NOAA Technical Memorandum NWS ER-86

RHODE ISLAND HURRICANES AND TROPICAL STORMS
A FIFTY-SIX YEAR SUMMARY
1936-1991

DAVID R. VALLEE

National Weather Service Office
Providence, Rhode Island

Scientific Services Division
Eastern Region Headquarters
Bohemia, New York
March 1993

United States
Department of Commerce
Ronald H. Brown
Secretary

National Oceanic and
Atmospheric Administration
D. James Baker
Under Secretary

National Weather Service
Elbert W. Friday, Jr.
Assistant Administrator

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1. INTRODUCTION

Hurricanes and tropical storms are no strangers to Rhode Island. Thirty-one such storms have affected the state in the past 56 years, either making landfall along the coast of southern New England, or passing close enough over the offshore waters to spread tropical storm or hurricane force conditions into the area. The intensities of these systems have ranged from weak, disorganized tropical storms to full fledged major hurricanes. The one feature common to almost all of the storms was a rapid acceleration toward Rhode Island, which greatly reduced the time to prepare and evacuate.

Tropical cyclones that affected Rhode Island have brought a variety of weather conditions. Some of the weaker storms passed with hardly a whimper, producing only occasional heavy showers and periods of gusty winds. Some systems have brought torrential rains and inland flooding, especially those systems that passed over or south and east of the state. Other storms that passed to the west were associated with strong winds, widespread tree and structural damage, and statewide power outages. Still others that hit at astronomical high tide produced extremely large storm surges that crashed onto the south coast of Rhode Island and up Narragansett Bay, and severely crippled coastal communities.

This paper was compiled to provide a general overview of all tropical cyclone activity near Rhode Island since 1936. The year of 1936 is arbitrary, chosen mainly to include a "not so well known" system prior to the well documented Great New England Hurricane of 1938. The year 1936 was also selected due to the very limited amount of information that was available prior to this time.

2. DATA

All information, regarding the tracks of each tropical cyclone, was obtained through the National Climatic Data Center publication, *Tropical Cyclones of the North Atlantic Ocean, 1871-1990.* Much of the data regarding storm intensity and damage information were gathered through use of several sources, including the *Monthly Weather Review* seasonal summaries, disaster survey reports, and numerous newspaper articles from the *Providence Journal* and the *Westerly Sun.* A complete list of references has been provided at the end of this report.

A discussion is available for each storm, including the storm's location of origin, as well as the types and severity of damage that occurred. A map has been provided for each storm, detailing its track toward Rhode Island. The intensity of each hurricane is given by Category, based on the Saffir/Simpson Hurricane Scale, at time of landfall or closest approach to Rhode Island.

Graphs of actual storm tides and associated storm surges are shown for six major hurricanes: the Great New England Hurricane of 1938; the September Hurricane of 1944; Hurricane Carol of 1954; Hurricane Edna of 1954; Hurricane Gloria of 1985; and, most recently, Hurricane Bob of 1991. The observed tide height data for the storms of 1938, 1944, and 1954 were gathered at the South Street Station Dock at the Narragansett Electric Company facility in Providence. The data for the hurricanes of 1985 and 1991 were collected at the Fox Point Hurricane Barrier, which was constructed in 1966, approximately 400 yards south of the South Street Station Dock. In addition, rainfall analyses have been provided for seven storms.

A glossary of terms is given in Appendix A. The Saffir/Simpson Hurricane Classification System is provided in Appendix B. A map of Rhode Island is shown in Appendix C, denoting the more commonly referenced coastal communities. Finally, a detailed map of Narragansett Bay has been provided in Appendix D, including various flood stages, as well as the location of the Fox Point Hurricane Barrier.

The September Hurricane of 1936
(CAT 1 - September 18-19)

The September Hurricane of 1936 was first noticed approximately 1000 miles east of the Windward Islands on September 8. This storm tracked steadily northwest over the next 10 days, eventually grazing the Outer Banks of North Carolina on September 18 with winds of 80 mph and severe coastal flooding (Figure 1). The hurricane turned sharply northeastward and accelerated during September 18, passing about 75 miles southeast of Block Island, RI, during the early morning hours of September 19.

The September Hurricane of 1936 delivered a glancing blow to Rhode Island. Sustained winds at the National Weather Service Office in Warwick were measured at 38 mph. Sustained winds of 30 to 50 mph occurred statewide and caused substantial tree damage and widespread power outages. Block Island recorded the highest sustained winds, 64 mph, as the eye passed to the southeast.

Some minor coastal flooding occurred, with tides running several feet above normal. Northeast winds of 40 to 60 mph buffeted the coastline of Rhode Island. Some beach erosion occurred, as well as damage to several sea walls. One hundred boats were damaged or destroyed on Narragansett Bay. Twenty-six boats capsized near the Edgewood Yacht Club in Cranston.

The Warwick Office received 3.99 inches of rainfall, while Block Island recorded 4.18 inches during the storm's passage. These rains caused a dam to break on the Woonasquatucket River, resulting in some flood damage along the river.

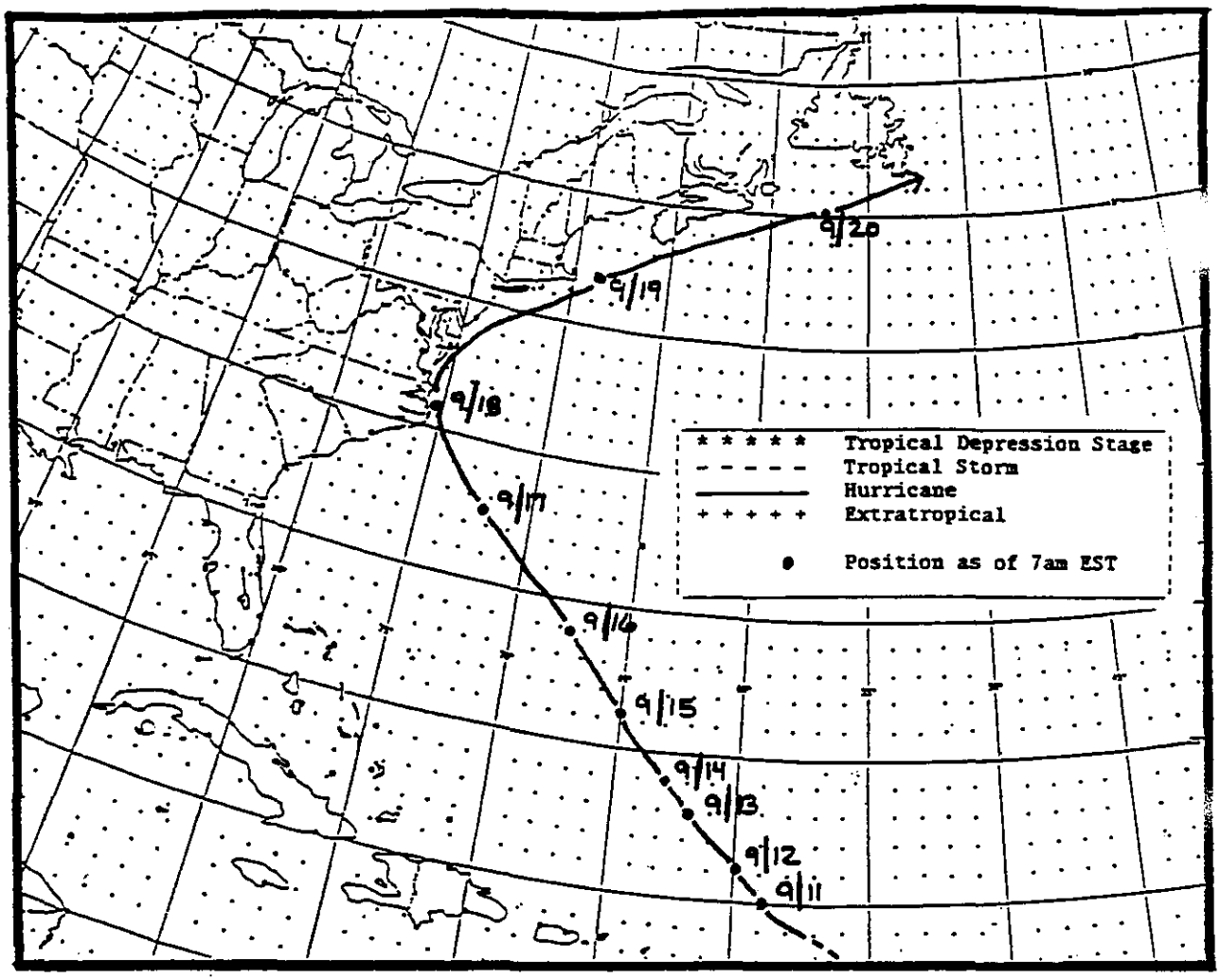


Figure 1. Track of the September Hurricane of 1936.

The Great New England Hurricane of 1938
(CAT 3 - September 21)

The Great New England Hurricane of 1938 was one of the most destructive and powerful storms ever to strike Rhode Island. This system developed in the far eastern Atlantic, near the Cape Verde Islands, on September 4. It made a 12 day journey across the Atlantic and up the eastern seaboard before crashing ashore in New England (Figure 2). The center made landfall at the time of astronomical high tide, moving north at over 50 mph. The hurricane did not weaken on its way toward New England due to its rapid forward speed and its track, which kept the center of the storm over the warm waters of the Gulf Stream.

The National Weather Service Office in Warwick recorded sustained winds of 87 mph before the anemometer blew away. Block Island recorded sustained winds of 91 mph, with a peak gust of 121 mph. Wind damage inland was extensive, including roof damage and severe tree damage. Widespread power outages occurred, which in some areas lasted several weeks. The lowest pressure recorded in Warwick was 28.90 inches.

A storm surge of 13.8 feet was recorded on the upper part of Narragansett Bay, as measured at the State Street Station Dock (Figure 3). The storm tide reached 19.01 feet above mean lower low water (MLLW), or 12.01 feet above flood stage. During the last hour prior to the maximum storm tide, waters on Narragansett Bay rose 8.5 feet, with a rise of 1.75 feet every 10 minutes during the last half hour.

The storm surge, arriving near high tide, completely flooded downtown Providence. The storm tide destroyed many coastal communities. Streets, houses, and restaurants were washed away. Extensive beach erosion was also widespread. Hundreds of boats were destroyed, including most of the fishing fleets based in Galilee, Wickford, and Bristol (see Appendix C and D). Four hundred and forty-one homes were destroyed, with over 1000 damaged. Two hundred and sixty-two people were killed in Rhode Island; 204 persons were injured.

Figure 4 is an analysis of the rainfall across southern New England the day the hurricane made landfall. Amounts in Rhode Island ranged from as little as 0.1 inch across eastern Rhode Island to 1 inch over the northwest hills. Maximum amounts of 6-7 inches occurred in Connecticut. The rainfall from the hurricane added to the amounts that had occurred with a frontal system several days before the hurricane made landfall. Figure 5 is an analysis of the rainfall from September 17-21. The combined effects from the frontal system and the hurricane produced rainfall amounts of 4 to 8 inches in Rhode Island.

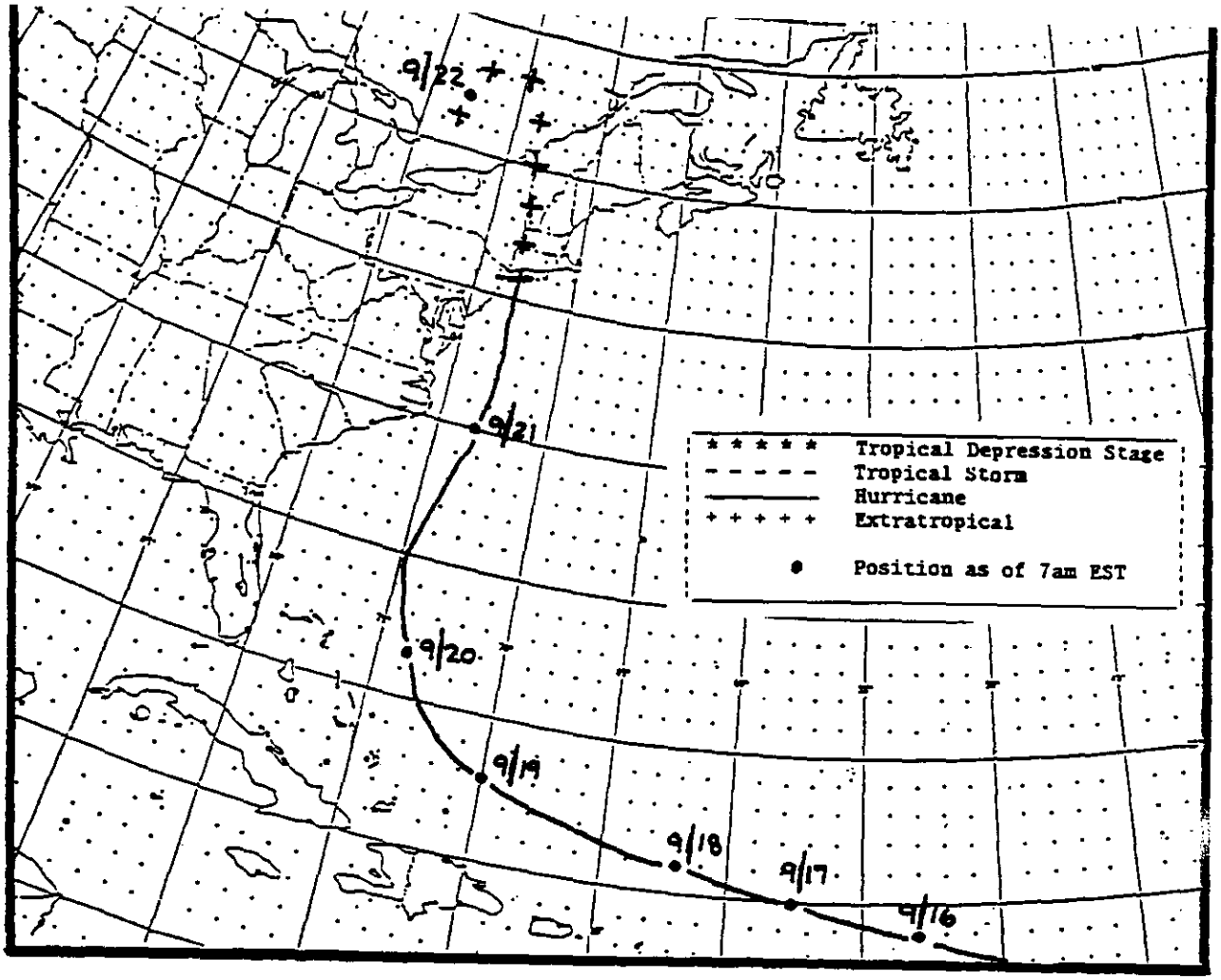


Figure 2. Track of the Great New England Hurricane of 1938.

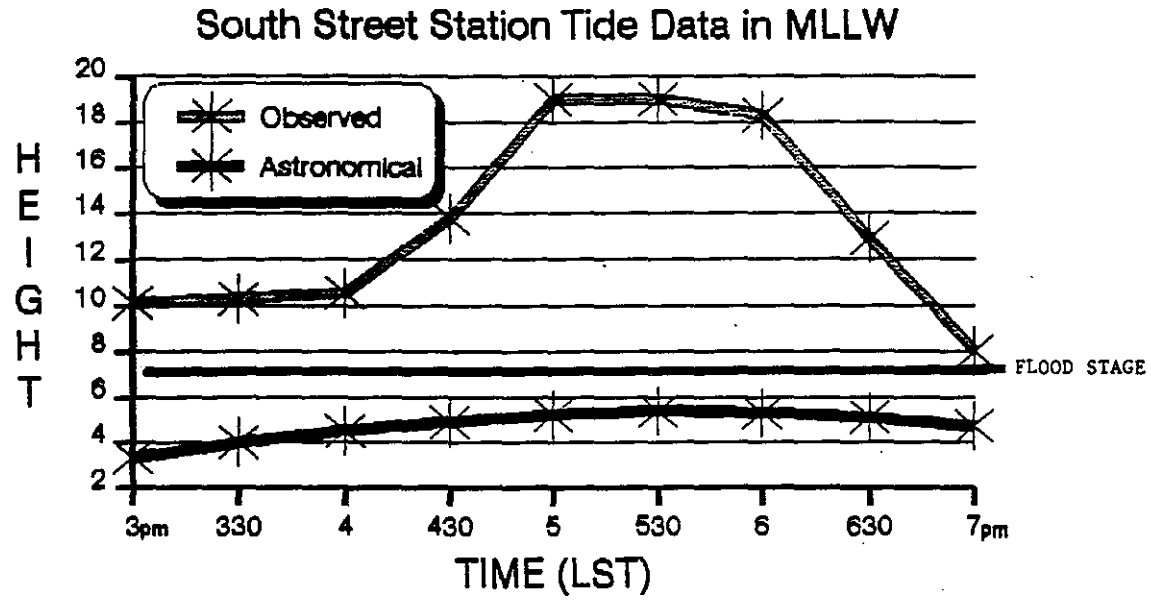


Figure 3. Storm surge height (feet) on September 21, 1938, associated with the Great New England Hurricane of 1938, recorded at the South Street Station Dock on upper Narragansett Bay.

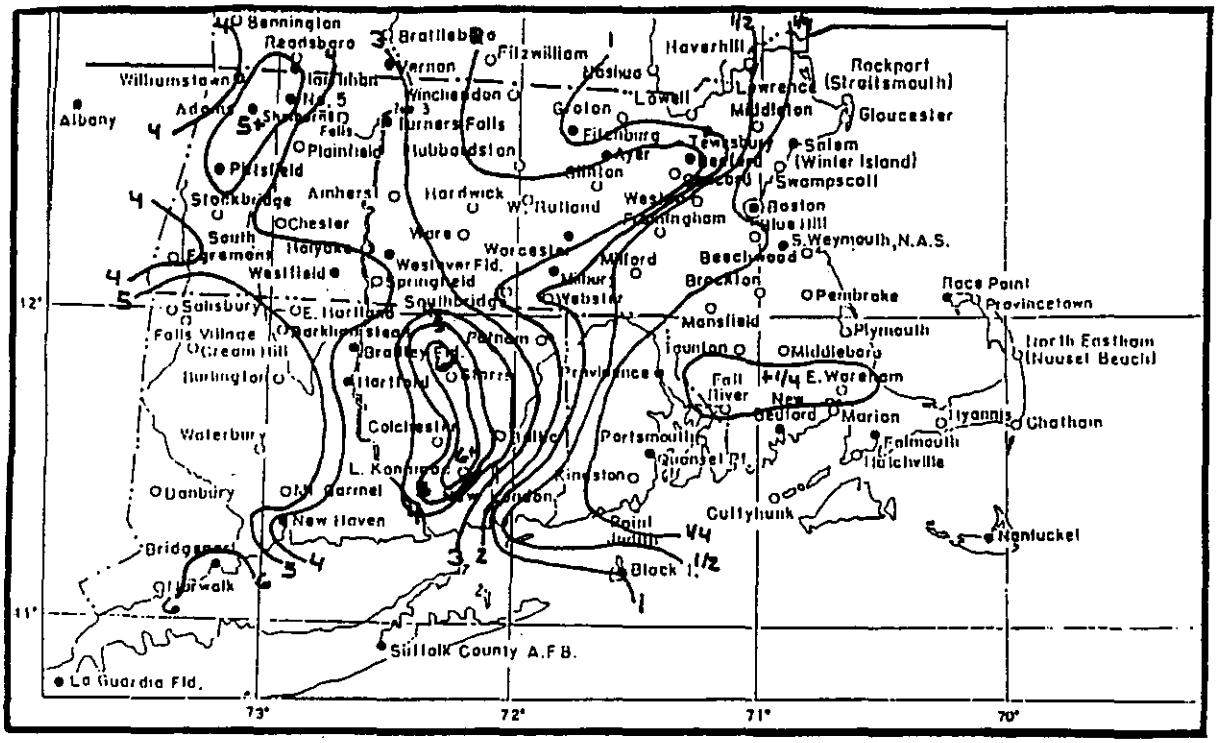


Figure 4. Analyzed precipitation field (inches) for rainfall associated with the Great New England Hurricane of 1938.

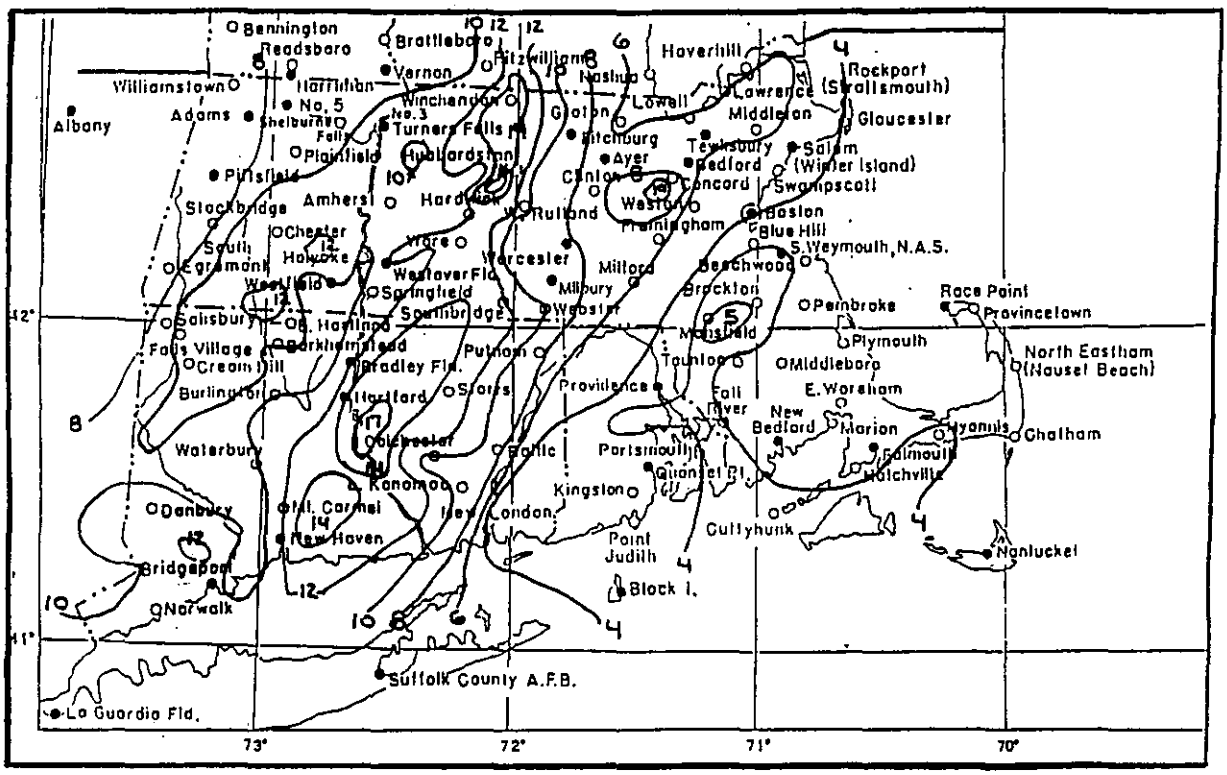


Figure 5. Analyzed precipitation field (inches) for the five day period of September 17-21, 1938, which includes the Great New England Hurricane (from U.S. Geological Survey 1938).

Hurricane of 1940
(CAT 1 - September 2)

On August 30, 1940, a tropical storm was detected several hundred miles east of the Bahamas (Figure 6). The storm intensified into a hurricane later that evening while heading northwestward toward the North Carolina coast. Most of the damage associated with this storm occurred along the North Carolina shoreline as the center passed east of Cape Hatteras. After passing Cape Hatteras, the hurricane curved northeastward and began to weaken. The center passed about 100 miles east of Cape Cod on September 2.

Damage was minimal in Rhode Island. The highest sustained wind recorded at the Weather Service Office was 25 mph from the north. Wind gusts to over 50 mph were recorded on Block Island. Tides rose several feet above normal due to the close proximity of the storm center, but resulted in only some areas being affected by minor coastal flooding. Rainfall was generally less than 0.25 inch.

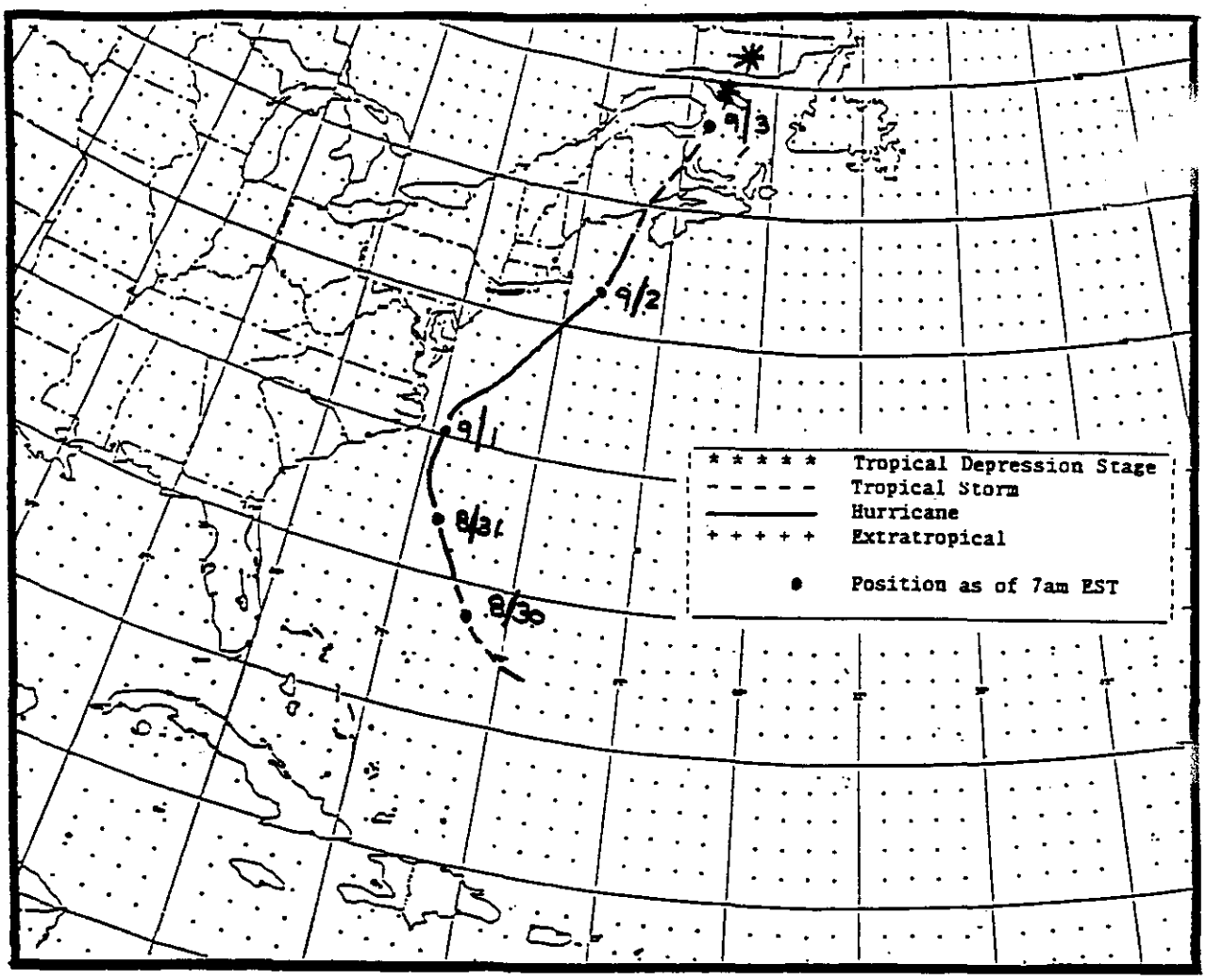


Figure 6. Track of the Hurricane of 1940.

Tropical Storm of 1944
(August 3)

The Tropical Storm of 1944 developed north of the Dominican Republic late in July (Figure 7). It intensified to hurricane strength before making landfall on the North Carolina coast on August 1. After making landfall, the system turned toward the northeast, weakening to tropical storm strength. The storm center re-entered the Atlantic just south of Atlantic City, NJ, on August 2, then passed 120 miles south of the Rhode Island shore during the morning of August 3. The storm weakened to a tropical depression by the time it passed east of Cape Cod.

No damage was reported from this storm in Rhode Island. Winds of 20 to 40 mph were common statewide. Rainfall of 1 to 1.5 inches accompanied this system.

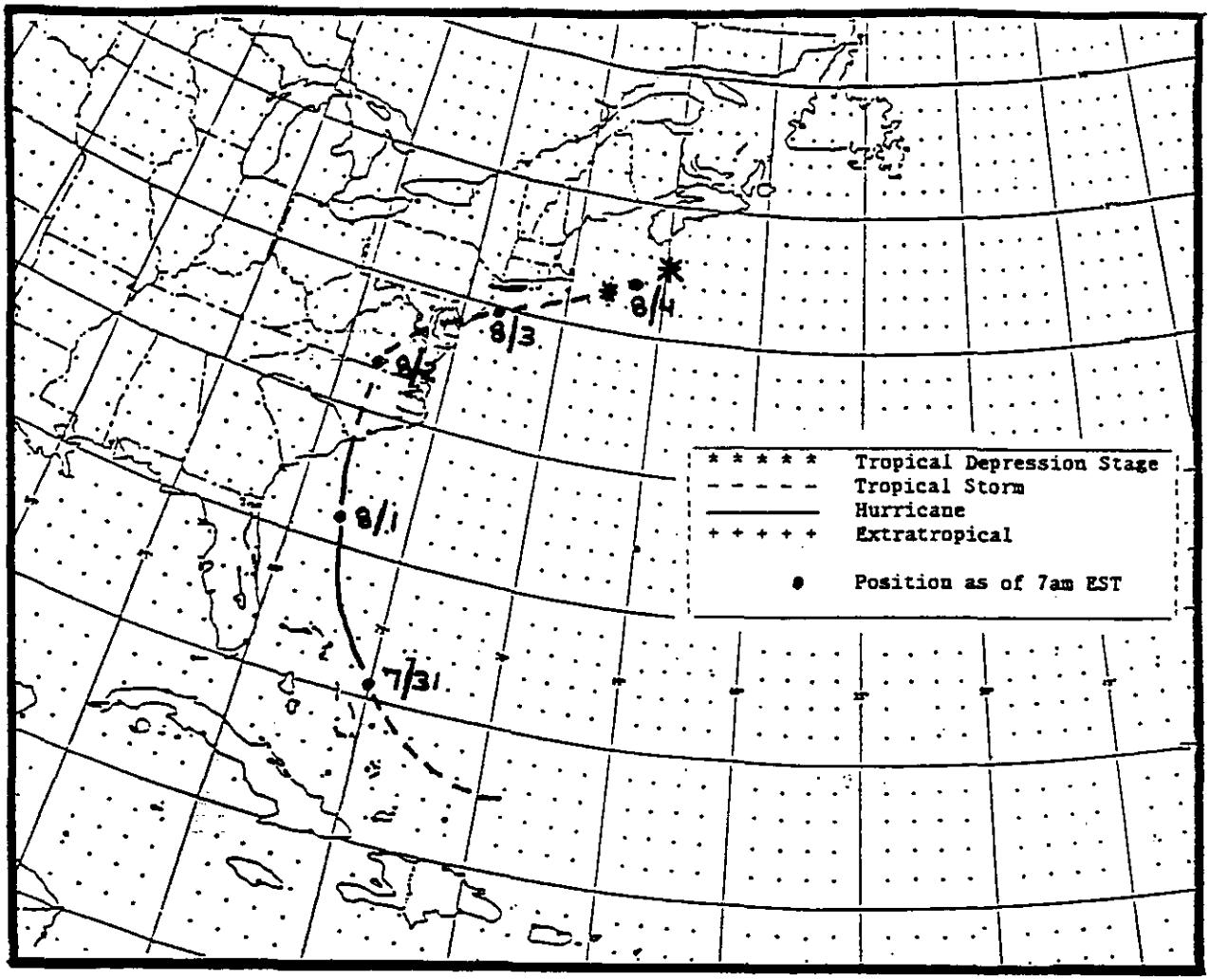


Figure 7. Track of the Tropical Storm of 1944.

The September Hurricane of 1944
(CAT 3 - September 14-15)

The Great September Hurricane of 1944 earned its place in Rhode Island history as one of the more intense storms to hit the area. This system developed several hundred miles northeast of the Virgin Islands on September 8 (Figure 8). It headed steadily northwestward for the next 5 days, then began its turn and acceleration toward the north and northeast. The center grazed the Outer Banks of North Carolina on the morning of September 14, and then made landfall between Charlestown and Narragansett, RI, at 11 pm. The storm hit Rhode Island head on, with the eye passing over the National Weather Service Office in Warwick at about 11:30 pm.

Sustained winds of 49 mph were recorded at the Weather Service Office, with a peak gust to 90 mph. Block Island reported sustained winds of 82 mph. Widespread power outages occurred. At the height of the storm, nearly 90 percent of the state was without electrical power. The lowest barometric pressure recorded at the Weather Service Office was 28.48 inches, with a reading of 28.34 inches on Block Island.

The Hurricane of 1944 made landfall approximately 1 hour before low tide, with a storm surge of 10 to 12 feet. A storm surge of 11.47 feet was recorded at the South Street Station Dock, pushing the storm tide to 12.18 feet (MLLW) or 5.18 feet above flood stage (Figure 9).

Significant coastal flooding still occurred along Narragansett Bay and across the south shore of Rhode Island, even though the storm arrived near low tide. Coastal communities along the east side of Narragansett Bay and southeast Rhode Island, from Bristol to Little Compton, were especially hard hit, having only recently been rebuilt following the Great New England Hurricane of 1938.

Generally 3 to 5 inches of rain fell statewide, with nearly 6 inches reported in downtown Providence. One to 2 inches of rain had occurred just 2 days before, on September 12-13. This brought state rainfall totals for September 12-15 to between 4 and 8 inches, with localized amounts of over 9 inches recorded in downtown Providence.

Damage was estimated at $2 million. A total of 701 homes and businesses were destroyed, while over 12,000 were damaged.

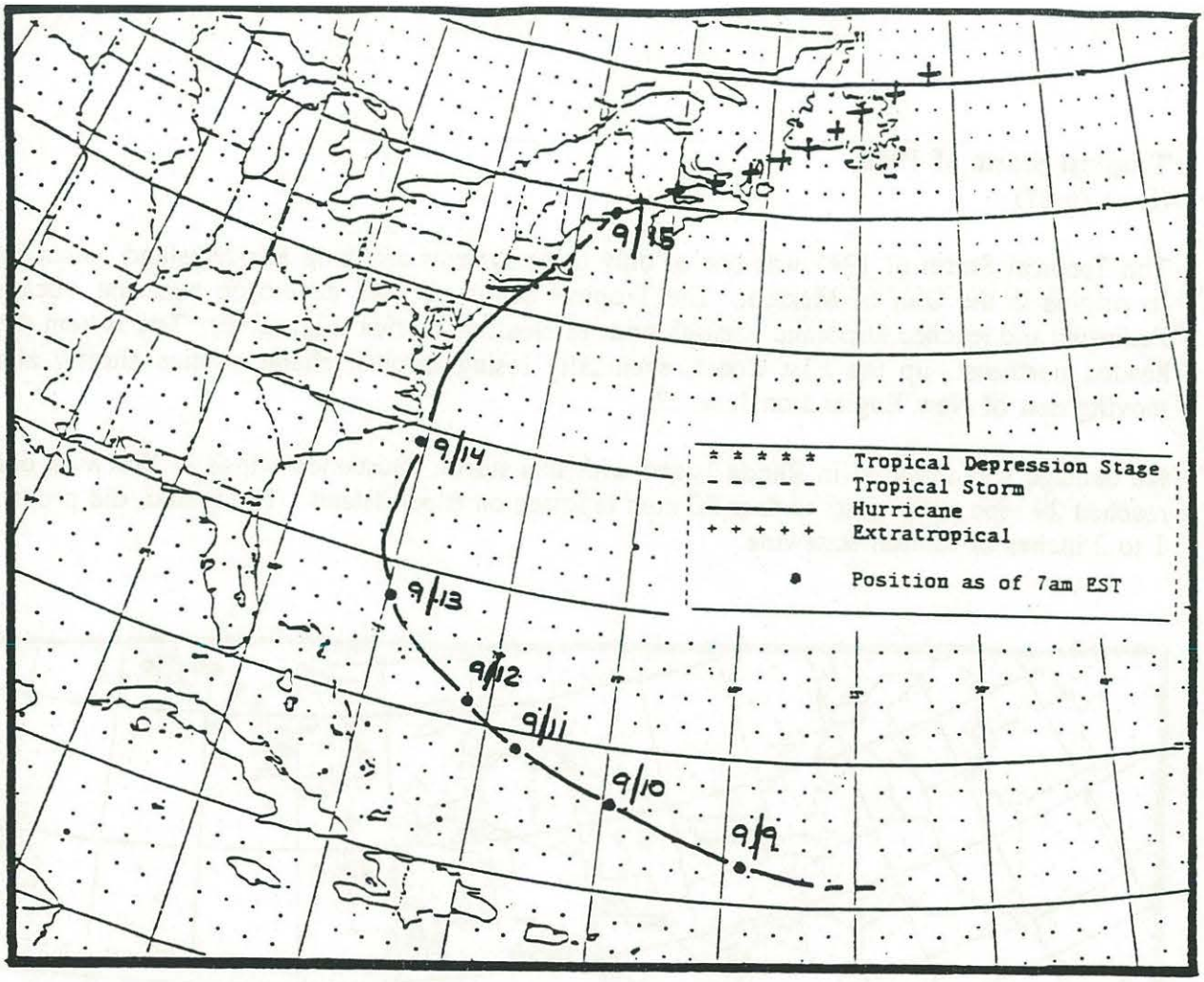


Figure 8. Track of the September Hurricane of 1944.

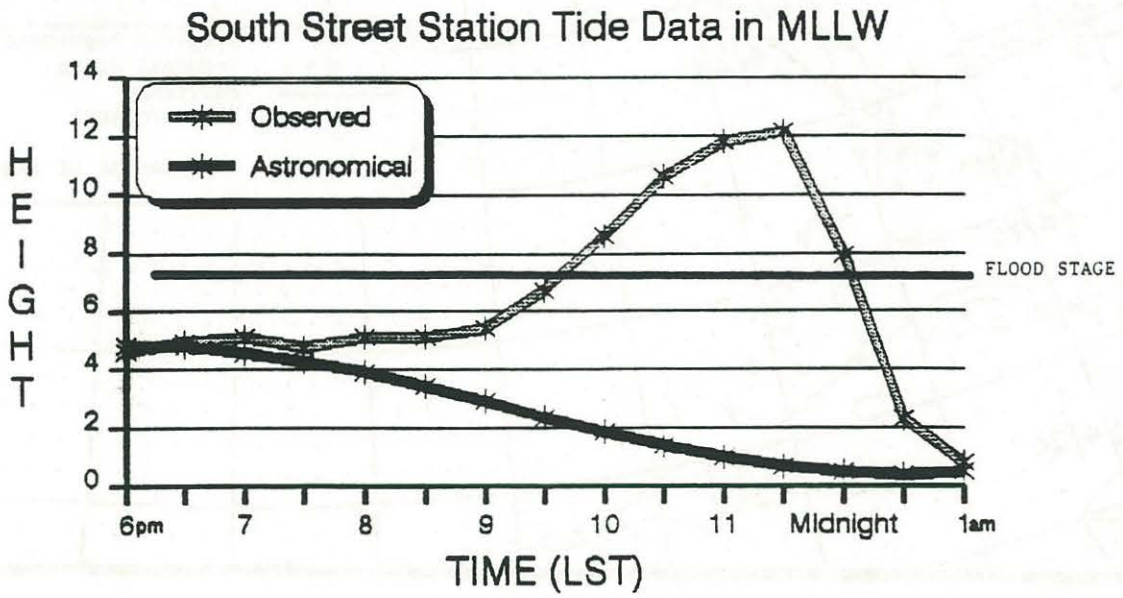


Figure 9. Storm surge height (feet) on September 14-15, 1944, associated with the September Hurricane of 1944, recorded at the South Street Station Dock on upper Narragansett Bay.

Tropical Storm of 1945
(June 26-27)

The Tropical Storm of 1945 was one of only three systems affecting Rhode Island which had its origins in the Gulf of Mexico. The Tropical Storm of 1945 developed near the Yucatan Peninsula and reached hurricane strength prior to crossing Florida (Figure 10). The system then headed northeast, up the East Coast, eventually losing tropical characteristics shortly after moving east of New England on June 27.

No damage was reported in Rhode Island with this storm. Sustained winds in Warwick only reached 29 mph, with gusts to near 50 mph reported on Block Island. The system did produce 1 to 2 inches of rainfall statewide.

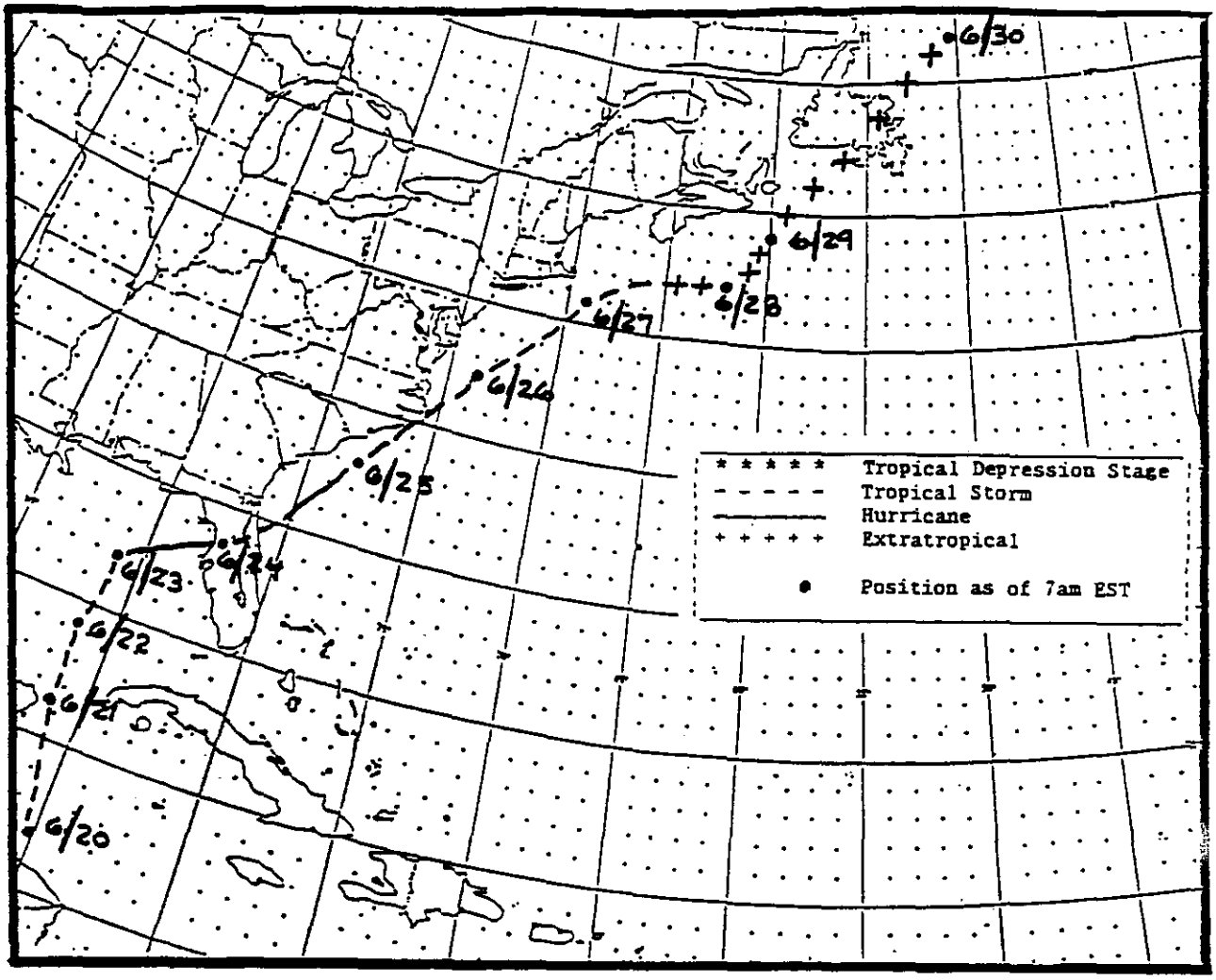


Figure 10. Track of the Tropical Storm of 1945.

Tropical Storm of 1949
(August 29)

On August 26, 1949, one of the most intense hurricanes in Florida history struck the lower east coast of that state, causing widespread damage (Figure 11). After making landfall, the system turned sharply northward, moving along the eastern slopes of the Appalachian Mountains. This storm maintained tropical storm strength as it continued northward, passing across southeast New York on August 29.

Strong south winds accompanied this system in Rhode Island. Sustained winds of 35 to 45 mph buffeted the area resulting in numerous power outages, caused mostly by fallen tree branches.

Tides ran 2 to 4 feet above normal along the Rhode Island south shore and Narragansett Bay at the time of high tide. Minor coastal flooding occurred, resulting in some coastal property damage. Most of the state received less than 1 inch of rain with this system.

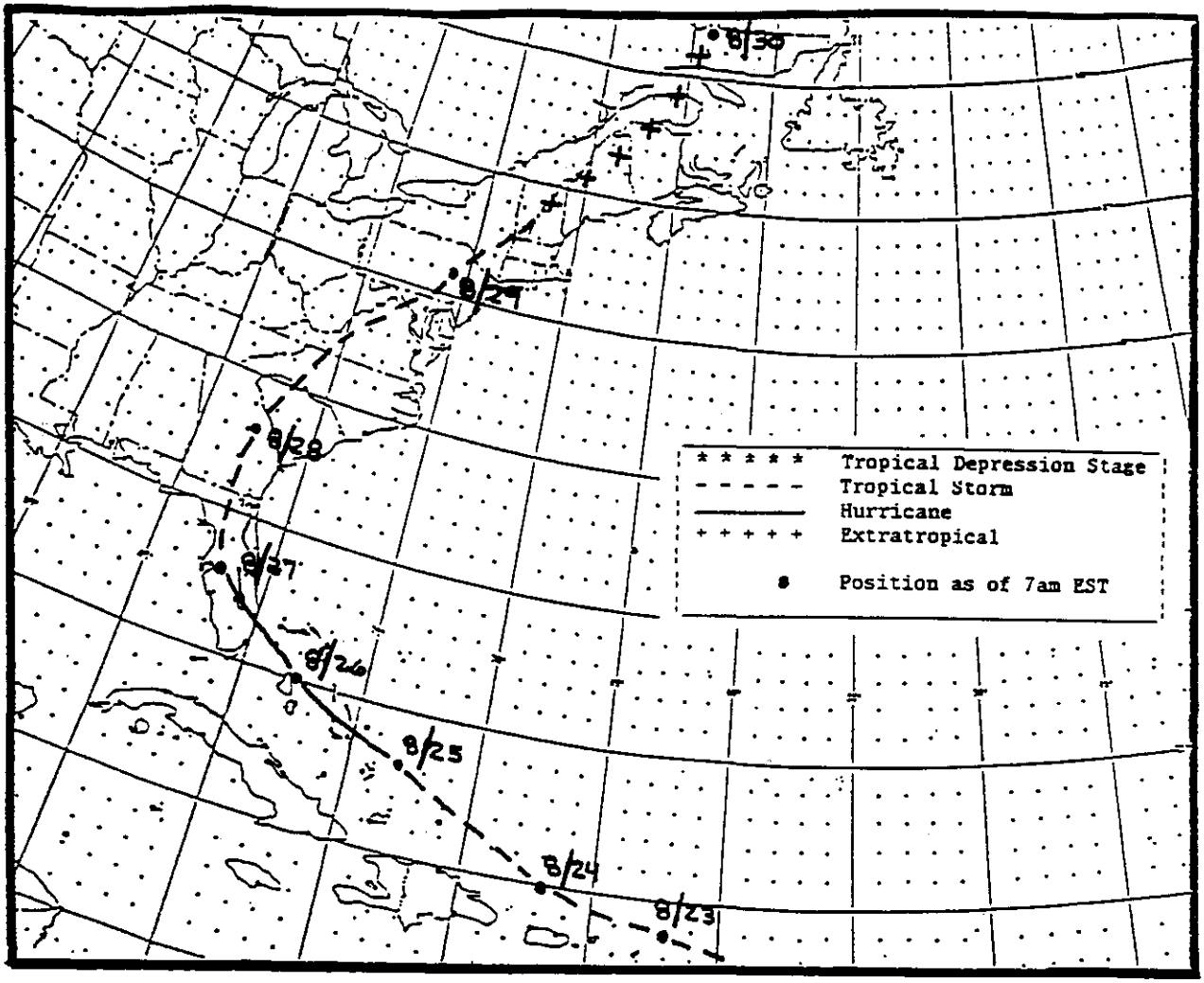


Figure 11. Track of the Tropical Storm of 1949.

Hurricane Able
(CAT 2 - August 20, 1950)

Hurricane Able developed several hundred miles east of the Leeward Islands in the western Caribbean Sea. The system intensified to hurricane strength while passing northeast of Puerto Rico on August 13 (Figure 12). Able began to turn to the northeast just prior to moving into the Bahamas on August 17. Able then paralleled the East Coast during the next 3 days, passing about 250 miles southeast of Rhode Island on August 20.

Hurricane force conditions associated with Able remained offshore to the south and east of Rhode Island. Sustained winds of only 20 to 30 mph were common statewide.

Able did produce significant rainfall in Rhode Island. The previous 3 months had been unusually dry, but the 2 to 5 inch rainfall associated with Able brought relief to the dry conditions.

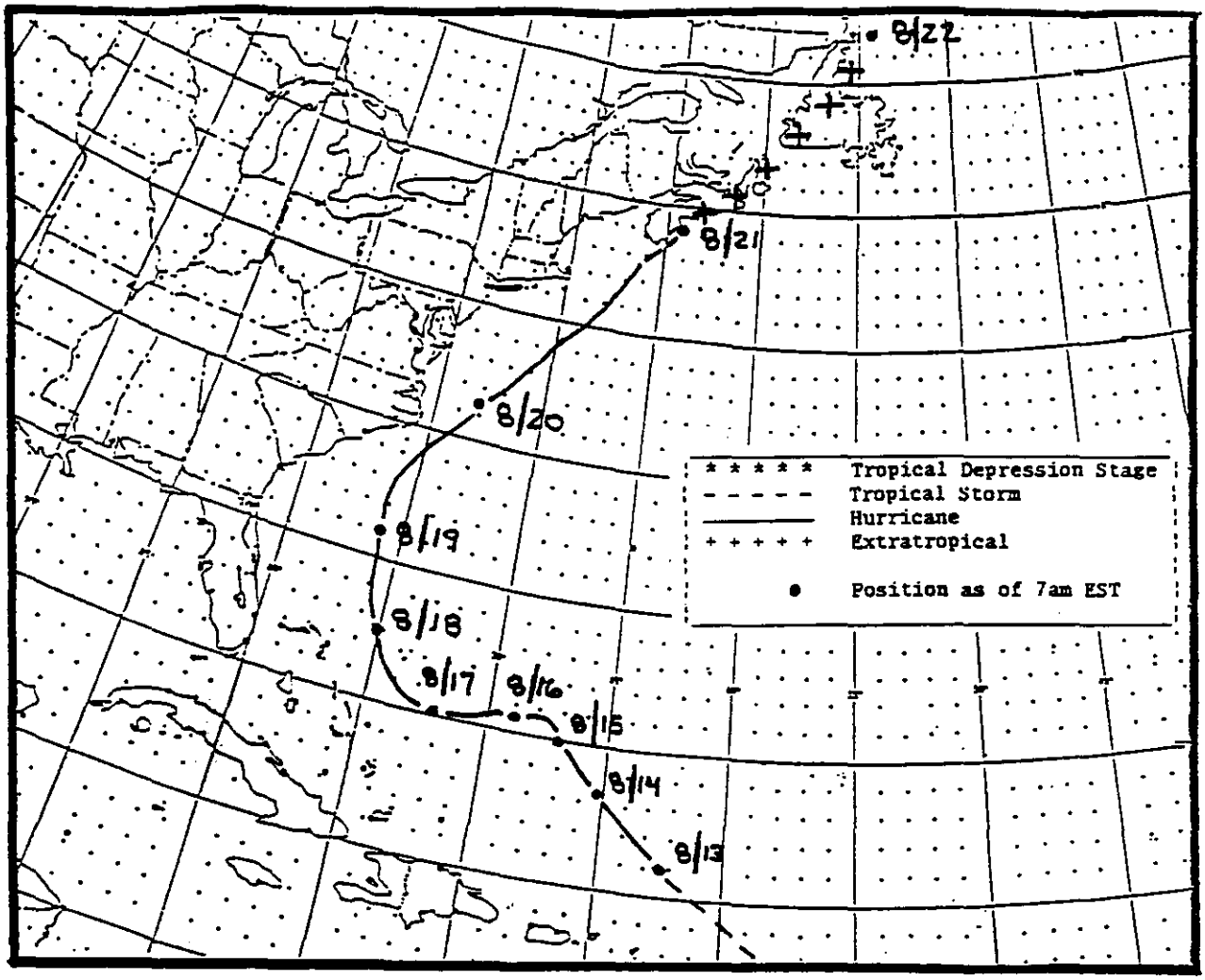


Figure 12. Track of Hurricane Able of 1950.

Hurricane Dog
(CAT 1 - September 11, 1950)

A weakening hurricane, named Dog, passed south and east of Rhode Island in the evening on September 11 (Figure 13). Earlier in the storm's life, while located north of the Leeward Islands, Hurricane Dog produced winds of up to 184 mph. However, by the time it approached New England, it had weakened considerably and eventually lost tropical characteristics as it passed southeast of Nantucket Island on September 11.

Strong northeast winds of 35 to 45 mph affected most of the state, with wind gusts to 70 mph on Block Island. Scattered power outages were reported, mostly on Block Island and in coastal communities. Some minor coastal flooding occurred as tides ran approximately 2 feet above normal. Some minor damage to small pleasure crafts did occur on Narragansett Bay. Rainfall from Hurricane Dog was generally around 0.5 inches statewide.

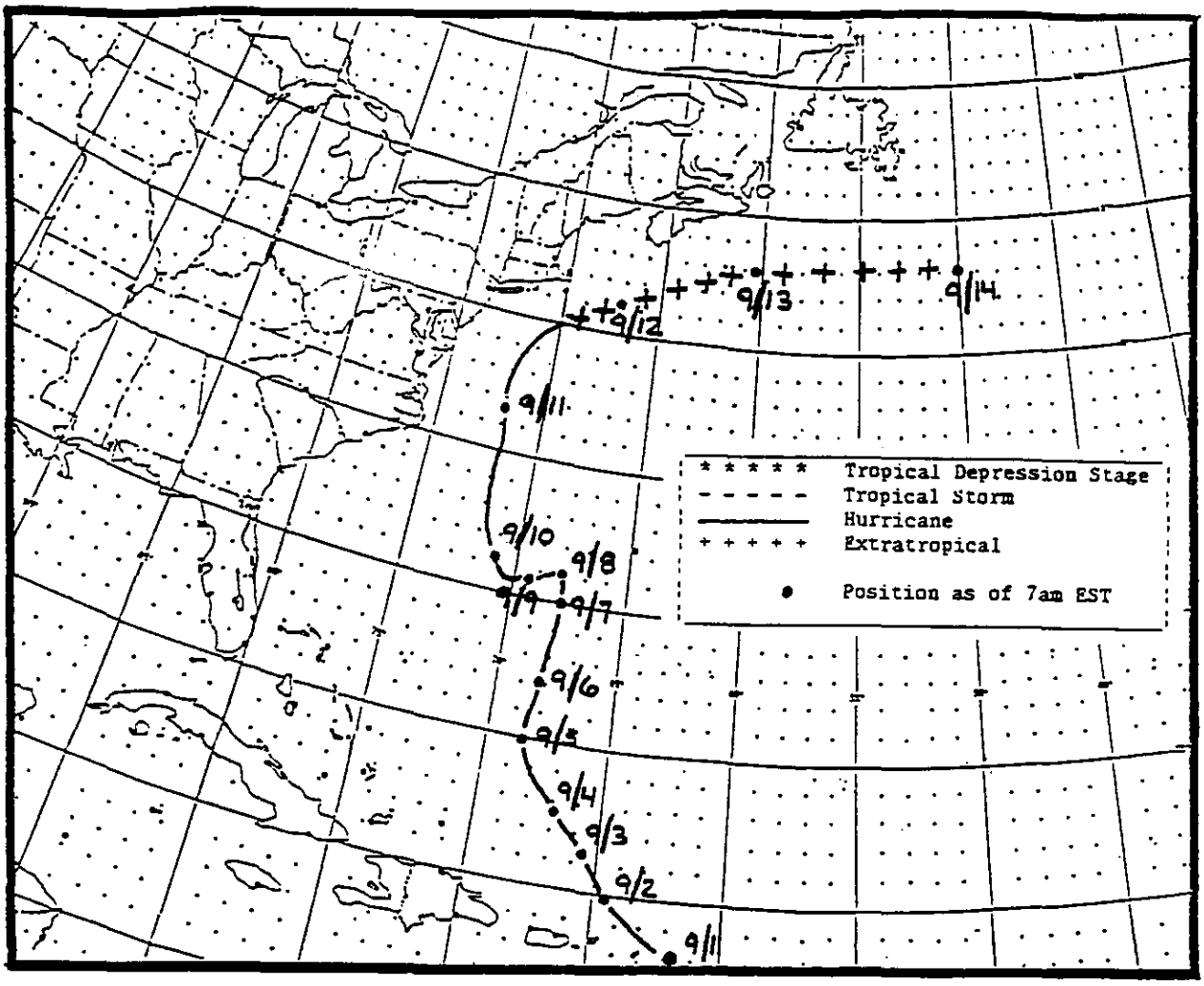


Figure 13. Track of Hurricane Dog of 1950.

Hurricane Barbara
(CAT 1 - August 14-15, 1953)

Hurricane Barbara gave Rhode Island a glancing blow as it passed south of the state during the late night hours on August 14 (Figure 14). Barbara had developed in the southeast Bahamas 4 days earlier. The hurricane headed north, making landfall along the east shore of North Carolina. Barbara continued to weaken as the center turned northeastward, passing about 85 miles southeast of Rhode Island.

The immediate south coast of Rhode Island and Block Island felt the worst of Barbara, with sustained winds of 40 to 50 mph and gusts to 70 mph on Block Island. Sustained winds of 20 to 30 mph were felt over interior Rhode Island. Scattered power outages were reported, mostly along the coast. Tides ran 2 to 4 feet above normal, but did not result in serious coastal flooding. Storm totals of 2 to 4 inches of rain were reported statewide from Barbara, with Block Island receiving 4.86 inches.

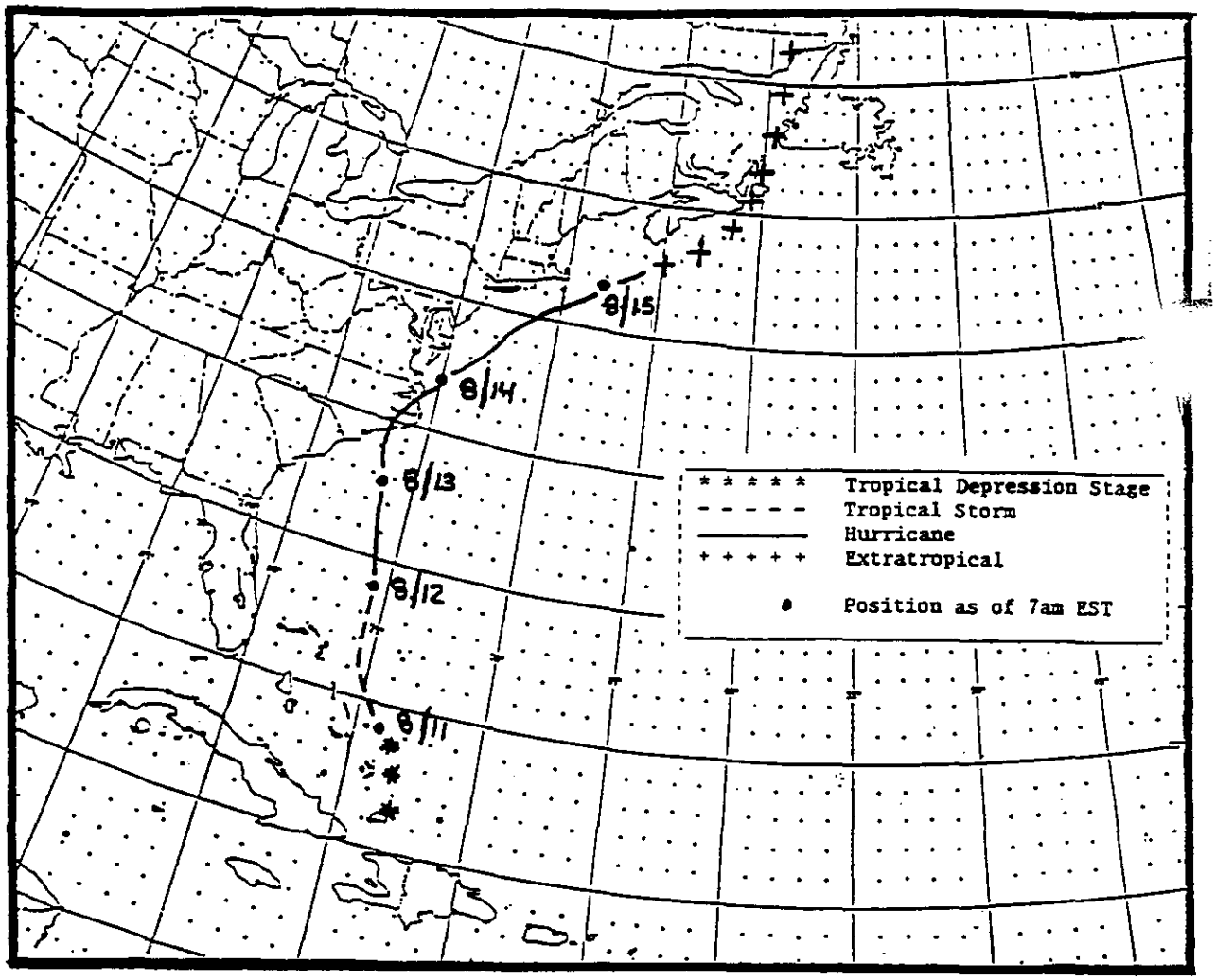


Figure 14. Track of Hurricane Barbara of 1953.

Hurricane Carol
(CAT 3 - August 31, 1954)

On the morning of August 31, Hurricane Carol, the most destructive hurricane in Rhode Island since the Great New England Hurricane of 1938, came crashing into the state, leaving 19 people dead in her wake. Carol had developed in the Bahamas several days earlier, making only slow progress northward (Figure 15). Carol rapidly accelerated during the evening of August 30, while passing just east of Cape Hatteras, NC. Carol made landfall on eastern Long Island and southeastern Connecticut about 12 hours later, moving at over 35 mph.

Sustained winds of 80 to 100 mph blew down trees and power lines statewide. The National Weather Service Office in Warwick recorded the strongest wind speeds ever reached at the office, a sustained wind of 90 mph with a peak gust to 105 mph before the anemometer failed. Block Island also set a record for a peak wind gust of 130 mph! Low barometric pressures also accompanied Carol. The pressure in Warwick dropped to 28.69 inches, while Block Island recorded a lowest pressure of 28.50 inches.

Hurricane Carol arrived shortly after high tide, causing widespread storm tide flooding. A storm surge of 13.7 feet was recorded at the South Street Station Dock on upper Narragansett Bay (Figure 16). This was only 0.1 foot below the surge which accompanied the Great New England Hurricane of 1938. The storm tide reached 17.51 feet (MLLW), or 10.51 feet above flood stage. The rate of rise prior to the maximum tide was very similar to the Great New England Hurricane of 1938. During the last hour prior to the maximum storm tide, the waters on Narragansett Bay rose 7.75 feet, with a rate of 1.5 feet every 10 minutes during the last half hour period.

Coastal communities from the south coast of Rhode Island to downtown Providence were devastated. Entire coastal communities were washed away by the storm tide, which ran 10 to 11 feet above flood stage. Downtown Providence was completely flooded, as was the case in 1938. Rainfall amounts ranged from 2.5 to 5 inches and resulted in some minor stream flooding inland (Figure 17).

Damage was severe, estimated at over $2 million. Nearly 3800 homes were destroyed, along with 3500 automobiles and 2000 boats. The whole state was without electrical power from the early afternoon on August 31 into the morning hours of September 1. In addition, 95 percent of all phone service was lost.

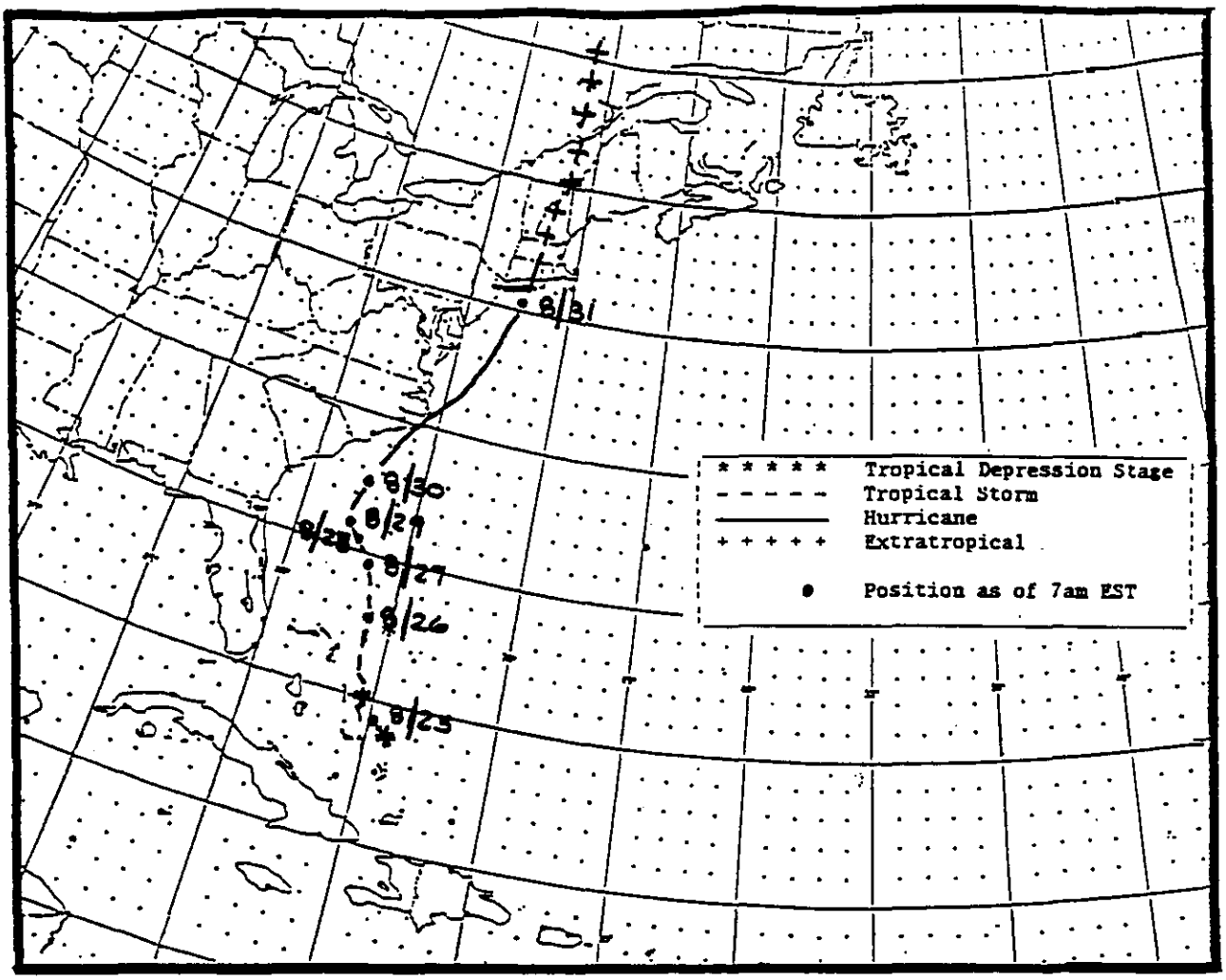


Figure 15. Track of Hurricane Carol of 1954.

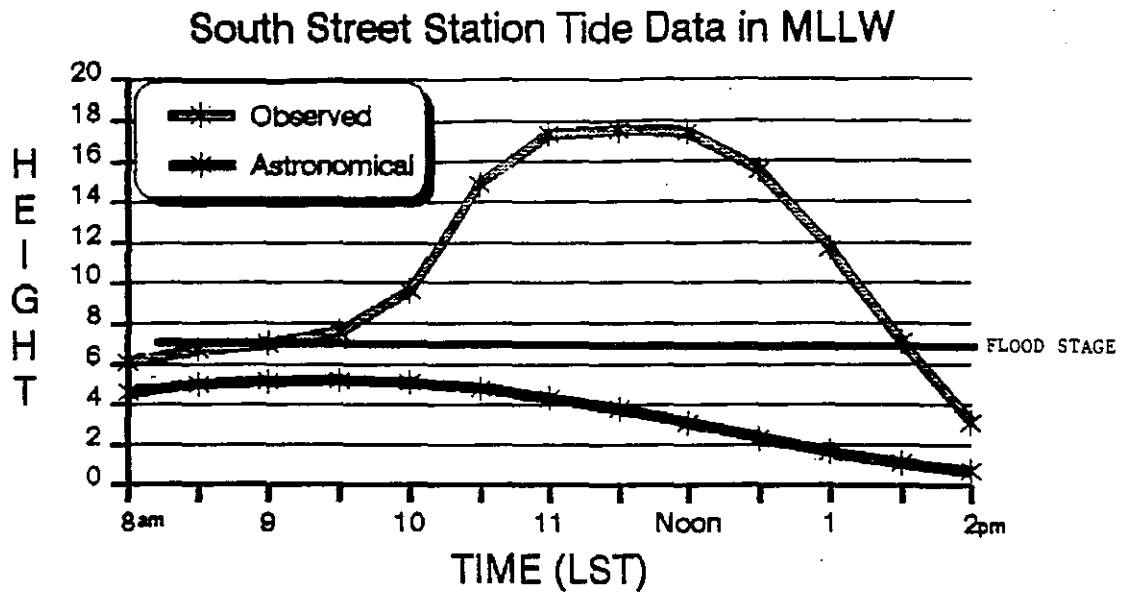


Figure 16. Storm surge height (feet) on August 31, 1954, associated with Hurricane Carol, recorded at the South Street Station Dock on upper Narragansett Bay.

Figure 17. Analyzed precipitation field (inches) for rainfall associated with Hurricane Carol.

Hurricane Edna
(CAT 3 - September 11, 1954)

Following closely on the heels of Hurricane Carol was Hurricane Edna. Edna followed a track up the East Coast that was slightly east of Carol's track (Figure 18). Edna raced toward Rhode Island at over 45 mph, but veered about 100 miles farther east. Edna made landfall during the morning of September 11 over the eastern tip of Cape Cod.

Strong north winds, sustained at 50 to 70 mph, occurred over mainland Rhode Island as Edna passed east of the state. The strong winds knocked out electrical power in many locations, power which only several days before had been restored following Carol. Hurricane force winds did affect Block Island with sustained winds of 87 mph and a peak gust to 110 mph. The barometric pressure on Block Island fell to 28.59 inches as Edna passed to the east. The National Weather Service in Warwick recorded a lowest pressure of 28.73 inches.

Rhode Island was spared severe coastal flooding due to a track south and east of the state and the storm's passage near low tide. A storm surge of 4.1 feet was recorded at the South Street Station Dock, resulting in a storm tide of 4.7 feet (MLLW) (Figure 19).

Edna's track to the east placed Rhode Island on the rainy side of the storm. Rainfall amounts of 4 to nearly 7 inches occurred statewide (Figure 20). This rainfall aggravated the already saturated conditions caused by Hurricane Carol 11 days earlier. The total combined rainfall for Carol and Edna ranged from 6 to 11 inches across Rhode Island and resulted in considerable street, river, and small stream flooding (Figure 21). Portions of the Blackstone River in northern Rhode Island rose several feet above flood stage and inundated some residential areas.

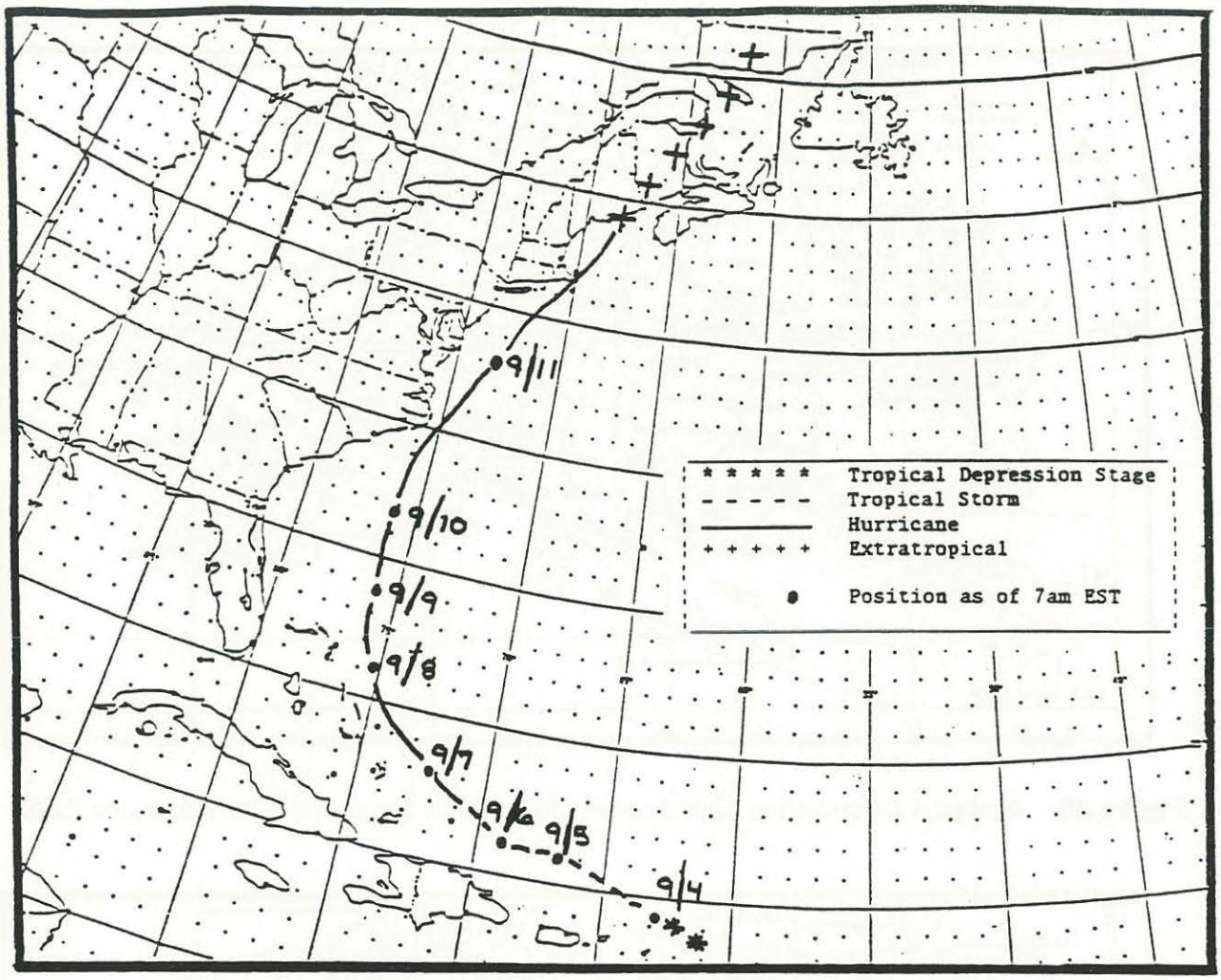


Figure 18. Track of Hurricane Edna of 1954.

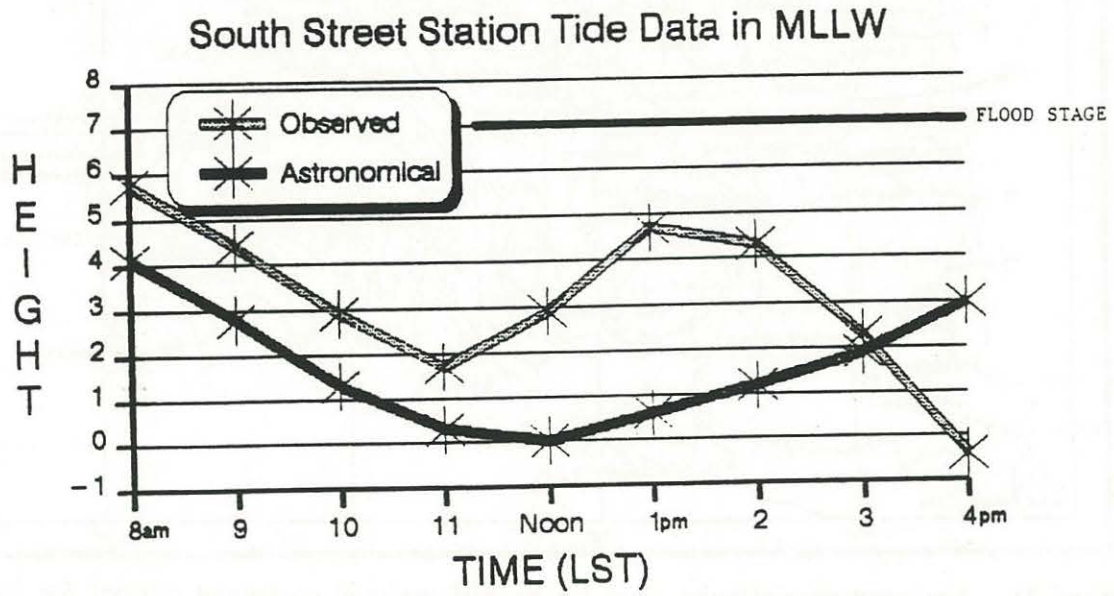


Figure 19. Storm surge height (feet) on September 11, 1954, associated with Hurricane Edna, recorded at the South Street Station Dock on upper Narragansett Bay.

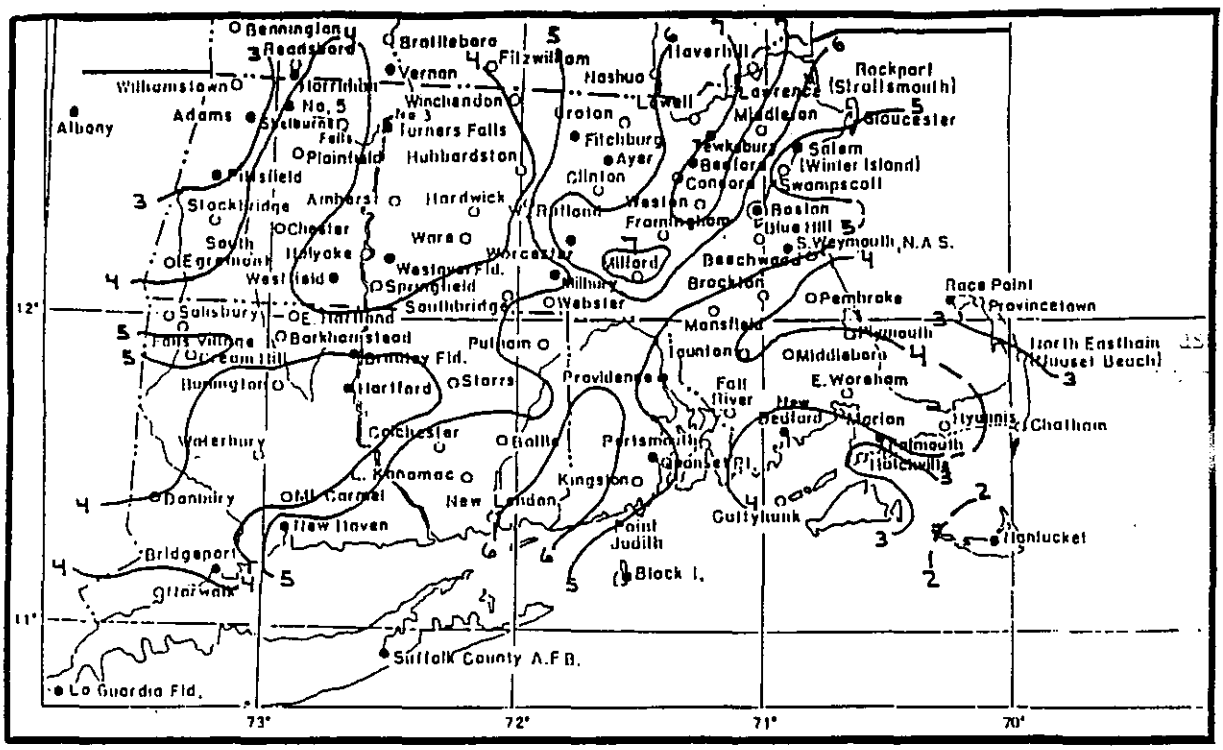


Figure 20. Analyzed precipitation field (inches) for rainfall associated with Hurricane Edna.

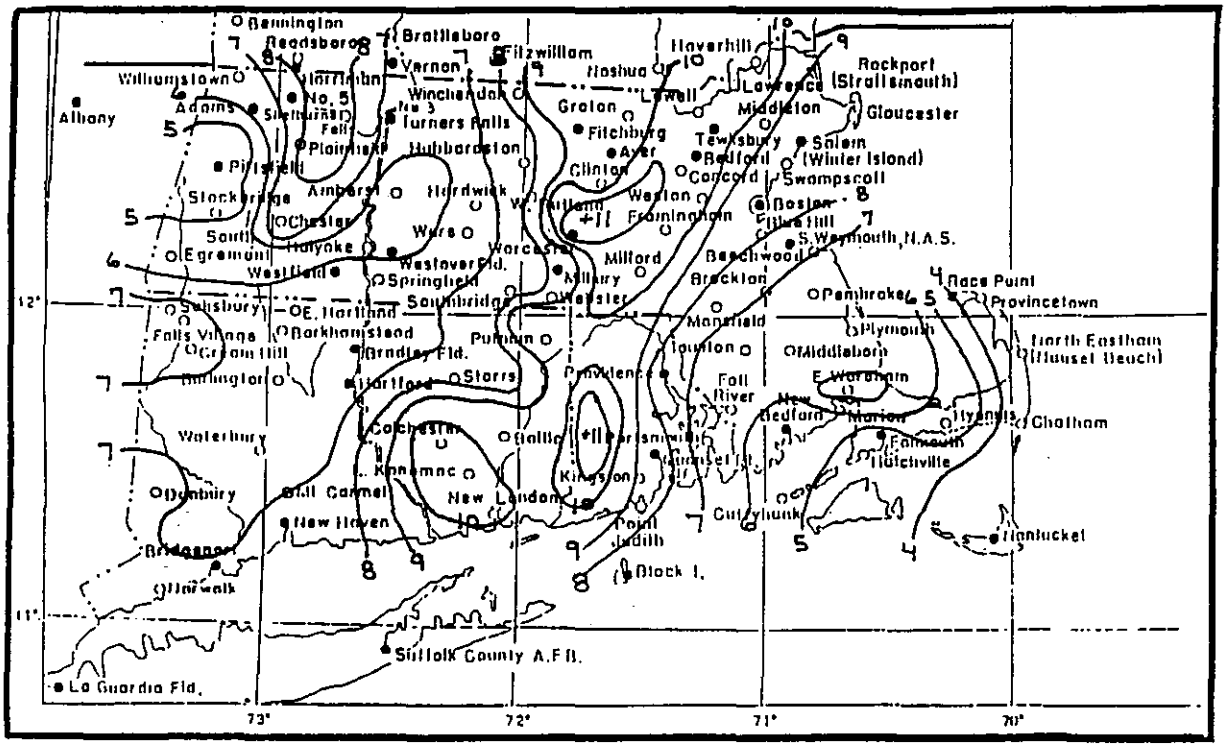


Figure 21. Analyzed precipitation field (inches) of the total combined rainfall for Hurricane Carol and Hurricane Edna.

Tropical Storm Connie
(August 12-14, 1955)

Connie developed in the eastern Atlantic on August 3. The system moved steadily west-northwest and reached hurricane strength during the evening of August 4. Connie strengthened substantially while passing north of the Virgin Islands. By August 9, Connie began to lose strength and forward speed. The system continued very slowly northwestward during the following 3 days, eventually making landfall on the North Carolina coast on August 12 (Figure 22).

Most of the damage from Connie occurred along the Carolina coast due to the prolonged period of east to southeasterly winds that pushed tides several feet above normal. The system continued inland and remained a tropical storm as far north as extreme southwestern New York.

The main impact on Rhode Island was substantial rainfall. Much of the moisture associated with Connie was carried northward up the coast into New England. Rhode Island received 3 to 6 inches of rain from the system (Figure 23). Relatively dry conditions preceded the storm, so the rainfall seemed beneficial at the time. However, the rainfall from Connie set the stage for what would turn out to be some of the worst inland flooding in Rhode Island's history due to the affects of approaching Tropical Storm Diane.

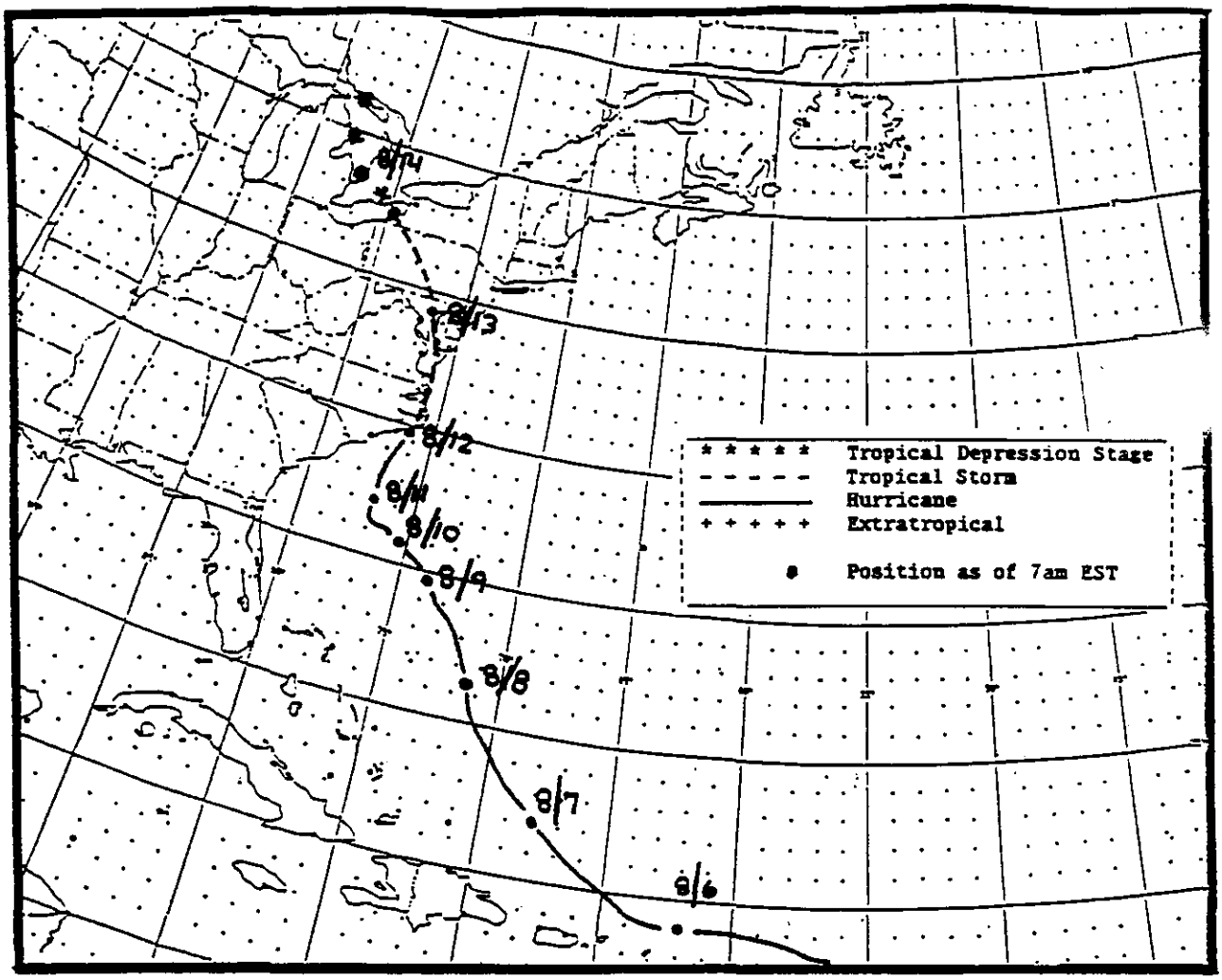


Figure 22. Track of Tropical Storm Connie of 1955.

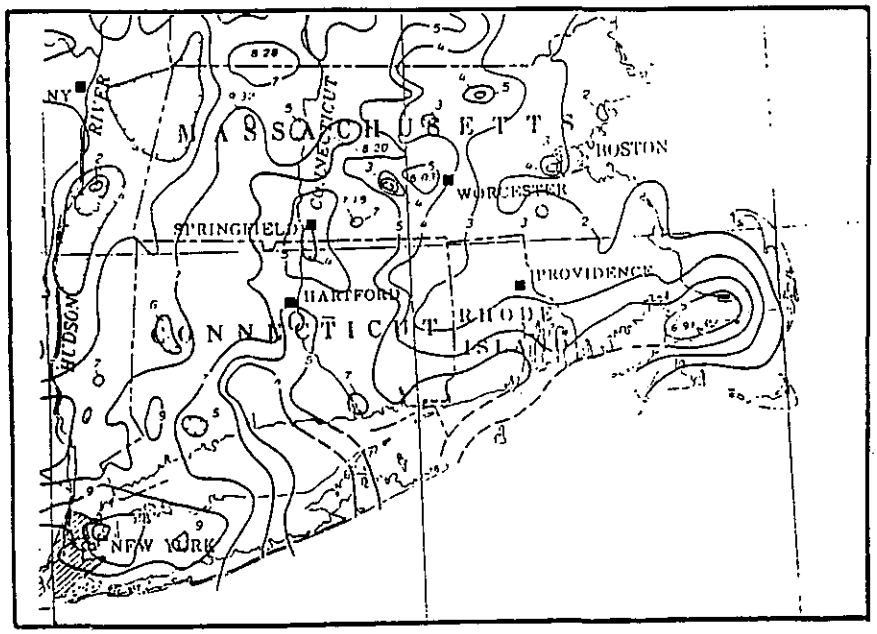


Figure 23. Analyzed precipitation field (inches) for rainfall associated with Tropical Storm Connie (from U.S. Geological Survey 1955).

Tropical Storm Diane
(August 18-20, 1955)

Tropical Storm Diane affected Rhode Island with torrential rain and gusty winds from August 18 through August 20. Diane made initial landfall as an intense hurricane along the lower coast of North Carolina on August 17 (Figure 24). The system weakened to tropical storm strength shortly thereafter, then continued a slow movement northward into Virginia. Heavy rain began to affect Rhode Island as Diane made a sharp turn to the east-northeast on August 18, eventually re-entering the Atlantic just south of New York City. The center passed over Block Island on August 19, then continued on east of Cape Cod on August 20.

Diane dumped rainfall amounts of 6 to 9 inches across the state (Figure 25). The highest amounts fell over the higher terrain of northern and western Rhode Island. Diane's rainfall, in addition to the 3 to 6 inches of rain which had accompanied the remnants of Tropical Storm Connie just 5 days earlier, resulted in widespread flooding across Rhode Island. Catastrophic flooding occurred along the Blackstone River in northern Rhode Island. The river rose to 17 feet above flood stage in Woonsocket, destroying hundreds of homes and killing two people. In Scituate, along the Pawtuxet River, the Horseshoe Dam failed. The width of the river just below the dam site was usually 70 feet. Immediately following the dam failure, the river width increased to 1.5 miles. Property damage from flooding statewide was estimated at nearly $170 million, $150 million of which was associated with the Blackstone River flooding.

Gusty east to southeast winds of 25 to 45 mph occurred statewide and caused some minor coastal flooding in Rhode Island, primarily along the immediate south shore from Narragansett to Little Compton.

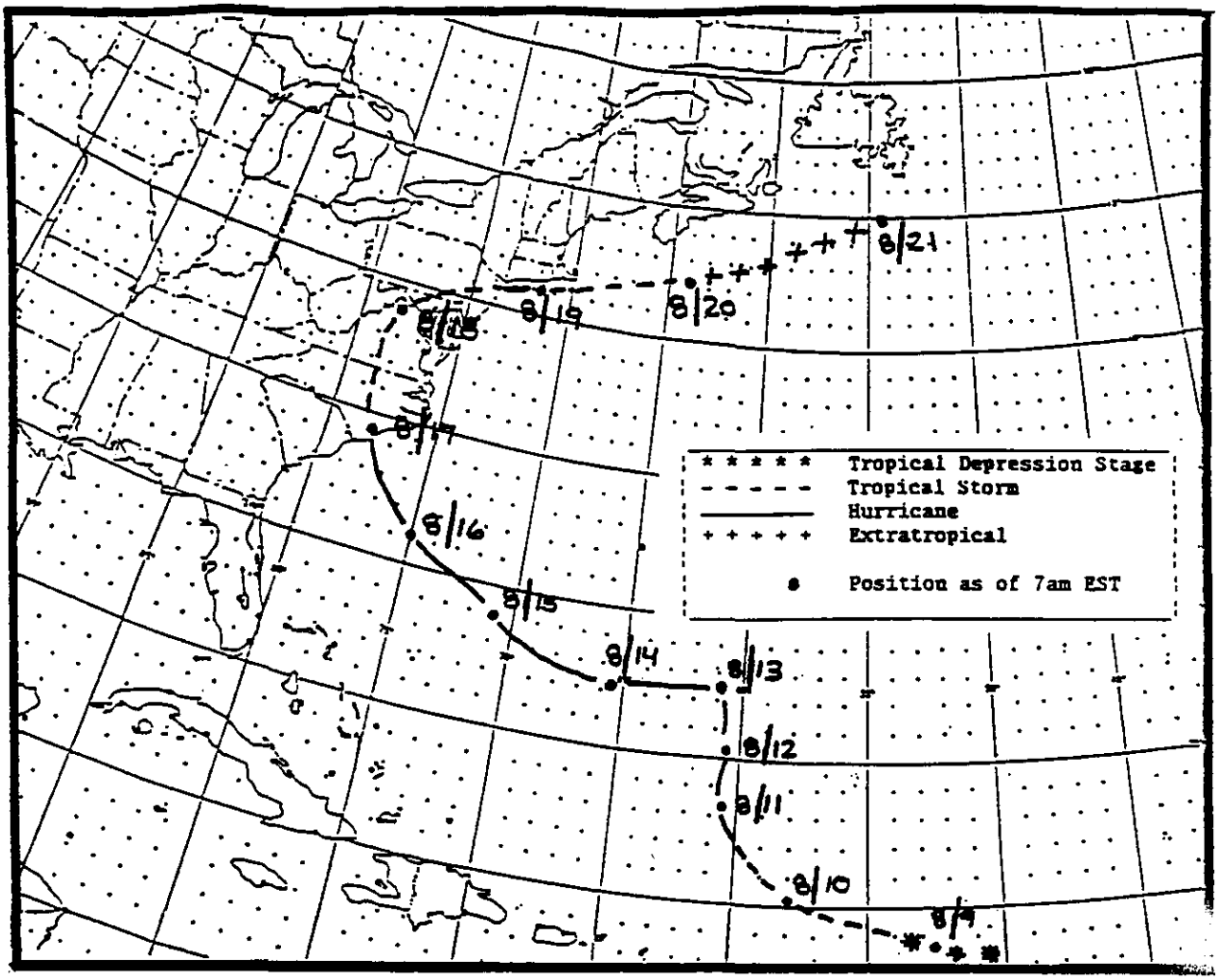


Figure 24. Track of Tropical Storm Diane of 1955.

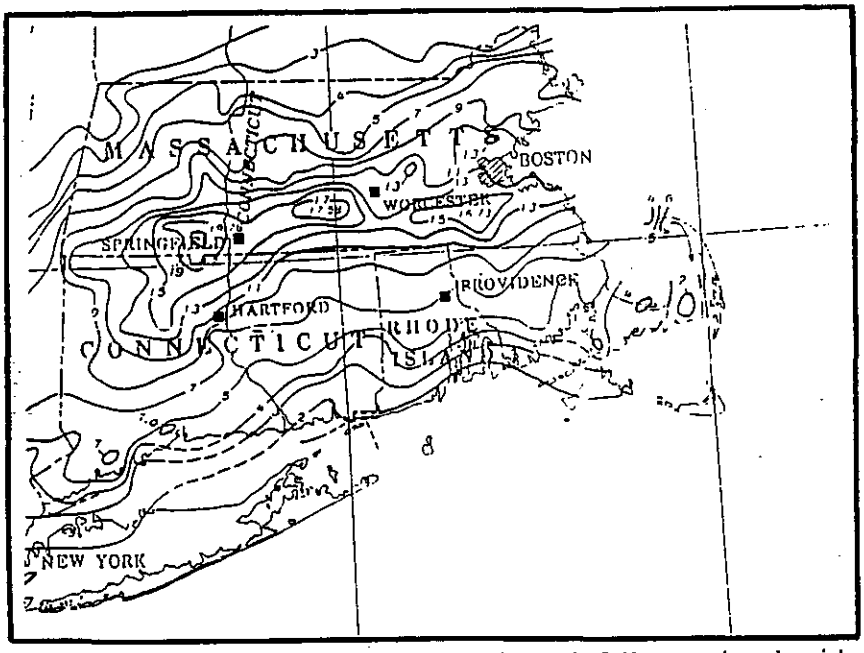


Figure 25. Analyzed precipitation field (inches) for rainfall associated with Tropical Storm Diane (from U.S. Geological Survey 1955).

Hurricane Daisy
(CAT 3 - August 29, 1958)

Hurricane Daisy developed east of the Bahamas on August 24, rapidly strengthened to hurricane intensity and headed north up the East Coast (Figure 26). Daisy, like many New England hurricanes, began to accelerate while passing east of the North Carolina coast. Daisy turned northeastward on August 28 and passed about 75 miles south of Block Island during the morning of August 29.

Daisy's track to the south of Rhode Island spared the area from hurricane conditions. Sustained winds of 20 to 30 mph were felt statewide, with gusts to over 50 mph confined to Block Island. Tides ran 2 to 3 feet above normal. Rainfall was generally less than 0.5 inches.

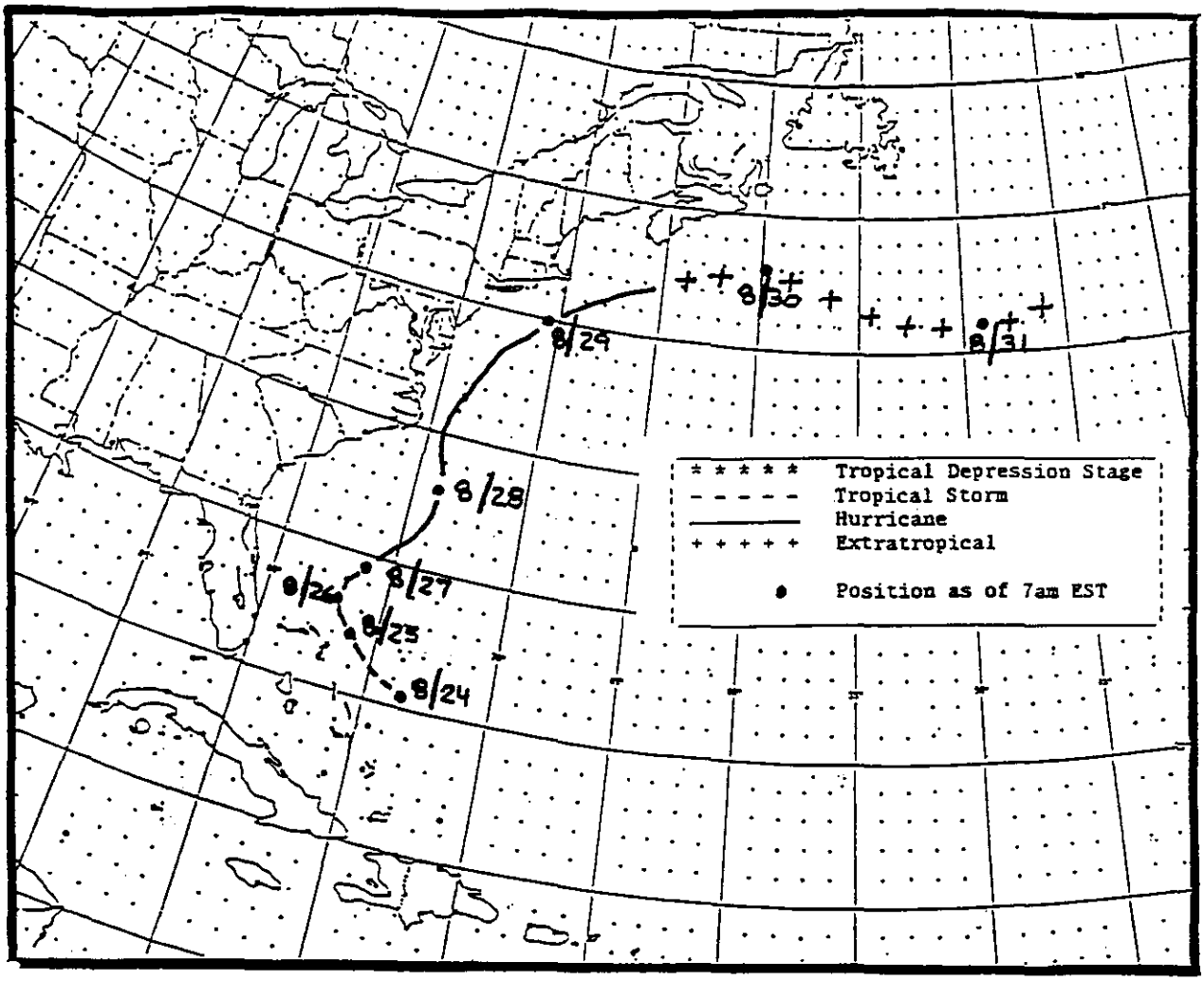


Figure 26. Track of Hurricane Daisy of 1958.

Tropical Storm Cindy
(July 10-11, 1959)

Tropical Storm Cindy developed off the Florida coast on July 5 (Figure 27). Cindy moved very slowly northward during the next 2 days, slowly intensifying to hurricane strength. Cindy turned westward on July 7 and made landfall on the South Carolina coast on July 9. The system weakened to a depression as it turned northeastward, passing across eastern North Carolina. Cindy re-entered the Atlantic along the Virginia coast on the evening of July 10, th reintensified to tropical storm strength. Cindy continued northeastward, passing across eastern tip of Cape Cod on July 11.

Cindy brought northwest winds of 20 to 40 mph to Rhode Island, with gusts to near 70 mph recorded along the Rhode Island south coast and on Block Island. Some minor coastal flooding accompanied the storm, but no serious damage was reported. Rainfall statewide was quite uniform, generally around 2 inches, although isolated amounts of over 3 inches were recorded over the higher terrain of northwest Rhode Island.

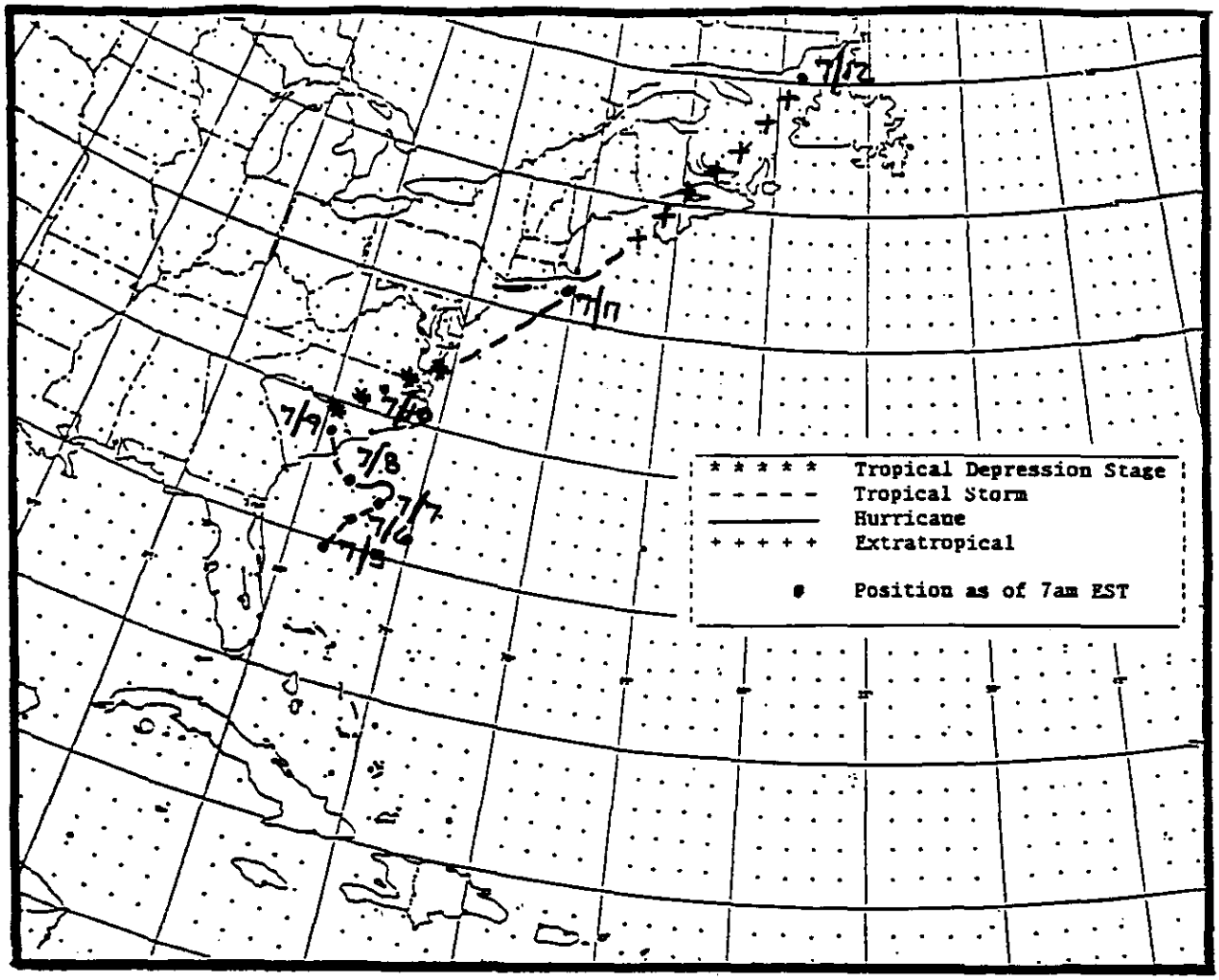


Figure 27. Track of Tropical Storm Cindy of 1959.

Tropical Storm Brenda
(July 30, 1960)

Tropical Storm Brenda was the first of two tropical systems to affect Rhode Island during the summer of 1960. Brenda developed from a tropical depression in the northeast Gulf of Mexico, strengthened to a tropical storm along the Georgia coast on July 29, and then made rapid progress northward during the next 24 hours, passing over New York City by late morning on July 30 (Figure 28). The system lost tropical characteristics later that afternoon as it moved across western Maine.

Brenda brought gusty south winds of 20 to 30 mph to Rhode Island, along with tides of up to 4 feet above normal. No coastal flooding or power outages were reported. Rainfall amounts ranged from 0.75 inches over the southern two thirds of Rhode Island, to as much as 1.5 inches over the higher terrain of northwest Rhode Island.

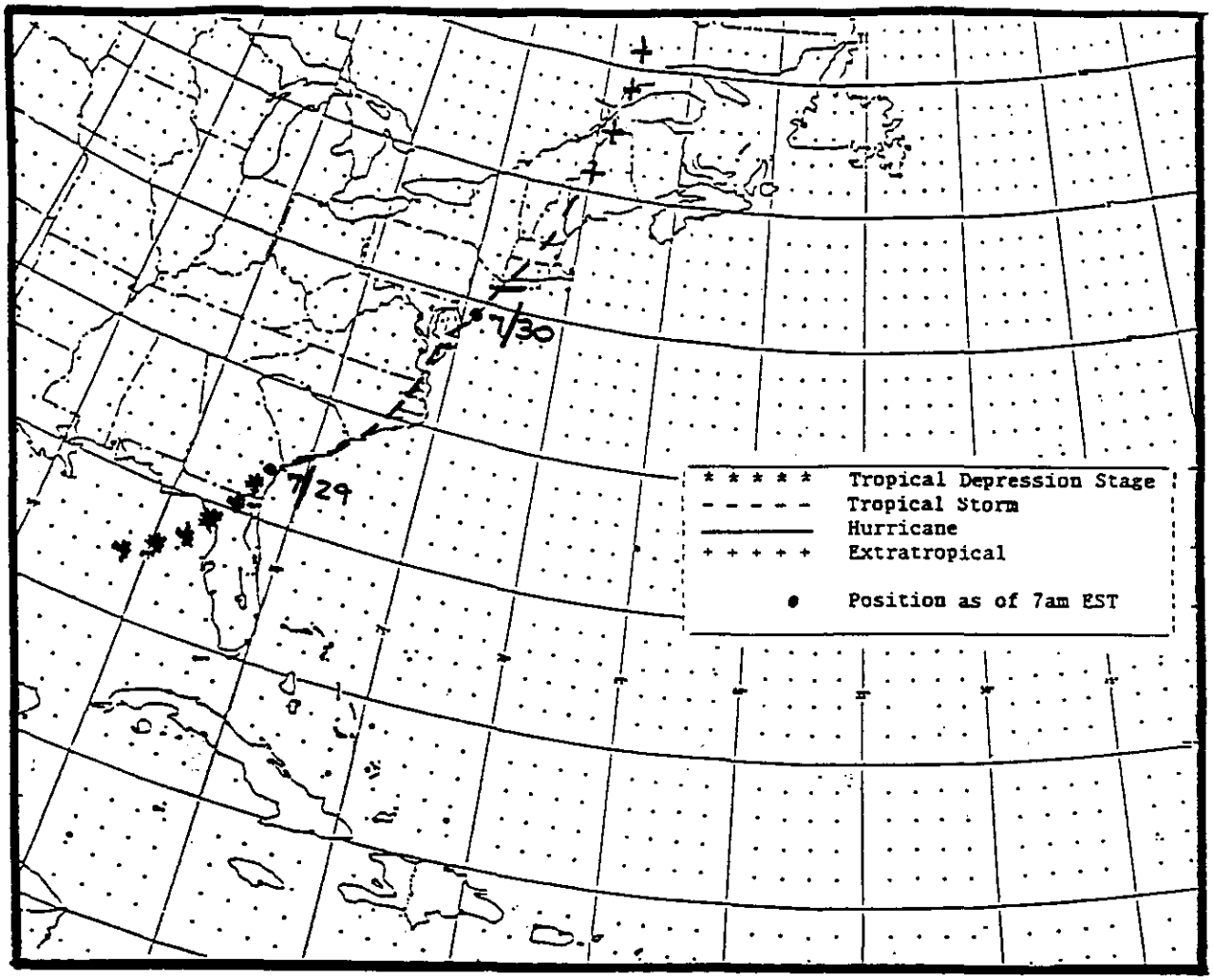


Figure 28. Track of Tropical Storm Brenda of 1960.

Hurricane Donna
(CAT 2 - September 12, 1960)

Hurricane Donna wreaked havoc along the entire eastern seaboard from September 10 through September 12, seemingly saving the worst for the New England south shore. Donna developed over the far eastern Atlantic on August 30, tracking steadily westward for 12 days before making a direct strike in south Florida (Figure 29). Donna then turned abruptly northward and began a track up the East Coast. The system maintained hurricane strength after crossing extreme eastern North Carolina while rapidly accelerating northeastward. Donna was moving at nearly 40 mph by the time the center made its final landfall on eastern Long Island during the afternoon of September 12.

Sustained winds of 60 to 80 mph blew across inland Rhode Island, while 80 to 100 mph sustained winds roared through the Rhode Island south shore and Block Island. Block Island recorded sustained winds of 95 mph with a peak gust to 130 mph, tying its all time strongest wind gust previously set during Hurricane Carol of 1954. The strongest gust at the National Weather Service Office in Warwick was 81 mph. The strong winds blew down numerous trees and power lines, which resulted in a loss of electrical power to 82 percent of the state. Low barometric pressures occurred as well. The barometer in Warwick dipped to 28.66 inches as the eye passed about 15 miles to the west. Block Island recorded 28.58 inches.

Donna brought a storm tide of 9 to 12 feet onto the south coast of Rhode Island and up Narragansett Bay. The storm surge at the South Street Station Dock was estimated at 7 to 8 feet. Coastal damage was extensive, but Donna's arrival shortly before low tide spared the state catastrophic damage. Widespread coastal flooding occurred with many unprotected beach front homes, as well as hundreds of boats, badly damaged or destroyed along the Rhode Island south shore and on Narragansett Bay.

Rains of 2 to 5 inches accompanied Donna, creating considerable street and urban flooding statewide. The total amount of damage in Rhode Island from Donna was $5 million.

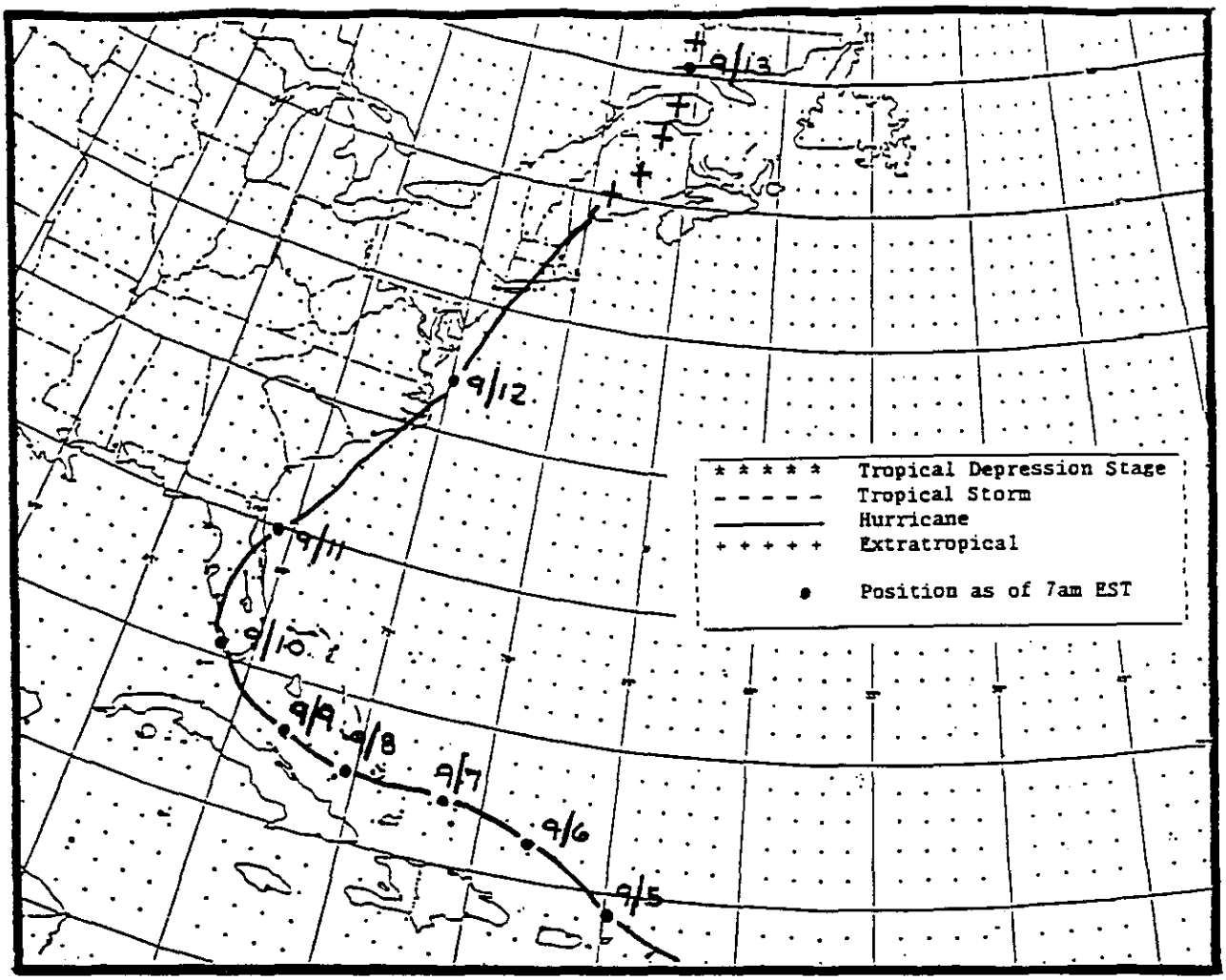


Figure 29. Track of Hurricane Donna of 1960.

Hurricane Esther
(CAT 3 - September 20-21 and 25, 1961)

Hurricane Esther was the most peculiar storm. The system actually affected the Rhode Island region twice due to its looping track: first as a hurricane, passing only 30 miles south of Block Island on September 21, then a second time as a weakening tropical storm passing over outer Cape Cod on September 25 (Figure 30). In addition, this was the only storm during the 55 years that moved slowly while approaching Rhode Island, with an average speed of mph.

When Esther made her first pass at Rhode Island on September 21, strong northeast gales of 35 to 50 mph buffeted the region. Block Island recorded a peak gust to 84 mph and a lowest pressure of 29.18 inches as the center passed just to the south. Tides ran 3 to 6 feet above normal but caused only minor coastal flooding. Spotty power outages were reported, with some structural damage reported on the Rhode Island south coast. During this time, Esther's slow forward motion allowed for 4 to nearly 8 inches of rain to fall statewide. Scituate recorded 7.7 inches during September 20 and 21, the highest recorded amount in Rhode Island for this event. Considerable urban and street flooding occurred.

On September 22, Esther weakened to tropical storm strength and began her clockwise loop south of New England, which lasted 4 days. Finally, on September 25, Esther began to increase speed and head due north. The center passed over the outer tip of Cape Cod and continued to weaken further as it moved into Maine.

During the storm's second pass at Rhode Island, winds were much lighter, generally 15 to 25 mph statewide. However, the state did not escape the rain. An additional 1 to 2 inches of rain aggravated the already saturated conditions, resulting in more inland flooding.

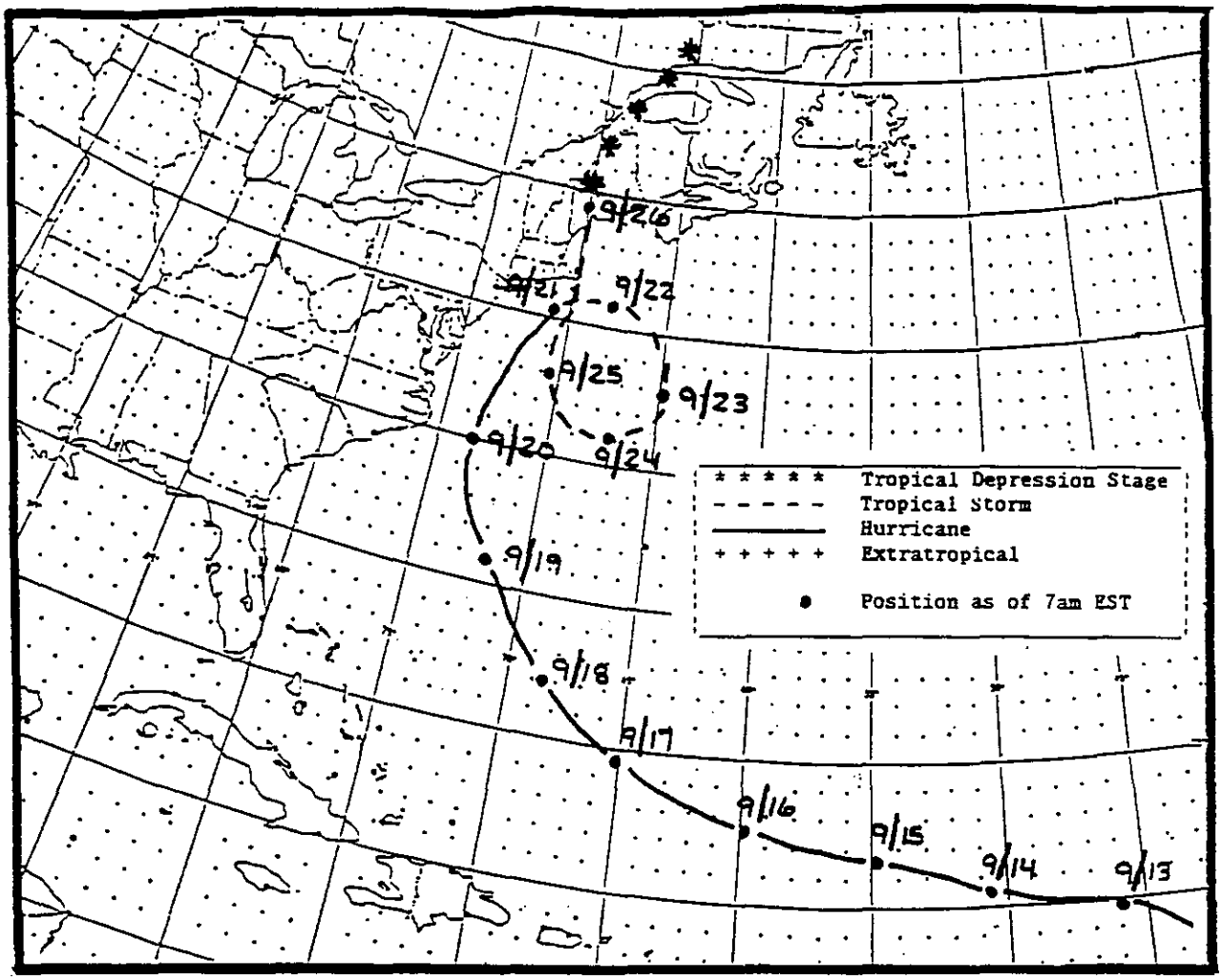


Figure 30. Track of Hurricane Esther of 1961.

Hurricane Alma
(CAT 2 - August 28-29, 1962)

Hurricane Alma originated about 100 miles off the northeast coast of Florida (Figure 31). The system moved steadily northeast, intensifying to hurricane strength as it passed Cape Hatteras on the morning of August 28. The system continued northeastward, passing just south of Nantucket on the morning of August 29.

Alma gave Rhode Island a glancing blow, spreading gusty northwest winds and locally heavy rainfall throughout the state. Sustained winds of 30 to 40 mph were common across Rhode Island, with gusts to 60 mph on Block Island and along the Rhode Island south shore. Some minor beach erosion occurred, primarily along east facing beaches. Also, small pleasure craft damage was reported. Rainfall of 1 to 2 inches occurred over mainland Rhode Island, with Block Island receiving 3.11 inches.

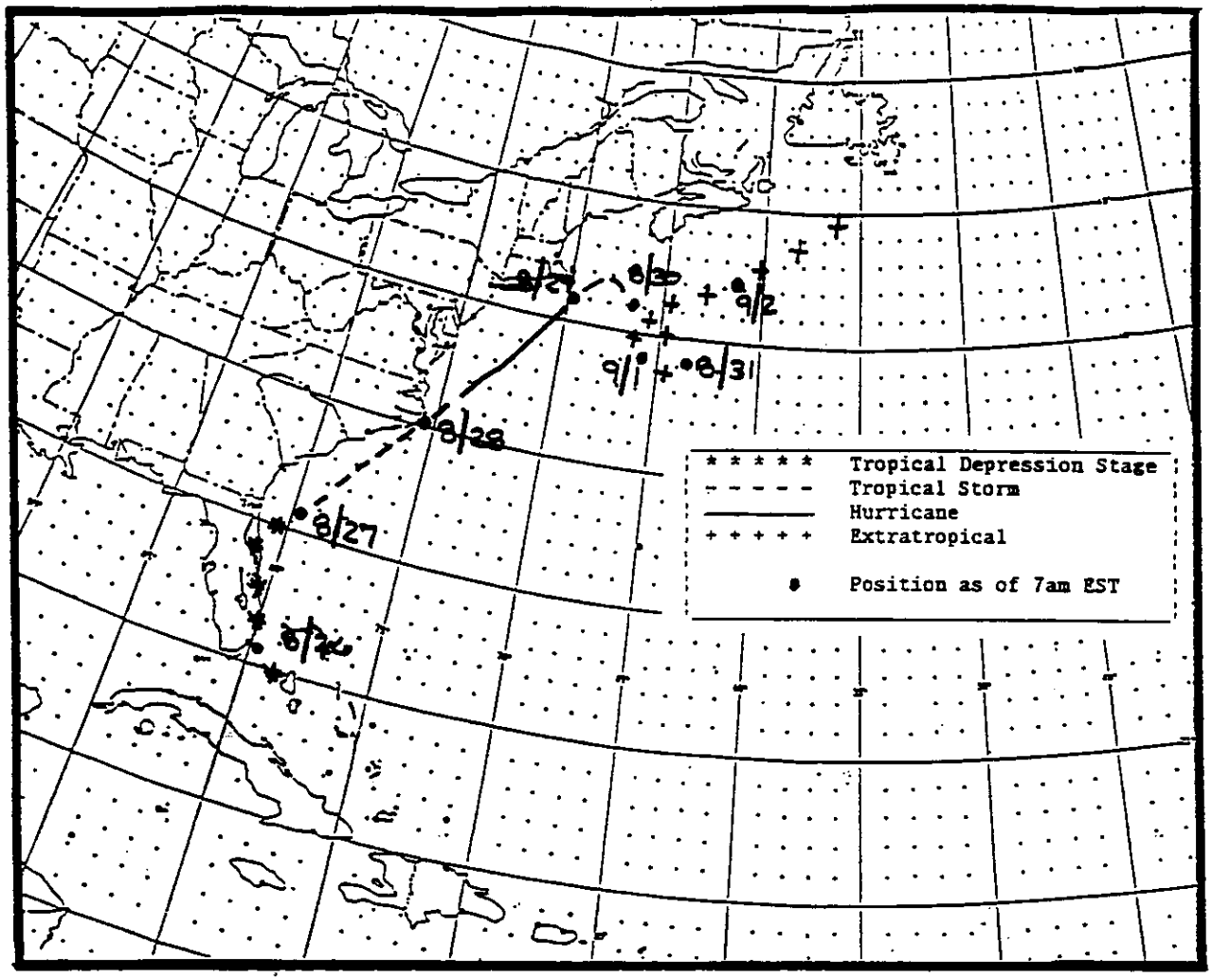


Figure 31. Track of Hurricane Alma of 1962.

Hurricane Daisy
(CAT 1 - October 7, 1962)

Hurricane Daisy developed north of the Virgin Islands on October 1 (Figure 32). The system continued to intensify as it recurved northward, passing west of Bermuda and making landfall over southwest Nova Scotia on October 7. Although the center of the storm passed about 275 miles east of Rhode Island, its large circulation spread gusty winds and rain across the state.

Sustained winds of 25 to 40 mph buffeted the state, along with tides of 2 to 4 feet above normal. Gusts to 60 mph were frequently felt on Block Island. However, the most significant feature of Daisy was the rainfall which accompanied her passage.

Four to nearly 7.5 inches of rain occurred during Hurricane Daisy. Woonsocket recorded the highest amount, 7.46 inches. This resulted in considerable urban and lowland flooding. Daisy's rain, combined with rain from a coastal storm on October 5 and 6, produced serious flooding. The National Weather Service Office in Warwick recorded a 3 day total rainfall of 9.46 inches.

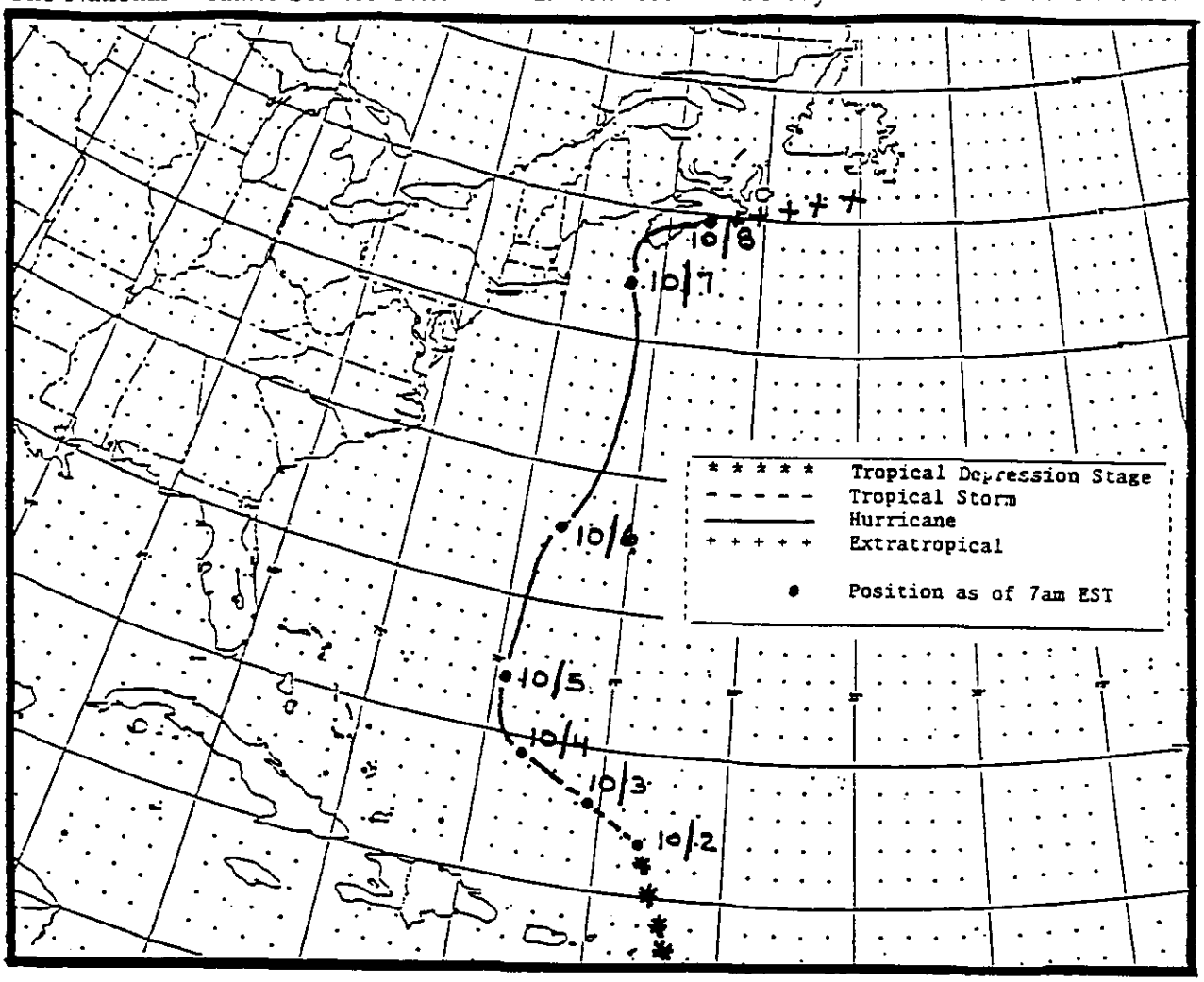


Figure 32. Track of Hurricane Daisy of 1962.

Hurricane Ginny
(CAT 2 - October 29, 1963)

Hurricane Ginny was a late season storm that developed north of Haiti on October 16 (Figure 33). Ginny moved steadily north, reaching tropical storm strength on September 19. Ginny spent the next 9 days meandering over the warm waters of the Gulf Stream, east of the Carolinas, gradually strengthening to hurricane force. The system finally began to accelerate northeastward on October 28.

Hurricane Ginny passed approximately 275 miles southeast of Rhode Island on the morning of October 29. This storm spared Rhode Island from its hurricane force winds. Rainfall of 1 to 2 inches fell statewide, bringing some relief to what had been a dry start to the fall season. Sustained winds of 30 to 40 mph were common as Ginny approached. Gusts to 55 mph were recorded on Block Island.

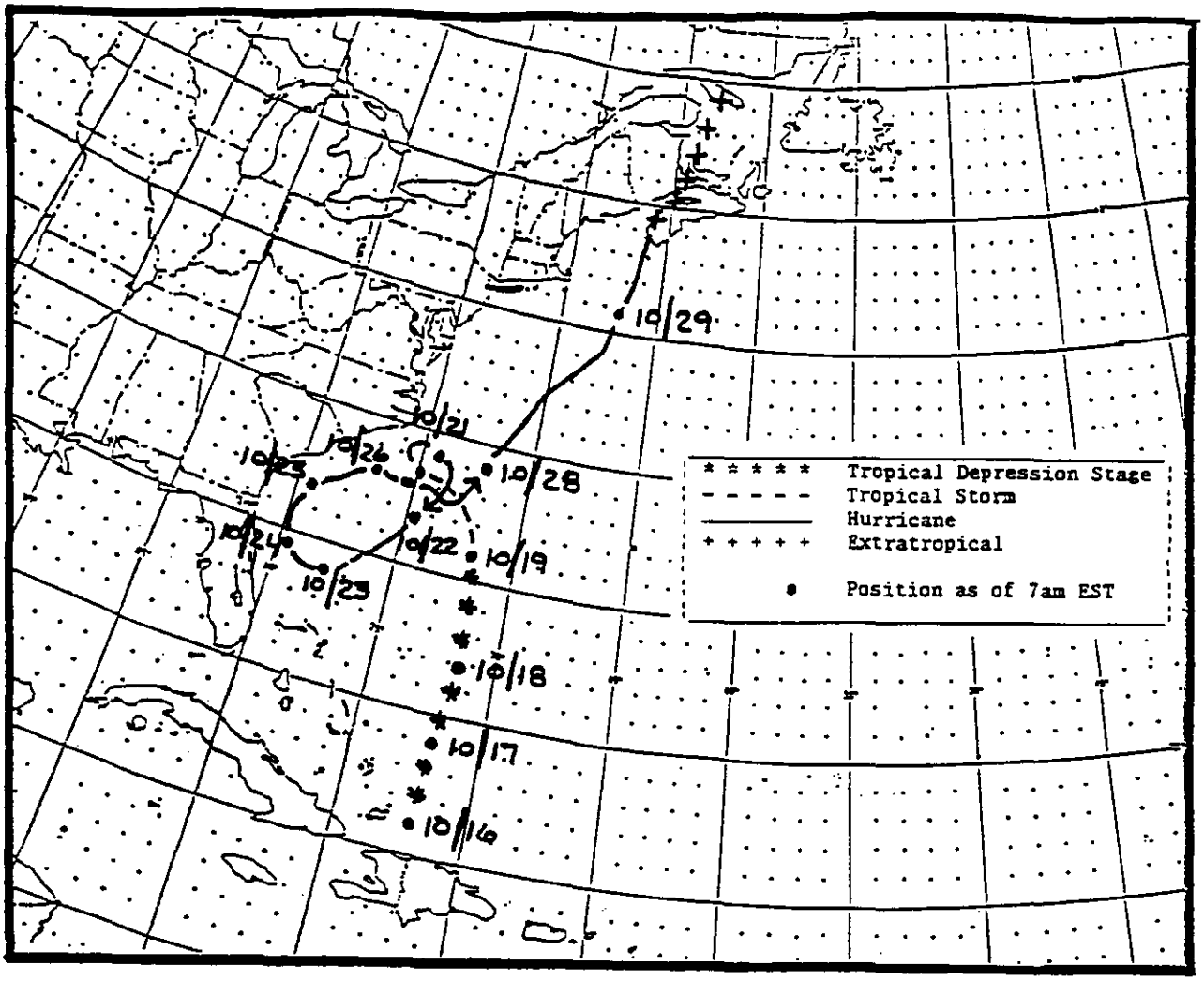


Figure 33. Track of Hurricane Ginny of 1963.

Hurricane Gerda
(CAT 3 - September 8-9, 1969)

Hurricane Gerda developed east of Jacksonville, FL, on the evening of September 7, then rapidly intensified to hurricane strength 12 hours later (Figure 34). Gerda accelerated to the northeast and passed about 100 miles southeast of Rhode Island around midday on October 9, moving at nearly 50 mph.

Gerda's track to the southeast of Rhode Island kept her hurricane force winds out at sea, where gusts to 140 mph were recorded over the fishing banks southeast of Nantucket Island. Sustained winds of 20 to 30 mph were common in Rhode Island. Block Island, being closest to the storm center, reported frequent gusts to around 65 mph.

Most of the state received between 2 and 2.5 inches of rainfall from Gerda, while Newport recorded over 3.5 inches. Some minor urban and street flooding was observed.

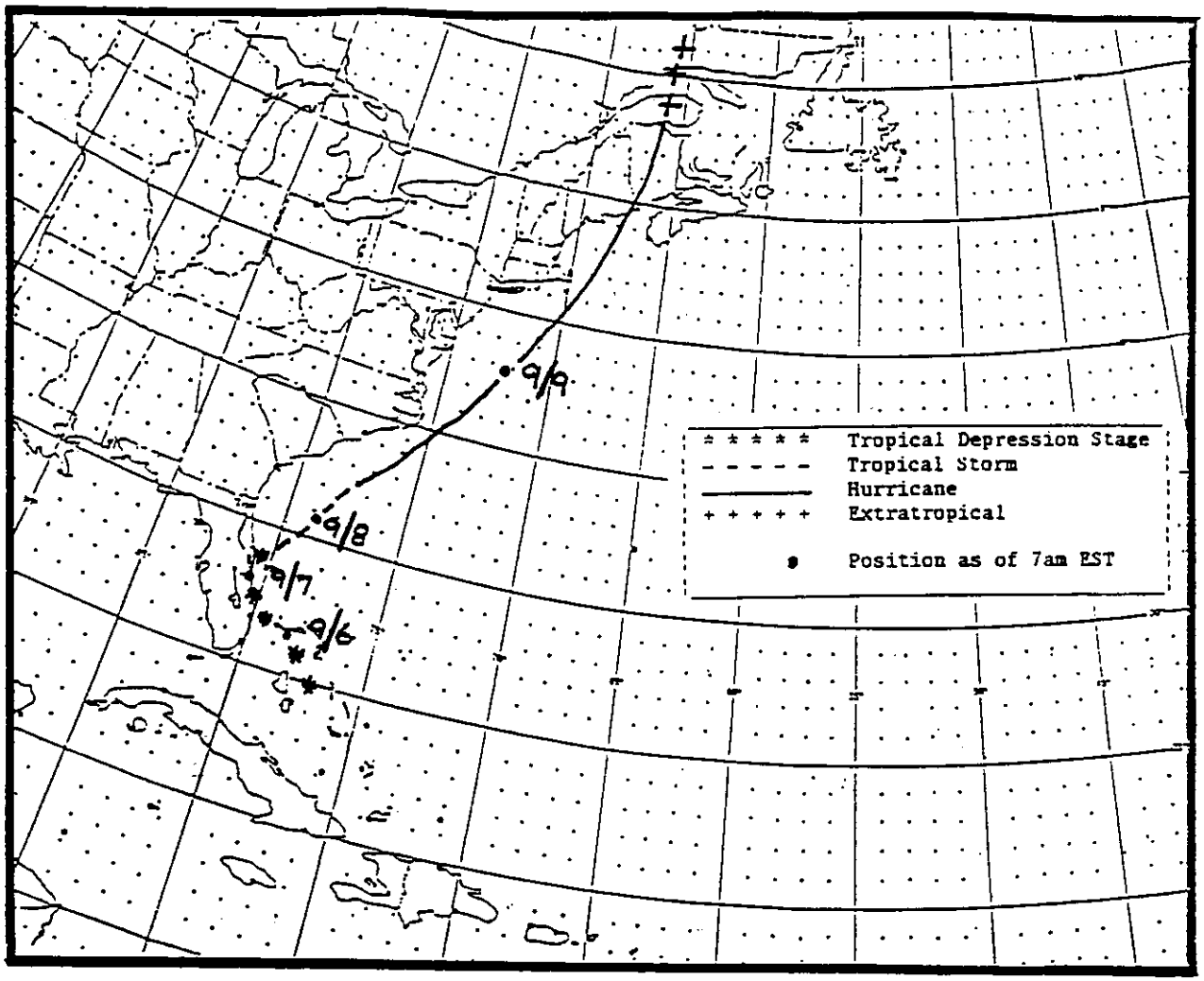


Figure 34. Track of Hurricane Gerda of 1969.

Tropical Storm Doria
(August 27-28, 1971)

Tropical Storm Doria developed east of Florida on August 26 and headed northward along the eastern seaboard (Figure 35). The center stayed inland once it made initial landfall along the coast of North Carolina. The center passed over New York City on August 28, then continued northeastward into Maine.

Doria was accompanied by gusty southeast winds in Rhode Island. The National Weather Service Office in Warwick recorded sustained winds of 44 mph with a peak gust to 61 mph. Gusty winds resulted in numerous power outages throughout the state.

Strong southeast winds also helped to drive tides 2 to 4 feet above normal along the Rhode Island south coast, and up to 6 feet above normal over the upper part of Narragansett Bay. Some minor coastal flooding occurred, but damage was minimal. Rainfall in Doria ranged from 0.25 inches on Block Island to 1.32 inches in Newport.

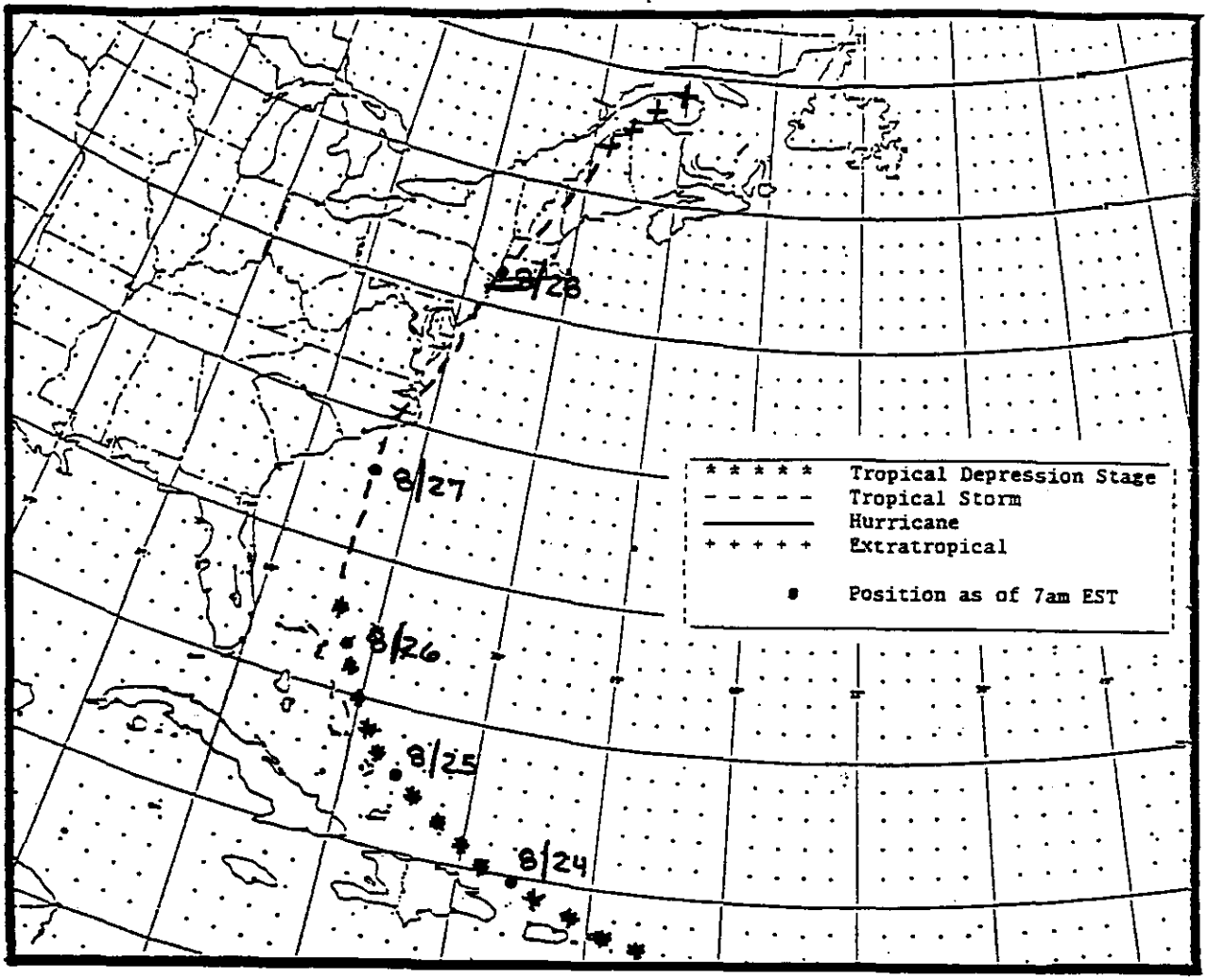


Figure 35. Track of Tropical Storm Doria of 1971.

Tropical Storm Heidi
(September 14, 1971)

Tropical Storm Heidi developed about 600 miles east of the Florida shore on September 11 (Figure 36). The system progressed steadily northward, passing about 60 miles east of Cape Cod on the morning of September 14. Tropical Storm Heidi kept her strongest winds at sea, but did produce rain over Rhode Island.

Sustained winds during Heidi never exceeded 25 mph in Rhode Island. Gusts to 30 mph were confined to the immediate south coast of Rhode Island and Block Island. Rainfall statewide ranged from 1 to 2 inches. Southeast Rhode Island was again the recipient of the heaviest amounts, with 2.10 inches recorded in Newport.

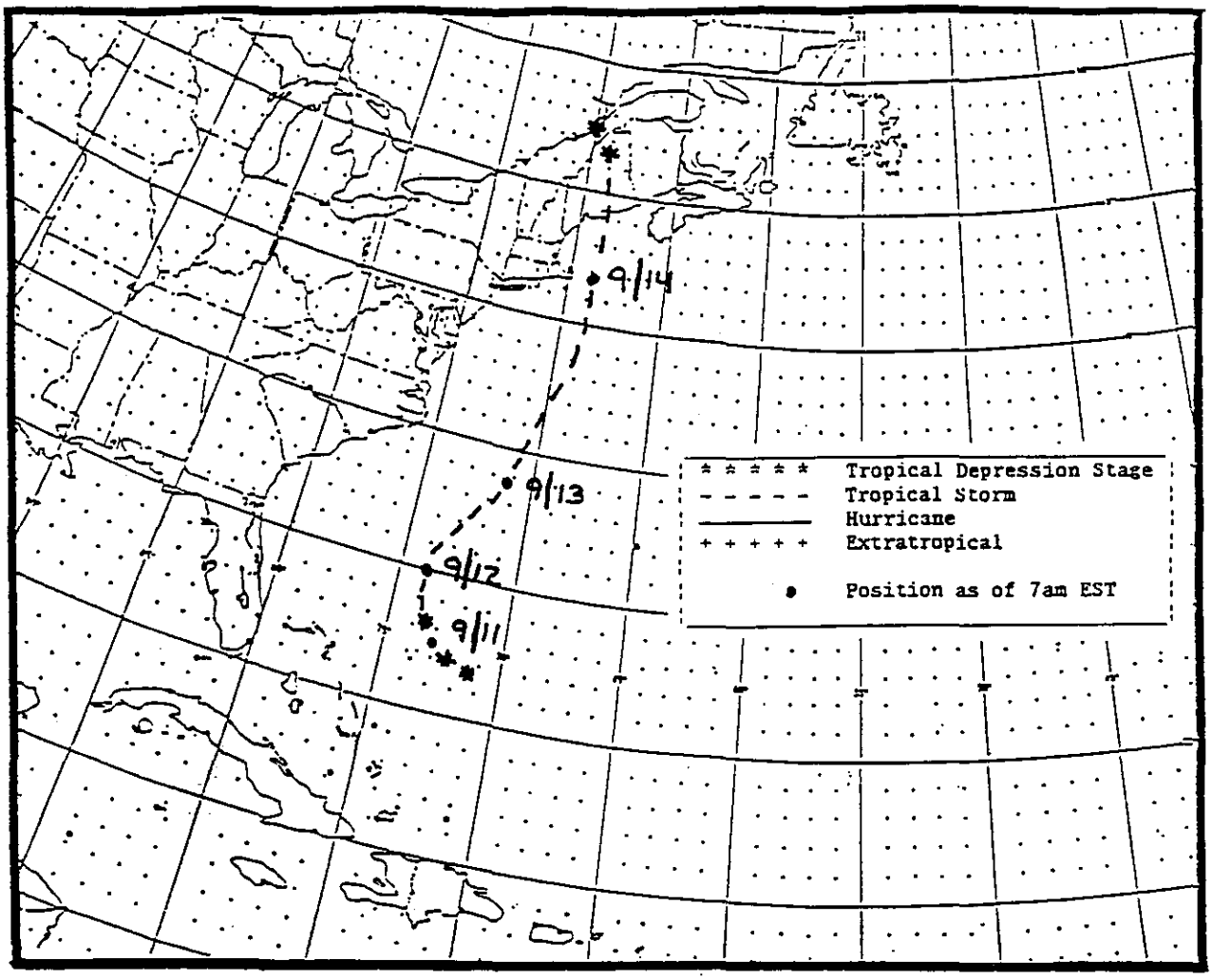


Figure 36. Track of Tropical Storm Heidi of 1971.

Tropical Storm Agnes
(June 22, 1972)

Tropical Storm Agnes, the third system during this period to affect Rhode Island that had origins in the Gulf of Mexico, developed southwest of Cuba on June 16 and made landfall as an intense hurricane over the Florida panhandle on June 19. Agnes weakened rapidly to a depression after making landfall (Figure 37). The system turned northeastward on June 20, passing across Georgia and the Carolinas. It reintensified to a tropical storm upon reaching eastern North Carolina on June 21. Agnes turned north, then northwestward during the following 24 hours and passed across western Long Island and New York City during the afternoon of June 22.

Agnes was a dry storm in Rhode Island but was accompanied by strong winds and above normal tides. Sustained southerly winds of 20 to 40 mph affected the state during her passage. Gusts to over 60 mph were common along the immediate south shore of Rhode Island and Block Island. Tides ran around 3 feet above normal but did not result in any coastal flooding. Rainfall statewide was less than 0.5 inches.

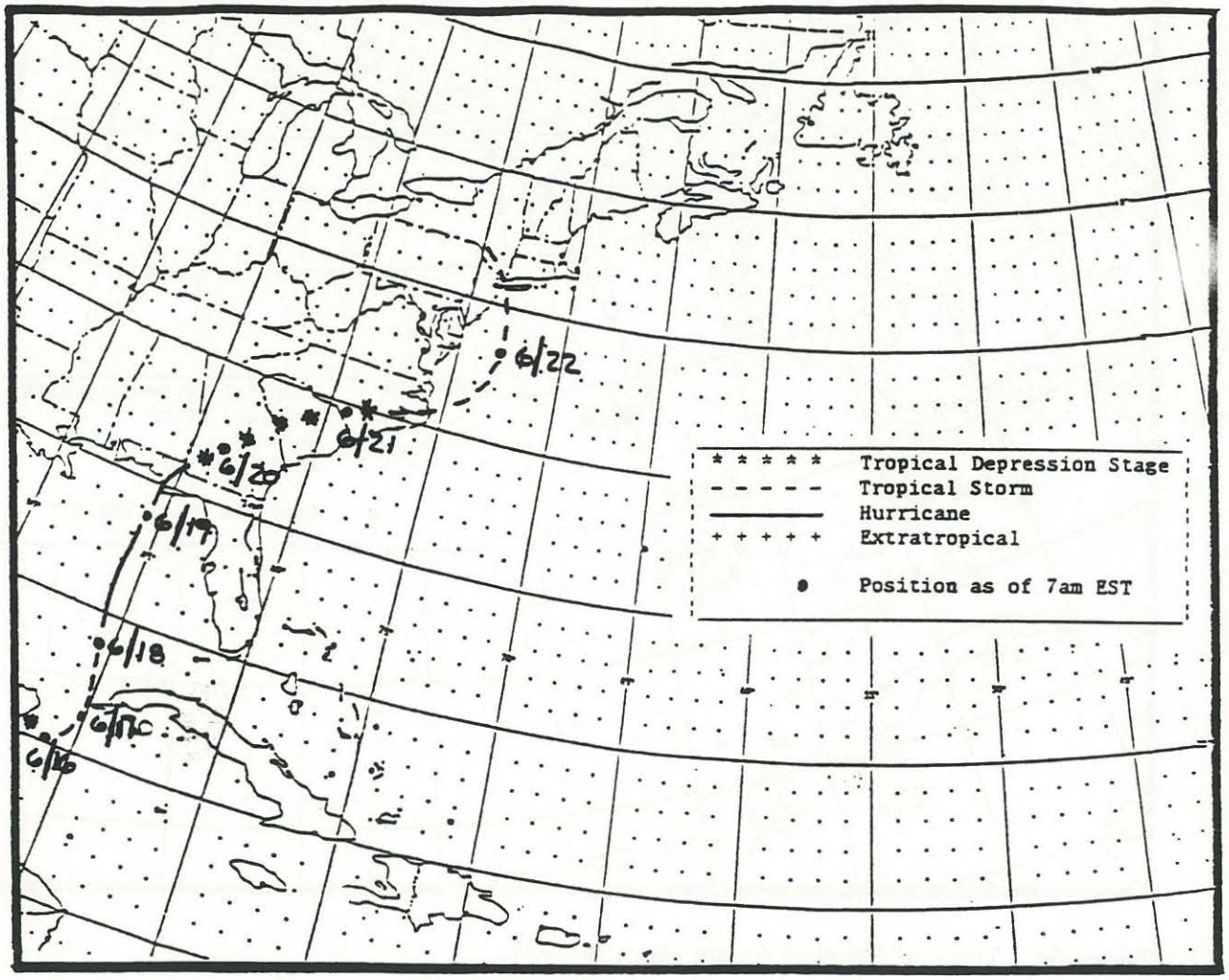


Figure 37. Track of Tropical Storm Agnes of 1972.

Tropical Storm Carrie
(September 3, 1972)

Tropical Storm Carrie developed just east of Jacksonville, FL, on August 29 (Figure 38). The system moved steadily northeastward until August 31, when it turned toward the north and northwest. The system resumed a northeast track on September 2, skirting the east shore of Nantucket Island and outer Cape Cod on September 3, before losing tropical characteristics.

Carrie brought a combination of rain and gusty north winds to Rhode Island. Sustained winds of 30 to 50 mph affected the state, with gusts to 65 mph on Block Island and 78 mph at the Point Judith Coast Guard Station at the mouth of Narragansett Bay. Rainfall from Tropical Storm Carrie ranged from 2 to 4 inches statewide.

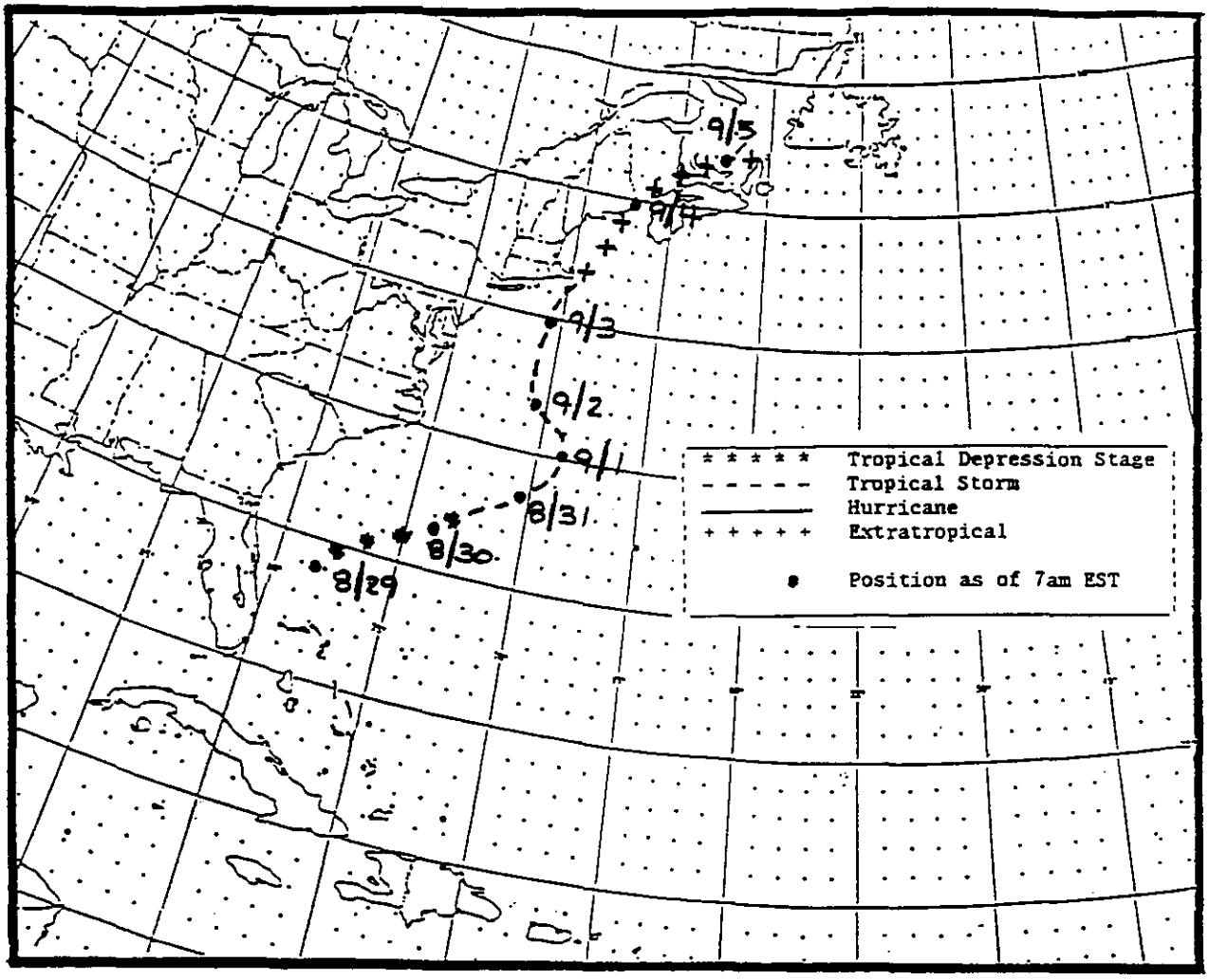


Figure 38. Track of Tropical Storm Carrie of 1972.

Hurricane Belle
(CAT 1 - August 9-10, 1976)

Belle developed approximately 300 miles east of Vero Beach, FL, on August 6, intensifying to hurricane strength a day later (Figure 39). Belle proceeded to head nearly due north, but began to weaken as it moved across colder waters off the middle Atlantic coast. Belle made landfall across central Long Island during the evening of August 9, weakening to a tropical storm as the center moved into Connecticut.

Belle was accompanied by strong southeast winds of 40 to 60 mph statewide. Gusts to near hurricane force were common along the Rhode Island south shore and over Block Island. Storm surge caused water levels to rise several feet above normal tide levels. In fact, a storm surge of 3.3 feet was recorded at the Fox Point Hurricane Barrier on the upper part of Narragansett Bay. Some minor flooding occurred, but damage was minimal.

Two to 3 inches of rain fell over Rhode Island during the 2 days prior to Belle's arrival. Belle brought an additional 1.5 to 2.5 inches of rain, which resulted in considerable inland flooding. The National Weather Service Office in Warwick recorded 1.77 inches during Belle and a 3 day total of 5.05 inches.

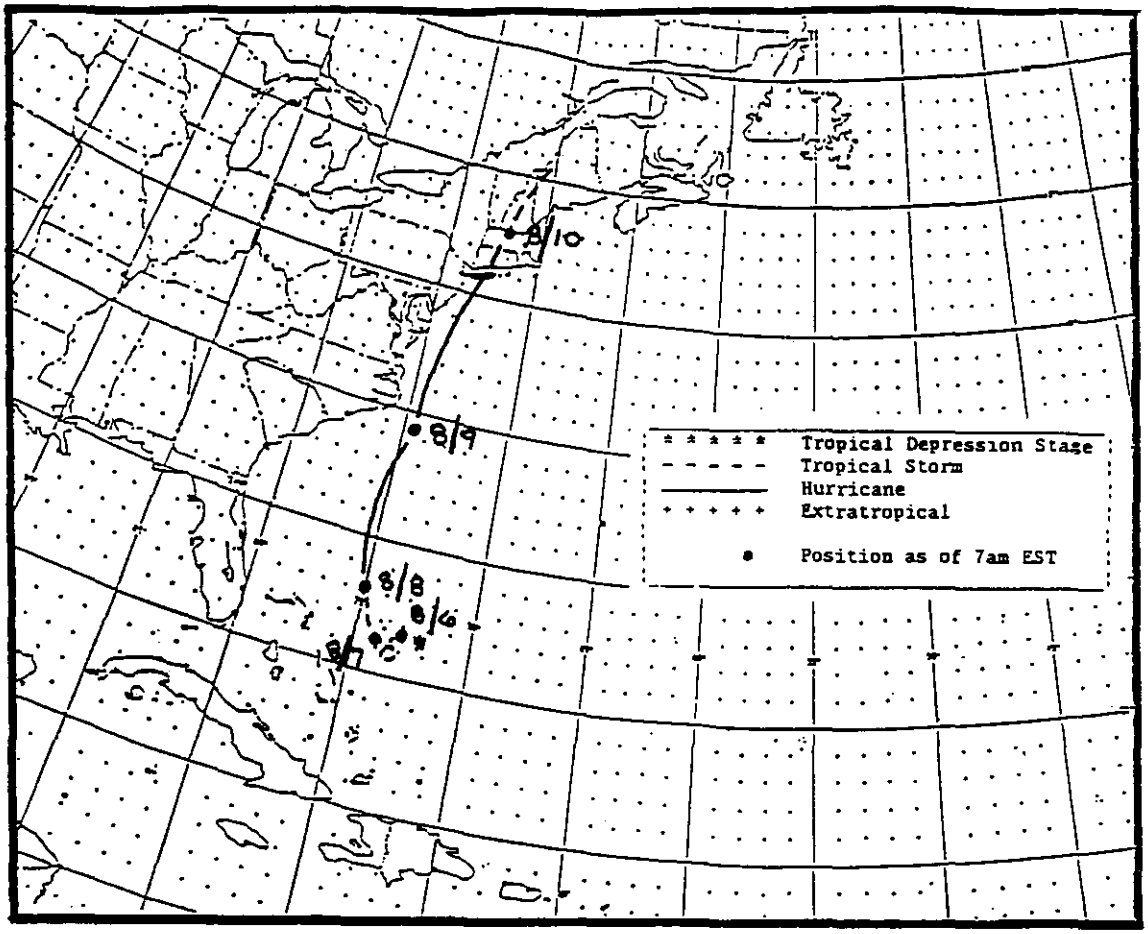


Figure 39. Track of Hurricane Belle of 1976.

Tropical Storm Henri
(September 24, 1985)

Tropical Storm Henri was the forerunner to a strong hurricane named Gloria. While intense Hurricane Gloria was making her way across the Atlantic, a small tropical depression developed east of Florida. This system moved northward and developed into Tropical Storm Henri, east of the North Carolina coast on September 23 (Figure 40). Henri continued northward and made landfall on the Rhode Island south shore during the early evening of September 24. The system dissipated rapidly as it moved into south coastal Massachusetts later that night.

Henri was a very weak tropical storm by the time it reached Rhode Island. Sustained winds were only around 20 mph inland, and rainfall was generally around 0.5 inches.

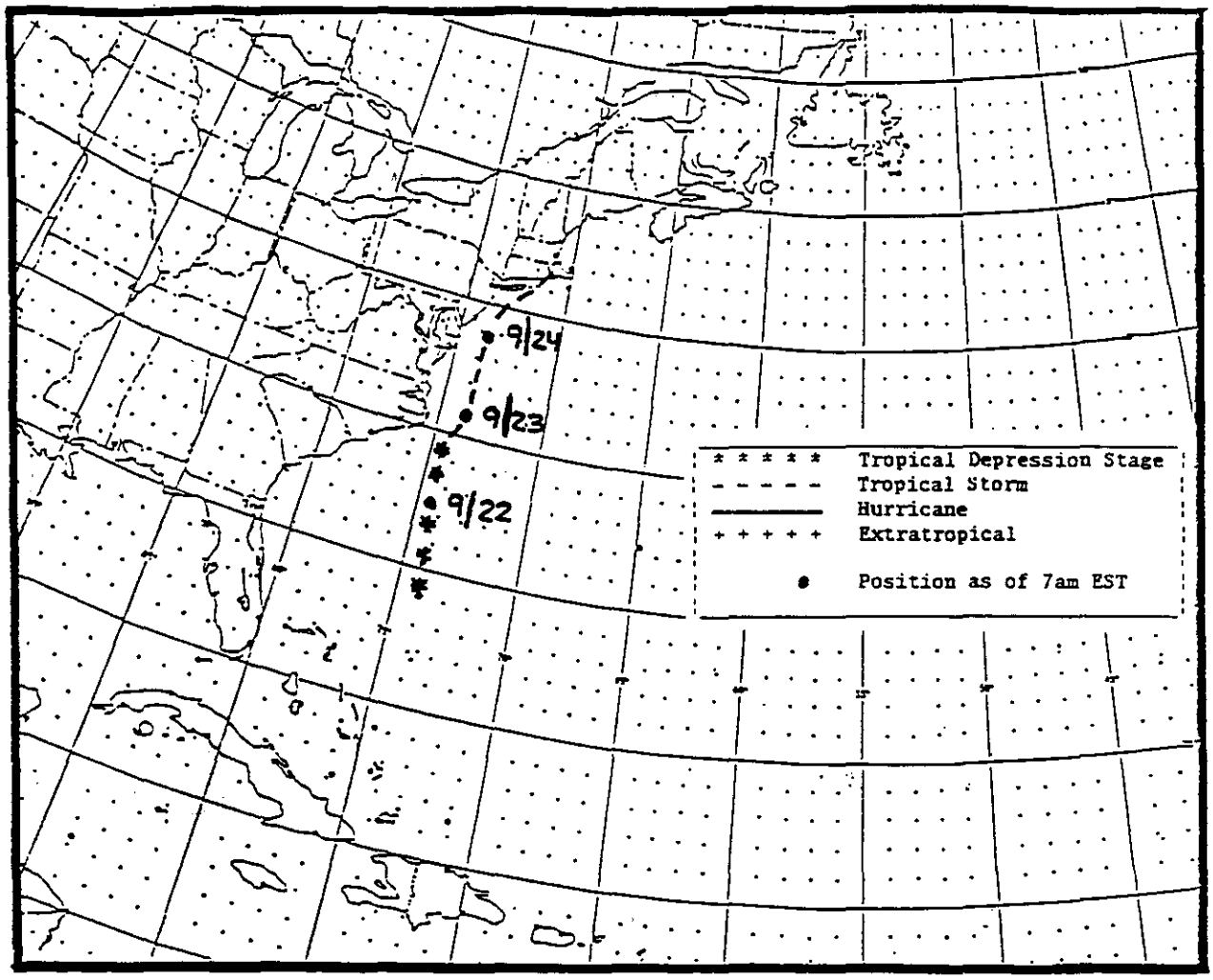


Figure 40. Track of Tropical Storm Henri of 1985.

Hurricane Gloria
(CAT 2 - September 27, 1985)

Hurricane Gloria developed into one of the more intense hurricanes ever in the Atlantic. Gloria formed in the far eastern Atlantic on September 17 and made a 9 day journey west-northwestward toward the eastern seaboard, reaching Cape Hatteras during the evening of September 26 (Figure 41). Gloria accelerated northward during the following 24 hours, making final landfall on Long Island in the afternoon on September 27, moving at nearly 45 mph. During her passage north of Puerto Rico, sustained winds were measured near 150 mph. Gloria lost much of that strength by the time the center made landfall on Long Island.

Sustained winds of 50 to 70 mph were common across Rhode Island. A peak gust to 81 mph was observed at the National Weather Service Office in Warwick. The State Airport in Westerly observed a peak wind gust to 90 mph. These strong southeast winds brought down numerous trees, branches, and power lines statewide, which resulted in a loss of electrical power to 65 percent of the state. Repair crews from as far away as Quebec were called in to help with cleanup efforts.

Hurricane Gloria brought a storm surge of 7 to 9 feet onto the south coast of Rhode Island and up Narragansett Bay. A storm surge of 8.25 feet was recorded at the Fox Point Hurricane Barrier on upper Narragansett Bay. The storm tide reached 9.46 feet (MLLW), or 2.46 feet above flood stage (Figure 42).

Approximately 23,700 Rhode Islanders were evacuated from coastal communities in preparation for the potentially deadly storm surge. The surge arrived 2 hours after low tide, sparing Rhode Island from severe coastal flooding. Minor coastal flooding was common, but little structural damage to homes was reported. However, many of the yacht clubs and marinas on Narragansett Bay were not as fortunate and did not escape the rising waters. Hundreds of boats were either destroyed or heavily damaged due to the high tides. Some were tossed onshore while others, more securely anchored in marinas, collided with one another.

Most of eastern Rhode Island received less than 0.25 inches of rainfall (Figure 43). Amounts of up to 1 inch occurred over the highest terrain of extreme northwest Rhode Island.

Gloria was responsible for two deaths in Rhode Island. One person died while attempting to ride out the storm in a boat. The other person was struck by a falling tree. Total damage in Rhode Island from Gloria was estimated at $19.8 million.

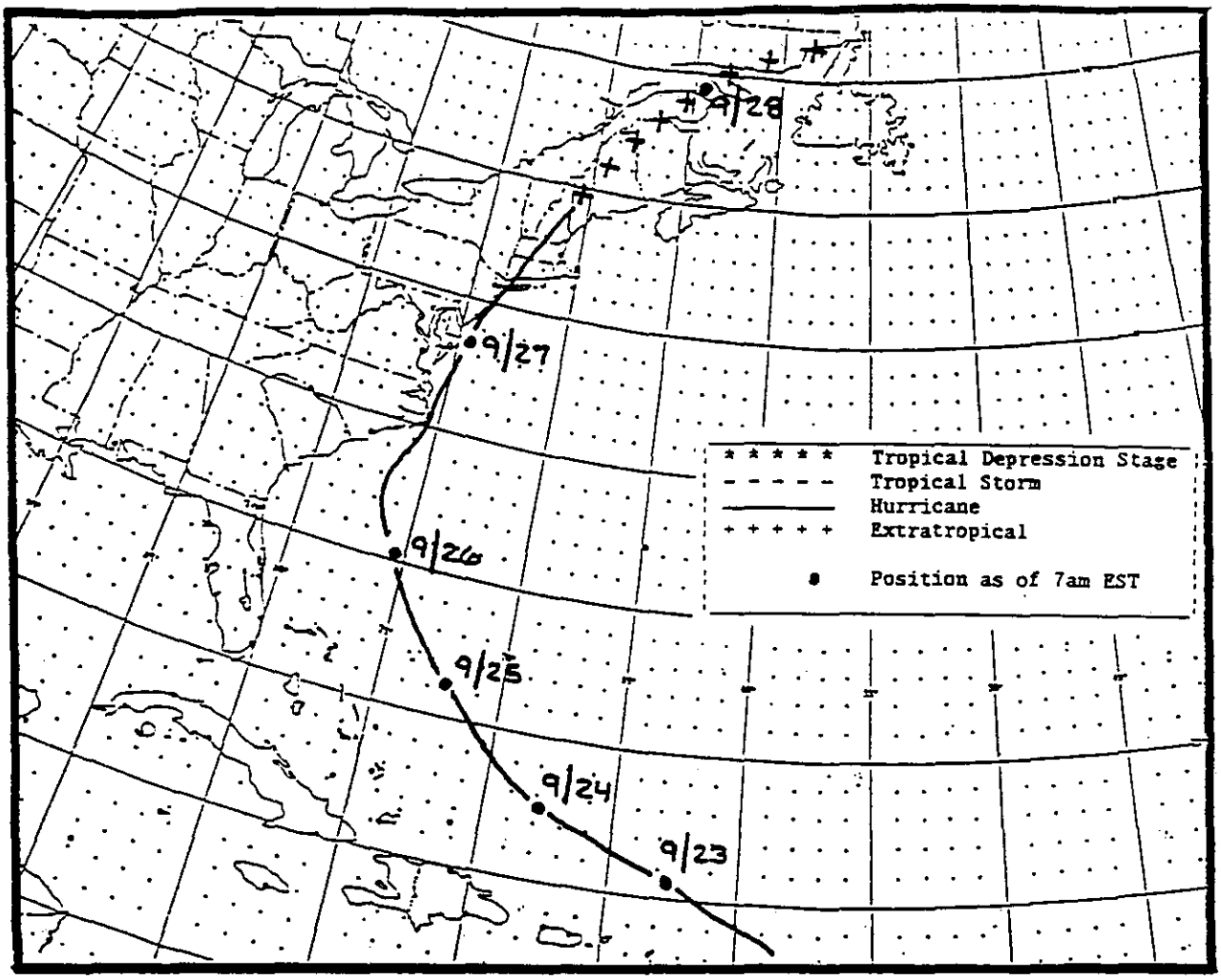


Figure 41. Track of Hurricane Gloria of 1985.

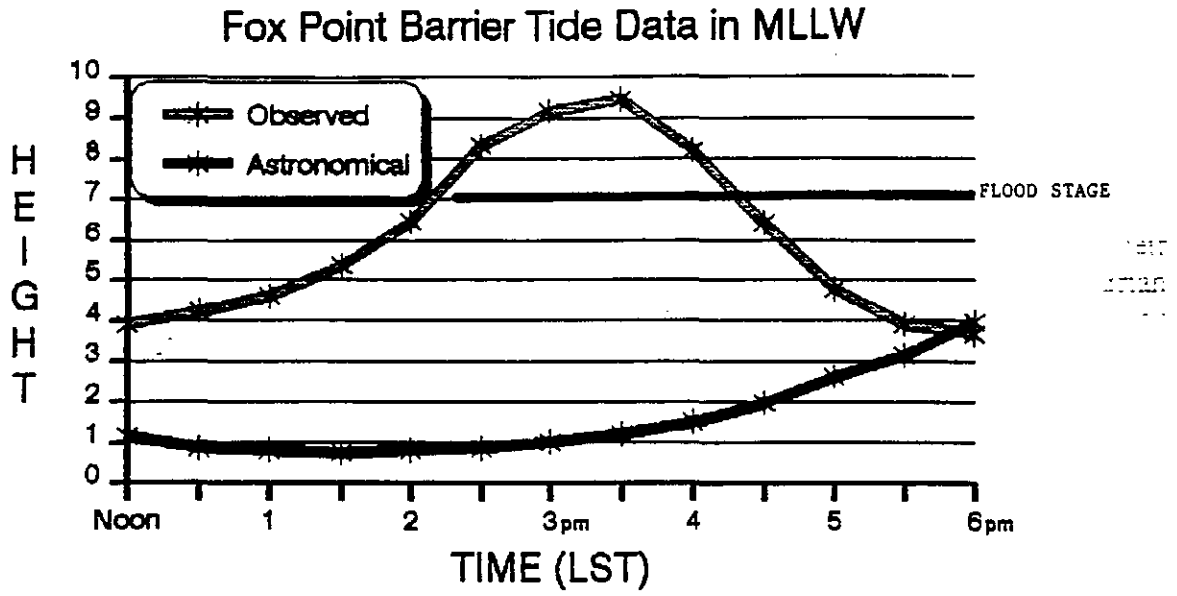


Figure 42. Storm surge height (feet) on September 27, 1985, associated with Hurricane Gloria, recorded at the Fox Point Hurricane Barrier on upper Narragansett Bay.

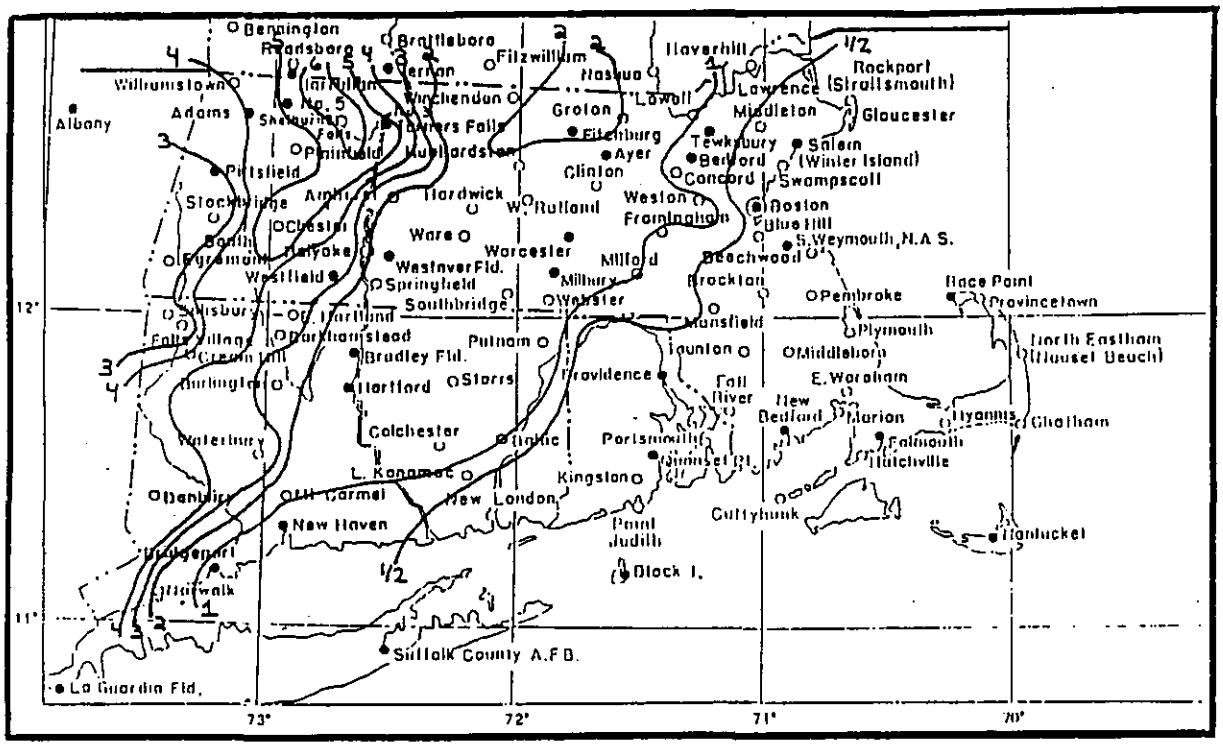


Figure 43. Analyzed precipitation field (inches) for rainfall associated with Hurricane Gloria.

Hurricane Bob
(CAT 2 - August 19, 1991)

Hurricane Bob developed in the central Bahamas on August 16, then steadily intensified and reached hurricane status on the evening of August 17 (Figure 44). Bob continued to strengthen during the next 48 hours as it began an acceleration north-northeastward, paralleling the East Coast. The eye of Hurricane Bob passed over Block Island at approximately 1:30 pm and made landfall over Newport shortly before 2 pm.

Hurricane Bob brought sustained hurricane force winds to the immediate coastal communities of Rhode Island and strong tropical storm force winds to inland Rhode Island. Wind damage to trees and utility poles was common and resulted in numerous power outages. Over 60 percent of the residents across southeast Rhode Island lost power.

Coastal communities bore the brunt of the storm, with sustained winds between 75 to 90 mph. Block Island reported sustained winds of 90 mph, with gusts in excess of 105 mph (maximum speed of equipment). Wind gusts to near 100 mph were recorded in Newport and by the Navy Ship *Samuel B. Roberts*, which was riding out the storm on the east passage between Newport and Jamestown. The lowest barometric pressure was recorded by the *USS Valdez* while in the east passage of Narragansett Bay, with a reading of 28.47 inches.

Hurricane Bob caused a storm tide of 8 to 12 feet, occurring less than 2 hours before high tide. Bob produced a storm surge of 6.5 feet on Narragansett Bay, resulting in a storm tide of 10.40 feet (MLLW), or 3.40 feet above flood stage, as measured at the Fox Point Hurricane Barrier (Figure 45).

Boat damage was significant, as many boats were torn from their moorings. Coastal flooding was widespread along the south shore of Rhode Island and on Narragansett Bay, although most of the damage was confined to southeast Rhode Island, from Bristol to Little Compton. The highest storm tide was along the shore of Little Compton where extensive home and beach damage occurred.

Rainfall amounts across Rhode Island ranged from 0.59 inches in Little Compton, to 2.51 inches in Warwick, to as much as 7.01 inches in Foster (Figure 46). Damage from Bob was estimated at $9 million, with over $750,000 in crop damage.

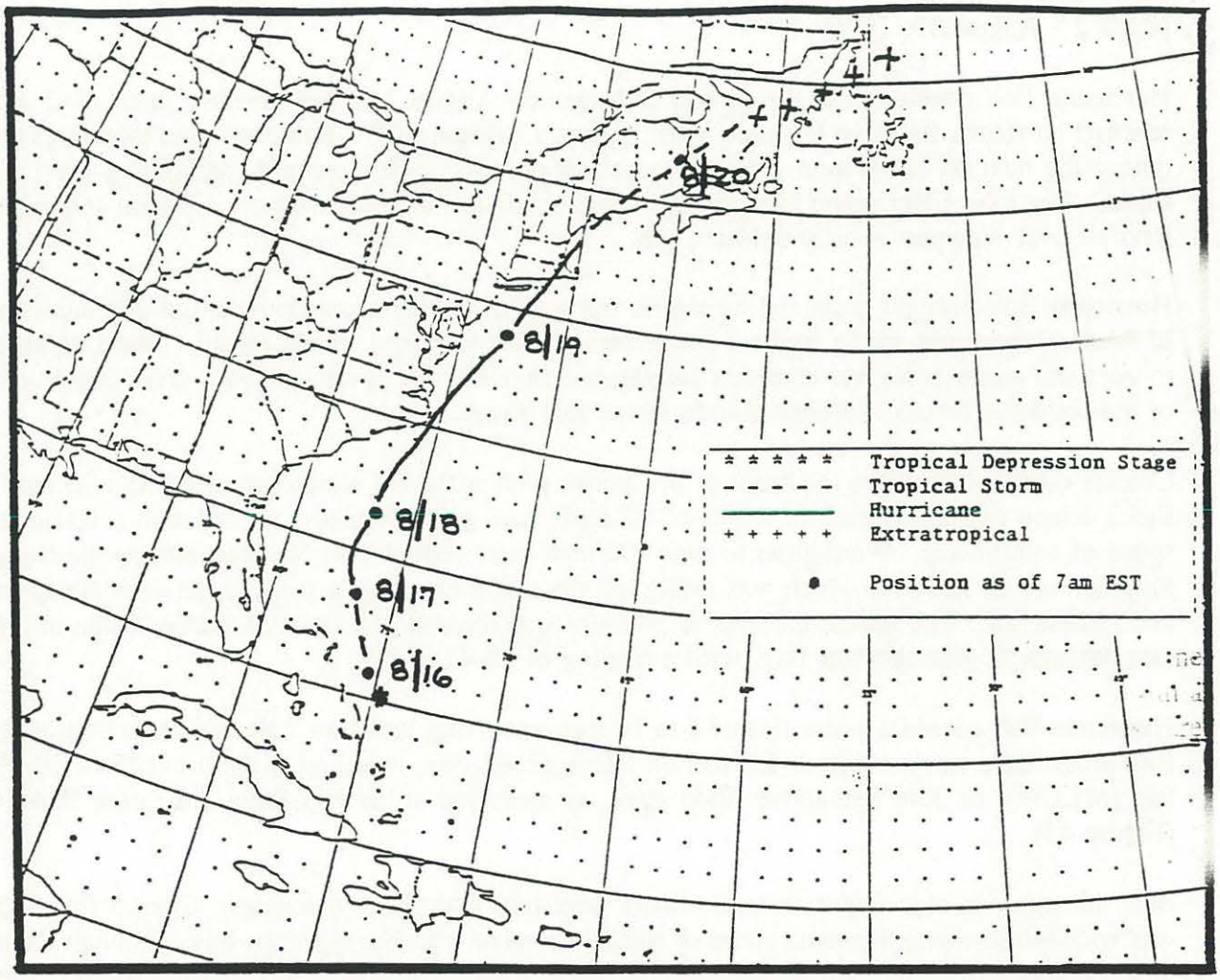


Figure 44. Track of Hurricane Bob of 1991.

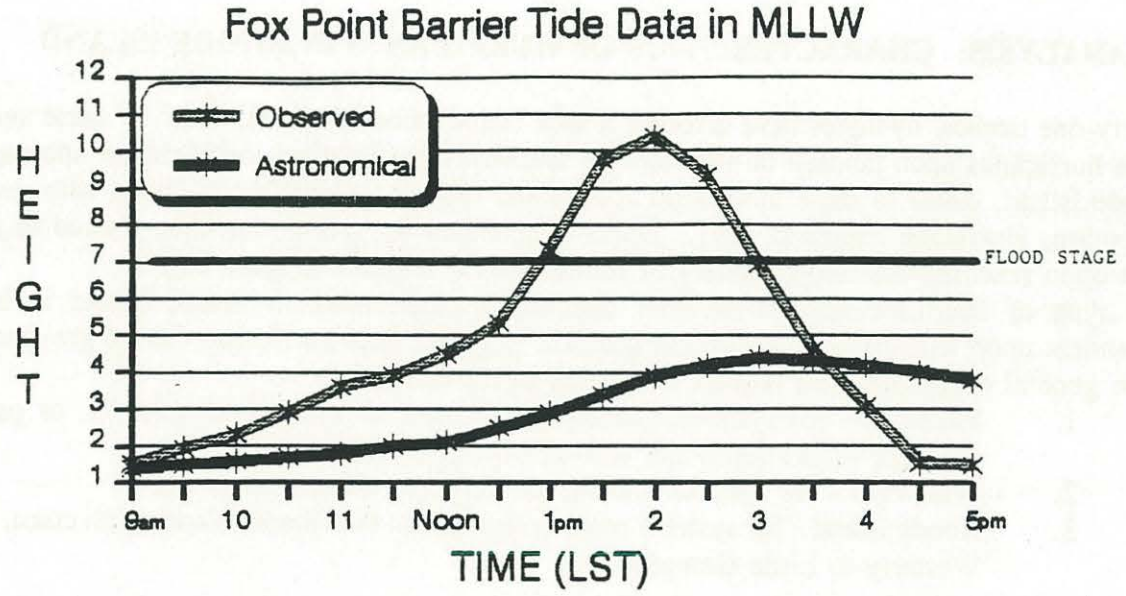


Figure 45. Storm surge height (feet) on August 19, 1991, associated with Hurricane Bob, recorded at the Fox Point Hurricane Barrier on upper Narragansett Bay.

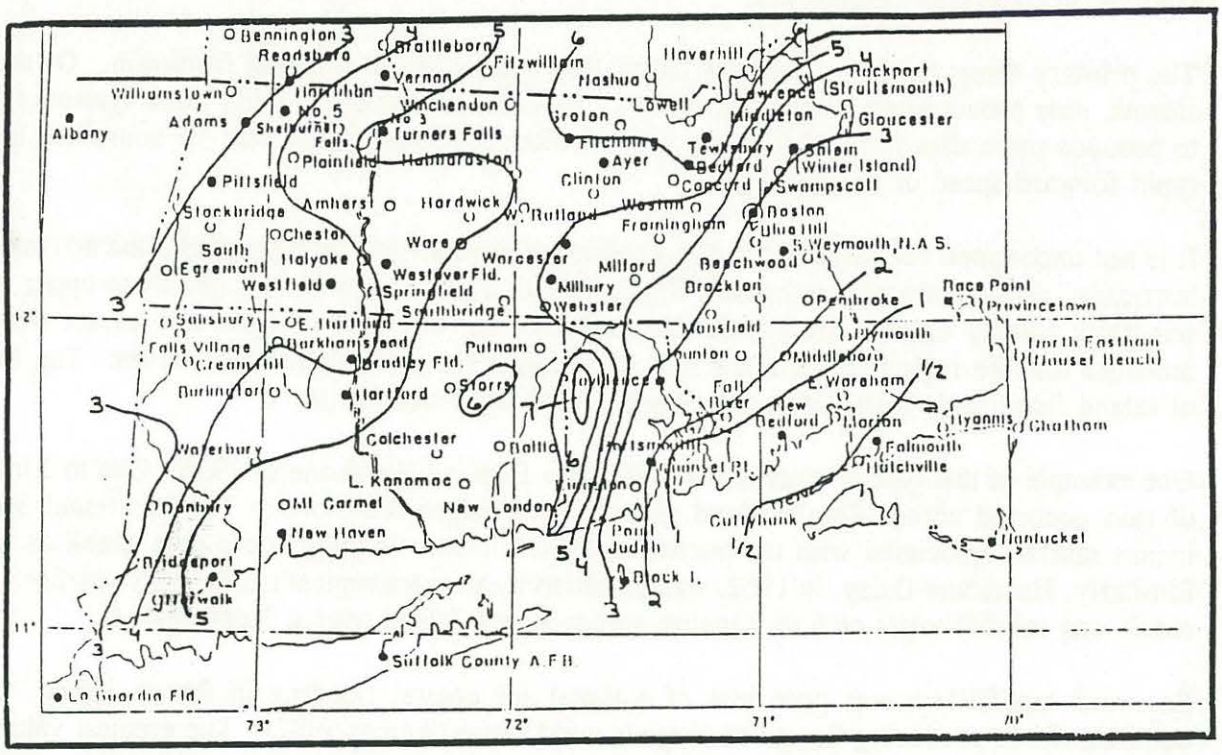


Figure 46. Analyzed precipitation field (inches) for rainfall associated with Hurricane Bob.

3. ANALYSIS: CHARACTERISTICS OF HURRICANES IN RHODE ISLAND

Thirty-one tropical cyclones have affected Rhode Island since 1936. Nineteen of these systems were hurricanes upon landfall on the coast of southern New England, or at closest approach to Rhode Island. Most of these hurricanes accelerated rapidly toward Rhode Island with just one exception, Hurricane Esther in 1961. Esther accelerated for a time, but then slowed to just 6 mph upon reaching the coastal waters of southern New England (Figure 30).
The type of hurricane-induced weather conditions experienced in Rhode Island is highly dependent upon where the center makes landfall. Rhode Island hurricanes can be grouped into three general categories with respect to landfall of the center:

1. Eastward - for systems making landfall east of Little Compton, RI, or passing over the waters south and east of New England.
2. Westward - for systems making landfall west of Westerly, RI.
3. Rhode Island - for systems making landfall on the Rhode Island south coast, from Westerly to Little Compton, RI.

3.1. Eastward

Since 1936, 12 hurricanes have passed east of Rhode Island. Most of these hurricanes stayed offshore, passing south and east of Cape Cod, MA. Hurricane Edna was the only one to make landfall on Cape Cod (Figure 18).

The primary threat from an Eastward Landfall system is inland flooding from rain. Of the 12 storms, nine produced an average rainfall of 2 to 4 inches statewide. Only three systems failed to produce more than 0.5 inches. The rainfall often occurred in less than 12 hours due to the rapid forward speed of the systems.

It is not uncommon for Rhode Island to experience rainfall several days before the arrival of a hurricane. For a hurricane to threaten Rhode Island, a south to southwest middle to upper level windflow usually exists. During the summer months, this type of flow can advect tropical moisture into the region and produce rain days before the actual hurricane arrives. The threat of inland flooding is dramatically increased if such conditions exist.

One example of this type of situation was the New England Hurricane of 1936. One to 2 inches of rain occurred across Rhode Island several days before this storm. The additional 3 to 5 inches rainfall associated with the hurricane caused inland flooding and a dam break as well. Similarly, Hurricane Daisy, in 1962, was preceded by an extratropical storm 2 days earlier. The result was rainfall totals of 6 to 9 inches across Rhode Island over a 3 day period.

Eastward landfall systems pose less of a threat for coastal flooding in Rhode Island. The dominant force producing the storm surge is wind stress (Anthes 1982). The greatest values of wind stress are generated in the northeast quadrant of the hurricane. Therefore, when a hurricane passes east of Rhode Island, the greatest wind stress and surge values are generated over the waters well east of the state. The observed rise in water level on Narragansett Bay is

mostly the result of induced water currents that develop in advance of the hurricane and then propagate into Narragansett Bay. Further reducing the flood threat is the prevailing northeasterly wind flow. A northeasterly trajectory is not conducive to the development of large waves due to its short fetch. In addition, a northeasterly trajectory is an offshore wind for much of the Rhode Island coast and exposes fewer locations to damaging wave action.

Hurricane Edna was the only eastward landfall storm that produced a measurable storm surge (Figure 19). Some of these systems produced high surf and some minor coastal flooding due to wave action, but only when the strongest winds coincided with high tide. Widespread coastal flooding from an organized storm surge did not occur.

3.2. Westward

Since 1936, five hurricanes have made landfall west of Rhode Island. (Two were Category 3 intensity and two were Category 2 intensity.)

When a hurricane makes landfall west of Rhode Island, the state is placed in the dangerous right semicircle of the storm; the region where the greatest storm surge and strongest winds occur. Prevailing south or southeasterly surface winds accompany Westward Landfall systems. This aids in forcing the oncoming storm surge directly up Narragansett Bay and exposes much more of the Narragansett Bay shoreline and south coast of Rhode Island to the extremely large waves which ride atop the storm surge. In addition, Narragansett Bay has a conical shape--wider at the bay entrance and narrower over the upper part of the bay. The conical shape acts as a funnel, dramatically increasing the surge height as it progresses northward up the bay.

The average peak storm surge for these five hurricanes was 10 feet. The height of the surge increased with storm intensity. The greatest storm surge accompanied the Great New England Hurricane of 1938 (Figure 3). This Category 3 storm produced a storm surge of 13.8 feet. Hurricane Belle of 1976, a weak Category 1 system, produced a storm surge of only 3.3 feet.

With the exception of Hurricane Belle, the remaining westward landfall systems exhibited a similar storm surge characteristic--rapidly rising water levels on Narragansett Bay within the last two hours of landfall. For the Category 3 hurricanes, a rise of 8 to 10 feet occurred, with rises of 1 to 2 feet every 10 minutes during the last half hour prior to the maximum storm tide. For the Category 2 hurricanes, a rise of 4 to 6 feet occurred within 2 hours of landfall.

Bay waters receded quite rapidly after the storm center passed northwest of Rhode Island. Tides returned to normal between 2½ to 3 hours after the maximum storm tide was reached.

Strong, damaging winds accompanied each of these storms. Wind gusts of 130 mph were recorded on Block Island during Hurricane Carol of 1954 and Hurricane Donna in 1960. Each of these systems produced severe tree and crop damage, as well as widespread power outages.

Rainfall with westward landfall systems was dependent upon the eye's proximity to Rhode Island. The amounts were, on average, less than those for the eastward landfall systems. Between 2 and 4 inches of rainfall occurred with Hurricane Carol and Hurricane Donna. Both hurricanes made landfall across eastern Connecticut and passed close to northwestern Rhode Island (Figures 15 and 29). A track across eastern Connecticut likely caused the east side of the storm's eye wall to pass across much of Rhode Island. The remaining three storms produced far less rainfall. Hurricane Gloria of 1985, which made landfall farthest west, produced less than 0.25 inches of rainfall across most of the state (Figure 43).

3.3. Rhode Island

Since 1936, only the September Hurricane of 1944 and Hurricane Bob of 1991 made landfall on the south coast of Rhode Island, between Westerly and Little Compton. These systems produced a deadly combination of strong winds, coastal flooding from the storm surge, and rainfall.

Strong winds affected Rhode Island during both systems and resulted in widespread power outages. Coastal flooding occurred with both systems and was generally of equal severity. Although the September Hurricane of 1944 produced a storm surge 5 feet greater than Hurricane Bob, it struck at low tide. Therefore, the resulting storm tides differed by only 1 to 2 feet (Figures 9 and 45). Both storms were Category 2 intensity; however, the center of the September Hurricane of 1944 passed across the western half of Rhode Island, placing most of the coastline, from Narragansett to Little Compton, and all of Narragansett Bay in the right semicircle.

Both hurricanes produced significant rainfall, generally between 3 and 6 inches. However, parts of southeastern Rhode Island received much less rain from Bob. This was due to the marked reduction in organized convection across the eastern portion of the storm as it approached Rhode Island.

4. SUMMARY

4.1. Frequency

4.1.1. Yearly Statistics

Thirty-one tropical cyclones have affected the state since 1936; 12 were tropical storms, and 19 were hurricanes. The most active decade for tropical cyclone activity was the 1950s, when nine tropical cyclones affected the area; six were hurricanes. The decade of the 1960s ranked second, with seven tropical cyclones; six were hurricanes. For six consecutive years, from 1958 to 1963, at least one tropical cyclone affected the state each season. The longest period between tropical cyclone events was 8 years, from 1977 through 1984. The most storms to affect the state in one season were two, occurring in 1944, 1950, 1954, 1955, 1960, 1962, 1971, 1972, and 1985. However, the 1954 season was the only season in which both systems were hurricanes and made landfall on the southern New England coast.

4.1.2. Monthly Statistics

August and September were the most likely months for tropical cyclone activity in Rhode Island. Thirteen tropical cyclones occurred in September, and 12 in August. The remaining storms were evenly divided between June, July, and October; each month had two storms.

The earliest that a tropical cyclone affected Rhode Island was on June 22, 1972--Tropical Storm Agnes. The earliest that a hurricane affected the state was on August 9 and 10, 1976--Hurricane Belle. The latest the state was affected by a tropical cyclone was on October 29, 1963--Hurricane Ginny.

4.2. Wind Data

Observed wind speed data were available from the National Weather Service Offices in Warwick and on Block Island, and, occasionally, from the state airports and Coast Guard installations. Hence, the values given here represent actual recorded data and do not account for any "eye witness" estimates of sustained wind speeds or wind gusts.

The strongest recorded sustained 1-minute wind speed and wind gust at the office in Warwick occurred during Hurricane Carol, with a sustained southeast wind of 90 mph and a peak gust to 105 mph. The Great New England Hurricane of 1938 brought sustained winds of 87 mph before the anemometer blew away. Therefore, it is possible that stronger winds occurred during this hurricane. In addition, wind equipment during this time was not as sensitive as current wind systems. Therefore, values from the older systems may be lower.

Statewide, the all-time highest sustained wind speed of record occurred during Hurricane Donna with a sustained wind speed of 95 mph at Block Island. However, sustained wind speed data were not available for this station for either the Hurricane of 1938 or Hurricane Carol. The

strongest wind gust occurred on Block Island during both Hurricane Carol and Hurricane Donna when peak wind gusts of 130 mph were recorded.

4.3. Storm Surge

The Great New England Hurricane of 1938 produced the greatest storm surge and storm tide in the history of Rhode Island. The storm surge reached 13.8 feet and resulted in a storm tide of 19.01 feet (MLLW) at the State Street Station Dock on the upper part of Narragansett Bay. Hurricane Carol ranked a close second, with a storm surge of 13.7 feet and a storm tide of 17.51 feet (MLLW).

4.4. Precipitation

Precipitation information was gathered from several sources, including the National Weather Service Offices in Warwick and Block Island, and from cooperative observing sites.

The National Weather Service Office in Warwick averaged 2.18 inches of rain for all 31 storms. The greatest storm total occurred during Hurricane Esther in 1961 when 6.61 inches fell. This occurred during two separate periods because of the loop the system made southeast of the state. Tropical Storm Diane in 1955 brought 6.13 inches to the office.

Statewide, the greatest storm total occurred on Block Island during Hurricane Esther when 9.32 inches fell. A cooperative observer in the Greenville section of Smithfield recorded the second highest rainfall total of 8.45 inches during Tropical Storm Diane.

One of the worst inland flooding events in Rhode Island history occurred in August of 1955 when Tropical Storms Connie and Diane combined to produce rainfall totals of 7 to 14 inches statewide in 1 week. The intense rainfall over such a short period put many rivers and streams well above flood stage. The Blackstone River in Woonsocket crested 17 feet above flood stage, destroying several neighborhoods and business districts.

4.5. Pressure Data

Sea-level pressure data were gathered from several sources, including the National Weather Service Offices in Warwick and Block Island, as well as from state airports, Coast Guard installations, and several ship reports.

The lowest barometric pressure recorded in Rhode Island occurred at the Pt. Judith Coast Guard installation during the September Hurricane of 1944 when the pressure fell to 28.31 inches. The Hurricane of 1944 also brought the lowest pressures ever recorded at the National Weather Service Office in Warwick, 28.48 inches, and on Block Island, with a reading of 28.34 inches.

4.6. Storm Speed

The Great New England Hurricane of 1938 had the fastest forward speed when it struck Rhode Island, 51 mph. Hurricane Gerda ranked second with a forward speed of 48 mph. The slowest moving system to affect Rhode Island was Hurricane Esther with an average speed of only 6 mph.

5. ACKNOWLEDGEMENTS

The author thanks Paul Sisson, MIC, WSO Providence, for allowing me the time and resources necessary to complete this project. The author is indebted to Marion Raiche for the time and effort spent reviewing this paper.

Thanks also to Stephen Hrebenach and the entire Scientific Services Division for their constructive comments and suggestions during the preparation of this paper. Thanks to Brian Jarvinen of the National Hurricane Center and Wilson A. Shaffer from the Techniques and Development Laboratory for their helpful suggestions. In addition, I am grateful to Bruce Whyte, DHIC, Northeast River Forecast Center, for the rainfall data and analyses. Thanks to Robert Case, DMIC, WSFO Boston, for his comments and suggestions on the storm surge information. And most importantly, a sincere thank you to my wife Mary for her patience and understanding throughout the many hours spent on this project.

APPENDIX A

GLOSSARY

Eye	The relatively calm center of a tropical cyclone.
Eye Wall	An organized band of clouds which often contain the strongest winds and heaviest rains in a tropical cyclone. The eye wall surrounds the eye.
Hurricane	A tropical cyclone in which the maximum sustained surface wind speed is 74 mph (64 kts) or greater.
Hurricane Season	The portion of the year having a relatively high incidence of hurricanes. The season for the Atlantic Ocean, Caribbean Sea, and Gulf of Mexico runs from June 1 to November 30.
Mean Lower Low Water	A tidal datum. The arithmetic mean of the lower low water heights of a mixed tide observed over a specific 19-year Metonic cycle (the National Tidal Datum Epoch).
Saffir/Simpson Hurricane Scale	A scale ranging from one to five based on the present intensity of a hurricane. This can be used to give an estimate of property damage and flooding expected along the coast in the path of a storm.
Storm Surge	An abnormal rise in sea level accompanying a hurricane or other intense storm. Storm surge is estimated by subtracting the normal or astronomical tide from the observed storm tide.
Storm Tide	The actual level of sea water resulting from the astronomical tide combined with the storm surge.
Tropical Cyclone	A warm-core, nonfrontal low pressure system of synoptic scale that develops over tropical or subtropical waters and has a definite organized circulation.
Tropical Depression	A tropical cyclone in which the maximum sustained surface wind speed is 38 mph (33 kts) or less.
Tropical Storm	A tropical cyclone in which the maximum sustained suace wind speed ranges from 39 to 73 mph (34 to 63 kts).

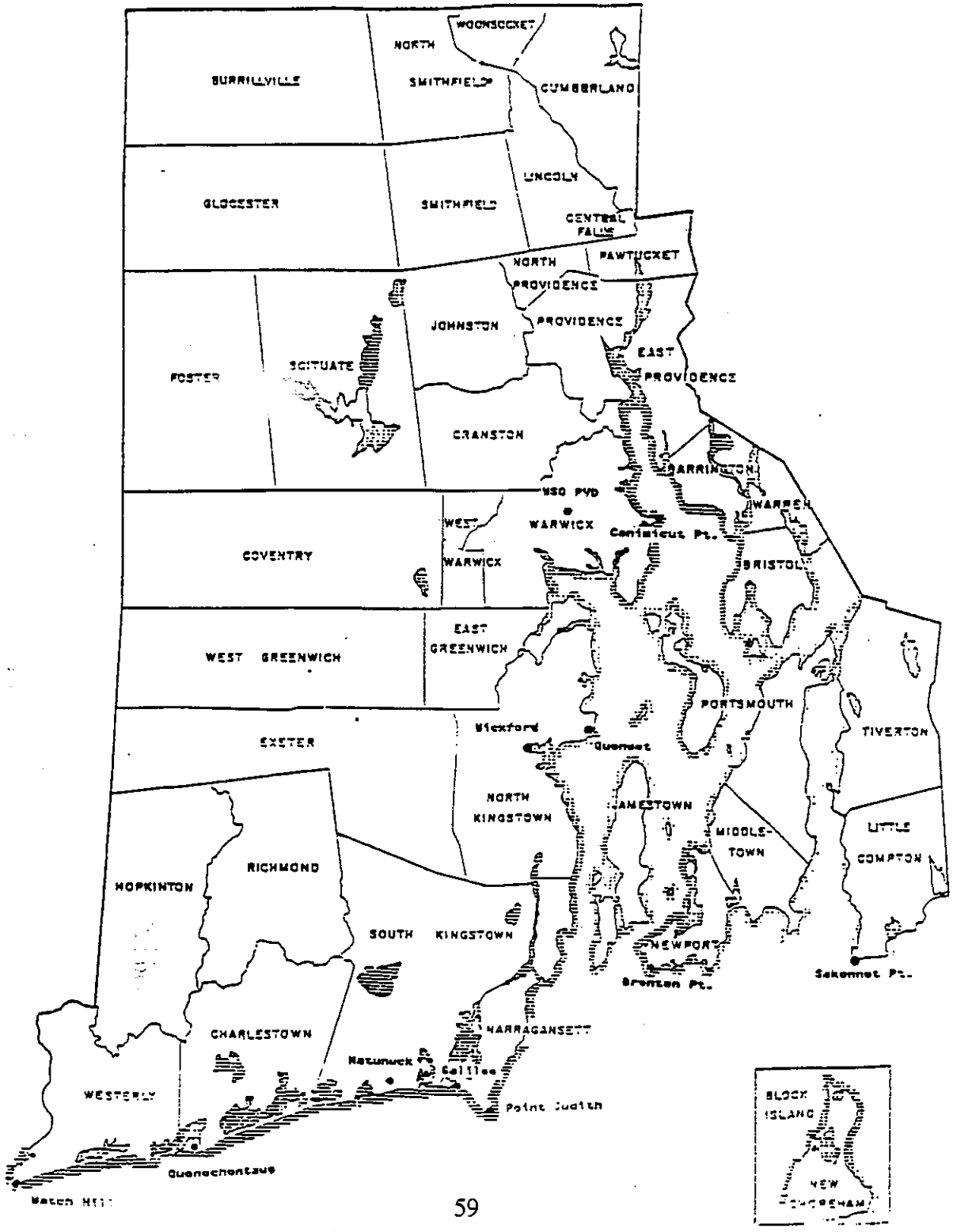
APPENDIX B

SAFFIR/SIMPSON HURRICANE SCALE

Category	Description of damage
ONE	*Winds 74-95 mph or storm surge 4-5 feet above normal*. No real damage to building structures. Damage primarily to unanchored mobile homes, shrubbery, and trees. Also, some coastal road flooding and minor pier damage.
TWO	*Winds 96-110 mph or storm surge 6-8 feet above normal*. Some roofing material, door, and window damage of buildings. Considerable damage to vegetation, mobile homes, and piers. Coastal and low-lying escape routes flood 2-4 hours before arrival of center. Small craft in unprotected anchorages break moorings.
THREE	*Winds 111-130 mph or storm surge 9-12 feet above normal*. Some structural damage to small residences and utility buildings with a minor amount of curtainwall failures. Mobile homes are destroyed. Flooding near the coast destroys smaller structures, with larger structures damaged by floating debris. Terrain continuously lower than 5 feet above mean sea level (ASL) may be flooded inland as far as 8 miles.
FOUR	*Winds 131-155 mph or storm surge 13-18 feet above normal*. More extensive curtainwall failures with some complete roof structure failure on small residences. Major damage to lower floors of structures near the shore. Terrain continuously lower than 10 feet ASL may be flooded requiring massive evacuation of residential areas inland as far as 6 miles.
FIVE	*Winds greater than 155 mph or storm surge greater than 18 feet above normal*. Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. Major damage to lower floors of all structures located less than 15 feet ASL and within 500 yards of the shoreline. Massive evacuation of residential areas on low ground within 5-10 miles of the shoreline may be required.

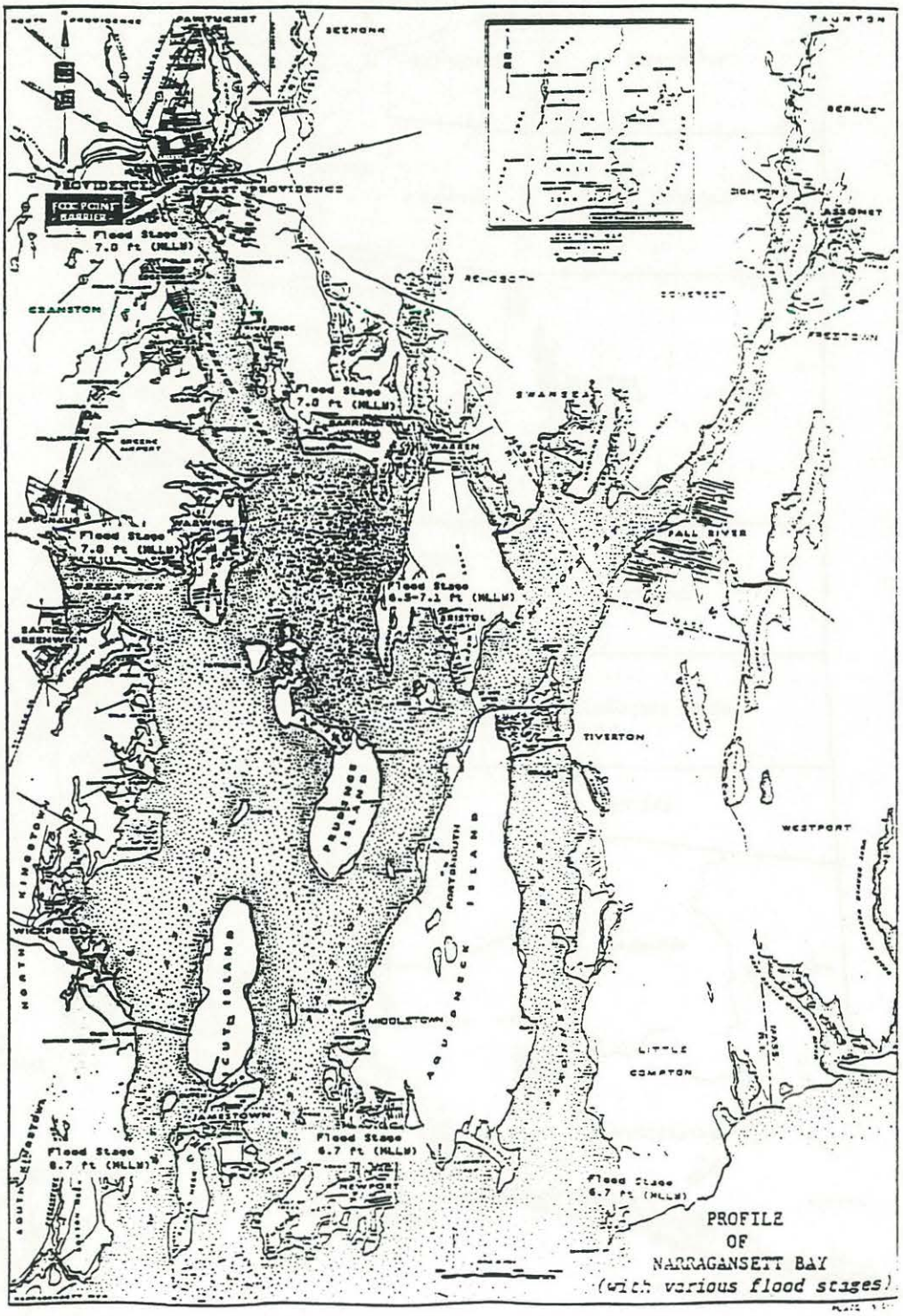
APPENDIX C

RHODE ISLAND CITIES AND TOWNS



APPENDIX D

NARRAGANSETT BAY



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