SOUTHERN NEW ENGLAND TROPICAL STORMS AND HURRICANES

A Ninety-seven Year Summary
1900-1996
including several Early American Hurricanes

David R. Vallee
NOAA/NWS Northeast River Forecast Center
Taunton, MA

Michael R. Dion
National Weather Service Headquarters
Silver Spring, MD

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1. INTRODUCTION

Hurricanes and tropical storms are no strangers to southern New England. The earliest colonial records in the region note several extremely intense hurricanes which caused considerable destruction. Forty such storms have affected the region since 1900, either making landfall along the coast 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 southern New England, which greatly reduced the time to prepare and evacuate.

Tropical cyclones that have affected southern New England have brought a variety of weather conditions. Some of the weaker storms have passed with hardly a whimper, producing only some occasional heavy showers and periods of gusty winds. Some systems have brought torrential rains and inland flooding, while still others have brought a combination of fierce winds and widespread tree and structural damage. Some have also brought devastating storm surges that crashed onto the coast, severely crippling coastal communities.

This paper was compiled to provide a detailed review of all tropical cyclone activity near southern New England since 1900. The year of 1900 is arbitrary, selected due to the very limited amount of reliable climatological data that was available concerning storms prior to this date. In addition, a brief look at eight of the most significant early century hurricanes is included for historical purposes. These storms were not included in the climatological summary which appears at the end of this paper.

2. DATA

All information regarding the tracks of each tropical cyclone was obtained through the National Climatic Center publication, *Tropical Cyclones of the North Atlantic Ocean, 1871-1992*. Much of the data regarding storm intensity and damage information was gathered through several sources, including the *Monthly Weather Review* seasonal summaries, disaster survey reports, *Climatological Data for New England*, and numerous newspaper articles from the *Providence Journal*, *Westerly Sun* and *Boston Globe*. In addition, information pertaining to the Early Century Hurricanes was gathered through several Blue Hill Observatory Publications, and *Early American Hurricanes, 1492-1870, by David M. Ludlum*. A complete list of references has been provided at the end of this report.

For the early century storms, prior to 1900, a brief narrative of the storm's impact on the region is provided. Tracks were available for only the Hurricanes of 1815 and 1821. For storms after 1900, a discussion is provided including the storm's location of origin, the types and severity of damage, and a map detailing its track toward southern New England. The intensity of each hurricane is given by category, based on the Saffir-Simpson Hurricane Scale, at time of landfall or closest approach to southern New England.

Graphs of actual storm tides and associated storm surges have been provided for 6 major hurricanes: The Great New England Hurricane of 1938, The September Hurricane of 1944, Hurricanes Carol and Edna of 1954, Hurricane Gloria of 1985, and most recently, Hurricane Bob of 1991. Tide data locations are as follows: (see Appendix C)

1. South Street Station Dock, at the Narragansett Electric Company facility in Providence, RI, through 1954. This site was later replaced by the Fox Point Hurricane Barrier, which was constructed in 1966, 400 yards south of the South Street Station Dock.
2. Coasters Harbor Island, at the U.S. Navy Complex in Newport, RI.
3. Montaup Electric Company, Somerset Station in Somerset, MA.
4. New Bedford Harbor-Fairhaven Area, New Bedford, MA.
5. Mouth of the Pawcatuck River, Pawcatuck, CT.

Rainfall analyses for southern New England have been provided for fourteen storms including: The Great New England Hurricane of 1938, The September Hurricane of 1944, Hurricanes Carol and Edna of 1954, Tropical Storms Connie and Diane of 1955, Hurricane Donna of 1960, Hurricane Esther of 1961, Hurricane Daisy of 1962, Tropical Storm Carrie of 1972, Hurricane Gloria of 1985, Hurricane Bob of 1991, and Tropical Storm Bertha and Hurricane Edouard of 1996.

A glossary of terms is given in Appendix A. The Saffir/Simpson Hurricane Classification System is provided in Appendix B. A map of southern New England is provided in Appendix C, denoting major coastal communities, tide data locations, several rivers, as well as major Bays and Sounds. Appendix D provides a detailed map of southern New England denoting major inland cities and towns referenced throughout the paper.

EARLY AMERICAN TROPICAL CYCLONES - 1635 THROUGH 1893

THE GREAT COLONIAL HURRICANE OF 1635
(August 25, 1635)

The first documented tropical cyclone known to have struck New England occurred in August of 1635, only fifteen years after the Pilgrims settled in Plymouth, Massachusetts. It may also have been the most intense storm ever to have hit the region.

This hurricane is believed to have made landfall along the Rhode Island coast, near Westerly. Based on limited written observations of wind direction, it is thought that the center raced northeastward, passing just south of Boston, as it entered the Gulf of Maine; a track that would be similar to that taken by the New England Hurricane of 1944.

Early writings by local settlers noted widespread wind damage to forests, crops and structures throughout eastern New England. The most significant damage occurred along the south coast where a storm surge of at least 15 feet occurred. Tide records suggest that the storm tide in Providence, Rhode Island, on the upper reaches of Narragansett Bay, reached 20 feet. Damage to sailing vessels was extensive, leaving the region nearly paralyzed in the storm's wake.

THE COLONIAL HURRICANE OF 1638
(August 3, 1638)

This particular storm is believed to have moved northward through New England, with landfall somewhere along the eastern Connecticut shore. This storm was not nearly as well documented as the Great Colonial Hurricane of 1635. What information was available spoke of considerable coastal flooding along the shore, with tide heights approaching 20 feet in some locations including Narragansett and Buzzards Bays. Damage to inland structures and forests was also noted, but not to the extent of the 1635 storm.

THE NEW ENGLAND HURRICANE OF 1675
(September 7, 1675)

The New England Hurricane of 1675 is believed to have made landfall on the central Connecticut coast. Damage was more widespread throughout the region than that from the Colonial Hurricane of 1638. Connecticut was hardest hit, with widespread tree and crop damage inland, and considerable ship damage along the coast. The Stonington/New London area of coastal Connecticut experienced the most ship damage.

Several writers of the time compared this system's intensity to that of the Great Colonial Hurricane of 1635.

THE HURRICANE OF 1727
(September 27, 1727)

The track of this hurricane is somewhat in question. It is believed that the center of the storm either passed across extreme outer Cape Cod, or more likely remained just offshore on its track northeastward.

This storm was most noted by residents of eastern Massachusetts. The most significant damage occurred from Cape Ann southward to Cape Cod along the Massachusetts coast. Numerous reports of widespread crop and structural damage were documented. Strong northeast winds of hurricane force likely affected much of Rhode Island and the eastern most sections of Connecticut, where many trees were either blown down or uprooted.

Extremely high tides were reported along the east coast of Massachusetts. Significant damage occurred to ships and various ports from the Cape Cod Bay area northward.

Heavy rainfall was reported across much of eastern Connecticut, Rhode Island and central and eastern Massachusetts.

THE SOUTHEASTERN NEW ENGLAND HURRICANE OF 1761
(October 23-24, 1761)

The track of this system is also in question. It most likely sideswiped the region, with its center remaining off the coast of Cape Cod.

Most of the damage from this storm was due to strong northeast winds. Significant damage to houses, barns and trees was reported, especially in Rhode Island and southeastern Massachusetts. The church steeple of the Trinity Church of Newport, Rhode Island was destroyed by wind during the storm. Also, the combined effects of strong winds and large ocean waves destroyed a bridge in downtown Providence.

THE GREAT SEPTEMBER GALE OF 1815
(September 23, 1815)

Though several minor storms affected New England with strong winds and heavy rain during the 1700's, the next significant storm of hurricane strength struck with awesome power on September 23, 1815.

This storm was first reported by ships to be just north of Puerto Rico, on August 19 (Figure 1). It made a classic turn toward the north and accelerated rapidly on August 22, before crashing ashore near Saybrook, Connecticut at approximately 9 AM on August 23.

This was one of the most intense hurricanes since the Colonial Hurricane of 1635. A storm surge of at least 10-13 feet accompanied this system. Severe coastal damage was reported across the entire coastline. Hundreds of boats were destroyed, with many more damaged. Narragansett and Buzzards Bays were hard hit due to the high winds and storm surge. Much of the city of Providence, Rhode Island was flooded by a storm tide estimated at around 18 feet. The storm tides measured at the mouth of the Pawcatuck River, in Pawcatuck, Connecticut were the highest ever recorded, exceeding those observed during The Great New England Hurricane of 1938.

Hurricane force winds ripped roofs off houses, blew crops down, and toppled scores of trees throughout eastern Connecticut, Rhode Island, and eastern Massachusetts. Nantucket and Martha's Vineyard were far enough east of the center to escape significant damage.

Rainfall amounts were light across Rhode Island and eastern Massachusetts. The heaviest rainfall occurred along and west of the storm track. A rainfall total of 6.71 inches was recorded on the campus of Yale University, in New Haven, Connecticut.

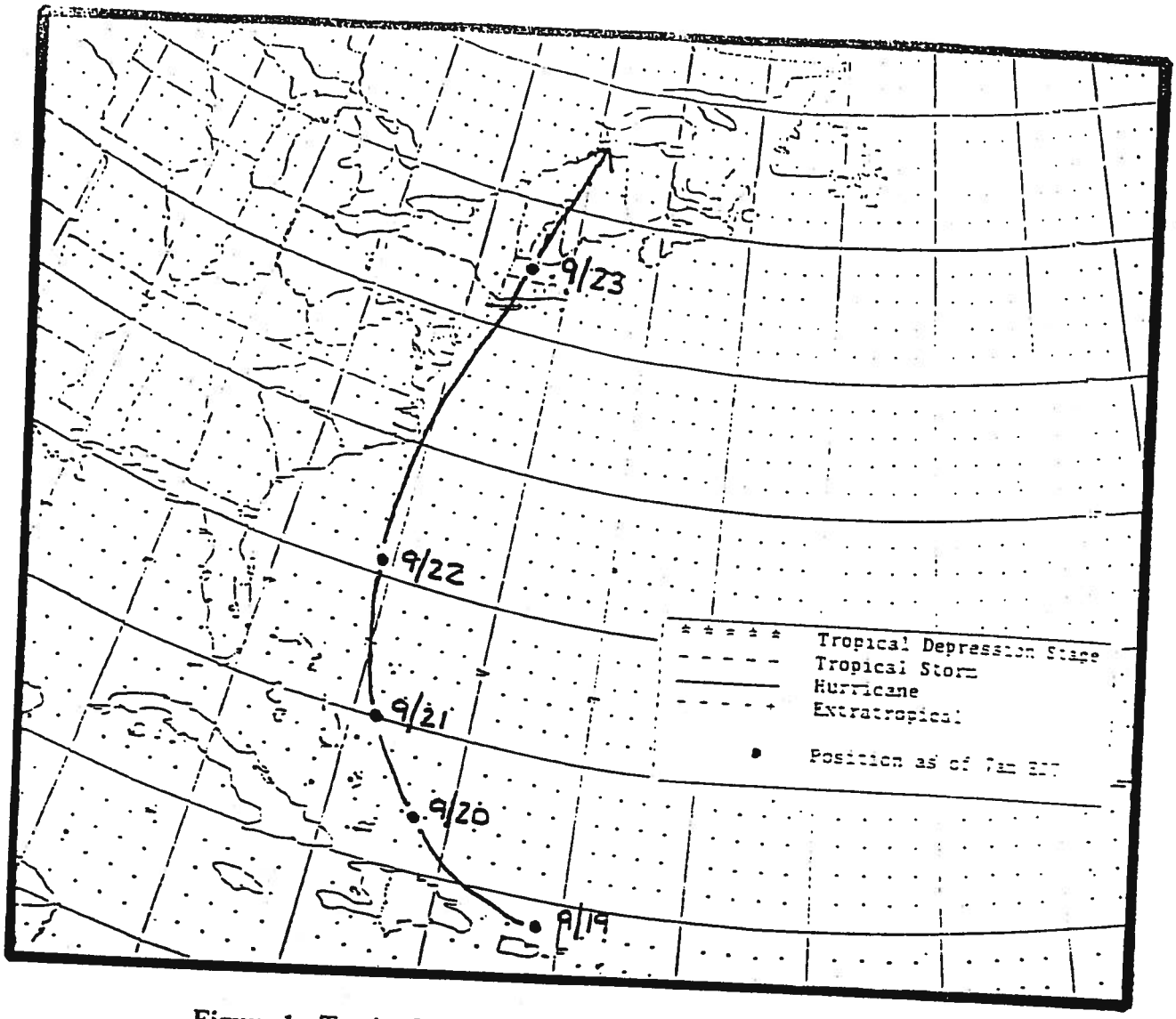

Figure 1. Track of the Great September Gale of 1815.

THE LONG ISLAND HURRICANE OF 1821
(September 3, 1821)

This storm was first reported by ships several hundred miles east of Turks Island in the far eastern Bahamas on September 1 (Figure 2). It made a gradual turn toward the north before accelerating to the northeast during the evening of September 2. The center made landfall at Stamford, Connecticut at approximately 9 PM on September 3, and continued rapidly northeastward across southeastern Maine by the early morning of September 4.

This system produced the most damage in western parts of Southern New England. Widespread tree and crop damage was reported across much of western Massachusetts and nearly all of Connecticut. However, farther to the east, across Rhode Island and eastern Massachusetts, damage was much less severe.

Along the coast, damage to boats, harbors and marinas was substantial, especially along the Connecticut coast. Damage could have been much worse in these areas. However, the hurricane arrived at low tide, sparing the region from catastrophic coastal flooding.

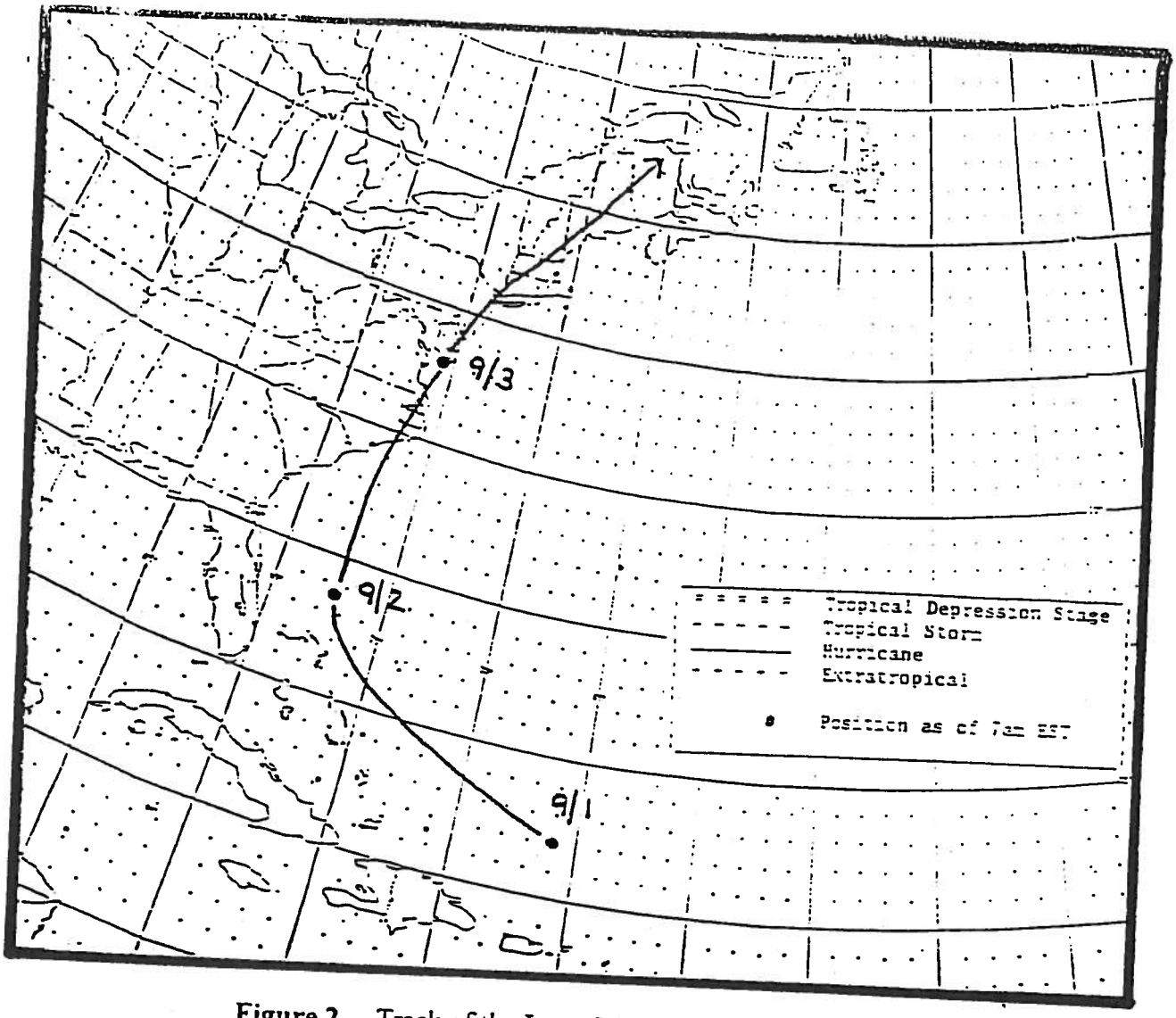

Figure 2. Track of the Long Island Hurricane of 1821.

THE SEPTEMBER GALE OF 1869
(September 8, 1869)

This storm struck eastern sections of southern New England with intense wind and rain. It is believed that landfall occurred near Watch Hill, Rhode Island. The center then raced northeast passing across Massachusetts between Worcester and Boston, before heading into Maine. Widespread coastal damage due to high storm tides occurred throughout the Rhode Island, Massachusetts and the southeast Connecticut coasts. This time, Buzzards Bay was hardest hit. The storm tide near Wareham, MA was estimated to have been the highest recorded since the Colonial Hurricane of 1635. Farther east, coastal flooding was not as severe due to the storm's arrival several hours prior to high tide.

Hurricane force winds buffeted Rhode Island and eastern Massachusetts. Widespread structural damage was reported along with trees uprooted. Damage west of the storm center, across western Massachusetts and most of Connecticut, was considerably less.

TROPICAL STORM OF JULY 1916
(July 21, 1916)

The Tropical Storm of July 2, 1916, formed east of the Windward Islands on July 10. It strengthened to a Hurricane as it moved beyond the Island of Puerto Rico on the 14. It displayed a classic though gradual recurvature toward New England during the next six days, before coming ashore as a strong Tropical Storm on the morning of July 21. Landfall occurred first over Martha's Vineyard, then on the west shore of Cape Cod, near Woods Hole, in Falmouth, Massachusetts. (Figure 3).

Little significant damage was reported from this system. Gale force winds affected a portion of Cape Cod and the islands of Martha's Vineyard and Nantucket on July 21. Rainfall of over one inch occurred west of the storm track, affecting eastern Massachusetts and Rhode Island. Rainfall east of the track was generally less than one half inch.

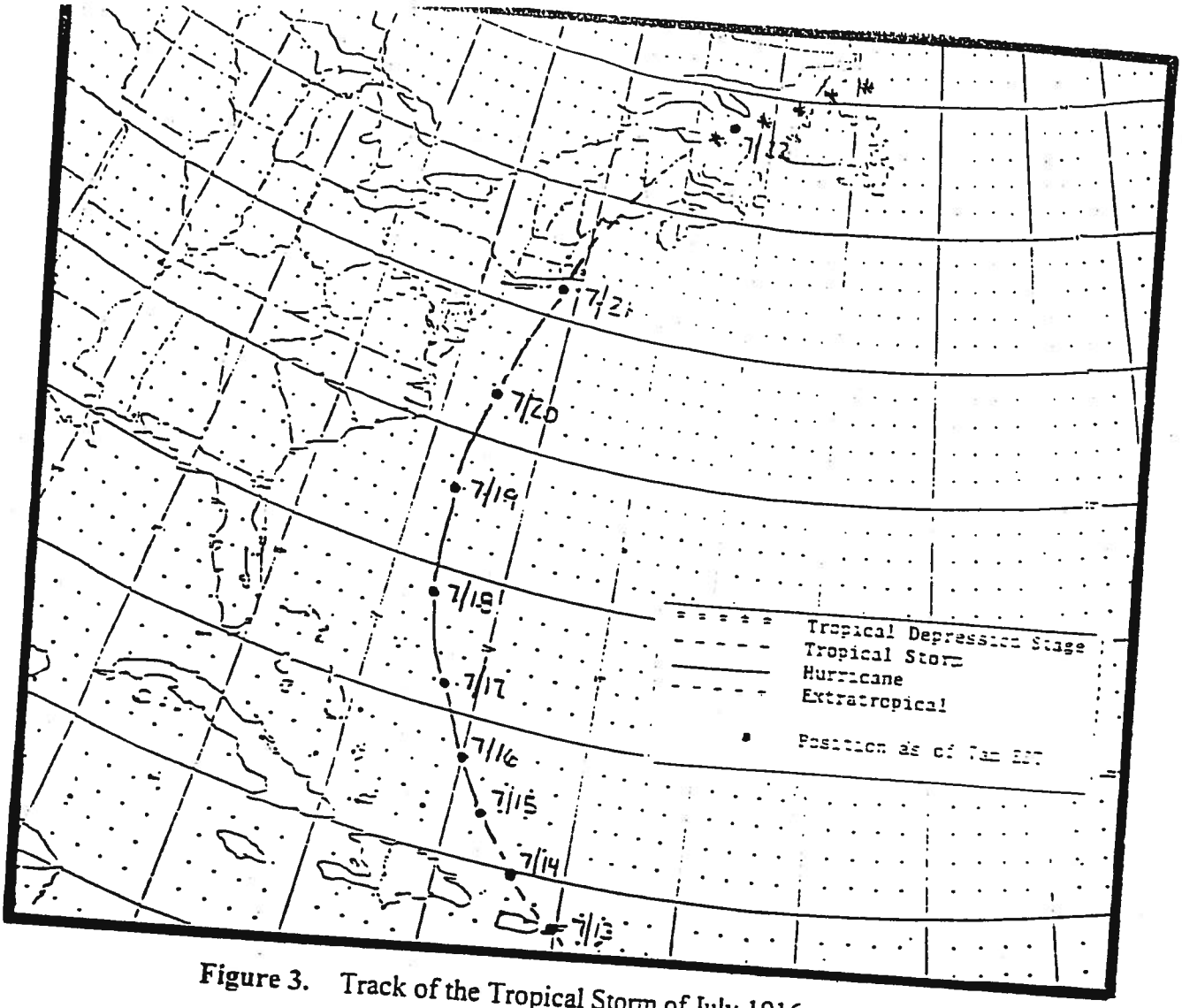

Figure 3. Track of the Tropical Storm of July 1916.

THE AUGUST HURRICANE of 1924
(CAT 2 - August 26)

The August Hurricane of 1924 was first noticed as a weak tropical storm on August 16, approximately 600 miles east of the Windward Islands (Figure 4). It remained a tropical storm as it headed slowly northwest across Puerto Rico on August 18. It strengthened to a hurricane while east of Florida on August 20, then curved abruptly northeastward on August 24. It grazed the Outer Banks of North Carolina on August 25 and passed about 50 miles east of Nantucket Island on August 26.

Sustained winds of 50 to 60 mph were confined to outer Cape Cod and the Islands, but wind gusts to over 60 mph were common throughout southeastern New England. The strongest wind gust, 80 mph, was recorded at the Blue Hill Observatory, in Milton, Massachusetts, at an elevation of 681 feet above sea level. Considerable damage to trees and power lines was reported throughout all of Rhode Island and eastern Massachusetts. Hundreds of trees were uprooted or blown down, with several reports of structural damage to homes. These winds also damaged much of the late summer corn and tree fruit crops. The lowest barometric pressure recorded was 28.71 inches on Nantucket Island.

Rainfall across the area varied considerably. One to two inches was common west of the Connecticut River. The remainder of the region received 2 to 4 inches, with over 6 inches in sections of south coastal Rhode Island and south coastal Massachusetts. South Kingston, Rhode Island recorded the highest amount of 6.90 inches.

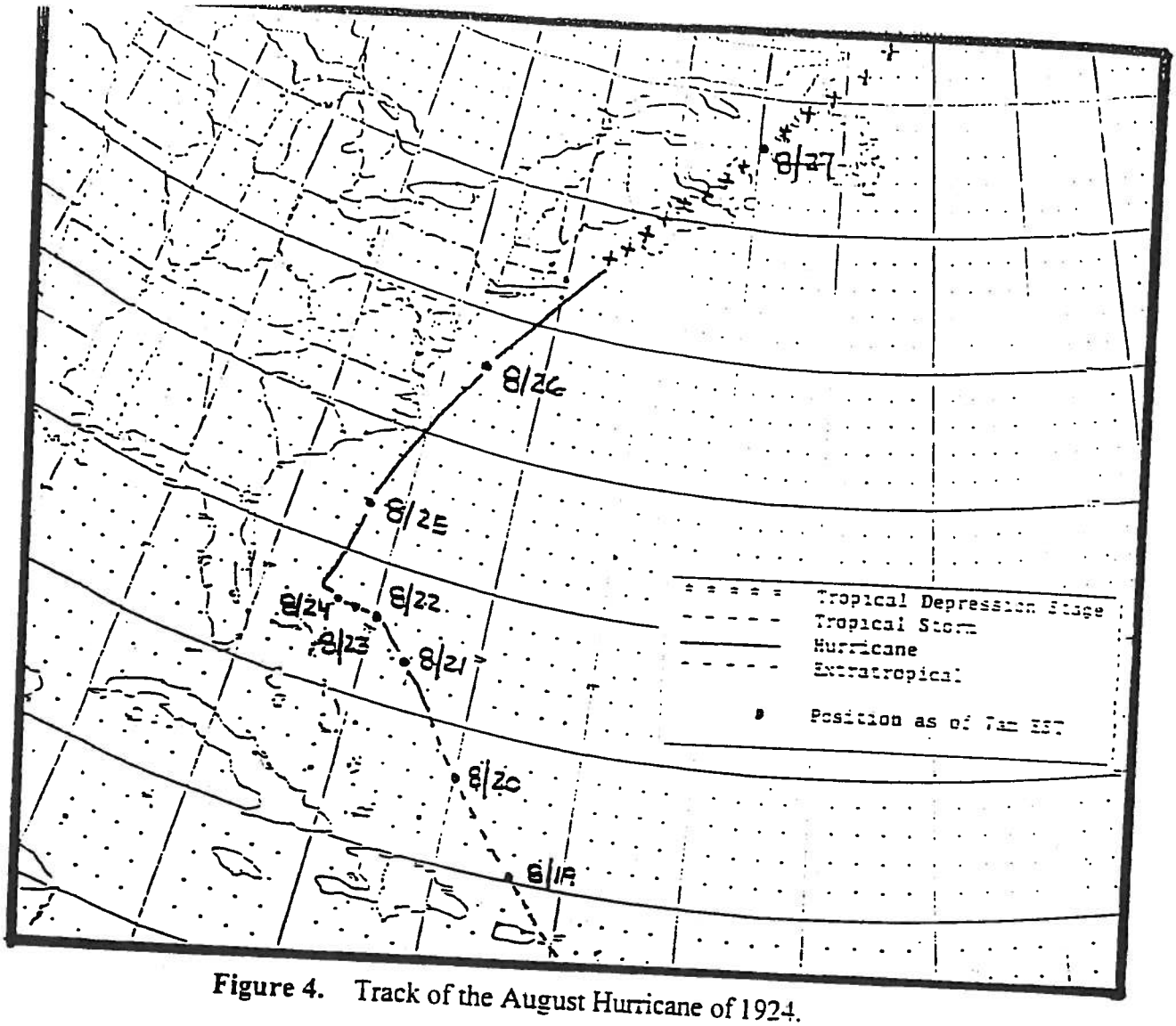

Figure 4. Track of the August Hurricane of 1924.

THE AUGUST HURRICANE OF 1927
(CAT 1 - August 24)

This system formed from a tropical wave on August 19, several hundred miles east of the Lesser Antilles (Figure 5). The system quickly intensified to a hurricane later that evening. The storm gradually accelerated as it recurved toward the northwest, then north. The hurricane began to lose some of its tropical character as it accelerated and recurved northeastward on August 24, eventually passing just east of Nantucket Island.

The storm produced moderate wind and surge damage to the islands of Martha's Vineyard and Nantucket. Winds gusted to 68 mph on Nantucket Island. Significant tree damage occurred on the islands. High winds were also responsible for damage to roofs on the islands.

A moderate storm surge of 2 to 4 feet accompanied the system. Numerous boats were tossed onshore, while others were removed from their moorings. The Schooner Yacht Constance was forced ashore near Monomay, even though it had all 3 of its anchors in the water. In addition, steamboat service to and from the islands was crippled due to damage to both the steamboats and their docks.

Heavy rainfall occurred along and west of the storm center. Rainfall of 2 to nearly 4 inches was quite common from Providence, Rhode Island east and south across the islands.

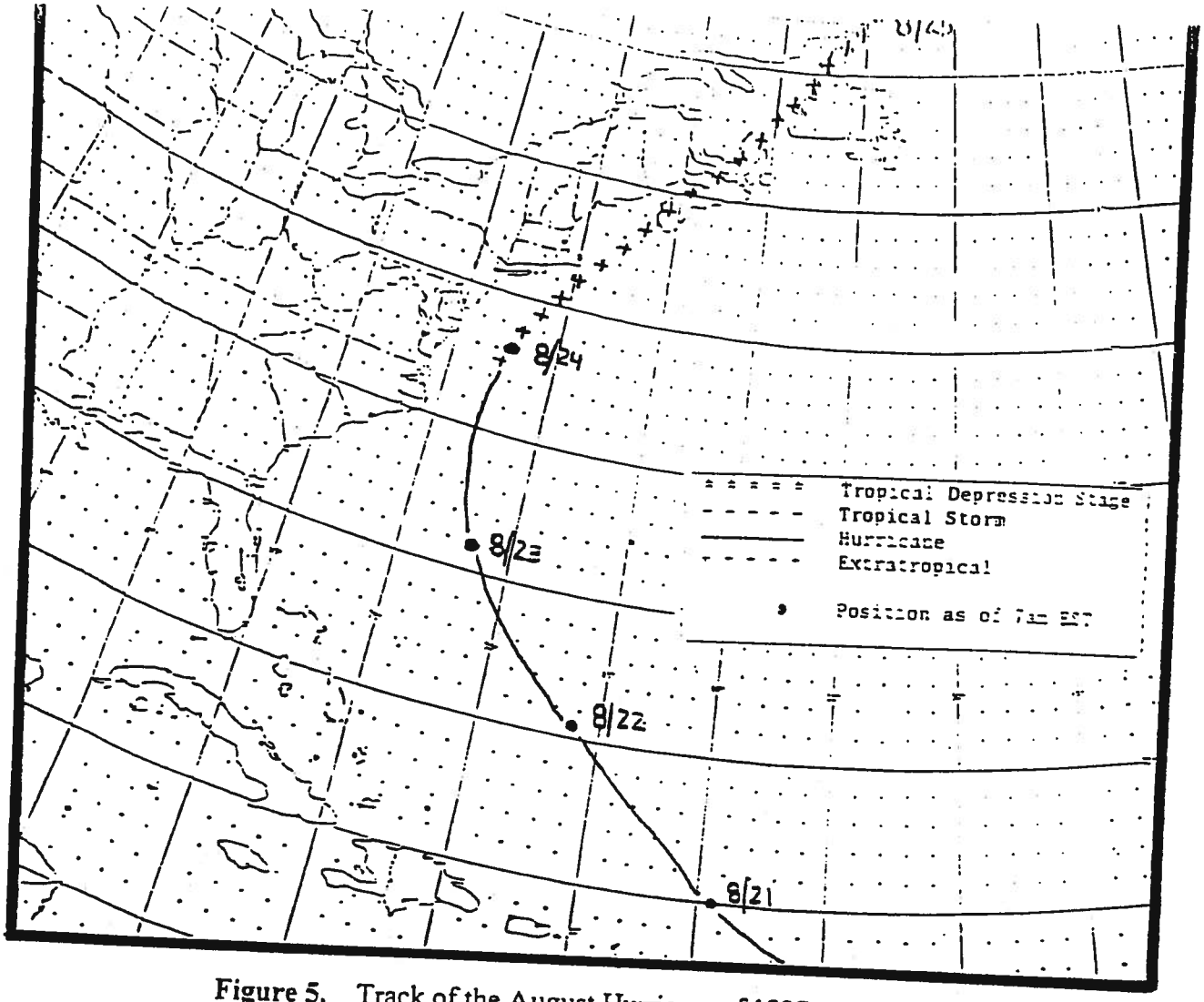

Figure 5. Track of the August Hurricane of 1927.

THE SEPTEMBER HURRICANE OF 1933
(CAT 1 - September 17)

The September Hurricane of 1933 was first noticed as a weak tropical storm approximately 300 miles east of the Leeward Islands on September 7 (Figure 6). It quickly strengthened to a hurricane by September 9 as it made a turn toward the northwest. The hurricane continued steadily northwestward eventually making landfall across eastern North Carolina on September 16. The hurricane recurved northeastward and passed approximately 75 miles east of Nantucket Island on September 17.

No significant wind damage was reported with this storm. Wind gusts to 50 mph were confined to coastal Rhode Island east to Cape Cod. The strongest gust was 54 mph, recorded on Nantucket Island. This hurricane did approach near the time of high tide, and pushed water levels two feet above normal across eastern Massachusetts and Cape Cod.

The most significant feature was heavy rainfall. One to three inches fell across western Massachusetts and most of Connecticut. Amounts of 4 to 8 inches were common across Rhode Island and eastern Massachusetts. The greatest amounts occurred over Cape Cod. Provincetown received 9.92 inches in 24 hours, and a storm total of 13.27 inches. Considerable urban and street flooding occurred throughout coastal Rhode Island and southeastern Massachusetts.

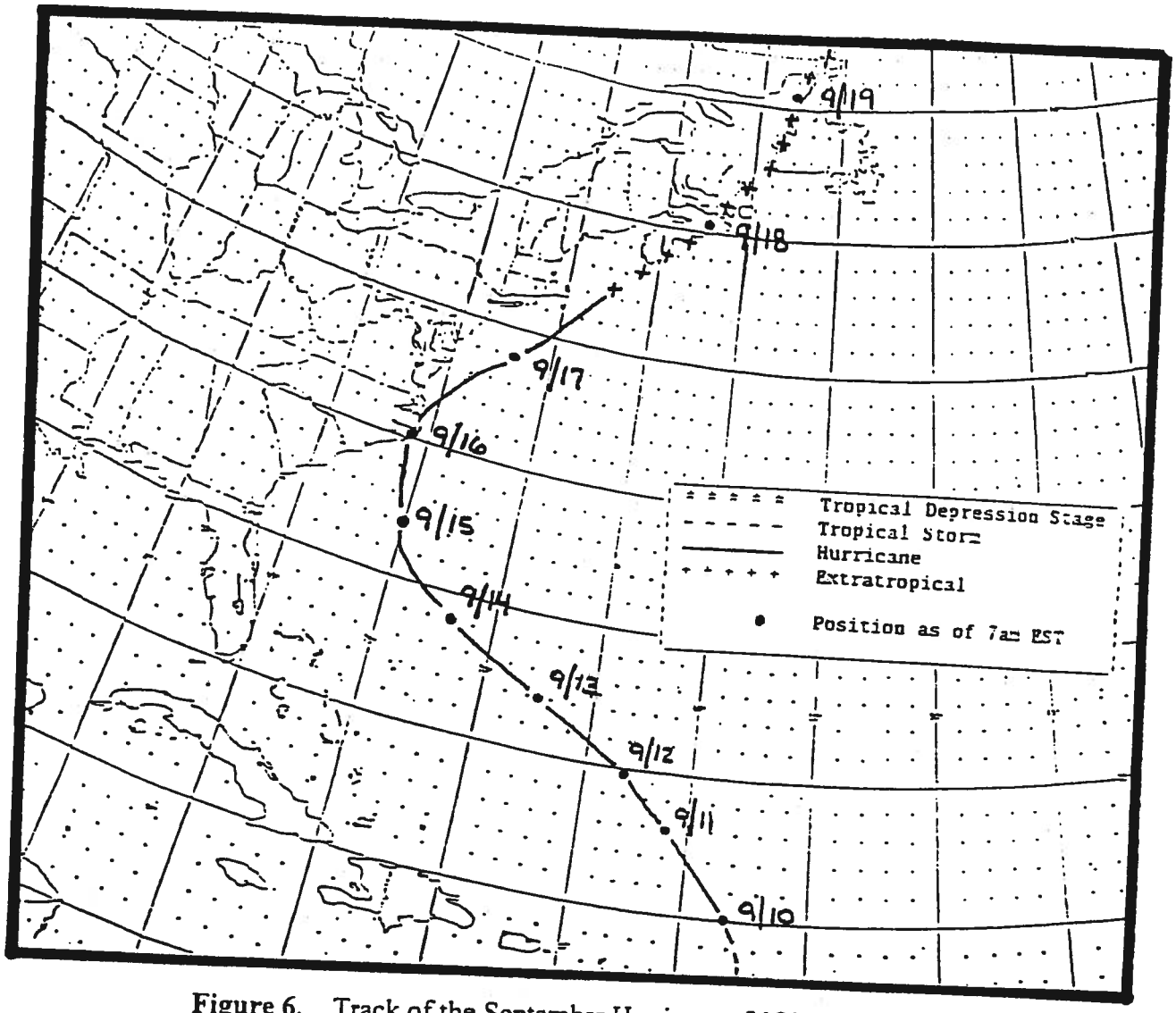

Figure 6. Track of the September Hurricane of 1933.

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 (Figure 7). It tracked steadily northwest over the next ten days, eventually grazing the Outer Banks of North Carolina on September 18 with winds of 80 mph and severe coastal flooding. The hurricane turned sharply northeastward and accelerated during September 18, passing about 50 miles south of Nantucket Island during the early morning hours of September 19.

The September Hurricane of 1936 delivered a glancing blow to southern New England. Sustained winds of 30 to 50 mph occurred throughout most of the region with near hurricane force winds along the immediate coast. Block Island, RI recorded the highest sustained winds, 64 mph, as the eye passed to the southeast. Substantial tree damage and widespread power outages were reported from eastern Connecticut to Cape Cod.

Some minor coastal flooding occurred, with tides running two to three feet above normal. Some beach erosion also occurred, as well as damage to several break walls. One hundred boats were damaged or destroyed on Narragansett Bay, with several hundred damaged throughout coastal Southern New England.

Rainfall amounts of 3 to 6 inches were reported across the region. The heaviest amounts fell across Cape Cod, where Provincetown received 7.79 inches. Heavy rains had affected the area earlier in the month. This additional rainfall did result in river flooding across the entire region. In addition, heavy rains caused a dam to break on the Woonasquatucket River in northern Rhode Island, resulting in some flood damage along the river.

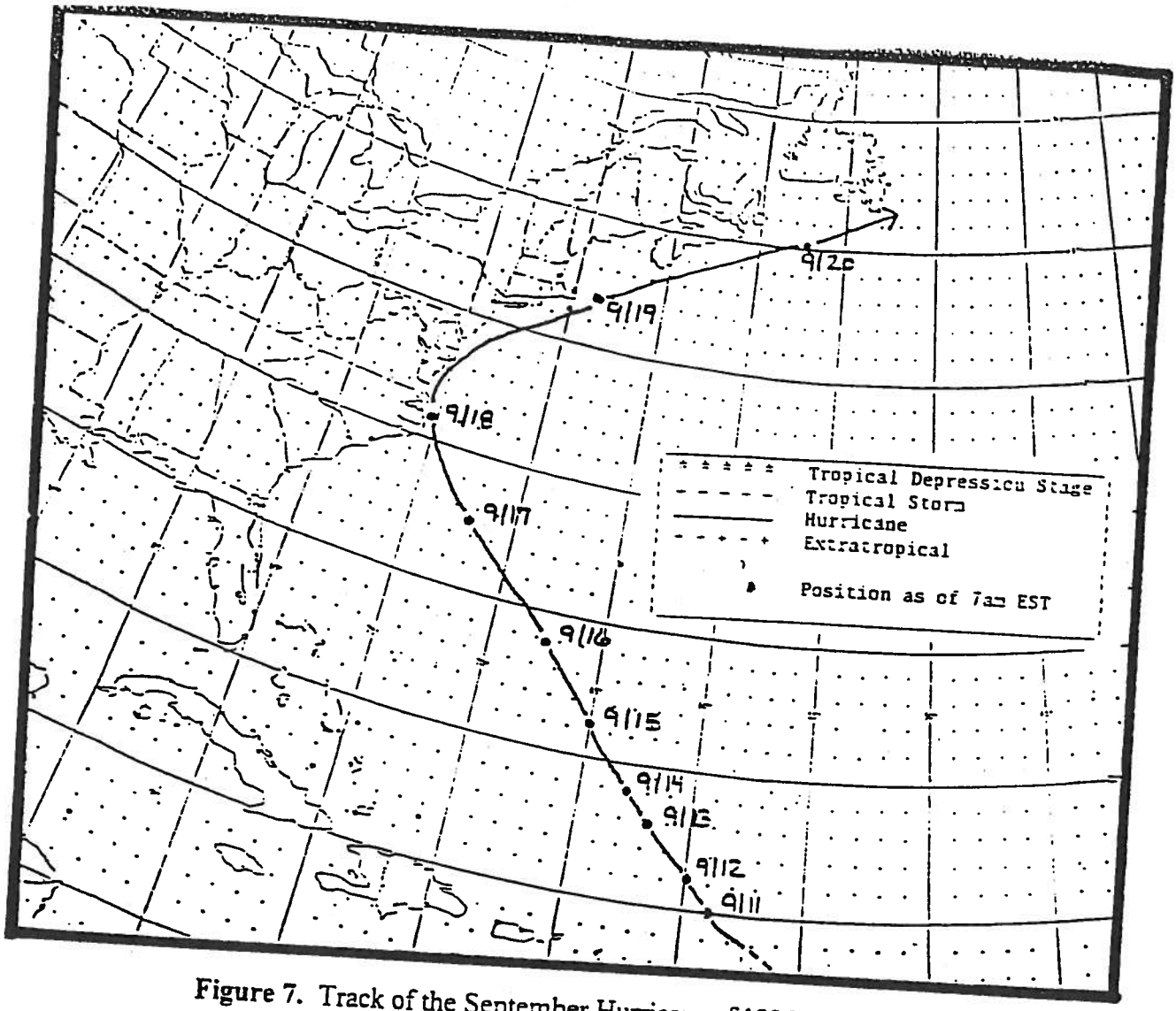

Figure 7. Track of the September Hurricane of 1936.

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 southern New England. This system developed in the far eastern Atlantic, near the Cape Verde Islands on September 4. It made a twelve day journey across the Atlantic and up the eastern seaboard before crashing ashore on September 21 at Suffolk County, Long Island, then into Milford, Connecticut (Figure 8). The eye of the hurricane was observed in New Haven, Connecticut, 10 miles east of Milford. The center made landfall at the time of astronomical high tide, moving north at 60 mph. Unlike most storms, the hurricane did not weaken on its way toward southern New England, due to its rapid forward speed and its track. This kept the center of the storm over the warm waters of the Gulf Stream.

Sustained hurricane force winds occurred throughout most of southern New England. The strongest winds ever recorded in the region occurred at the Blue Hill Observatory with sustained winds of 121 mph and a peak gust of 186 mph. Sustained winds of 91 mph with a gust to 121 mph was reported on Block Island. Providence, Rhode Island recorded sustained winds of 100 mph with a gust to 125 mph. Extensive damage occurred to roofs, trees and crops. Widespread power outages occurred, which in some areas lasted several weeks. In Connecticut, downed power lines resulted in catastrophic fires to sections of New London and Mystic. The lowest pressure at the time of landfall occurred on the south side of Long Island, at Bellport, where a reading of 27.94 inches was recorded. Other low pressures included 28.00 inches in Middletown, Connecticut and 28.04 inches in Hartford, Connecticut.

The hurricane produced storm tides of 14 to 18 feet across most of the Connecticut coast, with 18 to 25 foot tides from New London east to Cape Cod. The destructive power of the storm surge was felt throughout the coastal community. Narragansett Bay took the worst hit, where a storm surge of 12 to 15 feet destroyed most coastal homes, marinas and yacht clubs. Downtown Providence, Rhode Island was submerged under a storm tide of nearly 20 feet. Sections of Falmouth and New Bedford, Massachusetts were submerged under as much as 8 feet of water. Figures 9 through 12 present the actual storm tide as the storm surge approached. All three locations show how rapidly tides increased within 1.5 hours of the highest water mark.

Rainfall from this hurricane resulted in severe river flooding across sections of Massachusetts and Connecticut. Figure 13 is an analysis of the rainfall in southern New England the day of the hurricane. Three to six inches fell across much of western Massachusetts and all but extreme eastern Connecticut. Considerably less rain occurred to the east across Rhode Island and the remainder of Massachusetts. The rainfall from the hurricane added to the amounts that had occurred with a frontal system several days before the hurricane struck. Figure 14 is an analysis of the rainfall from September 17-21. The combined effects from the frontal system and the hurricane produced rainfall of 10 to 17 inches across most of the Connecticut River Valley. This resulted in some of the worst flooding ever recorded in this area. Roadways were washed away along with sections of the New York, New Haven, and Hartford Railroad lines. The Connecticut River, in Hartford reached a level of 35.4 feet, which was 19.4 feet above flood stage. Further upstream, in the vicinity of Springfield, Massachusetts, the river rose to 6 to 10 feet above flood stage, causing significant damage. A total of 8900 homes, cottages and buildings were destroyed, and over 15000 were damaged by the hurricane. The marine community was devastated. Over 2,600 boats were destroyed, and over 3,300 damaged. Entire fleets were lost in marines and yacht clubs along Narragansett Bay. The hurricane was responsible for 564 deaths and at least 1700 injuries in southern New England. Damage to the fishing fleets in southern New England was catastrophic. A total of 2,605 vessels were destroyed, with 3,369 damaged.

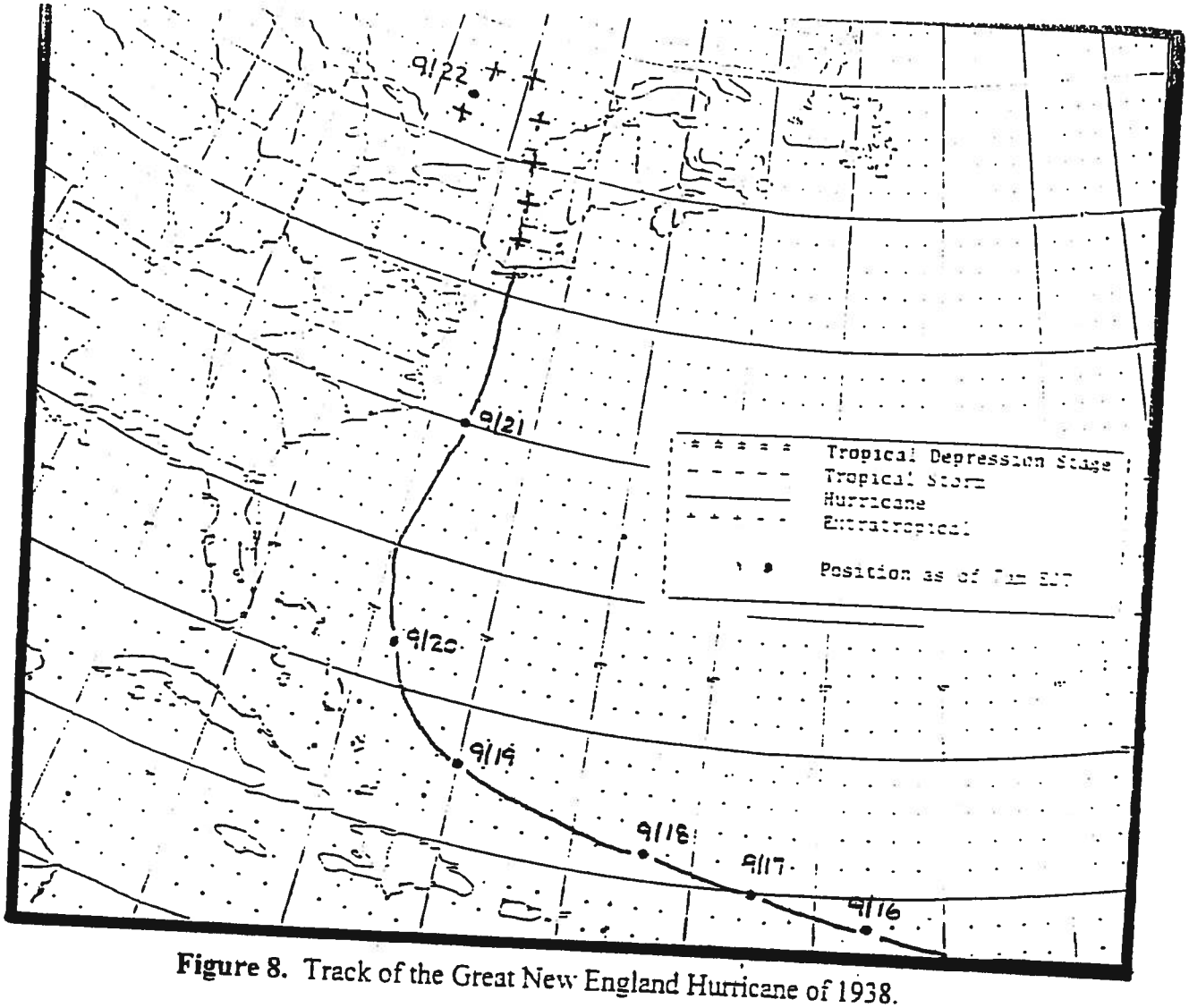

Figure 8. Track of the Great New England Hurricane of 1938.

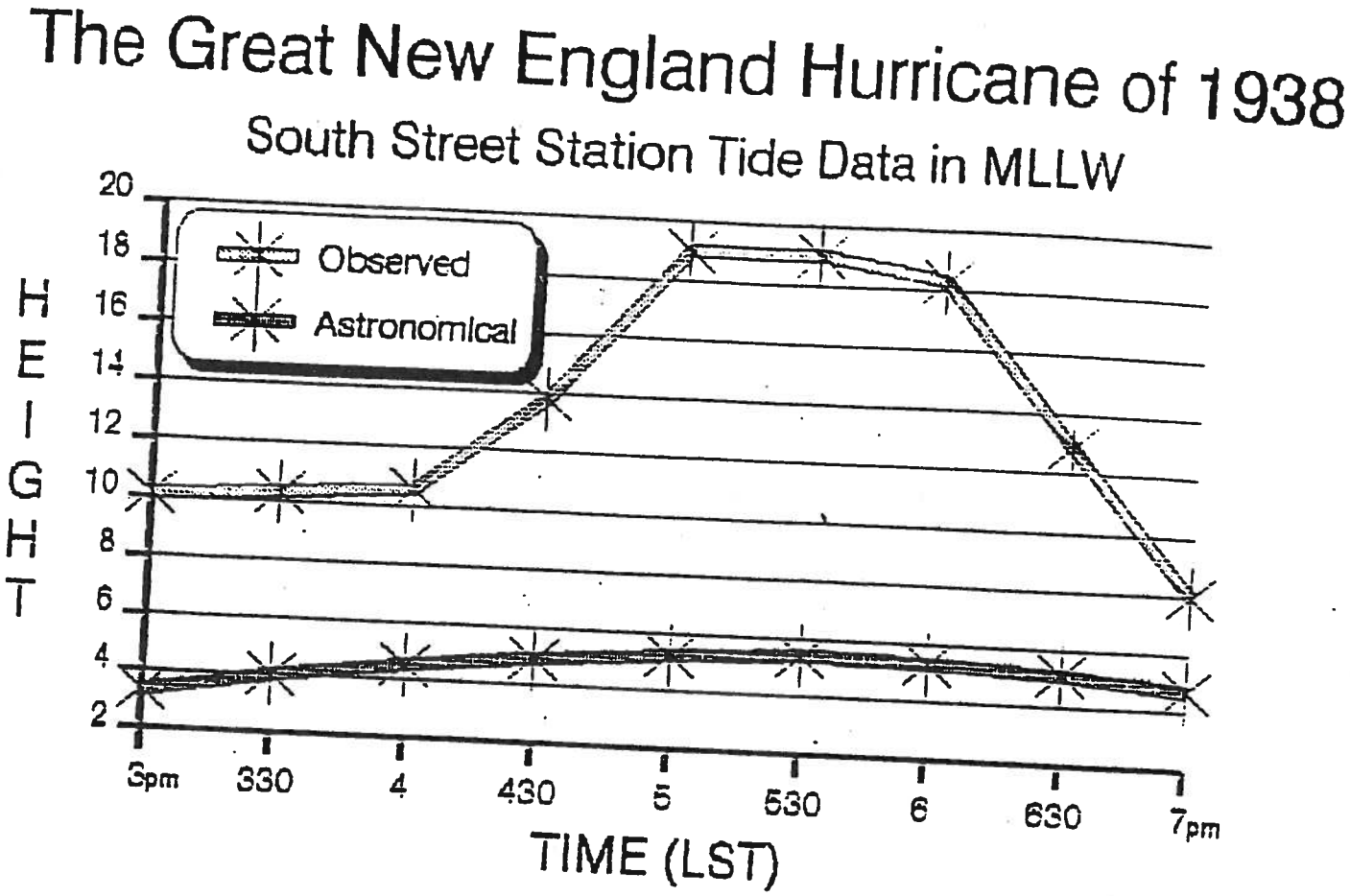

Figure 9. Storm surge height (feet) on September 21, 1938, associated with the Great New England Hurricane of 1938, recorded at the South Street Station Dock on upper Narragansett Bay.

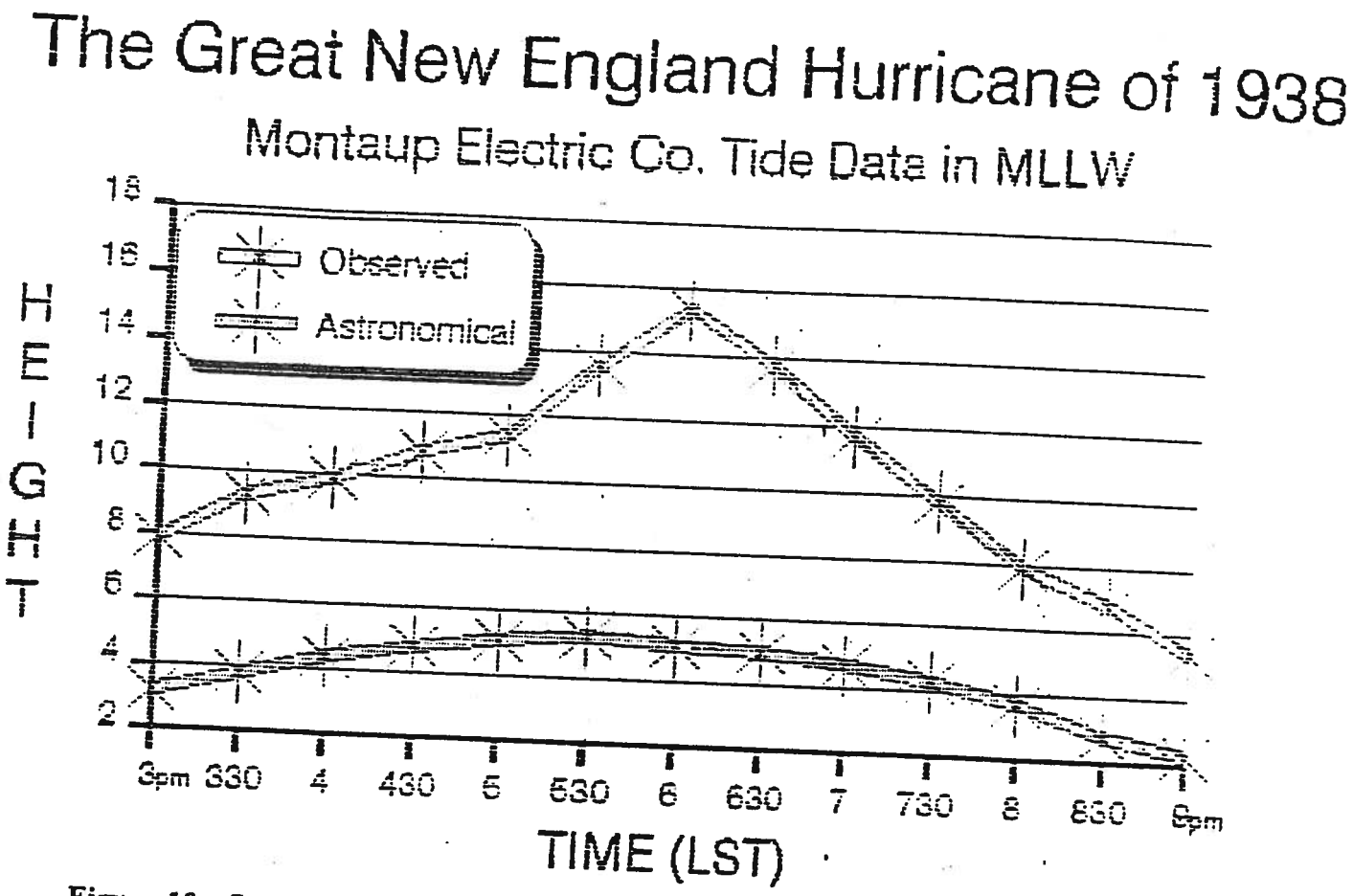

Figure 10. Storm surge height (feet) on September 21, 1938, associated with the Great New England Hurricane of 1938, recorded at the Montaup Electric Company at Somerset, Massachusetts.

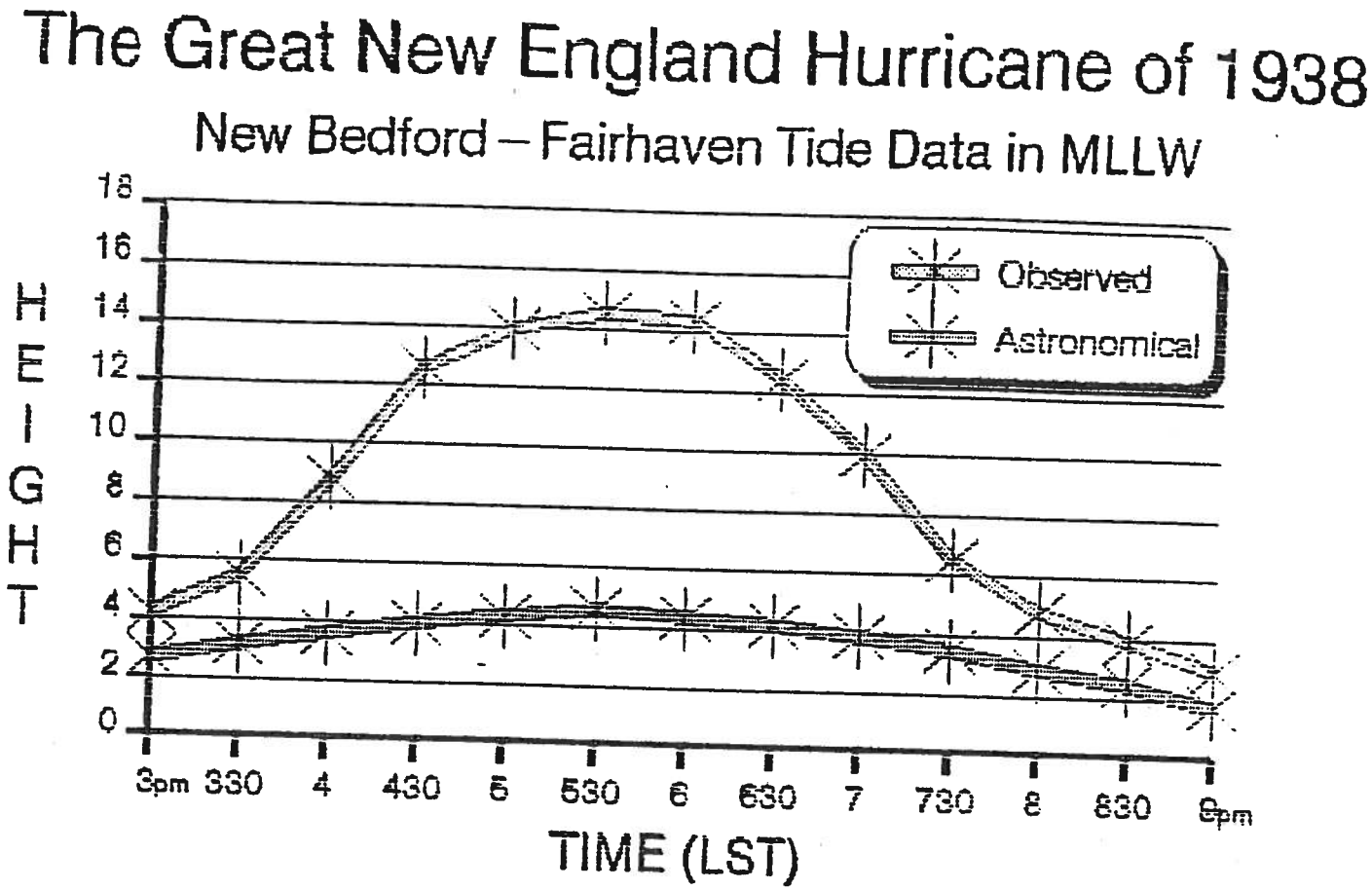

Figure 11. Storm surge height (feet) on September 21, 1938, associated with the Great New England Hurricane of 1938, recorded at the New Bedford harbor.

The Great New England Hurricane of 1938

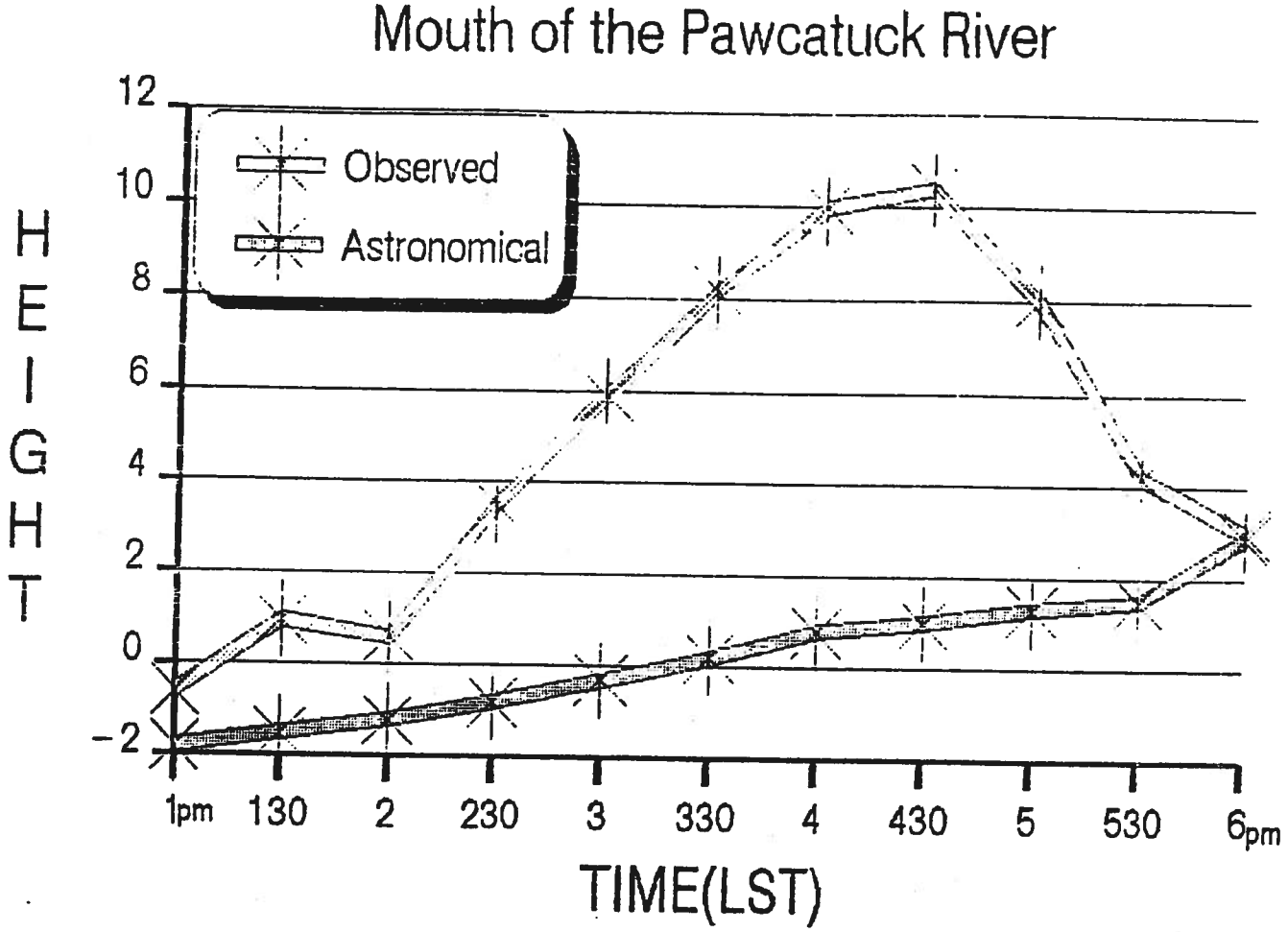

Figure 12. Storm surge height (feet) on September 21, 1938, associated with the Great New England Hurricane of 1938, recorded at the mouth of the Pawcatuck River, on the Connecticut/Rhode Island state border.

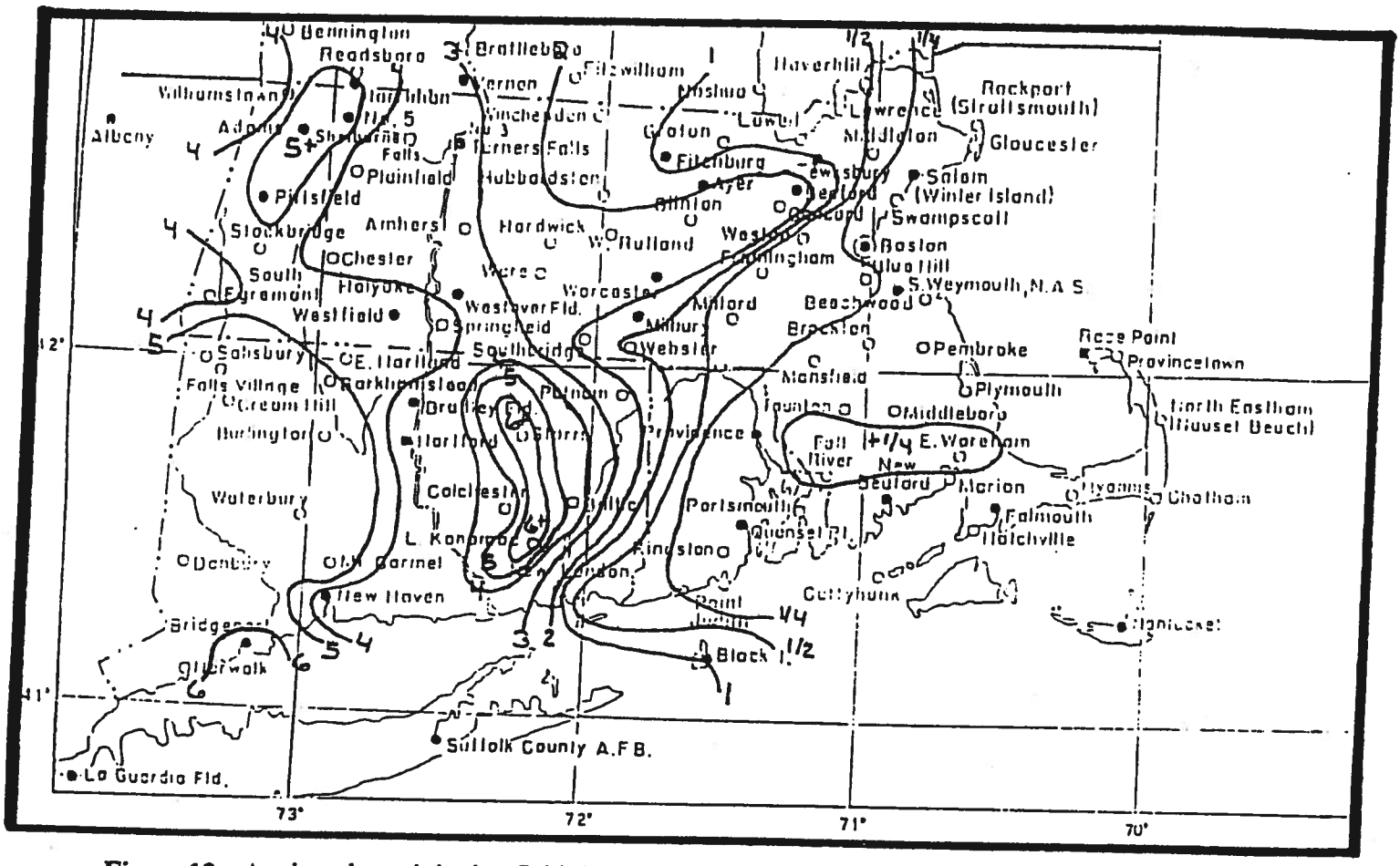

Figure 13. Analyzed precipitation field (inches) for rainfall associated with the Great New England Hurricane of 1938.

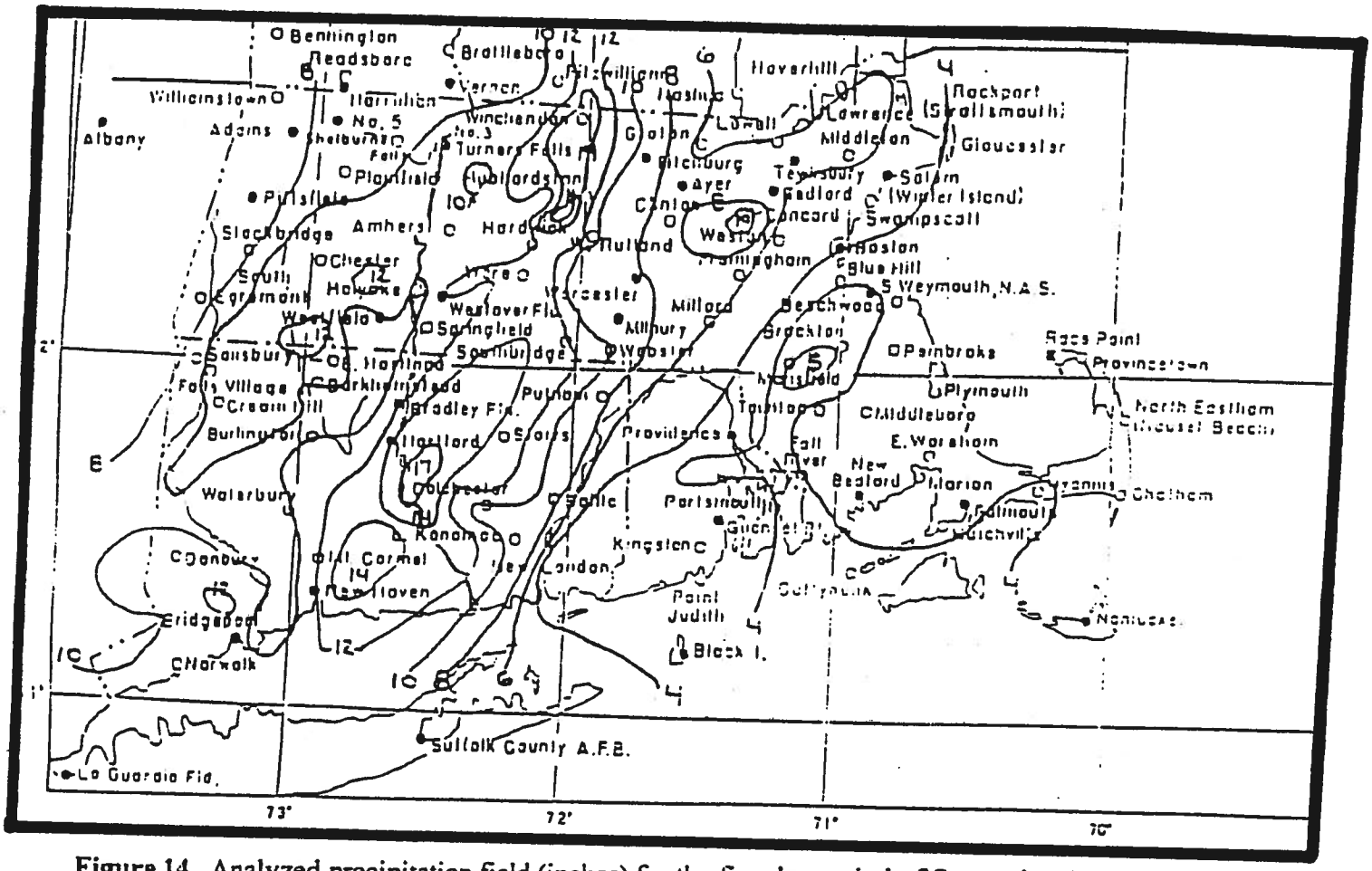

Figure 14. Analyzed precipitation field (inches) for the five day period of September 17-21, 1938, which includes the Great New England Hurricane (from U.S. Geological Survey 1938).

HURRICANE of 1940
(CAT 1 - September 2)

On August 30, 1940, a tropical storm was detected several hundred miles east of the Bahamas (Figure 15). It 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 across southern New England and was confined primarily to coastal sections of Rhode Island and Massachusetts. Sustained winds of 25 to 40 mph occurred from Rhode Island east to Cape Cod. Winds gusted to 50 mph on Block Island, and to 57 mph on Nantucket Island. Tides rose several feet above normal, due to the close proximity of the storm center, but resulted in only some localized minor coastal flooding. Rainfall was generally under ½ inch in southern New England. However, amounts of 3 to 4 inches were recorded closest to the storm center, over outer Cape Cod and the Islands.

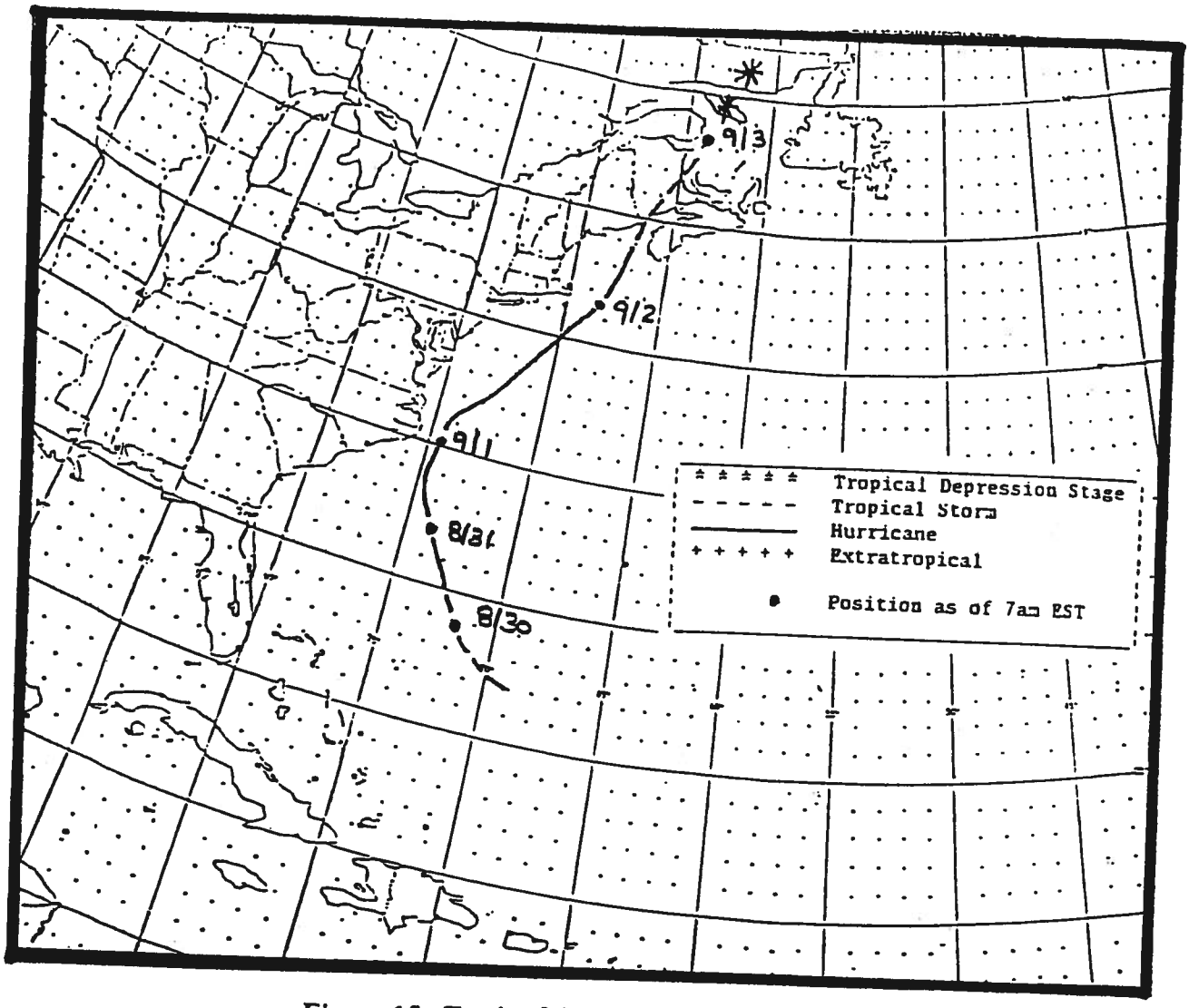

Figure 15. Track of the Hurricane of 1940.

TROPICAL STORM of 1944
(August 3)

The Tropical Storm of 1944 developed north of the Dominican Republic late in July (Figure 16). It intensified to hurricane strength before making landfall on the North Carolina coast 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, New Jersey on August 2, then passed 100 miles south of Cape Cod during the morning of August 3. The storm weakened to a tropical depression shortly after passing Cape Cod.

No damage was reported from this storm. Winds gusted occasionally to over 40 mph only over southeast sections. Rainfall was less than 0.5 inches over most of western southern New England, while eastern sections received 1 to 1.5 inches.

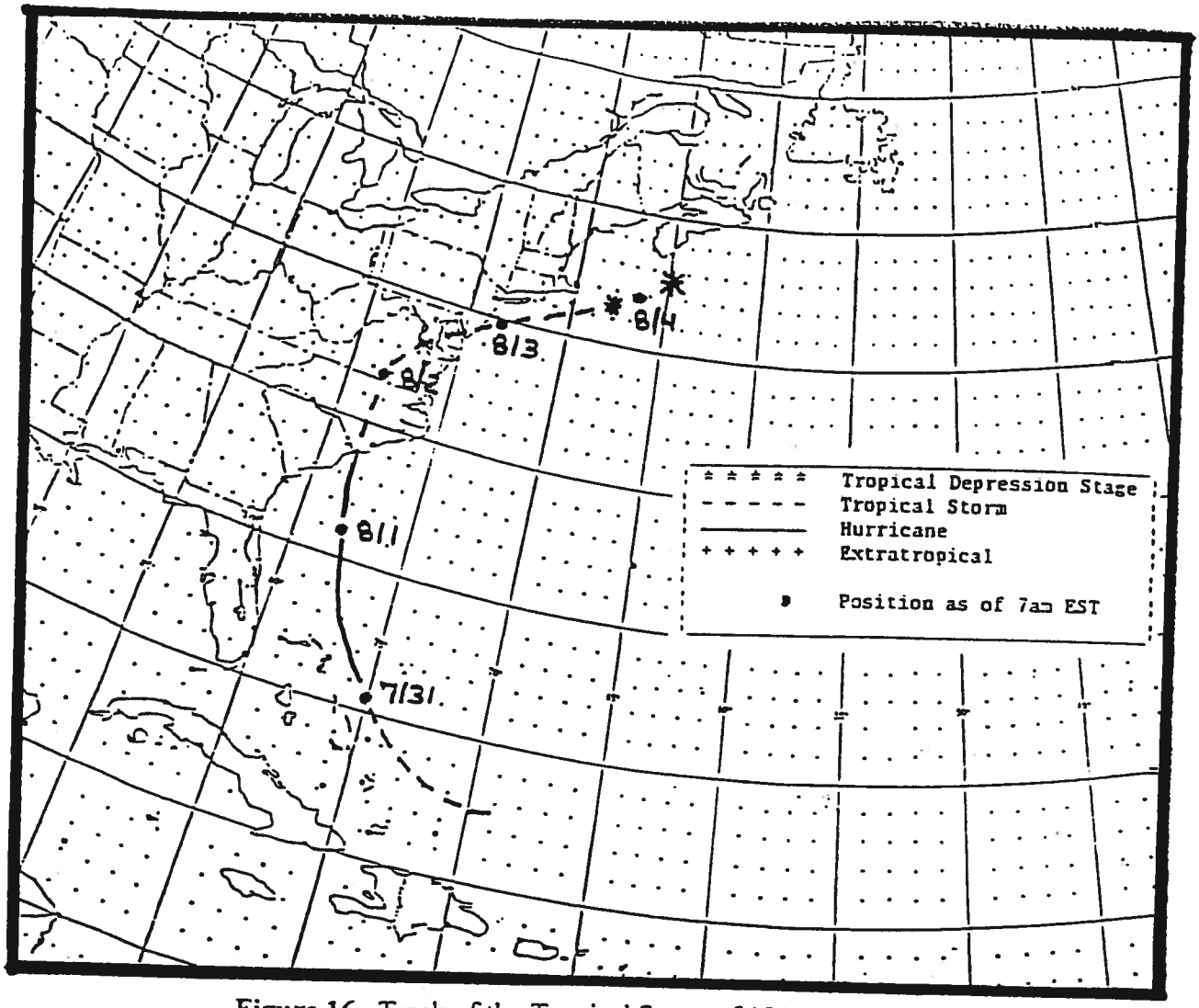

Figure 16. Track of the Tropical Storm of 1944.

THE SEPTEMBER HURRICANE of 1944
(CAT 3 - September 14-15)

The September Hurricane of 1944, sometimes referred to as the "Great Atlantic Hurricane", earned its place in southern New England 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 17). It headed steadily northwestward for the next 5 days, then began its turn and acceleration toward the north and northeast. The center passed across the Outer Banks of North Carolina on the morning of September 14, and then made landfall between Charlestown and Narragansett, Rhode Island at 11 pm that evening. 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 40 to 70 mph occurred across much of inland southern New England, while sustained winds of 70 to 90 mph affected the immediate south coast from New Haven, Connecticut east to Cape Cod. Winds were sustained at 88 mph on Block Island, Rhode Island, with gusts to 100 mph. The highest wind gust was reported at Chatham, Massachusetts on outer Cape Cod, where winds gusted to 105 mph. Wind damage was quite severe throughout eastern Connecticut, all of Rhode Island, and eastern Massachusetts. Structural damage to homes and businesses, as well as widespread power outages, were common. Most of southeastern Massachusetts and as much as 90 percent of Rhode Island lost electrical power. There were also several reports of small tornadoes across Rhode Island and southeastern Massachusetts. The lowest pressure recorded at time of landfall was 28.30 inches, in Westerly, Rhode Island, approximately 10 to 15 miles west of where the center is believed to have come ashore. Point Judith Coast Guard Station and Block Island, about 10 miles to the east of landfall, recorded a pressure of 28.34 inches. Based on wind observations near landfall, it has been estimated that the diameter of the eye was approximately 15 miles.

The Hurricane of 1944 made landfall approximately one to three hours before low tide. Storm surge heights ranged from 6 to 8 feet across much of the Connecticut shore, to 10 to 12 feet from New London east to Cape Cod. Figures 18 through 20 show the actual tide as the storm moved inland. It is easily seen that levels exceeded flood stages by only 2 to 4 feet. Had this storm hit at high tide, storm tide levels could have come within a few feet of those reached during the Great New England Hurricane of 1938.

Significant coastal flooding occurred along the southern New England coast, even though the storm arrived near low tide. The hardest hit areas included the south coastal beach communities of Rhode Island and most of Cape Cod.

Generally 2 to 5 inches of rain fell across most of the area, with amounts of up to 7 inches across south coastal Connecticut and Rhode Island. A frontal system had caused 2 to 4 inches of rain just two days earlier on September 12-13. This brought rainfall totals for September 12-15 to 5 to 10 inches across much of the area (Figure 21). The highest rainfall totals occurred across southwest coastal Connecticut, with 10.7 inches at Bridgeport, and 8.5 inches at New Haven.

The hurricane was responsible for 40 deaths in southern New England, with hundreds more injured. Damage to homes was significant throughout the eastern part of the region. Over 11,000 homes and buildings were either destroyed or severely damaged. The boating community was again hit hard, especially from Buzzards Bay east to Cape Cod where over 1,000 boats were either destroyed or severely damaged.

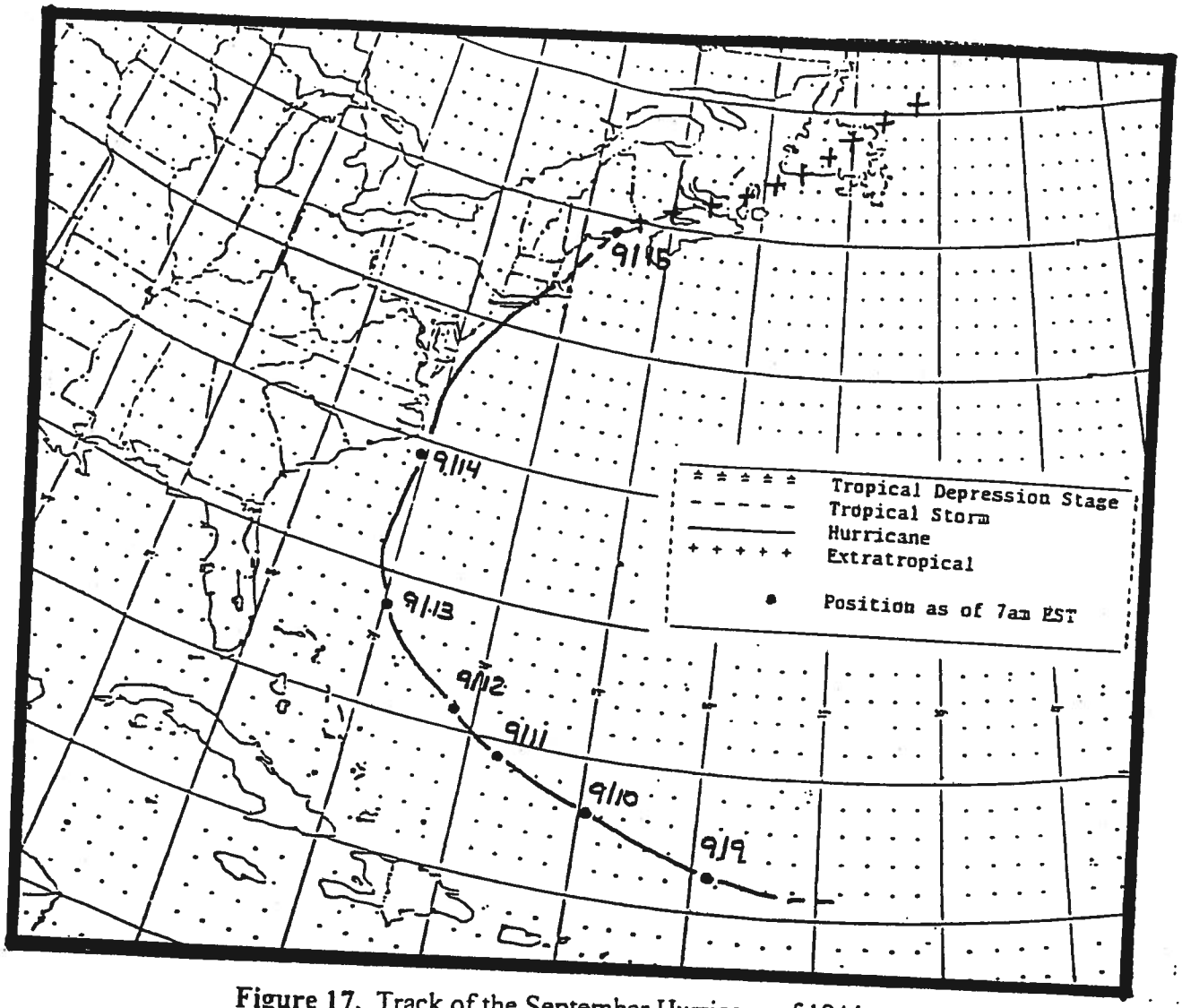

Figure 17. Track of the September Hurricane of 1944.

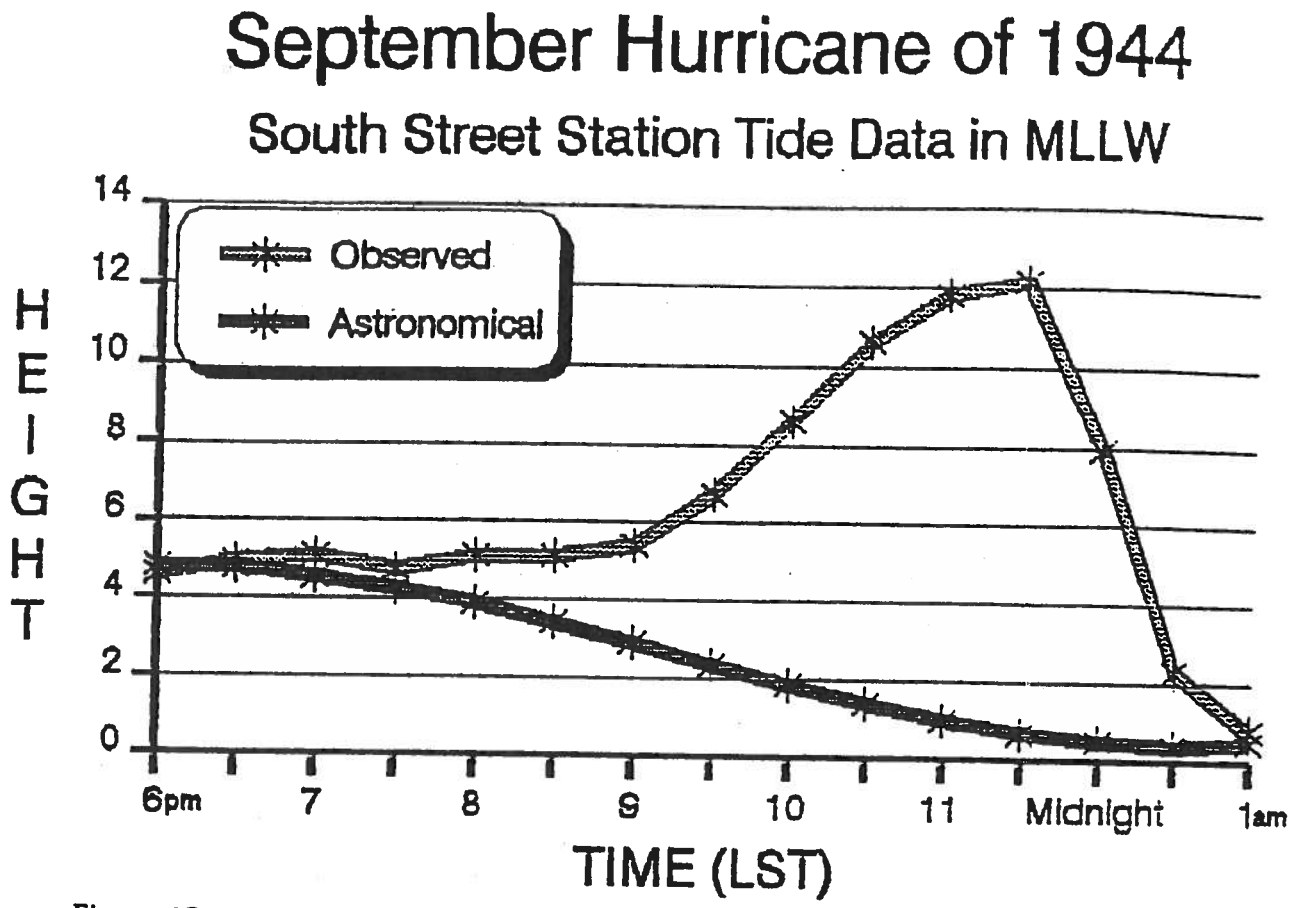

Figure 18. Storm surge height (feet) on September 14-15, 1944, associated with the September Hurricane of 1944, recorded at the South Street Station Dock on upper Narragansett Bay.

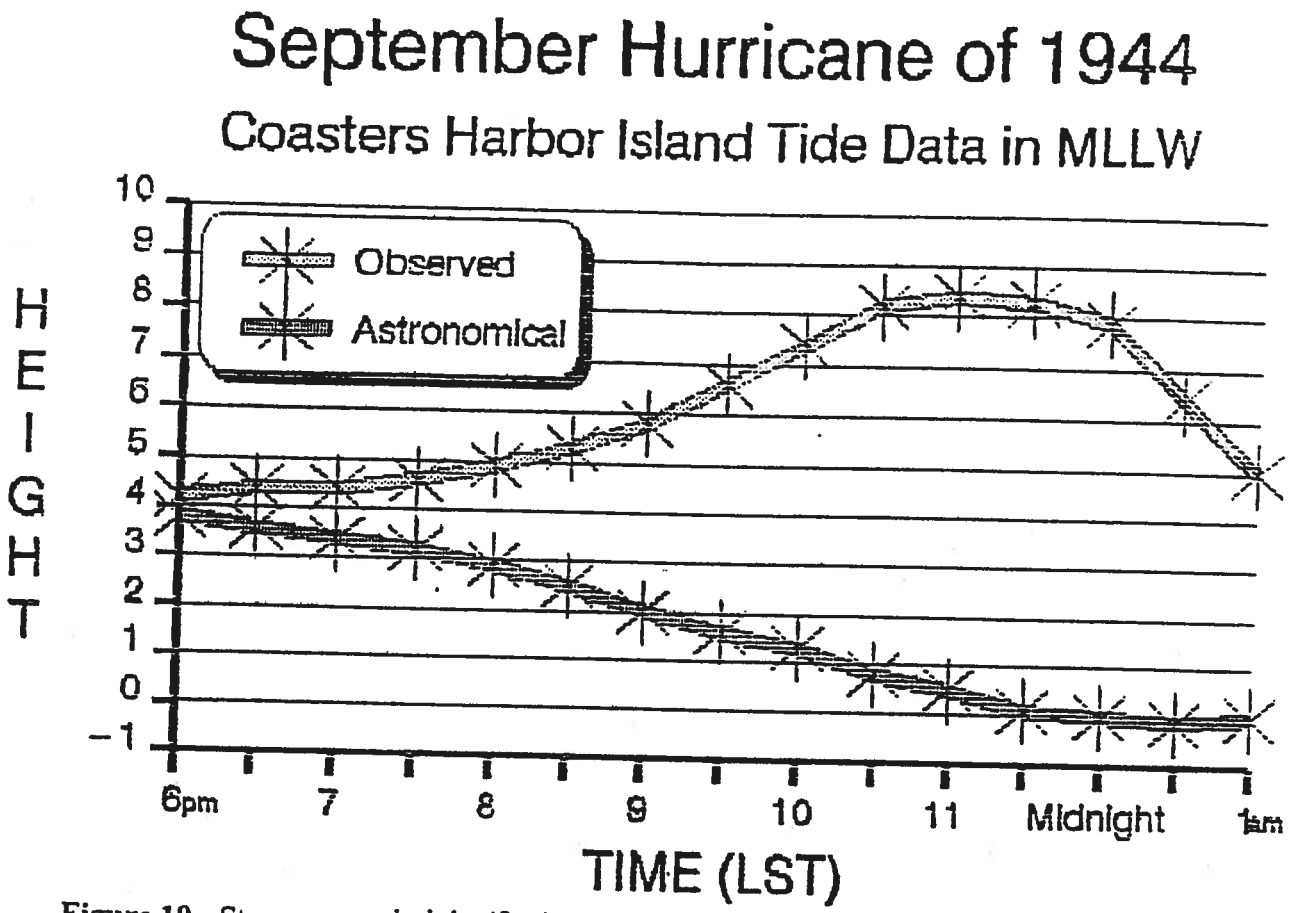

Figure 19. Storm surge height (feet) on September 14-15, 1944, associated with the September Hurricane of 1944, recorded at the Coasters Harbor Island Station in Newport, Rhode Island.

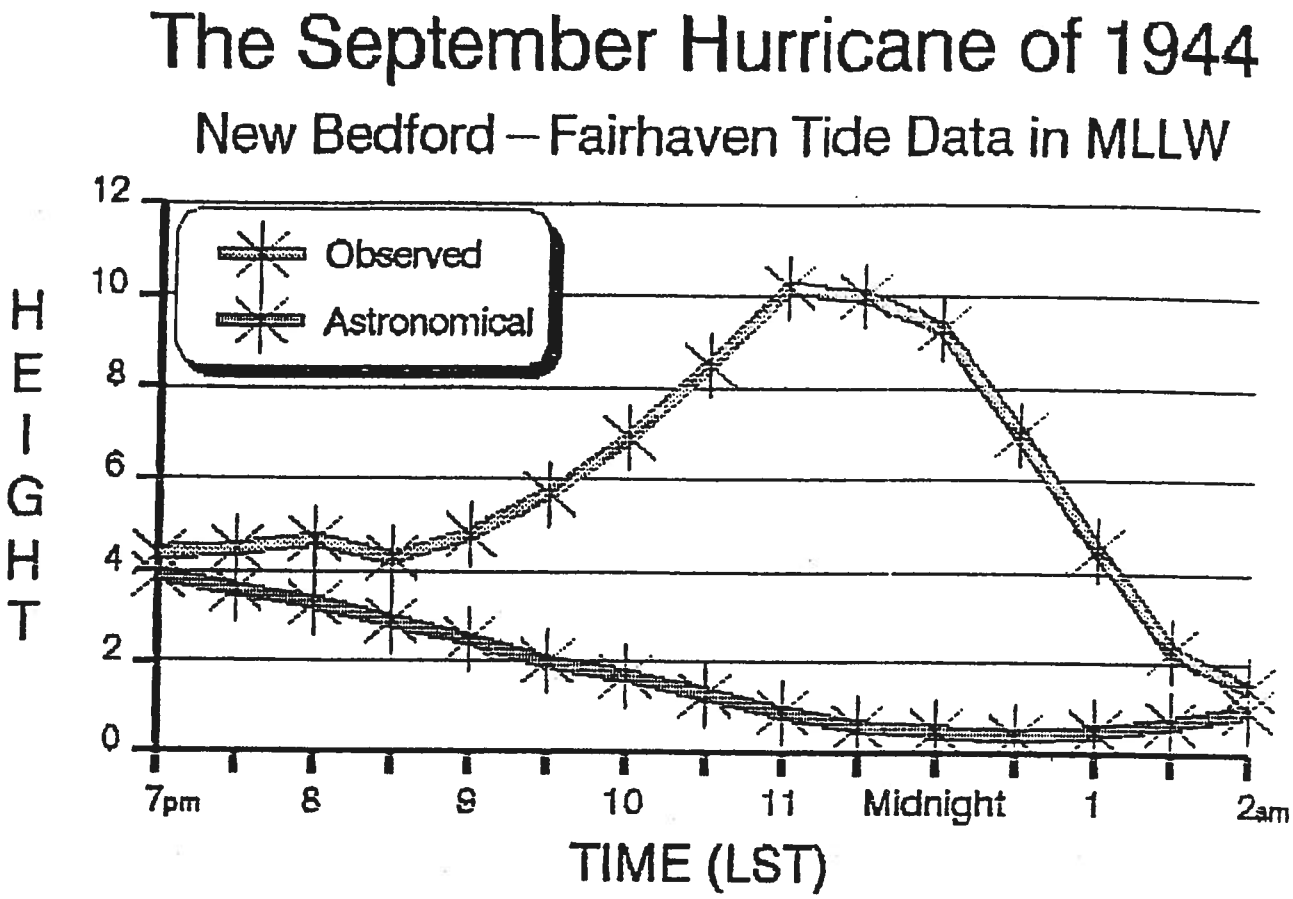

Figure 20. Storm surge height (feet) on September 14-15, 1944, associated with the September Hurricane of 1944, recorded at New Bedford harbor.

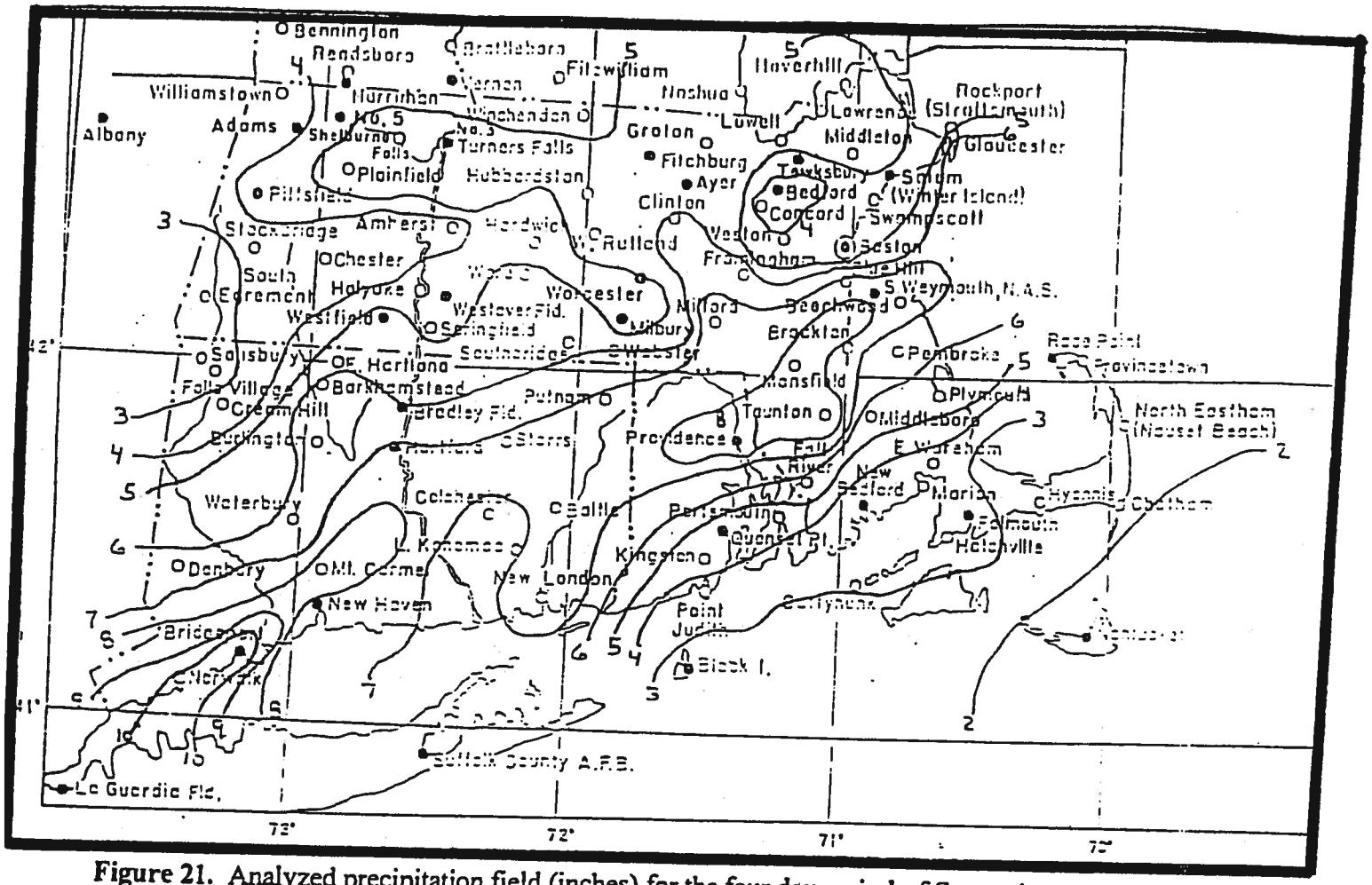

Figure 21. Analyzed precipitation field (inches) for the four day period of September 12-15, 1944, which includes the September Hurricane of 1944.

TROPICAL STORM of 1945
(June 26-27)

The Tropical Storm of 1945 was one of only three systems affecting southern New England 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 22). The system then headed northeast up the East Coast, eventually losing tropical characteristics shortly after moving east of Cape Cod on June 27.

No damage was reported in southern New England from this storm. Sustained winds of only 30 to 40 mph occurred for a brief time from coastal Rhode Island east to Cape Cod. The strongest winds were on Block Island, Rhode Island, where winds gusted to 50 mph.

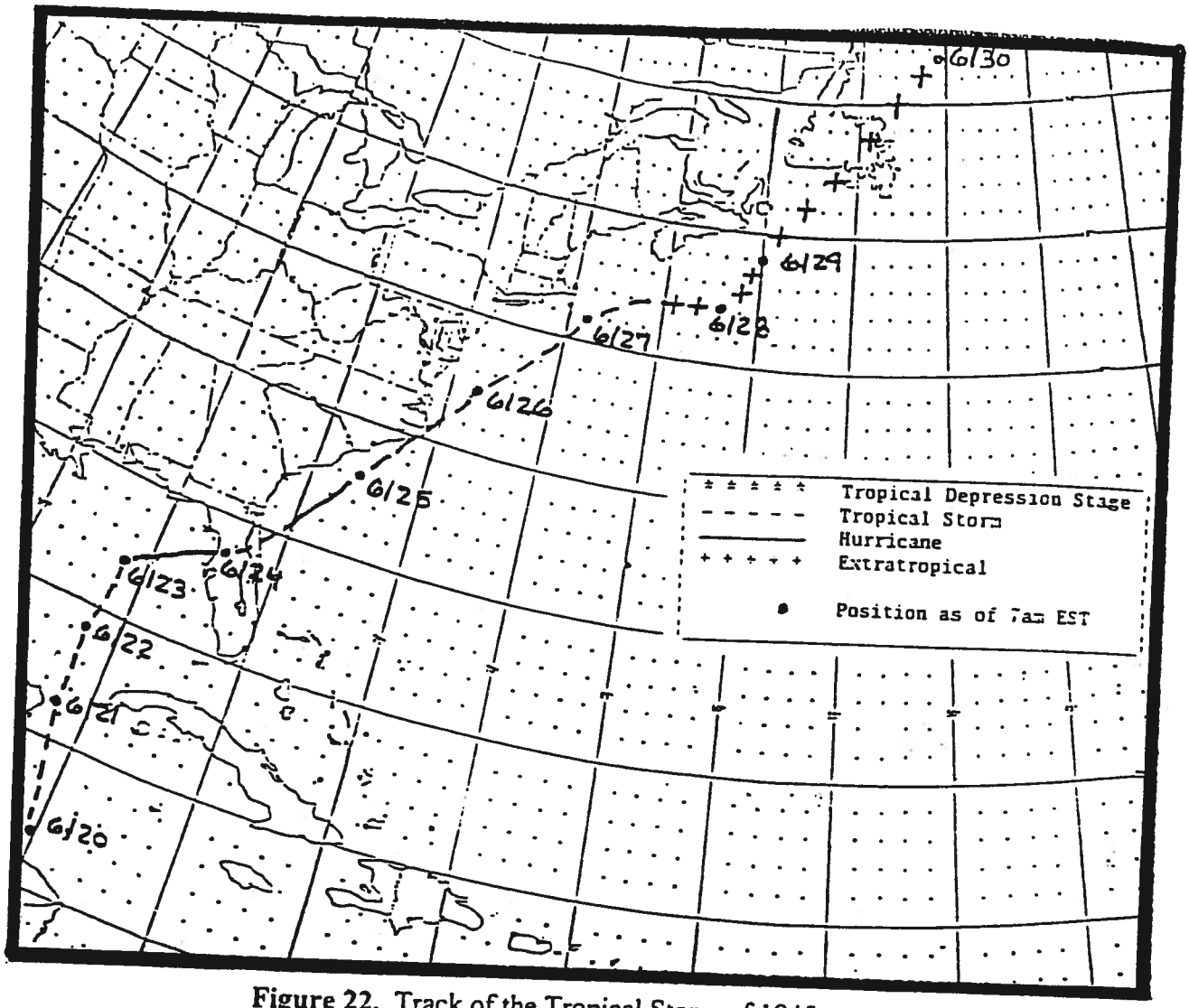

Figure 22. Track of the Tropical Storm of 1945.

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 23). After making landfall, the system turned sharply northward, moving up along the eastern slopes of the Appalachian Mountains. It maintained tropical storm strength as it continued northward, passing across southeast New York on August 29.

Strong south winds of 35 to 50 mph buffeted much of southern New England. This resulted in numerous power outages, caused mostly by fallen tree branches.

Tides ran two to four feet above normal along the southern New England coast, resulting in minor beach erosion and some damage to small pleasure craft. Most of the region received .75 to 2 inches of rain.

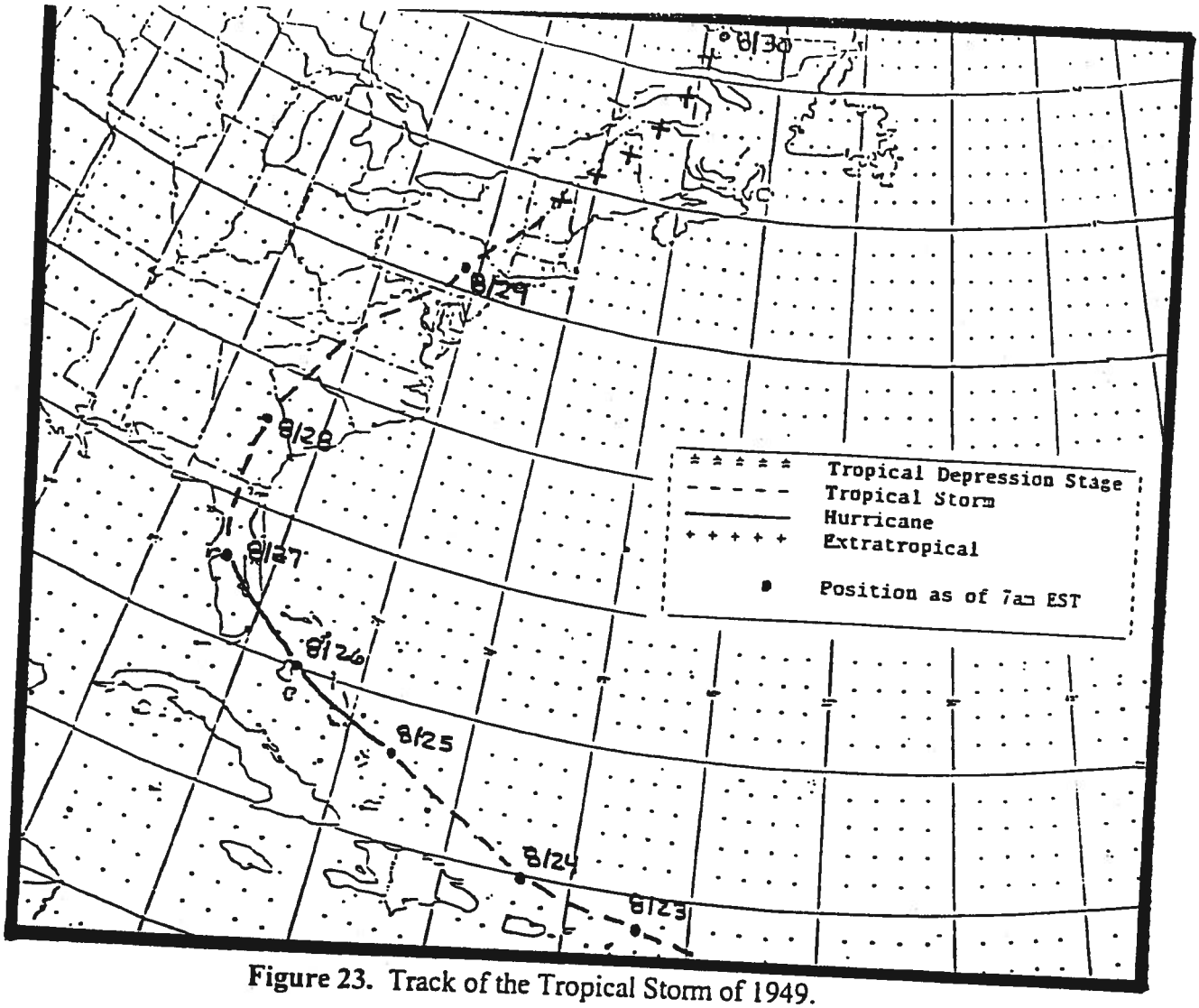

Figure 23. Track of the Tropical Storm of 1949.

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 24). 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 three days, passing about 225 miles southeast of Cape Cod on August 20.

Hurricane force conditions associated with Able remained offshore to the south and east of the region. Sustained winds of only 20 to 40 mph were confined to southeast coastal sections. The wind did cause unusually heavy surf, resulting in three deaths during the storm.

Able did produce much needed rainfall of 1 to 3 inches across most of southern New England. Several 4 to 5 inch amounts were recorded in northeast Connecticut and northwest Rhode Island.

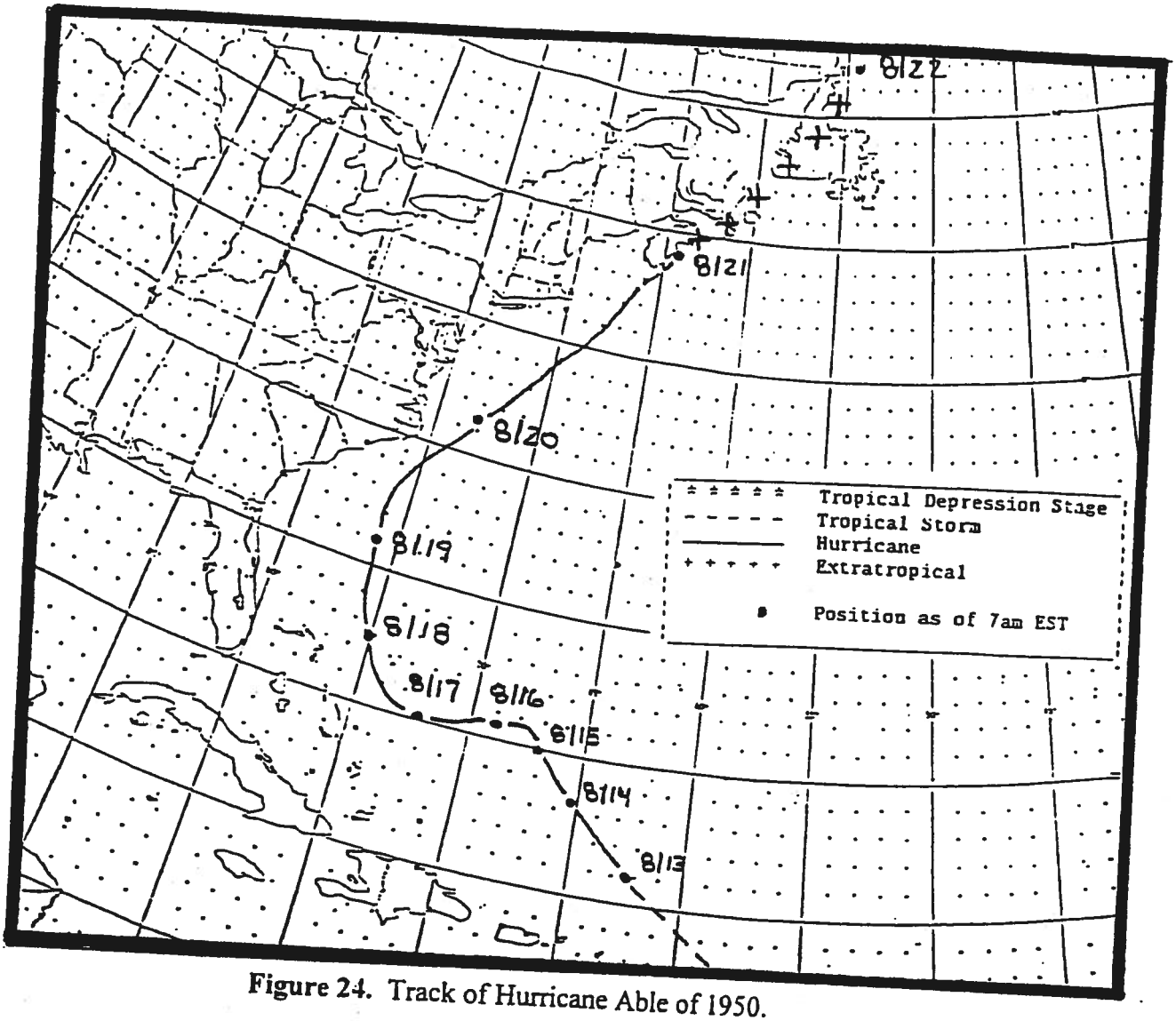

Figure 24. Track of Hurricane Able of 1950.

HURRICANE DOG
(CAT 1 - September 11, 1950)

A weakening hurricane, named Dog, passed south and east of southern New England the evening on September 11 (Figure 25). Earlier in the storm's life, while located north of the Leeward Islands, Hurricane Dog produced winds up to 184 mph. By the time it approached southern New England, it had weakened considerably and eventually lost tropical characteristics as it passed approximately 85 miles southeast of Nantucket Island on September 11.

Strong northeast winds of 35 to 50 mph affected much of the coast. Winds gusted to 70 mph on Block Island, Rhode Island and to 75 mph on Nantucket Island. Scattered power outages were reported, mostly in coastal communities of southeastern Massachusetts. Some minor coastal flooding occurred, as tides ran 2 to 3 feet above normal near the time of high tide. Boats were damaged on Narragansett and Buzzards Bays. A seawall was destroyed in Winthrop, Massachusetts due to the large waves.

Rainfall of 0.5 to 1.5 inches fell across most of southern New England. Nantucket received the heaviest rains, where 4.43 inches was recorded.

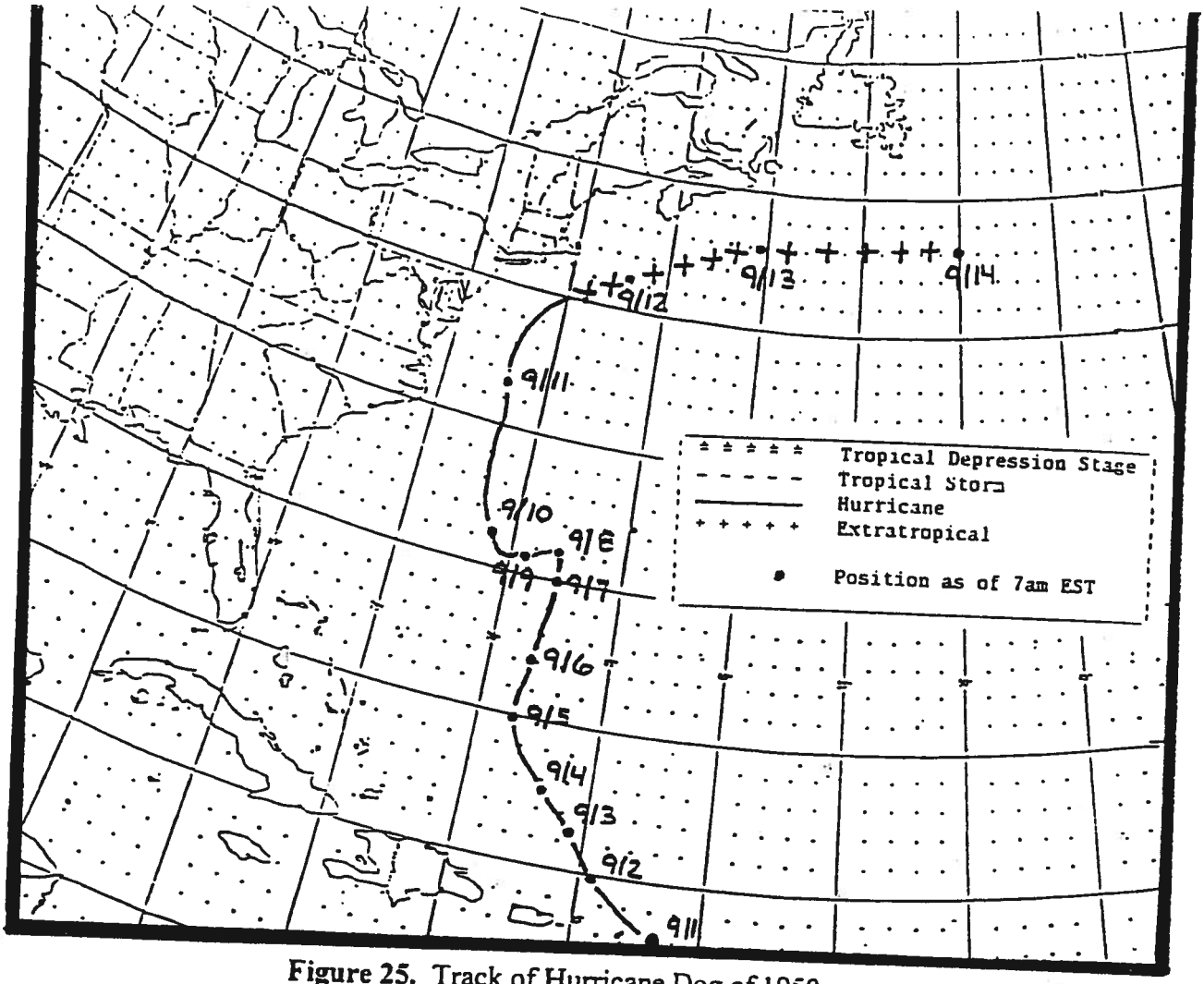

Figure 25. Track of Hurricane Dog of 1950.

HURRICANE BARBARA
(CAT 1 - August 14-15, 1953)

Hurricane Barbara gave southern New England a glancing blow, as it passed approximately 100 miles south of Nantucket Island during the late night hours of August 14 (Figure 26). Barbara developed in the southeast Bahamas four 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 south and east of the region.

The immediate south coast of Rhode Island and southeastern Massachusetts experienced sustained winds of 35 to 45 mph. The highest gust was 70 mph on Block Island, Rhode Island. Sustained winds of 20 to 30 mph were felt over interior Rhode Island and eastern Massachusetts. 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.

Rainfall ranged from less than 1 inch over western sections 3 to 4 inches across parts of Rhode Island and eastern Massachusetts. The greatest amounts were 4.86 inches at Block Island, and 4.73 inches at Plymouth, Massachusetts.

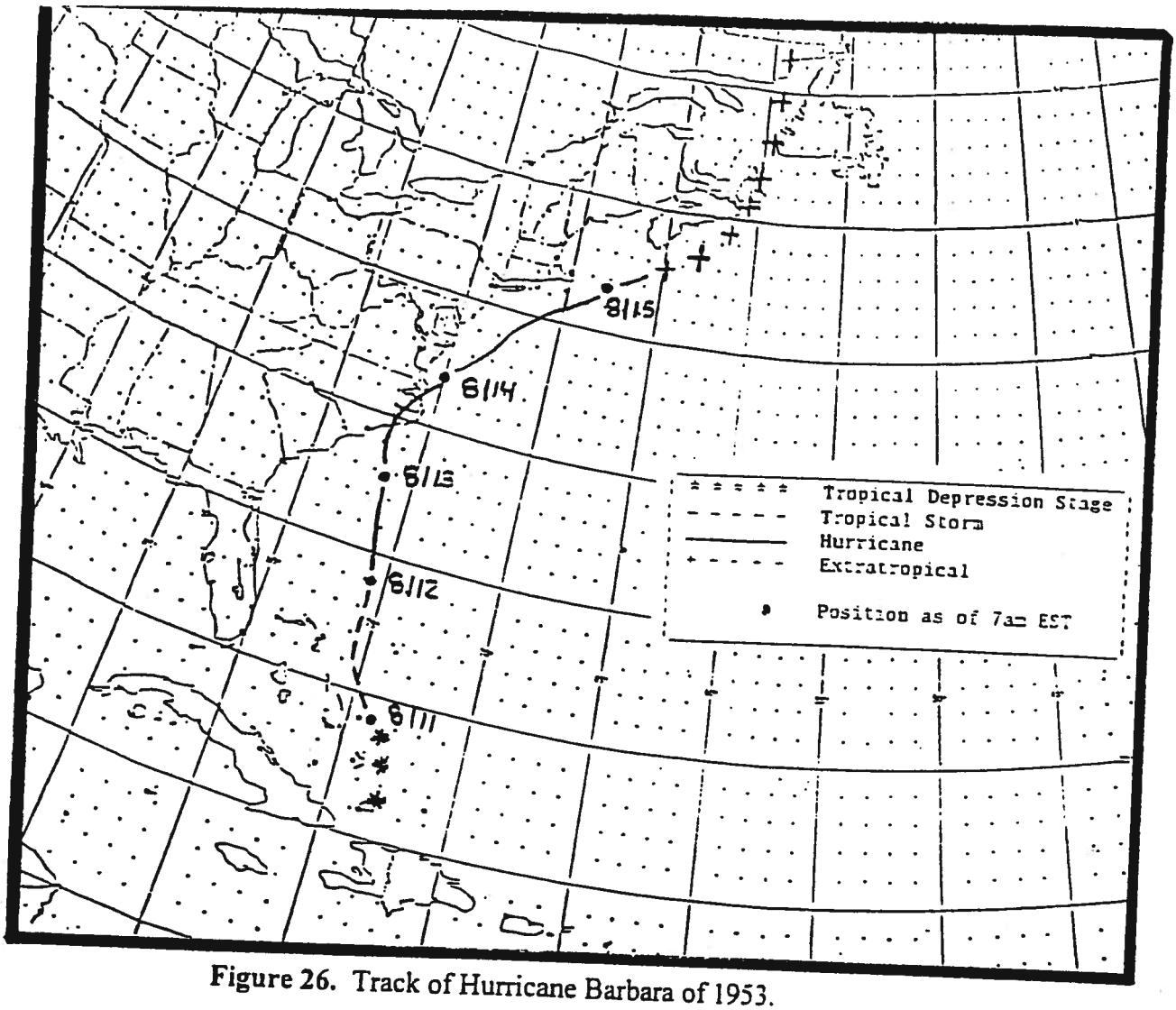

Figure 26. Track of Hurricane Barbara of 1953.

HURRICANE CAROL
(CAT 3 - August 31, 1954)

On the morning of August 31, Hurricane Carol, the most destructive hurricane to strike southern New England since the Great New England Hurricane of 1938, came crashing ashore near Old Saybrook, Connecticut, leaving 65 people dead in her wake. Carol had developed in the Bahamas several days earlier, making only slow progress northward (Figure 27). Carol began her rapid acceleration during the evening of August 30, while passing just east of Cape Hatteras, North Carolina. 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 roared through the eastern half of Connecticut, all of Rhode Island, and most of eastern Massachusetts. Scores of trees and miles of power lines were blown down. Strong winds also devastated crops in the region. Nearly 40 percent of apple, corn, peach, and tomato crops were ruined from eastern Connecticut to Cape Cod. Several homes along the Rhode Island shore had roofs blown completely off due to winds which gusted to over 125 mph. The strongest wind ever recorded on Block Island, Rhode Island occurred during Carol when winds gusted to 135 mph. The National Weather Service in Warwick, Rhode Island recorded sustained winds of 90 mph, with a peak gust of 105 mph. Lowest recorded pressure was at Suffolk County Airport on the south shore of Long Island with a reading of 28.36. Block Island reported 28.51 while Quonset Airport in North Kingstown, Rhode Island reported 28.72.

Hurricane Carol arrived shortly after high tide, causing widespread tidal flooding. Storm surge levels ranged from 5 to 8 feet across the west shore of Connecticut, and from 10 to 15 feet from the New London area eastward. Storm tide profiles in Figures 28 through 32 show, as in 1938, how dramatically the tides increased just before landfall across Narragansett Bay, the Somerset, Massachusetts area and in New Bedford, Massachusetts harbor. Narragansett Bay and New Bedford harbor received the largest surge values of over 14 feet in the upper reaches of both water ways. On Narragansett Bay, just north of the South Street Station site, the surge was recorded at 14.4 feet, surpassing that of the 1938 hurricane. However, since Hurricane Carol arrived after high tide, the resulting storm tide was lower.

Coastal communities from central Connecticut eastward were devastated. Entire coastal communities were nearly wiped out in New London, Groton, and Mystic, Connecticut, as well as from Westerly to Narragansett, Rhode Island. Once again, as in the 1938 hurricane, downtown Providence, Rhode Island was flooded under 12 feet of water.

Rainfall amounts ranged from 2 to 5 inches across most of the area (Figure 33). The heaviest amounts, up to 6 inches, occurred in the New London, Connecticut area in the vicinity of landfall, and across extreme north central Massachusetts.

Hurricane Carol destroyed nearly 4000 homes, along with 3500 automobiles and over 3000 boats. All of Rhode Island, much of eastern Connecticut and much of eastern Massachusetts lost electrical power. In addition, as much as ninety-five percent of all phone power was interrupted in these locations.

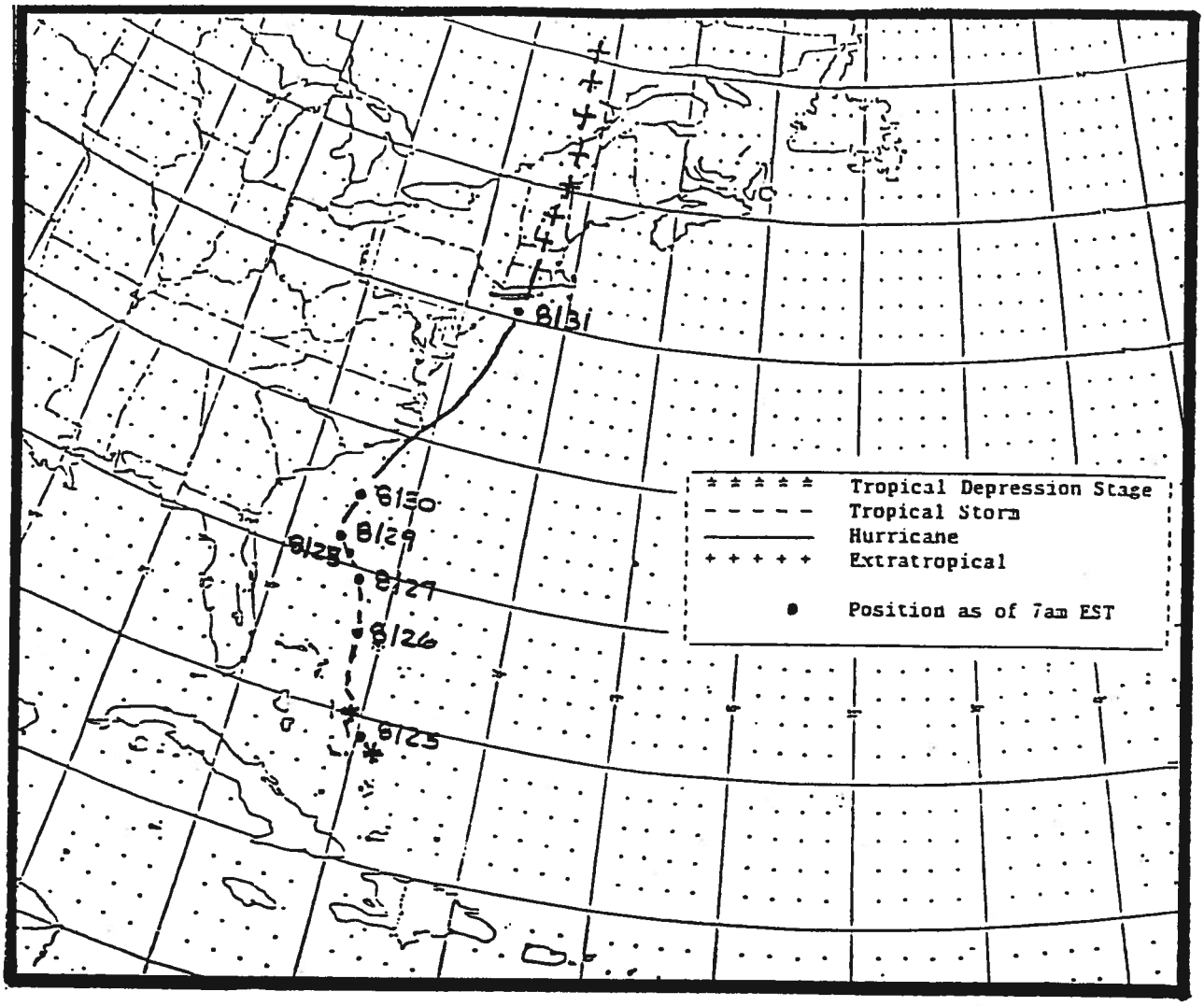

Figure 27. Track of Hurricane Carol of 1954.

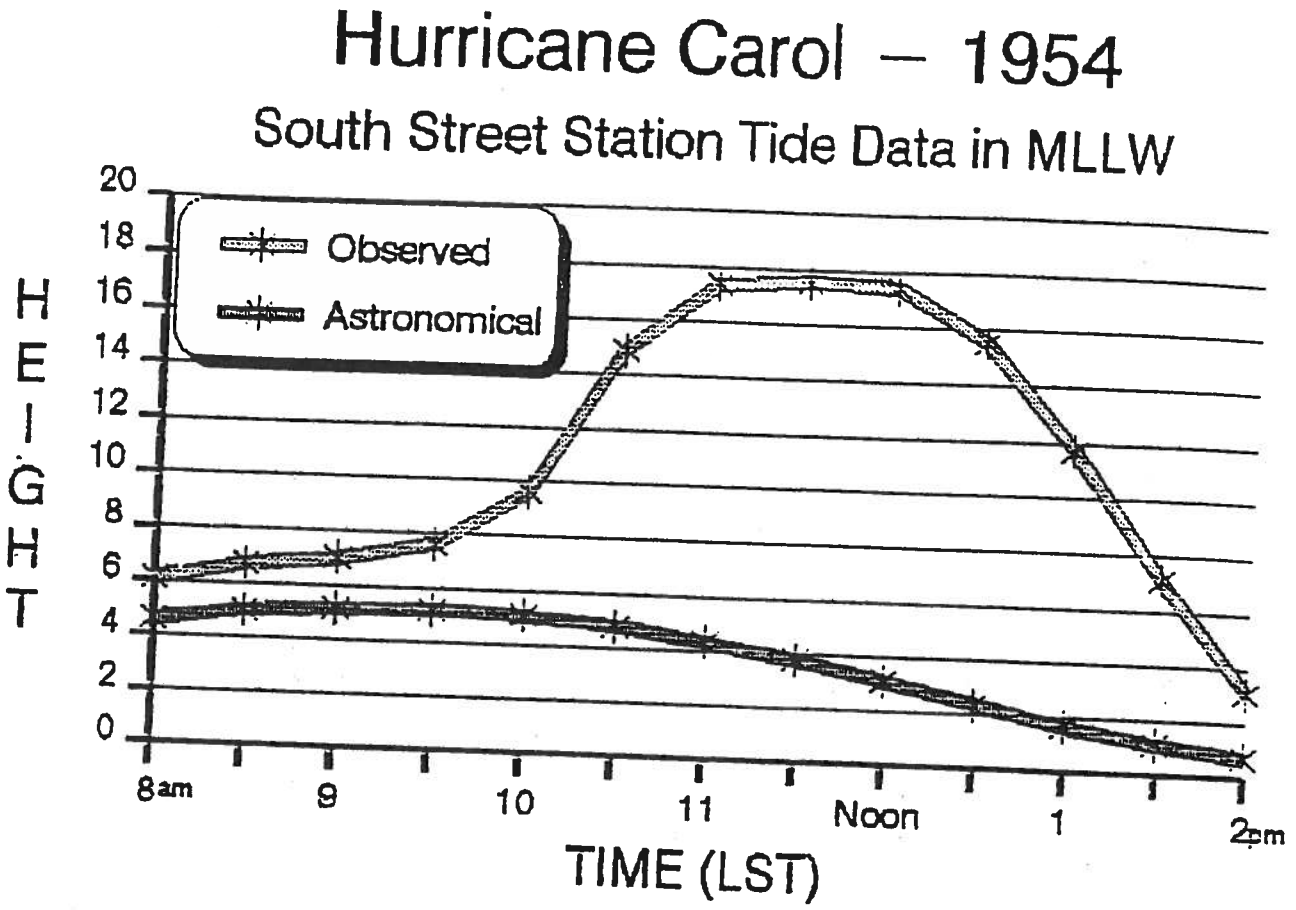

Figure 28. Storm surge height (feet) on August 31, 1954, associated with Hurricane Carol, recorded at the South Street Station Dock on upper Narragansett Bay.

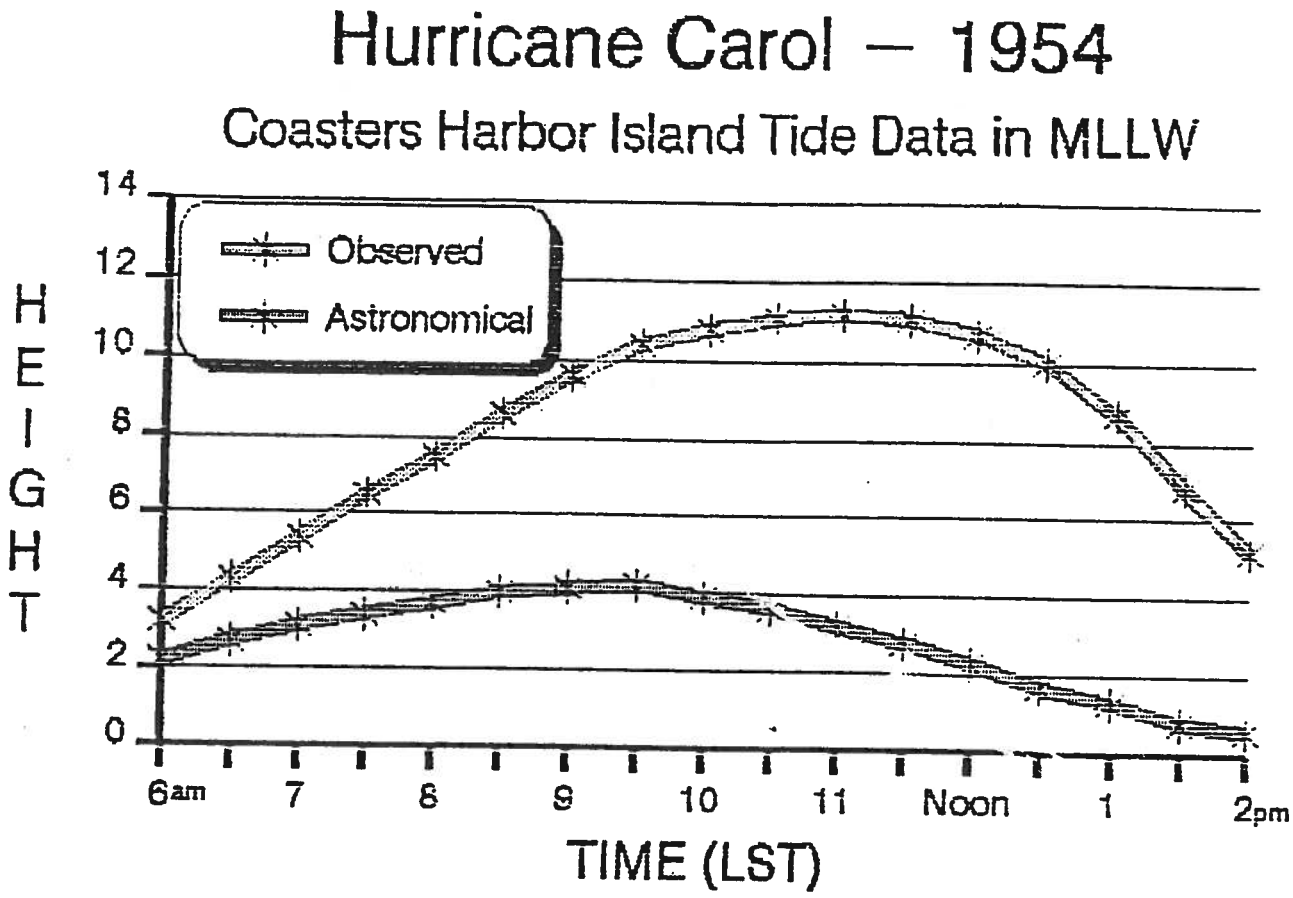

Figure 29. Storm surge height (feet) on August 31, 1954, associated with Hurricane Carol, recorded at the Coasters Harbor Island Station in Newport, Rhode Island.

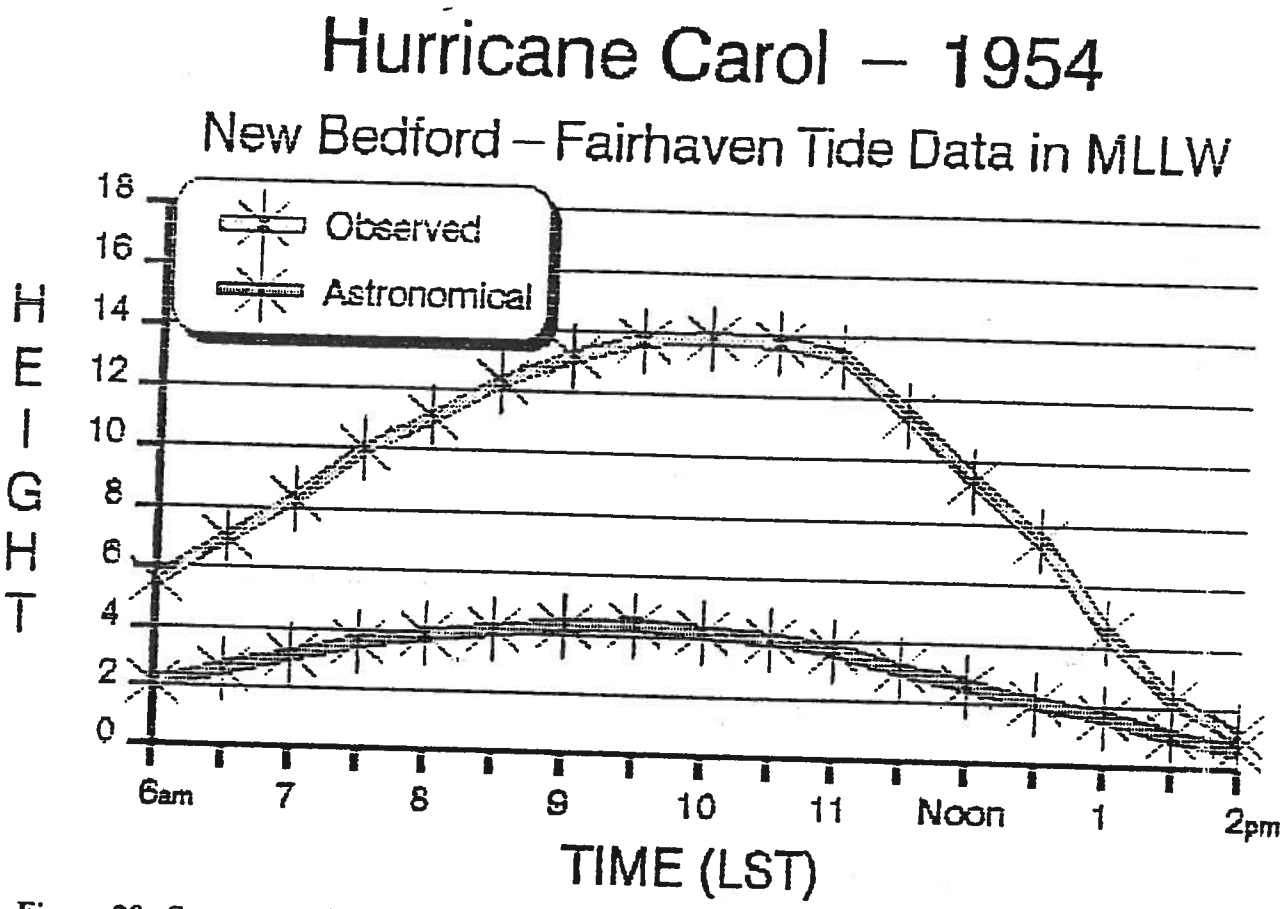

Figure 30. Storm surge height (feet) on August 31, 1954, associated with Hurricane Carol, recorded at New Bedford harbor.

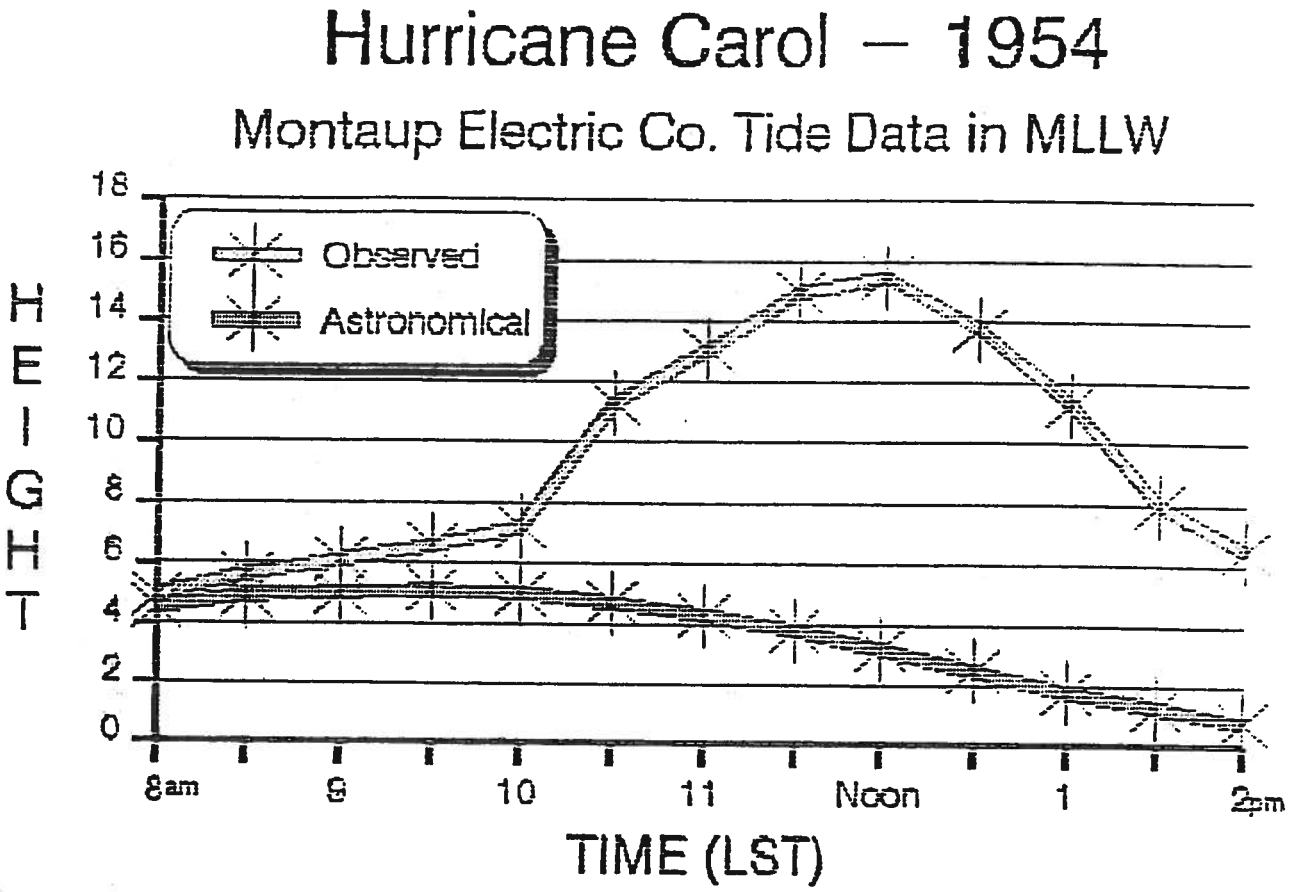

Figure 31. Storm surge height (feet) on August 31, 1954, associated with Hurricane Carol, recorded at the Montaup Electric Company in Somerset, Massachusetts.

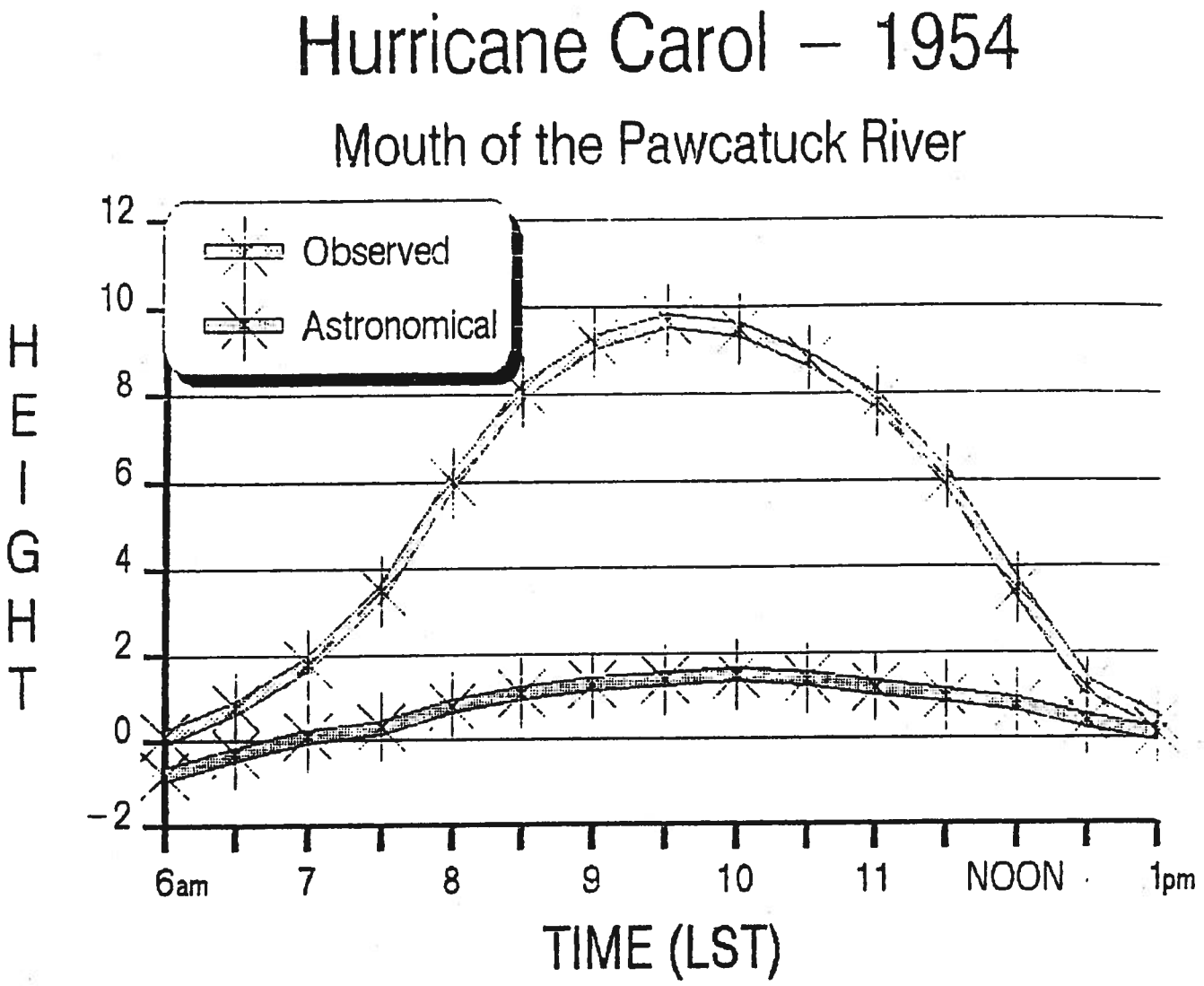

Figure 32. Storm surge height (feet) on August 31, 1954, associated with Hurricane Carol. recorded at the mouth of the Pawcatuck River, on the Connecticut/Rhode Island state border.

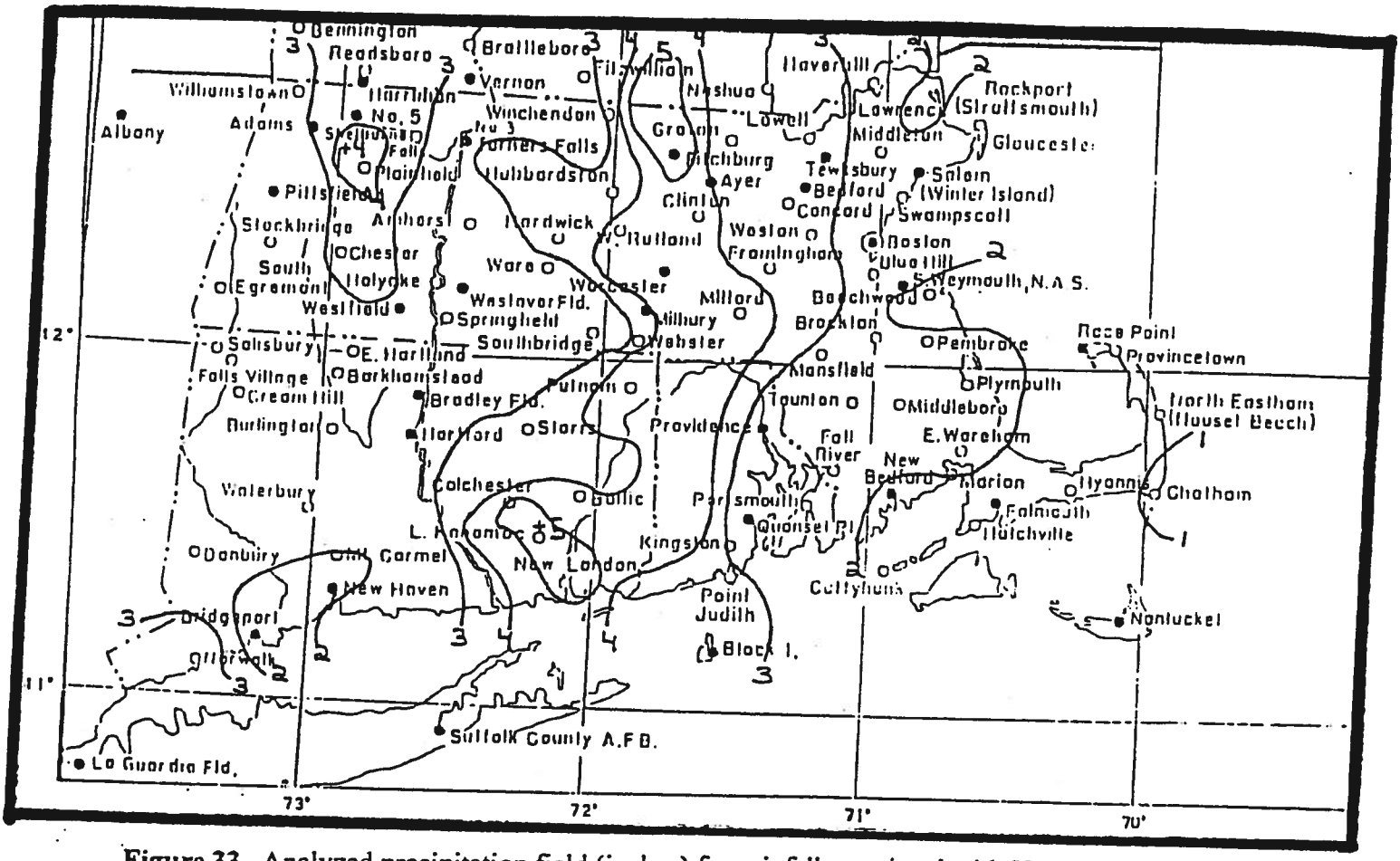

Figure 33. Analyzed precipitation field (inches) for rainfall associated with Hurricane Carol.

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 34). Edna raced towards southern New England at over 45 mph, but veered about 100 miles further east. Edna made landfall during the morning of September 11, passing over Martha's Vineyard and Nantucket, then across the eastern tip of Cape Cod, Massachusetts.

Hurricane force winds of 75 to 95 mph buffeted all of eastern Massachusetts and coastal Rhode Island. Inland, sustained winds of 50 to 70 mph were common west of the Connecticut River Valley. Peak wind gusts included 120 mph on Martha's Vineyard, 110 mph on Block Island, and 100 mph at Hyannis, Massachusetts. The strong winds knocked out electrical power across sections of Rhode Island, eastern Massachusetts, and nearly all of Cape Cod and the Islands. The lowest recorded pressure was 28.02 inches at Edgartown on Martha's Vineyard. An unofficial pressure of 27.70 inches was recorded in Woods Hole, in Falmouth, Massachusetts, but this reading is believed to be in error based on the actual track of the storm center.

Edna arrived during a rising tide and resulted in severe flooding across Martha's Vineyard, Nantucket and Cape Cod, where storm surges of over 6 feet were common. Further west, storm surge values were 4 feet or less, resulting in storm tides that remained below flood stage (Figure 35). Damage to the boating community was severe across Cape Cod, but was much less across the remainder of Massachusetts and Rhode Island. Most of damage across extreme southeast Connecticut and Rhode Island occurred to locations that were left severely weakened by Carol.

Edna's track across the extreme eastern part of the region did result in heavy rainfall and inland flooding. Rainfall amounts of 3 to 6 inches were common, with over seven inches across northeastern Massachusetts (Figure 36). This rainfall aggravated the already saturated conditions caused by Hurricane Carol ten days earlier. The total combined rainfall for Carol and Edna ranged from 5 to 7 inches along and west of the Connecticut River and over Cape Cod, to as much as 11 inches from southeast Connecticut, across most of Rhode Island, to northeast Massachusetts (Figure 37). Considerable urban and small stream flooding occurred. Numerous street washouts were common, along with some major river flooding in Rhode Island and northeast Massachusetts, where rivers rose several feet above flood stage.

Edna was responsible for 21 deaths across the region.

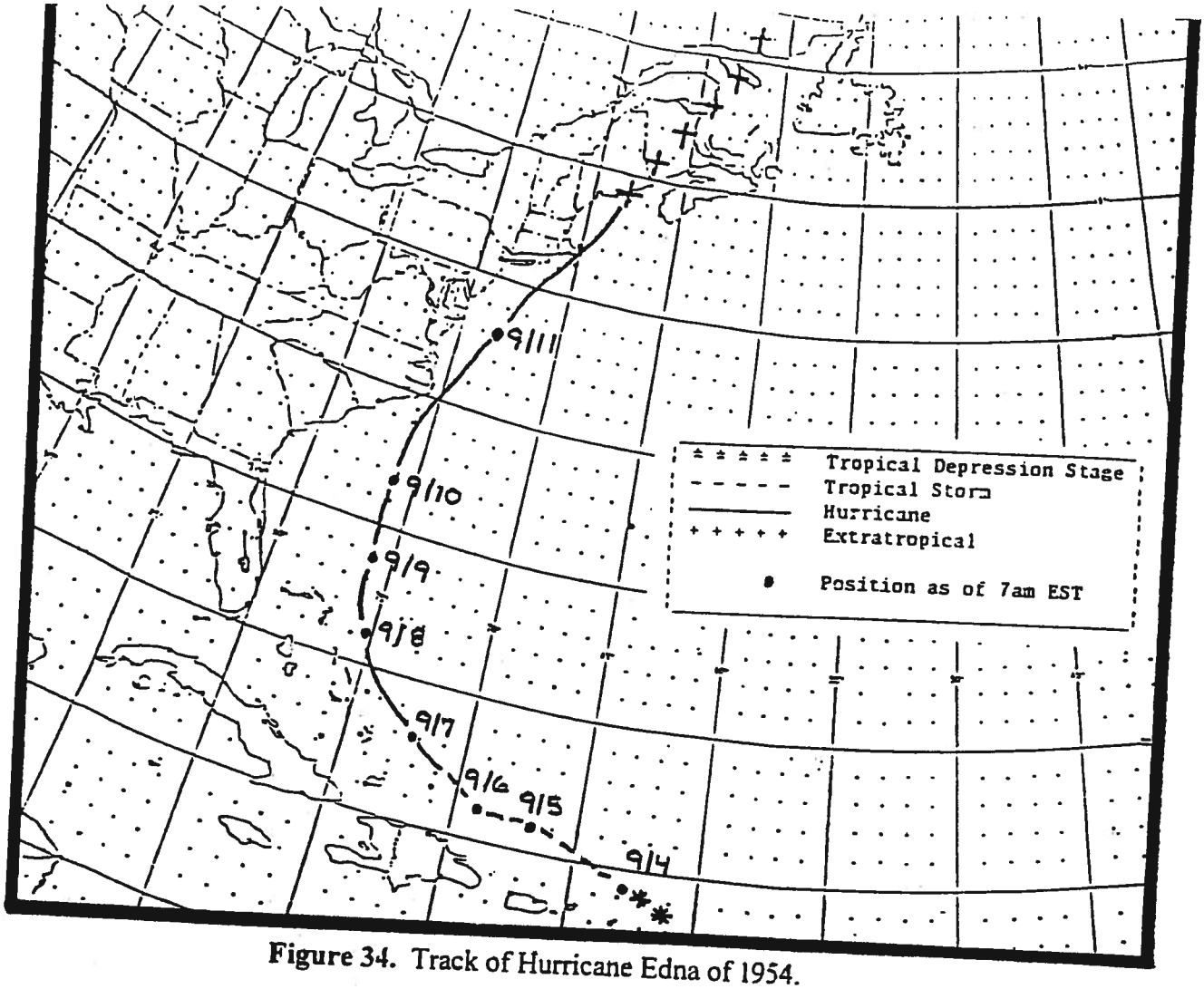

Figure 34. Track of Hurricane Edna of 1954.

HURRICANE HAZEL
(CAT 1 - October 15, 1954)

Hurricane Hazel developed near the Windward Islands on October 5 and rapidly intensified to hurricane status (Figure 38). It headed west until turning sharply north on October 9. The hurricane continued to strengthen as it moved across Haiti October 12, where it was responsible for hundreds of deaths due to high winds, torrential rains and mudslides. Hazel turned northwest and began to accelerate as she grazed the eastern most Bahama Islands on October 13. Hazel then turned back to the north and came crashing ashore, with winds gusting to over 150 mph, near Myrtle Beach, South Carolina on October 15. Hazel continued to race northward passing through Virginia, Pennsylvania, and New York, before dissipating in southern Canada on October 16.

Hazel brought high winds to extreme western parts of Massachusetts and Connecticut where winds frequently gusted to near hurricane force. Wind gusts to near 100 mph were confined to the southwest corner of Connecticut, near Stamford, with gusts to 113 mph in New York City. Winds elsewhere in southern New England gusted from 45 to 55 mph, except over outer Cape Cod and the Islands where gust to only 30 mph were recorded. The strong south winds arrived near high tide and did result in tides running 2 to 4 feet above normal.

Rainfall across the area was heaviest along and west of the Connecticut River, where amounts ranged from 1 to 2 inches. Elsewhere, rainfall from .10 to .50 inches was common.

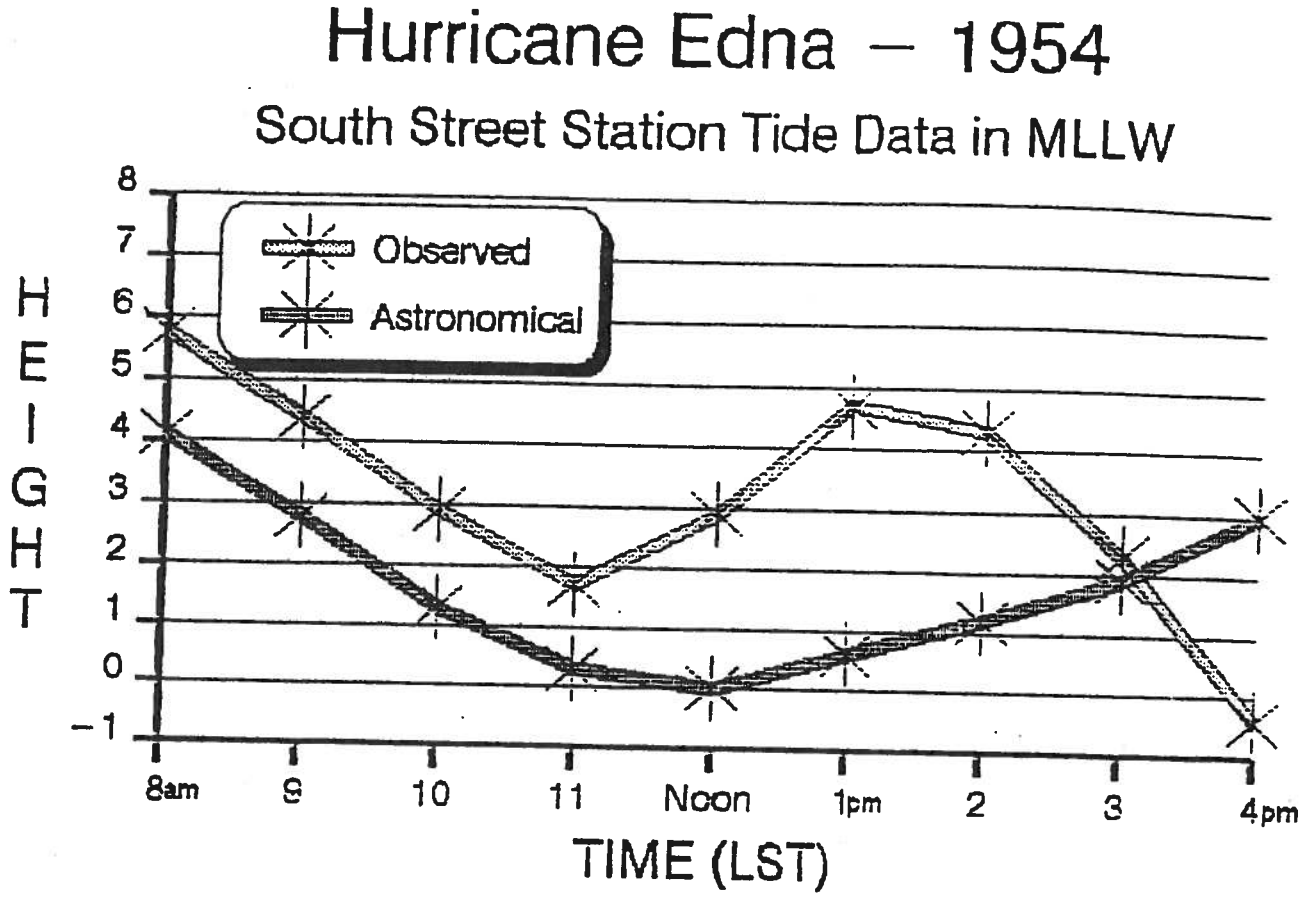

Figure 35. Storm surge height (feet) on September 11, 1954, associated with Hurricane Edna. recorded at the South Street Station Dock on upper Narragansett Bay.

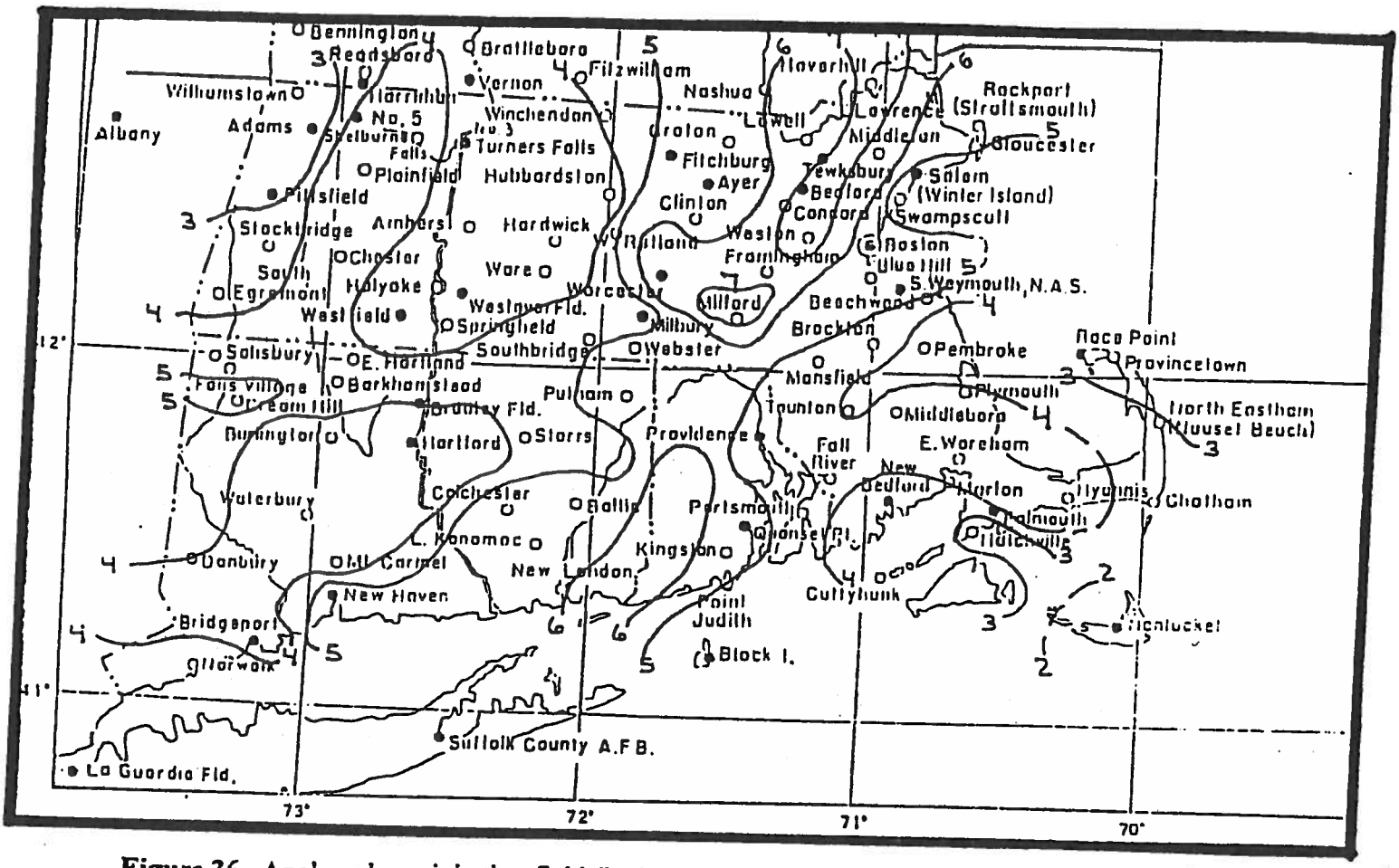

Figure 36. Analyzed precipitation field (inches) for rainfall associated with Hurricane Edna.

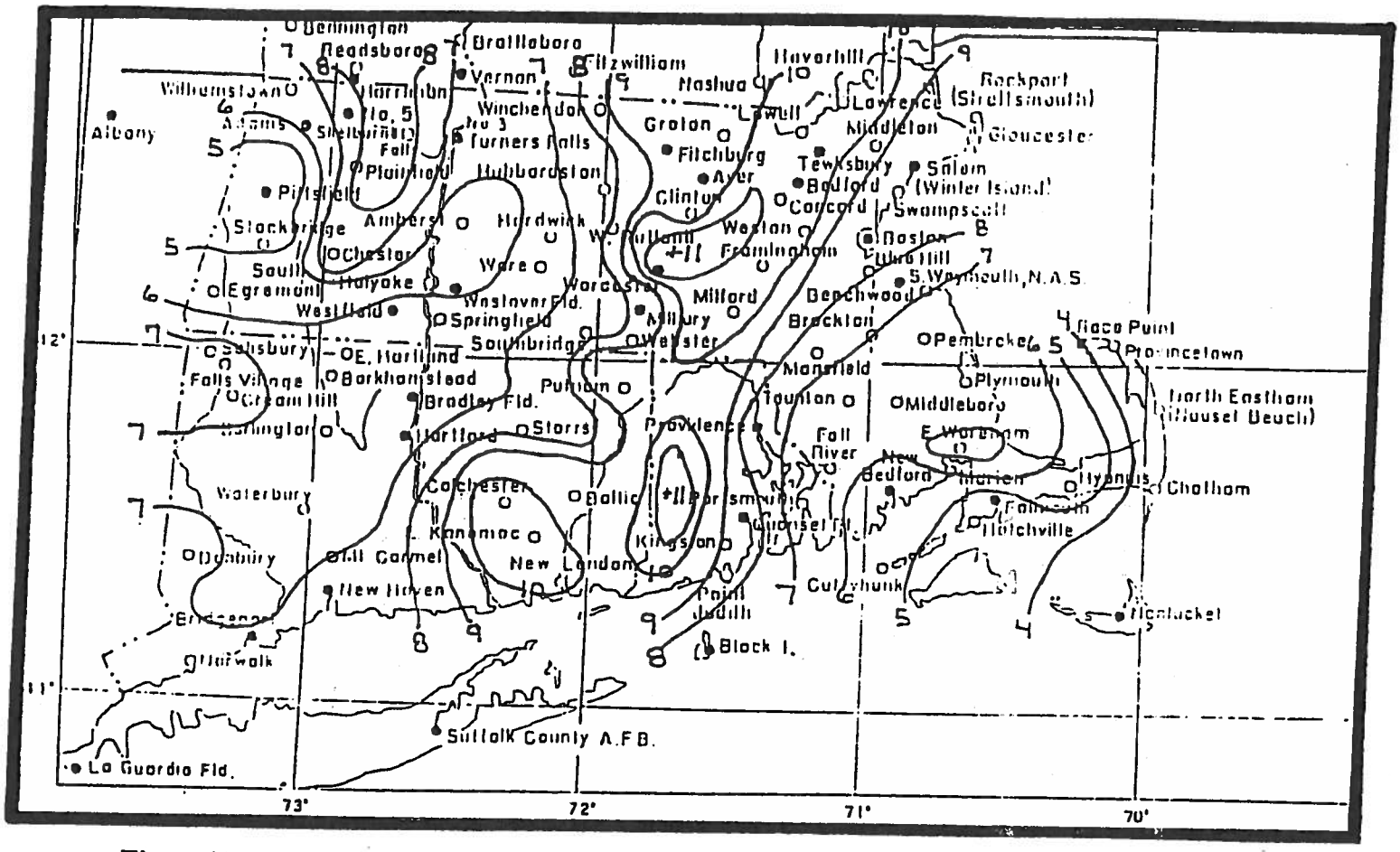

Figure 37. Analyzed precipitation field (inches) of the total combined rainfall for Hurricane Carol and Hurricane Edna.

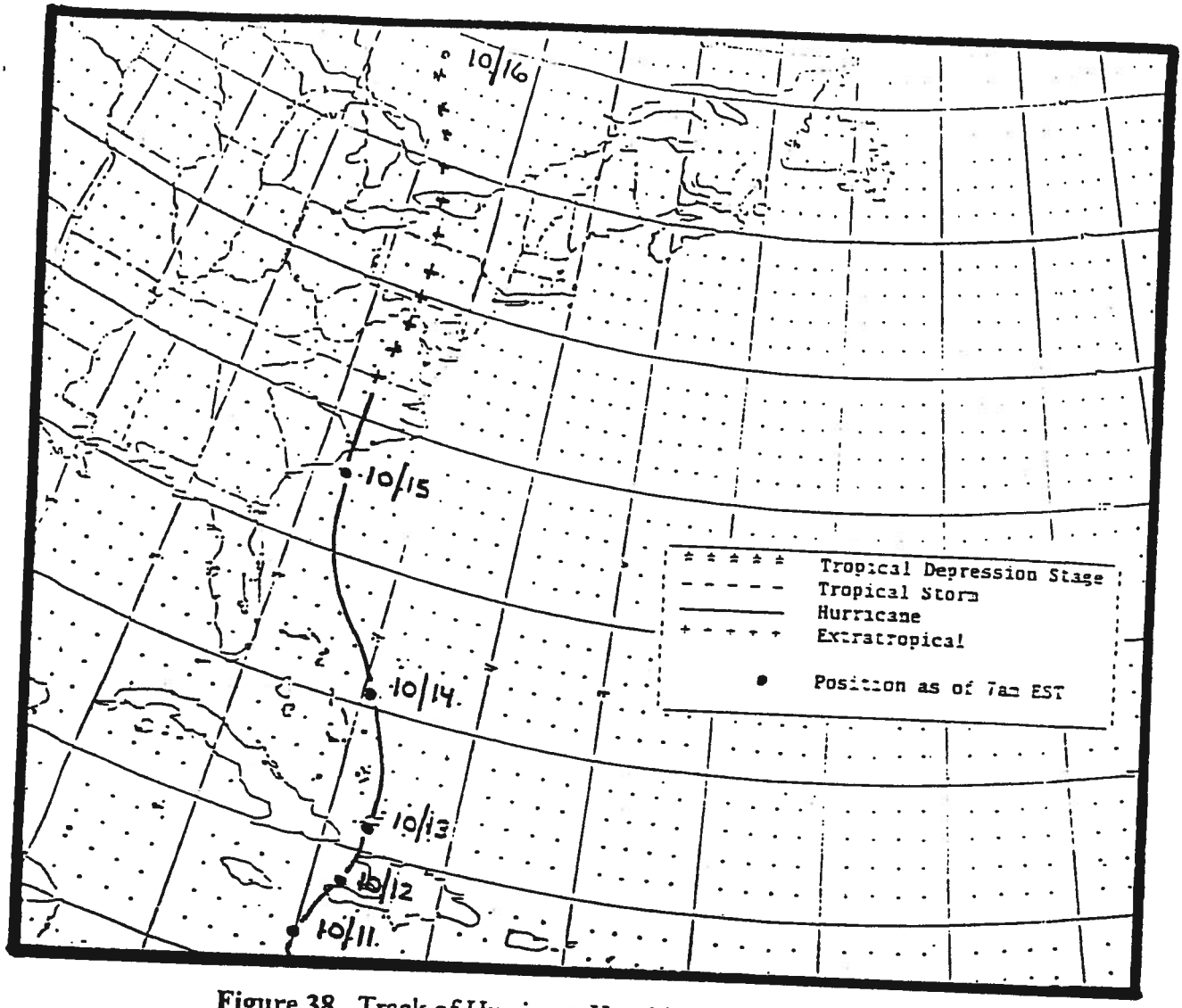

Figure 38. Track of Hurricane Hazel in 1954.

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 significantly while passing north of the Virgin Islands. By August 9, Connie began to lose both strength and forward speed. The system continued very slowly northwestward during the following three days, eventually making landfall on the North Carolina coast on August 12 (Figure 39).

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

Strong winds of 30 to 50 mph were confined to extreme western Massachusetts and Connecticut. Some trees and power lines were downed.

The main impact on southern New England was substantial rainfall. Much of the moisture associated with Connie was carried northward up the coast into New England. The heaviest amounts, depicted in Figure 40, occurred along and west of the Connecticut River, where 5 to 8 inches fell. Isolated amounts of over 9 inches were recorded in Danbury, Connecticut and Plainfield, Massachusetts. To the east of the Connecticut River, 3 to 6 inches was reported, with an isolated amount near 7 inches in Falmouth, Massachusetts.

For most of the region, dry conditions preceded this storm, so only isolated flooding of streams was reported; primarily across western Massachusetts and Connecticut. This heavy rainfall did, however, set the stage for what would be one of the worst and most widespread flood events in southern New England, due to the effects of Tropical Storm Diane, which struck 4 days later.

Connie was responsible for one death and five injuries in Southern New England.

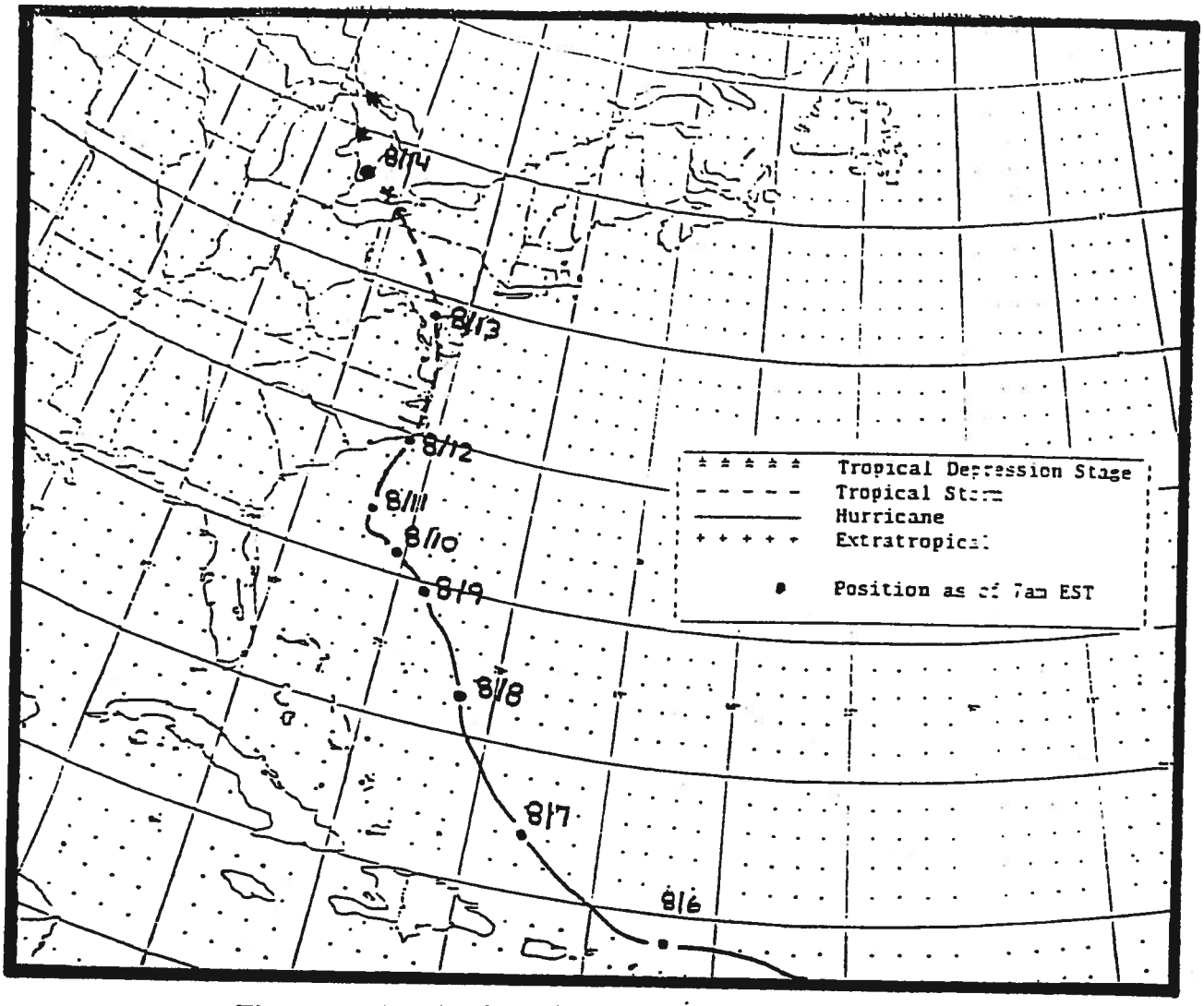

Figure 39. Track of Tropical Storm Connie of 1955.

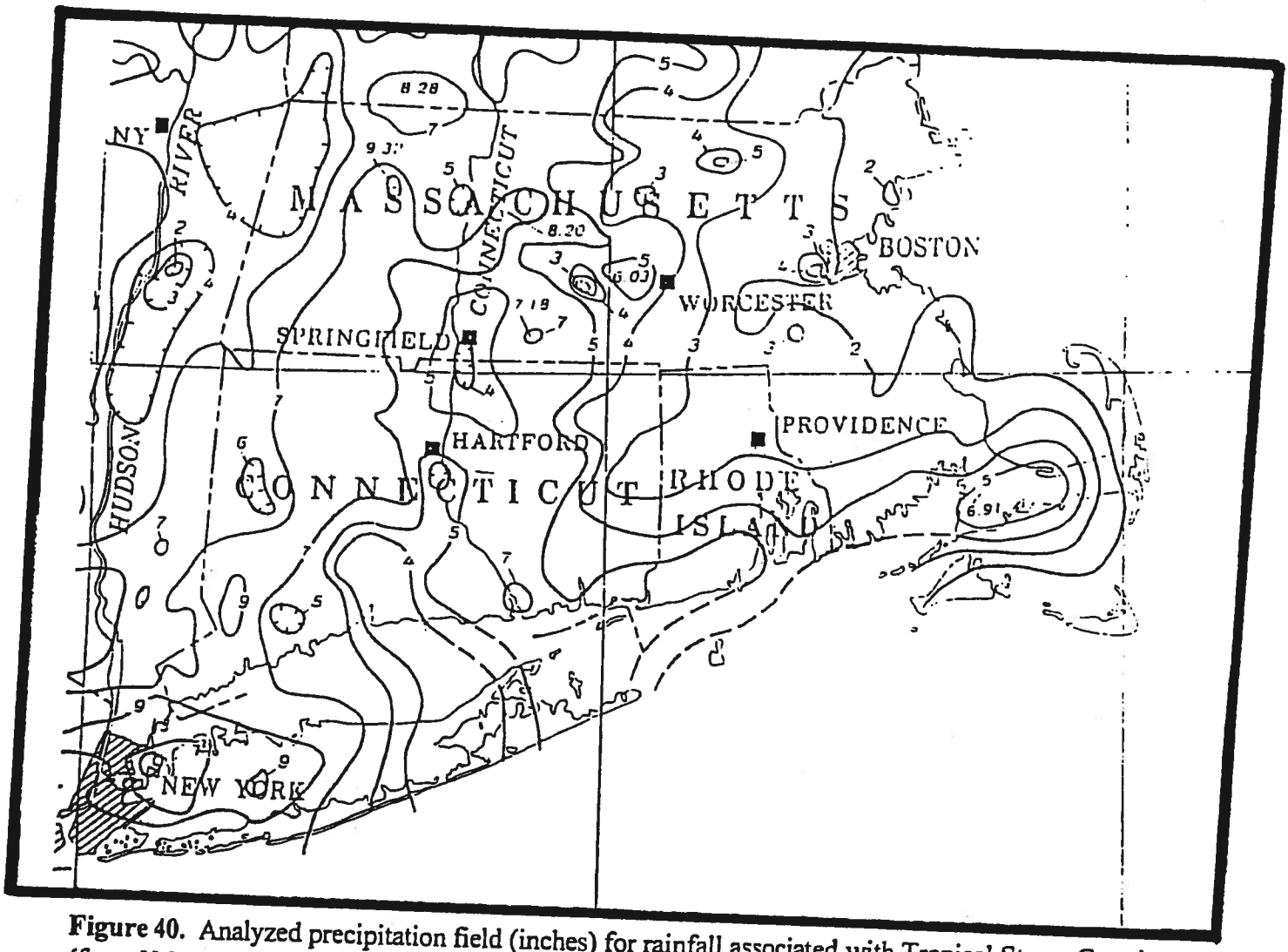

Figure 40. Analyzed precipitation field (inches) for rainfall associated with Tropical Storm Connie (from U.S. Geological Survey 1955).

TROPICAL STORM DIANE
(August 18-20, 1955)

Tropical Storm Diane affected southern New England with torrential rains 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 41). The system weakened to tropical storm strength shortly thereafter, then continued a slow movement northward into Virginia. Heavy rains began to affect southern New England 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, Rhode Island on August 19, then continued on east of Cape Cod on August 20.

Diane dumped excessive rainfall across the midsection of southern New England, as seen in Figure 42. Rainfall amounts of 15 to 20 inches fell from northern Connecticut east to the Boston area. The greatest storm total of 19.76 inches occurred in Westfield, Massachusetts which also set the highest 24 hour rainfall total ever recorded in the region of 18.15 inches. Rainfall amounts of 5 to 10 inches fell across most of the remainder of the region, except across the south coast, and in extreme northern Massachusetts.

Catastrophic flooding occurred throughout most of southern New England. Rainfall totals from Connie and Diane averaged 25 inches across parts of central and western Massachusetts, and northern Connecticut. Nearly all of the major rivers and their tributaries in Connecticut exceeded flood stage. Some rivers went over 20 feet over their banks. The Connecticut River near Hartford reached 14.6 feet above flood stage. The Westfield River exceeded its flood stage by 20.2 feet, while the Quinebaug River at Jewett City, Connecticut reached 11.5 feet above flood stage.

Severe flooding occurred across most of Massachusetts, where as much as 40 percent of downtown Worcester was submerged. In Woonsocket, Rhode Island, the Blackstone River rose to 17 feet above flood stage. Sections of Woonsocket were completely destroyed, as water rose to the height of the street lights in some sections. Much of the destruction in Woonsocket was aggravated when the Horseshoe Dam failed. Dam failures were also common upstream of the Quinebaug River in Southbridge, Massachusetts.

Roads, bridges and railroads were badly damaged or destroyed along rivers in southern New England. In low lying and poor drainage sections of Rhode Island and eastern Massachusetts, widespread street washouts and flooded basements were common.

Gusty east to southeast winds of 25 to 45 mph occurred along the coast, but caused only minor coastal flooding.

One hundred and twelve homes were destroyed, and 1,480 were damaged by flood waters in southern New England. Diane was responsible for 90 deaths in the region; 77 in Connecticut, 12 in Massachusetts, and 1 in Rhode Island.

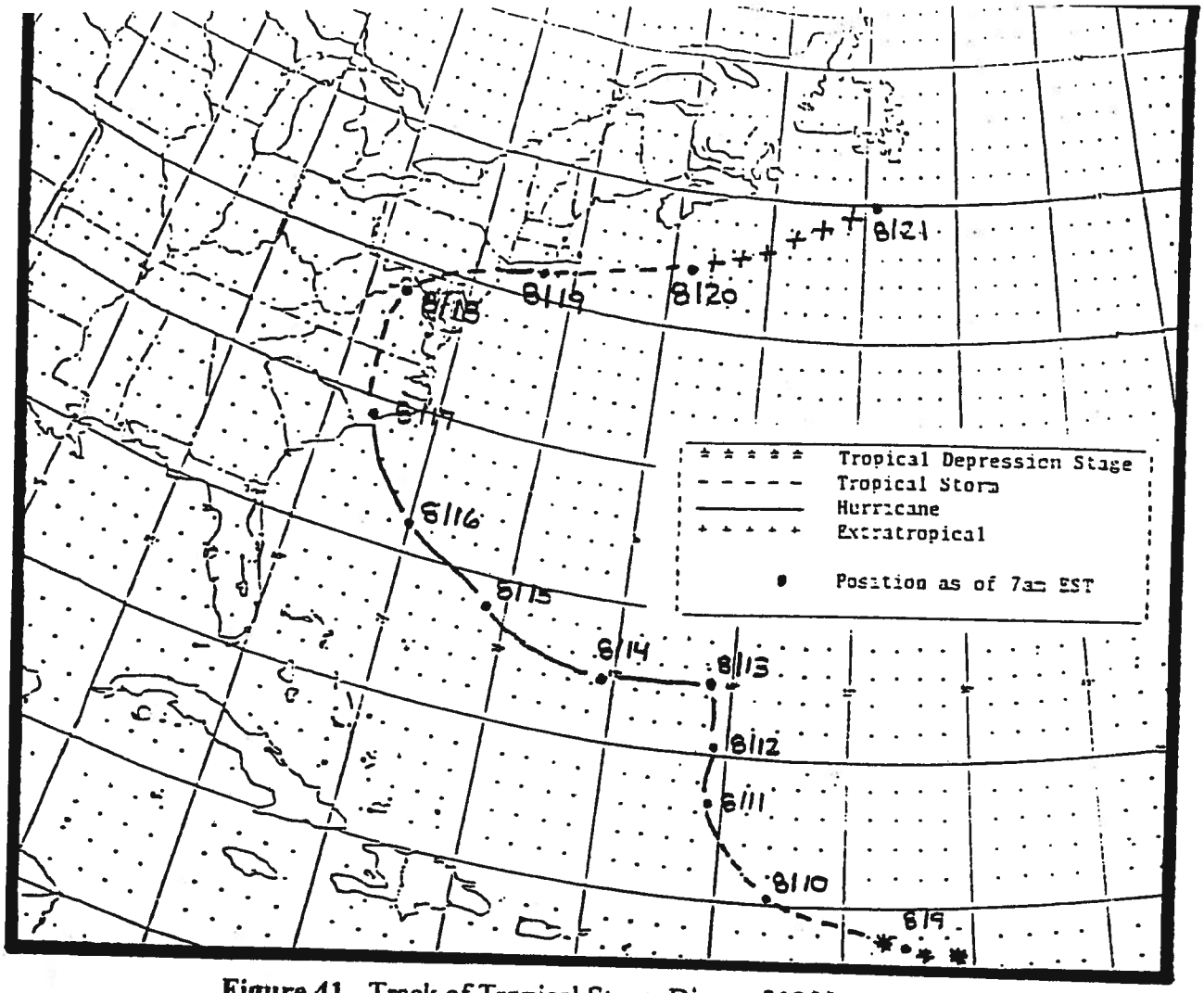

Figure 41. Track of Tropical Storm Diane of 1955.

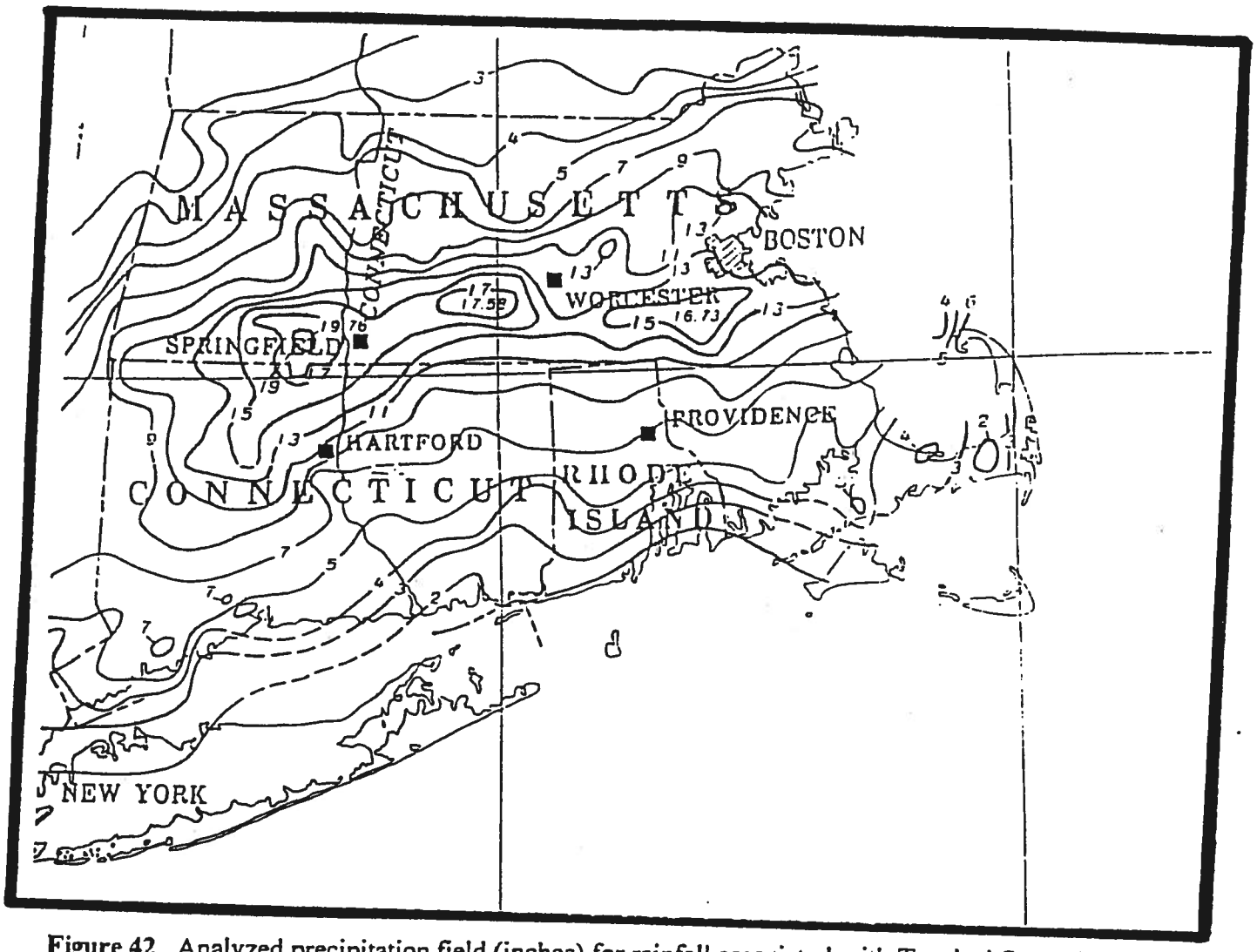

Figure 42. Analyzed precipitation field (inches) for rainfall associated with Tropical Storm Diane (from U.S. Geological Survey 1955).

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 43). 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 65 miles southeast of Chatham, Massachusetts during the morning of August 29.

Daisy's track to the south of New England spared the area from hurricane conditions. Sustained winds of 20 to 30 mph were felt only across Rhode Island and eastern Massachusetts. The highest wind gust was only 45 mph recorded on Block Island, Rhode Island. Tides ran 1 to 3 feet above normal, but no coastal flooding was observed.

The heaviest rainfall occurred over Cape Cod and the Islands where over 3 inches fell. Nantucket Island received 3.26 inches. Elsewhere, rainfall was generally less than .50 inches.

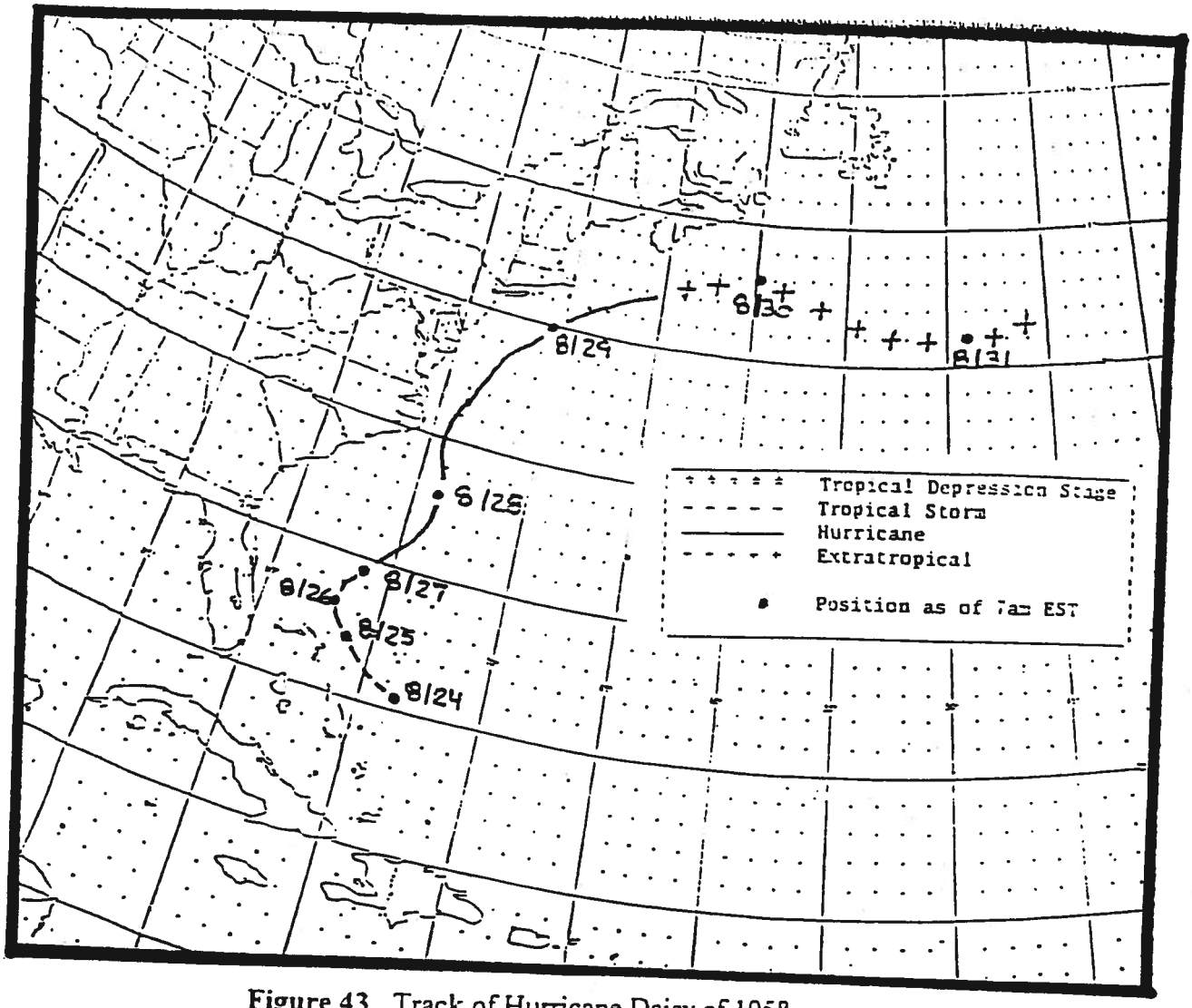

Figure 43. Track of Hurricane Daisy of 1958.

TROPICAL STORM CINDY
(July 10-11, 1959)

Tropical Storm Cindy developed off the Florida coast on July 5 (Figure 44). Cindy moved very slowly northward during the next two days, slowly intensifying to hurricane strength. Cindy turned westward on July 7 and made landfall on the South Carolina coast July 9. The system weakened to a tropical 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, then reintensified to tropical storm strength. Cindy continued northeastward, passing across the eastern tip of Cape Cod near 8 am on July 11.

Cindy brought northwest winds of 20 to 40 mph to Rhode Island and eastern Massachusetts. Winds gusted to 65 mph on Block Island and Martha's Vineyard Islands. Some minor coastal flooding accompanied the storm, but no serious damage was reported. Rainfall throughout the region ranged from 1 to 3 inches, with the heaviest amounts over 4 inches occurring on Martha's Vineyard and Nantucket.

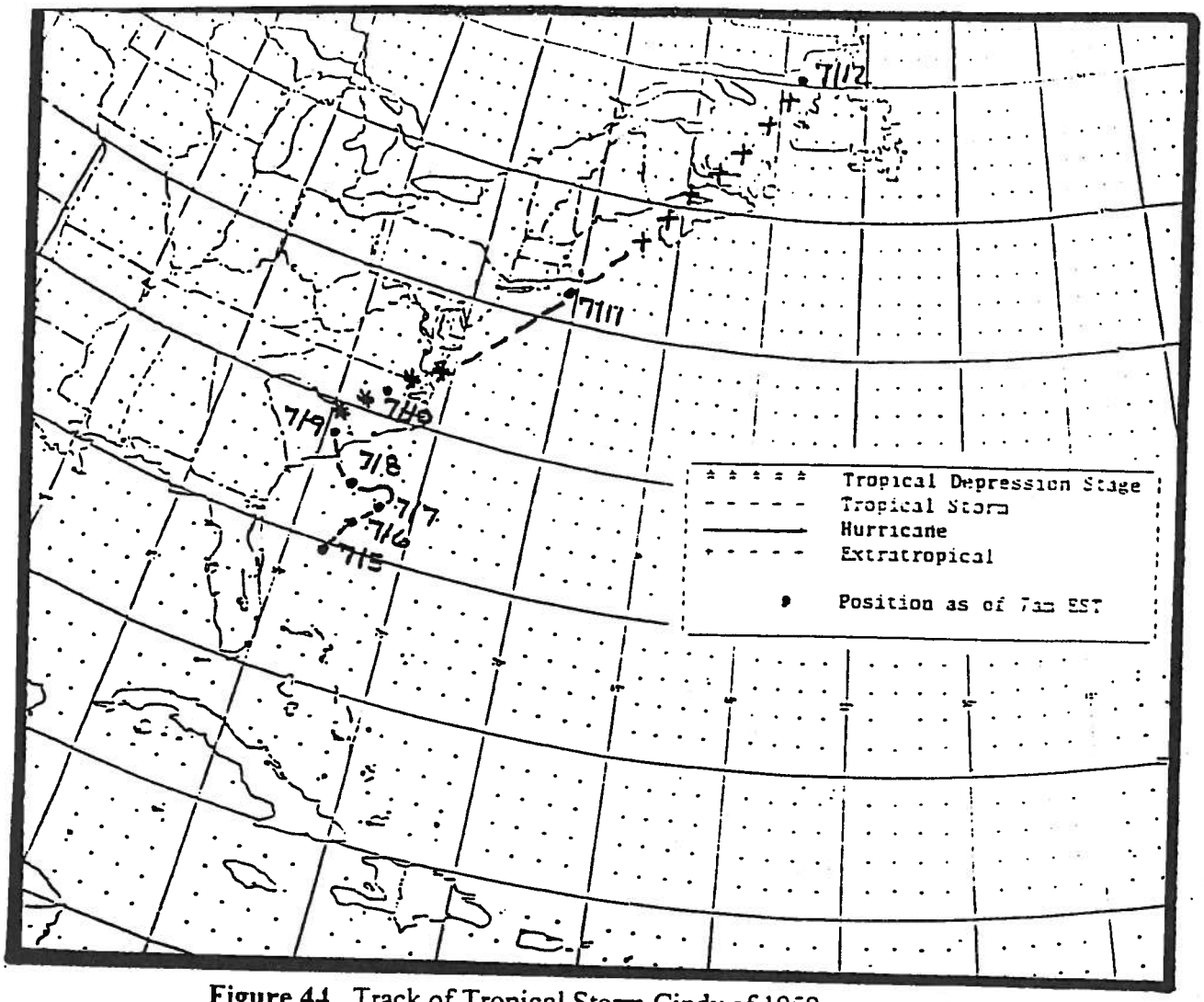

Figure 44. Track of Tropical Storm Cindy of 1959.

TROPICAL STORM BRENDA
(July 30, 1960)

Tropical Storm Brenda was the first of two tropical systems to affect southern New England during the summer of 1960. Brenda developed from a tropical depression in the northeast Gulf of Mexico. It strengthened to a tropical storm along the Georgia coast on July 29, then made rapid progress northward during the next 24 hours, passing over New York City by late morning on July 30 (Figure 45). The system lost tropical characteristics later that afternoon, as it moved across western Maine.

Brenda brought gusty south winds of 20 to 40 mph to southern New England, which pushed tides up to 4 feet above normal. No coastal flooding or power outages were reported.

The heaviest rainfall amounts fell across southern Connecticut northeastward across inland Rhode Island and eastern Massachusetts, where 1 to 3 inches fell. Elsewhere, amounts were less than .75 inches.

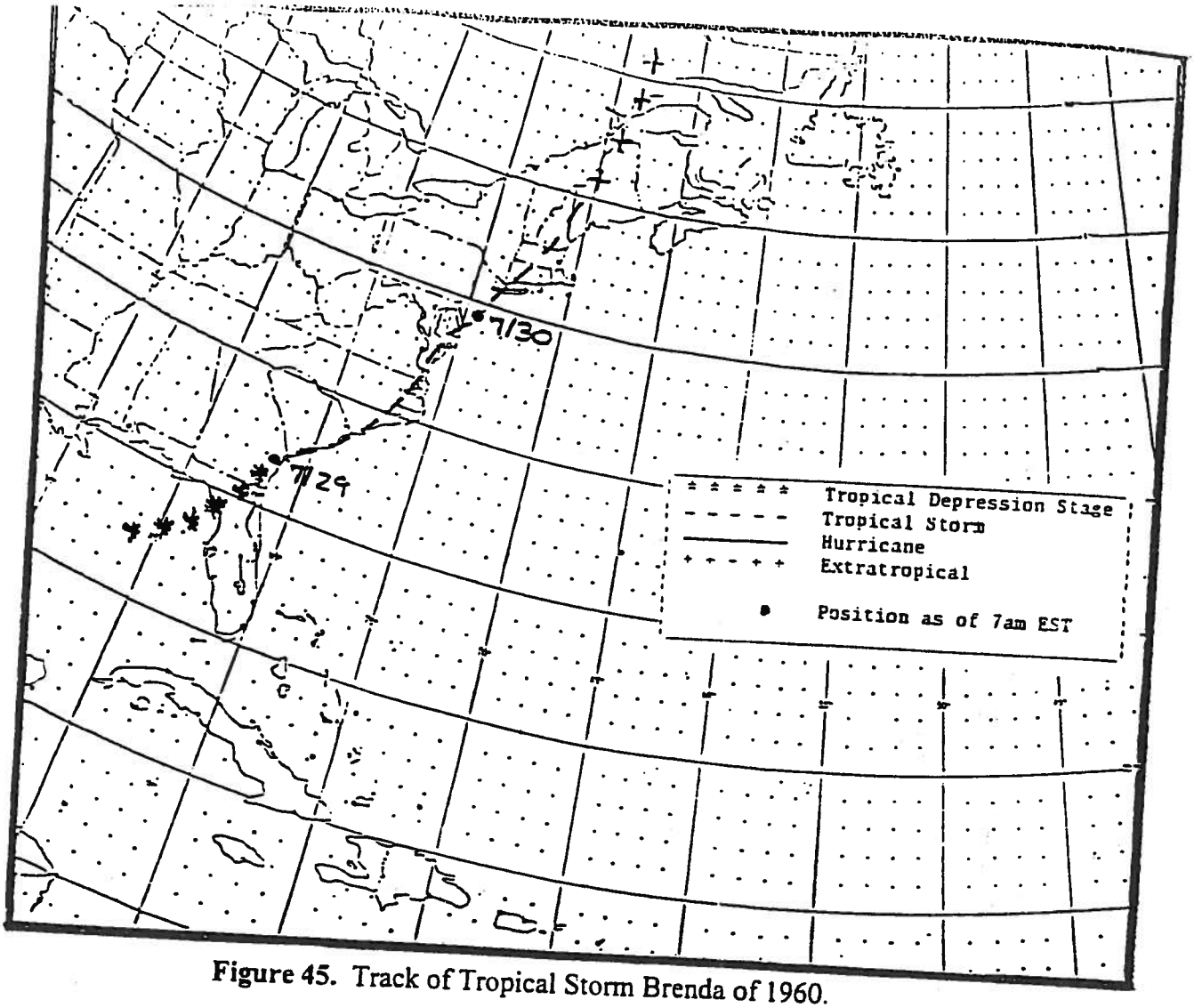

Figure 45. Track of Tropical Storm Brenda of 1960.

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 New England's 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 46). 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 landfall on eastern Long Island during the afternoon of September 12. The center continued rapidly northeastward, passing over New Haven, Connecticut, then continuing northeastward into the Canadian Maritimes.

Sustained winds of 70 to 90 mph blew across much of coastal southern New England, with wind gusts to over 100 mph common along the south shore. The storm's highest wind gust of 140 mph was recorded on Blue Hill, in Milton, Massachusetts. Block Island, Rhode Island gusted to 130 mph. Further inland, winds were sustained at 30 to 50 mph with gusts to near hurricane force. The strong winds blew down scores of trees and power lines, which resulted in a loss of electrical power for much of eastern and south coastal locations. In Rhode Island, 82 percent of the state lost power. On Cape Cod, power was interrupted for up to 5 days. High winds also severely damaged much of the apple and corn crops across the region. The lowest barometric pressure occurred at New Haven, Connecticut, where the pressure dropped to 28.55 inches. Based on other pressure readings along the south coast of southern New England, it is estimated that the diameter of Donna's eye at landfall may have been nearly 100 miles across.

Donna caused a storm surge of 6 to 9 feet on the south shore of southern New England, and a surge of 4 feet along the eastern Massachusetts coastline. Coastal damage was extensive across southeast Connecticut eastward to Cape Cod, but Donna's arrival shortly before low tide spared the region from catastrophic damage. Hundreds of boats were heavily damaged or destroyed along the shore, with significant damage to many marinas.

Rainfall was heaviest to the west of the storm track (Figure 47). Rainfall amounts of 5 to 7 inches were common along and west of the Connecticut River. Rainfall decreased eastward, with less than 1 inch common across Cape Cod and the Islands.

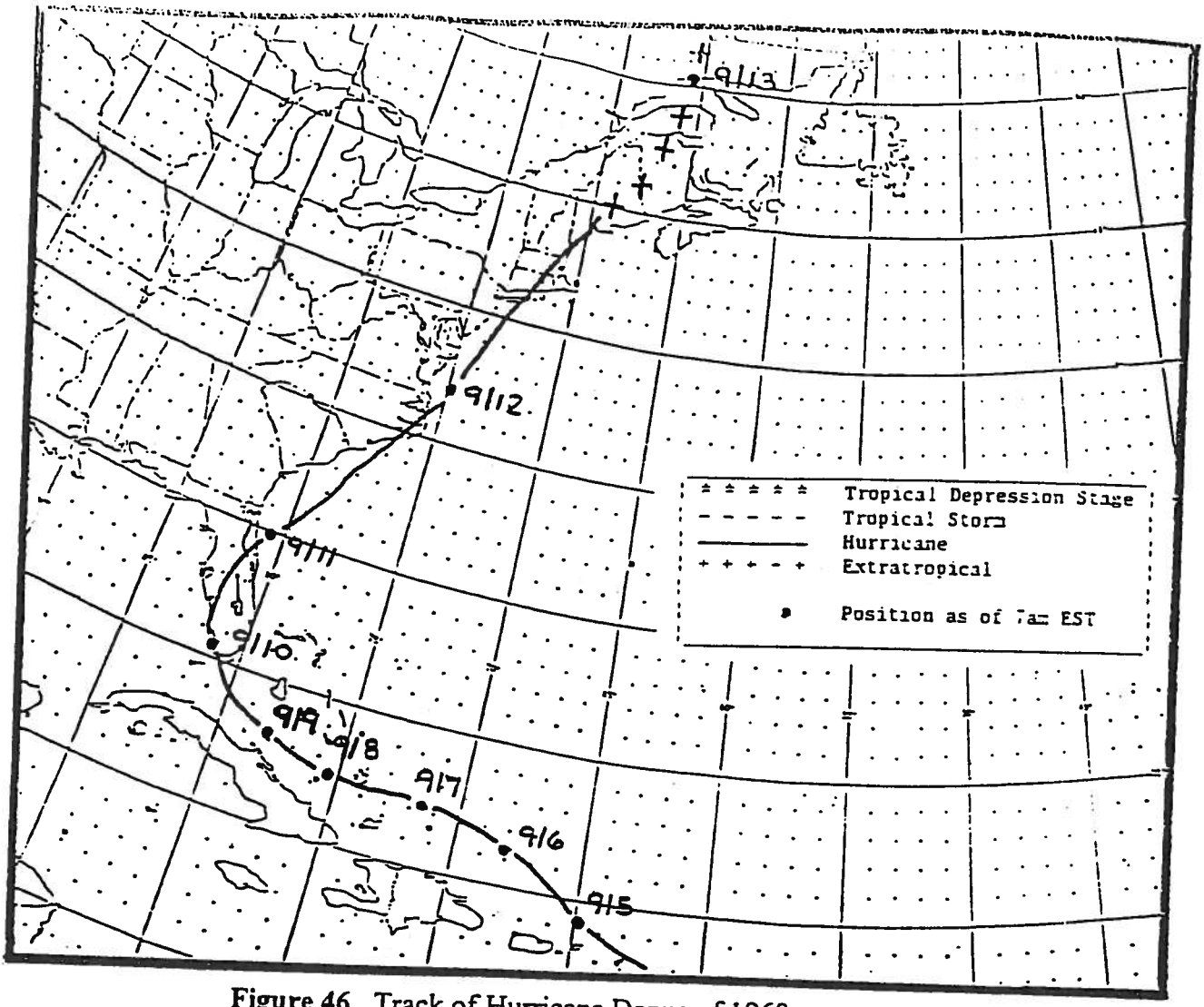

Figure 46. Track of Hurricane Donna of 1960.

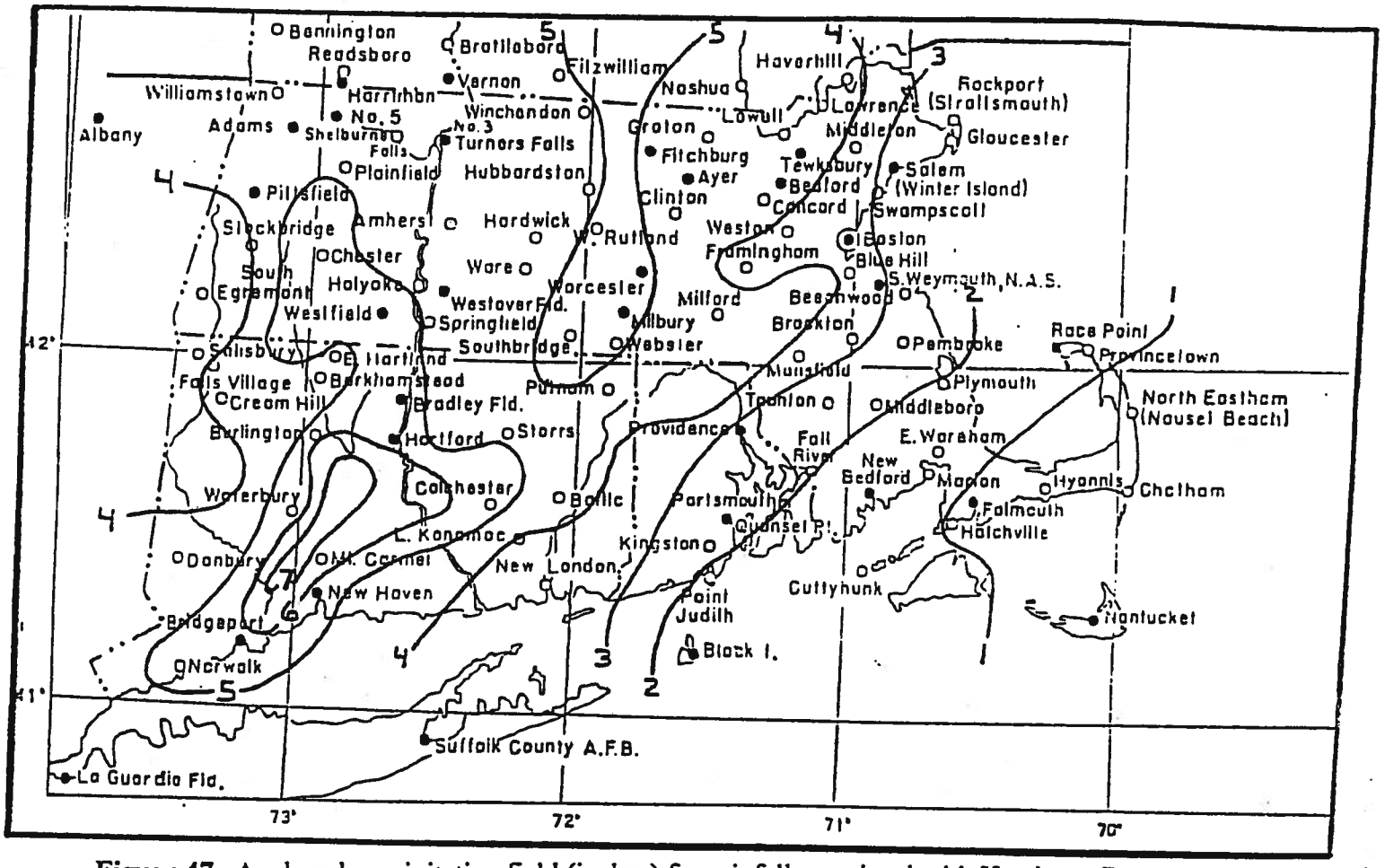

Figure 47. Analyzed precipitation field (inches) for rainfall associated with Hurricane Donna.

TROPICAL STORM of 1961
(September 14)

This storm developed from a tropical depression in the Bahamas, on September 12. It reached tropical storm status shortly before landfall near Wilmington, North Carolina, on September 14. It then accelerated northeastward passing across central Long Island and central Connecticut during the evening of September 14, then dissipated as it moved through the Canadian Maritimes (Figure 48). This system was unnamed because it was not determined until after the season that it had minimal tropical storm characteristics.

Sustained winds of 30 to 50 mph were common along and east of the storm track. Several gusts to near hurricane force were recorded on Block Island and across south coastal Massachusetts. Wind damage was confined to the south coast where some trees and power lines were downed. Apple orchards were damaged in sections of Rhode Island. The storm arrived at low tide, but did produce tides of up to 4 feet above normal.

Most of the region received .50 to 1.5 inches of rain, while the south coast of Rhode Island received around 2 inches. The heaviest rainfall total was 2.19 inches recorded on Block Island.

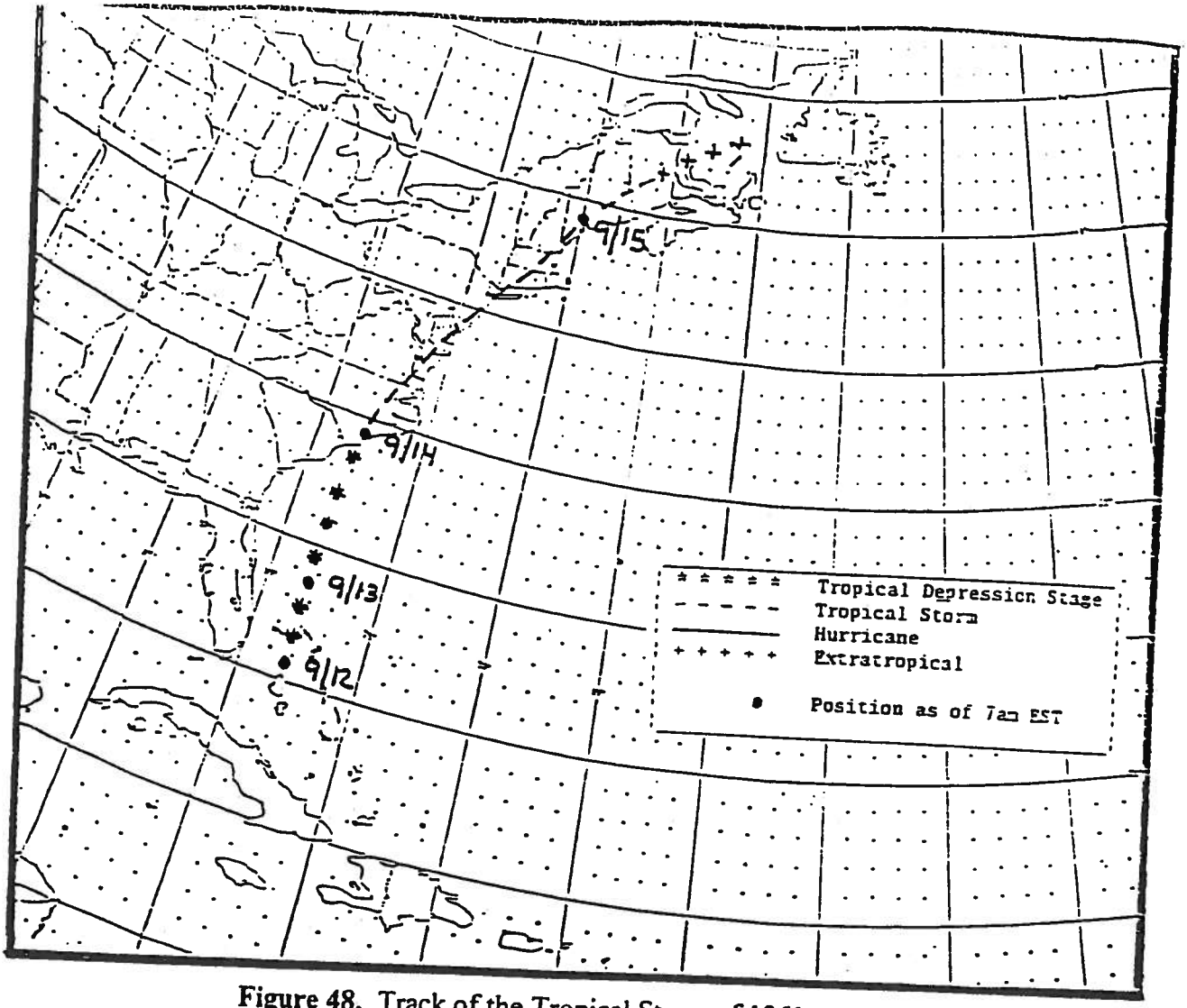

Figure 48. Track of the Tropical Storm of 1961.

HURRICANE ESTHER
(**CAT 3** - September 20-21, and 25, 1961)

Esther had her origins southwest of the Cape Verde Islands on September 10. The system rapidly strengthened to hurricane status by the evening of September 11. The system moved steadily northwestward for the next 7 days before beginning a gradual turn toward the north. Unlike many New England Hurricanes, Esther did not accelerate toward the region, but instead slowed down as it approached the area on September 20. A hurricane watch was issued well in advance, at 8 pm September 19. The watch was later changed to a hurricane warning at noon September 20. Hurricane Esther was the most peculiar storm to affect southern New England. The system actually hit the 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 49). In addition, it was the only storm studied which moved so slowly while approaching the area, with an average speed of only 6 mph.

When Esther made her first pass on September 21, strong northeast gales of 35 to 50 mph buffeted inland sections, with sustained winds of 60 to 80 mph along the coast. The strongest wind gust occurred on Block Island, with a peak gust to 84 mph. Power outages were common, due to tree limbs being blown down. Damage also occurred to the fruit tree and grape orchard industries. Winds during the second pass and eventual landfall were much weaker. Sustained winds of 30 to 40 mph were confined to Cape Cod and the Islands.

Storm surge values ranged from 4 to 6 feet from southeast coastal Connecticut eastward to Cape Cod. The highest surge values occurred on the southwest coast of Connecticut, in Stamford, where a surge of over 9 feet was estimated. This high surge value was likely the result of "tidal piling" brought on by the slow movement of Esther which caused a prolonged period of easterly winds. Damage to the coast was scattered and primarily confined to beach erosion and boats and marinas.

Esther's slow 6 mph forward motion allowed for 4 to 8 inches of rain to fall across eastern Connecticut, Rhode Island, and central and eastern Massachusetts (Figure 50). Western sections of Massachusetts and Connecticut, as well as most of Cape Cod received only 1 to 3 inches. Considerable urban and street flooding occurred in many locations affected by the heaviest rainfall. In Rhode Island, the most serious flooding occurred along sections of the Pawtuxet River.

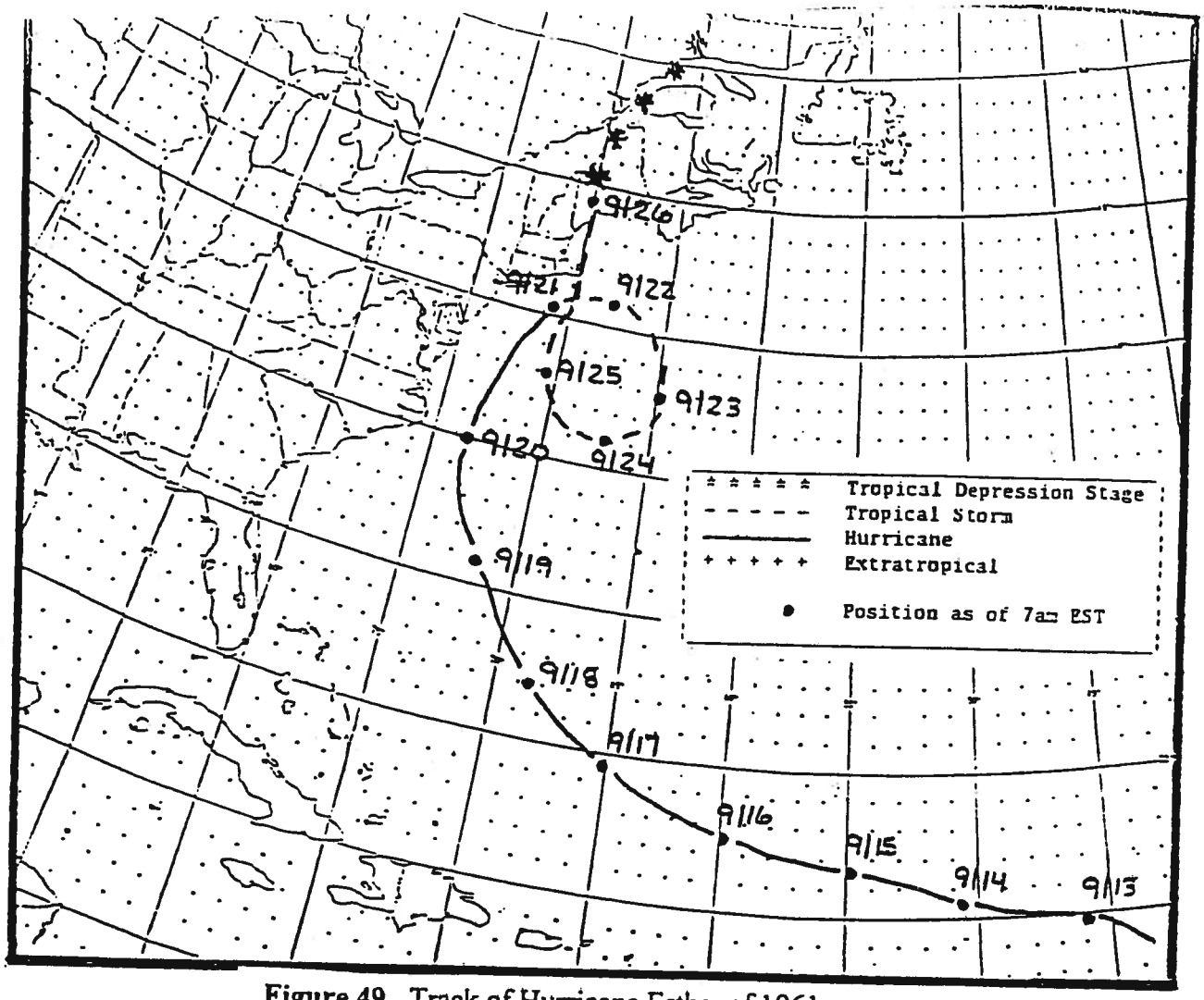

Figure 49. Track of Hurricane Esther of 1961.

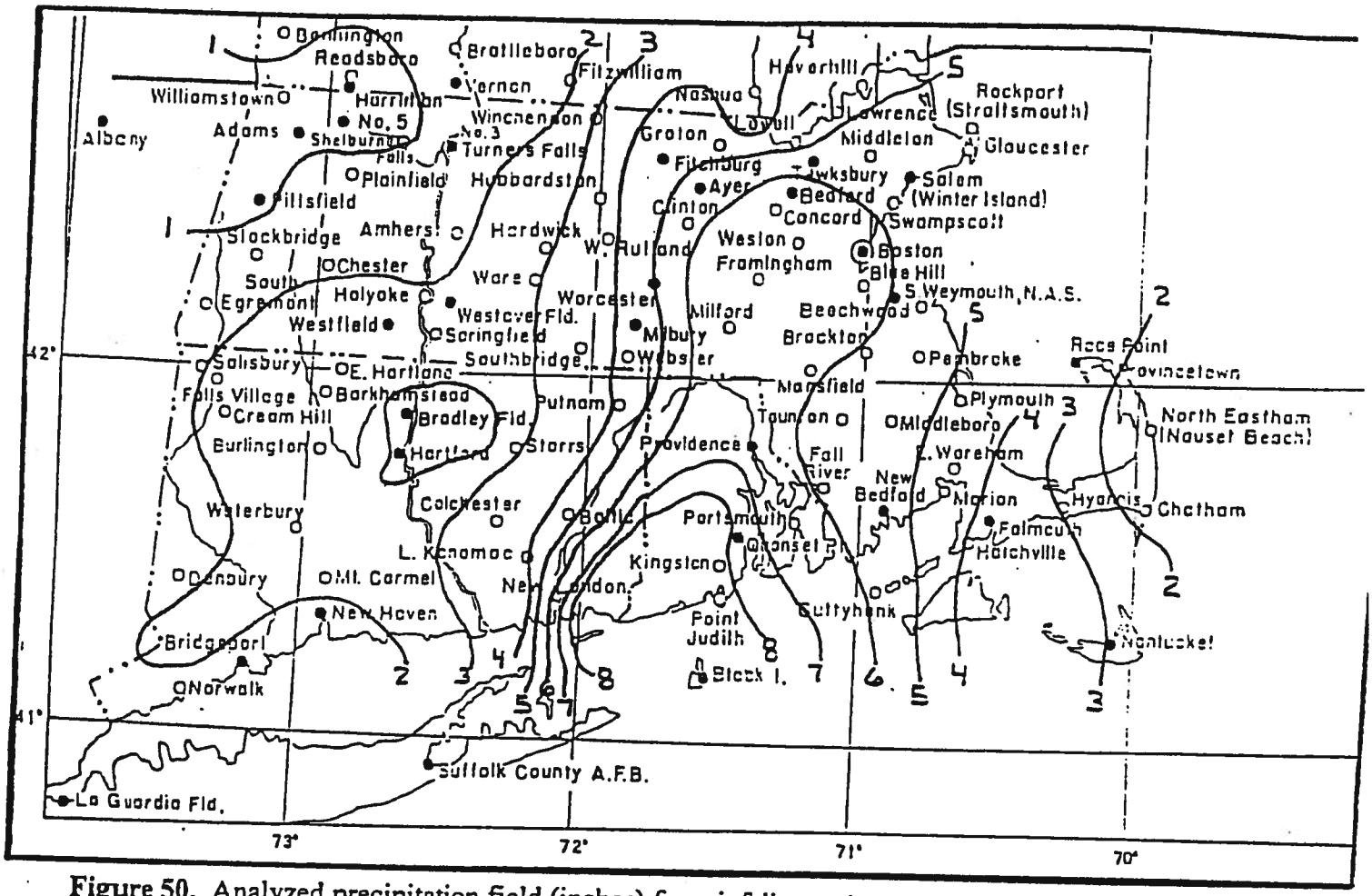

Figure 50. Analyzed precipitation field (inches) for rainfall associated with Hurricane Esther.

HURRICANE ALMA
(CAT 2 - August 28-29, 1962)

Hurricane Alma originated about 100 miles off the northeast coast of Florida (Figure 51). 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 50 miles south of Nantucket on the morning of August 29.

Alma gave southeastern sections a glancing blow, spreading gusty north winds and locally heavy rainfall throughout that area. Sustained winds of 30 to 40 mph were common across Rhode Island, with gusts to 60 mph on Block Island and along the Massachusetts shore. Some minor beach erosion occurred, primarily along east facing beaches. Some small pleasure craft damage was reported, with 100 boats damaged along the Massachusetts coasts. Rainfall of 1 to 2 inches occurred over eastern Connecticut, Rhode Island and much of Massachusetts, with Block Island, Rhode Island and much of Cape Cod receiving 3 to 6 inches.

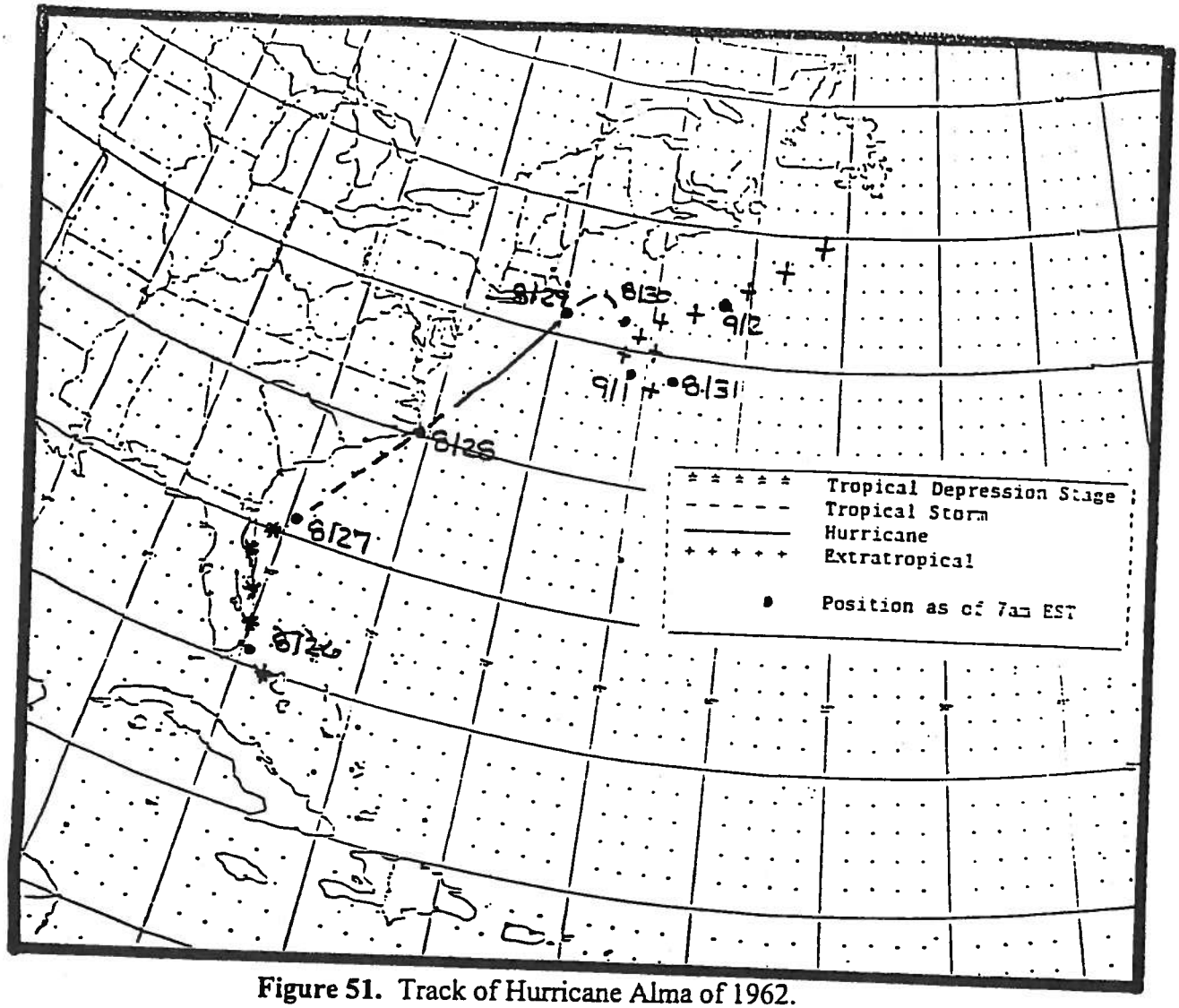

Figure 51. Track of Hurricane Alma of 1962.

HURRICANE DAISY
(CAT 1 - October 7, 1962)

Hurricane Daisy developed north of the Virgin Islands on October 1 (Figure 52). The system continued to intensify as it recurved northward, passing west of Bermuda and making landfall over southwest Nova Scotia on October 7. Though the center of the storm passed about 175 miles east of Cape Cod, its large circulation spread gusty winds and heavy rains across all of eastern New England.

Sustained winds of 25 to 40 mph buffeted coastal Rhode Island and Massachusetts, 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 heavy rainfall which accompanied her passage.

Rainfall of 4 to 8 inches fell across all of the eastern half of southern New England. Extremely heavy amounts over 8 to as much of 14 inches fell from northeast Rhode Island northward across all of northeast Massachusetts. The highest amounts of rainfall were reported in Middlesex and Essex counties of northeast Massachusetts; Wakefield reported a record 14.25 inches (Figure 53). Daisy's rains, combined with heavy rains from a coastal storm on October 5 and 6, produced serious flooding. Rivers and streams ran out of their banks across much of northeast Rhode Island and northeast Massachusetts. Damage to roads and bridges along the rivers was reported in some locations.

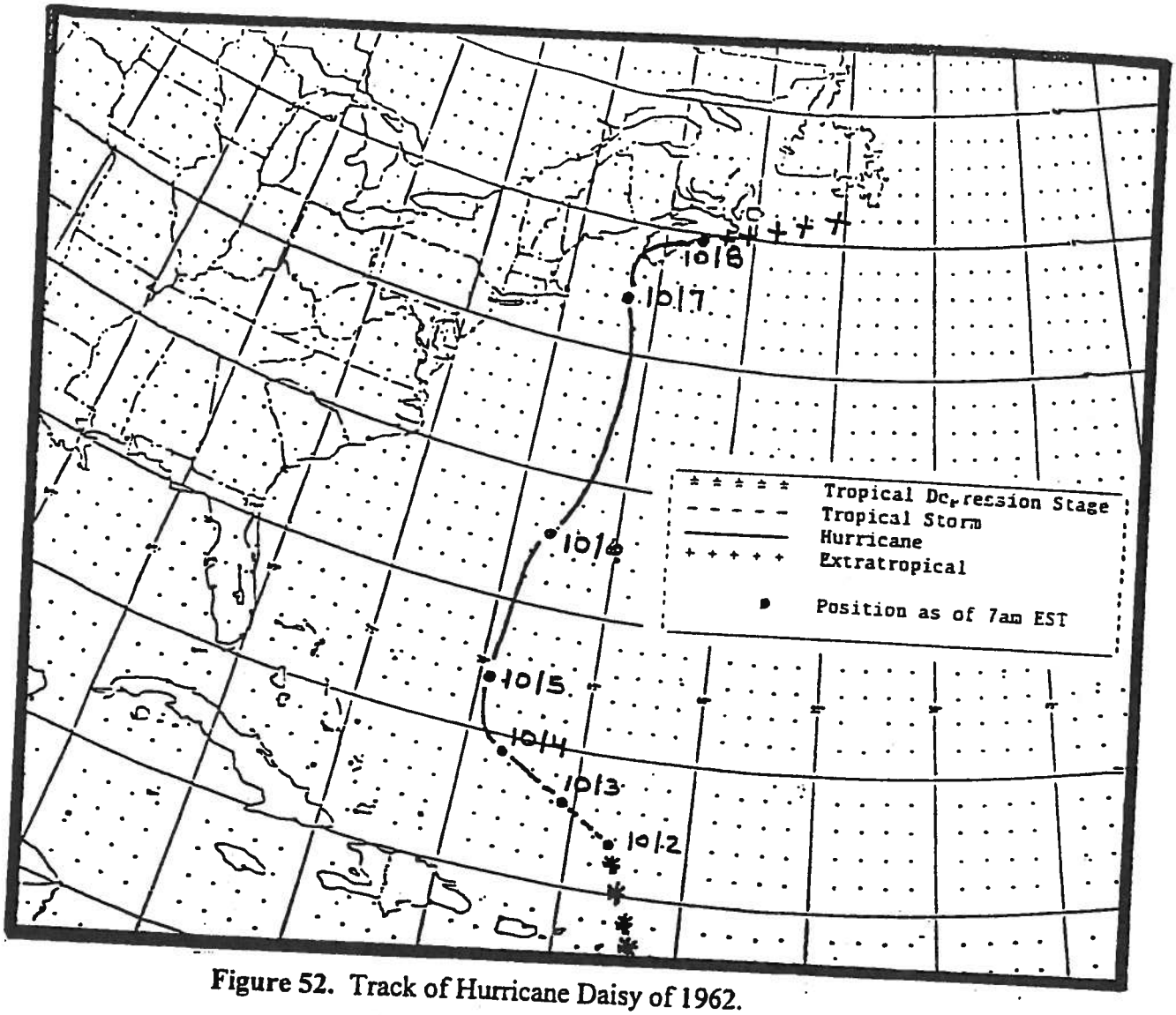

Figure 52. Track of Hurricane Daisy of 1962.

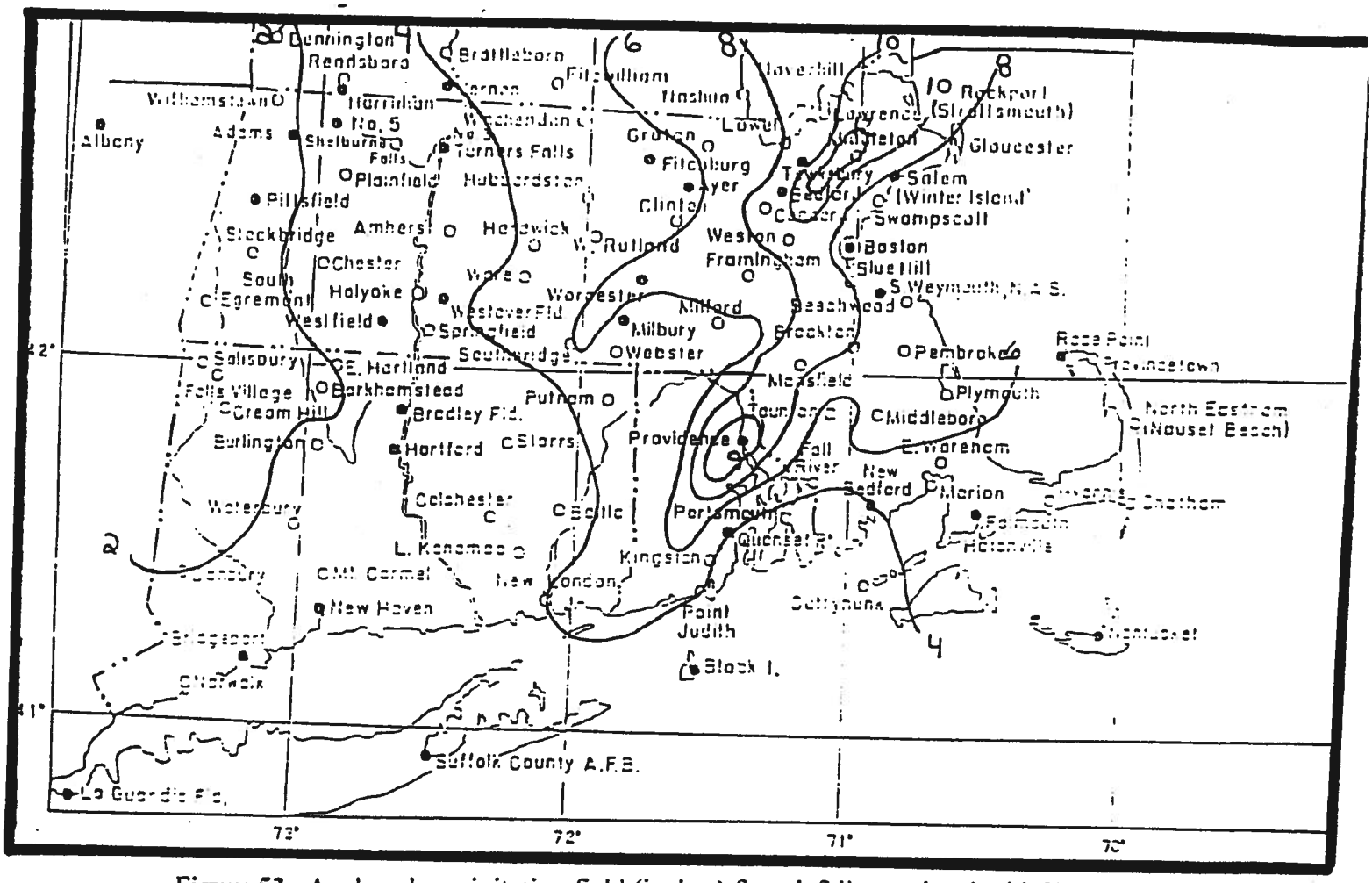

Figure 53. Analyzed precipitation field (inches) for rainfall associated with Hurricane Daisy.

HURRICANE GINNY
(CAT 2 - October 29, 1963)

Hurricane Ginny was a late season storm, which developed north of Haiti on October 16 (Figure 54). 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 warnings were issued from New Haven, Connecticut to Provincetown, Massachusetts at 10 pm September 28. Hurricane Ginny passed approximately 125 miles southeast of Cape Cod on the morning of October 29.

This storm spared southern New England from its hurricane force winds. Sustained winds of 30 to 40 mph were common across Rhode Island and eastern Massachusetts. Little effect was felt elsewhere. A peak gust to 65 mph was recorded on Nantucket Island, with a peak gust to 55 mph on Block Island.

Rainfall of 1 to 2 inches fell across eastern Rhode Island and eastern Massachusetts, with less than .75 inches elsewhere.

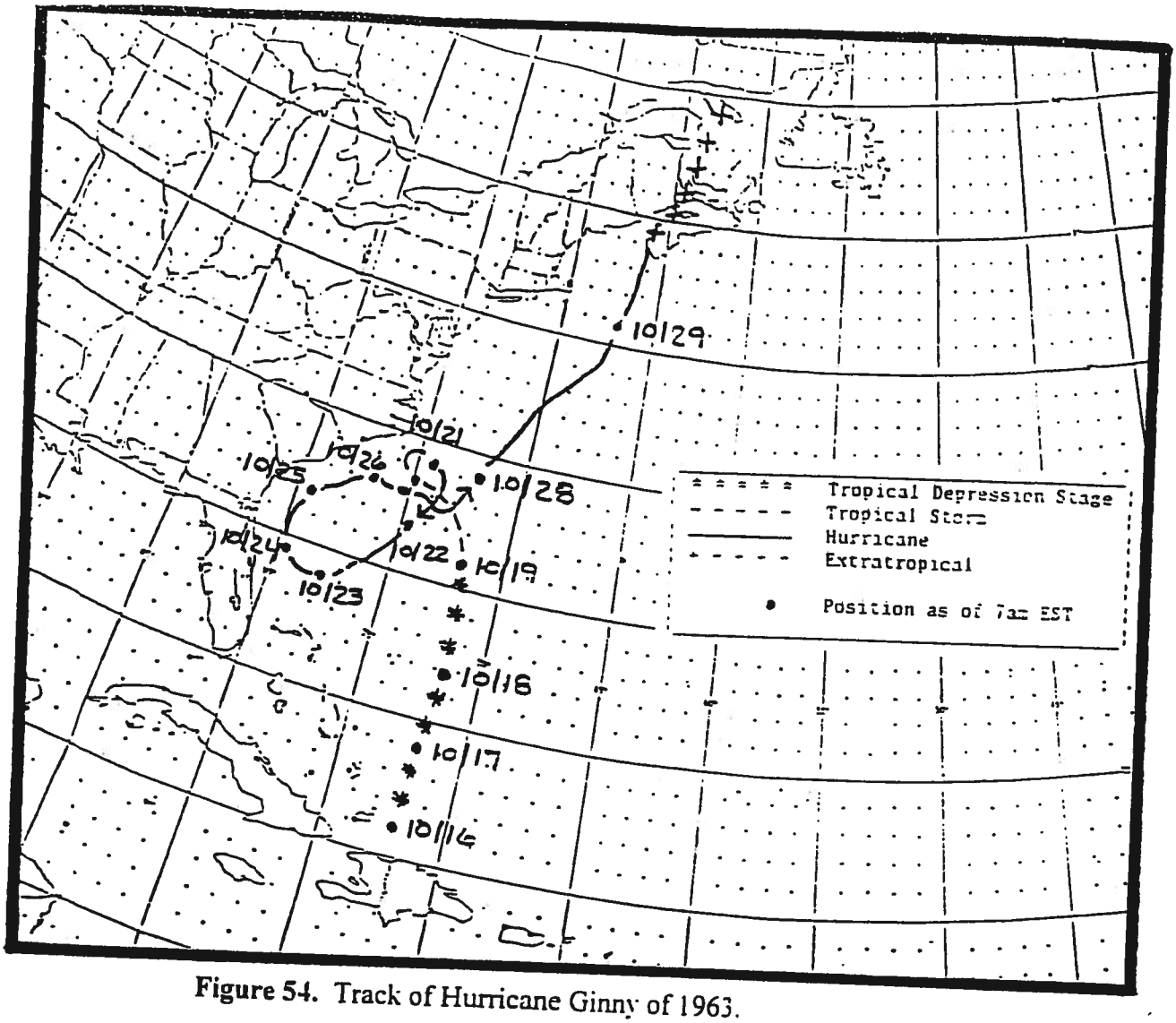

Figure 54. Track of Hurricane Ginny of 1963.

HURRICANE GERDA
(CAT 3 - September 8-9, 1969)

Hurricane Gerda developed east of Jacksonville, Florida on the evening of September 7, then rapidly intensified to hurricane strength twelve hours later (Figure 55). Gerda rapidly accelerated to the northeast and passed about 50 miles southeast of Cape Cod around noon September 9, moving at nearly 50 mph.

Gerda's track to the southeast of the region 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 inland, with the strongest winds of 40 to 60 mph confined to Cape Cod and the Islands. Some tree and power line damage did occur on Cape Cod, along with minor damage to marinas.

Gerda produced 1 to 3 inches of rain throughout southern New England, with as much of 4 inches over sections of Cape Cod, Nantucket Island, and northeast Massachusetts.

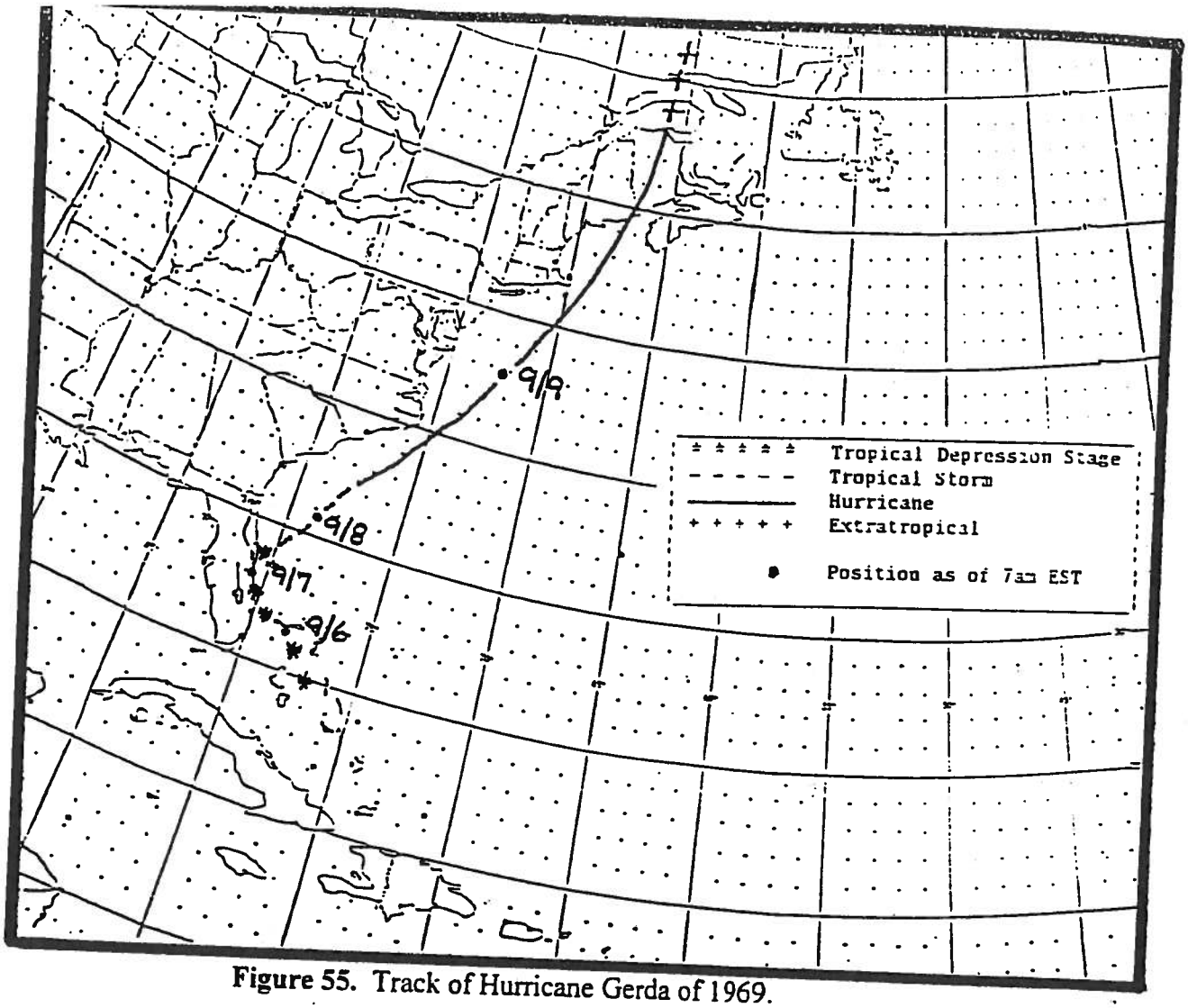

Figure 55. Track of Hurricane Gerda of 1969.

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 56). The center stayed inland, once it made initial landfall along the coast of North Carolina during the morning of August 27. Hurricane watches were posted for the south coast during the evening of August 27, but were later discontinued the morning of August 28. The center passed over New York City on August 28, then continued northeastward across western Connecticut and Massachusetts before becoming extratropical as it moved into northern Maine.

Doria was accompanied by gusty southeast winds of 35 to 60 mph throughout the region. Peak wind gusts included the Blue Hill Observatory, in Milton, Massachusetts with 87 mph and the National Weather Service Office in Hartford, Connecticut with a gust to 75 mph. Scattered tree damage and power outages were reported, along with some damage to the apple and peach orchards, where an estimated 10 to 15 percent of the crop was destroyed.

Strong southeast winds also helped to drive tides 2 to 4 feet above normal along the south coast, and up to 6 feet above normal over the upper parts of Narragansett and Buzzards Bays. Some minor coastal flooding occurred, but damage was minimal.

Rainfall in Doria was heaviest in western most Massachusetts and Connecticut where 4 to 6 inches was common. Two to 4 inches fell elsewhere in Connecticut and central Massachusetts, with 1 inch or less over Rhode Island and eastern Massachusetts.

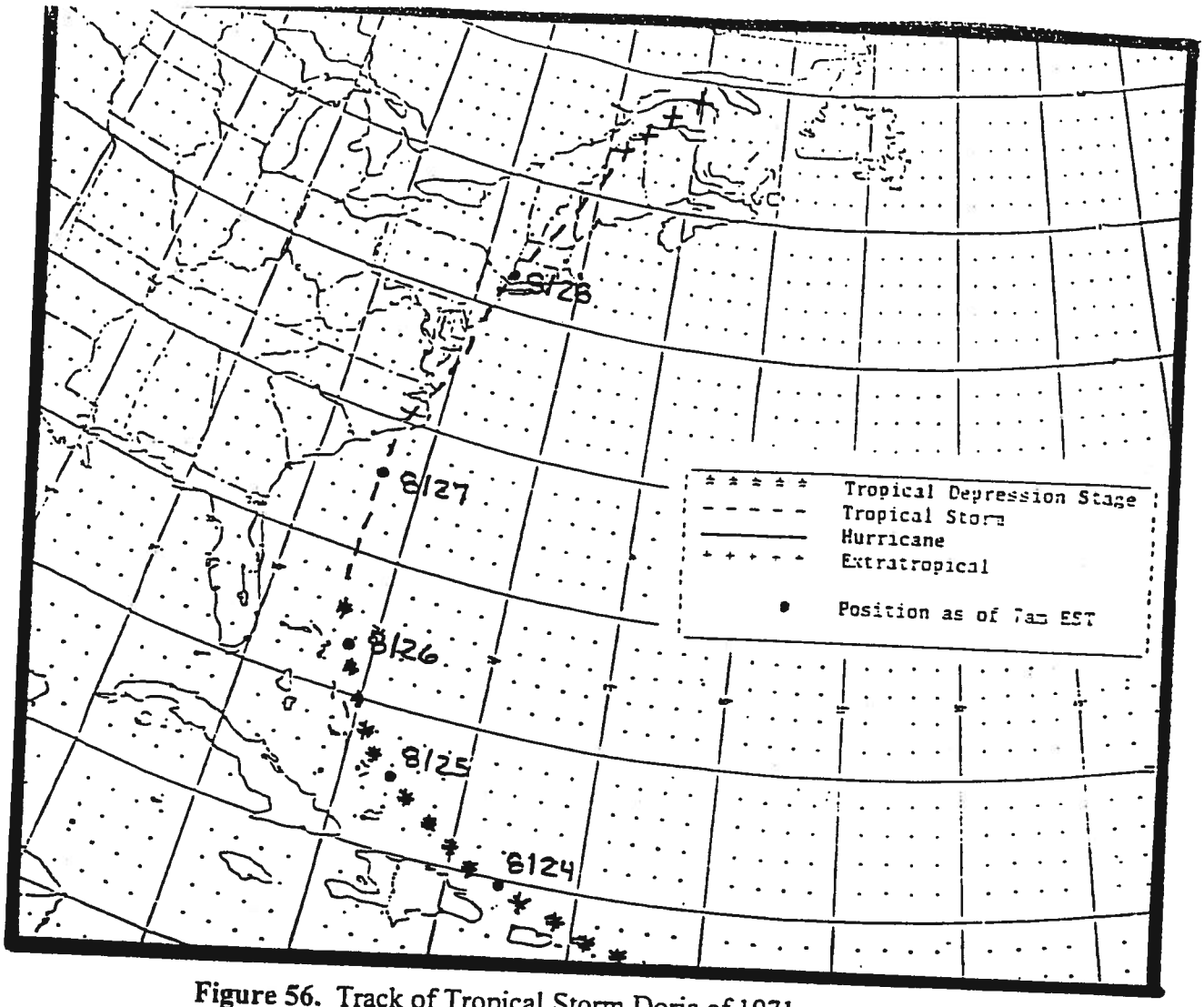

Figure 56. Track of Tropical Storm Doria of 1971.

TROPICAL STORM HEIDI
(September 14, 1971)

Tropical Storm Heidi developed about 600 miles east of the Florida shore on September 11 (Figure 57). The system progressed steadily northward, passing about 60 miles east of Cape Cod on the morning of September 14. The tropical storm kept her strongest winds at sea, but did produce beneficial rains over southern New England.

Sustained winds during Heidi never exceeded 30 mph in the region. Rainfall ranged from 1 to 3 inches across the area, with isolated 4 to 5 inch amounts along parts of the Connecticut coast.

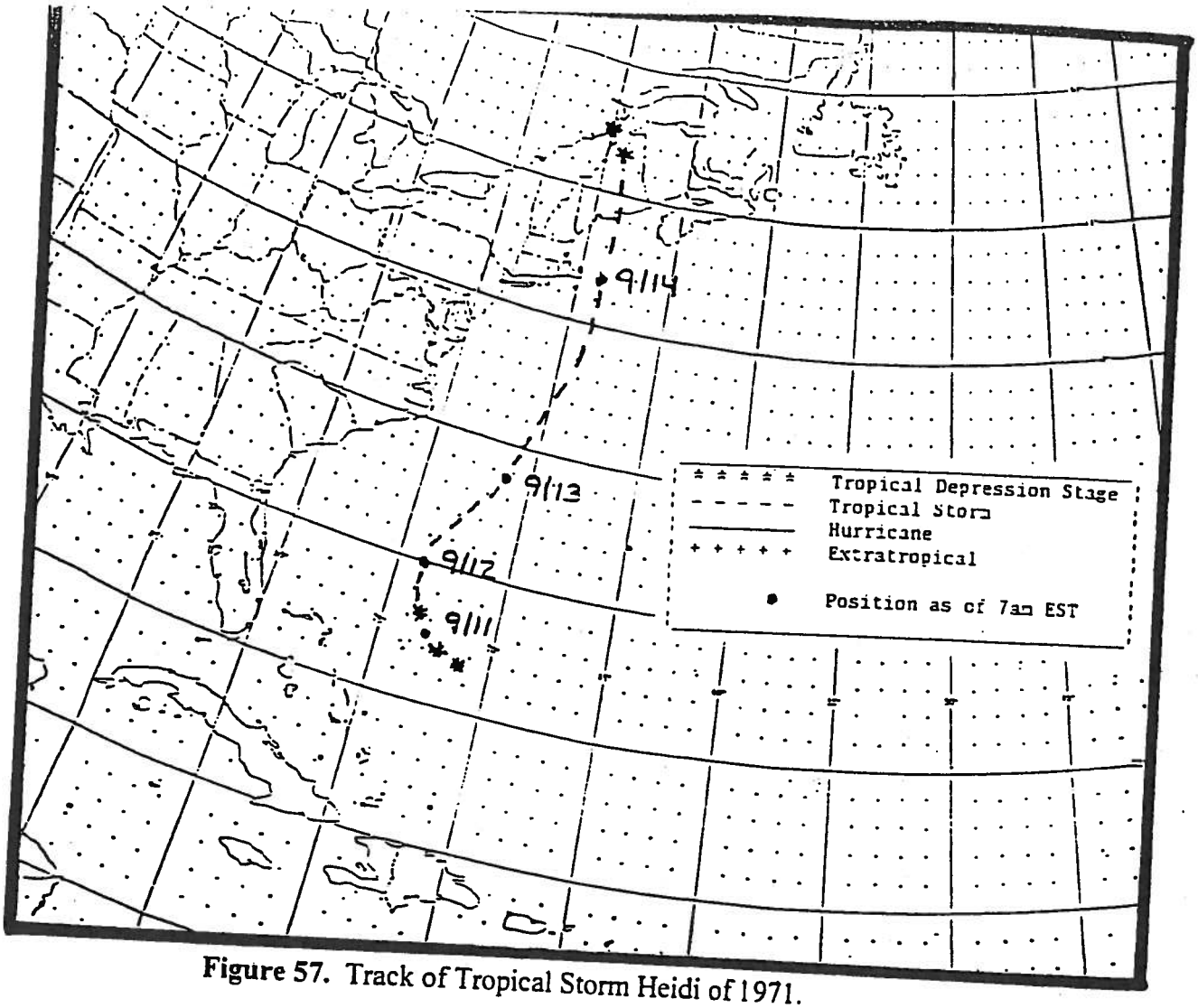

Figure 57. Track of Tropical Storm Heidi of 1971.

TROPICAL STORM AGNES
(June 22, 1972)

Tropical Storm Agnes, the third system to have origins in the Gulf of Mexico, developed southwest of Cuba June 16th and made landfall as an intense hurricane over the Florida panhandle June 19th. Agnes weakened rapidly to a depression after making landfall (Figure 58). The system turned northeastward on June 20, passing across Georgia and the Carolinas. Agnes 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 produced strong southeast winds of 40 to 60 mph along the south coast. A peak gust to 71 mph was reported at Chatham, Massachusetts on the eastern tip of Cape Cod.

Agnes did produce 1 to 3 inches of rain across all of southern New England, which for areas along the Connecticut River and across Cape Cod, was enough to produce localized small stream and urban flooding. A frontal system had affected southern New England during September 18 through 20. The combined rainfall from Agnes and the frontal system ranged from 4 to 6 inches across parts of western Connecticut and Massachusetts, as well as Cape Cod.

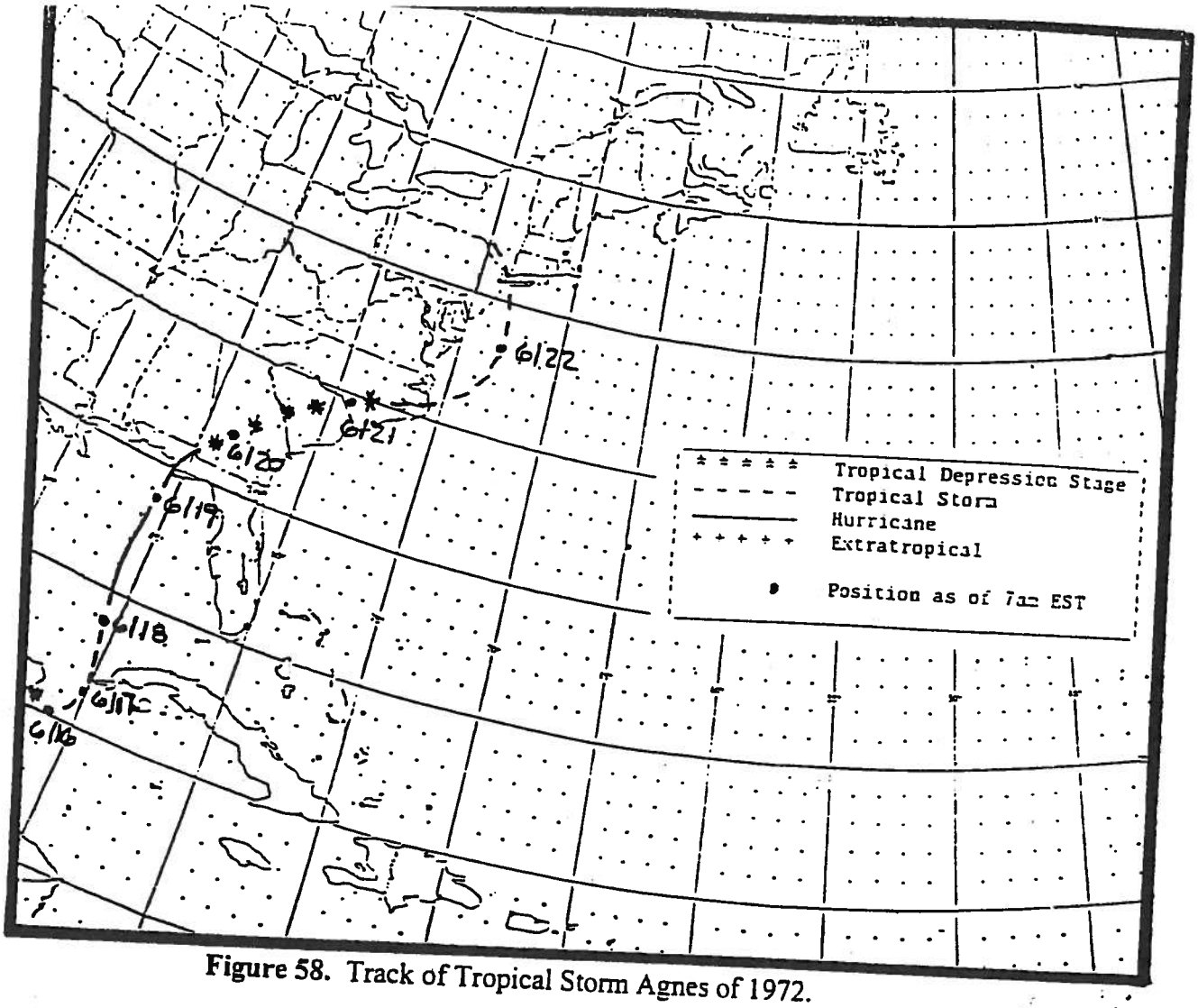

Figure 58. Track of Tropical Storm Agnes of 1972.

TROPICAL STORM CARRIE
(September 3, 1972)

Tropical Storm Carrie developed just east of Jacksonville, Florida on August 29 (Figure 59). 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 and remained a strong tropical storm as it skirted the east shore of Nantucket Island and outer Cape Cod on September 3, before losing tropical characteristics.

Carrie produced gusty winds of 30 to 50 mph across much of inland Rhode Island and eastern Massachusetts, with gusts of 80 to 100 mph along the immediate south coast. Lighter winds were felt across Connecticut and western Massachusetts. Peak wind gusts included 100 mph at Chatham, Massachusetts and 85 mph at the Coast Guard Station at Pt. Judith, Rhode Island.

Of even greater significance was the localized torrential rains which drenched Cape Cod and parts of east coastal Massachusetts. Rainfall of 6 to 12 inches occurred over all of Cape Cod, extending as far north as Plymouth, Massachusetts. Martha's Vineyard Island received a record breaking 12.5 inches (Figure 60). Basement flooding along with small stream and urban flooding was reported throughout Cape Cod and the Islands. Far lesser amounts of rain occurred over the remainder of southern New England. As little as a trace fell in northwest Connecticut and western Massachusetts to between 2 and 4 inches from southeast Connecticut to northeastern Massachusetts.

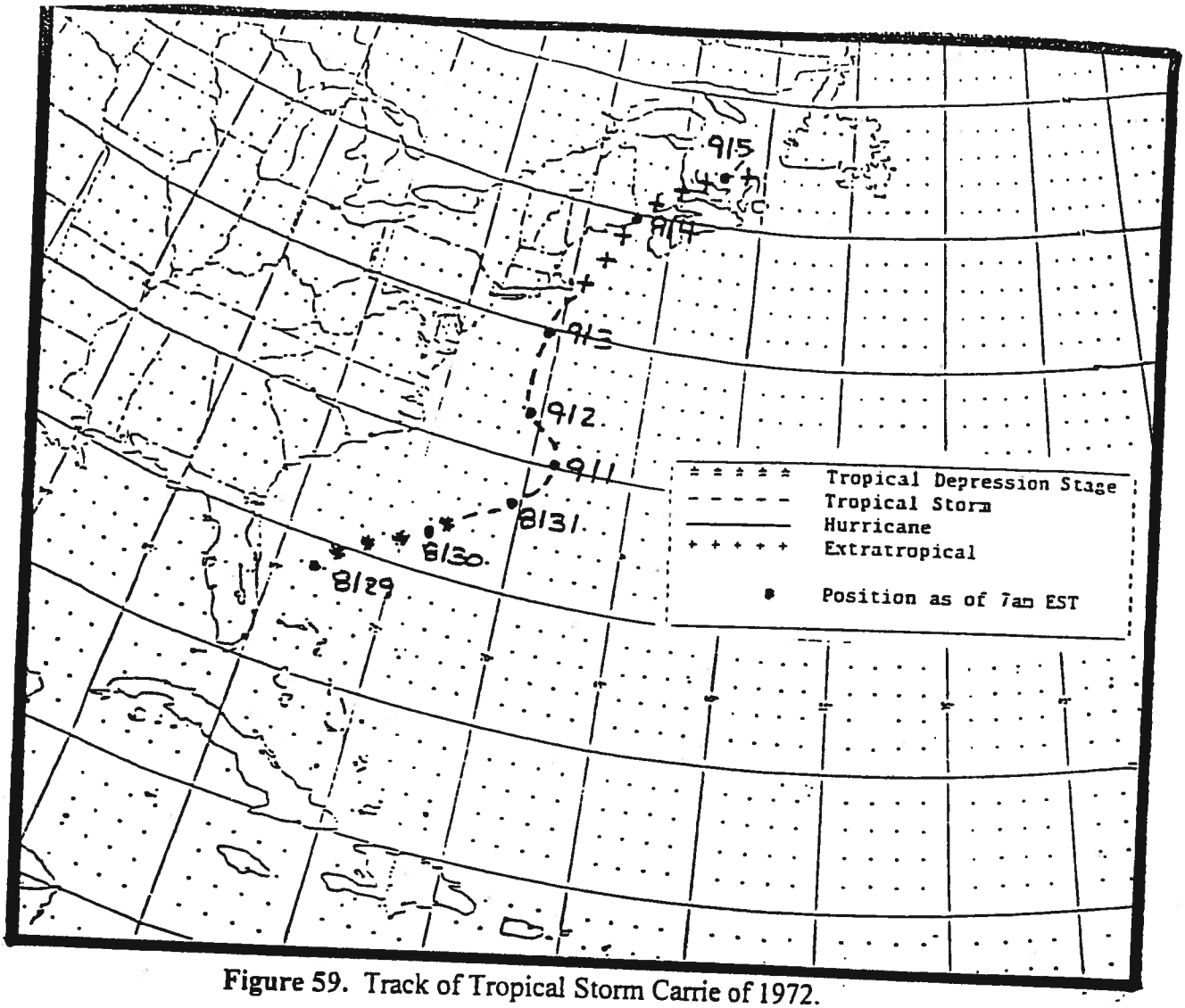

Figure 59. Track of Tropical Storm Carrie of 1972.

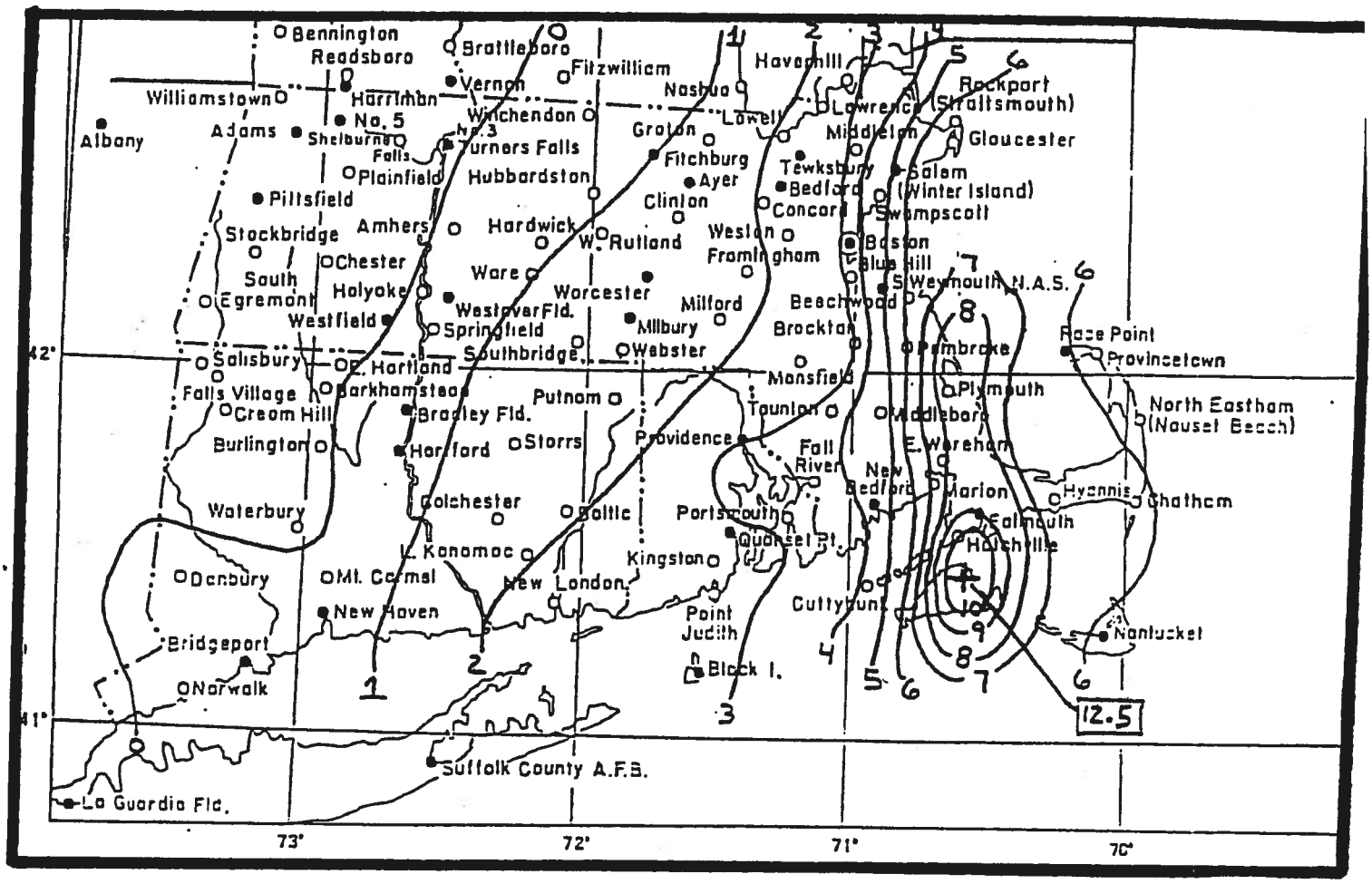

Figure 60. Analyzed precipitation field (inches) for rainfall associated with Tropical Storm Carrie.

HURRICANE BELLE
(**CAT 1** - August 9-10, 1976)

Belle developed approximately 300 miles east of Vero Beach, Florida on August 6, intensifying to hurricane strength a day later (Figure 61). Belle proceeded to head slowly 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 near New Haven. Belle dissipated as it moved into southern Quebec.

Belle was accompanied by strong southeast winds of 40 to 60 mph with peak gusts to hurricane force through parts of Connecticut. The peak wind gust was 81 mph recorded in Bridgeport, Connecticut. Sustained winds of 70 mph were recorded at the Blue Hill Observatory, in Milton, Massachusetts.

Trees and power lines were downed across much of Connecticut and Rhode Island, and to a lesser extent across Massachusetts. The lowest pressure, at time of landfall, was 29.05 inches at Fire Island Coast Guard Station on Long Island. Bridgeport, Connecticut reported 29.17 inches.

Belle brought a storm surge of 3 to 4 feet across the Connecticut and Rhode Island shores. This resulted in some coastal flooding with scattered reports of mostly minor damage to boats and marinas. The hardest hit area was the southwest coast of Connecticut, where several marinas were badly damaged.

Rainfall ranged from 2 to 4 inches over most of the region, but generally 1 inch or less was reported across eastern Massachusetts. Parts of Rhode Island and Connecticut received some urban and small stream flooding. This was the result of both Belle's rainfall and rainfall from a frontal system on August 7 and 8. Total 3 day rainfall from August 7 through 9 exceeded 5 inches across parts of Connecticut and Rhode Island.

Belle was responsible for one death in southern New England.

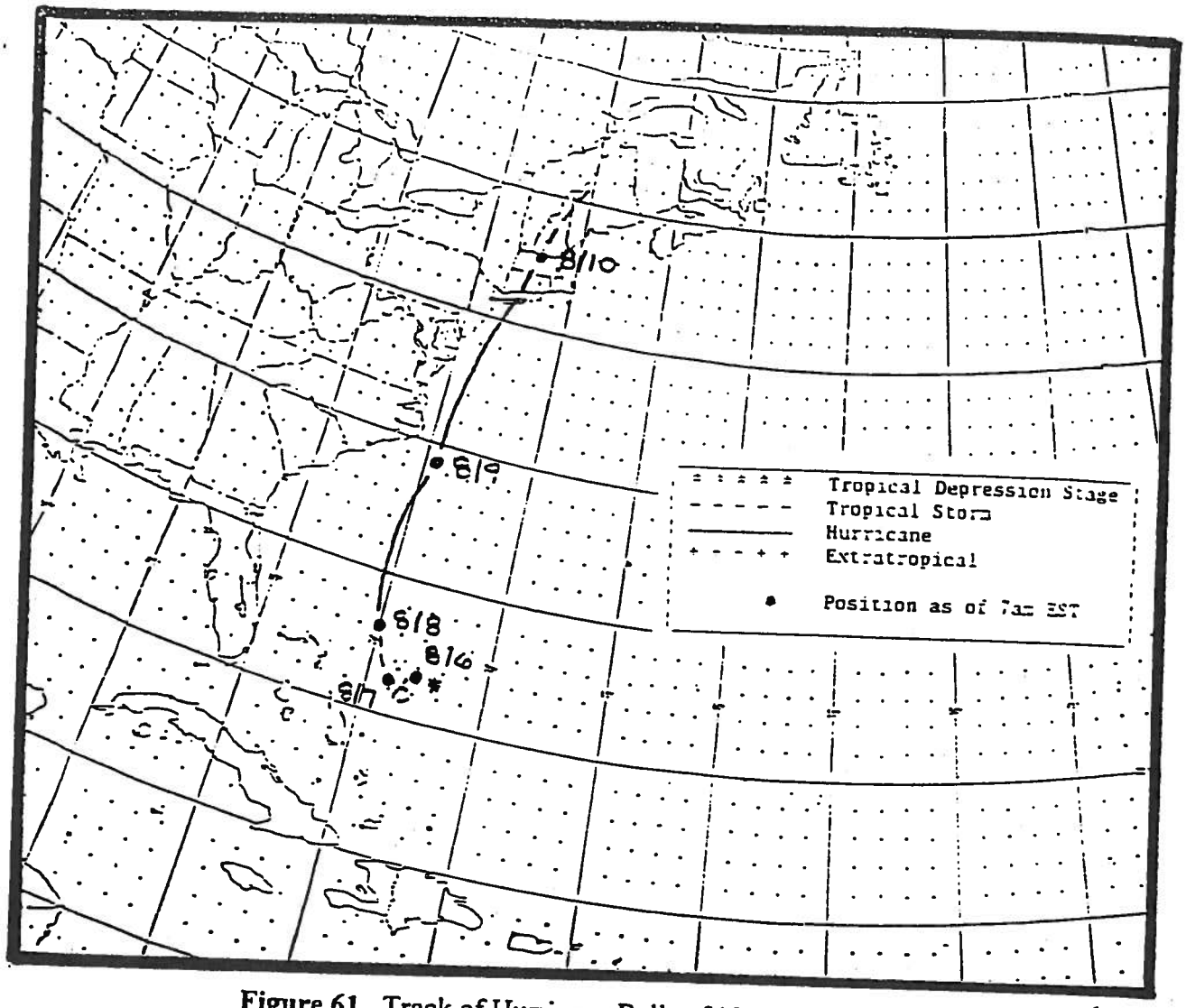

Figure 61. Track of Hurricane Belle of 1976.

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 62). 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 near Horseneck Beach later that night.

Henri was a very weak tropical storm by the time it reached southern New England. Sustained winds were only 20 to 30 mph with a few higher gusts confined to Martha's Vineyard and Nantucket Islands. Rainfall was generally around .25 to .50 inch across Rhode Island and eastern Massachusetts, with .10 inch or less elsewhere.

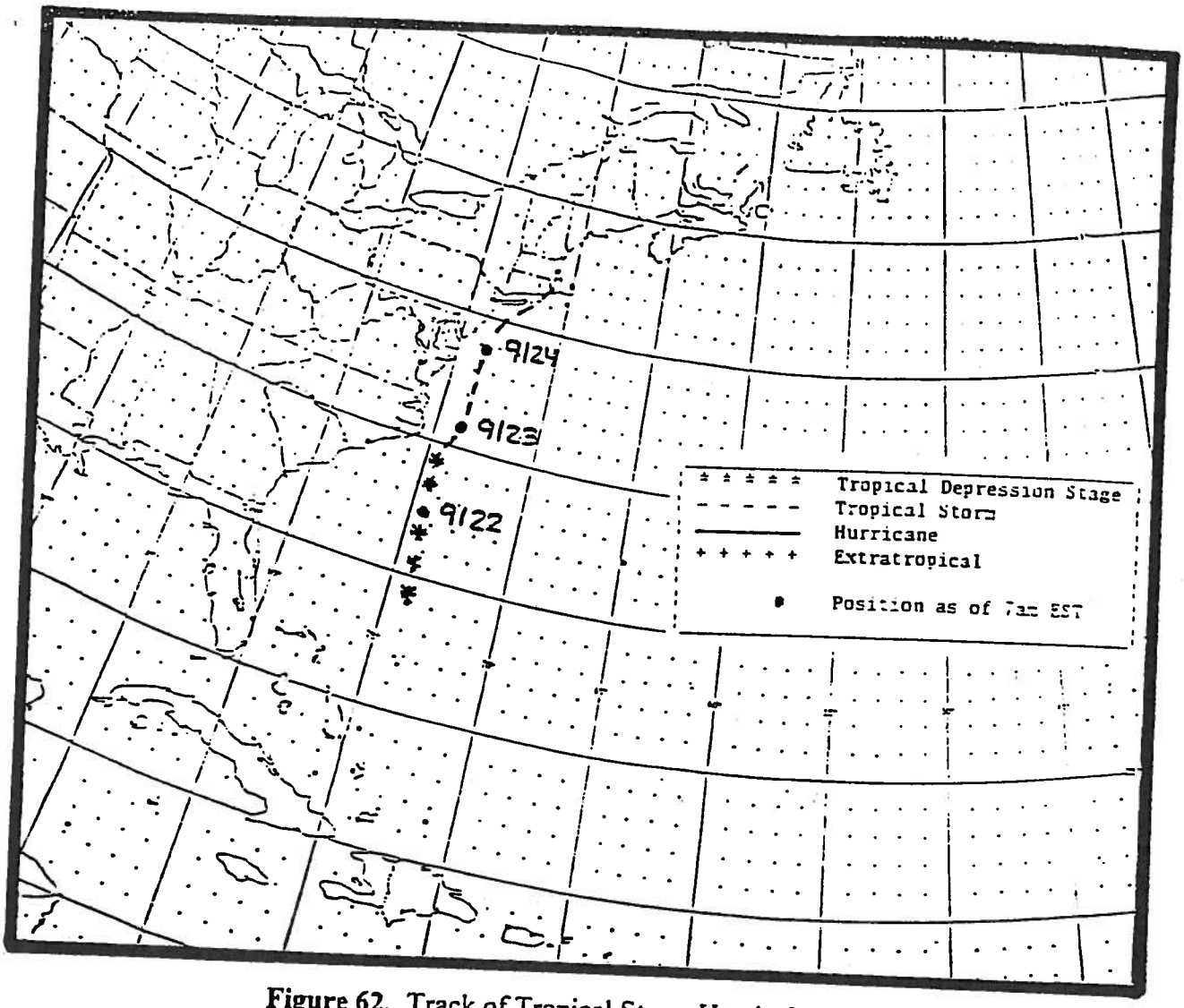

Figure 62. Track of Tropical Storm Henri of 1985.

HURRICANE GLORIA
(CAT 2 - September 27, 1985)

Hurricane Gloria developed into one of the more intense hurricanes ever in the Atlantic. Gloria developed in the far eastern Atlantic on September 17 and made a nine day journey west-northwestward toward the Eastern Seaboard, reaching Cape Hatteras during the evening of September 26 (Figure 63). Gloria accelerated northward during the following 24 hours, with the center moving right along the eastern seaboard. The hurricane made final landfall on Long Island the afternoon of September 27, moving at 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, due to the storm's center moving so close to the shore. The center moved onto the Connecticut shore near Bridgeport and continued rapidly northeastward, becoming extratropical is it moved into Maine.

Sustained hurricane force winds were confined to the immediate south coast of southern New England. Gusts exceeding hurricane force were common throughout the region. Peak wind gusts included 120 mph at Newport, Rhode Island, 109 mph at Chatham, Massachusetts, and a gust to 92 mph in Bridgeport, Connecticut. Trees and power lines were blown down throughout much of the region. Nearly 2 million residents in southern New England lost power during the storm. Some sections had power disrupted for up to 3 weeks. Repair crews from as far away as Quebec were called in to help with cleanup efforts. Crops were badly damaged including apple and peach orchards as well as corn crops.

Approximately 40,000 residents in southern New England were evacuated in preparation for the potentially deadly storm surge. Hurricane Gloria brought a storm surge of 7 to 9 feet onto the south coast of southern New England. The damage, however, was far less than what could have occurred because the storm arrived near low tide, sparing much of the coastal communities from extreme storm tides (Figure 64). Damage was heaviest to the marine industry. Thousands of boats across southern New England were torn from their moorings, while others were tossed into one another in marinas.

Gloria dumped its heaviest rainfall in extreme western Connecticut and Massachusetts where 4 to 6 inches occurred. Rainfall diminished rapidly to the east with less than .50 inch across Rhode Island and eastern Massachusetts (Figure 65).

Gloria was responsible for four deaths in southern New England. Three were the result of trees blown down, the other from a capsized boat.

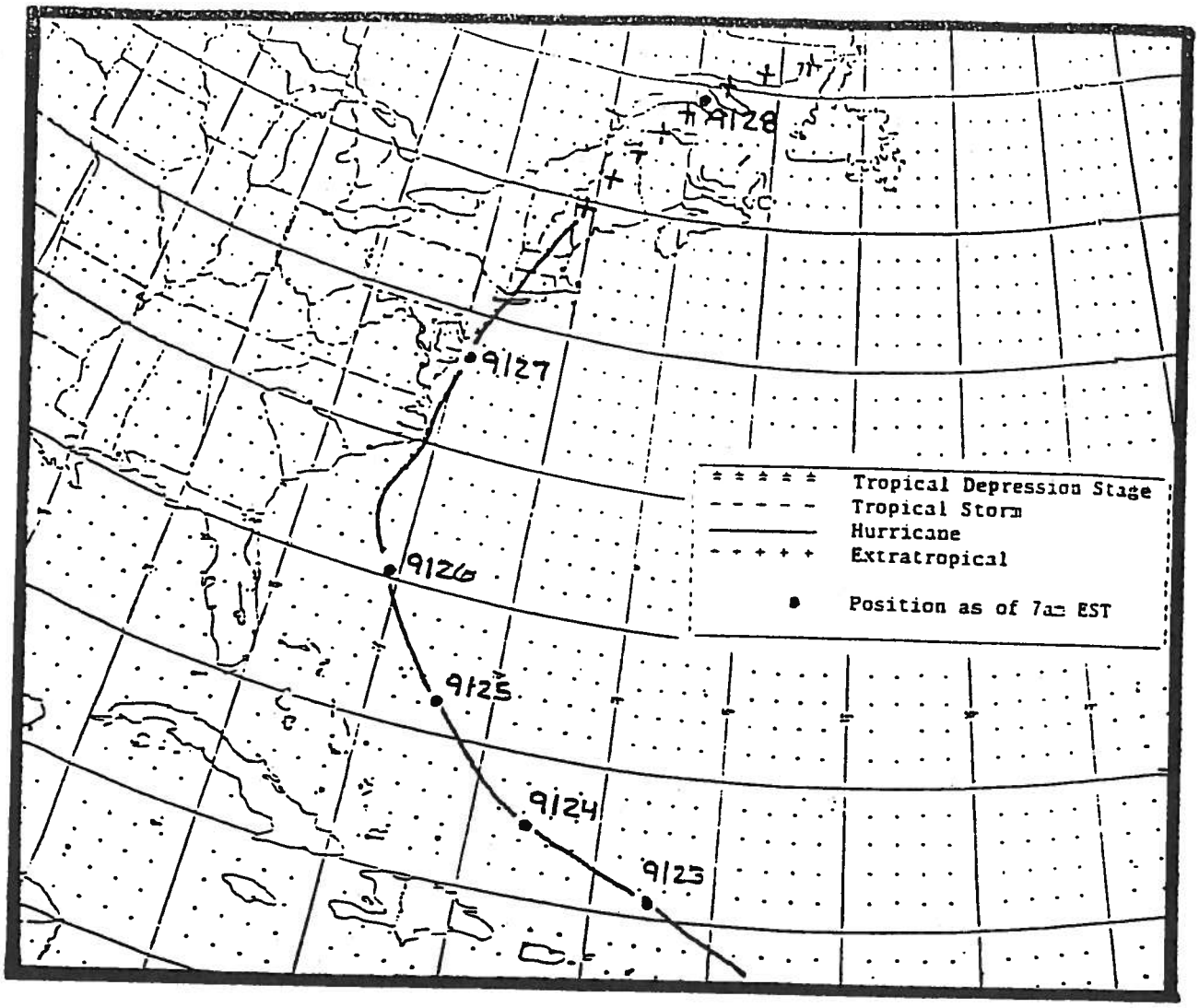

Figure 63. Track of Hurricane Gloria of 1985.

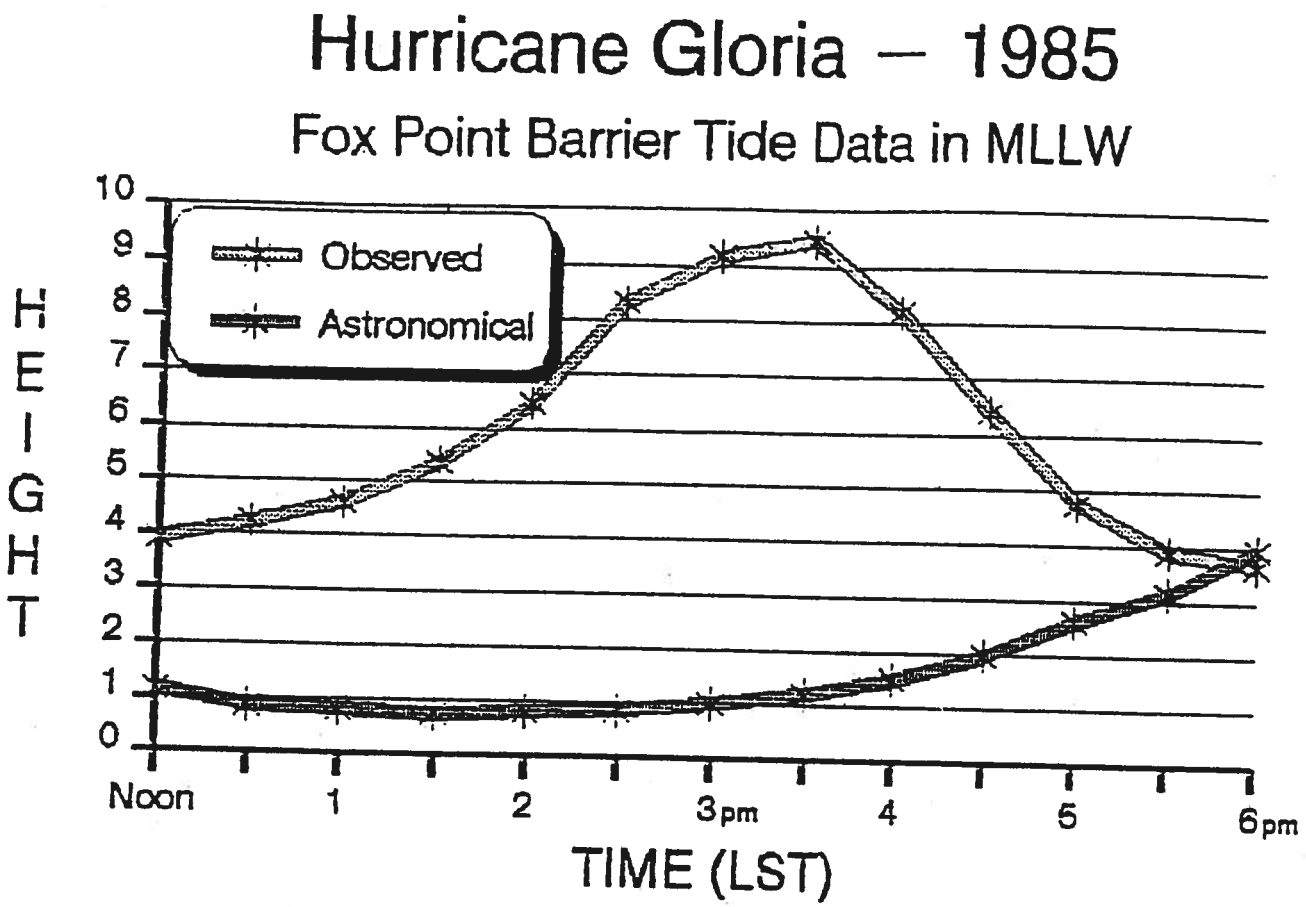

Figure 64. Storm surge height (feet) on September 27, 1985, associated with Hurricane Gloria, recorded at the Fox Point Hurricane Barrier on upper Narragansett Bay.

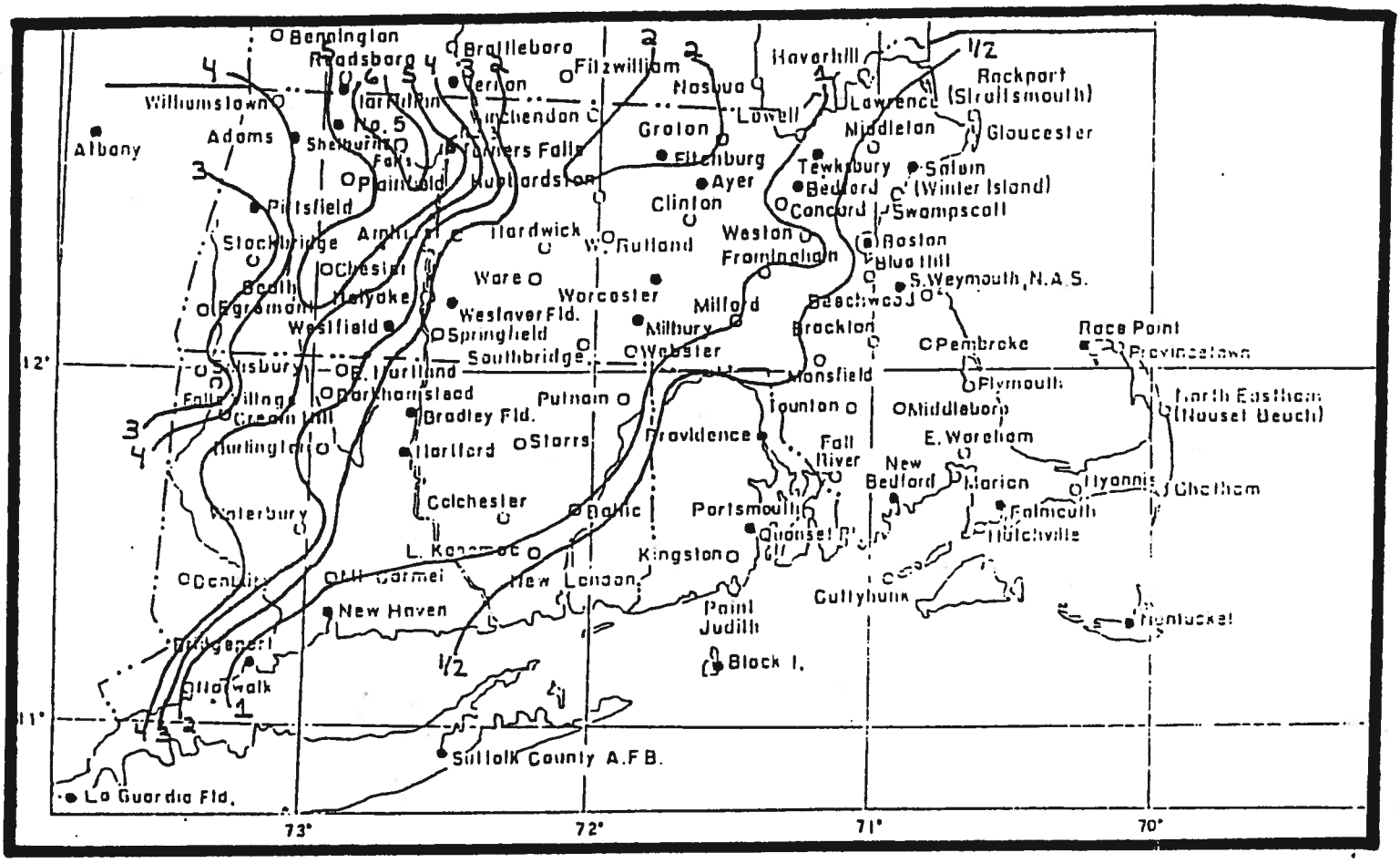

Figure 65. Analyzed precipitation field (inches) for rainfall associated with Hurricane Gloria.

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 66). 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, Rhode Island at approximately 1:30 PM, and made landfall over Newport, Rhode Island shortly before 2 PM.

Hurricane Bob brought sustained hurricane force winds to the immediate coastal communities of Rhode Island and most of southeast Massachusetts. Strong tropical storm force winds blew across the remainder of the region, with many areas receiving gusts to hurricane force east of the Connecticut River. 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 and southeast Massachusetts lost power. Damage was also extensive to apple and peach orchards across these areas.

Coastal communities bore the brunt of the storm, with sustained winds between 75 to 100 mph. Peak wind gusts to 125 mph were recorded on Cape Cod in the towns of Brewster and North Truro, as well as in Wethersfield, Connecticut. The highest sustained wind of 100 mph, was recorded in North Truro. 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, Rhode Island. Additionally, there were four reports of tornadoes as Bob came ashore. 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 surge of 5 to 8 feet along the Rhode Island shore, but drove a surge of 10 to 15 feet into Buzzards Bay (Figure 67). The Buzzards Bay shore east to Cape Cod was hardest hit. The highest surges, of 12 to 15 feet, were observed in Onset, Bourne, Mashpee and Wareham, at the head of Buzzard's Bay. Cove Road, in Mattapoisett, Massachusetts had 29 of 37 homes destroyed, while Angelica Point, Massachusetts lost 32 of 35 homes along the shore. Boat damage was significant, as many boats were torn from their moorings. Extensive beach erosion occurred along the shore from Westerly, Rhode Island eastward. Some south facing beach locations on Martha's Vineyard and Nantucket Islands lost up to 50 feet of beach to erosion.

Significant rainfall of 3 to 6 inches fell across all but southeast Rhode Island and eastward to Cape Cod, where less than 1 inch fell. The heaviest rainfall of over 7 inches affected western Rhode Island and extreme eastern Connecticut. Foster, Rhode Island had the highest amount of rain with 7.01 inches (Figure 68).

Bob was responsible for six deaths in the region, all in Connecticut. Total damage in southern New England was approximately 680 million dollars.

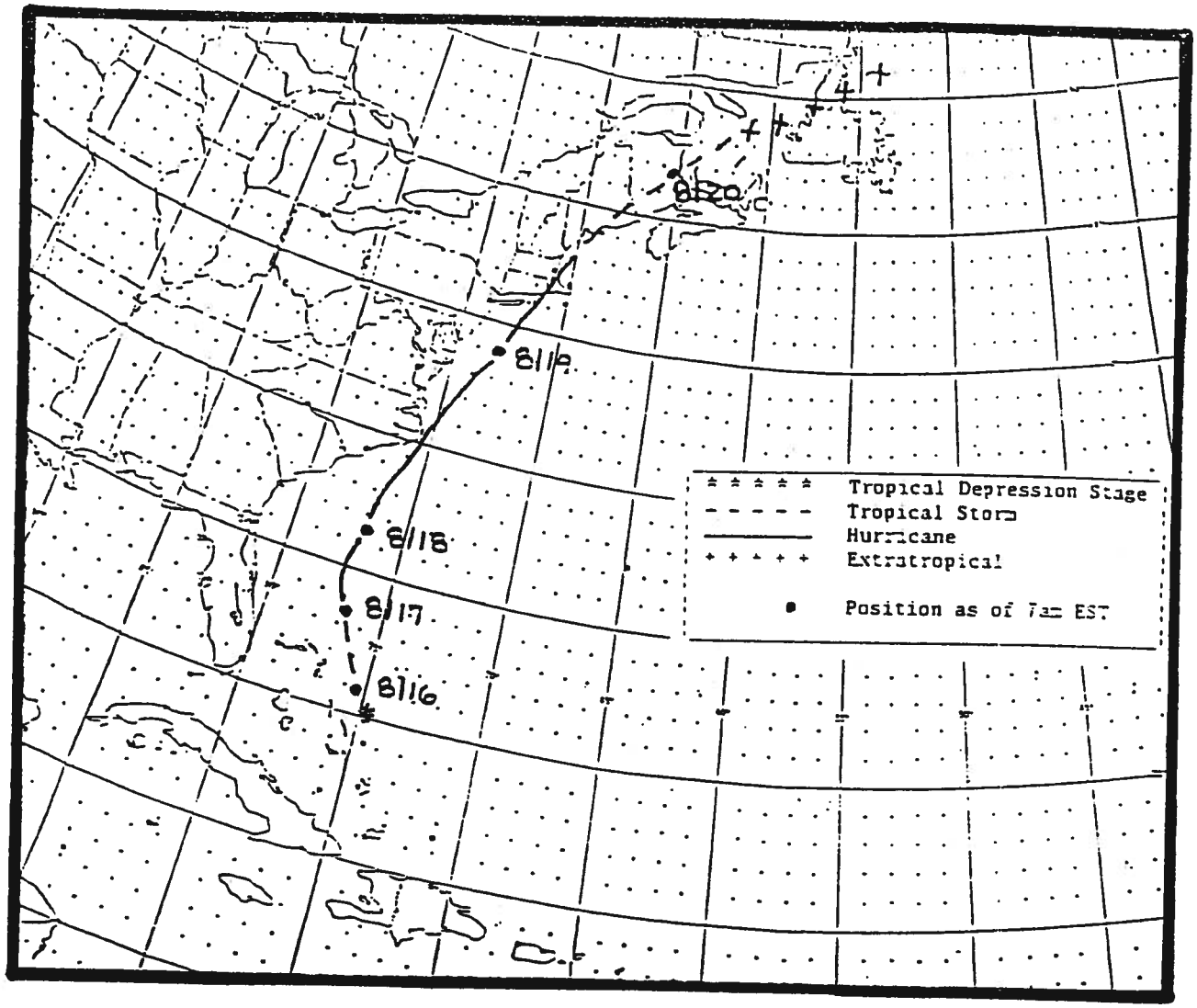

Figure 66. Track of Hurricane Bob of 1991.

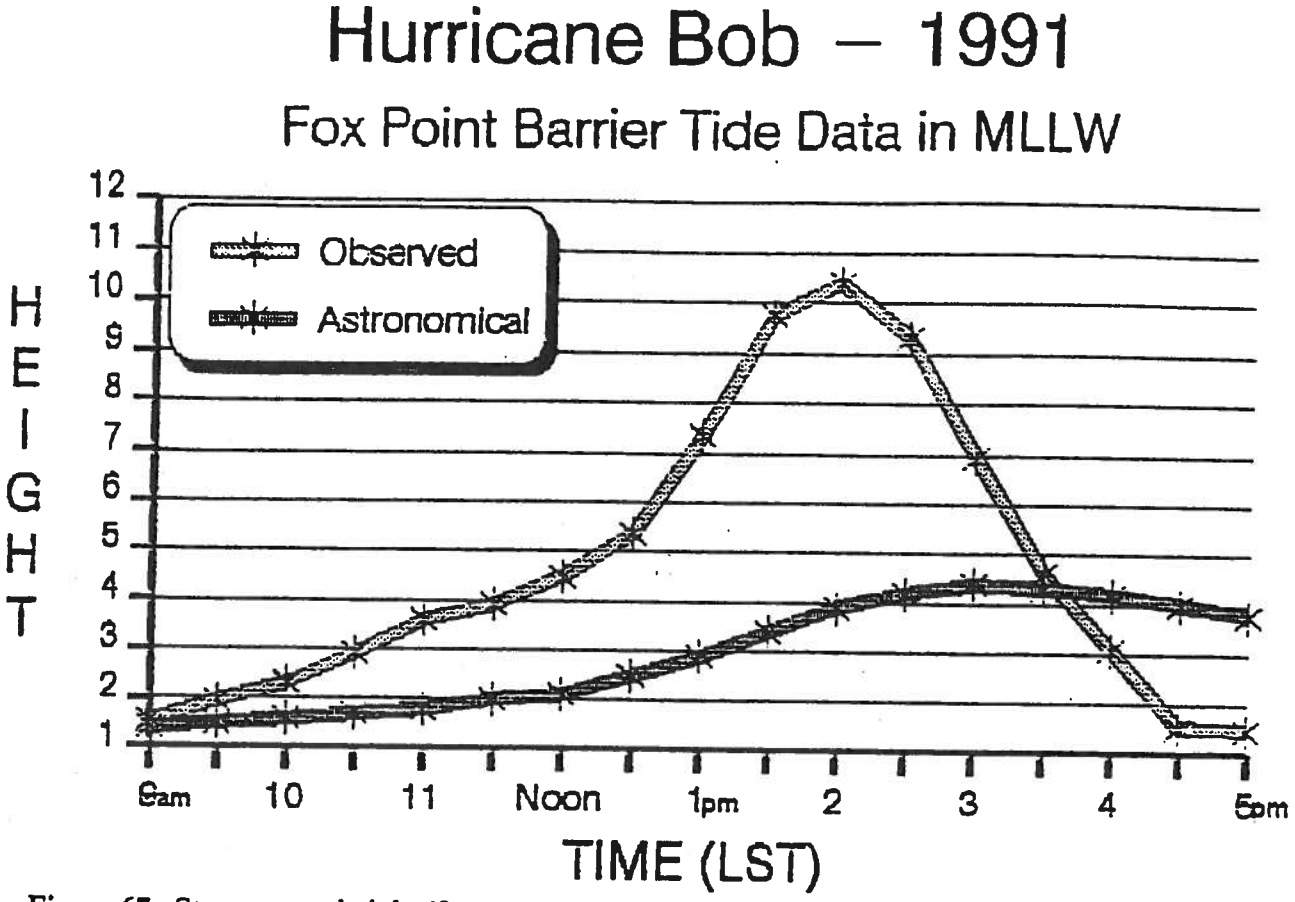

Figure 67. Storm surge height (feet) on August 19, 1991, associated with Hurricane Bob, recorded at the Fox Point Hurricane Barrier on upper Narragansett Bay.

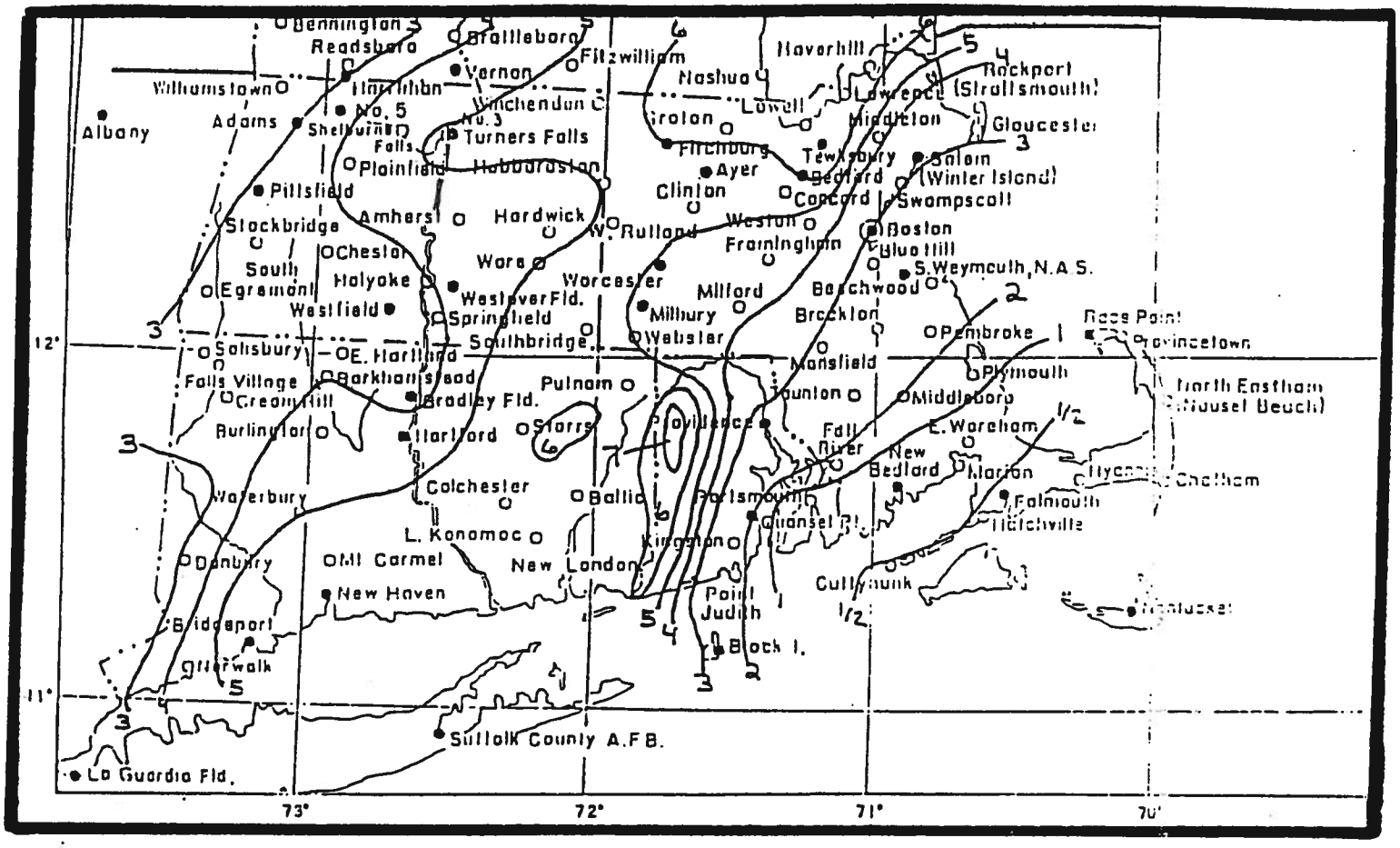

Figure 68. Analyzed precipitation field (inches) for rainfall associated with Hurricane Bob.

TROPICAL STORM BERTHA
(July 12-13, 1996)

Tropical Storm Bertha was just the 6th tropical cyclone since 1900 to impact New England prior to August 1st. Bertha formed 800 miles West-Southwest of the Cape Verde Islands on July 4, and moved north-northeast...becoming a hurricane in the late evening of July 7, about 500 miles east of the Lesser Antilles. Bertha made landfall near Wrightsville Beach, North Carolina late on July 12 as a category 2 hurricane (Figure 69). The storm then weakened to a tropical storm as it zipped northeast, passing across southern New England on July 13.

Bertha brought substantial rainfall to southern New England, with rainfall amounts averaging in the four inch range. Areas of 5 to just over 7 inches fell across the higher terrain of central and western Massachusetts, as well as across north central Massachusetts, where the maximum amount recorded was 7.2 inches in Billerica. Less than 1 inch of rain fell southeast of the Cape Cod canal (Figure 70).

Strong winds blasted sections of southeastern New England. Several locations reported gusts to hurricane force, with the highest gust of 88 mph reported at the New Bedford, Massachusetts Hurricane Barrier. There were numerous reports of downed tree limbs and power lines, as well as short-lived power outages. Coastal flooding was minor, with a storm surge of 2 to 4 feet reported in many south coastal locations. Beach erosion was reported as minor.

Some small stream flooding occurred across western Massachusetts, along with a small river rising above flood stage in north central Connecticut. There was also street flooding across much of Rhode Island and central Massachusetts.

There were no reports of deaths or injuries as a result of Bertha.

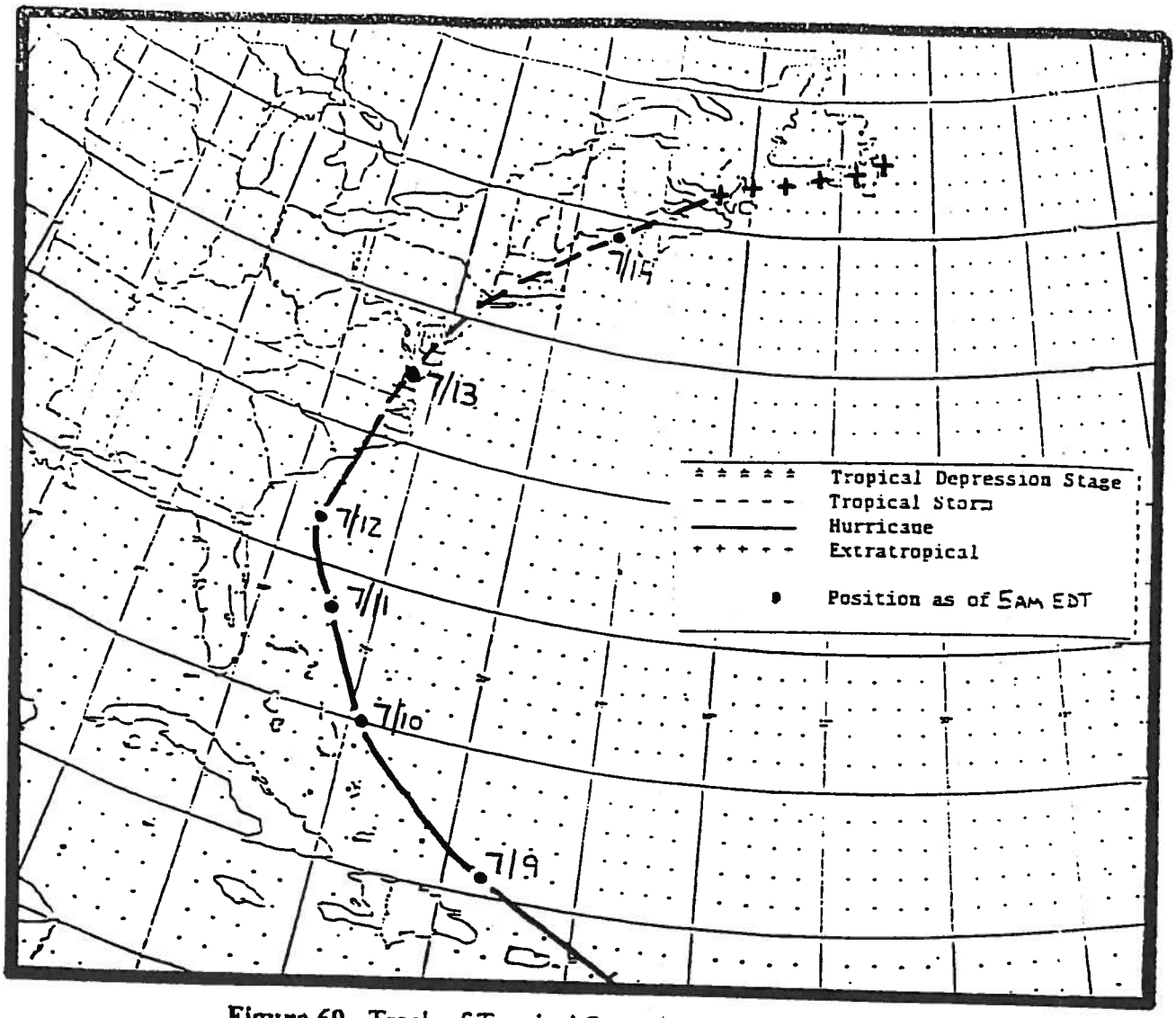

Figure 69. Track of Tropical Storm Bertha of 1996.

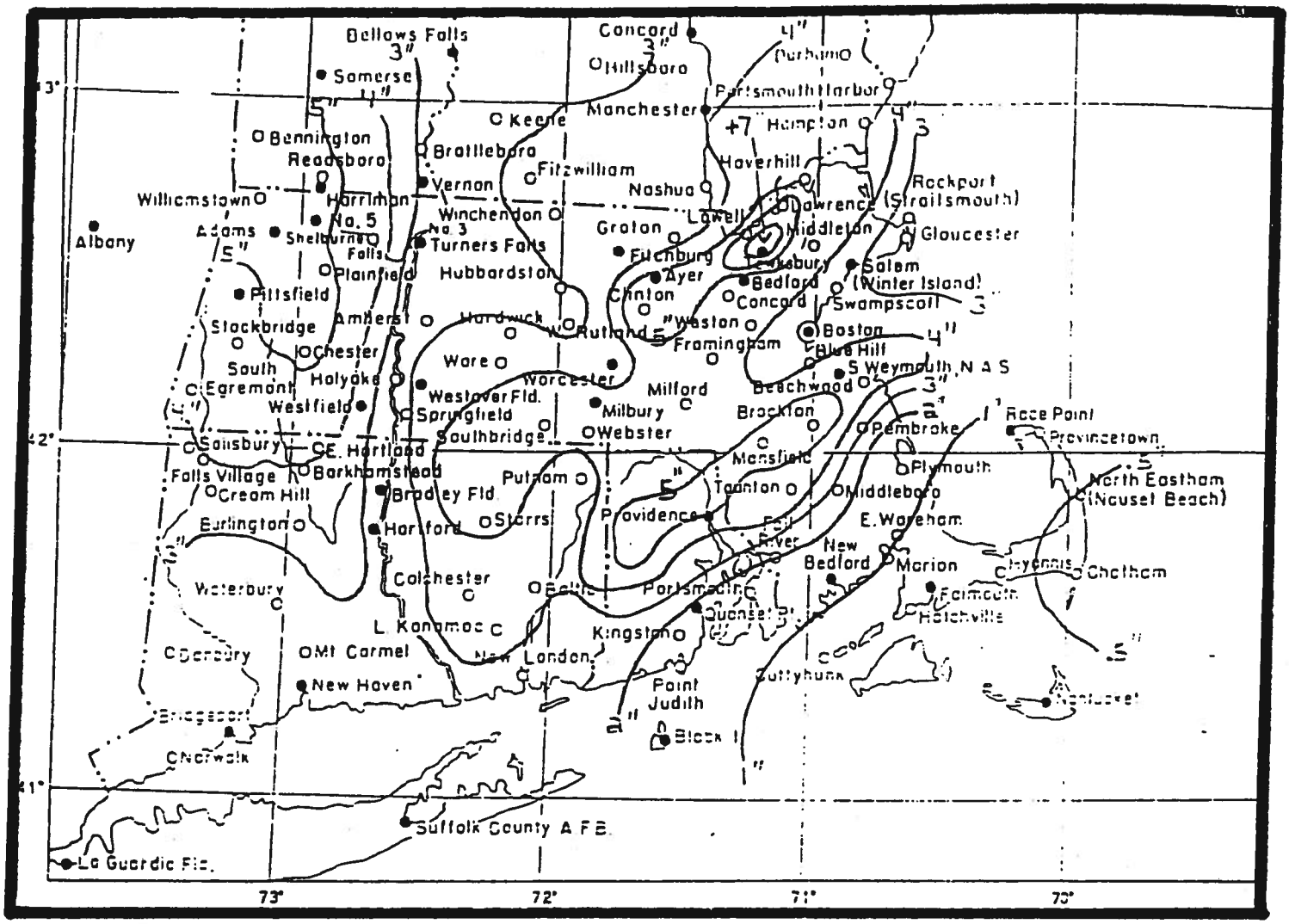

Figure 70. Analyzed precipitation field (inches) for rainfall associated with Tropical Storm Bertha.

HURRICANE EDOUARD
(**CAT 1** - September 1-2, 1996)

Hurricane Edouard formed in the eastern Caribbean sea on August 22 (Figure 71). The storm moved west, and became a hurricane on August 23. The hurricane moved west for several days, then headed generally northward, passing about 85 miles southeast of Nantucket island as a Category 1 hurricane on September 2, before becoming extratropical in the Gulf of Maine September 3rd. Unlike most tropical cyclones that accelerate as they pass through New England, Edouard moved rather slowly as it passed the region, prolonging its effects.

The main impact of Edouard was felt in southeastern New England, especially on Cape Cod and the islands of Martha's Vineyard and Nantucket. The storm brought wind gusts over hurricane force, with a gust to 79 mph reported on Nantucket island. There were unconfirmed reports of gusts to 80 or 90 miles per hour on Martha's Vineyard and Nantucket. Numerous shingles were blown off roofs on Martha's Vineyard, and there was some tree damage as well. Power was disrupted over Cape Cod and the islands for several hours during the storm. Tides from Edouard ran 1 to 3 feet above normal, resulting in some boat damage, especially on Martha's Vineyard and Nantucket, where over a dozen boats were reported lost due to the storm.

Rainfall from Edouard was confined to eastern and central sections of southern New England. Four to just over six inches of rain fell across parts of Cape Cod and Martha's Vineyard, with an inch or less west of the Rhode Island border. The highest amount reported was 6.37 inches at West Dennis, Massachusetts on Cape Cod (Figure 72). Minor street flooding was reported, but there were no reports of river or small stream flooding. Coastal flooding was minimal at most locations.

There were no reports of deaths or injuries from Edouard. Damage from Edouard was reported as 1.3 Million dollars, mostly due to downed trees and power lines.

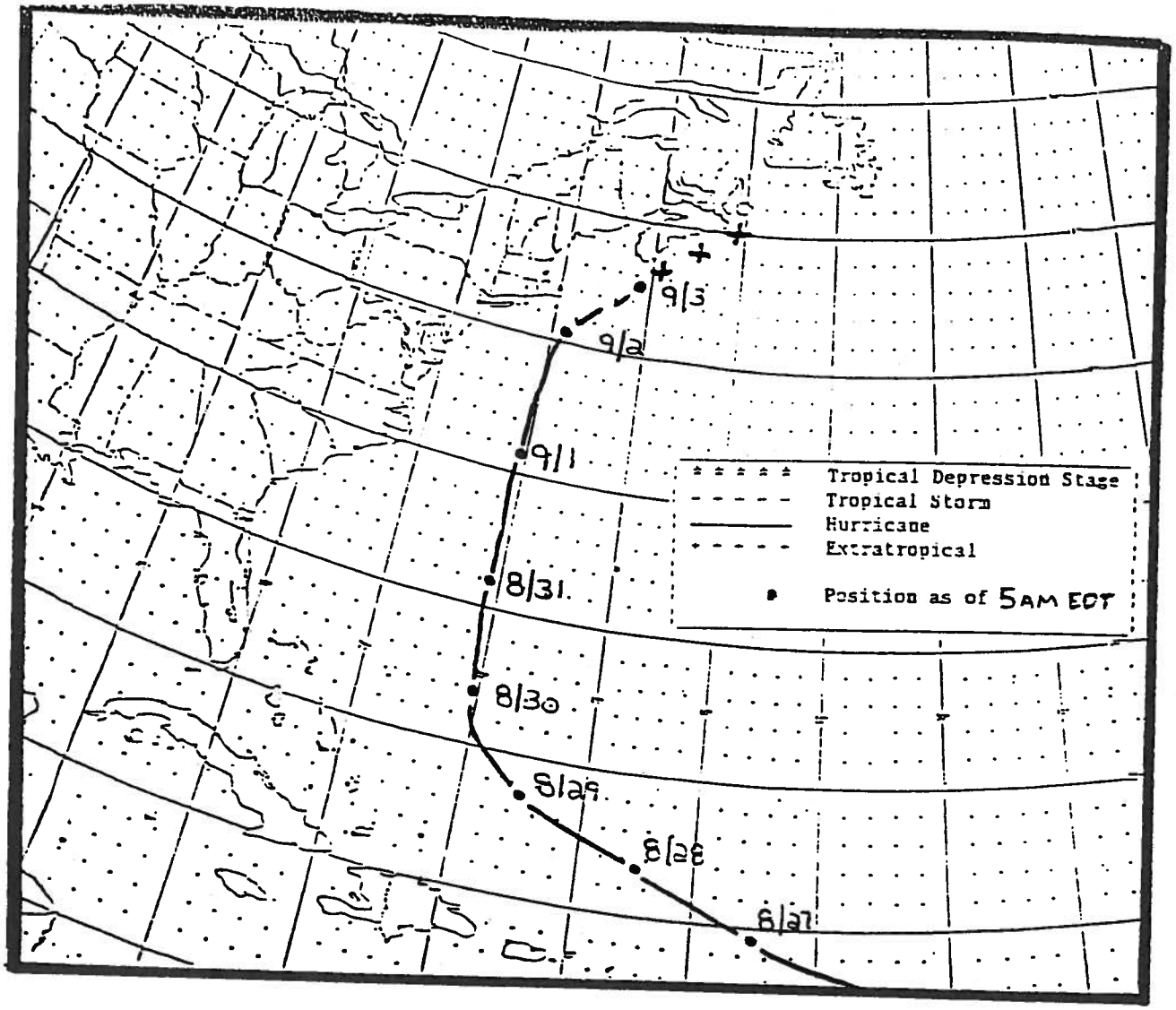

Figure 71. Track of Hurricane Edouard of 1996.

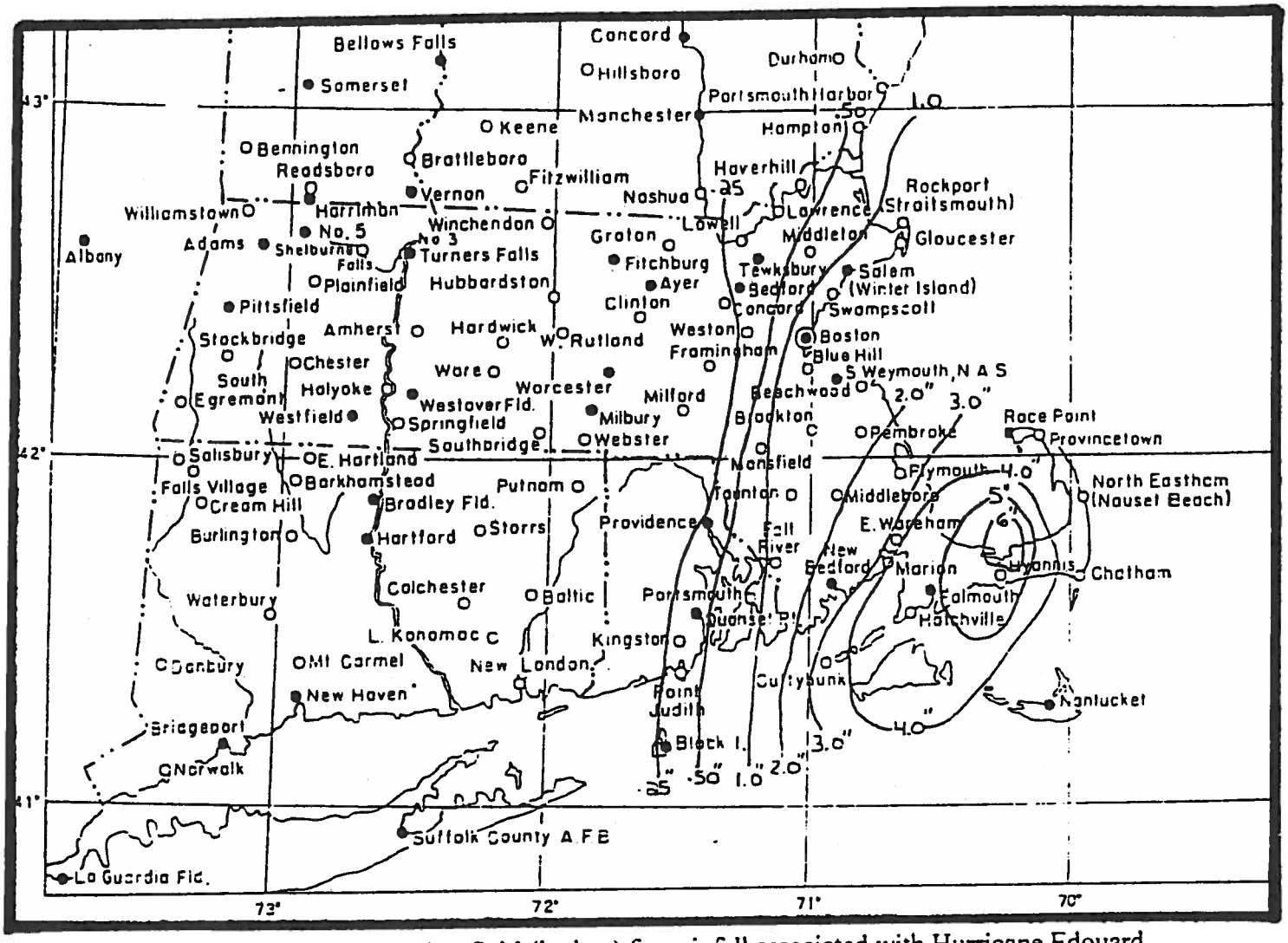

Figure 72. Analyzed precipitation field (inches) for rainfall associated with Hurricane Edouard.

3. ANALYSIS: CHARACTERISTICS OF HURRICANES IN SOUTHERN NEW ENGLAND

Thirty-nine tropical cyclones have affected southern New England since 1900. Twenty five of these systems were hurricanes upon landfall on the coast of southern New England, or at closest approach to southern New England. Most of these hurricanes accelerated rapidly toward southern New England with just two exceptions, Hurricane Esther in 1961 and Hurricane Edouard in 1996. Esther accelerated for a time, but then slowed to just 6 mph upon reaching the coastal waters of southern New England (Figure 49). Edouard also slowly moved up the east coast just off of Nantucket, prolonging the storm's effects on southern New England.

Hurricanes impact New England in three ways: wind, storm surge, and rainfall. The type and intensity of hurricane-induced weather conditions experienced in southern New England is highly dependent upon where the center makes landfall. Thus, this discussion will examine the various weather factors of wind, storm surge, and rainfall by the sector of the hurricane. Also, the timing of a hurricane's landfall or closest passage is important. The degree of coastal flooding from a hurricane depends upon the magnitude of the storm surge and the concurrent phase and amplitude of the astronomical tide.

Southern New England hurricanes produce distinct weather conditions in each sector of the storm. These sectors can be grouped into two general categories:

1. Eastern sector - for areas which pass through that region of the hurricane, east of the eye.
2. Western sector - for areas which are affected by that region west of the eye.

A. Eastern Sector

The Eastern Sector, or semicircle as it is sometimes referred to, is usually the most damaging portion of the hurricane. It is in the Eastern Sector of the storm where the greatest storm surge and strongest winds occur.

Since 1900, seven hurricanes have made direct landfall along the southern New England coast. More of the coastline is affected by the eastern sector the farther west the location of landfall. Of these hurricanes, three were Category 3 intensity. Six of the seven hurricanes made landfall along or west of Westerly, Rhode Island. This type of track placed a large portion of the southern New England coast in the eastern sector, including the larger bays such as Narragansett and Buzzards Bays. Hurricane Edna in 1954 and Hurricane Bob in 1991, were the only hurricanes to make landfall east of this point.

Prevailing south or southeasterly surface winds occur in the eastern half of an approaching hurricane. This aids in forcing the oncoming storm surge directly up south and southeast facing bays and inlets, including locations such as Mystic Harbor, Narragansett Bay, and Buzzards Bay. This also exposes the southern New England coastline to the extremely large waves which ride atop the storm surge. In addition, many of the bays and inlets have 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 height of the surge increases with storm intensity and the portion of the coastline in question. The largest surges will always be recorded on the upper reaches of bays. This was clearly demonstrated during Hurricane Carol. Figures 28 through 32 show that the surge ranged from 8 feet along the coast of Rhode Island, to 12 feet in Somerset, Massachusetts, to a record 14.4 feet at the upper reaches of Narragansett bay.

The time the storm surge arrives is the most significant feature. The closer to high tide, the higher the storm tide and the greater the damage. For example, one of the larger storm surges since 1900 accompanied Hurricane Carol, where a surge of 14.4 feet was recorded at the South Street Station. However, this did not produce the highest storm tide at this location, because the surge arrived just after high tide. The Great New England Hurricane of 1938 produced the greatest storm tide at South Street, with a level of 19.01 feet.

With the exception of Hurricane Belle, areas affected by the eastern sector exhibited a similar storm surge characteristic; rapidly rising water levels within the last two hours of landfall. Both Buzzards Bay and Narragansett Bays have experienced water levels increasing at over 2 feet every 10 minutes within the last hour of the highest recorded storm tide. Bay waters receded quite rapidly after the storm center passed northwest of southern New England. Tides returned to normal between 2½ to 3 hours after the maximum storm tide was reached.

Strong, damaging winds accompanied many of these storms. The strongest wind gust ever recorded in southern New England occurred during the Great New England Hurricane of 1938. The Blue Hill Observatory, located in Milton, Massachusetts, recorded a sustained wind of 121 mph with a peak gust to 186 mph. Wind gusts of 135 mph were recorded on Block Island during Hurricane Carol of 1954 and 130 mph during Hurricane Donna in 1960. Each of these systems produced severe tree and crop damage, as well as widespread power outages.

Inland flooding of rivers and streams is rarely ever a problem in the eastern sector. Rainfall in the eastern sector is generally much less than that which occurs in the western sector. The main variable in rainfall distribution in the eastern sector is the proximity to the eastern edge of the eye wall as well as the forward speed of the storm.

The amounts were, on average, between 1 and 3 inches within approximately 30 miles east of the storm center, then decreased dramatically farther east of the storm center. Hurricane Gloria produced around 2 inches of rain along and just east of the storm track, but produced less than ½ inch of rainfall beyond 50 miles from the storm center.

B. Western Sector

The primary threat for areas affected by the western sector of a tropical cyclone is river and stream flooding from heavy rains. Some of the worst floods in southern New England history were associated with tropical cyclones which passed south and east of the region placing southern New England in the western sector. Tropical cyclones which produced inland flooding include, The Great New England Hurricane of 1938, The New England Hurricane of 1944, Hurricane Edna of 1954, and the combination of Tropical Storms Connie and Diane in 1955.

The most immediate threat during a tropical cyclone is that of flash flooding. Western sections of Massachusetts and Connecticut have received rainfall amounts of 6 to 12 inches during several events, most of which occurred in less than a 12 hour period. An extreme event, the greatest 24 hour rainfall total ever recorded in southern New England, occurred during Tropical Storm Diane when 18.15 inches fell in Westfield, Massachusetts.

It is not uncommon for southern New England to experience rainfall several days before the arrival of a tropical cyclone. For a tropical cyclone to threaten southern New England, a south to southwest middle to upper level wind flow usually exists. During the summer months, this type of flow can draw tropical moisture into the region and produce significant rainfall before the actual storm arrives. The threat of inland flooding is dramatically increased if such conditions exist.

Several examples of this type of scenario have occurred. The most notable of these occurred during the Great New England Hurricane of 1938, and affected much of the Connecticut River in Connecticut and Massachusetts. A stalled out frontal system caused 4 to 8 inches of rain across New England from September 17 through 19. The Great New England Hurricane of 1938 produced an additional 6 inches along the Connecticut River bringing rainfall totals to 12 to 18 inches in just 5 days. Catastrophic flooding resulted.

Another example was the New England Hurricane of 1936. One to 2 inches of rain occurred across southern New England several days before this storm. The additional 3 to 5 inches of rainfall associated with the hurricane caused inland flooding and numerous dam breaks 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 southern New England over a 3 day period.

Lastly, southern New England has experienced severe inland flooding from back to back tropical cyclone strikes in one season. The 1955 hurricane season is one of the most significant examples. The combined rainfall amounts from Tropical Storms Connie and Diane, just 4 days apart, created record river and stream flooding throughout much of southern New England. Dam failures were common, along with washed out streets and bridges. Record flows were recorded on many area rivers from a combined rainfall event of 15 to 25 inches across much of Massachusetts, northern Connecticut, and northern Rhode Island.

Coastal areas affected by the western sector experience much less of a threat for coastal flooding in southern New England. 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 southern New England, the greatest wind stress and surge values are generated over the waters well east of southern New England. The observed rises in water levels along the shore are mostly the result of induced water currents which develop in advance of the hurricane and then propagate into bays and inlets. 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 southern New England coast and exposes fewer locations to damaging wave action.

The exceptions to this include areas such as Long Island Sound and the eastern shoreline of Massachusetts. In these locations, an east or northeasterly wind flow will rapidly pile water up along the shoreline and into the bays and inlets. These areas usually experience the most coastal damage and boating damage during tropical cyclones which pass east and south of the area.

4. SUMMARY

A. Frequency

1. Yearly Statistics

Thirty-nine tropical cyclones have affected southern New England since 1936; 15 were tropical storms, and 24 were hurricanes. The most active decade for tropical cyclone activity was the 1950s, when ten tropical cyclones affected the area; seven were hurricanes (Figure 73). The decade of the 1960s ranked second, with eight tropical cyclones; six were hurricanes. For six consecutive years, from 1958 to 1963, at least one tropical cyclone affected the area each season. The longest period between tropical cyclone events was 8 years, from 1977 through 1984. The most storms to affect the southern New England in one season were three, occurring in 1954, when hurricanes Carol, Edna and Hazel affected New England.

2. Monthly Statistics

August and September were the most likely months for tropical cyclone activity in southern New England. Eighteen tropical cyclones occurred in September, and 12 in August (Figure 74). The remaining storms were nearly evenly divided between June, July, and October, with four occurring in July, three in October, and two in June.

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

B. Wind Data

Observed wind speed data were available from various National Weather Service Offices, including those in Warwick and Block Island, RI, Boston, MA, the Blue Hill Meteorological Observatory in Milton, MA, and, occasionally, from state airports and Coast Guard installations. Hence, the values given here represent actual recorded data and do not account for any "eyewitness" estimates of sustained wind speeds or wind gusts.

The strongest sustained 1-minute wind speed and wind gust ever recorded from a hurricane was at the Blue Hill Observatory in Milton, MA, during the Great New England Hurricane in 1938. A sustained wind of 121 mph with a peak gust to 186 mph was recorded. Other notable wind records include wind gusts to 135 during Hurricane Carol and 130 mph during Hurricane Donna, both of which occurred on Block Island. Sustained winds of 100 mph with a peak gust to 125 mph occurred in Downtown Providence, during the passage of Hurricane Carol. Hurricane Bob produced sustained winds of 100 mph with a peak gust to 125 mph at North Truro on Cape Cod.

C. Storm Surge

The Great New England Hurricane of 1938 produced the greatest storm tides this century in southern New England. The storm tide reached 19.01 feet (MLLW) at the State Street Station Dock on the upper part of Narragansett Bay during the 1938 Hurricane, associated with a 13.7 foot storm surge. Hurricane Carol brought a slightly higher storm surge, 14.4 feet over the upper portions of Narragansett Bay, but produced a slightly lower storm tide of 17.51 feet (MLLW), due to its arrival shortly after high tide.

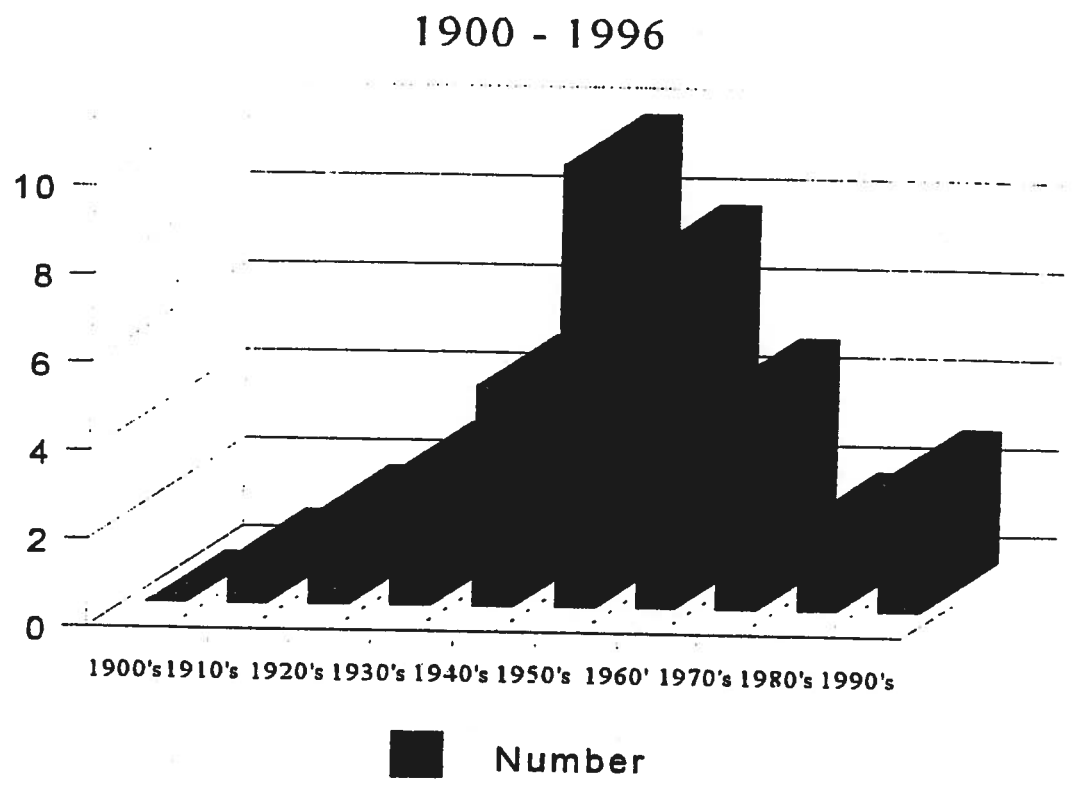

Figure 73. Tropical Cyclone Frequency in Southern New England, by decade for the period 1900 - 1996.

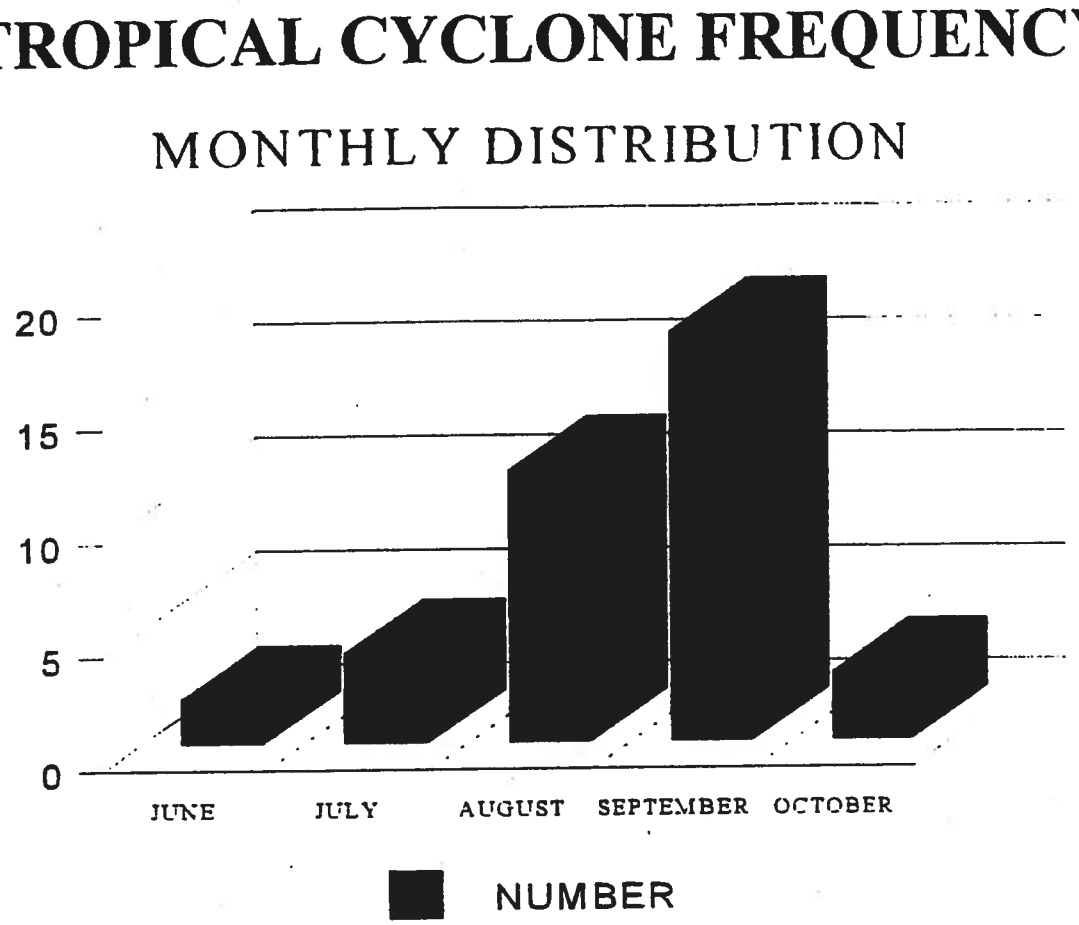

Figure 74. Monthly Tropical Cylone Freqency for Southern New England for the period 1900 - 1996.

D. Precipitation

Precipitation information was gathered from several sources, including various National Weather Service Offices and cooperative observing sites.

The greatest 24 hour rainfall ever recorded in Southern New England from a tropical cyclone occurred in Westfield, MA during Tropical Storm Diane in 1955. An incredible 18.15 inches fell during the storm, causing catastrophic flooding and a storm total of 19.76 inches.

E. Pressure Data

Sea-level pressure data were gathered from several sources, including National Weather Service Offices, from state airports, Coast Guard installations, and several ship reports.

The lowest barometric pressure ever recorded in southern New England was observed at Middletown, Connecticut during the Great New England Hurricane 1938, with a pressure of 28.00 inches. This hurricane brought a pressure of 27.94 inches to Bellport, Long Island as the center crossed the Island on its way toward Middletown. Hurricane Edna produced a pressure of 28.02 inches at Edgartown, on Martha's Vineyard. A report of 27.70 inches was observed at Woods Hole, in Falmouth, Massachusetts, but based on the storm track, this pressure is believed to be in error.

F. Storm Speed

The Great New England Hurricane of 1938 had the fastest forward speed when it struck southern New England, 60 mph. Hurricane Gerda in 1969 ranked second with a forward speed of 48 mph. The slowest moving systems to affect southern New England was Hurricane Esther in 1961 with an average speed of only 6 mph, and Hurricane Edouard in 1996 with an average speed of 14 mph.

5. ACKNOWLEDGMENTS

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Lastly, the authors owe Hurricanes Bertha and Edouard a debt of gratitude. For it was their impact to the region that became the catalysts for us to complete this work before the start of the 1997 Hurricane Season.

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).

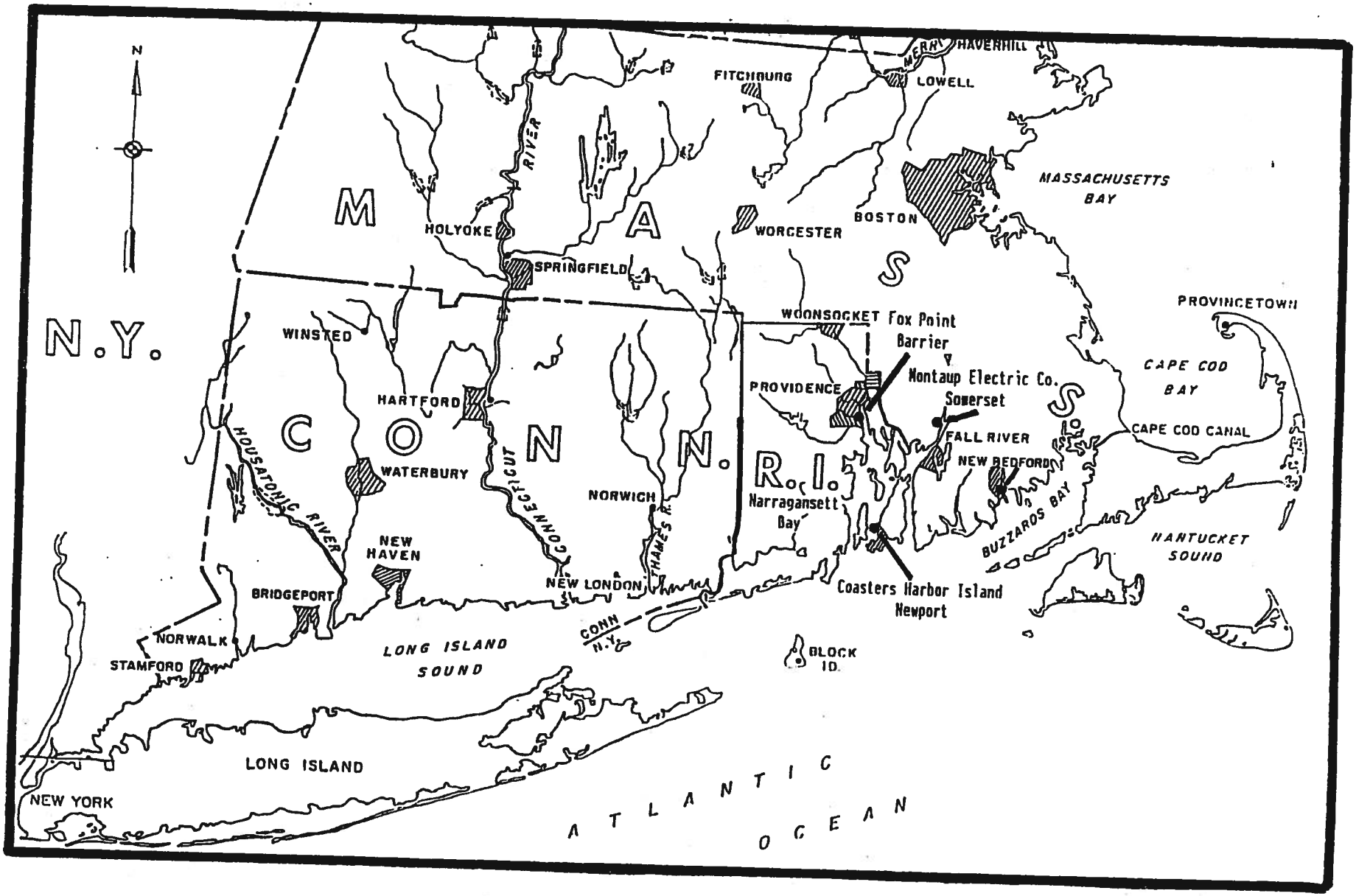
APPENDIX B

SAFFIR/SIMPSON HURRICANE SCALE

Category	Description of damage
ONE	*Winds 74-95 mph*. 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*. 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*. 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*. 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*. 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

Map of Southern New England, including several of the major cities and coastal locations referenced throughout the paper.



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