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FLORIDA HURRICANES

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FOREWORD

After the great hurricanes of 1926, 1928, and 1929, which so disastrously affected southern Florida, Richard W. Gray, Official in Charge of the Weather Bureau at Miami, wrote FLORIDA HURRICANES. Considerable historical information was assembled regarding hurricanes in Florida, and other useful information and descriptive matter were included. This rather brief paper was published in the January 1933 issue of the MONTHLY WEATHER REVIEW and reprinted in pamphlet form for distribution. It proved so popular that the first printing was soon exhausted. In 1936 a limited revision was made bringing the tables up to date and adding some information regarding storms that had occurred since the publication of the original paper.

By 1949 the second edition had become exhausted and Grady Norton, then Official in Charge, rearranged the material and again brought the statistics up to date but kept the paper for the most part in its original form.

The third edition has been out of supply for some seven years. Requests for the information contained in the pamphlet continue to be received. Statistical averages have been recomputed, the descriptive matter modernized, and considerable new material has been added.

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FLORIDA HURRICANES

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INTRODUCTION

A cyclone is the name of any atmospheric system in which the barometric pressure diminishes progressively to a minimum value at the center and toward which winds blow spirally inward from all sides, resulting in a rising of the air and eventually in clouds and precipitation. The circulation is counterclockwise in the Northern Hemisphere and covers an approximately circular or elliptical area at least 40 miles, but usually much larger, in diameter. The name does not signify any degree of intensity and is applied to storms of little as well as great intensity. Cyclones are divided into tropical and extratropical storms depending upon the characteristics of the surrounding air.

A hurricane is a tropical cyclone, accompanied by winds of 74 miles per hour or higher, and may occur in the Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico in summer and fall. The hurricane is identical with the typhoon of the western Pacific and the tropical cyclone of the Bay of Bengal and the Arabian Sea. Winds of 74 mph or more are often called hurricane-force winds regardless of the type of storm with which they are associated, but the term "hurricane" is properly applied only to tropical cyclones with winds equal to or greater than this value. Those with winds of less than 74 miles per hour but greater than 38 are called tropical storms and are included in tropical cyclone statistics. Tropical cyclones with winds of 38 miles per hour and less are called tropical depressions or tropical disturbances and are not included in the records. This pamphlet is principally concerned with those hurricanes and tropical storms affecting Florida.

THE LIFE CYCLE OF THE HURRICANE

Formation - Hurricanes develop only over tropical oceans, normally during the summer and fall months (June through November in the Atlantic area) although they have been known to form at other times of the year. An early season hurricane developed off the Florida coast during May 1951, and another was reported tn northeastern Antilles in early January 1955. Tropical cyclones have been observed in all the tropical oceans, except the South Atlantic. Most hurricanes form in existing disturbances, such as easterly waves and old troughs and in disturbances moving out of the intertropical convergence zone (ITC). These will be discussed briefly.

"Easterly wave" is a familiar term to most Floridians. It is a trough of low pressure which is embedded in the deep easterly winds that prevail in the Tropics during the summer. It moves from east to west, and its passage at any point is accompanied by an increase in cloudiness, frequent showers and thundershowers, and occasionally gusty winds and squalls.

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It is also accompanied by a deformation in the wind and pressure fields. Ahead of the wave winds are usually from east to northeast and the pressure falls, while behind the wave (to the east) the winds shift to the southeast and the pressure rises. Only a few easterly waves produce hurricanes, but in the Atlantic area the majority of hurricanes do develop from easterly waves.

The term "polar trough" is not quite as well known by the Florida public as easterly wave, although the two are similar in some respects. The polar trough is embedded in the prevailing westerly winds north of the oceanic subtropical high pressure area normally found in summer between latitudes 30° and 35°. Polar troughs are quite common in the middle latitudes and are associated with the passage of cold fronts and the migratory cyclones of the temperate zone. Occasionally during the hurricane season the subtropical high weakens, and the depth of the easterly winds over the tropical areas decreases to perhaps 10,000 to 15,000 feet, compared to the more normal depth of 30,000 to 40,000 feet. In such cases westerly winds from the temperate zone override the shallow easterly flow and a well-developed trough in the westerlies extends into the Tropics. This extension is also observed aloft and moves from west to east, or counter to the easterly winds at the surface. Its passage is accompanied by weather changes quite similar to those observed with an easterly wave, but the sequence is in the reverse order.

Occasionally hurricanes form in these polar troughs, but such occurrences are most common either early or late in the season; that is, in June or July and after October 1, since polar troughs seldom extend into the hurricane belt, even aloft, during August and September, when the Azores-Bermuda HIGH is well developed. Most cases of hurricane formation in old polar troughs are observed in the Gulf of Mexico or off the southeastern coast of the United States.

Low pressure areas in the intertropical convergence zone comprise the third type of disturbance which occasionally develops into hurricanes. This is the zone of convergence between the northeast trades of the Northern Hemisphere and the southeast trades of the Southern Hemisphere. This zone (commonly referred to as the ITC) moves with the sun, but lagging somewhat behind, and reaches its northernmost position in late August or early September in the Cape Verde region off the west coast of Africa, where its average position for this time of year is about 10° to 15° N. latitude. Few hurricanes form in the ITC but the great majority form from vortices or disturbances originating in the ITC. However, intensification only begins <u>after</u> they leave the ITC. Therefore, it is hardly correct to say "the doldrums (synonymous with the ITC) are the breeding grounds of hurricanes".

<u>Intensification</u> - In the initial stages of tropical cyclone development the wind circulation is weak, the pressure at the center is only slightly below normal, and the total area covered by the disturbance is usually small. Within a matter of days this tiny infant can grow into a severe hurricane with winds of 150 mph, and the central pressure may fall as much as 10 per cent below that of the surrounding areas.

It has been found that hurricanes rarely form over water having a temperature less than about 78° - 80° F. This limit seems to be rather critical and explains in large part the lack of winter hurricanes (although there are other factors of equal importance). To a certain degree the temperature of the water determines the energy available for the maintenance of the wind circulation of the storm. If other factors which determine the hurricane intensity are operating efficiently, movement over warmer water will result in some intensification and when the storm moves over colder water the circulation will weaken. Other processes are probably more important for intensification and dissipation than the temperature of the water over which the hurricane moves, but there is some correlation.

For hurricane formation some high-level mechanism is required to cause the air that has been lifted from the surface to be pumped away efficiently from the region of the storm. Obviously the same process must be operating during intensification. For the storm to increase in intensity and for the pressure at the surface to fall, more air must be pumped out at high levels than is lifted from the surface. Conversely, if less air is evacuated at high levels than is lifted from the surface, the storm will weaken and fill. Most meteorologists today believe that the high-level circulation, usually around 40,000 feet above sea level, is the primary key to the intensification process.

Dissipation - Storms usually dissipate when they move inland, although several days may be required. Two factors cause this dissipation. First, the increased friction over land causes air to flow more directly into the center of the storm, and this has a tendency to weaken the hurricane. Second, once the center passes inland, the hurricane is removed from its primary source of heat and moisture, which is the ocean, and consequently its energy supply is diminished. However, on many occasions a hurricane encounters a new source of energy as it moves into the temperate zone. In such cases, a new and vigorous non-tropical cyclone may be born, and the life of this storm may greatly outlast the tropical life span. Hazel, 1954, was such a hurricane. This seldom occurs, however, far enough south for the Florida area to be affected by the new development.

LOCATING AND TRACKING THE HURRICANE

Detection - During the early years of the twentieth century, it was not uncommon for a tropical cyclone to develop and remain undetected for days; even after the existence of a hurricane was established, its exact location frequently remained very uncertain. In the Atlantic area this is no longer true for a number of reasons. Travel over the oceans, both in the air and on the surface, has greatly increased, although unfortunately from the standpoint of hurricane detection the principal sea and air lanes do not cross some ocean areas where tropical cyclones frequently form. Additional weather stations have been established on islands around the periphery of the hurricane belt. Radar and satellites have supplied powerful new tools for hurricane tracking and aircraft reconnaissance is now routine.

Several times during the course of the average hurricane season, newspapers and other news media in Florida carry stories that the Weather Bureau is keeping close watch on a "suspicious area" somewhere in the normal regions of hurricane development. These stories indicate the existence on the weather map of one of the disturbances in which hurricanes usually form; they also mean that this disturbance has shown indications of developing into a tropical storm.

What constitutes an area of suspicion? Over the years meteorologists have learned to recognize these areas quite readily by making use of the observed cloudiness and rainfall patterns, pressure changes, and wind deformation around an easterly wave or other disturbance.

The passage of the easterly wave is accompanied by a steady progression from east to west of falling and rising pressure. Most of the falls are slight, but if there is any unusual squalliness or abnormal deformation in the wind field, even weak waves should be watched for possible development. Whenever localized pressure falls of a tenth of an inch or more are observed, this almost invariably indicates that a storm has developed or will develop within 48 to 72 hours. Also, if the pressure falls considerably below that normally observed within the trade wind belt, the possibility of the existence of a hurricane is greatly increased.

Much of the rain within the Tropics falls as "scattered showers" of short duration. The predominating cloud type is the "trade wind cumulus". A variation in this regime in the form of solid altostratus or cirrostratus and heavy or steady rainfall (as distinguished from showers) at several adjacent stations indicates that convection is well organized over a wide area and will lead the forecaster to suspect that a hurricane may form or is already developing. Most of the weather and cloudiness associated with the easterly wave occurs to the rear (or east) of the surface position of the trough. Strong convective activity in the form of showers or thundershowers extending ahead (or west) of the wave usually indicates that the wave is undergoing intensification.

The winds might naturally be expected to furnish clues to possible storm formation, and such is the case. The trade wind blows steadily over the oceans, from some easterly direction at about 15-20 mph, and an increase in the wind speed by as much as 25 percent (except where local influences such as the sea breeze reinforce the normal flow) indicates that a potential disturbed condition is developing. More importantly, if a wind with a westerly component of 10 mph or more is observed in the trade wind belt, a cyclonic circulation has developed. This may be in the form of a closed vortex in an easterly wave, or in the ITC which has moved north of its normal position.

In the absence of any other direct information, swells which are generated by a hurricane and outrun the storm area may indicate the existence of a tropical cyclone. These swells may arrive at the coast from a direction other than that of the prevailing wind. They will also have a longer period and wave length than the normal trade wind swells. In the Atlantic the normal frequency of swells is 8 to 10 per minute and in the Gulf of Mexico about 14 per minute. In an average hurricane, the number of swells will decrease to 5 or 6 per minute and in a severe hurricane to only 4 per minute. Above normal tide heights may also indicate the presence of a hurricane offshore.

In order to apply the above rules, frequent weather reports from the entire hurricane area are needed. Land stations in and around regions where hurricanes form supply much valuable information, but frequently by the time the incipient storm has developed sufficiently to be detected by clues derived from these stations, it is so close to a coastline that the desired early warning cannot be issued. For this reason extensive use is made of ships' weather reports. All of the rules listed above can be applied to ship reports as well as to those received from land weather stations.

A detailed analysis of the upper air charts will sometimes permit an early location of an incipient center. This is of particular importance in the Caribbean Sea and the Gulf of Mexico since the upper air patterns frequently indicate that a development is taking place 24 hours or more before any surface reports are received to confirm this fact.

Weather Satellites - The development during the past few years with the greatest potential for tropical cyclone detection, and possibly tracking, is the artificial earth satellite. The operational satellite system obtains cloud pictures over the entire sunlit earth at least once every 24 hours and also measures outgoing long-wave radiation from the earth's surface, or from the tops of cloud cover. Since the launching of TIROS I in April 1960, many tropical cyclones have been discovered by the satellites and many more disturbances or suspicious areas, which later developed into hurricanes, were first seen by them. The full potential of the weather satellite has yet hardly been scratched.

To facilitate the use of satellite data in locating and tracking hurricanes in the Atlantic area, a direct readout station for the reception of satellite photographs was installed at the National Hurricane Center in Miami in 1964. It is possible to receive as many as eight or nine different pictures each day from the three successive passes nearest Miami. In addition, the automatic picture transmission (APT) signals received at San Juan can be forwarded over a telephone line, providing three additional pictures. Each picture is approximately 2,000 statute miles square and the pictures overlap by about 30 percent; thus daily the NHC views an area extending from about 25°W to 130°W and from latitude 10°S to 65°N. Weather producing processes of all types are indicated by characteristic cloud types and arrangements. A tropical depression is shown in figure 1, a tropical storm in figure 2, and a hurricane in figure 3.

Reconnaissance - Once the existence of a suspicious area has been established, the next step is the dispatch of a reconnaissance flight into the region to determine the intensity and exact location of the storm. Many flights discover that the suspected area does not contain a storm and occasionally the same area will be reconnoitered several consecutive days before the expected development takes place. Many of the disturbances remain weak and finally dissipate before reaching storm intensity.

These reconnaissance flights greatly assist in tracking the storm as well as in detection and measuring intensity. After the first advisory has been issued, most ships in the path of the tropical cyclone change course and very few ship reports will be received from the inner portion of the storm. Therefore, almost complete reliance must be placed on aircraft reports. High level wind and pressure data obtained by aircraft are very useful in forecasting direction and speed of movement.

Regular hurricane reconnaissance was begun in 1944 and is now jointly performed by the Air Force and Navy. The Air Force hurricane hunting squadron is based at Ramey Air Force Base, Puerto Rico, and the Navy's at Jacksonville, Florida. The total area covered by these reconnaissance planes is approximately 1,500,000 square miles.

Observations of wind, pressure, and other weather elements are made by the aircraft personnel flying to and from the storm center and during penetration. These give the forecaster the speed of the strongest winds, the lowest pressure at the center, the radius of the hurricane force winds, the areal distribution of the storm winds (39 mph), as well as the distribution of the various weather elements around the storm. Usually at least two fixes on the storm's center position are obtained per day, from which the forecaster determines the direction and speed of the hurricane.

Radar - A powerful new tool for detecting and tracking hurricanes came out of World War II - radar. Produced for the purpose of detecting enemy aircraft and for other military purposes, radar has already demonstrated great value for varied meteorological uses. Briefly, the radar apparatus sends out a pulsed radio beam which upon striking a target (precipitation) is reflected back to the receiving portion of the set. The presence of the "target" can be displayed much as in television pictures, and is called an "echo". Thus the radio waves reflected by water droplets in the "spiral bands" (squall lines) around the center of a hurricane appear on the radar scope as echoes. The orientation of the bands is such that they can be used to locate the center of the hurricane quite accurately, as shown in figure 4. The "precipitation

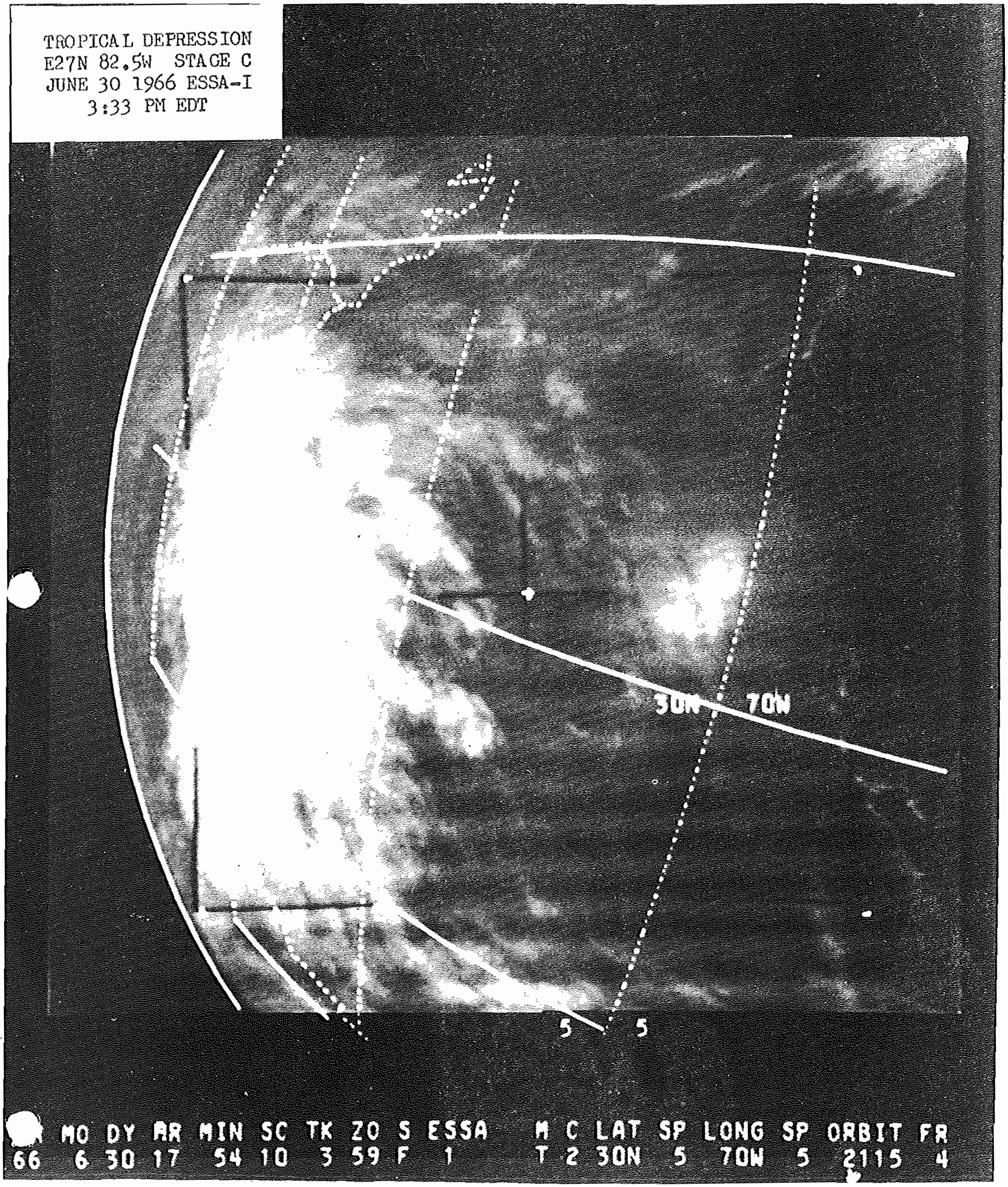

Figure 1. - A tropical depression off the east coast of Florida on June 30, 1966, as seen by ESSA 1.

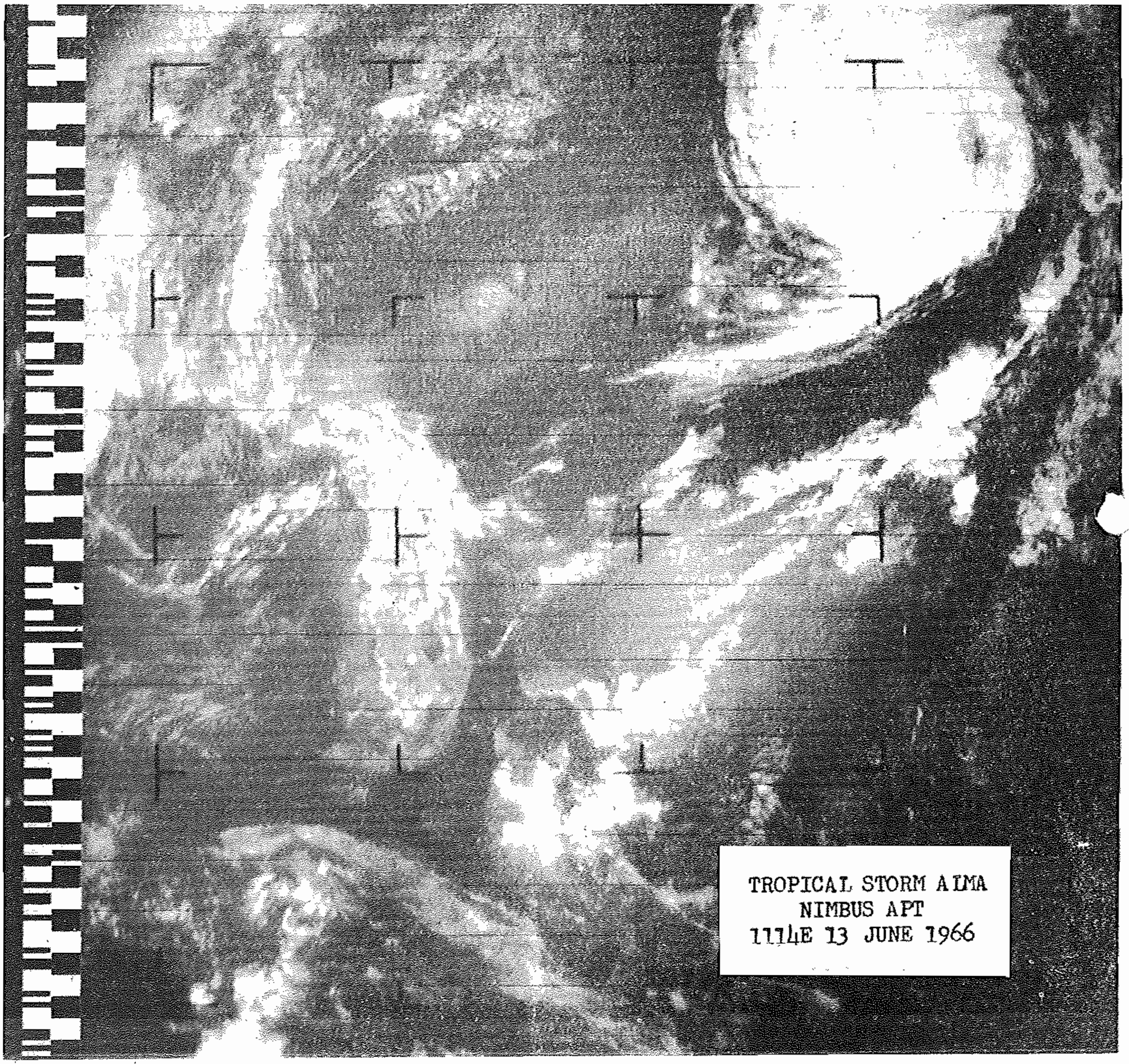

Figure 2. - An APT picture of tropical storm Alma made by Nimbus II June 13, 1966.

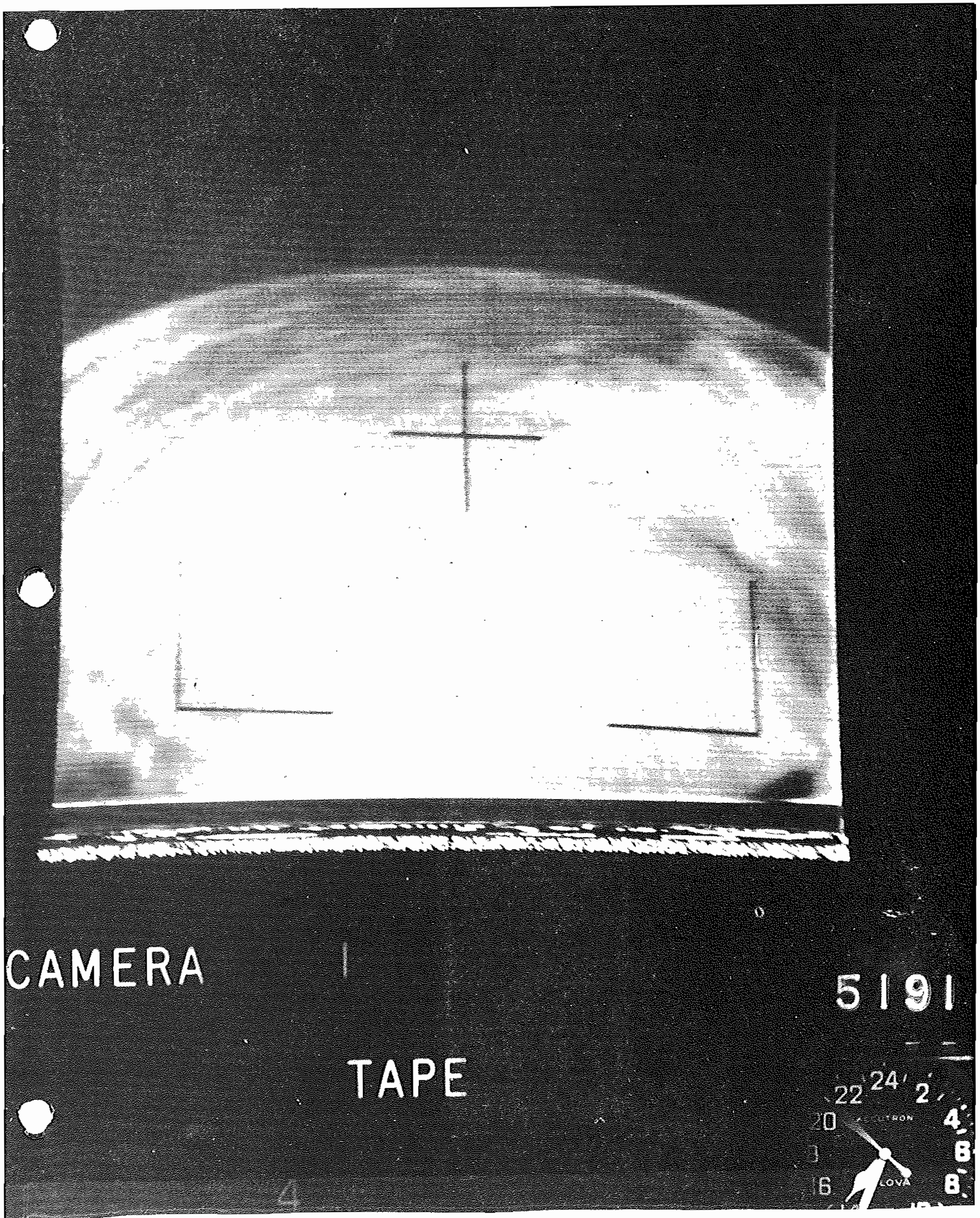

Figure 3. A hurricane as observed by a Weather Satellite

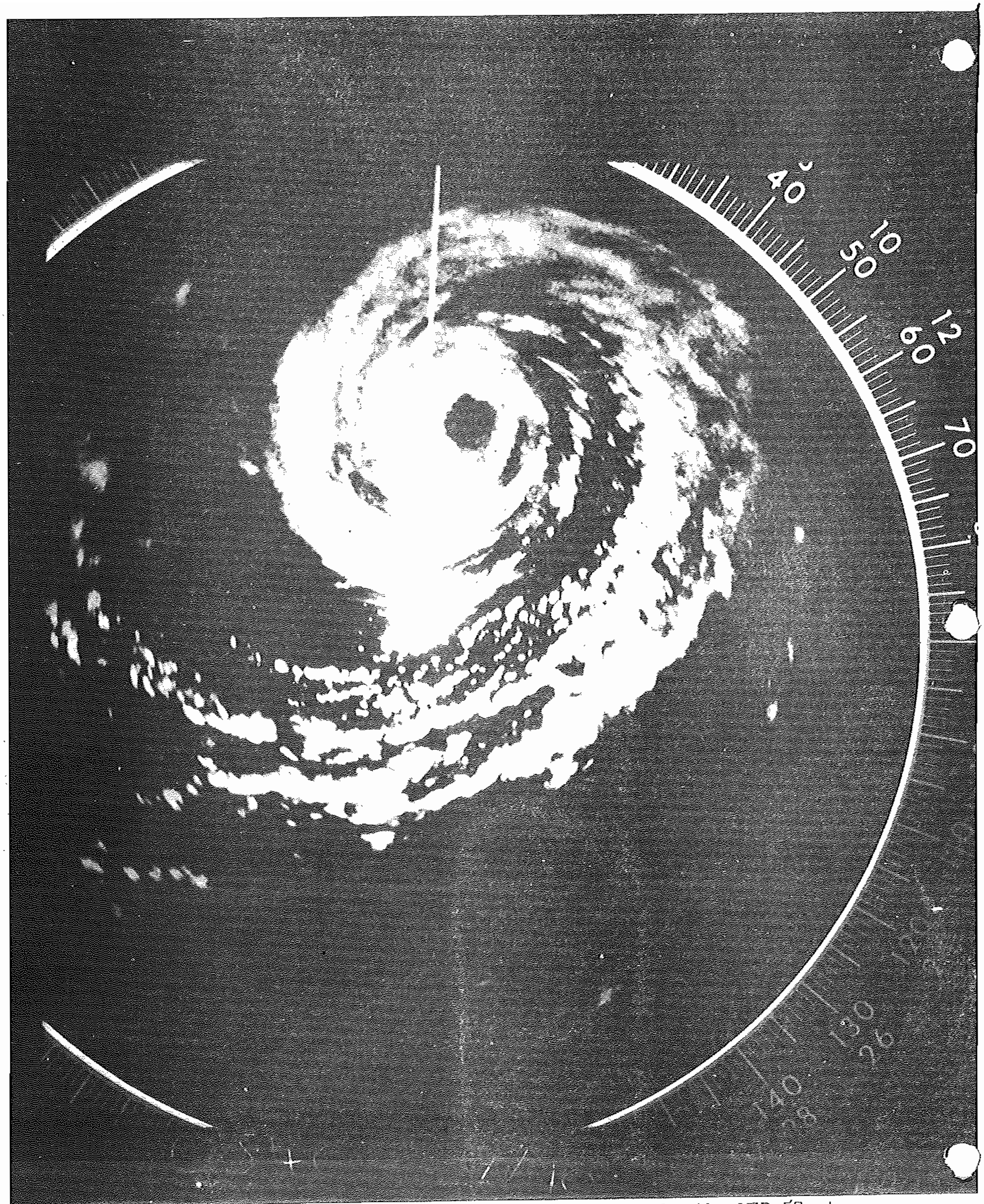

Figure 4. - Radar picture of hurricane Donna taken by the WSR-57 at Key West, Sept. 10, 1960. The center was about 65 miles from the station.

center" as seen by radar may not exactly coincide with the wind or pressure center, but in most cases the use of the radar eye as the center of the hurricane does not result in serious errors. Radar in current usage have a range of 150 to 250 miles.

Reconnaissance aircraft carry radar, and in cases where penetration of the center is not feasible, the storm center is located by radar. Most reconnaisance flights are made during the day. However, when a hurricane threatens a coastal area, night flights are made, but usually no attempt is made to penetrate the storm. The aircraft in such cases flies at high levels and remains on the outer periphery of the storm, keeping the hurricane under continuous surveillance by means of airborne radar. These aircraft fixes are supplemented by those obtained by land based radar installations as soon as the storm moves into range of the latter.

The Weather Bureau has now established a radar fence along the coast from Boston, Massachusetts, to Brownsville, Texas. Thus, any tropical cyclone within 200 miles of the coast is under constant surveillance. The semi-hourly locations of hurricane Cleo as indicated by the radar at Miami are shown on figure 5.

MOVEMENT

Forecasting the movement of hurricanes is at the same time one of the most difficult and one of the most important problems the forecaster has to face. During the past two decades, however, progress in this field has been significant. This has been due largely to the increase in the number of upper air stations both in the middle latitudes and in the hurricane area, which has led to a better understanding of the responses of the basic hurricane steering current to changes in the general circulation of the atmosphere and permitted the development of some objective forecasting techniques. Better methods of tracking, notably hurricane reconnaissance, radar and satellites have also made outstanding contributions toward progress in the solution of this forecast problem.

To a large extent the movement of a hurricane is determined by the direction and speed of the basic current in which the storm is embedded. Much of the emphasis in hurricane forecasting has been directed toward an evaluation of this basic steering current, which is generally believed to extend from near the surface to about 50,000 feet. There are a number of difficulties, both in determining the basic current and in relating this precisely to the storm movement. The winds of the hurricane obscure the basic current over a large area, both horizontally and vertically. If the undisturbed current could be determined, there would still exist the question of what part of the motion is due to the actual carrying along of the storm by this current and what part is due to forces originating within the storm itself.

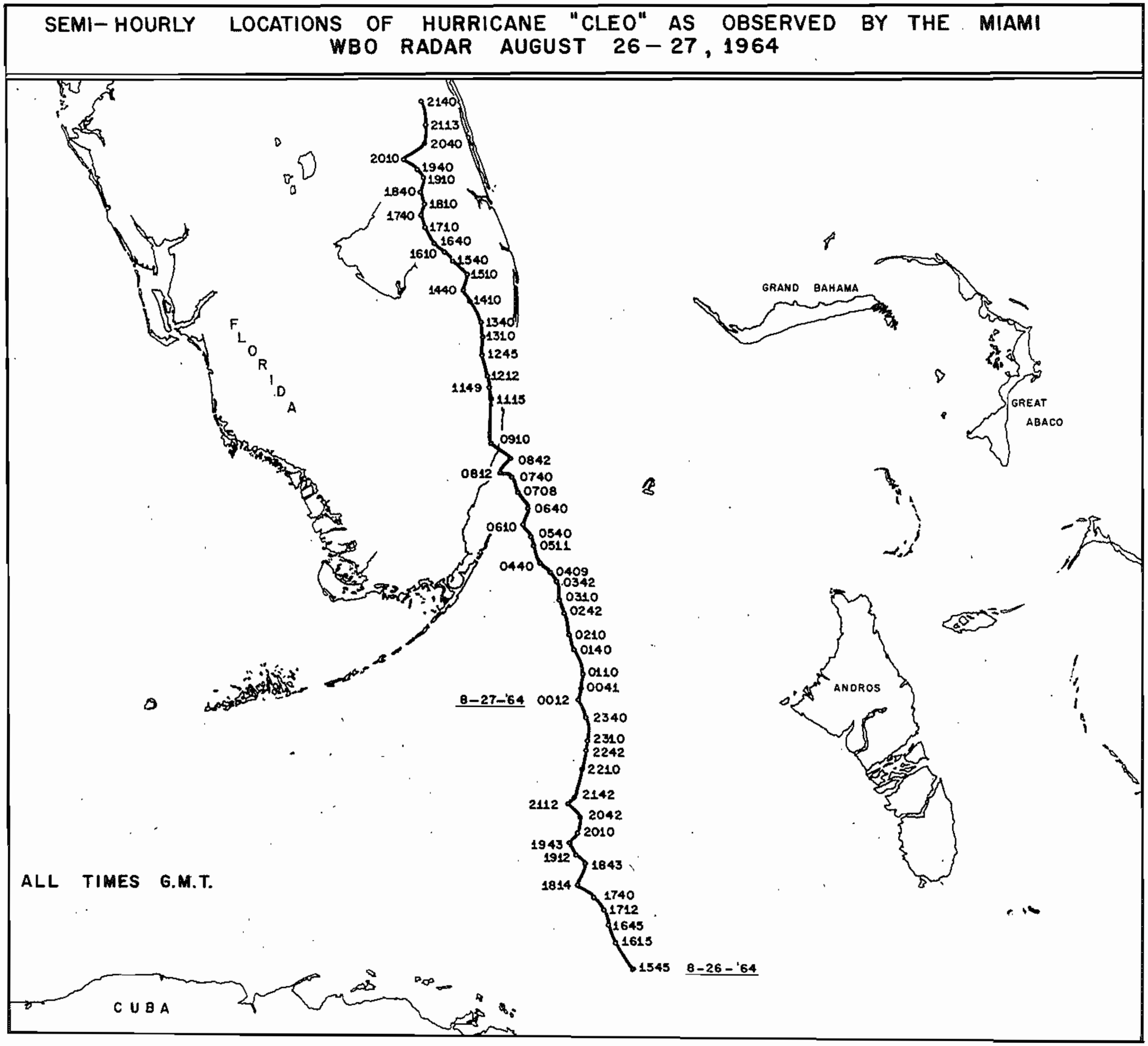

Figure 5. - Semi-Hourly Locations ? Hurricane "Cleo" as observed by the Miami WBO Radar August 26-27, 1964

Current methods of forecasting hurricane motion make judicious use of climatology, extrapolation of the past motion of the storm, an evaluation of the basic current in which the hurricane is embedded, and the changes this current is expected to undergo in response to the planetary wave patterns.

Fortunately, the hurricane usually moves forward at a rather leisurely pace, normally about 12 to 15 mph in the latitude of Florida, usually permitting ample warning. When tropical cyclones recurve, they tend to accelerate as they are picked up by southerly and westerly winds, and infrequently, by the jet stream. Both the New England hurricane of 1938 and Carol 1954 had accelerated to a forward speed of about 60 mph by the time they reached the coastline in northern latitudes. Accelerations pose a very difficult problem for the forecaster, but fortunately the rapidly moving storm is less subject to erratic changes in direction.

HURRICANE CHARACTERISTICS AND RELATED PHENOMENA

As the principal hurricane characteristics are discussed in the following paragraphs, it will be seen that these storms vary so widely with respect to size, intensity, maximum winds, rainfall, and other features that it is difficult to define a "typical" hurricane. From the standpoint of wind, a small hurricane may be as intense as a large one, since the maximum wind depends upon the pressure gradient between the center and the periphery rather than uniquely on either the central pressure or the size of the area covered by the storm.

A hurricane may be described, with much over-simplification, as a huge updraft of warm, moist air, spinning around in a counter-clockwise spiral. This circulation may extend more than 10 miles high but, in view of the great horizontal extent of the storm, would appear to an observer far above the earth more as a flat disc than the tall cylindrical shape sometimes pictured. The air spinning around the center usually reaches its maximum speed just outside the central eye where it rises to form a great wall of heavy cloud, releasing its moisture as torrential rain. At very high levels, the rising air is flung outward from the hurricane. In these currents moving away from the storm thin wisps of cirrus clouds may be observed as much as 24 hours in advance of a hurricane. This is not a reliable indication of an approaching storm, however, as cirrus clouds, while less frequent in the Tropics and subtropics than at higher latitudes, are also observed on other occasions, particularly when there are thunderstorms nearby.

If a hurricane is approaching, the cirrus clouds will be followed by thicker and lower layers, then by an arch of dense clouds called the bar, which is the leading edge of the main body of the storm. Low, ragged clouds appear in greater amounts as the winds increase and rain squalls begin. These squalls become more frequent as the center moves closer, with steadily increasing winds and heavy, almost continuous, rain. The decrease in velocity is quite sudden as the edge of the hurricane eye arrives. The wind becomes calm or nearly so, the rain ends, the clouds break, and the barometer stops its precipitant fall. After the passage of the eye, which may require anywhere from a few minutes to several hours, the wind begins again suddenly and with as much force as before--but from the opposite direction. It is important to remember that the hurricane is only half over when the wind lulls in the eye. Of course, most places affected by a hurricane will not have the eye pass over them and will therefore, not experience the sequence described above. Instead, the wind will rise to a maximum then slowly decrease, and changes in direction will be gradual with no intermediate lull and no clearing tendency as in the eye. The elapsed time between the first noticeable increase in wind or the beginning of occasional rain squalls and a return to a moderate wind after the hurricane is often of the order of 24 hours, but varies greatly depending on the size of the hurricane, the rate of forward movement, and the closeness of the center to the observer.

Wind - Wind records in a hurricane are often interrupted before the maximum speed is recorded. Because of the delicate design required of instruments for accurate readings at average speeds, anemometers have frequently failed or have been blown away when the speed reached the vicinity of 120 mph. With the spacing necessary between observatories and the fact that the strongest winds are confined to a relatively narrow band around the eye, it can be seen that it would be fortuitous to have the maximum winds of any hurricane occur at a first order weather station. Nevertheless, a few readings of over 150 mph have been obtained. From theoretical calculations, based on pressure gradients and structural damage, it is estimated that sustained winds in a few of the most severe hurricanes have exceeded 200 mph. It is possible for momentary gusts to be as much as 25 to 50 percent higher than the sustained winds. Therefore, in a storm with a sustained 100 mph wind, there could be gusts of 150 mph; and in one with 150 mph sustained winds, maximum gusts might be over 200 mph. Since the gustiness is responsible for the damaging intermittent pressures and wrenching effects, the speed of the peak gusts must be considered in designing structures to withstand hurricanes. The rapid rise in the actual force of the wind at higher speeds is another important factor in relation to construction and wind damage. The force exerted by the wind does not increase proportionally with the speed, but with the square of the speed, thus doubling the speed results in approximately four times the force. A wind of 60 mph produces a pressure of about 15 pounds per square foot, but a wind of 125 mph exerts a pressure of 78 pounds per square foot and results in a several-fold increase in destructive capacity over that of the 60 mph storm.

Record Winds in Florida - The Keys hurricane of September 2, 1935, which caused the loss of over 400 lives and great damage, is the most violent hurricane of record in Florida's history. This was a small storm with the strip of principal damage only about 40 miles wide. No anemometer reading of the maximum wind was obtained, but engineers estimated, from the force necessary to accomplish the observed destruction, that sustained winds exceeded 200 mph. A good central pressure value was obtained and calculations of maximum wind based on the pressure-gradient formula gave similar results. A speed of 121 mph (one minute) with gusts to 155 at Hillsboro Lighthouse, a short distance to the right of the center, was registered in the Fort Lauderdale hurricane of September 17, 1947. At Miami, in the October 1950 hurricane, sustained winds reached 122 mph with gusts of 150 mph. This was a very small storm compared to the 1926 Miami hurricane in which the wind reached 123 mph before the anemometer failed. Stations farther north on the Florida east coast have not reported speeds as high as these, the maximum of records prior to 1964 being under 100 mph. This does not indicate that major hurricanes cannot occur anywhere in the state; it may merely reflect the fact that since more hurricanes affect the extreme southern portion, there are more opportunities there for obtaining records of high winds. No section of Florida should be considered immune to violent hurricanes.

Pressure - The lowest reported sea-level barometric pressure in the Western Hemisphere occurred in the 1935 Florida Keys hurricane when a reading of 26.35 inches was recorded at Craig, Florida, between Lower Matecumbe and Long Key. The September 1928 hurricane, which caused many deaths and much damage across the state from West Palm Beach to Lake Okeechobee, had a minimum sea-level pressure of 27.43 inches at West Palm Beach. The next lowest pressure was 27.46 inches in Donna on the Florida Keys in September 1960. The fourth lowest known pressure of record in a Florida hurricane was 27.61 inches in the 1926 Miami storm. There are valid reasons why slightly lower barometric pressures might be expected to occur in hurricanes in extreme southern Florida than in those farther north, and records indicate this is actually the case. However, it is believed that the difference between minimum pressures of record for the southern extremity of the state and other coastal portions is also in some part attributable to the same factor mentioned in connection with wind records -- the fewer opportunities in northern Florida to obtain a wide sample of records because of less frequent storms. At interior stations it is likely that pressures will generally average slightly higher since there is a tendency for a gradual filling, or rising pressure in the center, after a hurricane moves over land.

Figure 6 shows an example of barograph traces in hurricanes. The rapid change in pressure is quite apparent. As mentioned earlier, the maximum wind is dependent upon the pressure gradient, rather than on the actual minimum pressure. In the 1935 Keys hurricane, it has been estimated that

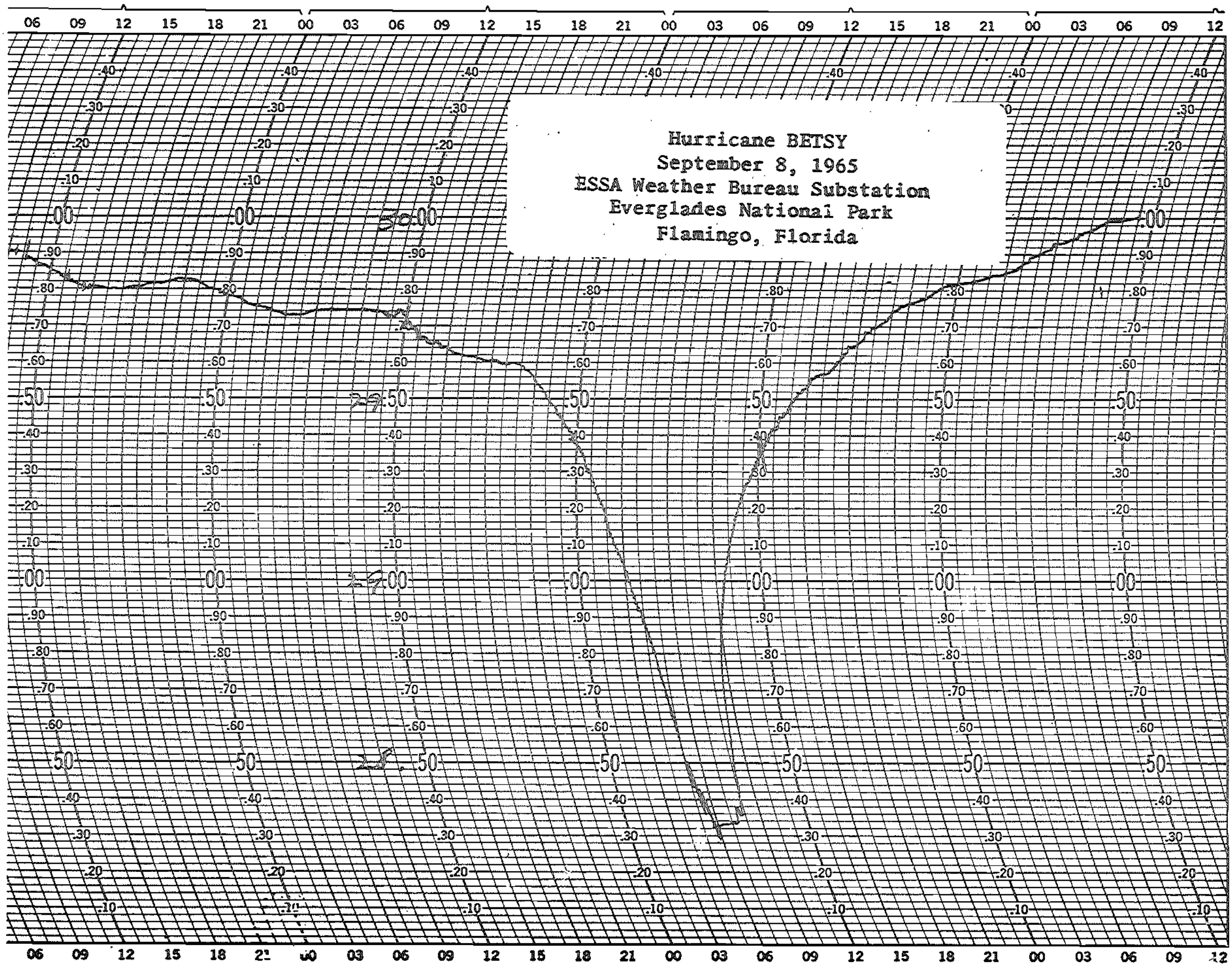

Figure 6. - Barograph trace of hurri ne Betsy, Flamingo, Fla., Sept. 8, 1965

at one time there was a pressure difference of one inch in only six miles. Pressure gradients of this magnitude are exceeded only in tornadoes. Storms in the category of the Miami and Palm Beach hurricanes of 1926 and 1928 can be expected to occur with more or less frequency in Florida, but one such as the 1935 Keys hurricane is likely only once in every one or two hundred years.

Hurricane Rainfall - Several factors determine the hurricane precipitation at any given point. Among the most important are (1) the rate of ascent in the storm's circulation; (2) the temperature and lapse rates within the storm area; (3) the location of the rain gage with reference to the storm center; (4) the rate of movement of the storm; and (5) the moisture content of the air, which must be continually renewed in order for the precipitation to continue. Some of the heaviest rainfalls have occurred in connection with comparatively minor tropical storms. However, our hurricane rainfall records may have a built-in error. Raindrops propelled by winds of 75 mph or more are broken into many small pieces upon impact with the rain gage and significant amounts are blown out of the gage as spray. Studies made at the University of Florida indicate the loss with winds of high speeds may be as large as 50 percent.

In the severe hurricane of September 1926, rainfall was estimated at 8 to 10 inches as the center passed over the Miami area. In the October 1950 storm, smaller in both area and intensity, rainfall was estimated at 3 to 4 inches. Only about 4 inches occurred at Miami in connection with the severe and extremely large hurricane of September 1947. Miller (3) has computed average hourly rainfall rates from sixteen Florida hurricanes and found average maximum values of 0.26 inches per hour immediately around and just ahead of the center. However, individual storm rates vary widely and about 6 inches fell in Hialeah in one hour in connection with the October 1947 hurricane. Miller calculated a storm moving directly across a rainfall station at a speed of 10 knots would result in a little more than 5½ inches. This is about one-half of the 48-hour total calculated by Hughes (2) from theoretical considerations. Perhaps the possible loss in the rainfall catch under high speed winds may account for at least a part of this difference.

The rainfall pattern varies considerably in hurricane paths. Greatest symmetry is found in those storms moving from east to west. With recurvature, assymmetry increases and there is a tendency for the rainfall maximum to shift to the right front quadrant.

The heaviest rainfall in Florida in connection with a tropical storm occurred at Trenton, some 30 miles west of Gainesville, October 1941, when 35.0 inches fell in a 48-hour period as a weak tropical disturbance moved into the peninsula from the Gulf in the Cedar Keys area. It became almost stationary for two days on the 20th and 21st. A total of 12.9 inches fell at Trenton in 6 hours, and in the first 24 hours 30.0 inches was recorded.

Rainfall in the amount of 24.5 inches was recorded at Bonifay in July 1916 and at Cedar Keys in 1950 in connection with hurricanes. A violent hurricane entered the Gulf coast just west of Mobile, Alabama, during the evening of July 5, 1916, causing very heavy rains just ahead and to the right of the center. On the 6th it curved sharply to the east and moved into northern Georgia and dissipated. The hurricane that passed inland on the Florida west coast about over Cedar Keys on September 5, 1950, became blocked and consequently remained about stationary in that area and caused heavy rains from the 4th to the 6th. A total of 24.5 inches of rain was recorded during this period.

Hypoluxo recorded 21.6 inches in connection with a tropical disturbance that entered the southwestern part of the peninsula during the evening of October 17, 1910, and moved slowly northward. Rainfall amounts farther north in the peninsula were not as heavy as the storm moved along the coast, and the heaviest rains were confined to the coastal regions.

Other heavy occurrences of rainfall in connection with tropical disturbances, storms, and hurricanes in Florida are as follows:

Place	Amount (in.)	Date	Storm Intensity
DeFuniak Springs	21.3	August 11-13, 1939	Hurricane
St. George	19.1	August 28-29, 1911	Hurricane
Clermont	17.8	September 3-5, 1933	Hurricane
Jupiter	16.8	October 17-20, 1904	Hurricane
St. Petersburg	16.6	August 1-3, 1915	Tropical Storm
Bonito Springs	15.7	October 2, 1951	Tropical Storm
West Palm Beach	15.7	July 30-August 1, 1933	Hurricane
Miami	15.5	November 30-Dec. 1, 1925	Hurricane
Pensacola	15.3	October 6, 1934	Tropical Storm
Ft. Meade	14.5	September 13-15, 1903	Hurricane
SW Florida Coast	13-15	September 2-4, 1935	Hurricane
Pompano Beach	14.3	October 11-12, 1947	Hurricane

In general, from 5 to 10 inches of rainfall may be expected in connection with tropical cyclones, whether minor or severe. The amount will usually be determined by whether the storm moves rapidly or at about a normal speed of 12-15 miles per hour or whether it is blocked and becomes slow moving or nearly stationary.

The Eye - One of the most spectacular features of the hurricane is the central area of light winds and relative calm called the "eye". As the center of the storm approaches, the wind diminishes quite rapidly from extreme violence to sometimes 15 mph or less, but probably only rarely to an absolute calm. As the eye of the hurricane of 1926 passed over downtown Miami, the wind decreased to about 10 mph at the Weather Bureau Office while at the same time the anemometer atop the Allison Hospital on Miami Beach, less than 6½ miles away, was recording a sustained wind of 80 mph. Observers in the eye have reported hearing the roar of the hurricane winds around the edge.

As the eye moves over the observer, the rain ceases, the middle cloud deck vanishes, but low clouds often remain with occasional breaks through which the sun may shine briefly or stars may be seen. In a plane above the low cloud, the hurricane eye can usually be seen in all its glory and has been described by Simpson (5) as follows:

> "Soon the edge of the rainless eye became visible on the (radar) screen. The plane flew through bursts of torrential rain and several turbulent bumps. Then suddenly we were in dazzling sunlight and bright blue sky.
>
> "Around us was an awesome display. Marge's eye was a clear space 40 miles in diameter surrounded by a coliseum of clouds whose walls on one side rose vertically and on the other were banked like galleries in a great opera house. The upper rim, about 35,000 feet high, was rounded off smoothly against a background of blue sky. Below us was a floor of smooth clouds rising to a dome 8000 feet above sea level in the center. There were breaks in it which gave us glimpses of the surface of the ocean. In the vortex around the eye the sea was a scene of unimaginably violent, churning water."

The average diameter of the eye is about 14 miles. The master of a fishing boat in one small intense hurricane off the Texas coast estimated the eye in that storm as only 1½ miles in diameter. Another tropical storm in the formative stage possessed an eye of only 4 miles in width. In some mature hurricanes, particularly if they are weakening or have moved inland, eyes may become distorted and have been observed as much as 70 to 100 miles in length. While many exceptions are reported, the size of the eye tends to vary directly in proportion to the maturity and size of the hurricane.

Storm Surge - The most dangerous single element of the hurricane is the accompanying high tides and rough seas as the storm moves across a coastal area. It is here that by far most of the death and destruction occurs. Every hurricane crossing a coast produces a change from the normal sea level, which is variously called the "storm surge", "storm tide", and incorrectly a "tidal wave". The highest and consequently most dangerous portion of the storm surge usually develops near the center and extends 20 to 50 miles in the direction of the on-shore hurricane winds. On the other side of the storm center, the off-shore winds may, but do not necessarily, result in tides well below normal. This means that for Atlantic hurricanes, the dangerous storm tide is usually at and to the right of the center if the storm is moving from sea to land and at and to the left if it moves from land to sea looking in the direction the storm is moving.

A gradual rise above the normal level of the sea frequently begins while the storm is still centered a considerable distance off shore, sometimes as much as 300 to 500 miles. This is a result of water being transported shoreward over the continental shelf by swells from the storm area. Sometimes this rise persists even though the prevailing local wind may be off shore. As the center of the storm nears the coast, moving from sea to land, and as the on-shore winds reach hurricane force, the rate of rise in water level increases until it reaches a maximum about the time that the "eye" moves inland, or the barometer reads the lowest. However, dangerous tides may occur even though the center does not cross the coast. Figure 7 shows the tide record during the passage of hurricane Betsy, with the center almost 250 statute miles to the southwest, at St. Marks, September 1965. The greatly reduced atmospheric pressure in the hurricane center is effective in raising the water level about one foot elevation for each inch of reduced pressure. This is frequently called the "inverted barometer effect". Some amplification of this height likely takes place as a storm moves over the continental shelf. Whether or not such amplification or even all of the inverted barometer effect occurs depends upon several factors, among which are the forward speed of the storm and the topography of the continental shelf. Of all the varying factors that contribute to the height of the storm surge, the intensity of the storm itself seems to be the most directly related.

Storm surges ranging up to 15 feet or more above mean sea level have been reliably reported in connection with Florida hurricanes. Records of these surges are rather incomplete and tides higher than those indicated in this graph may have occurred at some places. The highest, about 18 feet or more, occurred in the "Labor Day" hurricane on the Keys in 1935. Other historic storm surges in Florida include one up to 14 feet, mean sea level, in Tampa Bay in 1848, another of 10.9 feet in Biscayne Bay in 1926, and 13.0 feet at Islamorada in 1960. However, the greatest toll in lives taken by a Florida hurricane occurred in 1928 when the water from Lake Okeechobee was blown over the levee flooding several communities and drowning nearly 2000 persons. Since then, protective dikes have been constructed around the Lake.

While the storm surge heights given above as well as heights included in forecasts refer to the undisturbed or "still water" level, places exposed to the open sea may be subjected to strong wave action reaching almost as high again as the storm surge height. It is primarily this wave action and accompanying strong currents which batter down and float away buildings and undermine sea walls and foundations. The scarcity of choice sites for construction near the ocean has prompted some developers to build up sub-marginal lands to meet minimum requirements for homes which in many instances are occupied by persons unaware of the potential danger of hurricane tides and floods, thus creating a growing disaster potential.

Tornadoes in Hurricanes - The first well-authenticated occurrences of tornadoes in connection with hurricanes in Florida were noted on September 10, 1919, and September 28, 1929. Both of these hurricanes passed through the Florida Straits moving westward, and when they were centered off the extreme lower southwestern coast, tornadoes occurred on their northeastern periphery along the lower east coast. In the second storm, several tornadoes occurred from Miami northward to Stuart. The tornadoes moved from southeast to northwest with the wind on the edge of the hurricane circulation, possibly forming as waterspouts at sea. Their paths were short and did not extend far inland. Later, tornadoes were observed in connection with the hurricane of October 4-5, 1933, which moved northeastward just south of the Keys and the extreme southeastern coast. Several tornadoes occurred between Miami and Fort Lauderdale while the hurricane center was moving northeastward some distance out in the ocean to the east, thus placing them on the western or northwestern rim of the hurricane circulation. Their paths were narrow and short. One occurred in the western suburbs of Miami and caused considerable property damage.

In recent years tornadoes have been associated with the majority of tropical cyclones in Florida. In every case they have occurred in the outer portion of the hurricane circulation and not near the central vortex, with a tendency to develop on the leading edge of hurricanes moving northward and on the right edge of those moving westward. The occurrence of tornadoes in connection with hurricanes has been so frequently observed in recent years that the question has been raised whether the actual number is increasing, or whether the increase in population permits more of them to be observed. It seems likely the latter is correct. While a few have been quite destructive, the hurricane tornado seems more closely related, at least from the standpoint of intensity, to the waterspout than to the vicious Mid-Western tornado.

Hurricane Damage and Casualties - The most destructive Florida hurricane was Donna in September 1960. It caused $300,000,000 property damage mostly in Monroe, Collier, and Lee Counties. The great Miami hurricane of September 1926 probably actually caused even greater damage although it was assessed at only $75,000,000. The difference is due to the inflation in values which has occurred since that time. With the tremendous increase in construction a storm of the same intensity would now cause damage approaching a billion dollars even with the improved building code. The hurricane of October 1944 caused damage in Florida estimated at $63,000,000, but by far the greater proportion was to citrus and vegetable crops rather than to buildings. The hurricane of

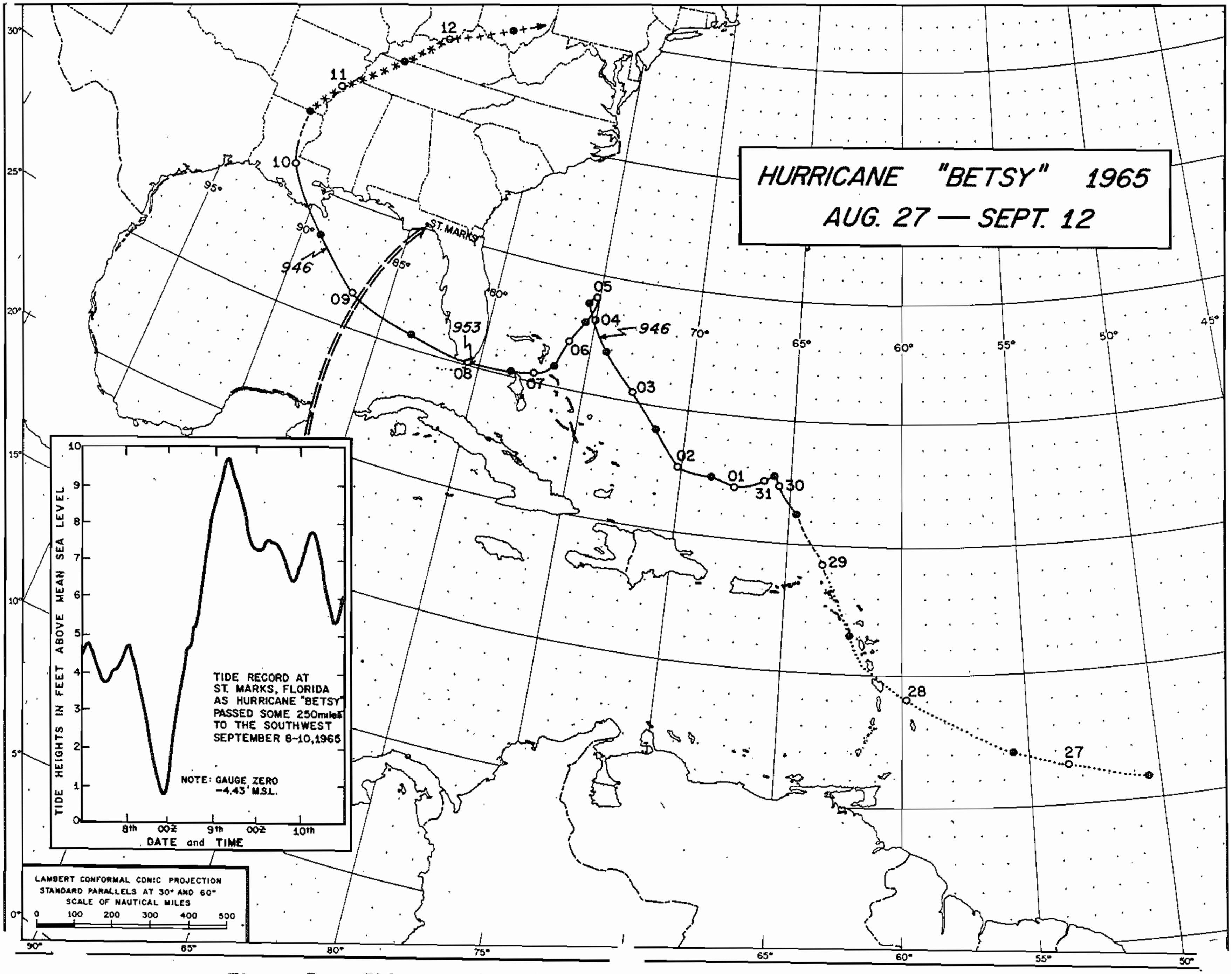

Figure 7. - Tide record at St. Marks, Fla., as hurricane Betsy passed some 250 miles to the southwest.

September 15, 1945, resulted in $54,000,000 damage (a 30 to 35 million dollar loss was sustained in the destruction of the great Navy blimp hangars at Richmond). The hurricane of September 17, 1947, which passed inland at Fort Lauderdale and entered the Gulf at Naples, caused damage estimated at $31,000,000 and this figure would have been much greater if the storm center had not passed between Palm Beach and Miami so that these larger communities escaped the highest winds and tides.

On August 26-27, 1949, another hurricane made landfall at Palm Beach and moved over Lake Okeechobee and up through the center of the peninsula. Total damage in Florida was $45,000,000. Another major hurricane to strike Florida a direct blow passed directly over Miami on October 17-18, 1950, with gusts to 155 mph and some $28,000,000 damage. Three hurricanes - Cleo, Dora, and Isbel in 1964, caused the greatest damage for any one year, $348,875,000. Betsy in 1965 resulted in $139,300,000 damage in the State, mostly in the extreme south.

From these figures it can be seen that the economic loss from the more severe hurricanes can be truly appalling. While it would seem that losses are not being greatly reduced over the years, this is not the case. With the strong inflationary trend beginning during the last war and the phenomenal growth of the State of Florida, the total property value in the State exposed to possible hurricane damage has multiplied many times. In percentage, the losses have been much smaller in the last two decades. This has been brought about by the introduction of excellent building codes in the various communities along the southeastern Florida coast and particularly in Dade and Broward Counties. These strict "hurricane building codes" include many of Gray's suggestions and have gradually evolved through the efforts of many building engineers, particularly those of Mr. Herbert Saffir, formerly of the Dade County Engineers' office, and his colleagues. Damage surveys in connection with hurricanes during the 1940's have shown that buildings erected in conformity with these codes are withstanding hurricane winds up to 100 mph and even 125 mph or more, without serious injury.* However, windows without storm shutters and buildings with roofs in disrepair continue to suffer heavily. It cannot be questioned that the new building codes are paying off in greatly reduced property loss where they are properly adhered to and enforced.

Grady Norton stated in the previous edition of FLORIDA HURRICANES that the above paragraph cannot be expected to apply to super-hurricanes such as the Labor Day storm on the Florida Keys in 1935. Fortunately, such violent hurricanes are very rare and probably the chances of one occurring in any one specific locality are less than once in several thousand years. Construction adequate to protect against a storm of that intensity is uneconomic but an examination of the damage on the Keys after the Labor Day storm indicates that structural damage would have resulted to the most substantial buildings now constructed under

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* In hurricane Cleo in 1964 with sustained winds of 110 mph,less than a dozen roofs of homes were seriously damaged in Dade County.

the present building code. Neither will the codes protect completely against damage from the tornadoes that not infrequently are associated with hurricanes. Although these extreme conditions are not provided for, there can be no question about the great value of the efforts made since the violent storms of the late 1920's to construct hurricane resistant buildings and minimize property loss.

Damage and fatalities in Florida since 1926 from hurricanes and other tropical storms are shown in Table 1.

Table 1 -- Damage and Fatalities in Florida from Hurricanes since 1926

Year	Fatalities	Damage	Year	Fatalities	Damage
1926	243	$115,495,000	1947	17	$ 51,900,000
1927	0	0	1948	3	17,500,000
1928	1838	26,235,000	1949	2	45,000,000
1929	3	821,000	1950	6	31,600,000
1930	0	75,000	1951	0	2,000,000
1931	0	0	1952	0	0
1932	1	150,000	1953	0	4,952,000
1933	2	4,120,000	1954	0	0
1934	0	0	1955	0	0
1935	405	11,500,000	1956	7	7,299,605
1936	7	200,000	1957	5	75,000
1937	15	5,000	1958	0	(a)
1938	0	0	1959	0	1,656,000
1939	1	52,000	1960	13	305,050,000
1940	0	0	1961	0	0
1941	6	690,000	1962	0	0
1942	0	0	1963	1	50,000
1943	0	0	1964	11	362,000,000
1944	18	60,000,000	1965	13	139,300,000
1945	4	54,130,000	1966	9	15,000,000
1946	0	7,200,000			

(a) Minor

HURRICANE FREQUENCY IN FLORIDA

The earliest known hurricane in Florida struck the Pensacola area on September 19, 1559, and caused severe damage. During the next 200 years, eight hurricanes seriously affected this same area. No information is available from other sections of Florida during this same period.

In the nineteenth century, hurricane statistics in Florida gradually became more complete. On October 11-12, 1846, the infant city of Key West was almost completely destroyed and two lighthouses in the vicinity were washed away. On September 25, 1848, probably the worst hurricane of record on the west-central coast of Florida struck the Tampa Bay area and at Fort Brooke (Tampa) the barometer fell to 28.18 inches and the tide in Tampa Bay rose 15 feet above the normal low-water mark. In 1873 between October 7 and 9, a hurricane moved inland on the southwestern coast with a tide of 14 feet above normal at Punta Rassa and that small village was destroyed. On August 28-29, 1880, a very severe hurricane passed over the Palm Beach-Okeechobee area.

Beginning with 1885, information is much more complete but occasionally small hurricanes and tropical storms may have passed unnoticed in certain areas, especially southern Florida, until 1905.

Five-year running averages of tropical cyclones affecting Florida are shown in figure 8. One peak of high frequency occurred around 1894, and others in the middle 1930's and 1940's. Hurricane frequency was low from 1909 to 1919. Projecting the frequency curve, another minimum might have been expected in the 1950's. This occurred, although the smoothness of the curve was disturbed by a sub-maximum around 1947.

A greater proportion of all storms approached the east coast in the second maximum in the mid-30's than in the earlier one in the 1890's. In general it can be said that the hurricane frequency curve in Florida closely corresponds with that for the Atlantic hurricane area as a whole (fig. 8).

During the past 82 years, from 1885 to 1966 inclusive, 148 tropical cyclones of all intensities have affected Florida; 78 are known to have been of hurricane intensity, and 70 are known or estimated to have been less than hurricane force. The distribution of these storms throughout the period is shown in Table 2. The average for the 82 years is 1.8 per year, but individual years range from none to as many as 5. The table indicates a high storm incidence in progress at the beginning of the period and this extended through 1906. Fifty-one storms were noted in this period or an average of 2.5 per year. There were only 20 tropical cyclones during the 17 years between 1907 and 1923 or an average of 1.2 per year. Another period of high storm frequency began in 1924 and continued through 1950. During this 27-year period, there were 48 tropical storms or 1.8 per year. From 1951 through 1963 only one major hurricane occurred in the State. During the 6-year period from 1891 to 1896, 20 storms occurred or an average of 3.3 per year, and other 6-year periods with high tropical storm frequency were 15 from 1932 to 1937, and again from 1945 to 1950. The higher frequency from 1932 to 1950 cannot be wholly explained by improved methods of detection, and it is believed the apparent increase in number during this period is real. It occurred simultaneously with a significant warming of the atmosphere. This warming trend, as well as that of increased hurricane incidence, appears to have been reversed beginning around 1951.

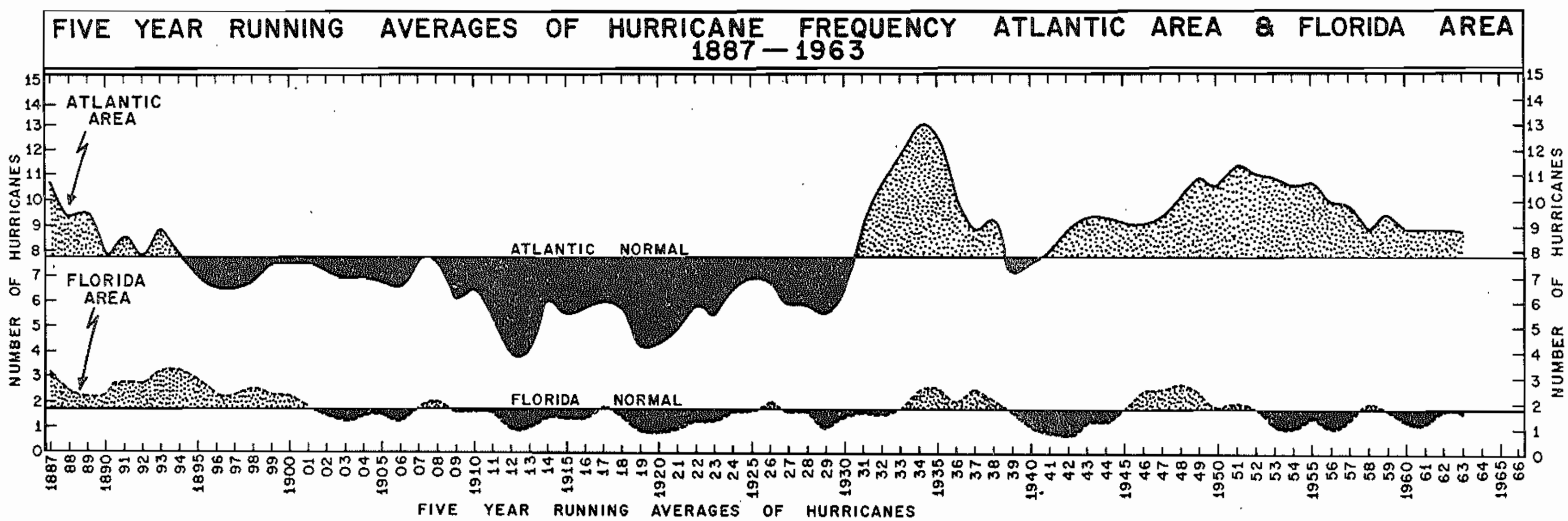


Figure 8. - 5-year running averages of hurricane frequency for Florida and the entire Atlantic area.

Table 2 Frequency of Tropical Cyclones by Years in Florida

Year	Of known hurricane intensity	Not or of doubtful hurricane intensity	Total	Year	Of known hurricane intensity	Not or of doubtful hurricane intensity	Total
1885	3	2	5	1928	3	0	3
1886	3	1	4	1929	1	0	1
1887	1	1	2	1930	0	1	1
1888	2	1	3	1931	0	0	0
1889	1	2	3	1932	1	1	2
1890	0	0	0	1933	2	2	4
1891	1	2	3	1934	0	0	0
1892	0	2	2	1935	3	0	3
1893	3	2	5	1936	1	2	3
1894	2	1	3	1937	0	3	3
1895	1	3	4	1938	0	1	1
1896	3	0	3	1939	1	1	2
1897	0	1	1	1940	0	0	0
1898	2	1	3	1941	1	1	2
1899	1	2	3	1942	0	0	0
1900	0	2	2	1943	0	0	0
1901	0	2	2	1944	1	0	1
1902	0	1	1	1945	2	1	3
1903	1	0	1	1946	1	1	2
1904	1	0	1	1947	2	1	3
1905	0	0	0	1948	2	0	2
1906	3	1	4	1949	1	0	1
1907	0	1	1	1950	2	2	4
1908	0	0	0	1951	0	1	1
1909	1	3	4	1952	0	1	1
1910	1	0	1	1953	1	2	3
1911	1	1	2	1954	0	0	0
1912	1	0	1	1955	0	0	0
1913	0	0	0	1956	1	0	1
1914	0	0	0	1957	0	3	3
1915	1	1	2	1958	0	1	1
1916	3	0	3	1959	0	2	2
1917	1	0	1	1960	1	2	3
1918	0	0	0	1961	0	0	0
1919	1	1	2	1962	0	0	0
1920	0	1	1	1963	0	1	1
1921	1	0	1	1964	3	2	5
1922	0	0	0	1965	1	1	2
1923	0	1	1	1966	2	0	2
1924	2	1	3				
1925	1	0	1	Total:	78	70	148
1926	3	0	3	Average:	1.0	0.9	1.8
1927	0	0	0				

POINTS OF ENTRY AND DIRECTION OF TRAVEL OF ALL OF THE HURRICANES WHICH HAVE AFFECTED FLORIDA FROM 1885 TO 1965

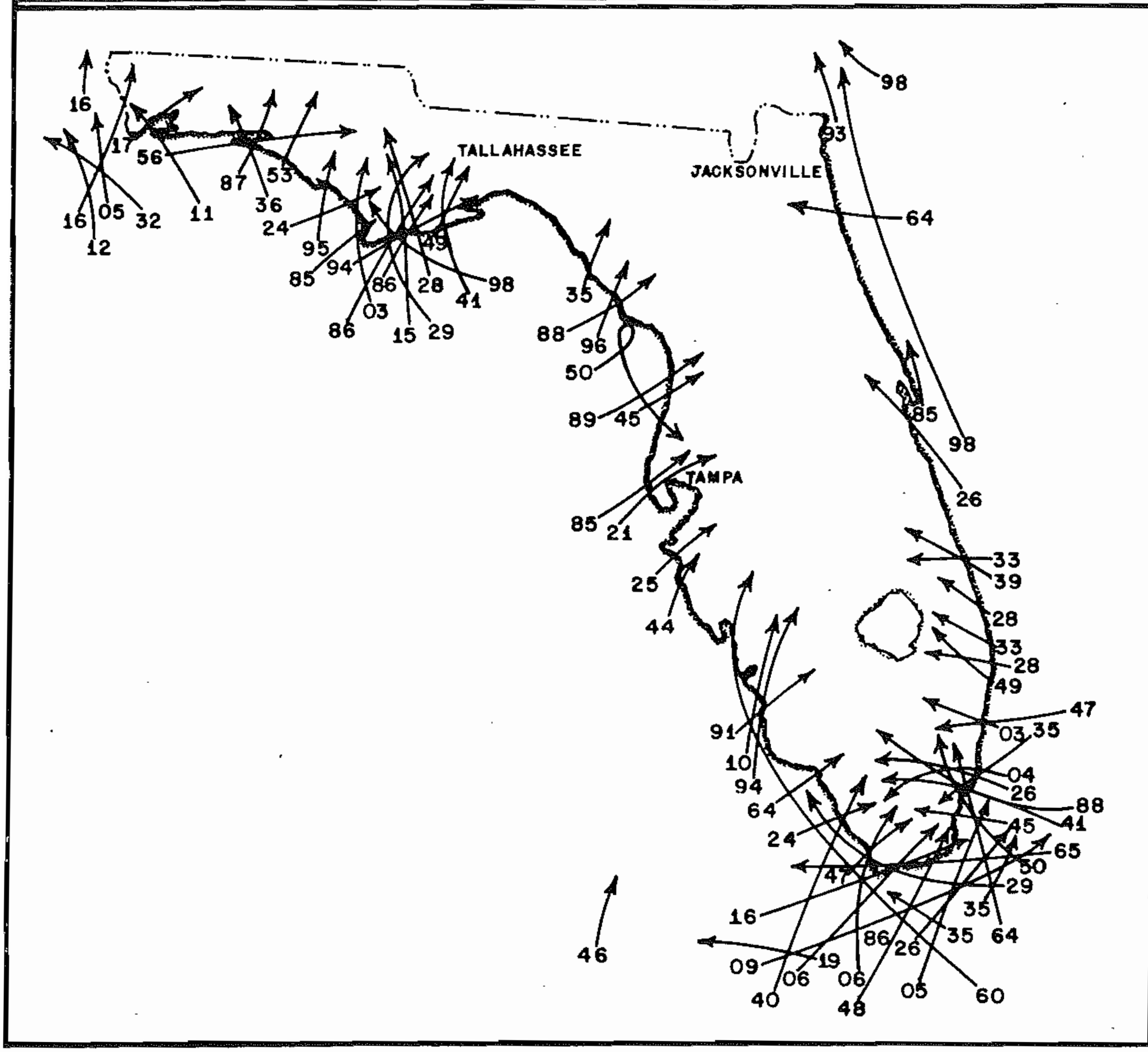


Figure 9. - Points of Entry and Direction of Travel of all of the Hurricanes which have affected Florida from 1885 to 1965

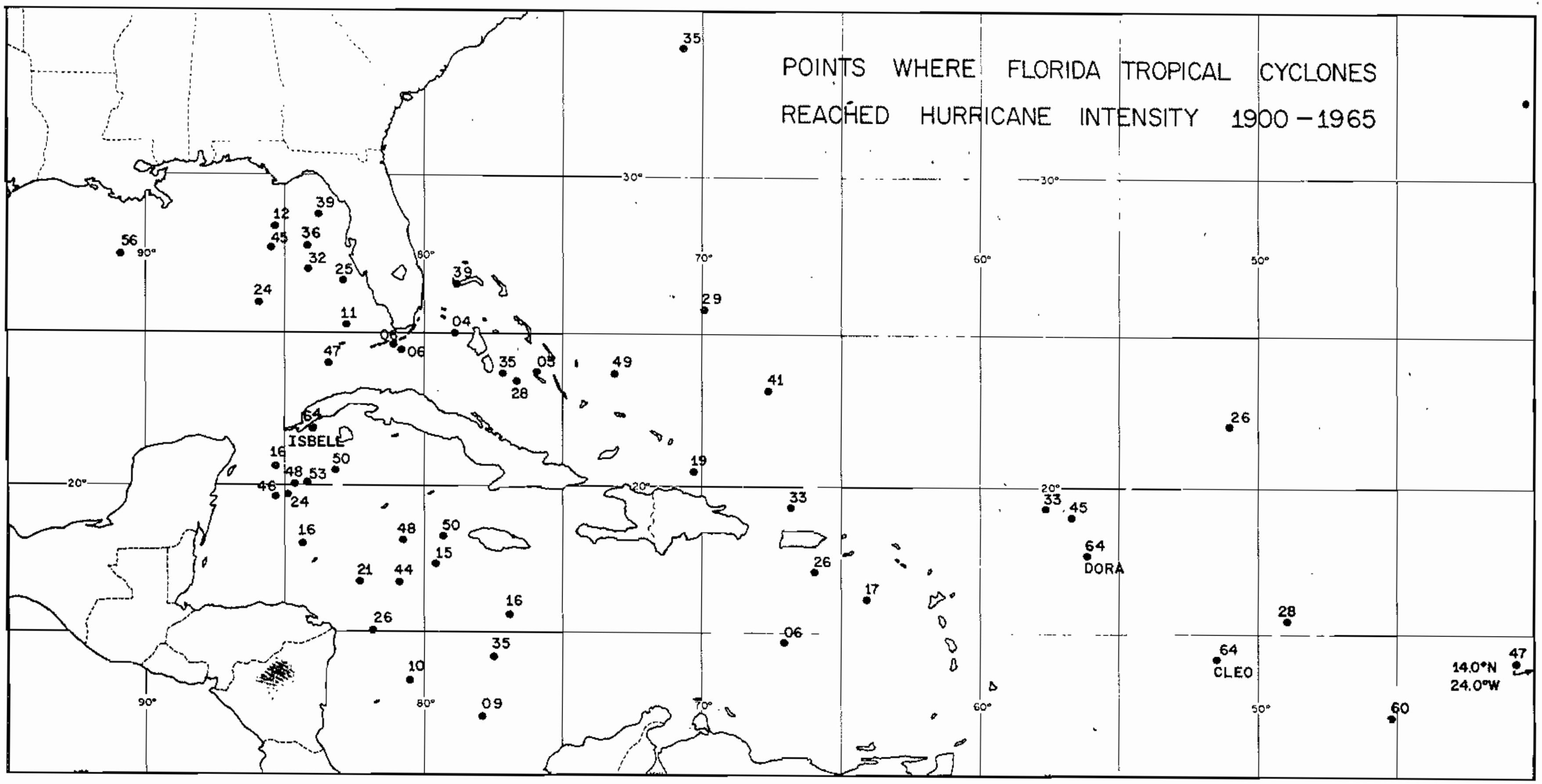

POINTS WHERE FLORIDA TROPICAL CYCLONES
REACHED HURRICANE INTENSITY 1900 – 1965
ISBELL
DORA
CLEO
14.0°N
24.0°W

Figure 10.

The average hurricane frequency for different parts of the State varies greatly. The frequency per 100 miles of coastline for storms of hurricane force is 1 in 8 years on the lower east coast and 1 in 14 years on the west coast. Two principal concentrations of hurricanes are found, one in extreme northwestern Florida from Carrabelle to Pensacola, where 24 hurricanes have occurred in 82 years, and on the southeastern coast and Keys where 32 hurricanes have occurred during the same period. The approximate point entry on the coast of the centers is shown on figure 9. In a few cases, the center remained offshore, but the storm was close enough to cause hurricane winds on land. It is noted that no hurricane appears to have reached the coast along a considerable stretch of the coastline from east of Carrabelle to Steinhatchee. Because of the long stretches of sparsely inhabited coastline in this area, the exact path of many centers was never known and, no doubt, at least some did make landfall in that section. Only 8 hurricanes have crossed the coastline on the west coast from Cedar Keys to Fort Myers in 82 years. Tampa and St. Petersburg, located in this coastal area, have been more free from hurricanes than any other cities in western Florida. The city of Jacksonville is unique in that it is the only large port in Florida, and indeed along the whole Atlantic and Gulf coast from Cape Hatteras to Brownsville, which at least since 1885 and until 1964, never had sustained winds of full hurricane force in a tropical cyclone. The highest extreme wind speed recorded in Jacksonville in a tropical cyclone was 76 miles per hour on September 29, 1896 until 82 mph was recorded in 1964. This is based on a measurement of the "fastest mile" recorded.

There was heavy damage from Mayport to Fernandina on October 2, 1898, when a large hurricane moved inland over Georgia with the center some 50 to 60 miles north of Jacksonville. On October 12 and 13, 1893, a severe hurricane moved northward a short distance offshore and the storm tide inundated the streets of St. Augustine. In August of that same year another hurricane took a rather similar path and moved inland between Jacksonville and Savannah. Thus Jacksonville had some very near misses.

Most of the hurricanes making landfall on the west coast have originated in the Gulf of Mexico or Caribbean. The Keys and the southeastern Florida coast are in the paths of storms originating in both the Atlantic Ocean and the Caribbean Sea. A number of storms have crossed Cuba from the south, either after formation in the western Caribbean or after a northward curvature, and struck the southern end of the peninsula. All hurricanes that have crossed the east coast from the Atlantic, with two exceptions, have moved north of Cuba and Hispaniola, many passing through the Bahama Islands. The northwest coast from Cedar Keys to Pensacola is especially exposed to storms from the western Caribbean, or those that traverse the Caribbean and curve northward by way of the Yucatan Channel and the Gulf. This area is also exposed to storms which cross the peninsula moving northwestward. The locations where Florida hurricanes first reached hurricane intensity are shown in Figure 10.

Table 3, prepared by Norton (4), indicates, on the basis of records through 1948, the chances in any given year for a hurricane to come sufficiently close to certain coastal cities in Florida to cause hurricane winds. The records since 1948 indicate no significant change in hurricane expectancy in any of the 10 areas. However, statistics over several hundred years will be required to determine hurricane expectancies which will stand the test of time.

Table 3 Chances of Hurricane Force Winds in any Given Year.

Weighted averages based on all available records

Cities	Chances	Cities	Chances
Jacksonville	1 in 50	Key West	1 in 7
Daytona Beach	1 in 30	Fort Myers	1 in 12
Melbourne - Vero Beach	1 in 20	Tampa-St. Petersburg	1 in 20
Palm Beach	1 in 10	Apalachicola-St.Marks	1 in 15
Miami	1 in 7	Pensacola	1 in 10

In this connection, storms crossing the peninsula reach the opposite coast weakened in force, but the organization remains intact, and intensity can be regained shortly after the center passes out over open water. The more severe storms retain hurricane winds all the way across. A notable example was the Miami hurricane of September 18, 1926, which retained hurricane force and passed near Pensacola two days later with winds of 88 miles per hour. Another was the Fort Lauderdale hurricane of September 17, 1947, which passed over New Orleans two days later with winds of 90 mph and gusts to 110 mph for one minute. This storm caused winds of 100 miles per hour on the west coast from Naples to Punta Gorda after crossing from the east.

As shown by Table 4, August, September, and October are the principal hurricane months with the largest number in September and October. The October 17-18, 1950 hurricane is the only one which has struck the east coast from the east. Cleo, of August 27, 1964, moved into the Miami area from the southeast. The "Yankee Hurricane" of November 4, 1935, moved inland over Miami from the northeast off the Atlantic. All other October storms have made landfall on the west or extreme south coasts, or have curved to the northeastward off the lower east coast. There is a decided tendency for hurricanes to form over the western Caribbean Sea or southern Gulf of Mexico near the end of the hurricane season, and most October and November storms that have affected Florida had their origin in that area.

Table 4 Tropical Cyclones by Months for Florida since 1885

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Hurricanes	0	0	0	0	0	6	6	12	27	24	3	0	78
Tropical Storms	0	1	0	0	0	11	4	12	19	22	1	0	70
Total	0	1	0	0	0	17	10	24	46	46	4	0	148

The latest storm of full hurricane intensity in Florida and the United States developed over the western Caribbean, moved through the Yucatan Channel, and crossed the coastline a short distance south of Tampa late on November 30, 1925. It passed into the Atlantic off the upper east coast on December 1. This storm was attended by hurricane force winds on the lower west coast and by excessive rainfall throughout much of the peninsula.

Great Hurricanes - Norton (4) has listed the "great" Florida hurricanes since 1880 based on size and intensity. His criteria eliminated the Keys storm of September 1935, the most intense hurricane of record to reach the coastline of the Unites States and perhaps the entire world. It would appear the hurricanes could be classed as "great" on the basis of size, intensity, minimum pressure, storm tides, amount of destruction, and number of fatalities.

Table 5 Great Florida Hurricanes from 1880 to 1966

1880, August 28-29	Vero Beach, Palm Beach, Lake Okeechobee area
1886, June 21	Apalachicola - Tallahassee section
1888, August 16	Miami to Fort Myers
1896, September 28	Cedar Keys
1906, September 27	Mobile-Pensacola section
1910, October 17-18	Key West to Fort Myers
1916, July 5	Pensacola-Mobile section
1916, October 18	Pensacola
1919, Sep. 9-10	Key West
1921, October 25	Tarpon Springs-Tampa Bay area
1926, Sep. 18-20	Miami and Pensacola areas
1928, Sep. 16-17	Palm Beach to Lake Okeechobee
1929, Sep. 27-30	Key Largo and Panama City areas
1935, Sep. 2-4	Matecumbe Key and Taylor County
1944, Oct. 18-19	Key West, Tampa, and Jacksonville
1947, Sep. 17-18	Fort Lauderdale to Fort Myers
1949, August 26-27	Palm Beach
1950, September 3-6	Cedar Keys
1960, September 10	Middle Keys, Naples, Ft. Myers
1965, September 7-8	Keys, Dade County

Criteria could include diameter of hurricane winds 100 miles or more, sustained winds in excess of 125 mph, tides 9 feet or more above normal, central pressure 28.20 inches or lower, and unusually heavy damage and casualties. A revised list, Table 5, has been prepared and all hurricanes in it meet at least half of the above criteria. In the early portion of the period, southern Florida was relatively uninhabited and little meteorological data for many hurricanes are available. Therefore, in some cases, certain data have been estimated based on observed wind, pressure, or tide. The tracks of major Florida hurricanes since 1900 are shown in figures 11a and 11b. Figure 11b includes some of the most severe hurricanes.

THE HURRICANE WARNING SERVICE IN FLORIDA

District and Local Organizations - The U. S. Weather Bureau has five separate forecast offices which issue hurricane warnings. The offices and geographical areas of warning responsibility are:

SAN JUAN : The Caribbean area south of latitude 20°N. and between longitudes 55°W and 75°W

MIAMI, NHC : (National Hurricane Center) All areas not otherwise assigned in addition to supervision and coördination of all forecasts.

NEW ORLEANS: Gulf of Mexico west of longitude 85°W.

BOSTON : New England coast and waters north of latitude 40°N and west of longitude 65°W

WASHINGTON : The Atlantic west of longitude 65°W between latitudes 35° and 40°N.

Hurricane advisories for Florida east of the Apalachicola River are issued from Miami and for west of the Apalachicola River from New Orleans.

Local Weather Bureau offices in Florida are located at Jacksonville, Daytona Beach, West Palm Beach, Key West, Fort Myers, Tampa, Lakeland, Orlando, Tallahassee, Apalachicola, and Pensacola. When hurricane warnings are in effect, many of these stations issue local statements supplementing the regular advisories and bulletins with additional information of local interest.

A special teletypewriter circuit is established during the hurricane season which connects all weather offices on both the Gulf and Atlantic coasts. All stations on this circuit receive simultaneously all special weather observations, alerts, warnings, and advisories without the loss of time that otherwise might result.

When the storm is approaching an area into which small vessels from a coastal section sometimes operate, small craft will be advised not to

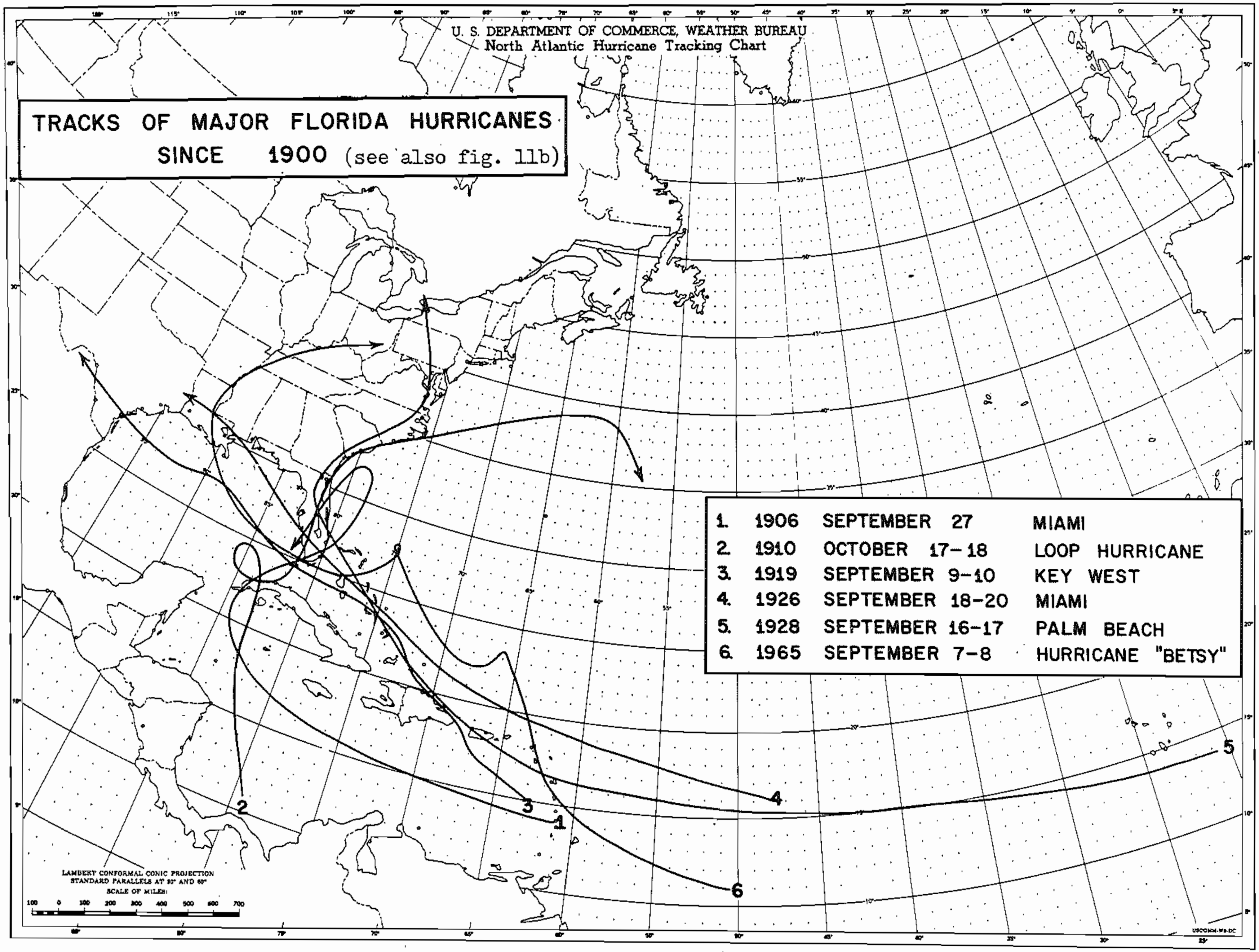
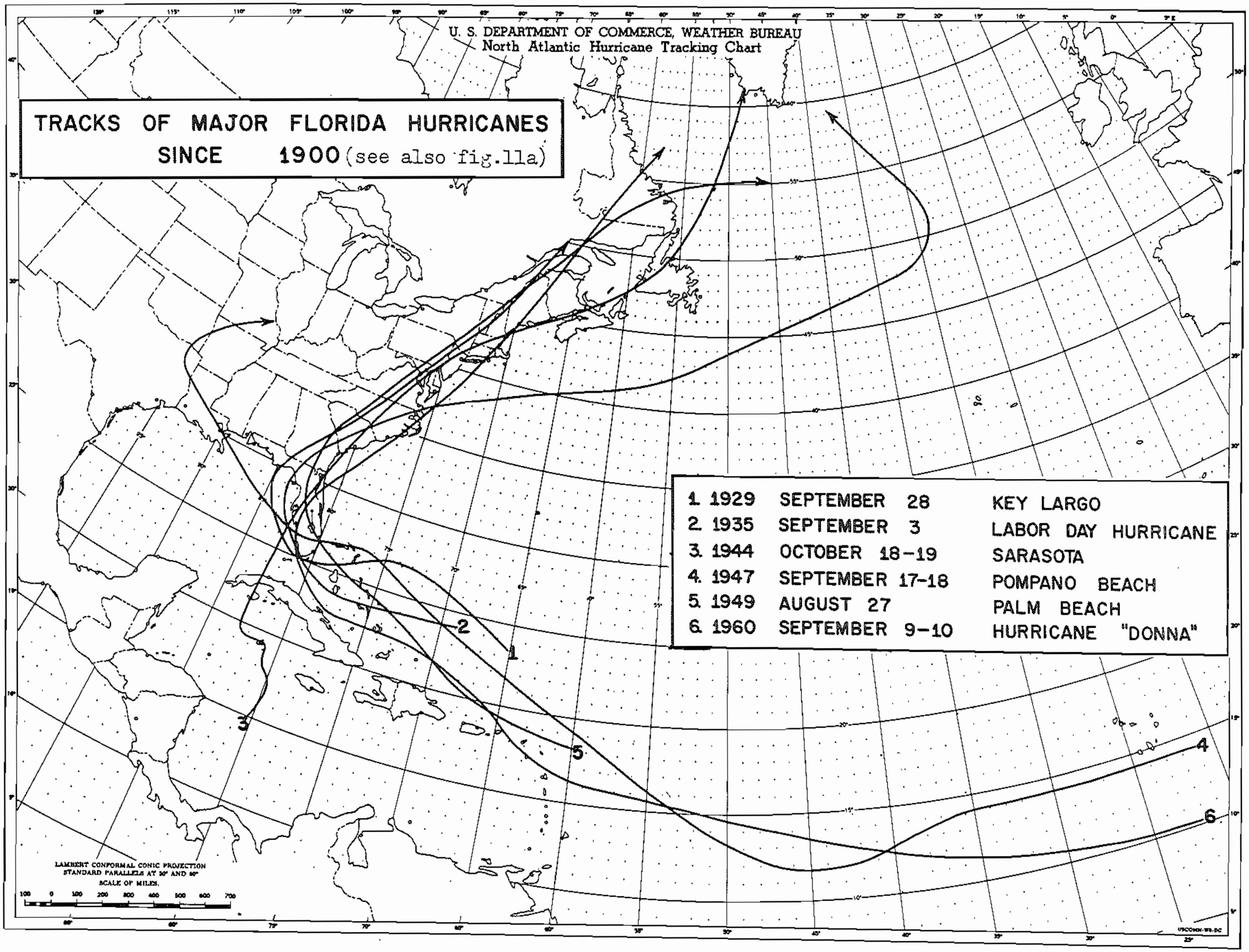

U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
North Atlantic Hurricane Tracking Chart
TRACKS OF MAJOR FLORIDA HURRICANES
SINCE 1900 (see also fig. 11b)
1. 1906 SEPTEMBER 27 MIAMI
2. 1910 OCTOBER 17-18 LOOP HURRICANE
3. 1919 SEPTEMBER 9-10 KEY WEST
4. 1926 SEPTEMBER 18-20 MIAMI
5. 1928 SEPTEMBER 16-17 PALM BEACH
6. 1965 SEPTEMBER 7-8 HURRICANE "BETSY"
1
2
3
4
5
6
LAMBERT CONFORMAL CONIC PROJECTION
STANDARD PARALLELS AT 30° AND 60°
SCALE OF MILES
100 0 100 200 300 400 500 600 700

Figure 11 a



U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
North Atlantic Hurricane Tracking Chart
TRACKS OF MAJOR FLORIDA HURRICANES SINCE 1900 (see also fig.11a)
1. 1929 SEPTEMBER 28 KEY LARGO
2. 1935 SEPTEMBER 3 LABOR DAY HURRICANE
3. 1944 OCTOBER 18-19 SARASOTA
4. 1947 SEPTEMBER 17-18 POMPANO BEACH
5. 1949 AUGUST 27 PALM BEACH
6. 1960 SEPTEMBER 9-10 HURRICANE "DONNA"
LAMBERT CONFORMAL CONIC PROJECTION
STANDARD PARALLELS AT 30° AND 60°
SCALE OF MILES

Figure 11 b

venture far from shore and perhaps, a little later, to remain in port. When the hurricane may possibly or is likely to affect a land area within 24 to 48 hours, a hurricane watch is issued. The hurricane watch is not a warning but is intended to make the public cognizant that the storm may affect their particular area within the next day or two and that everyone should keep in touch with all succeeding advisories until either the watch is cancelled or hurricane warnings are issued. Some industries may require more than 24 hours for necessary preparations and perhaps may need to take some preliminary action at this time. If the storm continues to move toward the coast, a hurricane warning is issued. At this time all possible precautions should be rushed to completion.

Immediate and the most widespread distribution is given all alerts and warnings by every available means of communication. The hurricane teletypewriter circuit makes this information immediately available to all local Weather Bureau offices. Each local office in turn gives the warning local and regional dissemination by radio, television, newspaper, telephone, and by other communication facilities. Broadcasts are often made directly from weather offices. Civil defense, Red Cross, governmental units and others relay the latest emergency information to their own and often to other agencies.

The Hurricane Advisory - The primary function of the Weather Bureau's Hurricane Warning Service is the preparation and dissemination of the best possible warnings in sufficient time for all individuals and interests in the storm affected areas to make all practicable preparations for the safeguarding of lives and property. However, organized emergency precautionary measures based on these warnings are the responsibility of local authorities. Almost all Florida coastal counties, and the larger cities as well, have hurricane emergency committees. These committees, composed of Civil Defense, Red Cross, and governmental officials, decide upon areas to be evacuated, based on the official advisories. Hurricane emergency plans, prepared long in advance, are activated. All public utilities have similar plans.

No two hurricanes are exactly alike and hurricanes may range from comparatively weak with winds barely of hurricane force to storms of extreme intensity with winds of 150 mph or more. Advisories and warnings should be scrutinized carefully. The reader or listener should answer these questions: Is this storm barely of hurricane intensity, severe, or unusually violent? Is the center expected to come directly over me or will I be on the outer edge? Will the tides be only 2 or 3 feet above normal, 6 feet above normal, or 12 feet above normal? Will the forecast tides reach my home or place of business? If so, when will my escape route be cut off? These questions everyone in the hurricane area must answer whether he is an official of the county, hurricane emergency committee, or merely a private citizen responsible only for the safety of his home and family.

Long periods without hurricanes breed complacency. Everyone must respect and remain on guard against them. The words of Messrs. Gray and Norton(4) are still valid: "...it is possible to protect life and property from hurricanes, and it is especially true that all who avail themselves of safe shelter away from the waterfront have little to fear". There is no need of loss of life from hurricanes in Florida if beaches, keys, and a few blocks of the waterfront areas are evacuated when indicated. On the other hand, unnecessary evacuations lead to resistance to evacuation when a major storm eventually comes. Thus responsible officials must read advisories carefully and should consult with their nearest local Weather Bureau office to determine necessary emergency action.

Precautionary Measures - Past records indicate that approximately 90 percent of all loss of life in hurricanes can be attributed to the storm surge (storm tides) and wave action. Probably about 75 percent of the total damage is also due to this cause. Thus it is obvious that the most hazardous locations are the beaches, the keys, and for 4 or 5 blocks inland from any sizeable body of water. Evacuation of these areas must always be considered. Wind may cause some loss of life from flying debris, fallen live wires, and buildings collapsing because of faulty or flimsy construction. Flooding caused by the torrential hurricane rains may cause considerable discomfort and inconvenience but it is an unimportant factor in causing casualties in Florida.

What precautionary measures should be taken prior to the hurricane season? Long range planning should include adequate hurricane building codes and zoning laws which will provide proper safety regulations for all construction along the coast. Scientific coastal engineering advice should be secured by all communities along the coast for the protection of their beaches and property. Causeways and roads from keys and beaches to the mainland should be built high enough that they can serve as escape routes until the main hurricane surge arrives.

What precautionary measures should be taken when hurricane warnings are hoisted? Of paramount importance is the determination of areas which should be evacuated and the rapid and orderly evacuation of all persons in these areas to a safe location. Because of many factors such as the fact that weather forecasting is an imperfect science and that responsible officials in charge of evacuation must operate with some safety factor, perhaps 50 percent of all evacuations may prove unnecessary. Every thoughtful person will realize one unnecessary evacuation every 5 or 10 years is a small price to pay for the safety of his loved ones and himself. Other desirable precautionary advice can be obtained from the Red Cross, Civil Defense, local Weather Bureaus, radio and TV broadcasts, and, from time to time, in special newspaper hurricane editions. Among the more important precautions are the shuttering of windows, remaining inside a safe building during the storm, and keeping up with the latest official storm bulletins.

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