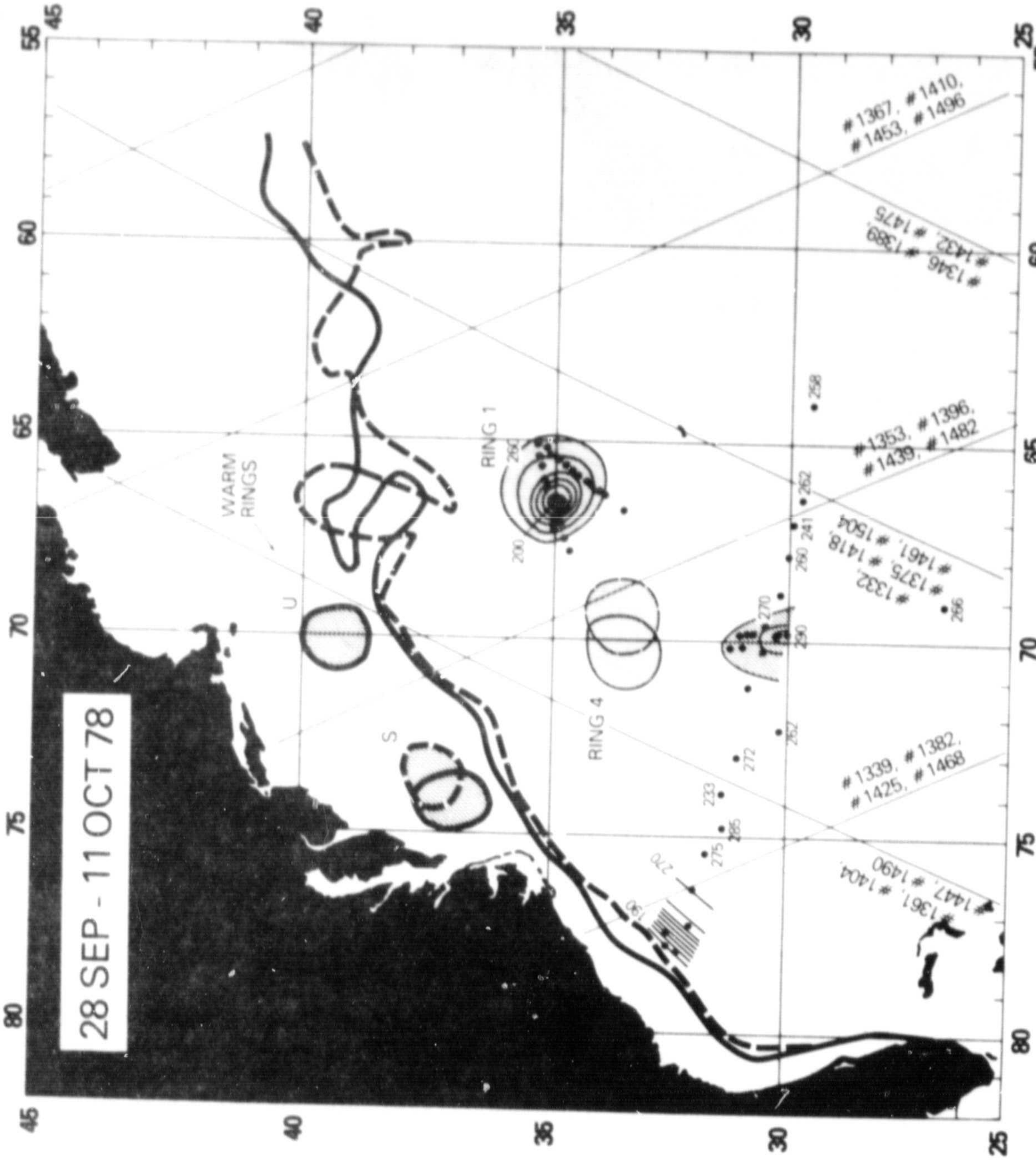

28 SEP - 11 OCT 78
WARM RINGS
RING 1
RING 4
U
S
#1367, #1410, #1453, #1496
#1346, #1389, #1432, #1475
#1353, #1396, #1439, #1482
#1332, #1375, #1418, #1461, #1504
#1339, #1382, #1425, #1468
#1361, #1404, #1447, #1490

Figure 3g

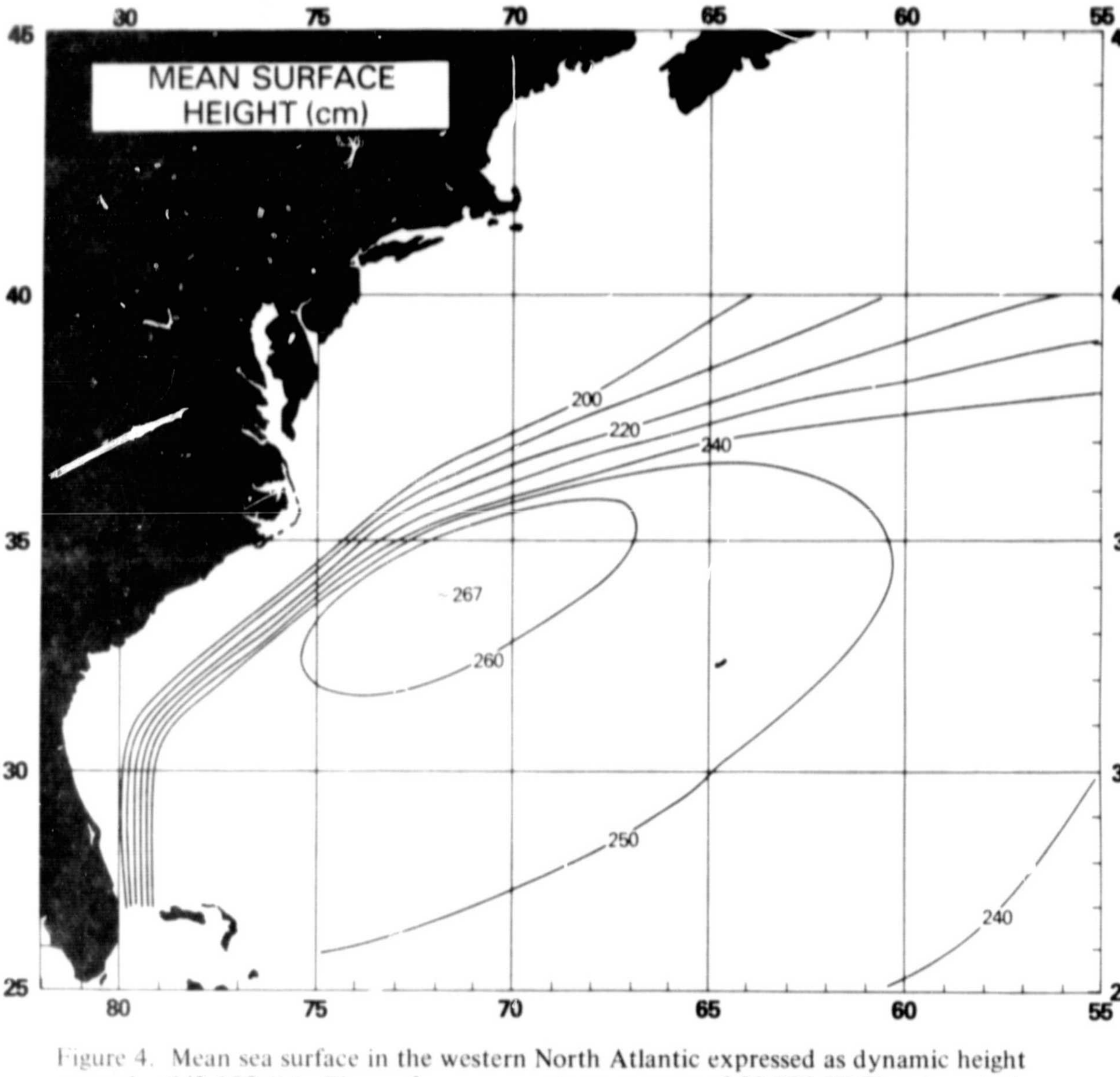


Figure 4. Mean sea surface in the western North Atlantic expressed as dynamic height anomaly (0/3,000 db). The surface represents an average of 50,000 XBT's taken during 1970–76 with cold ring observations deleted and was derived from the average 15°C depth given in Richardson, Cheney, and Worthington (1978). Isotherm depths were converted to heights with the relation shown in Figure 2.