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Reprinted from JOURNAL OF PHYSICAL OCEANOGRAPHY, Vol. 2, No. 3, July, 1972, pp. 218–224
American Meteorological Society
Printed in U. S. A.

HURRICANE HEAT POTENTIAL OF THE GULF OF MEXICO

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Hurricane Heat Potential of the Gulf of Mexico[1]

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(Manuscript received 5 January 1972, in revised form 29 March 1972)

ABSTRACT

It has been demonstrated that a large input of energy from the ocean is necessary to establish and maintain hurricane force winds over the sea. However, there has been no suitable data which could serve as a basis for calculating this input. Now, observations are available to show that, early in the hurricane season, there are varying initial conditions in the Gulf of Mexico which could lead to significantly different total heat exchanges. The sea can provide some seven days of energy flow into a hurricane at some times and at some locations, but less than one day in others depending upon the amount of heat initially available in the Gulf waters. In the four summers represented by the data, a quantity defined as hurricane heat potential was found to vary from a low of 700 cal cm^{-2} column north of Yucatan to a high of 31,600 in the central east Gulf. Synoptic data on hurricane heat potential, if made regularly available to forecasters, might serve as a basis for improved forecasts of changes in intensity and movement of hurricanes.

1. Introduction

The problem of predicting the development and movement of hurricanes over the sea is one of the most urgent ones in marine meteorology. At times, with present knowledge, there can be almost no confidence in such predictions. However, it is known that hurricanes form only over the warm sea (Byers, 1959; Ramage 1959), that they tend to be more intense where the sea temperature is highest (Miller, 1958; Perlroth, 1967), and that they often tend to move along tongues of warm water (Fisher, 1958; Tisdale and Clapp, 1963). Also, theoretical models show marked changes when different ocean temperatures are introduced (Ooyama, 1969). Malkus (1962) compares a hurricane to a thermal engine and reviews Byers arguments showing that a large oceanic input in the form of latent and sensible heat is necessary to establish and maintain the pressure gradients which in turn produce and maintain the tremendous hurricane winds.

Not only are hurricanes affected by the temperature of the underlying ocean; they in turn affect the sea, and their passing has been shown to lower the sea temperature of the surface layers considerably under certain circumstances (Jordan, 1964; Stevenson and Armstrong, 1965; Leipper, 1967). The rate at which this temperature decrease occurs determines the change in rate at which energy is fed into the storm from below. This results from the fact that evaporation and conduction are directly dependent upon the sea-air temperature difference. When the sea is cooled to the temperature of the air in a hurricane, approximately 26C, this difference becomes small and little energy, if any, is extracted from the sea by the hurricane.

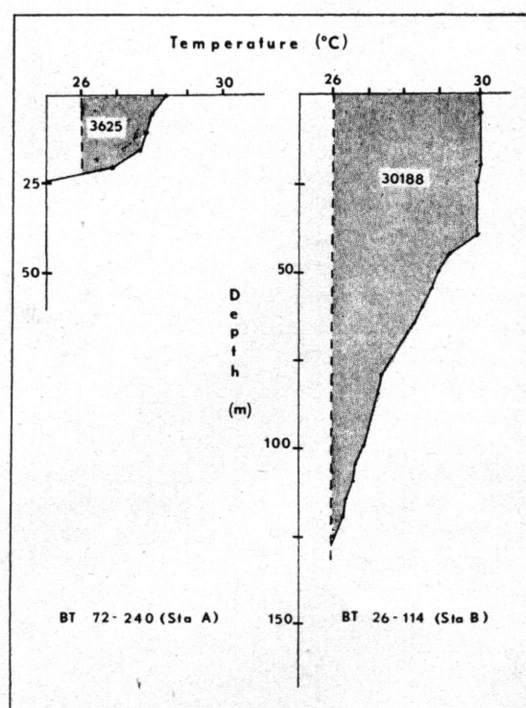

FIG. 1. Sea temperature structure for BT Stations A and B taken on *Aliminos* Cruise 68-A-8, 17 August–5 September 1968, showing examples of high and low hurricane heat potentials.

[1] Presented at the Conference on the Interaction of the Sea and the Atmosphere, 1–3 December 1971, Ft. Lauderdale, Fla.

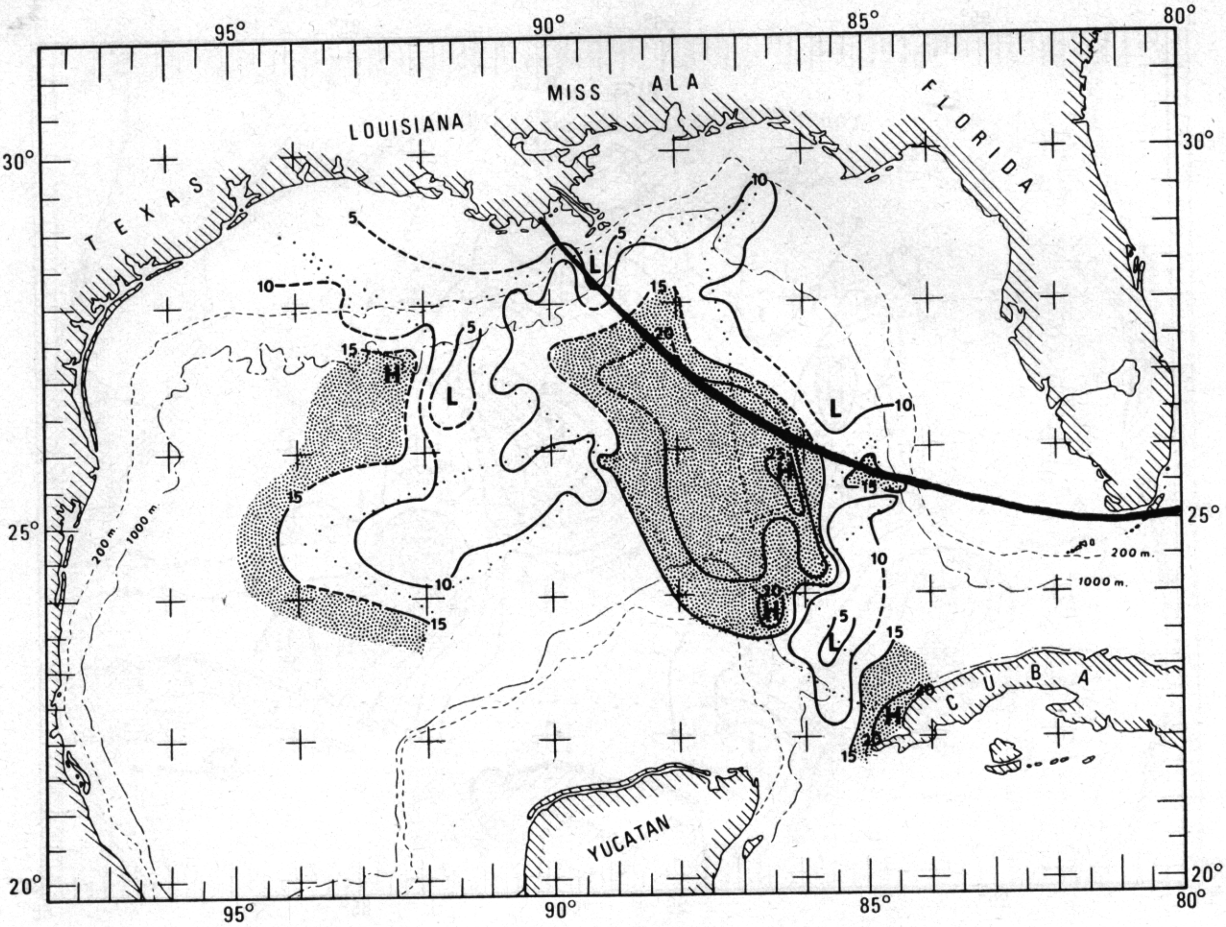

FIG. 2. Ocean hurricane heat potential (10^3 cal cm^{-2}) for Cruise 65-A-11, 1–24 August 1965. Path of hurricane Betsy is superimposed.

2. Previous studies

Most previous studies have concentrated their attention on the temperature of the sea surface. However, Jordan (1964) and Perlroth (1967) have mentioned the importance of considering not only this temperature but also the temperature of the upper ocean layers. Further, from temperatures obtained by averaging all available data, Perlroth (1969) found indications that hurricane development was more likely over nearly isothermal water of high temperature than over regions where the sea temperature decreased noticeably with depth in the upper layers. It seems reasonable that this should be so since waters of the former type would contain significantly more heat at a given sea surface temperature.

The approximate amount of heat extracted from the ocean by a passing hurricane is known from direct measurements before and after a storm (Leipper, 1967; Whitaker, 1967) and can be estimated from the exchange formulas (Malkus, 1962). It appears to be about 4000 cal cm^{-2} day^{-1}, or some ten times the exchange rate in normal weather situations. Thus, if the initial heat content of the ocean is known, the number of days during which an overlying hurricane might be supported can be estimated. Also, the rate at which energy is provided to a particular storm may be calculated by utilizing the changing values of the sea surface temperature which may be determined from an assumed average heat loss and observed initial conditions; this will be the subject of a separate study.

3. Data available

Observations providing full synoptic coverage of sea temperature through the surface layers are not available for any of the major ocean regions where hurricane development and movement occurs. The lack of such data has significantly limited the study of associated hurricane behavior. However, a series of short cruises was planned and conducted in the Gulf of Mexico in the warmest and coldest months of the year (Leipper, 1968). In this series were included cruises in August in four different years. August is a month which is early in the hurricane season and the sea temperature distributions at this time of year are indicative of those which may affect hurricanes. (The cruises of this series are not complete in time nor space coverage and one result of the present study is to demonstrate the need for con-

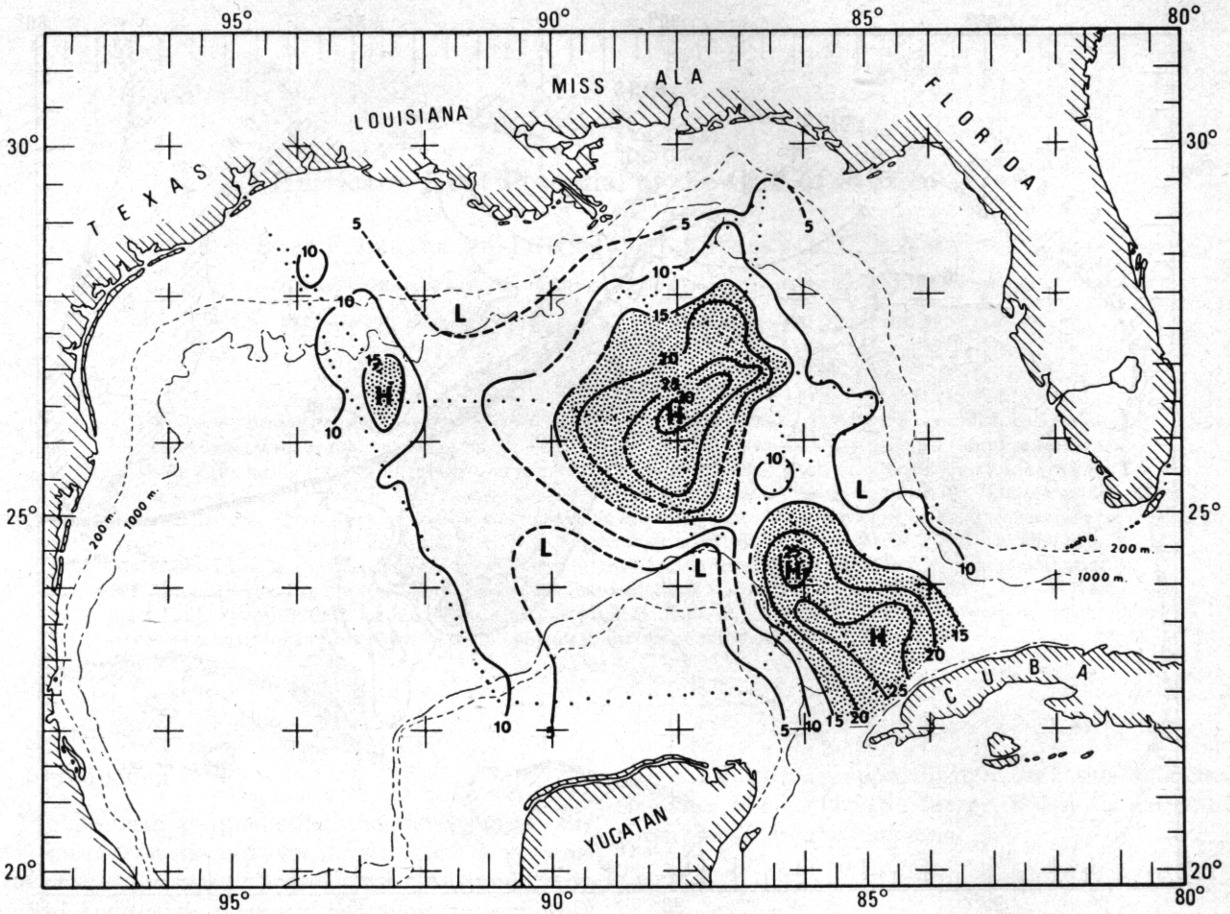

FIG. 3. Ocean hurricane heat potential (10³ cal cm⁻²) for Cruise 66-A-11, 4–18 August 1966.

ducting cruises or other observational programs giving improved summer coverage in the future.) The data now available do indicate major differences in heat content from place to place and from year to year in the Gulf. It is quite likely that such differences will help to provide an explanation for the varying ways in which hurricanes develop and move.

The unusual areal distributions of sea temperature structure and heat content which are observed in the Gulf of Mexico are the result of changes in the Gulf current patterns, particularly in that part known as the East Gulf Loop Current. Indications of the nature of these changes and their relation to sea temperatures in the Gulf were presented by Leipper (1970). In brief, the intrusion of the warm Caribbean waters into the Gulf of Mexico is not consistent. Sometimes very little of the Gulf is filled with this warm water and at other times it dominates large areas. Occasionally, segments of the warm current break away from the strong, central flow which enters the Gulf through the Yucatan Channel. These segments may then drift to various locations within the Gulf carrying with them their high heat content and other individual water mass characteristics.

4. Hurricane heat potential

Heat content is a relative quantity. Water of any temperature can be chosen as a reference. However, there seem to be at least two reasons for choosing water at 26C: it is the sea temperature below which hurricanes do not form (e.g., Byers, 1959), and it is the air temperature at the surface for the mean tropical atmosphere in hurricane season (Malkus, 1962). Thus, to show the heat content of the Gulf waters early in the hurricane season, the quantity "hurricane heat potential" was defined as the excess of heat over that in water at 26C. This quantity was first used in a thesis by Whitaker (1967).

The sea loses heat to the atmosphere in a hurricane situation by conduction and evaporation from the sea surface. Both of these processes lead to cooling, and the associated increase in density of the surface waters causes convection through the mixed layer. If the air temperature is 26C, as is common in hurricanes, transfer from the sea to the atmosphere would continue until the temperature of the mixed surface layer of the sea dropped to the 26C, i.e., until the sea-air temperature difference became zero. This would utilize the

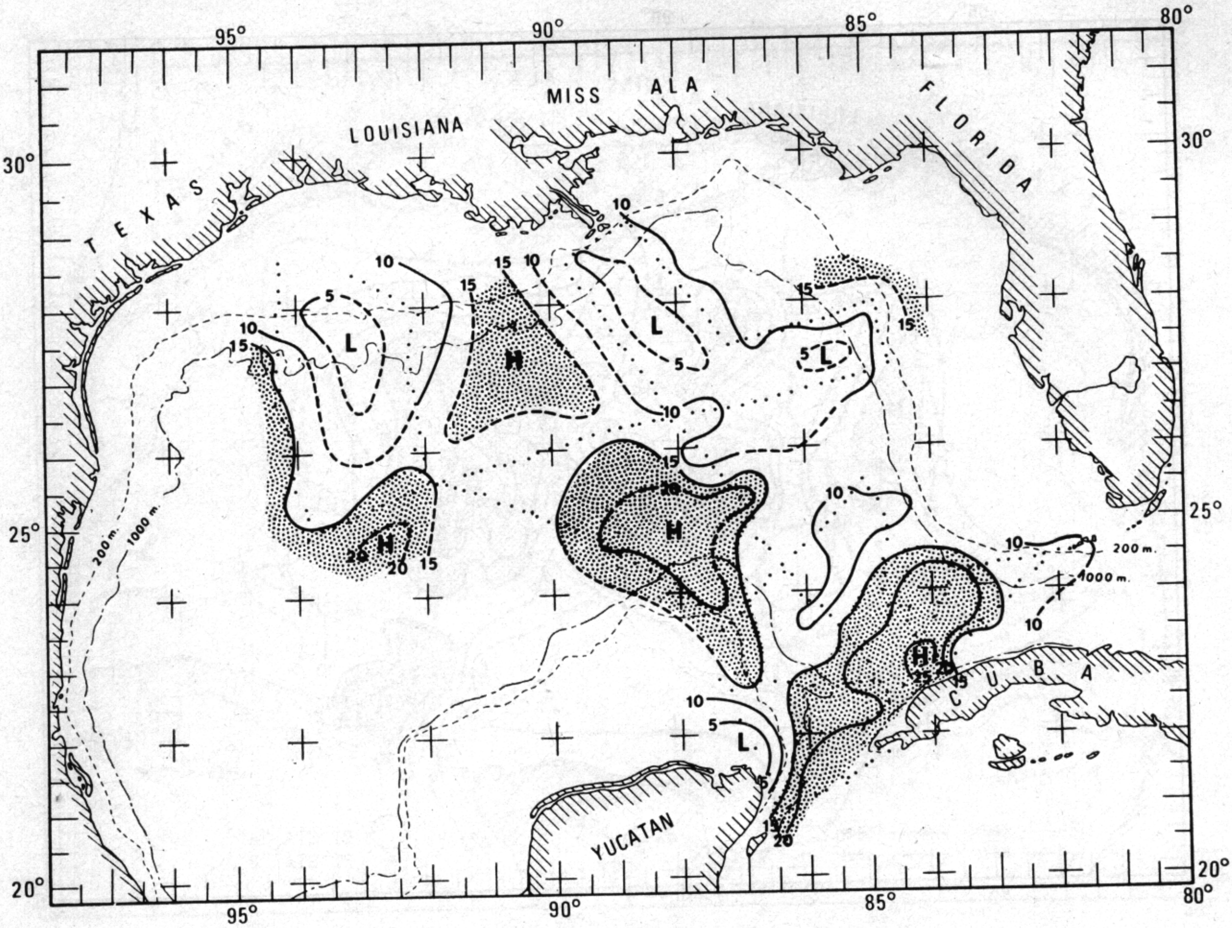

FIG. 4. Ocean hurricane heat potential (10^3 cal cm^{-2}) for Cruise 67-A-6, 4–22 August 1967.

entire "hurricane heat potential" at that given location, and transfer of energy to a storm having the 26C average air temperature and high humidity would cease. The hurricane situation may thus be most unusual in that the temperature of the air may control the eventual temperature of the sea surface. The reverse is true in most other situations.

As the surface layers of the sea lose heat to a hurricane through evaporation and conduction, the stress of the hurricane winds acting upon the sea surface cause a divergence of surface waters outward from the central area of the storm (O'Brien and Reid, 1967). This leads to a thinning of the warmer surface layers near the center of the hurricane and eventually may lead to upwelling of the colder water beneath the thermocline as it did in hurricane Hilda (Leipper, 1967). The effect of this divergence pattern is to lower the hurricane heat potential in the central areas. Thus, the heat initially available at a given central location may not all be available for utilization at that location, and the computed times that the initial hurricane heat potential would support a hurricane are therefore maximum times.

To compute the hurricane heat potential Q at a given station the following relationship was used:

$$Q=\rho c_p \Delta T \Delta Z,$$

where the density ρ was taken as 1 gm cm^{-3}, the specific heat at constant pressure c_p was taken as 1 cal cm^{-3} (°C)$^{-1}$, ΔT was the average temperature difference above 26C for a given depth increment; and ΔZ was the depth increment, taken as 500 cm. The products of these quantities were then summed through the layer having temperatures above 26C, to obtain the total hurricane heat potential at a given station. The potential was computed at a sufficient number of stations on each cruise to enable contour charts to be drawn.

As examples illustrating the relation between temperature structure and heat potential, two stations in the deep Gulf on the same cruise are shown (Fig. 1). Heat content is directly proportional to the area between the 26C isotherm and the observed structure. The large difference between this particular pair of stations may readily be noted. Their locations are indicated in Fig. 5.

5. Results

Charts showing the areal distribution of hurricane heat potential were prepared for the years 1965–68 and

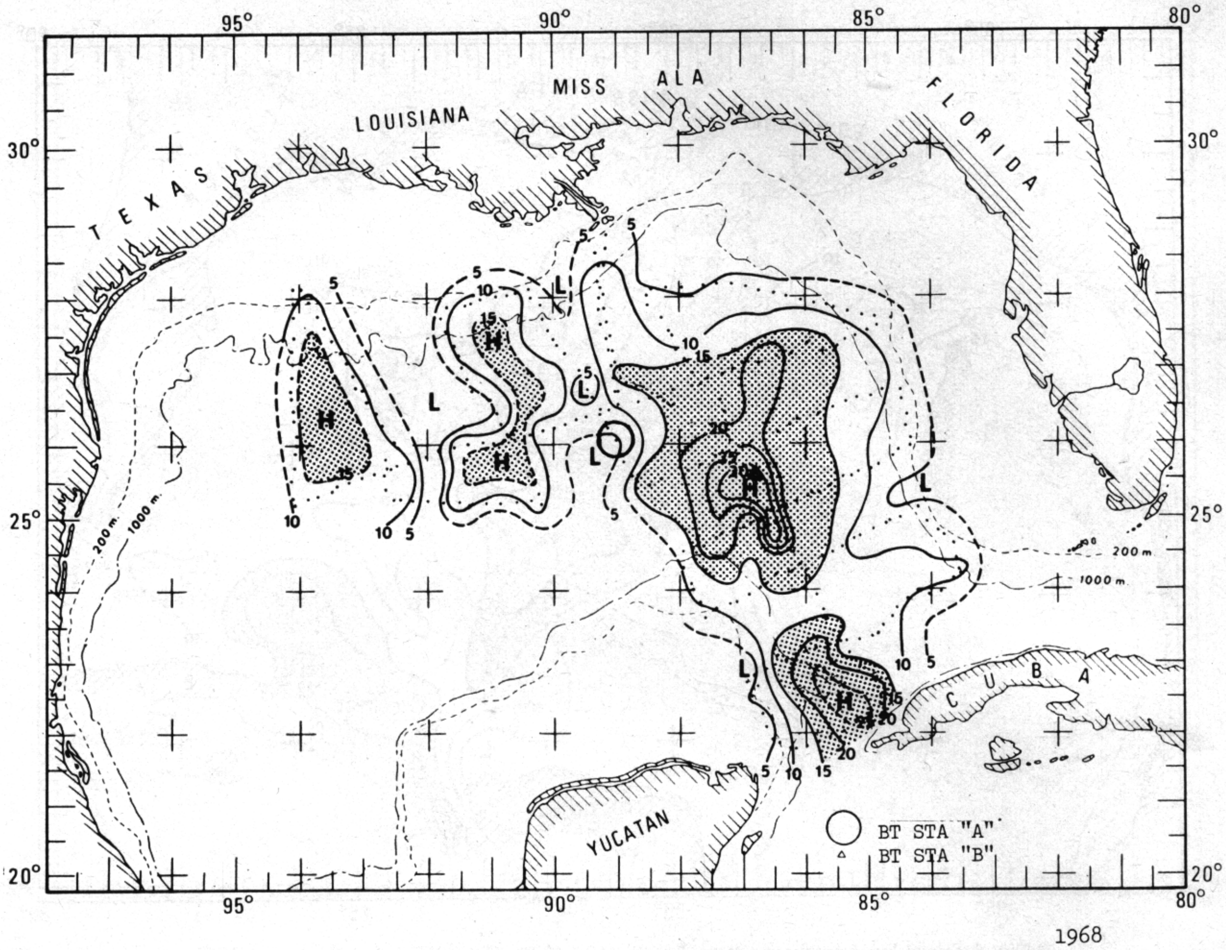

FIG. 5. Ocean hurricane heat potential (10^3 cal cm^{-2}) for Cruise 68-A-8, 17 August–5 September 1968. The circle and small triangle are the locations of stations A and B.

are shown in Figs. 2–5. In the first two years (Figs. 2 and 3) there is considerable similarity. A tongue of high potential (>15,000 cal cm^{-2}) runs from the western tip of Cuba toward the Mississippi Delta. It is cut in two from east to west in both years northwest of Cuba. The tongue weakens as it approaches the shelf region off the Delta. In 1965 the area of low potential cutting across the tongue of high was 160 km closer to Cuba than in 1966. The maxima in 1965 were not as high as in 1966 when one region of high shows the presence of more than 30,000 cal cm^{-2}. This is enough energy to sustain an average hurricane for more than seven days, assuming the loss is ~4000 cal cm^{-2} day^{-1}.

Both 1965 and 1966 have indications that tongues of low potential (<10,000 cal cm^{-2}) run completely across the Gulf from Yucatan north-northwestward toward the central Louisiana coast. Along these tongues a storm could be supported only one or two days. In the western Gulf, areas of moderately high potential are indicated but the data are scarce here.

Although studies of particular hurricanes with respect to heat potential in these years have not been made, the path of hurricane Betsy is superimposed upon Fig. 2. The cruise from which the heat potentials were computed in this figure was completed just 15 days before the hurricane. It can be noted that Betsy passed over the region of high heat potential. Although she was traveling at 15 kt, Betsy appeared to have extracted some 488×10^{16} gm-cal of heat from the Gulf (Whitaker, 1967), and she arrived at the Louisiana coast as one of the most powerful and destructive hurricanes on record.

The hurricane heat potential distribution for 1967 (Fig. 4) shows the path of high potential shifted some 100 mi to the west of the 1965–66 position with lower maximum values than 1966. The Galveston and Mississippi regions appear to be "protected" toward the southeast by areas of low potential while there is an area of high potential to the southwest off Brownsville. An area of high is also indicated in an unusual zone on the Florida shelf south of Panama City and west of Tampa. This was the only year in the four observed when no heat potential contour above 15,000 was found north of 25.5N.

In 1968 (Fig. 5) the very high potentials again appeared north-northwest of western Cuba and two significant areas of heat potential in excess of 15,000 cal

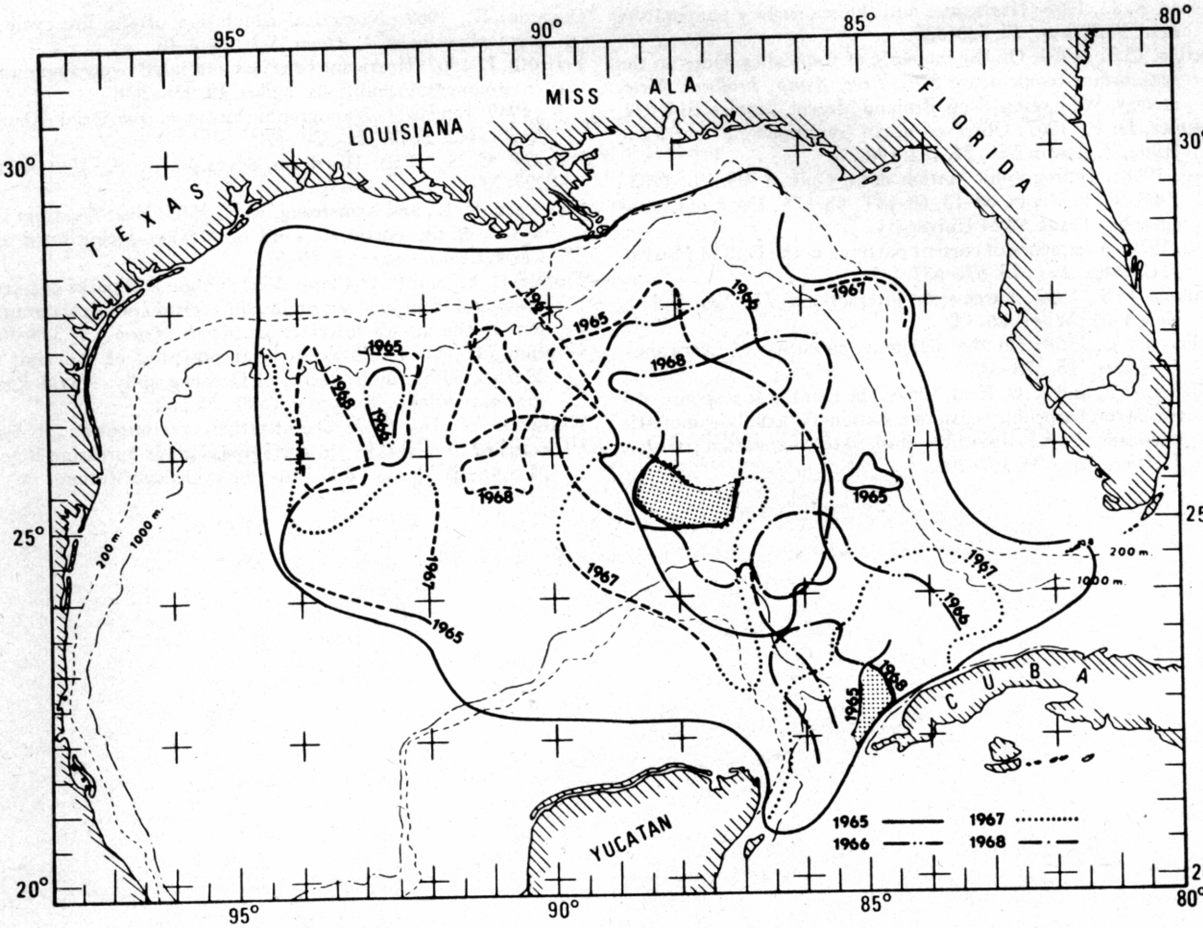

FIG. 6. Superimposed 15,000 cal cm^{-2} ocean heat contours for all August cruises, 1965–68. Areas in excess of 15,000 cal cm^{-2} for the four-year period are stippled.

appeared in the northwestern Gulf. The situation is similar to those in 1965 and 1966 except that the north-south path of low potential, which appeared in those years across the Gulf, is relatively narrow in the northern Gulf in 1968.

To compare years, the 15,000-cal contours for all years have been superimposed in Fig. 6. Two stippled areas, one just north of the western tip of Cuba and one midway across the Gulf north of Yucatan, had potentials >15,000 cal in each of the four years observed. From the common central Gulf position it can be seen that the 1965 area broadly surrounded this position, 1966 extended only northward and westward from it, 1967 extended mostly south-southwest, and 1968 extended generally east and north. At the west tip of Cuba the area enclosed by the 15,000-cal contour in 1965 seemed quite limited in extent, in 1966 it had the deepest intrusion north-northwestward, in 1967 it reached north-eastward, and in 1968 it was much smaller and somewhat westward.

6. Conclusion

From the data presented it is obvious that the hurricane heat potential of the Gulf in August varies widely from place to place and from year to year. If this quantity is to be utilized in forecasting the development and paths of hurricanes, it will be essential to monitor it regularly, especially in the early months of the hurricane season. After the passage of a hurricane it is particularly essential to re-survey the area crossed by the storm since major changes in sea temperature and heat content may be expected, and knowledge of these changes would be required for improved prediction of future storms (Brand, 1971). It appears obvious that hurricane heat potential and vertical temperature structure must be considered in conjunction with sea surface temperature patterns if possible influences on hurricane intensity and movement are to be discovered.

Further data and a more complete analysis on the subject of this paper may be found in a thesis by Volgenau (1970).

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