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HURRICANES OF 1951

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GENERAL SUMMARY

Ten tropical disturbances, eight of them full hurricanes, were charted in the Atlantic during the 1951 season. This is slightly above the normal number, but generally speaking, the season was an average one, and presented no more than the usual tracking and forecasting problems.

No winds of hurricane force occurred on the coast of the United States, and only one disturbance, less than hurricane force, struck the mainland during the season. This storm crossed southern Florida from the Gulf of Mexico on October 2, and gave flooding rains and winds up to 60 m. p. h. in squalls. Damage has been estimated at about $2,000,000 but there was no loss of life. This is the smallest damage figure for tropical storms in the United States since 1939, but other places were not so fortunate. The Island of Jamaica suffered its worst hurricane disaster of the century on August 17–18 when hurricane "Charlie" caused about $50,000,000 in property and crop damage, killed 152 persons, injured 2,000 others, and left 25,000 homeless. The same storm did extensive crop damage when it crossed northern Yucatan the night of the 19th. On August 22 it entered Mexico near Tampico where upward of 100 people lost their lives, principally from bursting dams and flooding rivers. Property and crop losses were in the millions of dollars.

The first hurricane of the season developed east of the Florida coast during the night of May 16. This is the earliest date known for a fully developed hurricane in the Atlantic. There are records of several tropical storms in May during past years, but none developed hurricane force. Moore and Davis [1] have discussed the physical and dynamic forces involved in this hurricane and other interesting features surrounding its development.

The next storm was noted on August 2 and thereafter storm activity was brisk until October 20 when the last hurricane of the season dissipated over the Atlantic southwest of Bermuda.

The Miami Hurricane Central coordinated and dispatched more than 100 reconnaissance aircraft flights into hurricanes during the season, and coordinated and issued a total of 156 advisory bulletins. These indicate the active nature of the season, but the totals are well below the record established in 1950. Total damage in the Caribbean area will probably exceed $80,000,000 and there were more than 250 fatalities.

This was another season with several instances of two or more storms in progress simultaneously. Referring to the track chart (fig. 1), it will be noted that hurricanes "Dog" and "Easy" were in progress on September 3–5, while a third hurricane "Fox," appeared on September 5 and was a companion of "Easy" until the 10th. Again on October 15–16, hurricanes "Item" and "Jig" were in progress at the same time. This is the second consecutive year with multiple hurricanes, a rather rare occurrence in the Atlantic. An interesting feature of hurricanes "Easy" and "Fox" was their slight counterclockwise movement which took place when the two approached each other in the Atlantic near Bermuda. This apparently caused the great hurricane "Easy" to veer enough to miss Burmuda, which had been threatened with destructive winds before the counterclockwise tendency became apparent on September 8.

INDIVIDUAL HURRICANES

Able.—May 16–24.—The earliest fully developed hurricane of record in the Atlantic developed east of Florida during the night of May 16. At 0700 EST on the 17th, the steamship *R. P. Smith* reported winds of Beaufort force 9 to 10, falling pressure, and waves 25 to 30 feet high near 28.5° N., 79.5° W. This was the first definite

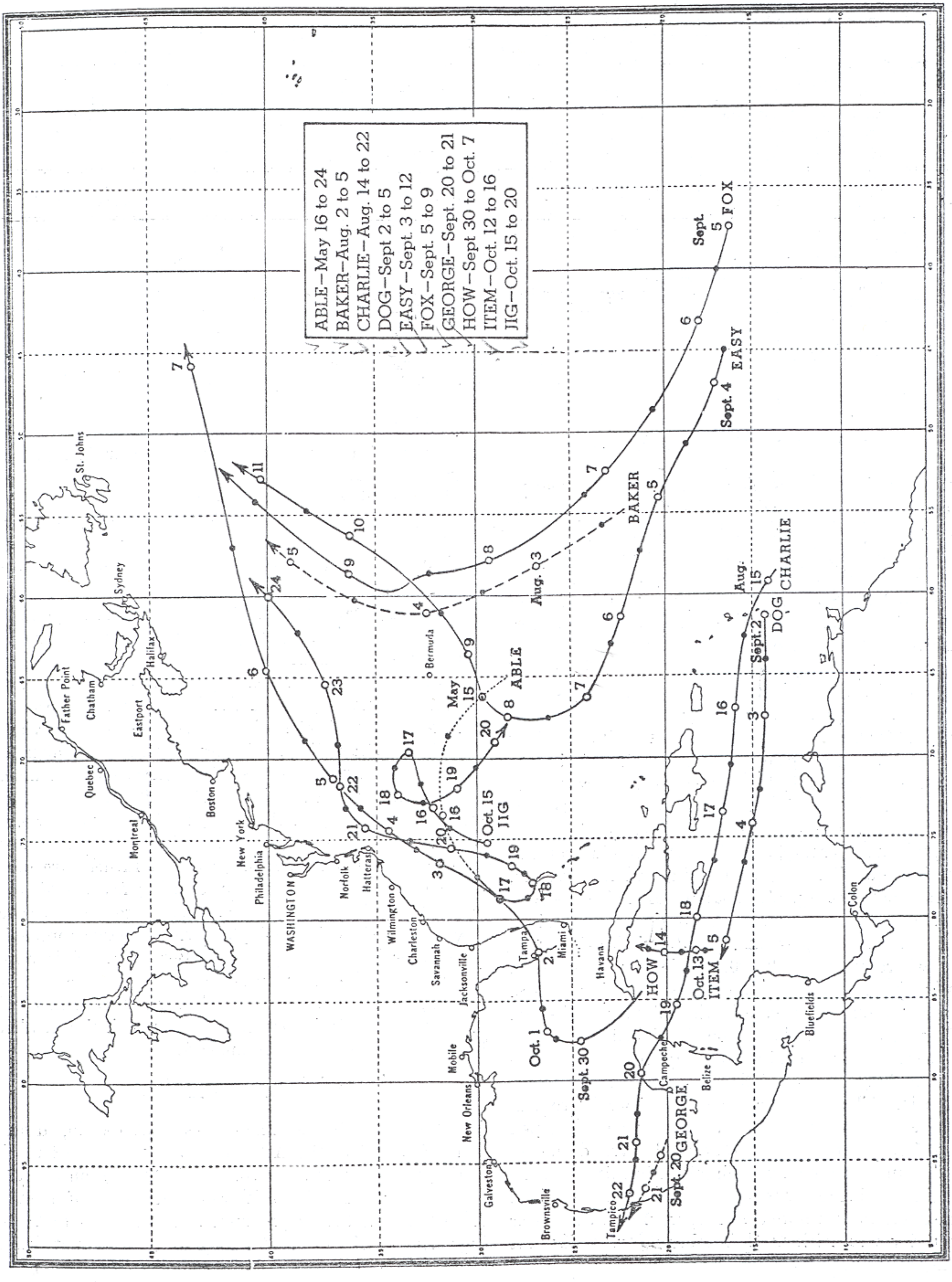

FIGURE 1.—Chart showing tracks of hurricanes observed during the 1951 season. Open circles on tracks indicate position of center at 7 a. m., EST., solid circles, position at 7 p. m. Solid tracks indicate full hurricane winds, dashed lines less than full hurricane winds. Dotted tracks represent probable course during incipient stage.

information that a severe storm had formed. The Navy reconnaissance squadron had just arrived at Miami for servicing prior to the beginning of the season and was ordered out immediately to get full reports. During the 17th they reported a storm of full hurricane strength moving southward. It was later determined that the hurricane was moving on a broad curving loop which brought it over the Little Bahama Banks during the night of the 17th and on the 18th. Walker's Cay on these banks reported 90 to 95 m. p. h. winds for 5 hours during the night of the 17–18th, and Grand Bahama and Little Abaco islands both reported about the lower limits of hurricane force. The completion of the loop turned the hurricane northeastward over the Atlantic and it passed 70 miles east of Cape Hatteras on the 21st. Thereafter it turned toward the east-northeast and dissipated over the Atlantic near 40° N., 60° W. on May 24. The strongest winds were estimated by aircraft at 100 knots (115 m. p. h.) on the 21st. The central "eye" was well formed and about 20 miles in diameter during much of the storm's life and the central pressure was well below 29 inches. (Moore and Davis [1] have investigated this hurricane more fully.)

Baker.—August 2–5.—An "easterly wave" developed into a tropical storm far to the northeast of the Leeward Islands on August 2, near 23° N., 56° W. It moved on a broad curving path to the northwest and north and passed about 275 miles east of Bermuda on August 4 and thereafter turned northeastward over the Atlantic. This storm did not develop hurricane force; the strongest winds reported were only 60 m. p. h.

Charlie.—August 14–22.—A partially developed "easterly wave" appeared east of the Lesser Antilles on August 14 and moved northwestward through the islands early on the 15th, without causing damage. Aircraft reported squalls of 90 knots east of Martinique on the afternoon of the 14th, but the island weather stations did not report winds stronger than 35 m. p. h. There is some evidence that a small center of strong winds passed between Dominica and Guadeloupe during the morning of the 15th. At any rate, there was regeneration to full hurricane force again during the next 24 hours. The center skirted the south coast of Jamaica during the night of the 17th and the entire island had destructive winds, which caused the worst hurricane disaster of the century on Jamaica. Property and crop damage was estimated at $50,000,000, 152 persons were killed, and 2,000 others injured, and about 25,000 made homeless. The strongest wind at Kingston was estimated at over 110 m. p. h.; lowest pressure, 28.74 inches (973 mb.); and rainfall, 17 inches. The center passed several miles south of the city.

After the hurricane left Jamaica, Grand Cayman experienced 92 m. p. h. winds in gusts, but the next land area seriously affected was the Yucatan Peninsula, which the hurricane crossed during the night of the 19th. Reports indicate heavy crop losses running to 70 percent, but no loss of life in the Yucatan area. The storm entered the Gulf near Merida and Progreso on the morning of the 20th considerably reduced in force, but it regained its former force before entering Mexico near Tampico on August 22. Tampico was near the southern edge of the "eye" and reported winds of 110 m. p. h. but winds were doubtless stronger to the north of the calm center. Property damage was estimated at $1,160,000 in the city of Tampico and 4 persons were killed; torrential rains flooded rivers and burst dams in the country west and northwest of the city and caused more than 100 deaths by drowning, according to final press reports.

The exact number of casualties could not be ascertained since many bodies were evidently not recovered in the flood area. Property damage was in the millions of dollars, but actual estimates are not available. The strongest winds reported in this hurricane were about 130 m. p. h. (by aircraft) just before it entered Yucatan, and again in the Gulf off Tampico. The pressure at Tampico dropped to 28.81 inches (975.7 mb.). The total loss of life in this hurricane was almost certainly over 250, while property and crop damage will probably reach a total of $75,000,000.

Dog.—September 1–5.—Reconnaissance planes located a disturbance several hundred miles east of Barbados on September 1, and on the morning of the 2d it was found to be a partially developed wave, with squalls of hurricane force in its northeastern quadrant, a short distance east of Martinique. Winds on the southern side were weak. On September 2, it moved through the Lesser Antilles between Santa Lucia and Martinique. Both islands suffered considerable damage. On Martinique 1,000 homes were reported destroyed and many others unroofed; 5 persons lost their lives by drowning; trees which were uprooted blocked roads and tore down telephone and power lines; 90 percent of the banana crop, and 30 percent of the sugarcane crop were lost; damage was about $3,000,000. On Santa Lucia, two persons lost their lives by drowning, and one sailing vessel was destroyed and two others damaged; flooding and high winds destroyed 70 percent of the banana crop in the northern part of the island. The strongest wind reported in the islands was 100 knots (115 m. p. h.) at Fort-De-France Airport on September 2. Total damage was well over $3,000,000 and seven people were killed.

After the hurricane entered the Caribbean Sea, it began losing force and by the time its westward course brought it to a position some 200 miles southeast of Swan Island on the 5th, it had dissipated into moderate squalls and thereafter disappeared entirely.

Easy.—September 3–12.—The steamship *Barn* sent three special reports on the morning of September 3 which indicated the existence of a circulation, probably of hurricane force, near 16.5° N., 42.5° W. It was followed thereafter by aircraft which reported it to be of hurricane force and increasing as it moved on a west-northwestward course. By the time it began curving northward on the 7th near 25° N., 67° W., aircraft reported it to be too severe for penetration. The wind reached an estimated 140 knots at deepest penetration on the south side when the plane had to turn back. This indicated that a possible wind of between 160 and 200 m. p. h. was prevailing near the center and on the stronger northern side. This was by far the most severe hurricane of the 1951 season. It curved sharply and passed a short distance southeast of Bermuda on the 9th and continued northeastward and was well off Newfoundland by the 12th. This great hurricane did not strike any land area, but a few ships were involved more or less and suffered damage to their superstructures. There was no loss of life. Lowest pressure reported as 28.26 in. (957.0 mb.) on the 6th.

Fox.—September 5–9.—This hurricane was first suspected when the steamship *Janecke Naess* encountered 45-knot south winds at 15° N., 35° W. on September 5. This wind report indicated that a small hurricane center was located a short distance northwest of the ship's position. It later proved to be a small, fast-moving hurricane which moved on a northwestward course and passed some 350 miles east of Bermuda on September 8. Thereafter it turned northeastward and continued its rapid movement over the Atlantic. It passed well to the east of Newfoundland on the 10th. It will be noted that this hurricane's entire life was co-existent with the great hurricane "Easy." When the two were nearest Bermuda on the 8th, they exerted the usual counterclockwise torque on each other, which probably prevented "Easy" from striking the island. The strongest winds reported by aircraft for "Fox" were 115 to 120 m. p. h. A few ships were involved to some extent but no damage reports have been received.

George.—September 20–21.—A tropical storm of less than hurricane force developed in the Gulf of Campeche on September 20 and moved into Mexico a short distance south of Tampico on the 21st. The strongest wind reported was about 60 m. p. h. (by aircraft) during the afternoon on the 20th. No damage has been reported in connection with this storm.

How.—October 1–7.—An easterly wave moved into the Gulf of Mexico through the Yucatan Channel the last 2 days of September, and on October 1 reconnaissance planes located a center of circulation near 26.0° N., 87.5° W. attended by squally winds of about 40 m. p. h. This center turned sharply eastward and crossed Florida from about Punta Gorda to Vero Beach on October 2. The strong winds associated with the disturbance while passing over Florida were confined to squalls along the Keys and on the east coast up to Palm Beach far to the southeast of the center; they reached 50 to 60 m. p. h. The center was not strongly organized at this time and was not attended by damaging wind, but it was attended by a belt of torrential rains along its path, which caused extensive flooding of farm and pasture lands, including much of the rich farm land around Lake Okeechobee. A considerable number of cattle were drowned and some that could not be moved from flooded ranges to high ground died of starvation. Wind damage was confined to canvas awnings, a few glass windows, and sinking or damage to some small craft along the Keys and lower east coast. In all, damage was estimated at about $2,000,000; no loss of life or injuries occurred.

After leaving Florida the storm increased to hurricane force as it moved northeastward in the Atlantic. It passed a short distance offshore from Cape Hatteras on October 4, without damaging winds on land, and continued northeastward and then east-northeastward and passed several hundred miles south of Nova Scotia and Newfoundland on the 6th and 7th. The strongest winds reported were about 110 m. p. h.

Item.—October 12–16.—A very small hurricane developed in the northwestern Caribbean Sea on October 12 near 18° N., 82° W. It moved slowly northward to a position 60 to 80 miles east-southeast of the Isle of Pines where it became stationary, or made a small loop, and slowly dissipated on the 15th and 16th. Strongest winds reported by aircraft were around 80 m. p. h. maintained from the 13th to 15th. No damage resulted from this hurricane. Lowest central pressure reported was 29.45 in. (997.3 mb.).

Jig.—October 15–20.—The last hurricane of the season developed off the south Atlantic coast on October 15 near 30° N., 75° W. A semicircular area of hurricane force winds of around 75 to 80 m. p. h. developed north of the center and persisted for a couple of days as it moved slowly northeastward. On the 17th and 18th, the center described a loop westward and then southward between Bermuda and Cape Hatteras and lost force. It finally died out several hundred miles southwest of Bermuda on October 20. Several ships were involved in the storm, but no reports of damage have been received.

REFERENCE

1. Paul L. Moore and Walter R. Davis, "A Preseason Hurricane of Subtropical Origin," *Monthly Weather Review*, vol. 79, No. 10, October 1951, pp. 189–195.

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A PRESEASON HURRICANE OF SUBTROPICAL ORIGIN

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ABSTRACT

The occurence of the May 1951 hurricane of subtropical origin in the western Atlantic before the beginning of the usual tropical storm season was precedent-setting. Through an analysis of the hurricane an attempt is made to explain (1) the unusually early occurrence, (2) the difference between this hurricane of subtropical origin and the usual tropical storm, and (3) the movement as related to vertical structure, upper air flow, and distribution of ocean surface temperatures. The analysis suggests that the following factors contributed to the intensification of the incipient storm which began in connection with a cold high-level Low: (1) superposition of a divergent upper-wind field; (2) heating of the surface layers of the air mass by the Gulf Stream; (3) occurrence of unusually low temperatures at high levels. The movement of the surface center is found to be in accord with the stream flow at the top of the warm core between the 700- and 500-mb. levels. A possible influence of the ocean surface temperature distribution is suggested on the basis of a striking coincidence between the Gulf Stream axis and the storm track.

CONTENTS

INTRODUCTION

The hurricane season in the western Atlantic area is generally acknowledged to be June through November. However, on the morning of May 17, 1951, a ship about 125 miles east of Daytona Beach, Fla., reported winds of 50 to 60 m. p. h. and waves 25 to 30 feet high. This was the first positive indication that a weak subtropical vortex had begun the intensification that was to result in a precedent-setting early season hurricane. Later in the day, aircraft reconnaissance confirmed the existence of a storm center about 80 miles off the Florida coast moving slowly southward, accompanied by winds of hurricane force. Subsequently the hurricane produced wind speeds of over 100 m. p. h. It aimed first at the Florida coast, but looped across the extreme northern Bahamas, then feinted at the middle Atlantic coast before turning eastward off the Virginia Capes. The track is shown in figure 1.

Although this hurricane was unique in that it was the first of its type noted so near to the United States coast outside the usual tropical storm season, a study of weather maps of the Atlantic area reveals quite similar cases of hurricanes, or near hurricanes, in the subtropic Atlantic even in midwinter. These have been far at sea for the most part, in the lesser-traveled portions of the Atlantic, and have therefore attracted little notice. Simpson [1] and Riehl [2] have called attention to this fact, and the Atlantic maps reveal an example as recently as January 1951 in which a storm, devoid of fronts and exhibiting most of the characteristics of a tropical storm, produced a wind speed of over 60 m. p. h. north of the Leeward Islands.

Analysts familiar with the North Atlantic recognize the cold-core Lows which occasionally appear at high levels

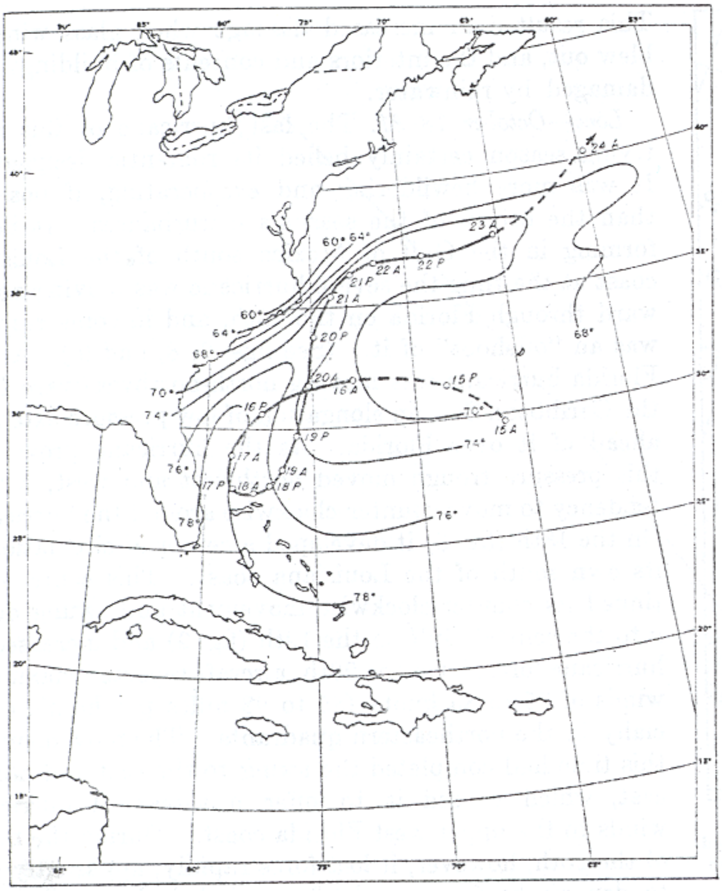

FIGURE 1.—Average May ocean surface isotherms (° F.) (thin lines) and hurricane track May 15-24, 1951 (heavy line; broken portions of track represent incipient and dissipating stages; open circles give positions of storm center on dates indicated by plotted numbers with A for a. m. and P for p. m.).

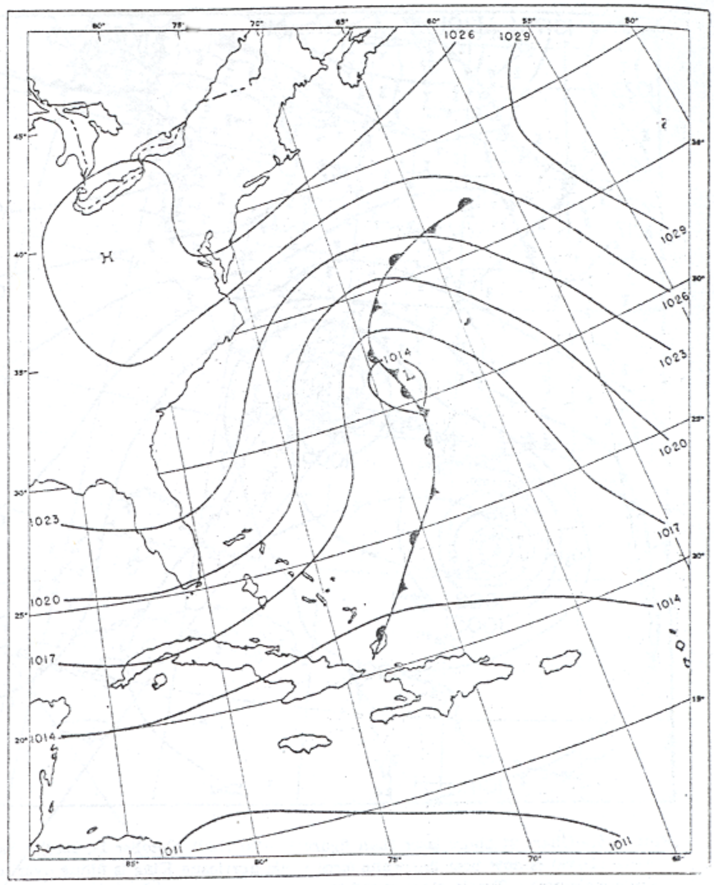

FIGURE 2.—Sea level weather chart, 1930 EST, May 15, 1951.

southwest of the Azores, frequently extending their influence downward to induce a surface low pressure center. The upper-level systems often drift southwestward but the surface perturbation may follow a curved path, apparently under the influence of the upper-level winds. Some of these move southwestward and behave much as tropical storms; others move northward, encounter a colder air mass, and develop as wave disturbances. Simpson [1] has described similar systems in the Pacific near the Hawaiian Islands, known as "Kona" Lows, some of which develop into severe storms with tropical characteristics. He found these to be very delicately balanced thermodynamically, ordinarily cold-core but becoming warm-core in the lower levels coincidental with the development of the wind and rainfall profiles of tropical storms. Many such cases of cyclogenesis in the subtropical Atlantic outside the usual hurricane season do not lend themselves to frontal analysis, nor do they have the exact characteristics expected of a tropical storm. The May hurricane falls in this category.

The purpose of this paper is to analyze the precedent-setting hurricane of May 1951 in an attempt to explain three features of the storm: first, the reason for the occurrence preceding the beginning of the usual tropical storm season; second, the difference between this hurricane, originating in the subtropics, and the usual tropical storm; third, the movement as related to the vertical structure of the hurricane, and the possible effect of the ocean surface temperature distribution.

CONDITIONS PRECEDING FORMATION OF HURRICANE

On May 12, an active cold front in a sharp low pressure trough passed eastward from the Atlantic coast. By the 13th it was near Bermuda. At first the trough was marked at the surface but not pronounced aloft. However, active cold air advection to the rear of the trough was apparent and the wave at the 500- and 300-mb. levels increased rapidly in amplitude. By the 14th a closed Low had formed and was completely secluded from the westerlies. Continued cold air advection had resulted in 300-mb. temperatures as low as —45° C. just east of Florida, in the western portion of the high-level Low. This is about 7° lower than the usual seasonal values. Concurrently, modification of the air mass in the lower levels west of the front was proceeding rapidly. At the 850-mb. level the warming amounted to about 5° C. on the 13th and 14th. The area in which this modification was taking place corresponds with the axis of the Gulf Stream where water surface temperatures are about 25° C. in May. Warming of the air to near the water temperature in the lowest level and to 10° C. at 850 mb., while −45° C. prevailed at 300 mb., was obviously conducive to instability.

With the warming in the lower levels, the polar trough had weakened. In fact, at the 700-mb. level a col separated it from an induced wave in the easterly current farther south. This pattern continued with little change through May 15. The first conclusive evidence of the circulation of the incipient storm was at 1930 EST on May 15 (fig. 2). In the absence of sufficient reports to guarantee an exact analysis, the map was drawn to show the eddy originating at the stationary front. It may have begun as a minute vortex farther to the east, possibly initiated by a minor easterly wave. It is of no great moment since the front was rapidly dissipating and little more than a slight wind velocity shear-line remained. As the polar air mass was becoming greatly modified, and the air was practically homogeneous, it was impossible to delineate the front on subsequent charts.

For the 24 hours following its appearance at 1930 EST on the 15th, the weak surface vortex moved in an arc closely parallel to the 700- and 500-mb. level contours. There was little deepening of the surface system during this period. At the same time the upper-level Low, beneath which the surface eddy was drifting, showed a slight movement towards the southwest. By 1930 EST of the 16th, the surface perturbation had moved to a position over the warmest portion of the Gulf Stream (fig. 1).

SOME FEATURES OF CYCLOGENESIS

Simultaneously with the arrival over the Gulf Stream, the vortex was reaching a position where the circulation in the upper troposphere appeared favorable to deepening. It is generally agreed that high-level divergence is a necessary element in the mechanism for the mass removal of air from the central portions of a hurricane. Previously, a field of convergence at high levels was over the path the surface center had followed. Now as the center was passing under the influence of the wind field between the upper cyclone and the High to the northwest, upper divergence was more in order. (See fig. 3.) Riehl [3] has described the dynamics of such superposition of high- and low-level pressure systems brought about by the interaction of the polar westerlies and the trades. This superposition appears to be one of the important factors in tropical cyclogenesis. Roland and Plouff [4] have also noted the applicability of this hypothesis to the May hurricane.

A clue to a source of energy for cyclogenesis can be found in the vertical structure of the air. Figure 4 is a sounding taken at Miami, May 16, 1951, at 1500 GMT. While it cannot be stated positively that this is representative of the vertical structure of the air in which the storm formed, there is good evidence that it is. At Tampa, also

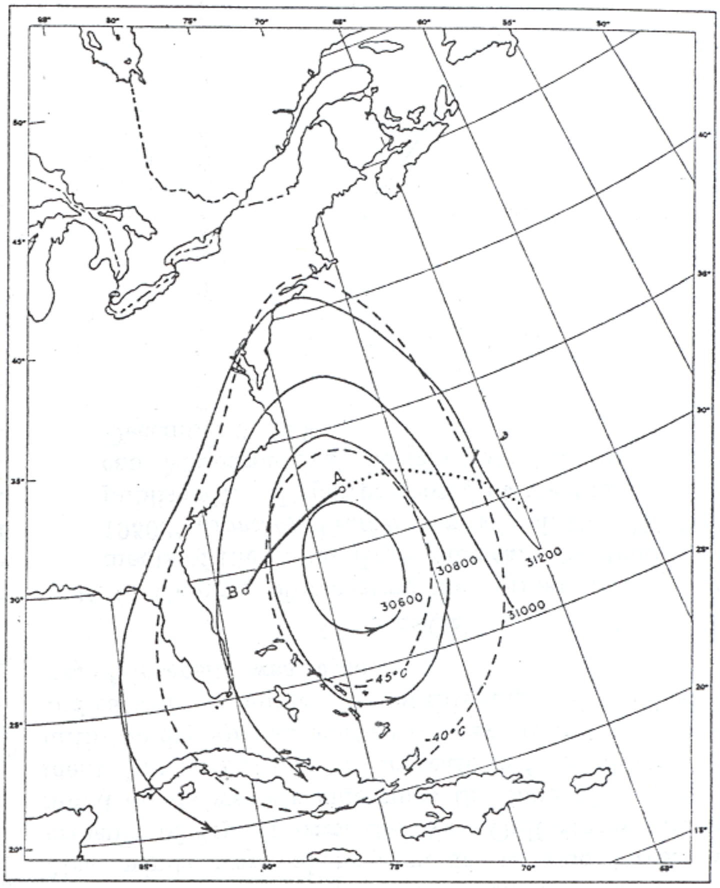

Figure 3.—300-mb. chart, 1000 EST, May 16, 1951. Contours in feet (thin solid lines); isotherms in ° C. (dashed lines); sea-level path of incipient vortex (dotted line). A is the position of first definite closed circulation. From A, the vortex followed track (heavy solid line) to B, the position of deepening to hurricane intensity.

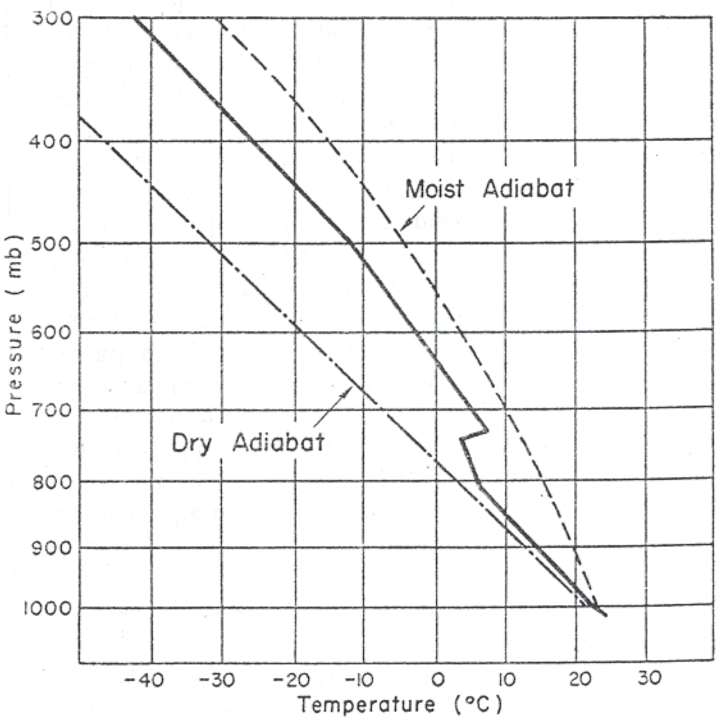

Figure 4.—Upper air sounding at Miami, Fla., 1000 GMT, May 16, 1951.

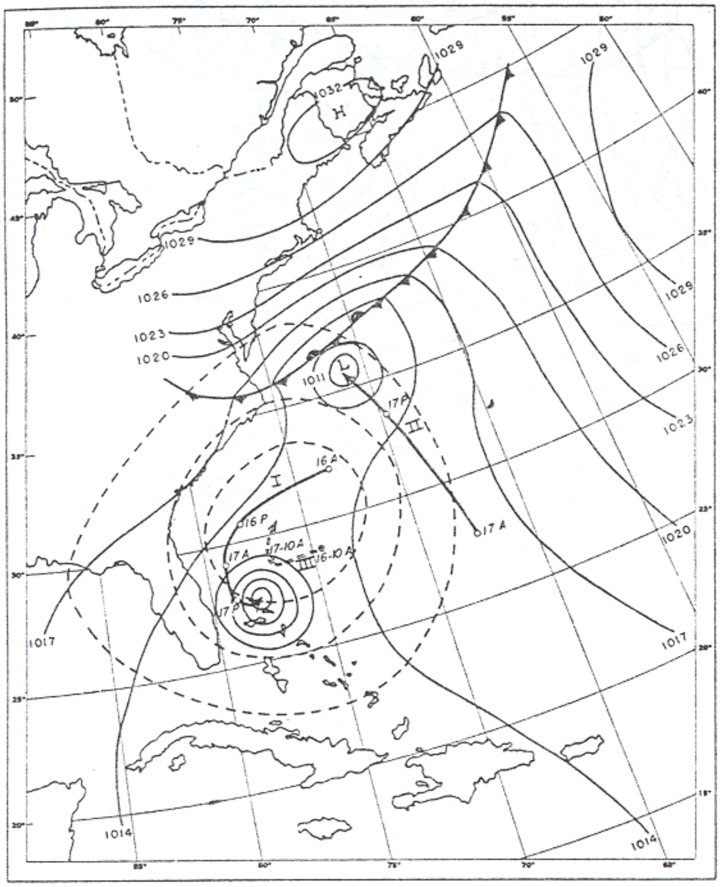

Figure 5.—Sea level weather chart, 0730 EST, May 18, 1951, with superimposed 500-mb. contours (dashed lines) 2200 EST, May 17, 1951. Arrows indicate: I—path of hurricane; II—path of secondary Low; III—path of 500-mb. Low.

in the same general air stream downwind from the point where cyclogenesis occurred, a similar sounding curve was obtained. Furthermore, both soundings showed the characteristic subsidence inversion of the southern edge of the High and the rather steep lapse rate below the inversion, produced by the rapid surface heating.

Up to a certain point, the inversion was sufficient to restrict convection, concentrating the moisture below the 700-mb. level. However, as the surface vortex moved across the axis of the Gulf Stream, three influences united to extend the convective processes to higher levels. These were: (1) active surface heating; (2) convergence in the surface layers; and (3) highly unstable lapse rate above the inversion. Strong convective instability existed between the surface and the 300-mb. level, or higher, and this apparently supplied a large amount of energy for the cyclogenesis.

Before some further aspects of the vertical temperature distribution and its implications are discussed it may be well to emphasize the importance, in the deepening of the surface vortex, of the concurrent features already mentioned. It might be noted that a second vortex (see fig. 5) with quite similar characteristics, lacked two of these potent factors in its history and failed to produce winds of more than about 45 m. p. h. The factors missing in this case were (1) trajectory over the warmest portion of the Gulf Stream, and (2) divergence at upper levels, which was not present in the eastern section of the high-level Low. This is attractive circumstantial evidence of the importance of these two factors in the development of the first vortex, and the failure of the second one similarly to intensify. However, sufficient data are not available to draw any positive conclusions.

With respect to the lapse rate and moisture distribution prevailing in the area in which the storm developed, the following appears pertinent: Riehl [3] has suggested that the optimum conditions for tropical cyclogenesis require that the temperature distribution and moisture content of the air be such that large scale vertical circulations can develop. He points out that if the air mass which is subjected to surface convergence and forced ascent is not saturated, sufficient cooling will take place in the rising air, contrasted with adiabatic warming in the descending current, to nullify the horizontal temperature gradient of the convective cell. The central portion of the storm would then become cooler than its surroundings and the circulation would die. In a nonsaturated air mass, only local and small-scale vertical overturning would occur, resulting in the dissipation of the energy in local showers. In the present case, an inversion (fig. 4) was present to cap the convection and the intense flux of heat and moisture from the warm surface was confined to levels below the 700-mb. surface.

The modified polar air was still not as moist as maritime tropical air. (This fact was subsequently borne out by the lack of rainfall as heavy as that of the usual tropical storm.) However, the air was becoming very unstable and the moisture content was increasing. Furthermore, the moisture deficiency was to some extent compensated for by some other unique features of this storm.

OCEAN SURFACE TEMPERATURE PATTERN

EFFECT ON CYCLOGENESIS

One of the unique features of the storm was its path over the warmer portions of the Gulf Stream at a time of year when the temperature difference between it and the surrounding waters is quite marked (fig. 1). This path resulted in a continuous supply of warm air from the surface being available to the central portion of the storm. Less rapid modification of the surrounding air mass assisted in maintaining the proper temperature gradient between the inner and outer portions of the circulation.

In a recent study, Mantis [5] states: "If the cyclone is considered a thermodynamic engine for transforming heat energy into kinetic energy . . . only the radial difference in heating aids the process and the total amount of heat added is not important." In view of this, the storm's position over the Gulf Stream at the time of intensification would assume special importance. In addition to the contribution of the Gulf Stream heating to the vertical

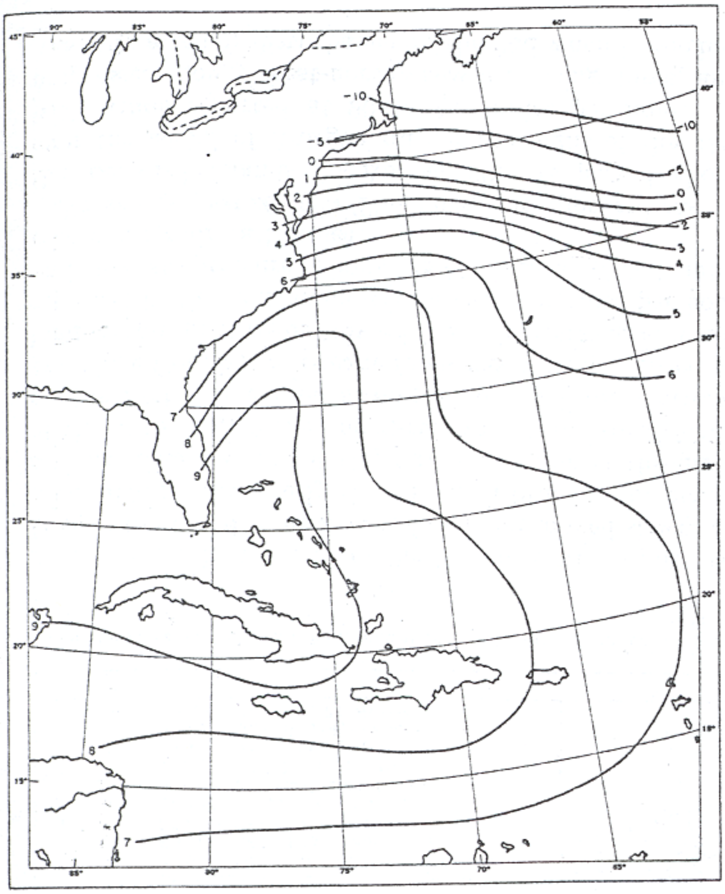

FIGURE 6.—September instability index lines showing difference (° C.) between temperature of air lifted adiabatically from sea surface to 300 mb. and average free air temperature at 300 mb.

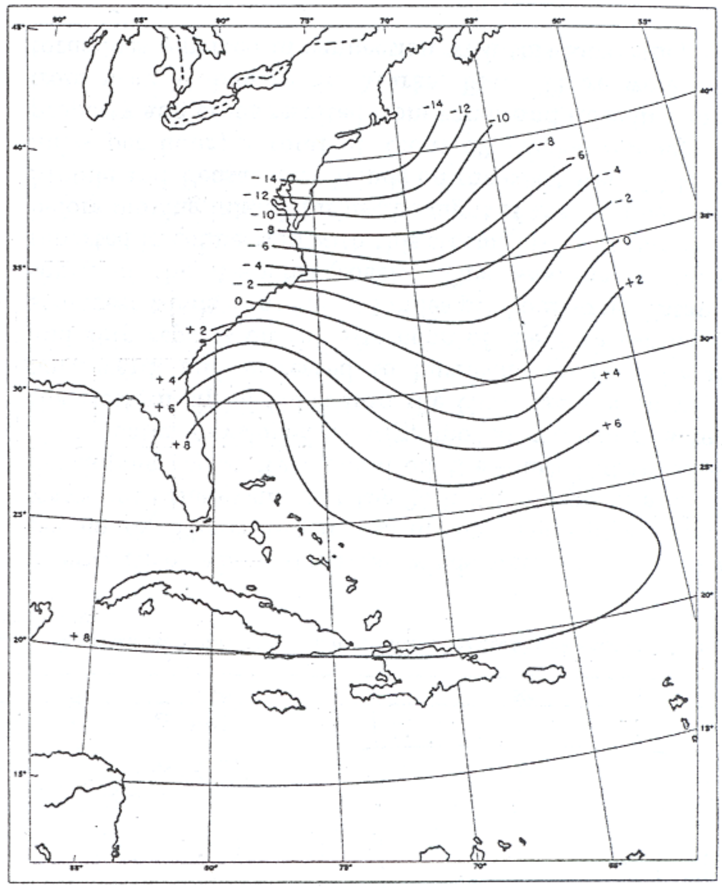

FIGURE 7.—May instability index lines showing difference (° C.) between temperature of air lifted adiabatically from sea surface to 300 mb. and average free air temperature at 300 mb.

instability, the radial temperature gradient was also affected by the unusual distribution of the heat source, i. e., the center of the vortex was over the warmest portion of the Gulf Stream while the outer portions of the cell were over somewhat cooler waters. The importance of this unique feature may be a partial explanation of why this was one of the more intense storms to develop in the subtropics.

If air overlying an ocean is assumed to have been modified until the temperature of the lowest layer approximates that of the water surface and has an average humidity of 85 percent—not an unlikely condition—and then is lifted adiabatically to 300 mb., the difference in the resultant temperature and the average air temperature at 300 mb. is a rough index of the instability energy available. On this basis, Palmén [6] constructed charts of this value for the Atlantic and Caribbean and examined the likelihood of hurricanes in the various oceanic areas from the standpoint of vertical instability considerations. Figure 6 is a chart of this index for September, about the peak month of hurricane activity in the western Atlantic. Figure 7 gives the same data for the month of May.

Although the water temperatures for any given month are not likely to vary much from the average values used, there is considerable aperiodic variation in the temperature at the 300-mb. level. Comparison of figures 6 and 7 shows that the instability index actually averages less for May than for September, apparently due to the spring lag in warming of the ocean surface. This is in contrast to the spring maximum of instability over land. If, however, the absolute minimum temperatures at 300 mb. are used instead of the average values, it is found that the instability in May (index 18) exceeds the maximum likely in September (index 16). In the case of the May 1951 storm, it was extremely cold at high levels and the instability criterion approached the maximum May value, so that the instability was somewhat greater than is likely in any peak-of-season hurricane. This large degree of vertical instability resulting from cold high-level Lows over warm water surface appears to be an important, possibly a primary, factor in the development of many of the storms that occur in the subtropic belt, especially outside the usual hurricane season.

POSSIBLE EFFECT ON MOVEMENT AND DECAY

The great amount of instability energy available in the development stage of the hurricane was noted. If the vertical temperature distribution on May 21 is investigated along the lines discussed in the preceding section, it is found that, as illustrated in figure 8, a temperature of

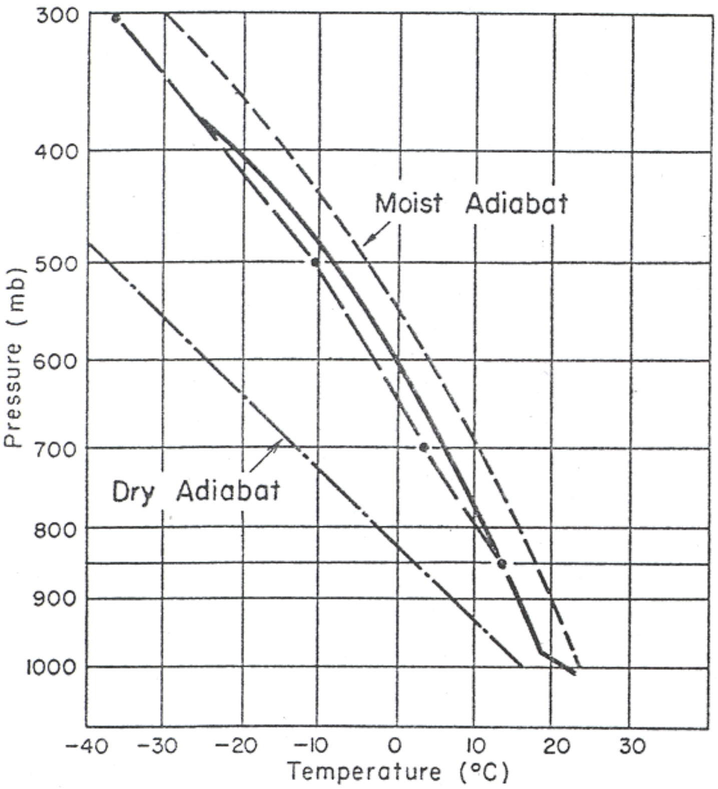

Figure 8.—Vertical temperature distribution (dashed line connecting dots) at 36° N., 74° W. as interpolated from constant pressure charts, 1000 GMT, May 21, 1951. Temperature of parcel lifted adiabatically from original temperature of 70° F. and 80 percent saturation at sea level is shown by solid line. Note that lower surface temperature would not favor convection.

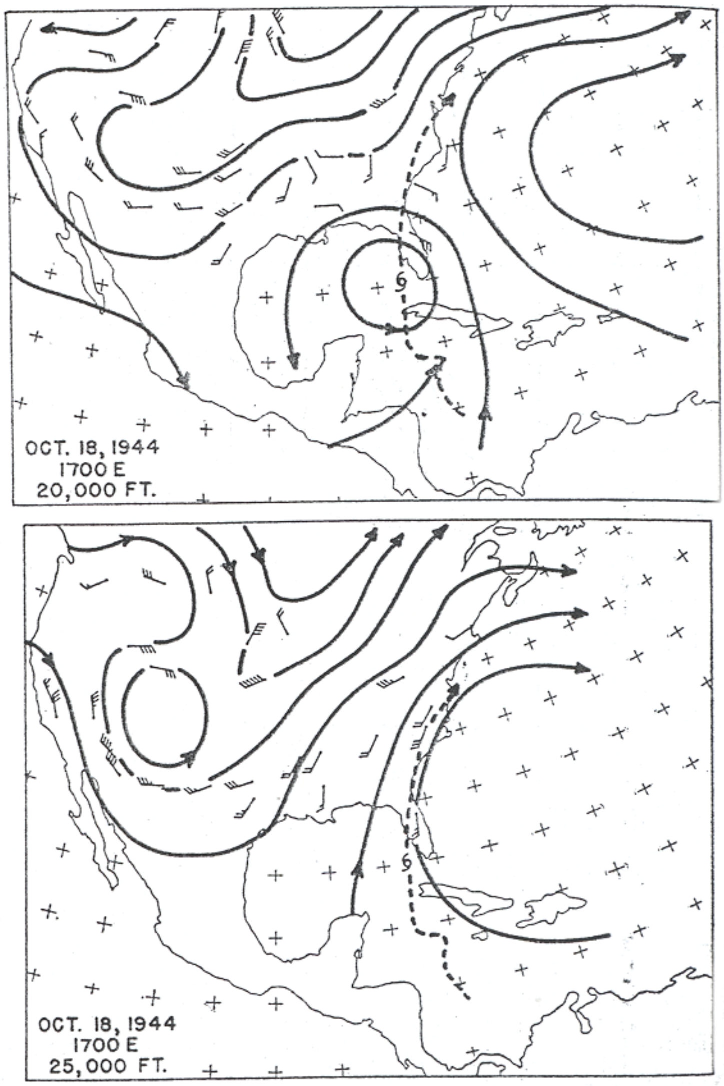

Figure 9.—Example of application of steering level concept to hurricane of October 18, 1944. Charts show streamline analysis at the 20,000-ft. level where the circulation of the storm is still closed, and at the 25,000-ft. level which is above the closed circulation. The hurricane track is shown by dashed line.

approximately 70° F. in the surface layer would be required to maintain the convective cell. Figure 1 shows how definitely the vortex curved abruptly eastward along the Gulf Stream axis, keeping within the area enclosed by the 70° ocean surface isotherm, and upon reaching the outer limit of this area, rapidly dissipated. No claim is made here that the control of the heating in the lower layers by the distribution of the water temperature was the determining factor in either the development or the path of this hurricane. However, the evidence certainly points to the conclusion that the ocean surface temperature charts should be given close attention in any forecast for storms developing in the subtropics since the vertical temperature distribution is especially critical in this type of cyclone. Furthermore, during the cooler seasons in which these storms occur, the water temperature contrasts are greater and currents such as the Gulf Stream more clearly defined.

VERTICAL STRUCTURE RELATED TO MOVEMENT

The concept of a steering level for tropical storms has been advanced and used with considerable success by Grady Norton of the Miami Hurricane Center (c. f., Gentry [7]). Basically, the theory is that the surface center will move approximately parallel to the wind stream near the top of the warm core, which usually coincides with the top of the closed cyclonic circulation of the storm. Figure 9 shows an example of the method applied to the hurricane of October 18, 1944. Note that the closed circulation of the storm is still in evidence at 20,000 ft. but not at 25,000 ft. The storm track on the 25,000-ft. chart shows the agreement with the streamlines at that level. Figure 5 gives some indication of the correlation of a portion of the path of the May hurricane with the flow at the 500-mb. level, which apparently was the best steering level in this case. To show the complete relationship between the track and the upper flow patterns throughout the storm's history would require a lengthy series of charts, since the upper circulation was gradually changing during the 7- or 8-day period. For a more complete examination of this feature, the reader may refer to back chart files.

It does not appear that the storm circulation had disappeared at the 500-mb. level. However, analysis of the upper air charts indicates that between the 700- and 500-mb. levels there was a layer of minimum radial pressure gradient, coinciding with the top of the warm-core cell of the storm. Above this level the cyclonic circulation intensified and gradually merged with an extensive cold Low at higher levels. Fair results would have been obtained by the use of a steering level higher or lower than the 500-mb. level for certain portions of the storm's track but the best over-all correlation was found with the 500-mb. chart.

CONCLUSIONS

The analysis presented in this study indicates that a combination of several favorable circumstances led to the preseason occurrence of the hurricane in May 1951. The hurricane began in connection with a cold high-level Low at subtropic latitudes. It appears that superposition of a divergent wind field at upper levels over the incipient storm was an important feature of the intensification. Heating of the surface layers of the air mass by the Gulf Stream and the unusually low temperatures aloft were also contributing factors. There was a striking coincidence between the track and the sea surface isotherm pattern, which indicates a possible influence of the sea surface temperature field on the storm's path. The movement of the surface center was in accord with the streamflow at the top of the warm core of the hurricane and paralleled the constant-pressure contours at about the 500-mb. level.

Storms such as this one are believed to comprise a category distinct from the extratropical, and the usual tropical cyclone. They are associated with a cold-core Low which becomes warm-core in the lower levels with intensification. The top of this warm core, and consequently of the steering level, appears to be at a considerably lower level than for a pure tropical storm with a similar radial pressure gradient.

It is felt that some distinctive term should be used to designate this particular type storm. Simpson [1] has suggested "subtropical cyclone". Further research should reveal whether it is a distinct type with no counterpart in the tropics or whether it may occur also in the tropics as a variation of the usual tropical storm structure.

ACKNOWLEDGMENTS

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