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Effects of Hurricane Betsy upon Atlantic Ocean Temperature, Based upon Radio-Transmitted Data

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ABSTRACT

Radio-transmitted synoptic data are used to determine the change brought about in the thermal structure of the Atlantic Ocean by the passage of hurricane Betsy in 1965. Such data for sea surface temperature and bathythermograph observations are regularly available from selected areas. Although they are not highly accurate and their interpretation is difficult, they could be more widely utilized in synoptic oceanography, as in this example and in oceanographic forecasting. The data for Betsy indicate thermal changes in the sea similar to those described previously for hurricane Hilda where research data were used. They give evidence of upwelling from 200 ft near the storm track, a 4F sea surface temperature decrease, and downwelling farther away from the track.

1. Introduction

Recent studies by Leipper (1967) present a description of changes in the ocean brought about by hurricane Hilda in 1964. O'Brien and Reid (1967) develop a theory which, although it has a number of seriously limiting assumptions, provides the best explanation to date of some of the processes involved. From these studies, although a number of questions remain unanswered, it would appear that the ocean responds to a hurricane first through the development of an Ekman type flow which, in the Northern Hemisphere, leads to a divergence of the ocean surface layers from the storm center outward in all directions. Next, upwelling occurs along the path of the storm to replace the diverging surface layers, and finally, the outward flowing warm water converges near the outer edges of the wind circulation and leads through downwelling there to the formation of a deep, warm mixed layer in the ocean. Most of the mixing which occurs is in this outward moving water. It is caused by the mechanical effect of the wind and by the convection brought about by heat loss from the sea surface to the atmosphere. The heat loss approximates 4000 gm cal cm^{-2} day^{-1}, which indicates the amount of cooling of the mixed layer.

The analysis of the effects of hurricane Betsy upon the Atlantic ocean was undertaken with radio-transmitted data because they were the only data available at the time and because analyses of this type, if successful, would have valuable applications in commercial fisheries and in military problems. Also, since a change in the ocean brought about by one hurricane may have a significant influence upon the development and movement of any second hurricane coming into the same area, the results may be useful in hurricane forecasting as well as in less extreme weather forecasting. Obtaining the fully processed bathythermograph data is still a formidable and time consuming effort. Until this is simplified, the radio-transmitted information has important advantages.

2. The data

Only two sources of data were utilized for this study. Both provided information within hours after the observation. The first was the synoptic ship weather report series consisting mostly of information from merchant vessels and including sea surface temperatures. The second was the series of temperature-depth observations from bathythermographs collected at the U. S. Navy Fleet Numerical Weather Facility at Monterey, Calif., in connection with its environmental data network (Wolff, 1968; Kesel, 1968).

Both types of data have limitations. One is in accuracy, due to the fact that observations are taken by nonscientific personnel. Also, errors may be introduced in coding or in transmitting the radio messages. The positions often are computed by dead reckoning and may not be exact. The BATHY message by which bathythermograph data is transmitted does not provide the full temperature-depth structure but only points at significant depths. The data are collected and utilized in Fahr-

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enheit and foot units. (We believe it is best to retain these units in this analysis for practical considerations.) Finally, bathythermograph readings, even those obtained from carefully calibrated instruments used by trained observers, may be expected to have a number of errors and sea surface temperature observations by untrained observers may have considerable variation from the true temperature (Hazelworth, 1966).

3. Hurricane Betsy and average currents in the Atlantic

Fig. 1 shows the path of hurricane Betsy in the southwest Atlantic ocean. The particular ocean surface currents for 1965 are not known in this region but the mean flow in August and September is described in atlases such as that of the U. S. Naval Hydrographic Office (1953). From this the currents in the area affected by Betsy east of longitude 77W are seen to be generally in the range of 2–5 n mi day^{-1} toward the west-northwest. This means that ocean anomalies resulting from the action of the hurricane might be expected to drift to the west-northwest at this speed after the hurricane. However, since it is not clear how a suitable correction can be made for the resulting advective changes, anomalous features will be plotted where they were observed.

4. Observed changes (horizontal distributions)

The observed changes in the ocean which occurred from before to after the passage of Betsy may be shown in several ways. One is by contrasting the sea surface temperature patterns and by plotting a contour map of the differences. Another is by describing the change in the topography of a particular isothermal surface. Also, attempts may be made to find data upon which to establish vertical sections across the path of the storm.

In order to have sufficient data for the preparation of sea surface temperature patterns, all observations for a 7-day period before Betsy were combined by averaging over 1° quadrangles. The same was done for 7 days after. This gave five or more readings in a large number of the quadrangles on each map and provided a reasonable basis for the drawing of contours. [The actual distribution of observations as well as other details related to this study are included in a thesis by Landis (1966)]. Results are presented in Figs. 2 and 3. Hurricane Betsy moved approximately along the path of warm water shown in Fig. 2. A comparison of the temperature ranges indicated on these charts to those of climatological atlases [such as Fuglister (1947)] indicates that the pattern before Betsy is closer to the mean than that after the storm. The latter showed sea surface temperatures generally lower than those of the atlas in the area where Betsy changed course.

Fig. 4 shows the change in sea surface temperature from before to after the hurricane, obtained by subtracting the values shown in Fig. 2 from those of Fig. 3. The area of greatest decrease, more than 4F, is on the hurricane path where the strong winds would have had their greatest duration. However, this alone would not

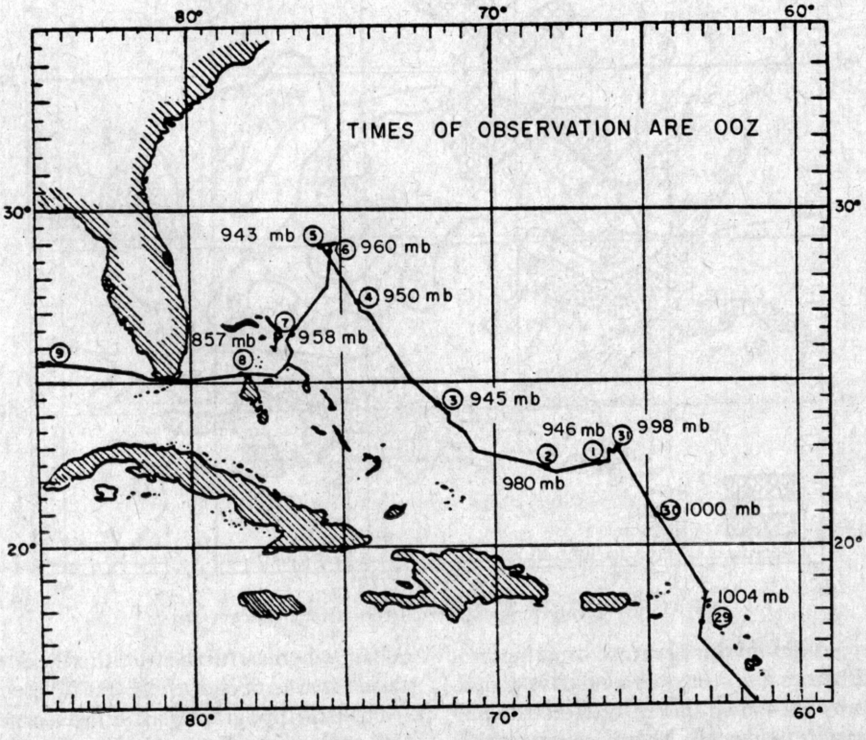

Fig. 1. Track of hurricane Betsy, 29 August to 9 September 1965, with indicated center pressures.

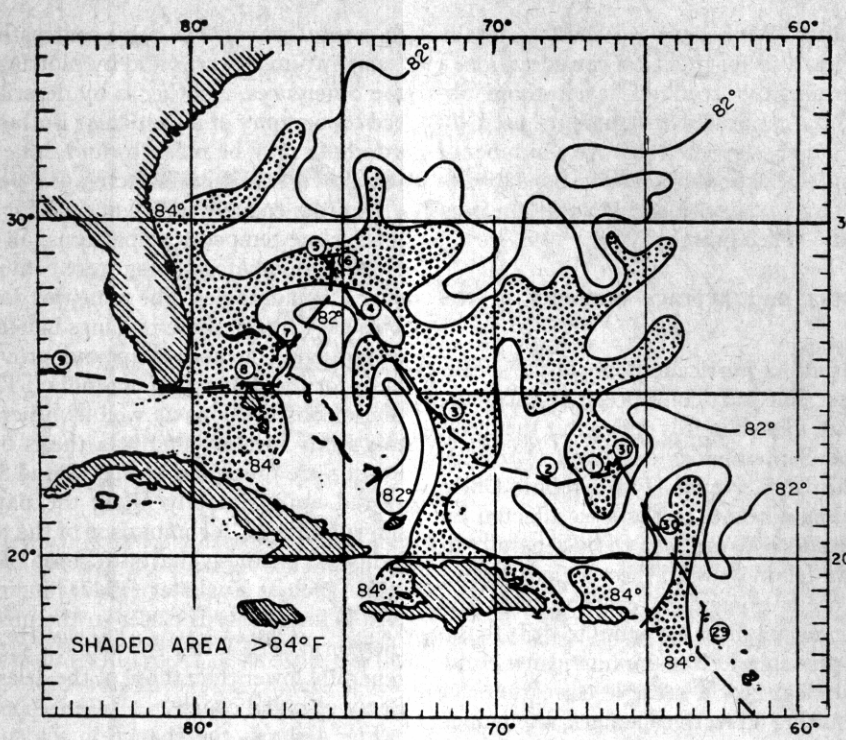

FIG. 2. Sea surface temperature pattern before hurricane Betsy.

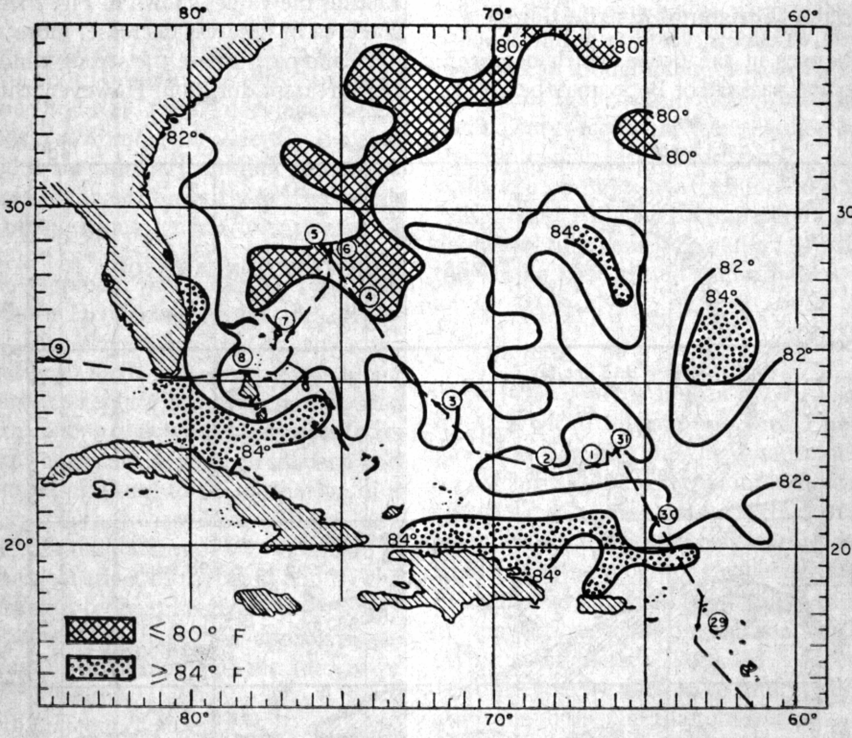

FIG. 3. Sea surface temperature pattern after hurricane Betsy.

have guaranteed a maximum temperature drop had not cold water existed before the storm at a relatively shallow depth in this area as shown in Fig. 5. Here the 82F isothermal topography before the storm comes within 50–100 ft of the surface so that it could readily be upwelled, whereas further south where the hurricane also passed it was deeper than 100 ft.

The 82F topography after the storm appears in Fig. 6. Although, as can be seen in Fig. 5, it had not appeared at the sea surface anywhere in the region before the hurri-

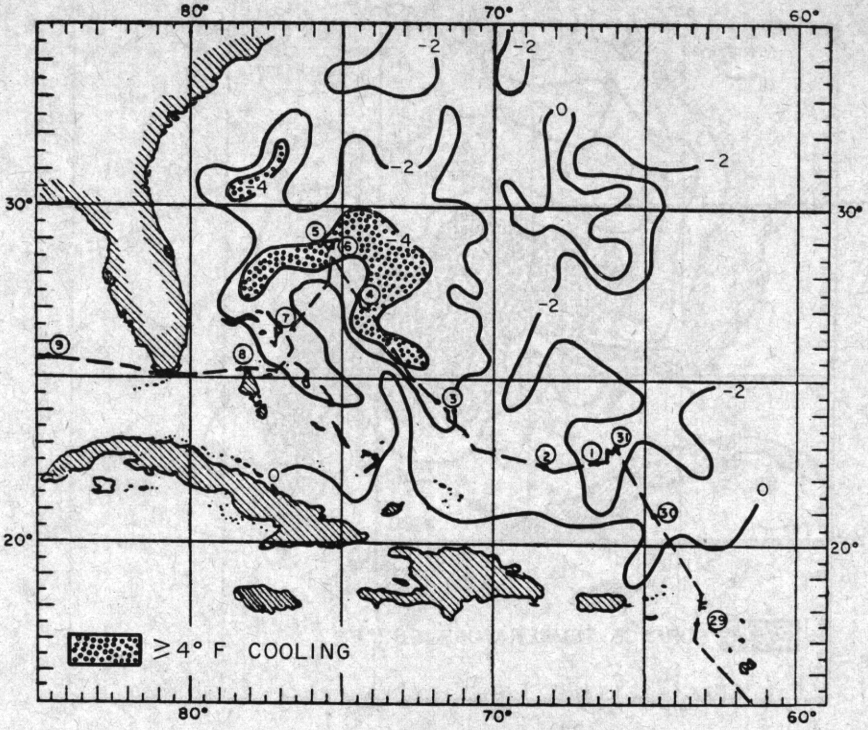

Fig. 4. Change in sea surface temperature from before to after Betsy.

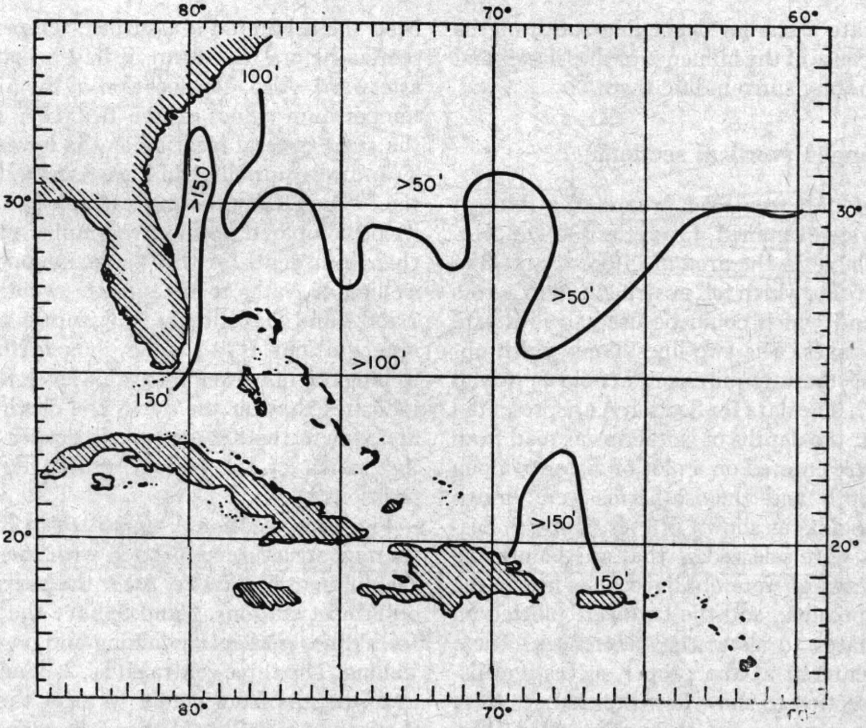

Fig. 5. Depth (ft) of 82F isotherm before hurricane Betsy.

cane, it now appears there over an area of some 200 mi in width along the storm path, indicating that the surface has risen from depths >100 ft. The mixed layer existing in this area before the hurricane no longer is present. North of the path, in an area where the isothermal surface had been at depths between 50 and 100 ft, a band somewhat paralleling the storm path is found where the depth has increased to more than 100 ft, presumably due to the convergence of surface layer waters moved outward from the hurricane center. The

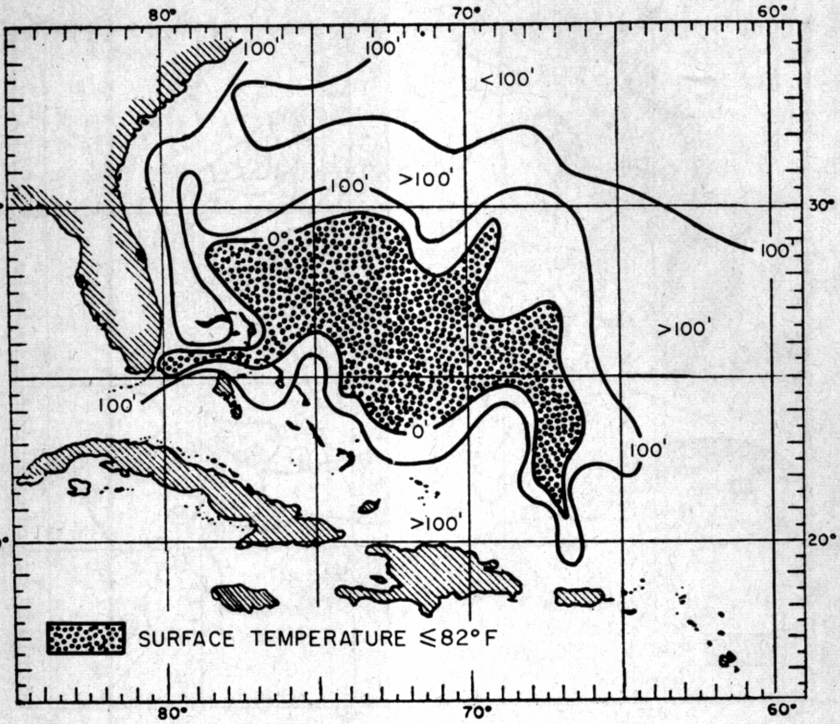

FIG. 6. Depth (ft) of 82F isotherm after hurricane Betsy.

data do not indicate a similar deepening south of the track, possibly because of the influence of the islands and the bottom topography surrounding them.

5. Observed changes (vertical sections)

Two months of data centered around the date of Betsy's passage were examined. From the 500 BATHY observations available in the area of interest, an effort was made to select sets which fell in straight lines across the storm path and which could be used to illustrate before-to-after changes. The two lines along which observations meeting these requirements could be found are shown in Fig. 7. The data for Section A are presented in two ways. First, the depths of isotherms as read from individual BTs were entered on a plot of distance along the section vs depth and the isotherms were drawn connecting these points as shown in Figs. 8 and 9. Second, pairs of BTs were selected so that one before the storm and one afterward were obtained at as nearly the same position as possible, and the two were plotted on the same coordinates to show the differences. These pairs were then entered at the proper successive distances along the section to show how the changes from before to after the storm varied along the section (Fig. 10). For section B, only the BT pairs are reproduced as shown in Fig. 11. The specific positions of the BTs used and the dates they were obtained are listed along with other information in Tables 1 and 2.

Studying the before and after sections of Figs. 8 and 9, several features become apparent. Whereas 82.5F had been the minimum sea surface temperature along this section before the storm, it had become the maximum afterward. Also, the location of the highest sea surface temperature values on the BATHYs before Betsy was the same general location as the lowest ones afterward. To indicate upwelling in Figs. 8 and 9, the band between the 79 and 80F isotherms is stippled so that it may readily be compared on the two graphs. From the observed change in depth of this band, it appears that the upwelling of water to the surface occurred between BTs 2 and 4 and that it came from depths of 150–200 ft. The outer stations, BTs 1 and 5, show neither significant upwelling nor downwelling at this level. Reference to Fig. 6 indicates that on the north the downwelling area (the area where the 82F surface is deeper than 100 ft) was just north of the end of section A. (See Fig. 7 for positions.)

Fig. 10 for section A as located in Fig. 7 presents the thermal structure associated with the 80F isotherm for the different BATHYs. After the hurricane passage the outermost stations, 1 and 5, have the deep mixed layer (solid lines) indicating mixing and possibly some downwelling. The three central BTs, 2, 3, and 4, show cooling at all depths from before to after the storm and they show the possibility of the more rounded temperature-depth curves typical of upwelling. No attempt is made to explain the indicated cooling below 200 ft at the locations of BTs 2 and 3. It might be due to advection or errors in the data. On the basis of studies of other situations it is not believed to result from vertical motion. The width of the upwelling band from BTs 2–4 ap-

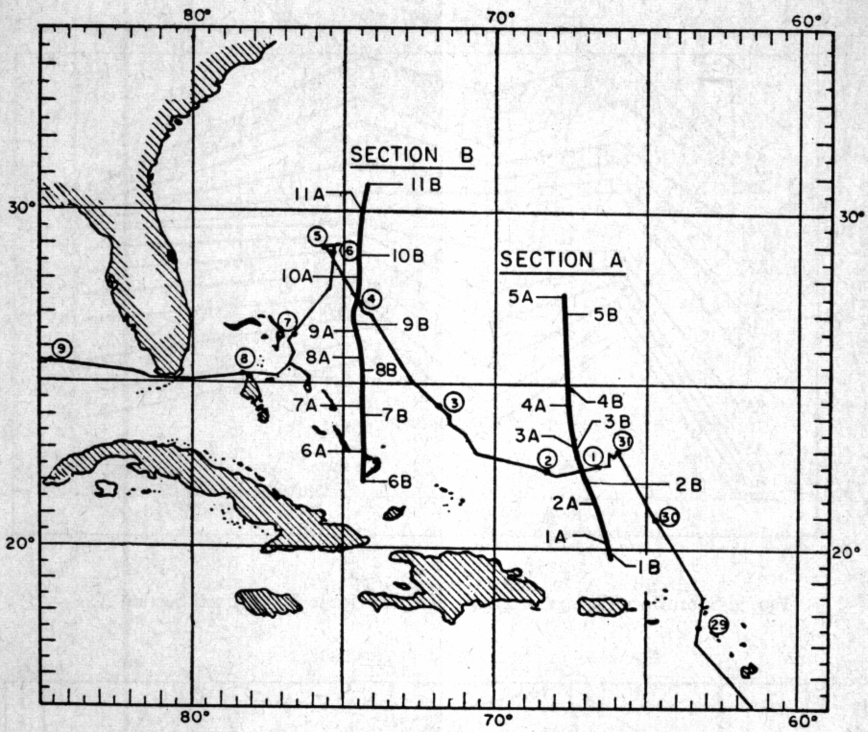

FIG. 7. Positions of Sections A and B across Betsy's path with location of BTs.

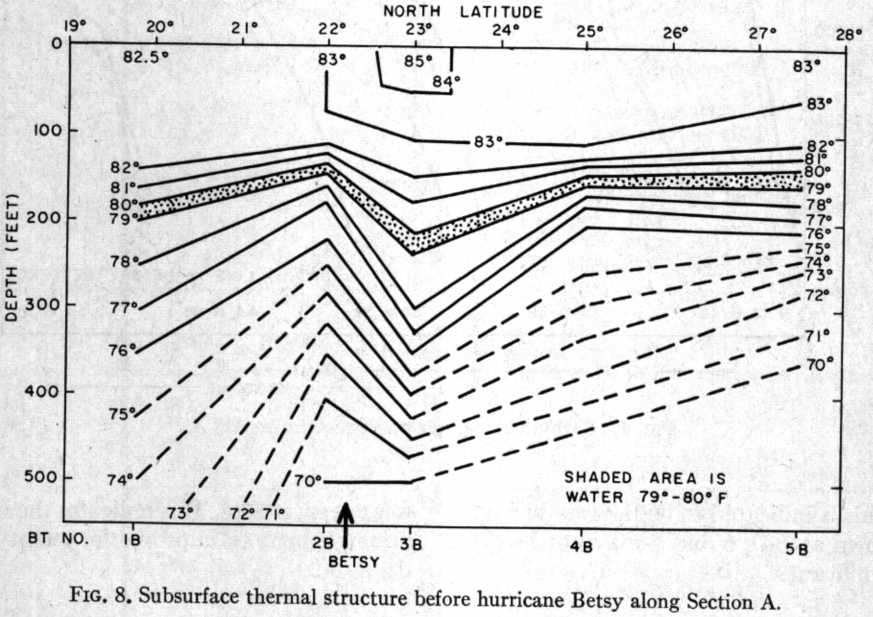

FIG. 8. Subsurface thermal structure before hurricane Betsy along Section A.

pears to be more than 200 mi and it extends further north of the path of Betsy than south of it.

Fig. 11 is the comparison of before-and-after BTs at selected points along section B which are located as shown in Fig. 7. The changes are more complicated here than in section A possibly because the section is near where the hurricane reversed its course and moved slowly for four days. Also, larger time intervals were involved. However, BT 10 which is just to the north of the path shows upwelling which could be over 100 mi in width, while BT 8 shows the well mixed layer of the downwelling zone. At BT 11 the layer did not appear to change greatly in depth nor temperature but it remained well mixed. Downwelling must have occurred

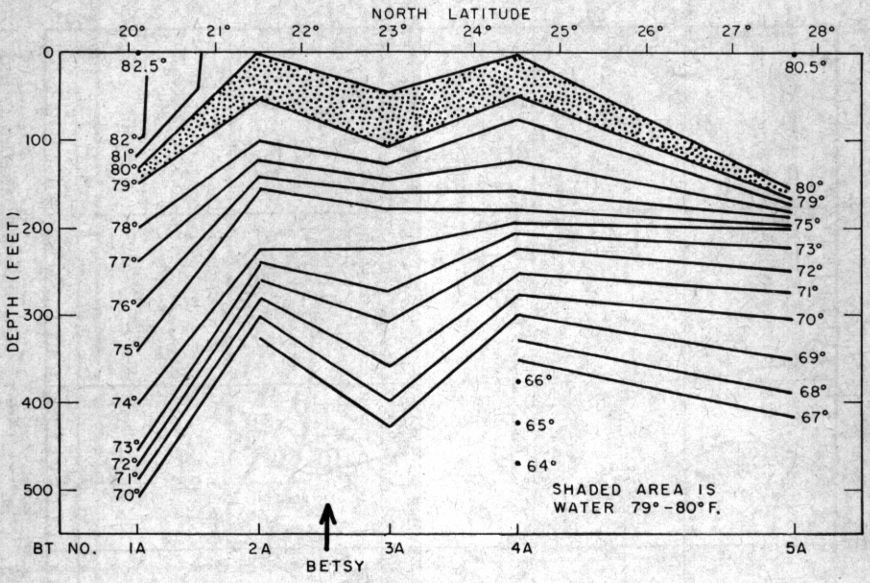

FIG. 9. Subsurface thermal structure after hurricane Betsy along Section A.

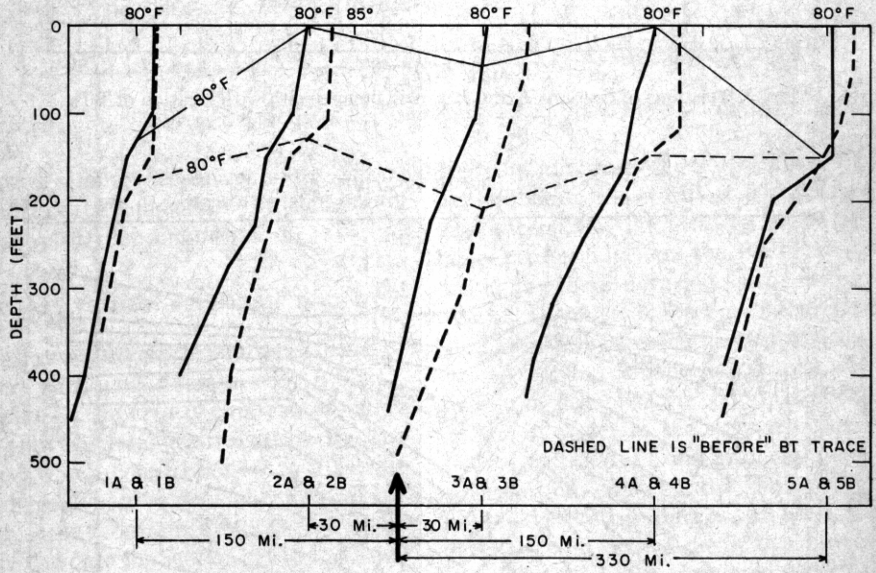

FIG. 10. Bathythermograph traces used in Section A.

farther north. This is indicated to be the case in Fig. 6. The changes shown at BTs 6 and 7 may not be great enough to be significant.

6. Heat exchange

Using the temperature structure changes from before to after hurricane Betsy along sections A and B, an effort was made to compute the amount of heat transferred by advection, upwelling, and exchange with the atmosphere. The time intervals involved, the variations in the data from different ships, and the shallow extent of some of the observations were such that this effort was not successful. This indicates the importance of continuing efforts to improve the quality and quantity of the data.

7. Conclusion

Radio-transmitted bathythermograph data have many sources of error and are difficult to interpret. Even so, the features of sea temperature variations described above serve to indicate the nature of the major changes which occurred in the ocean as a result of the passage of hurricane Betsy in the Atlantic Ocean. Comparison of these indicated changes with what is known about the

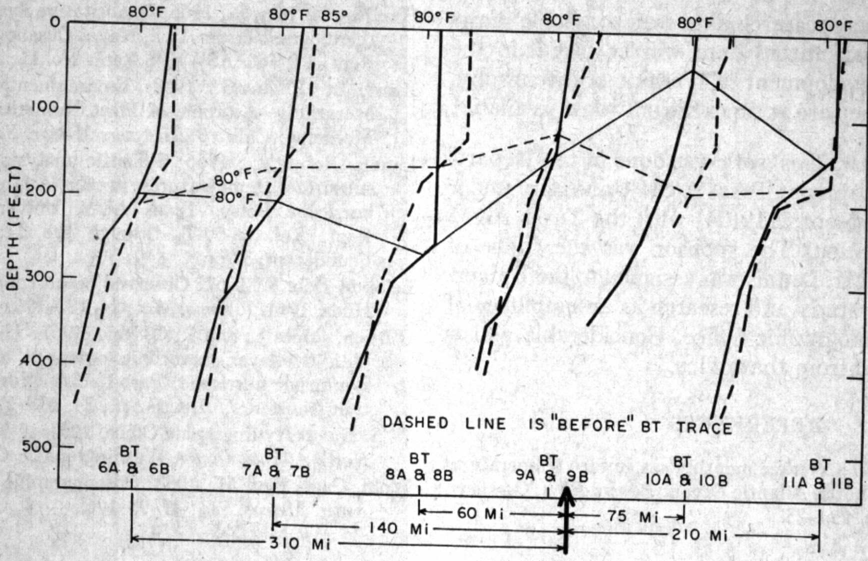

FIG. 11. Bathythermograph traces used in Section B.

TABLE 1. Bathythermographs used in Section A.

BT no.	Position	Sea surface temperature (°F)	Date of observation	Days between observation and hurricane passage
1B	19.8°N, 66.3°W	82.5	16 August 1965	16
1A	20.1°N, 66.1°W	82.5	5 September 1965	3
2B	22.0°N, 67.1°W	82.5	17 August 1965	15
2A	21.5°N, 66.8°W	80.0	10 September 1965	8
3B	22.9°N, 67.1°W	85.5	30 August 1965	2
3A	23.0°N, 67.2°W	80.5	10 September 1965	8
4B	25.0°N, 66.6°W	83.0	26 August 1965	6
4A	24.5°N, 67.4°W	80.0	10 September 1965	8
5B	27.1°N, 67.5°W	83.5	24 August 1965	8
5A	27.7°N, 70.3°W	80.5	20 September 1965	18

TABLE 2. Bathythermographs used in Section B.

BT no.	Position	Sea surface temperature (°F)	Date of observation	Days between observation and hurricane passage
6B	22.0°N, 74.4°W	84.0	28 August 1965	6
6A	22.8°N, 74.4°W	83.0	26 September 1965	22
7B	24.1°N, 74.3°W	84.0	28 August 1965	6
7A	24.4°N, 74.4°W	82.5	27 September 1965	23
8B	25.3°N, 74.3°W	85.5	27 August 1965	7
8A	25.6°N, 74.1°W	81.5	26 September 1965	23
9B	26.7°N, 74.2°W	85.0	27 August 1965	7
9A	26.5°N, 74.3°W	81.5	26 September 1965	23
10B	28.7°N, 74.5°W	84.5	27 August 1965	7
10A	27.9°N, 73.9°W	80.5	27 September 1965	24
11B	30.9°N, 74.2°W	83.0	27 August 1965	7
11A	29.9°N, 74.1°W	81.6	27 September 1965	24

few situations where research data were available shows that the radio-transmitted data will be useful in the greatly needed development of synoptic oceanography, especially since they are at times the only data available.

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