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Climatological Regime of Rainfall Associated with Hurricanes after Landfall

ROBERT W. SCHONER

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U.S. DEPARTMENT OF COMMERCE / ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

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UNITED STATES DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
WEATHER BUREAU

Weather Bureau Technical Memorandum ER-29

CLIMATOLOGICAL REGIME OF RAINFALL ASSOCIATED WITH HURRICANES AFTER LANDFALL

ROBERT W. SCHONER

EASTERN REGION HEADQUARTERS
SCIENTIFIC SERVICES DIVISION
TECHNICAL MEMORANDUM NO. 29

GARDEN CITY, NEW YORK
JUNE 1968

CLIMATOLOGICAL REGIME OF RAINFALL ASSOCIATED WITH HURRICANES AFTER LANDFALL

Robert W. Schoner
WBFC Washington, D. C.

INTRODUCTION

Although hurricane associated rains may be beneficial to agriculture and other water-requiring pursuits, they create flood problems. Some of the worst floods of record over the eastern and southern watersheds of the United States have been attributed to hurricane induced rains. Therefore, an understanding of the climatology of hurricane rainfall for this region could be useful to hydrologists and meteorologists as well as regional planners.

It was thought that a study which offered (1) the climatology of areal-average and maximum point rainfall depths for 24 hours after a hurricane's landfall, (2) the characteristic rainfall patterns for the duration of hurricanes as they neared then passed over a land mass, and (3) the unusual hurricane rainfall events of record, would provide valuable criteria, either for evaluating a region's hurricane flood potential, or for determining a hurricane precipitation forecast.

The basic data contained in "Rainfall Associated with Hurricanes," Schoner and Molansky[1], were utilized in the development of the climatology of hurricane rainfall characteristics. In addition, several pilot studies (2, 4, 5) also based on these basic precipitation data were incorporated into this study. In order to coordinate the information from the above source, it was decided to delineate the vast coastal region of the United States into six zones and to exclude storms of tropical origin that did not reach hurricane intensity.

The eastern and southern seaboard of the United States was separated into six zones, three along the Atlantic and three along the Gulf of Mexico coast. This separation, based on the climatology of hurricane tracks and coastal orientation, is shown by Figure 1.

Only those tropical storms that had a maximum wind velocity of 75 miles per hour or more as they neared or crossed the coast were included in this study. By using the 75 mph maximum wind criteria, a sample of 112 hurricanes that crossed the coast during the 1900-1955 period was obtained.

The reason for establishment of the maximum wind criteria was that storms of less than hurricane intensity often lose their compact wind circulation prior to, or shortly after landfall, which often results in producing an area of disassociated showers; whereas a well-defined hurricane maintains its circulation and produces a more uniform rainfall pattern with respect to its center after landfall.

Reproduced from "Characteristic and Generalized Isohyetal Patterns for Gulf and East Coast Hurricanes" U. S. Weather Bureau Manuscript

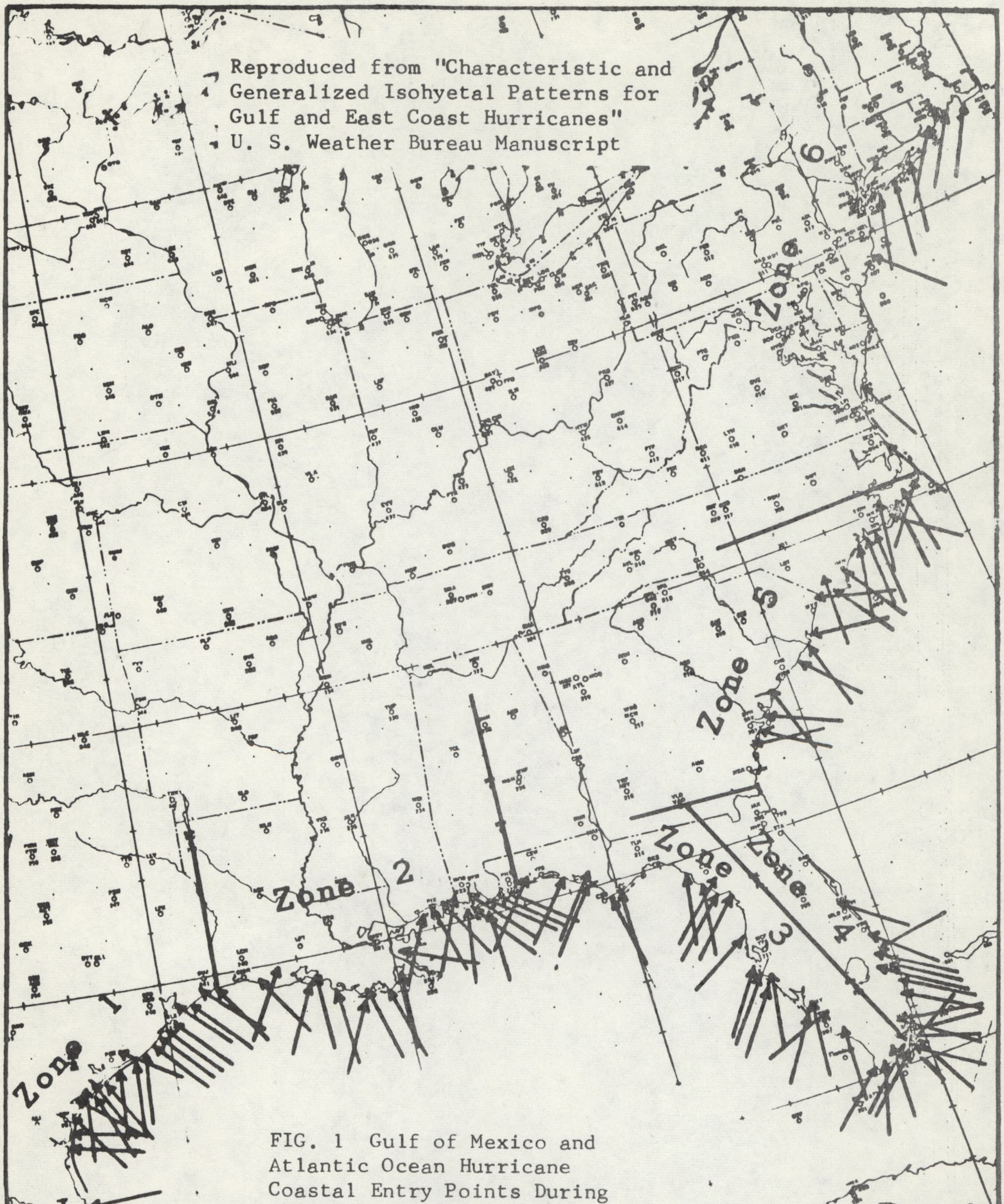


FIG. 1 Gulf of Mexico and Atlantic Ocean Hurricane Coastal Entry Points During the 1900-1955 Period

The climatological regime of hurricane rainfall offered for each of the selected zones is portrayed by: (1) a set of hurricane rainfall patterns considered to be characteristic, (2) a figure showing the 24-hour climatology of areal-average and maximum point 24-hour precipitation depths, (3) a summary of unusual hurricane rainfall cases and (4) a resumé of hurricane precipitation characteristics based upon the aforementioned items.

The rainfall patterns that are shown as typical were obtained from "Characteristic and Generalized Isohyetal Patterns for Gulf and East Coast Hurricanes".[2] All those patterns selected were duplicated at least once within the selected zone during the 1900-1955 period. It became necessary to select more than one pattern, due to the variations in individual hurricane characteristics and the topography of the zones and their effect upon the resulting rainfall patterns. The corresponding hurricane tracks shown on each typical pattern were obtained from "Tropical Cyclones of the North Atlantic," Cry.[3]

The 24-hour climatological rainfall depths shown for each zone were obtained in part from "Frequency and Distribution of Areal Rainfall Averages Associated with Tropical Storms Entering the Coast of the United States," Schoner.[4]

The 24-hour period after a hurricane's landfall was considered to be adequate to show the climatology of hurricane precipitation closely associated with a hurricane as it travelled over a land mass. Rainfall prior to, or subsequent to, this time period could be explained by the other items included in this study.

In the development of the 24-hour climatological precipitation data, the grid system of 100 x 100 mile grid squares was first placed over a selected 24-hour rainfall pattern with the grid origin placed at the approximate point of hurricane landfall and then rotated so that the grid ordinate was parallel to hurricane motion at landfall. When the grid system was oriented, the rainfall pattern was visually integrated for each grid square and areal-average precipitation depths were obtained. In addition, the maximum point rainfall depths in these same grid squares were also tabulated. From these data a set of areal-average and maximum point 24-hour precipitation amounts were obtained for each grid square. These developed data are shown for each zone by a figure representing a grid system of 100 x 100 mile squares. On each figure the maximum and mean areal-average precipitation depths are shown on the upper and lower left corners, respectively, and the maximum and average maximum point depths are shown in the upper and lower right-hand corners, respectively. At the center of each grid square the frequency (in percent) of precipitation occurrence, irrespective of amount, is shown.

A review of intense hurricane rainfall cases within each zone was made and those of noteworthy extent were summarized. In most cases these hurricane rain storms were not unusual during the 24 hours after hurricane landfall, but were of longer overall duration either prior to, or subsequent to, the 24-hour period after hurricane landfall. The dates used for these storms cover the entire storm period shown in "Tropical Cyclones," Cry.[3]

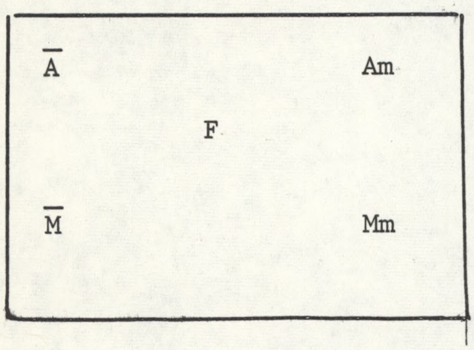
Finally, consideration was given to all of the developed data and a summary of hurricane precipitation characteristics was made for each zone.

Notes concerning the zonal figures:

1. Bold lines with arrows indicate hurricane track.

2. Rainfall patterns used show only the 3", 5" and 10" isohyets. Maximum center values are found within closed isohyets.

3. The following is the method used to show the 24-hour climatological rainfall data within each of the grid squares on Figures 4, 8, 12, 16, 20 and 24:



$\overline{A}$ = mean areal-average 24-hour precipitation

Am = maximum areal-average 24-hour precipitation

$\overline{M}$ = average 24-hour maximum point precipitation

Mm = highest 24-hour maximum point precipitation

F = frequency (in percent) of precipitation occurrence, irrespective of amount

ZONE #1 - THE TEXAS COAST

A study of the twenty-three hurricanes that crossed the Texas Coast during the period of study indicated that they came out of the western Gulf of Mexico, moving toward the north or northwest. Those that crossed the coast moving toward the north did so north of Corpus Christi and usually recurved toward the northeast during the 24-hour period subsequent to landfall. Hurricanes that entered the coast, then moved toward the northwest, usually did not recurve but dissipated over the inland highland areas of Texas within 24 hours after landfall.

Two typical rainfall patterns were selected from the basic data. The typical rainfall pattern shown by Figure #2 should apply to those storms that move northwest after coastal penetration. The rainfall pattern indicated by Figure #3 would be indicative of a hurricane that crosses the coast then moves northward.

The 24-hour climatological hurricane precipitation data shown by Figure #4 indicated that the most intense rainfall occurred over the area that extended inland some 300 miles from 100 miles to the left to 200 miles to the right of hurricane coastal penetration point. The maximum 24-hour precipitation depths for this area occurred in the 100 by 100 mile square located immediately ahead and to the right of the coastal entry point. Maximum 24-hour point precipitation depths in this area ranged from 5 to 12 inches, while the maximum areal-average depths varied from 3 to 6 inches. The frequency of precipitation, irrespective of amount, for the area varied from 100% over the first one-hundred miles inland, to 80 to 90% over the next one-hundred miles and to 70% in the area 200 to 300 miles inland.

The intense hurricane rainfall cases within this zone were considered to be either the result of a slow-moving hurricane that paralleled the coast, or from a hurricane circulation that redeveloped over the highland region of West Texas.

The hurricane of August 24-29, 1945 produced a maximum precipitation center of 19.6 inches at Hockley, Texas. This was a slow-moving hurricane that introduced intense rains along the Texas coast two days before hurricane landfall. It also caused heavy rain in association with initial landfall but these heavy rains ceased rapidly as the hurricane moved into the Texas interior. The heavy rainfall depths associated with this storm were confined to within 200 to 300 miles of the coastline.

The hurricane of June 24-26, 1954 (Alice) had a maximum rainfall center of 27.1 inches at Pandale, Texas. This hurricane crossed the coast on June 25 and passed up the Rio Grande at a moderate speed until the morning of the 26th, spreading only moderate rainfall along its path. During the 26th and 27th the hurricane decreased in intensity and finally dissipated over the highland area of west Texas. During the period of hurricane decay a region of convergence was established which, coupled with the orographic influence of the highland area, caused torrential rains over the area from June 26 to the 28th.

The storm of August 5-23, 1915 produced a maximum rain center of 19.8 inches at San Augustine, Texas. This storm slowed down as it approached the Texas coast and its circulation produced two days of rain before entering the coast on August 17. The storm moved slowly after crossing the coast and produced another two days of rain as it moved northeastward, up the Mississippi Valley into the Saint Lawrence Valley. This storm was noted for, unlike the previous rainfall cases mentioned, it induced an extensive precipitation pattern that extended from Texas to Canada.

The following generalizations were made concerning the climatology of hurricane rainfall in the Texas zone:

1. Storms of hurricane intensity usually show a rainfall pattern with an intense rainfall center along the immediate coast, an occasional lesser maximum some distance inland, and then a rapid cessation of precipitation beyond. The inland maximum usually occurred when the hurricane wind circulation reached the inland highland regions. The majority of hurricane rainfall patterns show little or no heavy rain beyond the area of secondary maximum where the wind circulation had to pass over the inland highland regions.

2. Intense rains frequently occur along the coastal areas for a period of one to two days as a slow-moving hurricane parallels the coast.

3. Hurricanes that pass inland near the mouth of the Rio Grande, then pass up the river valley, frequently stagnate over the highland area of west Texas and may cause intense precipitation two or three days after hurricane landfall.

4. The most intense rainfall directly associated with a hurricane circulation usually ceases by the end of the 24-hour period after landfall.

5. Only two of the hurricanes produced less than five inches of 24-hour point precipitation during the 24 hours after hurricane landfall. They were the hurricanes of June 28, 1929 and August 4, 1933, which dissipated rapidly after landfall.

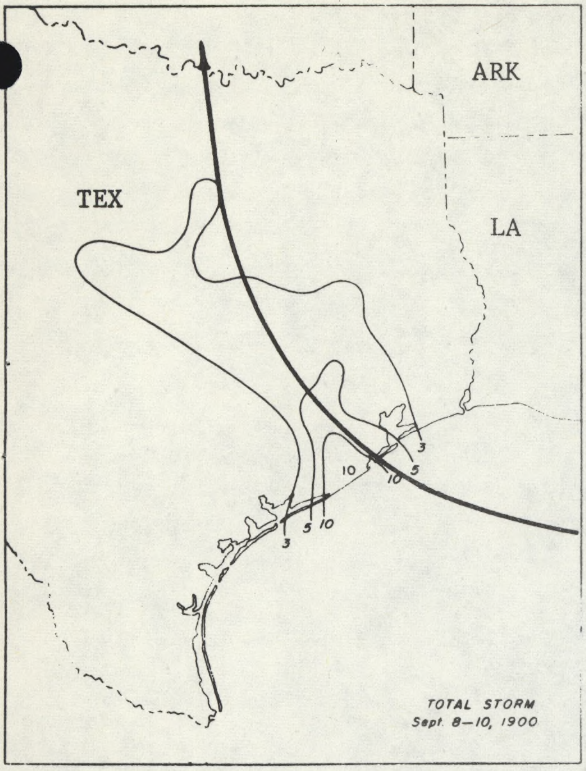


Fig 2. Typical Rainfall Pattern Suggested for Hurricanes that Cross the Texas Coast then Move Toward the Northwest

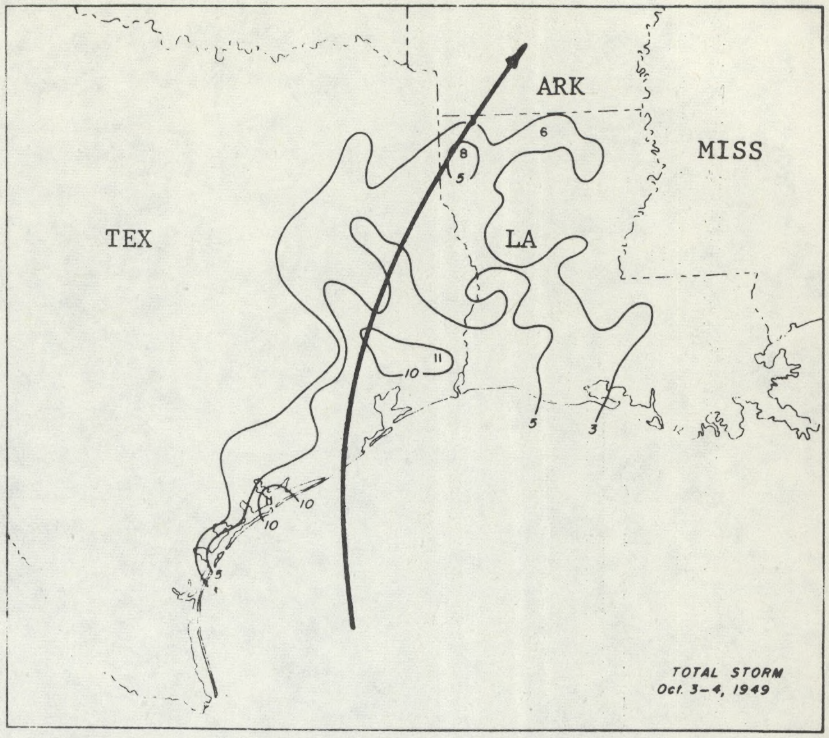


Fig 3. Typical Rainfall Pattern Indicative of a Hurricane that Crosses the Texas Coast then Moves Northward

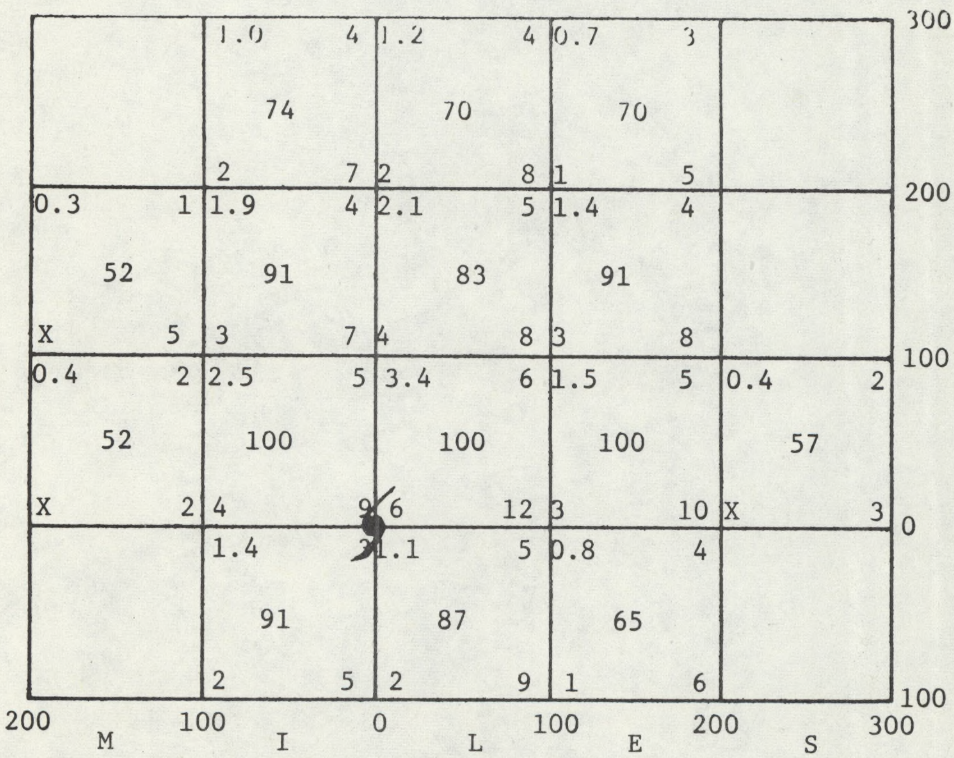


Fig 4. Average and Maximum 24-Hour Climatological Point and Areal-Average Rainfall Depths for Zone 1. (twenty-three hurricanes)

ZONE #2 - THE MIDDLE GULF COAST (PORT ARTHUR, TEXAS TO APALACHICOLA, FLORIDA)

In review of the rainfall patterns associated with the twenty-eight hurricanes included for this zone, three patterns are offered as characteristic. The first and most common, shown by Figure #5, applies to hurricanes that cross the coast from the south, then curve toward the east. The next rainfall pattern, shown by Figure #6, was selected to fit hurricanes that cross the coast from the southeast or south and curve toward the west. The third pattern, shown by Figure #7, applies to hurricanes that, after crossing the Florida peninsula, parallel the north Gulf Coast before re-crossing the middle Gulf Coast in the vicinity of Lake Pontchartrain.

The 24-hour climatological precipitation data shown by Figure #8 indicates that the area of most intense rains extends inland some 300 miles from the coastline and along the coast, from 100 miles to the left and 200 miles to the right of the coastal penetration point. The maximum 24-hour precipitation values for this area are contained in the 100 by 100 mile square immediately ahead and to the right of the hurricane coastal penetration point. The maximum 24-hour point precipitation depths over the area varied from 5 to 14 inches, while the maximum areal-average depths ranged from 3 to 7 inches. The frequency of precipitation for the area, irrespective of amount, varied from 97% to 100% over the first 200 miles inland, and from 82% to 93% for the area from 200 to 300 miles inland.

The unusual hurricane cases occurred when they stagnated after crossing the coast or crossed the coast from the southeast after moving parallel to the coast at a slow speed. Storms of the above types are listed below.

The hurricane of June 29 - July 10, 1916 produced a 24.5 inch rainfall center at Bonifay, Florida. Most of the intense rain associated with this storm occurred two or three days after hurricane landfall. The precipitation began 18 hours prior to landfall and continued for the next few days, with the maximum centers spreading from the Gulf Coast to the southeastern Appalachians three days after landfall. This storm had added significance for the southeastern states for on July 14, 1916 a hurricane entered the South Carolina coast and dumped more than ten inches of rain on these same mountain slopes.

The hurricane of September 11-22, 1926 produced an 18.5 inch center at Bay Minette, Alabama. The hurricane center passed over the Florida Peninsula on the 18th, depositing ten inches of rain along its path. The storm then entered the Gulf and moved parallel to the north Florida-Alabama coast, producing heavy rains to the coast as it moved northwest and finally crossed the Alabama coast. Rainfall ceased rapidly after the hurricane crossed the coast and moved westward.

The following observations concerning hurricane precipitation characteristics were noted:

1. The majority of hurricanes dropped their moisture within a few hours before, to about 24 hours after, crossing the coast. The hurricanes of September 22 - October 1, 1915 and Setpember 10-21, 1909 are excellent examples. Both hurricanes produced about 14 inches of point precipitation in 12 to 18 hours after landfall.

2. If a hurricane curves westward after landfall the intense hurricane-induced rains cease rapidly.

3. If a hurricane curves northeastward after landfall, the resulting isohyetal pattern is usually oriented along the path of the hurricane some 300 to 400 miles inland from the coast. In addition, if the hurricane circulation passes near the southern Appalachians, it will produce a secondary precipitation maximum along the southern mountain slopes. If the storm passes over the Appalachian Plateau and does not join with an extra-tropical weather system, the associated intense rains cease rapidly.

4. No hurricane produced a distinct precipitation maximum to the left of center. All storms studied showed a maximum ahead and to the right of the center.

5. The storm of August 1-6, 1918 was the only hurricane that produced less than five inches of point precipitation after landfall.

6. Hurricanes that penetrate this coastline usually pass through the inland area rapidly and the areal extent of hurricane rainfall is usually more widespread than that for the other studied zones.

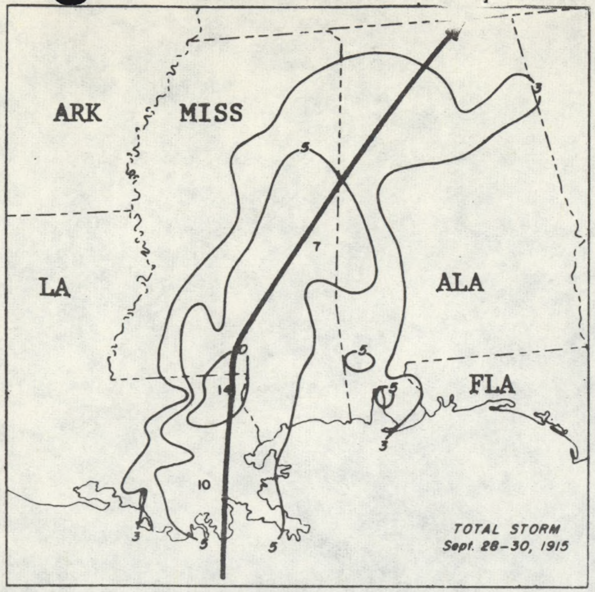


Fig 5. Rainfall Pattern for a Zone #2 Hurricane that Crosses the Coast from the South then Curves to East

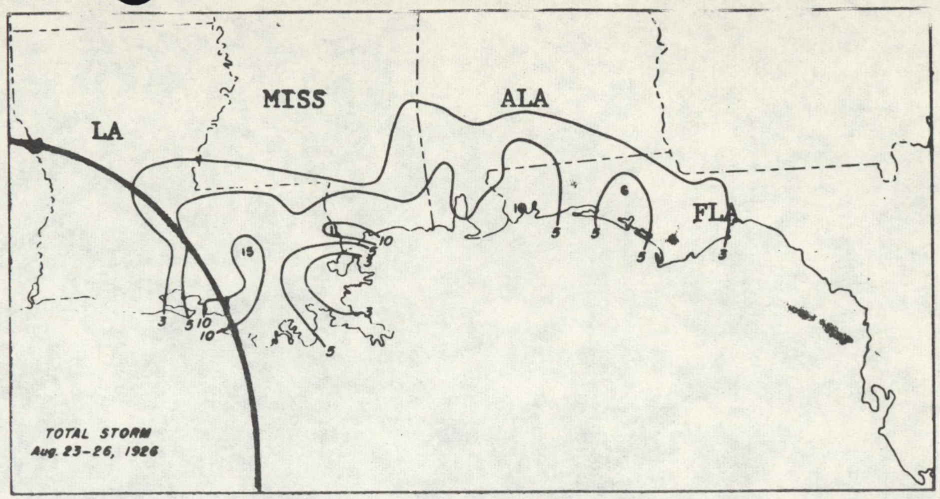


Fig 6. Rainfall Pattern for a Zone #2 Hurricane that Curves Toward the West after Crossing the Coast

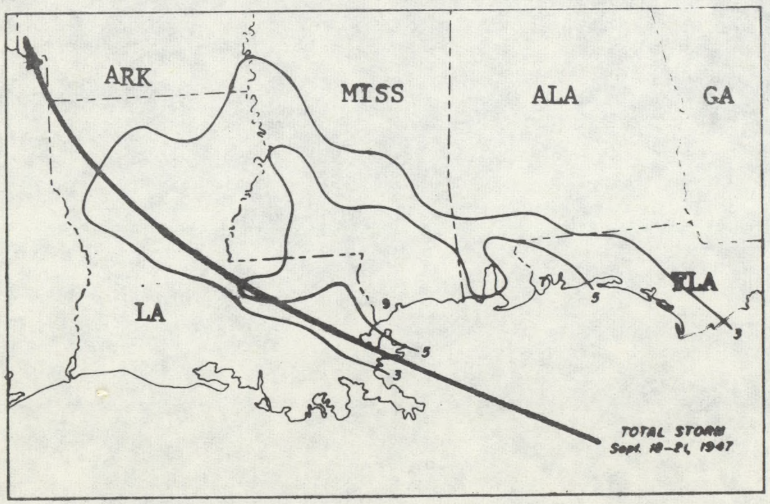


Fig 7. Rainfall Pattern for a Zone #2 Hurricane that Parallels the Gulf Coast then Crosses the Coast from the Southeast

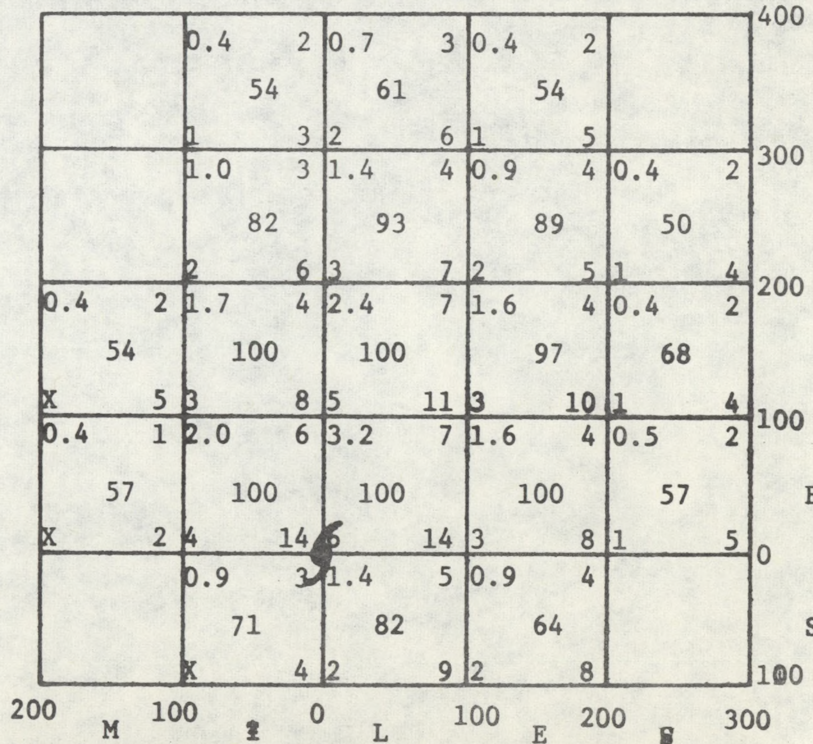


Fig 8. Average and Maximum 24-Hour Climatological Point and Areal-Average Rainfall Depths for Zone #2 (twenty-eight hurricanes)

ZONE #3 - FLORIDA WEST COAST

In review of the nineteen hurricanes studied that crossed the Florida west coast, three were considered to be characteristic. The first and most common, shown by Figure #9, is a hurricane that crosses the Florida west coast, traverses the peninsula and passes directly into the Atlantic. The second, shown by Figure #10, would apply to a hurricane that, after crossing the Florida panhandle, continues on a north northeast course, passing over the interior portions of the south Atlantic states. The third pattern, shown by Figure #11, represents the rainfall distribution associated with a hurricane that, after crossing the Florida west coast, traverses the coastal portions of the south Atlantic states.

The 24-hour areal average and point precipitation data, shown by Figure #12, indicates the rainfall is intense about 100 miles either side of the hurricane penetration point and extends inland about 200 miles from landfall. The maximum areal-average and point precipitation data for the area that extends from 100 miles either side of the coastal entry point to 200 miles inland, varied from maximum point depths of 4 to 12 inches. The maximum areal-average depths ranged from 4 to 7 inches. The frequency of precipitation, regardless of amount, was 100 percent for this area. The 100 by 100 mile grid square containing the maximum precipitation values was the square immediately ahead and to the right of the hurricane penetration point. It should be remembered that much of the area considered in the development of these particular climatological data was over oceanic areas where measurements were unavailable and are subject to error.

The more intense rain storms that were observed in this zone occurred when a hurricane stagnated offshore or, after crossing the Florida coast, remained inland or along the coastal plain as it traversed the south Atlantic states east of the Appalachians.

The hurricane of September 22 - October 4, 1929 produced 13.5 inches of rainfall at Vernon, Florida. During the four days prior to landfall, 20 inches of rain fell over Glenville, Georgia and about 12 inches of rain occurred over southeastern Florida on September 28 while the hurricane was passing through the Florida straits. The precipitation sequence associated with this storm period began with intense rains, starting in a zone of convergent air over the southern Appalachians on September 26, which shifted southward to southeastern Georgia on September 28. Little precipitation was evident on September 29 over Florida when the hurricane was centered over the eastern Gulf of Mexico. However, by September 30, the intense hurricane rains spread into northwest Florida and spread northeastward along the hurricane's path through the southeastern states on October 1st and 2nd, thus producing three more days of intense rainfall over the southeastern states.

The hurricane of August 29 - September 10, 1935 produced a 15 inch center over southwestern Florida and a 16.7 inch center over Easton, Maryland. The heavy rains spread from the Florida Keys on September 2 to the Middle Atlantic States by September 6. Intense rainfall associated with storm ceased rapidly to the rear of the storm but spread far ahead of the storm. The intense rainfall pattern also shifted from the hurricane's right quadrant to immediately ahead and to the left of the center as it passed through Georgia and the Carolinas during the afternoon of September 5.

The hurricane of September 1-9, 1950 (Easy) produced 24.5 inches of rain at Cedar Key, Florida. The hurricane traversed two loops in the Gulf of Mexico. Moving inland on the 5th, the hurricane turned eastward, then northward by the 6th, and dissipated over southern Georgia on the 7th. During the September 4 to 6th period, intense rains fell along a line from Tampa, Florida to Savannah, Georgia and two other areas of intense rains occurred after the 6th. On the 7th, heavy showers fell along the Georgia-South Carolina coasts near the decaying hurricane, and on the 8th and 9th over the western Carolinas as the residual moist tropical air underwent orographical lifting.

The following observations were made concerning hurricane precipitation characteristic to this zone:

1. Slow moving hurricanes that parallel the Florida west coast tend to spread intense rains along the coast, a good distance to the right of the storm center.

2. Hurricanes that, after crossing the Florida coast, move over the interior portions of the South Atlantic States beyond Georgia, tend to spread their precipitation to the left of the center along the eastern slopes of the Appalachians.

3. Hurricanes that cross the Florida west coast, moving in a northeasterly path, tend to reach the Middle Atlantic States before curving to sea, thus spreading their heavy rainfall over most of the Atlantic Seaboard.

4. The hurricane of October 17-21, 1950 was the only storm that produced less than 5 inches of precipitation. This hurricane dissipated almost immediately after landfall.

5. The hurricane of August 31 - September 6, 1915 was the only storm that had a distinct precipitation maximum to the left of the center.

6. Hurricanes that cross the Florida Peninsula, then skirt the Georgia and South Carolina coasts, usually produce a secondary precipitation maximum in the Jacksonville, Florida area.

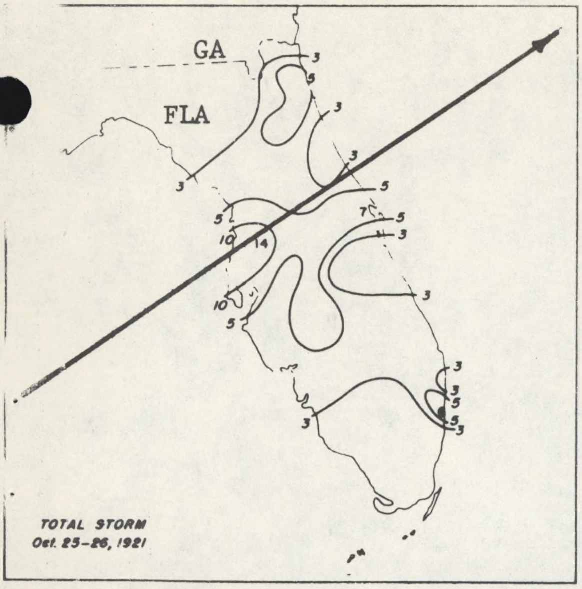


Fig 9. Typical Rainfall Pattern for a Hurricane that Enters the Florida West Coast then Passes Directly into the Atlantic

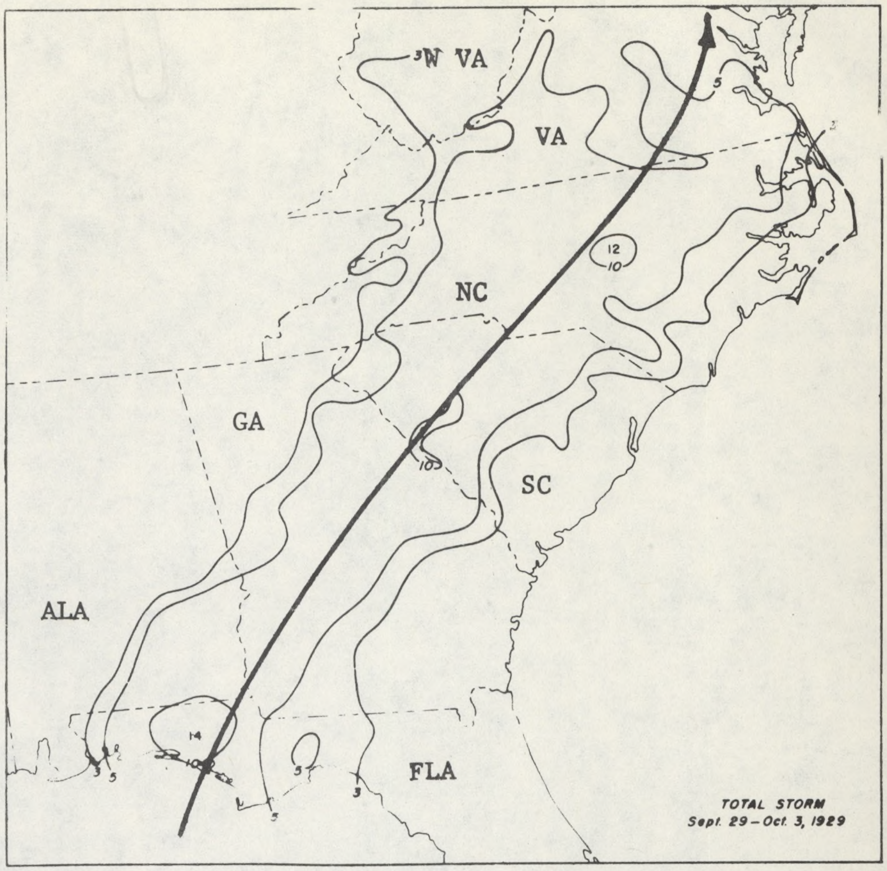


Fig 10. Hurricane Rainfall Pattern for Storm that Crosses the Florida West Coast and then passes over the Interior Portions of South Atlantic States

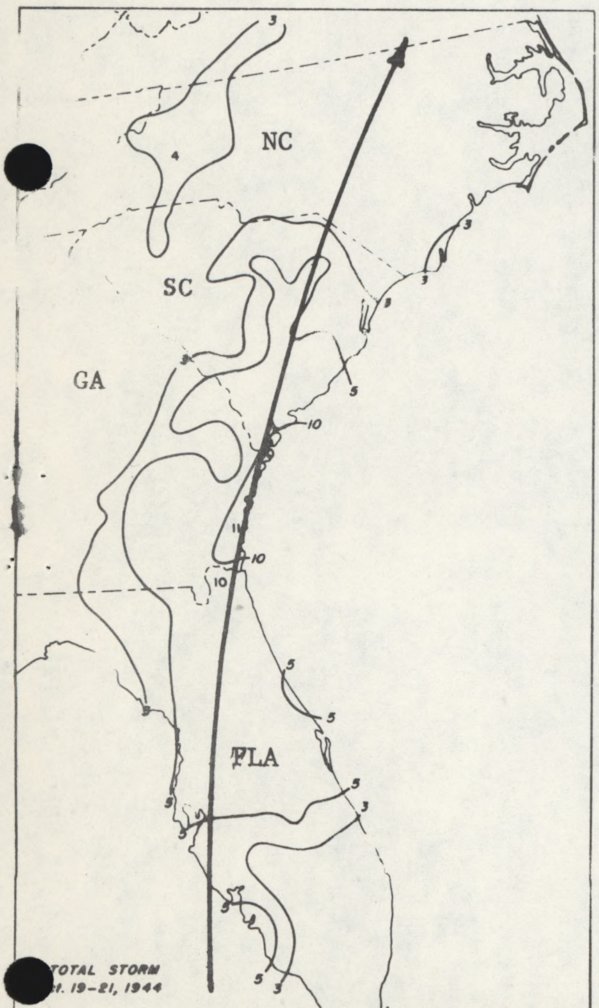


Fig 11. Hurricane Rainfall Pattern for a Storm that After Crossing Florida West Coast Moves North over Coastal Portions of South Atlantic States

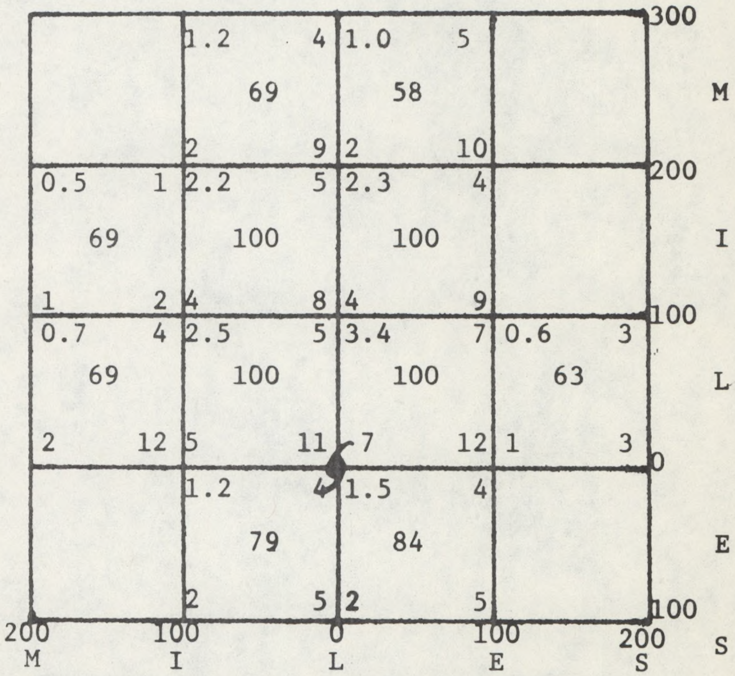


Fig 12. Average and Maximum 24-Hour Climatological Point and Areal Average Rainfall Depths for Zone #3 (nineteen hurricanes)

ZONE #4 - FLORIDA EAST COAST

Three typical hurricane rainfall isohyetal patterns were selected from a sample of fifteen hurricanes studied for this zone. Figure #13 is suggested for a hurricane that crosses the southeast Florida coast and continues northward, remaining inland close to the Atlantic Coast, before passing into the Atlantic off the Middle Atlantic States. Figure #14 is offered for hurricanes that cross the Florida Peninsula and do not recurve northward, passing into the Gulf of Mexico and recrossing the U. S. mainland coast in either the middle or western Gulf Coast. The third typical pattern, as shown by Figure #15, would apply to a hurricane that, after crossing the Florida coast, passes northward through the South Atlantic States just to the east of the Appalachians, before either recurving into the Atlantic or dissipating over the southern Appalachians.

The 24-hour climatological precipitation depths shown by Figure #16 reveal about the same distribution of precipitation as shown for Zone 3. The heaviest and most persistent rains occur over the area from 100 miles to the left and 100 miles to the right of the penetration point, extending inland about 200 miles. The maximum 24-hour point precipitation depths in this area range from 8 to 12 inches, while the maximum areal-average depths vary from 3 to 7 inches. The frequency of precipitation, regardless of amount, varied from 100% within 100 miles of the coast, to 93% to 100% in the area from 100 to 200 miles from the coast. The maximum overall depths were found in the two 100 by 100 mile squares immediately ahead and to the right and left of the hurricane coastal entry point. However, since some of the precipitation associated with the studied storms occurred over oceanic areas, some errors in the developed data must be assumed.

The unusual storms of this zone were of two types. The first type were those hurricanes that remained inland over the South Atlantic States, east of the Appalachians, before dissipating or recurving eastward into the Atlantic off the Middle or North Atlantic coast. The second type of unusual storms were those that, after crossing the Florida Peninsula into the eastern Gulf of Mexico, re-intensified and recrossed the U. S. mainland in either the middle or western Gulf of Mexico.

The hurricane of September 11-20, 1945 produced an 11.2 inch center at Laurenburg, North Carolina. The most unusual feature of this storm was the extensive area covered by intense rains along the eastern seaboard from southern Florida to New England as the hurricane moved across Florida, then northward over interior areas, until it passed to sea off the New England coast four days after landfall. Intense rain occurred from southern Florida to northern Virginia from September 16 through September 18 and moderate rain occurred over New England on September 19.

The hurricane of August 31 - September 4, 1933 produced a 17.8 inch center at Clermont, Florida. The precipitation associated with this storm advanced slowly northward with the weakening hurricane. Intense rains occurred over Florida on September 4 and 5, then spread along the Georgia-South Carolina coast on September 6, with a final burst of rain over western South Carolina on September 7 in the area of the decaying hurricane.

The hurricane of August 3-12, 1928 was unusual because after this storm had crossed the Florida coast and spread intense rains northward into Georgia and the Carolinas, it was followed by the hurricane of August 14, 1928 which, after crossing the west Florida coast, also spread intense rains to the same eastern slopes of the Appalachians.

The hurricane of September 4-21, 1947 caused intense rainfall over the Florida Peninsula, then re-entered the middle Gulf Coast on September 19, producing intense rainfall from western Florida to central Louisiana.

The following observations were made concerning hurricane precipitation characteristic to this zone:

1. Hurricanes that curve northward and remain inland east of the Appalachians, before recurving into the Atlantic or dissipating, produce widespread precipitation which can spread as far north as New England.

2. Storms that cross the Florida Peninsula and re-enter the middle Gulf Coast have a tendency to dissipate rapidly after re-entry. The hurricanes of September 11-22, 1926 and September 4-21, 1947 are good examples of this feature.

3. Hurricanes that move northward along coastal areas north of Florida tend to give maximum depths close to the hurricane path, while storms that pass inland tend to produce maximum depths to the left of the centers as they pass east of the Appalachians. Hurricanes that remain close to the coast do not spread intense rain westward to the eastern mountain slopes.

4. No hurricane produced less than 5 inches of precipitation.

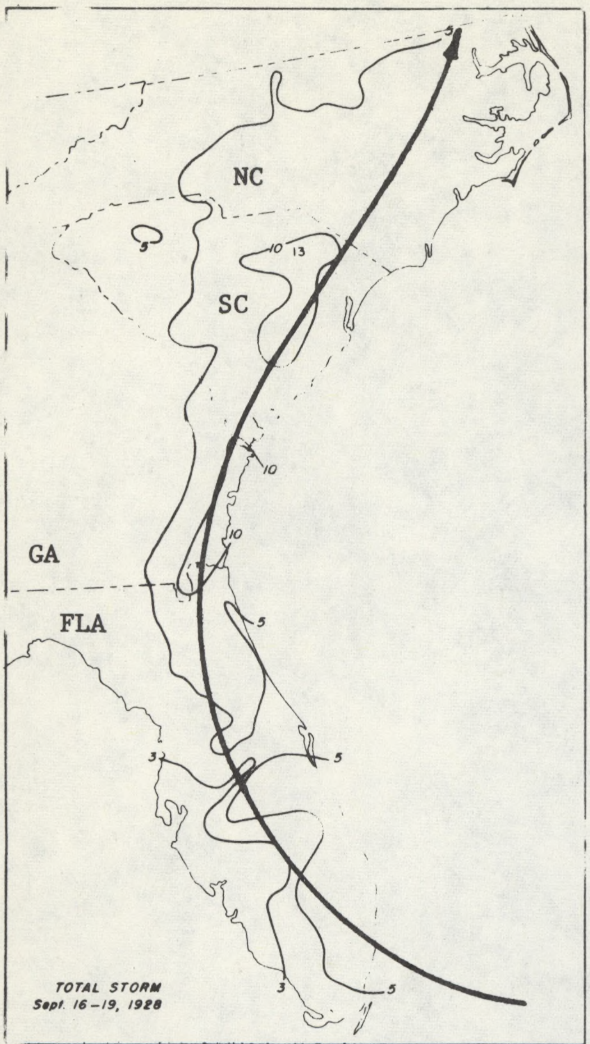


Fig 13. Suggested Rainfall Pattern for a Hurricane that Crosses the Florida Southeast Coast Remaining Close to the Atlantic Coast as it Moves Northward

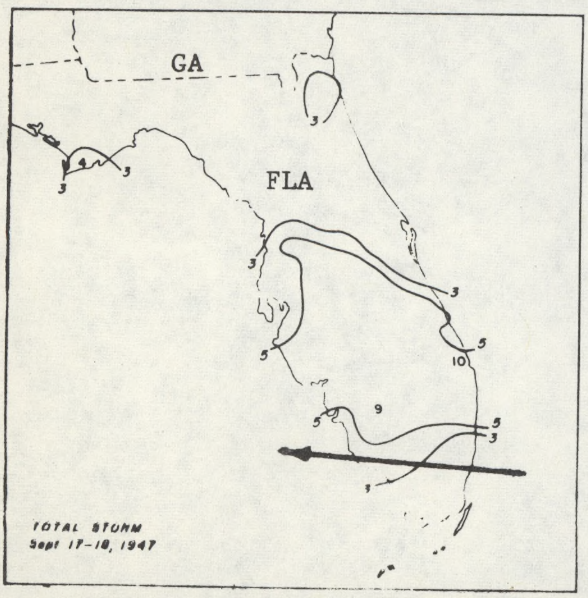


Fig 14. Typical Rainfall Pattern for Hurricanes That Do Not Recurve After Crossing Florida East Coast

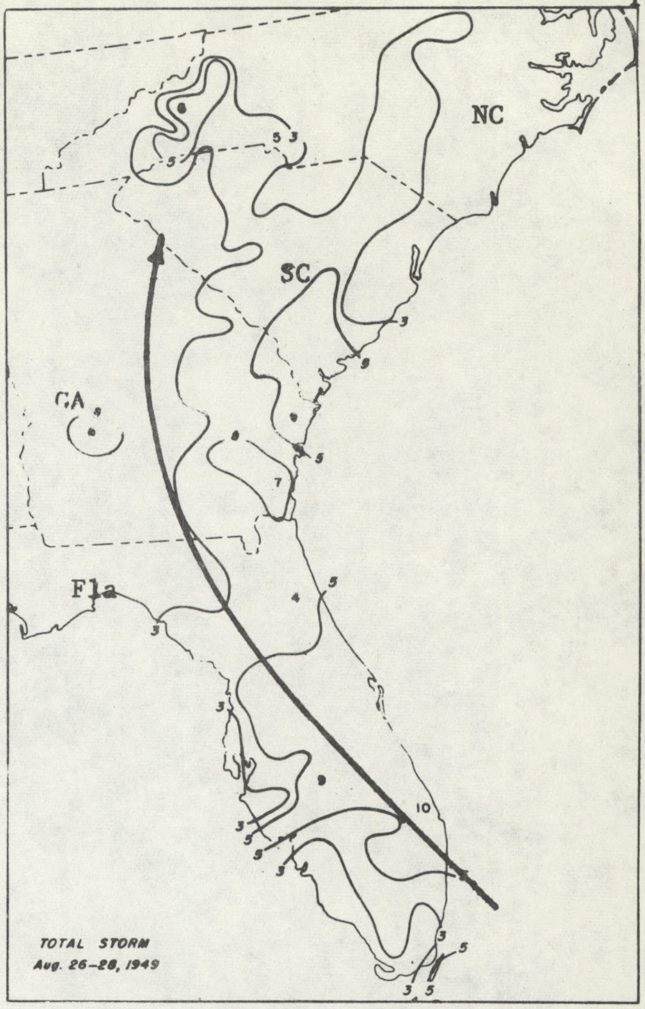


Fig 15. Rainfall Pattern for a Hurricane That After Crossing the Florida Coast Passes Through the South Atlantic States

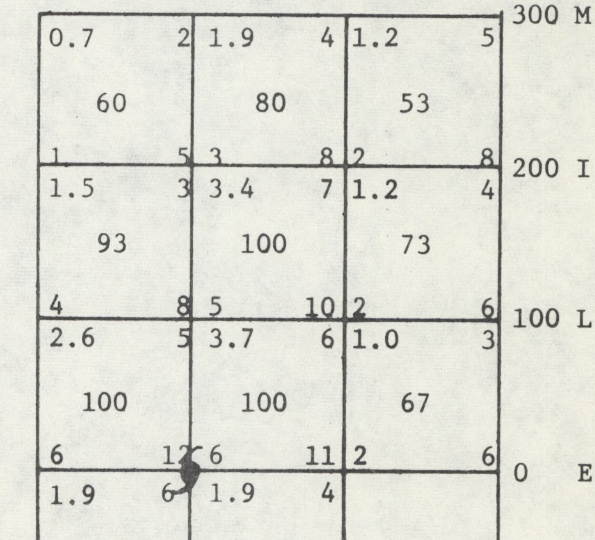


Fig 16. Average and Maximum 24-Hour Climatological Point and Areal-Average Rainfall Depths for Zone #4 (fifteen hurricanes)

ZONE #5 - THE SOUTH ATLANTIC COAST (JACKSONVILLE, FLORIDA TO CAPE HATTERAS, NORTH CAROLINA)

After a review of the seventeen hurricane cases in this zone, three rainfall patterns were considered to be characteristic for the zone. The first type, shown by Figure #17, is suggested for hurricanes that, after crossing the Carolina coast, either curve to the right or left after passing north of Virginia. Figure #18 portrays the pattern selected for hurricanes that cross the South Atlantic Coast and then curve abruptly to the east and pass into the Atlantic. The third pattern, shown by Figure #19, is offered for hurricanes that cross the South Atlantic Coast and do not recurve but dissipate over the eastern slopes of the Appalachians.

The area of maximum 24-hour climatological hurricane precipitation data shown on Figure #20 occurred over the area that extended from 100 miles to the right and 300 miles to the left of the coastal entry point, to 300 miles inland. The 24-hour maximum point rainfall values for this area varied from 5 to 15 inches. The maximum areal-average precipitation ranged from 1 to 6 inches. The frequency of precipitation, irrespective of amount, for this area varied from 100% to 71%. The percentage less than 100% occurred over the area from 200 to 300 miles inland and from 200 to 300 miles to the left of the hurricane penetration point. The absolute maximum precipitation values for this area were located in the 100 by 100 mile square immediately ahead and to the right of the hurricane penetration point.

The unusual rain storms associated with hurricanes in this zone occurred when a storm stagnated after coastal penetration, or when the storm joined with a prevailing extra-tropical weather system after coastal penetration.

The hurricane of August 5-15, 1940 produced a 19.6 inch rainfall center at Swansboro, North Carolina. The hurricane rainfall was not unique during the 24-hour period after landfall, but due to the long duration of intense rains associated with the hurricane circulation as it stagnated over the Carolinas. After depositing a normal distribution of rainfall as it crossed the coast, the storm reached the western Carolinas, weakened and stagnated, then began a slow progression toward the Atlantic Coast. The weakened storm passed off the Carolina Coast six days after coastal penetration. In the process of traversing the Carolinas, the storm produced five distinct 24-hour rainfall centers, with maximum point precipitation depths of greater than five inches.

The hurricane of October 5-18, 1954 (Hazel) induced 11.2 inches of rain at Big Meadows, Virginia. The storm was unique in that prevailing meteorological conditions were such that after coastal penetration the remains of the hurricane moved along an active cold front, thus bringing a rapid interaction along the cold front of the moist tropical air to the east and the colder polar air to the west. It is interesting to note the similarity of this storm to the storm of September 30, 1920 which also moved into a frontal zone and spread intense rains from Florida to New England during a 24-hour period.

The storm of July 11-15, 1916 gave a 23.8 inch maximum rainfall center to Altapass, North Carolina. Unlike the storm of August 1940, this storm produced more intense rain along the storm's path as it crossed the coast, with the intense rains diminishing rapidly after the storm reached the Appalachians and dissipated within two days after coastal penetration. Another notable feature of this rainstorm was the short return period of intense hurricane rainfall along the eastern Appalachians, for the rains associated with the July 5, 1916 hurricane had only ceased over this area on July 9.

The following observations of hurricane precipitation characteristics were noted for this zone:

1. It seemed that each rainfall pattern depended in some way upon the prevailing middle latitude weather systems.

2. Maximum rainfall depths are most likely in the forward quadrants of any hurricane, but the intense centers may be found a little to the left of the center, especially in the coastal areas. Heavy rains that spread inland with a non-curving hurricane were always in the forward right quadrants.

3. If a hurricane's wind circulation remains intact upon reaching the eastern slopes of the Appalachians, it will induce a secondary maximum in that area. However, if a hurricane circulation curves inland just to the east of the mountains, the maximum rain centers will be found within the wind circulation rather than along the mountain slopes (Schoner[5]).

4. The hurricanes of August 30 - September 4, 1913 and September 20-23, 1920 were the only two hurricanes noted that produced less than five inches of rainfall during the 24-hour period after landfall.

5. Offshore hurricanes that pass within 100 miles to the east of the Carolina Coast often produce an intense rainfall center along the immediate coastal plain.

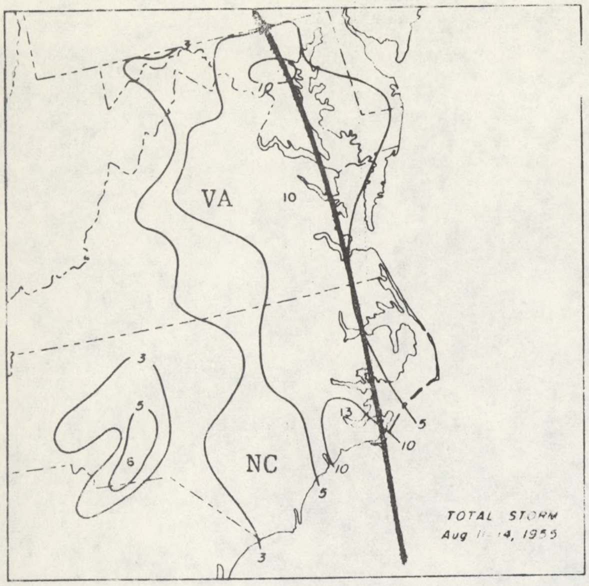


Fig 17. Rainfall Pattern for a Hurricane that After Crossing the Carolina Coast Curves to the Left or Right North of Virginia

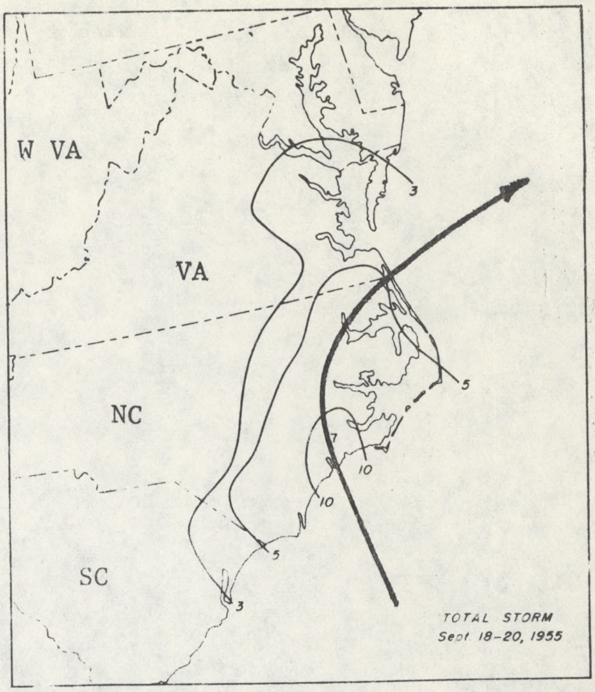


Fig 18. Hurricane Rainfall Pattern Suggested for Storms that Cross the Middle Atlantic Coast then Curve Rapidly to the East into the Atlantic

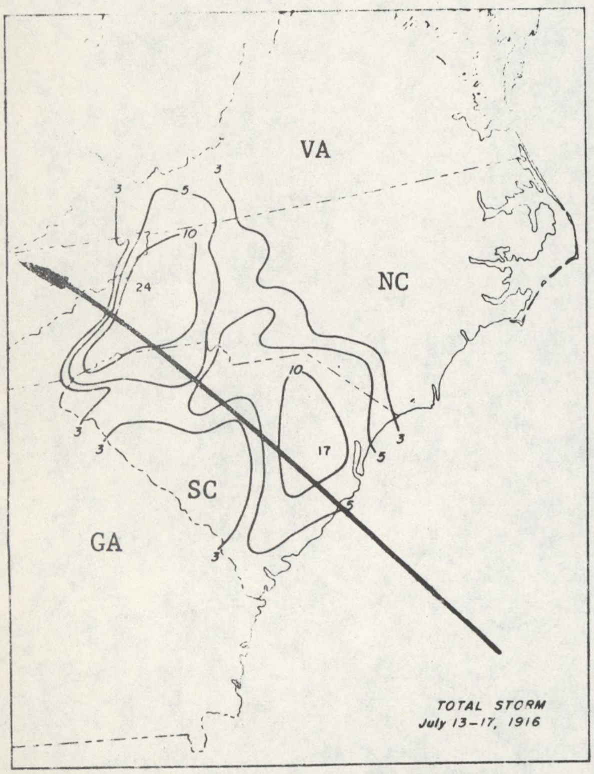


Fig 19. Rainfall Pattern Suggested for a Hurricane that Does not Re-curve

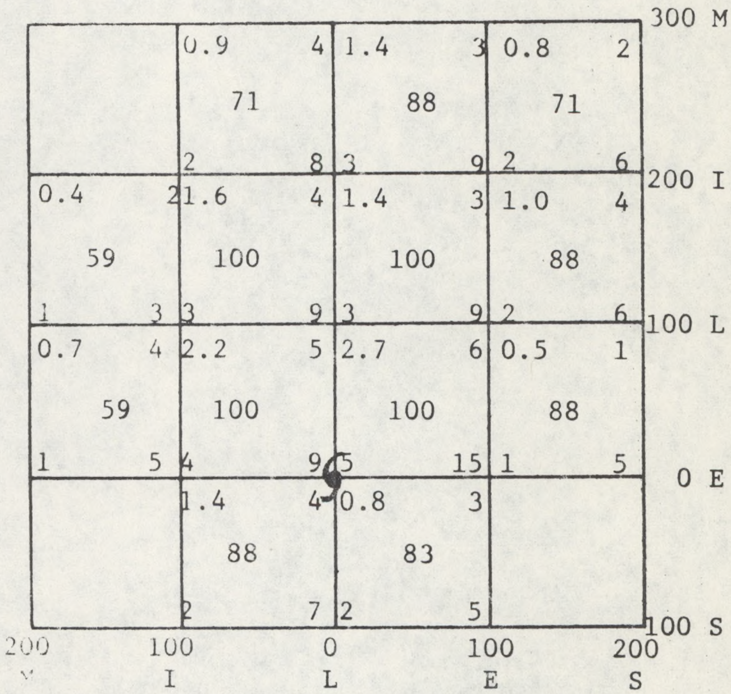


Fig 20. Average and Maximum 24-Hour Climatological Point and Areal-Average Rainfall Depths for Zone #5
(seventeen hurricanes)

ZONE #6 - THE NORTH ATLANTIC COAST

Three rainfall patterns were selected as characteristic from a sample of ten hurricanes studied for this zone. The selection of these patterns was based mostly on the point of hurricane penetration more than any other parameter.

The first rainfall pattern, shown by Figure #21, is offered for a hurricane that crosses Long Island with a southerly trajectory and passes over interior New England before recurving. The next pattern, shown by Figure #22, would apply to a hurricane that skirts the southern Long Island coast, then enters the mainland in the coastal sections of Rhode Island or Massachusetts. The last pattern offered, as in Figure #23, is suggested for hurricanes that enter the mainland near Chesapeake Bay.

The area of climatological areal-average and maximum 24-hour precipitation data shown by Figure #24 covers a more extensive area than for any other zone studied. The area extends from 200 miles either side of the coastal entry point to about 500 miles inland. The maximum 24-hour maximum point depths within this area ranged from 3 to 8 inches, while the areal-average depths ranged from 1 to 5 inches. The frequency of rainfall occurrence, irrespective of amount, varied from 60 to 100 percent. The absolute maximum values were found in the 100 by 100 mile square 100 miles inland and to the right of the hurricane penetration point.

The unusual rainstorms associated with hurricanes for the zone depended primarily upon prevailing extra-tropical weather systems, since almost all the heavy rains occurred several days prior to hurricane penetration and the hurricane rains just added more moisture to an existing flood condition.

1. The hurricane of September 10-22, 1938 produced a 17.1 inch rainfall center at Buck, Connecticut. These rains began about four days prior to hurricane landfall, slackened somewhat on the second and third days before landfall, then increased about a day before landfall, with rapid clearing to the south of the hurricane as it passed rapidly through the zone.

2. The hurricane of August 17-26, 1933 produced 16.0 inches of rain at Peekamoose, New York. Most of this precipitation, as in the 1938 storm, occurred prior to hurricane penetration of the coast. Rains began two days prior to the date the hurricane crossed the coast, with the major burst of rain occurring in eastern New York just ahead of the hurricane center, 24 hours after it crossed the coast. Rapid clearing followed the hurricane passage.

3. The hurricane of September 9-16, 1944 had a 12.0 inch rain center at New Brunswick, New Jersey. This storm showed the same characteristics as the two aforementioned storms with precipitation occurring three days before the storm crossed the coast. The maximum burst occurred within the 24 hours prior to hurricane penetration, with rapid clearing occurring to the rear of the hurricane as it passed through the zone.

The following observations of hurricane precipitation characteristics were noted for this zone:

1. Pre-hurricane precipitation is critical, with rains beginning two to three days ahead of the event of a hurricane and a maximum burst of hurricane-associated rain usually occurring during the 24 hours prior to hurricane penetration of the coast.

2. Storms in this zone move rapidly and precipitation ceases rapidly behind these systems. Therefore, rainfall after hurricane passage is usually of minor importance.

3. If a hurricane moves directly into the coast, it usually has a precipitation pattern that shows the maximum rainfall ahead and to the right of the hurricane center.

4. If a hurricane grazes the coast, fairly heavy rains are likely to occur along the immediate coastline ahead and to the left of the center.

5. The storm of September 12-17, 1903 was the only storm that produced less than five inches of rain during the hurricane period.

6. The prevailing extra-tropical weather systems have a profound influence upon hurricane behavior.

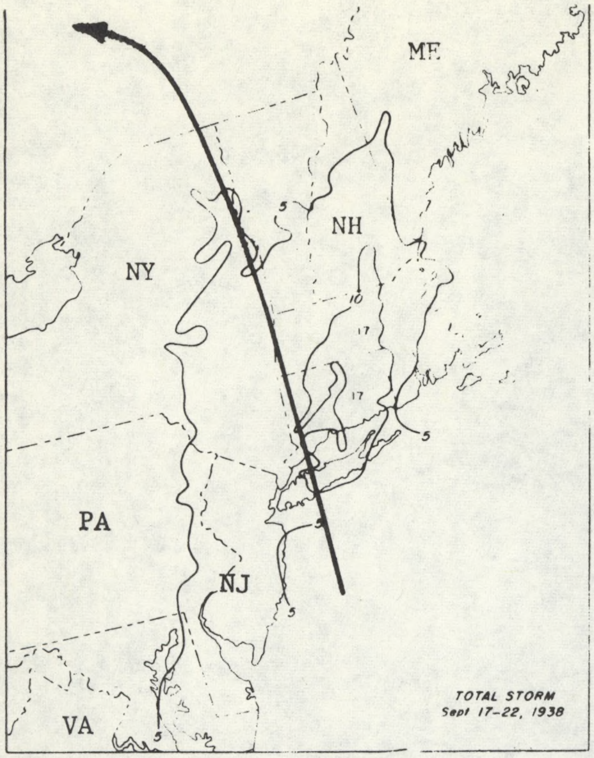


Fig 21. Typical Pattern for a Hurricane That Crosses Long Island then Moves Northward

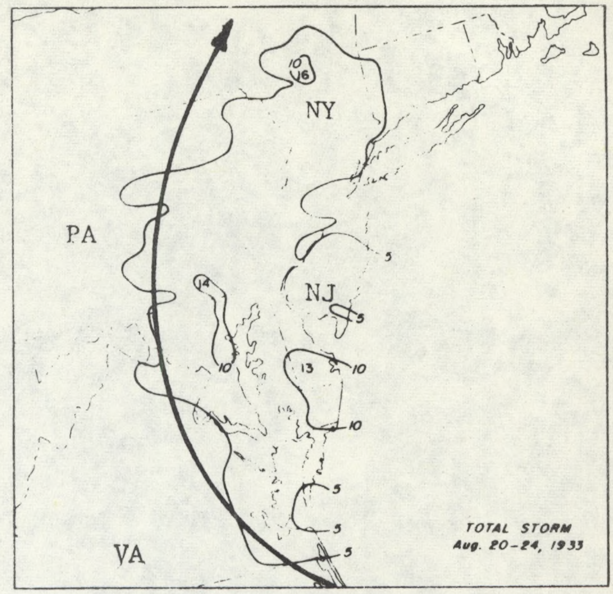


Fig 23. Suggested Rainfall Pattern for a Hurricane that Enters the East Coast Near Chesapeake Bay

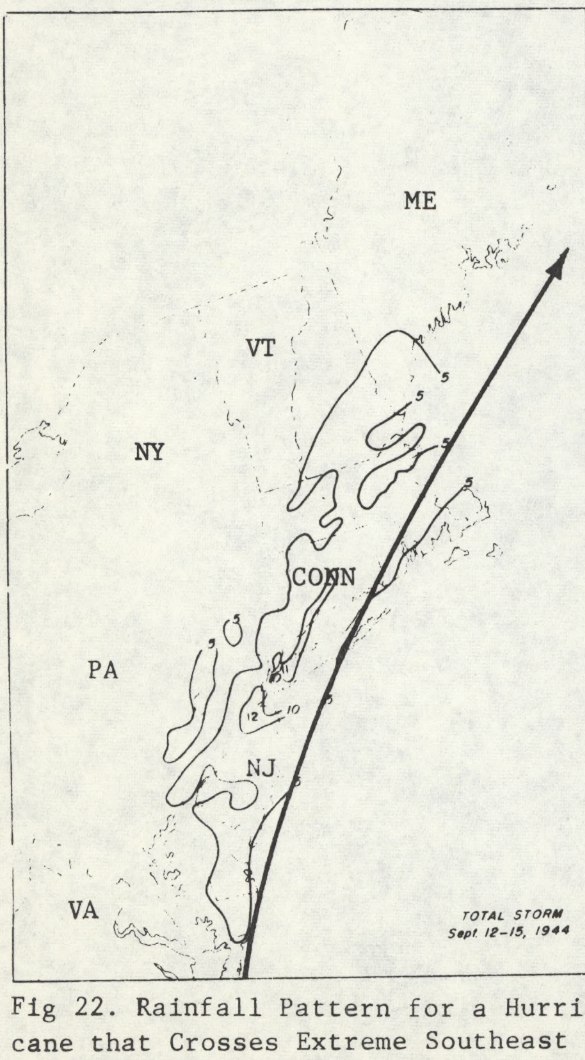


Fig 22. Rainfall Pattern for a Hurricane that Crosses Extreme Southeast New England

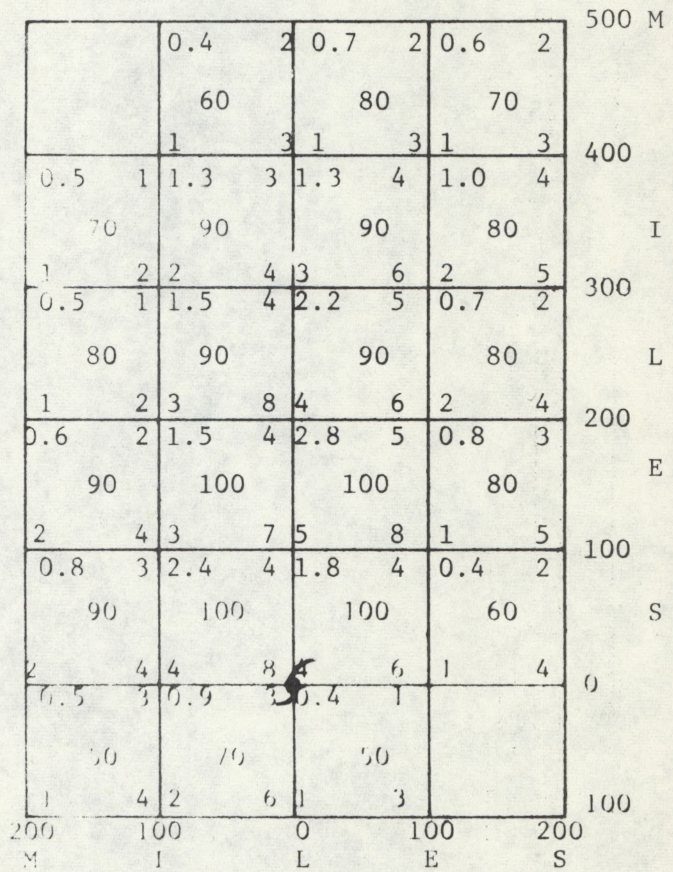


Fig 24. Average and Maximum 24-Hour Climatological Point and Areal-Average Rainfall Depths for Zone #6 (ten hurricanes)

SUMMARY AND CONCLUSION

The climatological summaries for each of the delineated zones contain information which can be utilized as guides for hurricane rainfall behavior for estimating an area's hurricane rainfall flood potential. The areal and point precipitation 24-hour precipitation data show the zonal distribution of hurricane areal and point 24-hour hurricane precipitation. They show at a glance the relative location of average and maximum observed depths as well as the area of most persistent hurricane rainfall. The typical isohyetal patterns portray geographically the distribution of precipitation in connection with a similarly-behaved hurricane. The patterns are for small zones and include the effect of local features that may influence the distribution of rainfall in a given zone. The unusual storms listed for each of the coastal zones represent the upper limits of zonal flood potential for they include rainfall situations that are the result of some of the worst combinations of meteorological events that have occurred in a given region. The summaries of hurricane rainfall characteristics indicate the peculiarities of the individual coastal zones, based upon the hurricane precipitation observations utilized.

The actual determination of a region's hurricane precipitation flood potential is beyond the scope of this study, for this evaluation depends upon a region's physiographical, hydrological and geological features, along with the climatological features of hurricane rainfall presented in this study. There are some areas where river basins are more vulnerable to hurricane rainfall than others. In an area such as south Texas (Zone #1), where most of the rainfall associated with hurricanes spread along the axis of the river basins, the flood potential is much greater than in the South Atlantic (Zone #5), where most hurricane-associated rainfall spreads transversely to the axis of the river basin's axis. Still, either of the two zones may experience equally severe hurricane flooding from a combination of meteorological events or antecedent conditions, as noted by the unusual storms of the respective zones.

It is believed that no one generalization as to the climatology of Gulf and Atlantic Coast hurricane rainfall can be made. There is a certain variation in the distribution of hurricane rainfall inland from the regional coastlines. This variation is not too great along the Gulf Coast, but it is quite noticeable along the Atlantic Coast.

The main features believed to be the greatest contributors to these variations are hurricane behavior, coastline orientation and latitude differences. As can be noted for the Gulf of Mexico coastal region (Zones #1 through #3) of this study, the distribution of intense rainfall is invariably in the forward quadrant of a hurricane, favoring the right side, which agrees with Cline.[6] This is not always the case for hurricanes in the Atlantic Coastal Region (Zones #4 through #6) where several storms have produced heavy rainfall in the forward left quadrant.

One thing can be said about the distribution which is consistent for all zones is that rainfall ceases rapidly after the hurricane crosses the coastline, with the inland intensity of rainfall dropping off quickly. The exception to the latter statement occurs when a hurricane reaches an inland mountain region with its wind circulation intact. However, even in these cases, one can see two distinct hurricane precipitation maxima, one along the coast and the other along the windward slopes of the mountains with an area of lesser rain between the two centers.

Finally, it should be mentioned that all the data presented deal with hurricane rainfall from hurricanes that crossed the regional coastline and passed over a land mass. The distribution of hurricane rainfall over oceanic regions may be entirely different from those presented in this study.

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List of Eastern Region Technical Memoranda
(continued from inside front cover)

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No. 26 The Sleet Bright Band. Donald Marier. October 1967

No. 27 A Study of Areas of Maximum Echo Tops in the Washington, D.C. Area During the Spring and Fall Months. Marie Fellechner. April 1968

No. 28 Washington Metropolitan Area Precipitation and Temperature Patterns. Clarence A. Woollum and Norman L. Canfield June 1968