The 1938 Great New England Hurricane

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1938

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■ ACKNOWLEDGEMENTS

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■ EXECUTIVE SUMMARY

The 1938 Great New England Hurricane, also known as the "Long Island Express," was the most powerful storm to make landfall along the northeastern coastline of the United States in the past two centuries. An incredibly fast-moving storm, it caused destruction along its path in the form of wind, storm surge, inland flood, and even fire. Damage across New York, Rhode Island, Connecticut, Massachusetts, and farther northward into New Hampshire, Vermont, and Maine was comparable to that experienced in Louisiana and Mississippi in the main footprint of Hurricane Katrina in 2005. While the loss of life was small in comparison to the over 8,000 fatalities caused by the 1900 Galveston Hurricane, the 1938 storm was still one of the deadliest hurricanes of the 20th century, with close to 700 people perishing as a result of the storm. The majority of the fatalities in the 1938 storm resulted from the storm surge as, unfortunately, no warnings were issued in time for residents to evacuate the low-lying coastal areas.

The 1938 Great New England Hurricane remains the storm to which all other New England storms are compared. The combination of storm surge and high waves altered the southern Long Island shoreline, creating the Shinnecock Inlet and expanding the Moriches Inlet. The combination of storm surge and extreme river flows washed away numerous bridges, completely severing railroad communications between New York and Boston, as well as the links between the principal cities in Connecticut and Rhode Island. The extreme high winds caused the devastation of many forests in the main path of the storm, from the coast through to Maine and New Hampshire, greatly impacting the region's timber industry.

For the 70th anniversary of the Great New England Hurricane, RMS investigated the impacts of a repeat of the event in 2008. Wind field, storm surge, and rainfall footprints across New England were generated and each peril was analyzed separately against the property at risk from wind and water damage. The unique conditions of the storm, which had started to undergo extratropical transition before making landfall, were considered in the analysis. The current conditions of the property at risk were also considered, including measures to reduce the impacts of inland flooding and the availability and penetration of insurance coverage for wind and water damage.

If the 1938 storm occurred today, it would be a major catastrophe for the region, leading to post disaster loss amplification—principally due to economic demand surge—which would raise the costs of insurance claims. A large proportion of the region's roads would be blocked by fallen trees, and extensive damage would occur to the power lines, telephone lines, and cell phone transmission towers across the affected region. Insured losses from wind, storm surge, and flooding would total approximately $40 billion to $55 billion, including losses to both the private insurance market and those policies covered under the National Flood Insurance Program (NFIP).

The particular situation that led to the 1938 storm, which was characterized by a very high forward speed and intense damaging winds, appears to occur on average around once a century. However, the impacts of climate change on hurricane risk in the Northeast U.S. remain unclear. An increase in sea surface temperatures (SSTs) in the main area for storm development would increase the intensity of storms making landfall along these coastlines. Intense storms in New England are also very much dependent on the pattern of mid-latitude circulation and any changes in that circulation during the hurricane season will also affect the potential for intense storms to make a New England landfall.

No matter the uncertainty in the size and timing of a major hurricane making landfall along the coastline of the northeastern U.S., it will happen again. It is imperative to educate the communities on the potential impacts and prepare well in advance of an impending storm. ■

Flooding in Ware, Massachusetts in the aftermath of the 1938 Great New England Hurricane (Source: NOAA)

1 THE GREAT NEW ENGLAND HURRICANE

The Great New England Hurricane was the fourth and most intense storm of the 1938 Atlantic storm season, which saw the development of five tropical storms and three hurricanes. Since the naming of hurricanes was not established by the U.S. Weather Bureau until 1950, the hurricane was the third of three "no name" hurricanes to make landfall along the Atlantic or Gulf coasts in August and September of 1938.

1.1 Genesis and Track of the Storm

The system that developed into the 1938 Great New England Hurricane had its origins in the far eastern Atlantic Ocean, near the Cape Verde Islands off the coast of Africa. A weather observer at the French observation station in the Sahara Desert first noted the circulating cluster of thunderstorms on September 4, 1938 as it moved westward. Because there were no weather satellites or radar to track the storm, the journey across the Atlantic Ocean was monitored by weather balloon observations and ships along the storm's path. As it moved closer to the U.S., land-based weather observation stations began reporting what could be inferred about the storm's path and intensity.

Storms that form from a circulation moving off of Africa in the eastern Atlantic Ocean are termed "Cape Verde" storms. The probability of storm development within different areas of the Atlantic Basin is dependent upon the month in which they occur. Although the hurricane season extends from June to November, in August and early September in particular, large areas of the tropical waters in the eastern Atlantic Ocean reach the 79ºF (26ºC) sea surface temperature threshold necessary for tropical cyclones to develop between the west coast of Africa and the Caribbean.
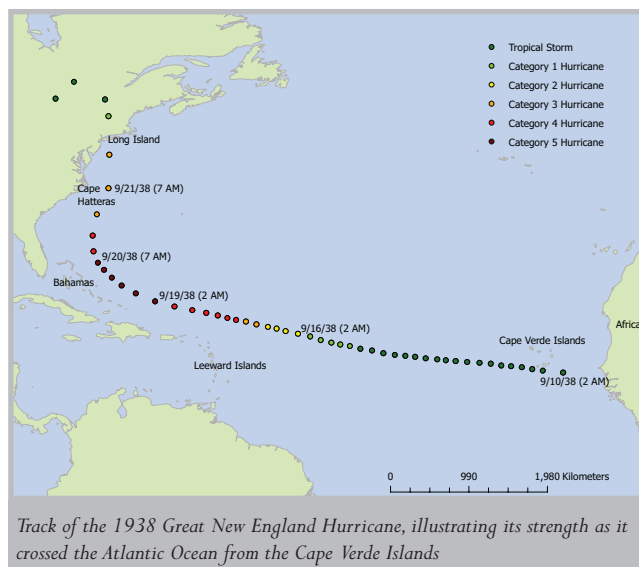
The year 1938 was also one that fell into a warm phase of the Atlantic Multidecadal Oscillation (AMO), which lasted from 1931 to 1960. The AMO oscillates between warm and cool phases over time, with the most recent warm phase beginning in 1995. Tropical storms are more prone to develop into severe hurricanes during warm phases rather than cool phases of the AMO. Moreover, 1938 can be classified as an intense La Niña year. La Niña is the cold phase of the El Niño-Southern Oscillation (ENSO) phenomenon in the tropical Pacific Ocean. It also remotely impacts the Atlantic Ocean, with a decreased wind shear in the region. This results in statistically significant above-average hurricane activity, and consequently damage, in a La Niña year as compared to an El Niño year (Pielke and Landsea, 1999).

At first, the storm was slow to strengthen, remaining a tropical storm with sustained wind speeds of less than 74 mph (119 km/hr) for five days during its westward traverse. It finally gained hurricane strength as it crossed the 45ºW longitude several hundred miles east of the Leeward Islands. The storm continued to steadily strengthen as it moved on a more northwesterly course. On September 19, east of the Bahamas, it matured into a Category 5 hurricane on the Saffir-Simpson Hurricane Scale as winds reached a sustained 160 mph (260 km/hr).

On September 20, as the system moved ever closer to the eastern seaboard, the storm took a definitive turn northward and began to accelerate. Over the course of 24 hours, it traveled north from the Bahamas, reaching
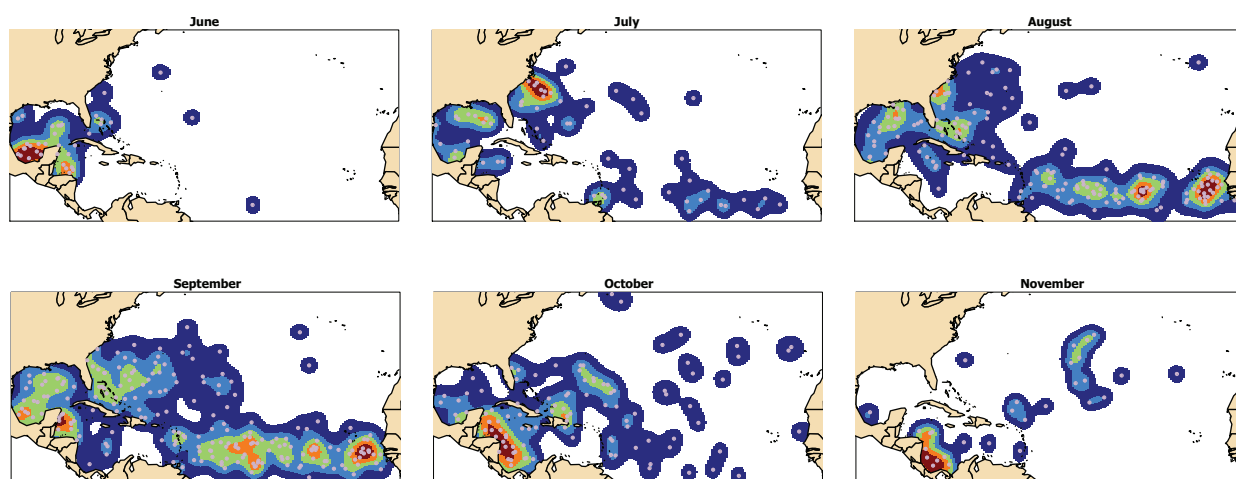
Probabilities of storm development in the Atlantic Ocean in the months of June through November, based on 56 years of the North Atlantic hurricane database (HURDAT) track set (1950-2006)

Track of the 1938 Great New England Hurricane, illustrating its strength as it crossed the Atlantic Ocean from the Cape Verde Islands

a position east of Norfolk, Virginia at 11:00 a.m. local time on September 21. By 1:00 p.m. local time, it was off the coast of southern New Jersey and winds began to increase along the southern New England coastline. The storm made landfall on September 21 with one of the highest forward speeds ever documented for a tropical cyclone. Its translational velocity was estimated at approximately 70 mph (113 km/hr) (Minsinger, 1988). The large forward speed of the 1938 hurricane was most evident in the last 12 hours before landfall, primarily due to the interaction of the storm with the jet stream.
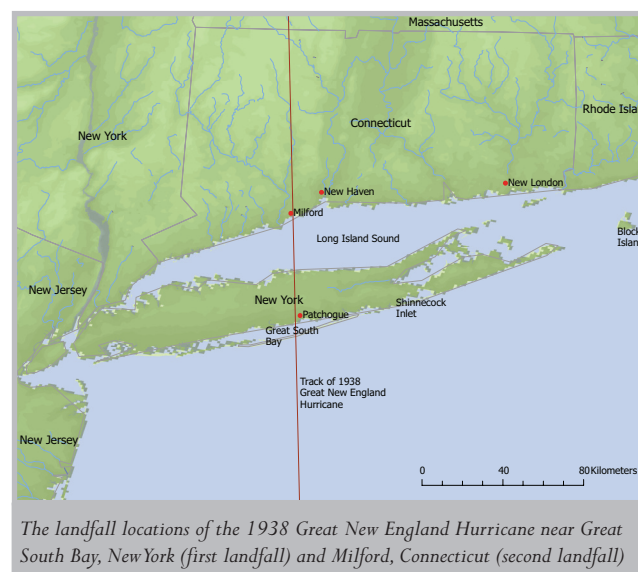
On Wednesday, September 21, the residents of Long Island woke to an overcast day with no indication of the impending storm. After an hour of intense wave and wind action, between 3:00 p.m. and 3:30 p.m. local time, the center of the hurricane came ashore near Great South Bay, crossing the Long Island Sound to make a second landfall near Milford, Connecticut. The storm's forward speed was so great that the waves did not warn of the approaching hurricane, as would have been the case for a storm along the Gulf Coast. In addition, unlike most storms, for which ground level wind speeds reduce within a few tens of miles from the coast, the hurricane's rapid speed and slow rate of filling caused damaging winds deep into New England. By 6:00 p.m. local time, the storm's center was over southern Vermont and by 2:00 a.m. local time on September 22, the storm had entered Canada, where it finally dissipated.
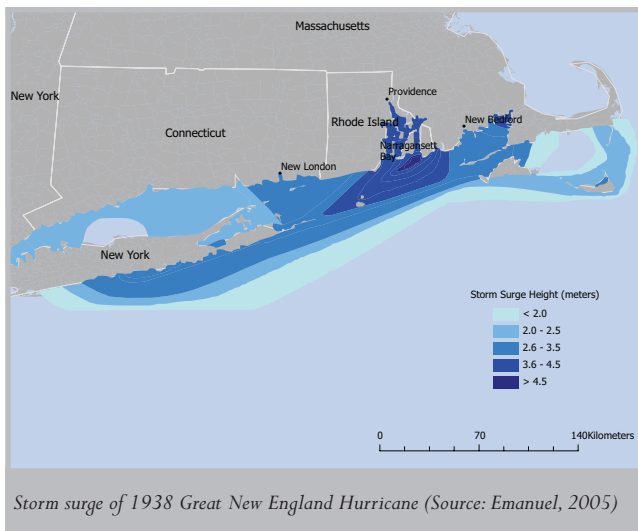
1.2 Measurements of the Storm

Hurricane-force winds were experienced over a wide area of southern New England during the passage of the 1938 hurricane. To the west of the storm, wind gusts of 120 mph (193 km/hr) were measured on the roof of the Empire State Building in New York City, although wind speeds at ground level in Central Park were only 60 mph (97 km/hr). To the east of the storm's eye, on Block Island, Rhode Island, sustained winds of 91 mph (146 km/hr) with gusts up to 121 mph (195 km/hr) were recorded. The strongest recorded winds, however, were at the Blue Hill Observatory (on top of a ridge south of Boston to the east of the storm), where sustained winds of 121 mph (195 km/hr) and a peak gust of 186 mph (200 km/hr) were measured. Along a large portion of the coastline, sustained winds exceeded 100 mph (161 km/hr). The lowest observed pressure associated with the storm was recorded in Bellport, New York, located east of Great South Bay and the track of the storm, where a reading of 946 mb was measured. Farther inland in Hartford, Connecticut, which was also east of the eye of the storm, the hurricane's pressure was measured at 949.5 mb.

Unfortunately for the residents along the coastlines of Long Island, Connecticut, Rhode Island, and Massachusetts, the hurricane struck only hours before high tide, which allowed a very rapid rise in sea level. Storm surges of approximately 10 feet (3 m) were observed along the southern coast of Long Island. As the storm moved up the eastern seaboard, the Delaware and New Jersey coastlines suffered some damage from wave action (e.g., to the Atlantic City Boardwalk). Along the Connecticut, Rhode Island, and Massachusetts coastlines, the surge was over 14 feet (3.4 m), but the surge became amplified in inlets to the east of the track. In Narragansett Bay in Rhode Island and Buzzards Bay in Massachusetts, water levels were raised close to 15 feet (4.6 m), flooding low-lying properties along the shoreline. In New Bedford, Massachusetts, the surge reached 9 feet (2.7 m) above sea level, while Newport, Rhode Island sustained 13 feet (4 m) of surge and Providence, Rhode Island sustained over 17 feet (5.1 m) of surge.

The landfall locations of the 1938 Great New England Hurricane near Great South Bay, New York (first landfall) and Milford, Connecticut (second landfall)

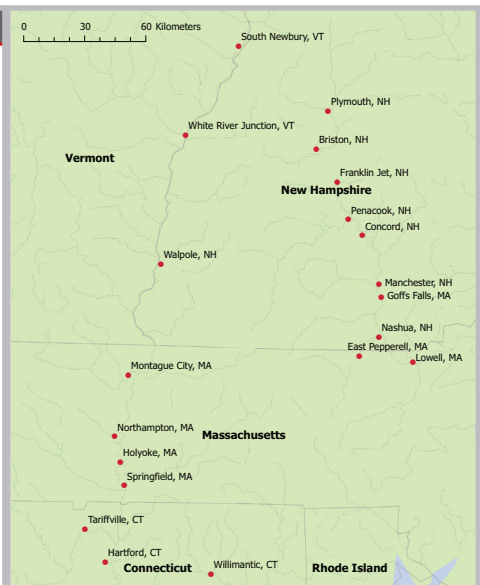*Storm surge of 1938 Great New England Hurricane (Source: Emanuel, 2005)*

In addition to the coastal storm surge flooding, the 1938 hurricane's rainfall increased the water levels of rivers and their tributaries across New England, which were already in flood stage. The summer of 1938 had been extraordinarily wet and the week before the storm, a slow moving frontal system left several inches of precipitation across much of western Massachusetts and most of Connecticut. The combined precipitation from the frontal system and the hurricane was over 10 inches (25 cm) across most of the Connecticut River Valley, and in particular, along the Connecticut, Thames, and Merrimack Rivers. On September 23, the Connecticut River in Hartford reached a level of 35.4 feet (10.8 m), which was 19.4 feet (5.9 m) above flood stage. Farther upstream, in Montague City, Massachusetts, where the flood stage was 28 feet (8.5 m), the river crested at 44.6 feet (13.6 m) on September 22. Along the Merrimack River in New Hampshire, levels in Concord measured 22.98 feet (7 m) on September 22, which was 10.98 feet (3.3 m) above flood stage.

1.3 FORECAST FAILURE

In 1938, without any possibility to combine the small number of offshore observations with the ability to model the predicted movements of the atmosphere, forecasts were heavily influenced by human judgment and, in particular, by precedence around what happened in previous storms. All historical records from the 1938 Great New England Hurricane note that the storm hit without any U.S. Weather Bureau hurricane warnings posted in New England. While storm advisories were issued on September 21, 1938 for watercraft from Atlantic City, New Jersey to Eastport, Maine, gale force warnings were only issued for the coast from the Virginia Capes to Sandy Hook, New Jersey before 3:00 p.m. local time that day. By the time the U.S. Weather Bureau office in Providence, Rhode Island received notification at 3:40 p.m. local time that a tropical storm was on its way to Long Island and Connecticut, it was too late.

Historical accounts relate how one junior forecaster in the Washington, D.C. office of the U.S. Weather Bureau, Charles H. Pierce, suspected the storm would hit New England (e.g., Scotti, 2003). However, his forecast was overridden by Charles Mitchell, the forecaster in charge. He believed that the storm would not make landfall, but would instead follow the path of previous similar storms, turning northeastward over the North Atlantic Ocean. Following the storm, the U.S. Weather Bureau was criticized for the lack of public warning—Charles Mitchell left the bureau and Charles Pierce was promoted. Today, based on the precautionary principle, the National Hurricane Center (NHC) of the National Weather Service provides a probabilistic set of potential tracks and landfalls for any storm threatening the U.S. coastline. ■

River	Station	Flood Stage (ft)	Crest (ft)	Date
Connecticut	South Newbury, VT	22	27.9	22-Sep-38
Connecticut	White River Junction, VT	18	26.6	22-Sep-38
Connecticut	Walpole, NH	30	39.1	22-Sep-38
Connecticut	Montague City, MA	28	44.6	22-Sep-38
Connecticut	Holyoke, MA	9	14.9	22-Sep-38
Connecticut	Springfield, MA	20	25.8	22-Sep-38
Connecticut	Hartford, CT	16	35.4	23-Sep-38
Connecticut	Northampton, MA	112	125	22-Sep-38
Contoocook	Penacook, NH	6	13.5	23-Sep-38
Farmington	Tariffville, CT	9	14	22-Sep-38
Mad	Moretown, VT	9	16.34	22-Sep-38
Merrimack	Franklin Jet, NH	14	28.5	22-Sep-38
Merrimack	Concord, NH	12	22.98	22-Sep-38
Merrimack	Manchester, NH	7	13.7	23-Sep-38
Merrimack	Nashua, NH	18	30.5	23-Sep-38
Merrimack	Lowell, MA	52	60.57	23-Sep-38
Merrimack	Goffs Falls, MA	11	25.87	23-Sep-38
Nashua	East Pepperell, MA	8	14.1	23-Sep-38
Pemigewasset	Plymouth, NH	11	23.6	21-Sep-38
Pemigewasset	Briston, NH	6	11.8	22-Sep-38
Shetucket	Willimantic, CT	13	27.6	21-Sep-38

Measurements and locations of flooding across New England following the 1938 Great New England Hurricane

2   DAMAGE AND LOSS FROM THE 1938 STORM

Property damage from the 1938 Great New England Hurricane totaled approximately $400 million, at the time a sum surpassing the "commonly accepted figure" of $350 million for the 1906 San Francisco Earthquake and Fire (Pierce, 1939). Recent studies on the costs associated with major U.S. hurricanes from 1851 to 2006, however, calculate the loss at approximately $300 million (e.g., Blake et al., 2007). Using the Consumer Price Index (CPI) to trend these losses, the estimate in 2008 dollars is between $4.5 and $6 billion. However, this adjustment does not take into consideration the significant increases in population and average wealth of householders in the region affected by the storm. If one considers these increases, estimates range from $37.3 billion to $39.2 billion (Pielke et al., 2008).

Estimates of casualties from the 1938 hurricane vary. At the time, the American Red Cross estimated approximately 500 fatalities, with an additional 100 missing and close to 1,800 injured. A survey by the U.S. Works Progress Administration (WPA) placed the loss of life closer to 700 (Minsinger, 1988). Most of the casualties in the storm were from drowning because people were unable to escape from the storm surge flooding, in particular at coastal locations where many houses were demolished by strong wave action.

2.1 PROPERTY DAMAGE

According to an account of the storm by Charles F. Brooks (Minsinger, 1988), close to 19,000 buildings

Homes driven from the shoreline of Fire Island, New York, as a result of the 1938 Great New England Hurricane; approximately 200 homes were swept away along the barrier beach

were destroyed by water, wind, or fire, including permanent and summer dwellings, barns, and other structures. In addition, 2,600 boats were destroyed in the storm surge and 26,000 automobiles were ruined by flying debris and floodwaters.

2.1.1 Wind and Storm Surge Damage

Storm waters from the 1938 hurricane inundated the coastlines of Long Island, New York, as well as the southern coastlines of Connecticut, Rhode Island, and Massachusetts. Nearly all of the 200 homes on Fire Island, New York, as well as over 150 homes along the beach of the Westhampton section of Long Island, New York, completely disappeared. Along the coastline of

Damage in Old Saybrook, Connecticut (left) and Old Lyme, Connecticut (right) at the mouth of the Connecticut River as a result of the 1938 Great New England Hurricane (Source: Connecticut State Library)

The Dunes Club, a landmark in Narragansett, Rhode Island, was destroyed by the storm surge during the 1938 Great New England Hurricane (Source: Connecticut State Library)

Rhode Island, entire beachfront communities vanished, such as the one in Watch Hill near Napatree Point along Little Narragansett Bay. Along Connecticut's southern coastline, water swept across the tidal flats, such as in Westbrook, Connecticut, where houses floated off their foundations. At the mouth of the Connecticut River, similar damage patterns were observed in Old Saybrook and Old Lyme. In addition, structures along the shoreline were undermined, as the ocean waves washed away the underlying soils. Fishing boats and recreational watercraft were destroyed, including 70% of a fishing fleet's fifty boats on Block Island, Rhode Island, and all the boats at a yacht club in Dorchester Bay, south of Boston, Massachusetts.

Across the New England area along the path of the hurricane, high winds ripped church spires off roofs in cities such as Sag Harbor, Long Island, and Danielson, Connecticut, as well as farther north in the towns of Dublin and Keene, New Hampshire. Ernest S. Clowes, a local newspaper editor, vividly described the loss of the steeple on the Presbyterian Church in Sag Harbor: "…a great lifting gust tore it whole and bodily from the church, carried it about twenty feet and then dropped it, a crashing mass of shapeless ruin" (Minsinger, 1988). Other famous landmarks were severely damaged along Narragansett Bay, including the Dune's Club and the seawall at Narragansett Pier. Farther inland, in Lebanon, Connecticut, the roof of the Meeting House of the First Church of Christ, designed by Revolutionary War hero Colonel John Trumbull, was torn completely off.

One of the most dramatic examples of storm surge flooding as a result of the 1938 hurricane was in the downtown area of Providence, Rhode Island, which lay at the northernmost point of Narragansett Bay. The high water mark on the Old Market Building surpassed the one recorded during the 1815 hurricane. The flooding began in the late afternoon, catching people by surprise as they tried to commute home from work. Within a span of minutes, the water height rose sharply by 2 to 3 feet (0.6 to 0.9 m), forcing commuters to abandon cars and the electric power for streetcars to be shut down. People on the streets were pulled to safety by those taking shelter in office buildings, where many rode out the storm. When the waters receded, tons of debris filled the streets.

Flooded streets in downtown Providence, Rhode Island as a result of the 1938 Great New England Hurricane (Source: Providence Journal)

Fire damage in New London, Connecticut as a result of the 1938 Great New England Hurricane, showing the roofless buildings of the burned-out section of town (Source: Connecticut State Library)

A secondary effect of the wind and storm surge was the triggering of fires. The most notorious incident was along the waterfront in New London, Connecticut. The "five masted school ship Marsala" was driven ashore during the hurricane, crashing into a building and causing a short circuit in the building's wiring, which started the blaze (Minsinger, 1988). Firefighters struggled to contain the conflagration through the flood waters and high winds, but the fire consumed a quarter square mile of the business district.

2.1.2 Inland Flooding Damage

For four days prior to the 1938 Great New England Hurricane, there was steady rainfall across Southern New England, in particular in Connecticut and Massachusetts, as well as up into New Hampshire. By the morning of September 21, various observing stations along the Connecticut, Thames, and Merrimack rivers were perilously close to or above flood stage. Supplemented by the intense rainfall from the hurricane, many rivers and their tributaries began to flood.

Flooding particularly affected the town of Norwich, Connecticut, along the Thames River, as well as the towns of Middletown and Portland, Connecticut along the Connecticut River. The industrial area of Hartford, Connecticut flooded in the days following the hurricane's passage. The flood damage proved too much for some factories already hurting from the Great Depression, causing them to close their doors.

A number of towns in Massachusetts were also hard hit from flooding, including Springfield on the Connecticut River, Ware on the Ware River, and Southbridge on the Quinebaug River. Farther north, in Weare, New Hampshire, the Deering and Weare reservoir dams were overwhelmed, causing the Piscataquog River to flood the town. Fires were also started by the rising flood waters short-circuiting electrical wiring, as in Peterborough, New Hampshire, where several buildings within the business district were lost to a blaze.

2.2 Tree and Infrastructure Damage

The wide swath of high winds in the storm felled an estimated 275 million trees, creating 2.6 billion "board feet of timber" debris (Minsinger, 1988), a record for a single hurricane. In 1943, total tree damage across Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, and Maine was compiled by the Northeastern Timber Salvage Administration (NETSA), a forerunner to the U.S. Forest Service, and was later studied by Boose and others (Boose et al., 1994; Boose et al., 2001). Timber damage was defined by the volume of timber "blown down," with extreme damage defined

Inland flooding in the industrial section of Hartford, Connecticut as a result of the 1938 Great New England Hurricane (Source: Connecticut State Library)

as over 10 million board feet of timber felled in a township. Note that 1 million board feet is equivalent to 2,400 m³ of timber.

Across New England, mature parkland elms and conifers fell at college campuses such as Wesleyan University in Middletown, Connecticut; Dartmouth College in Hanover, New Hampshire; and Worcester Polytechnic Institute in Worcester, Massachusetts. The town common of Amherst, Massachusetts, which is home to Amherst College, lost 3,000 trees. Farther north, downed trees lined Main Street in Windsor, Vermont, as well as neighborhoods in Montpelier, Vermont. In Keene, New Hampshire, pine trees proved particularly susceptible to damage and were lost to the high winds in large numbers.

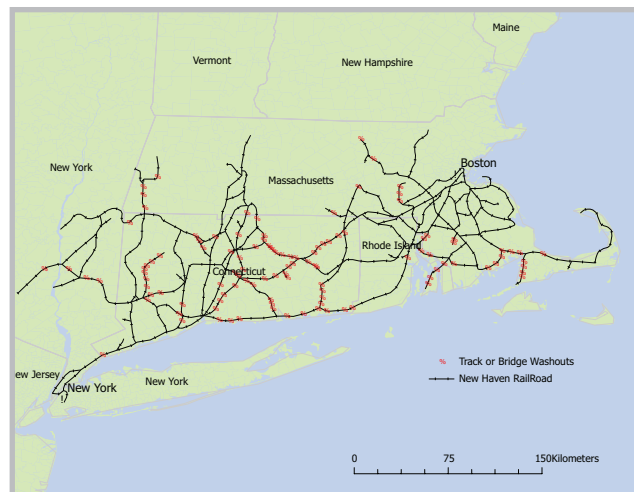Tree damage as a result of the 1938 Great New England Hurricane
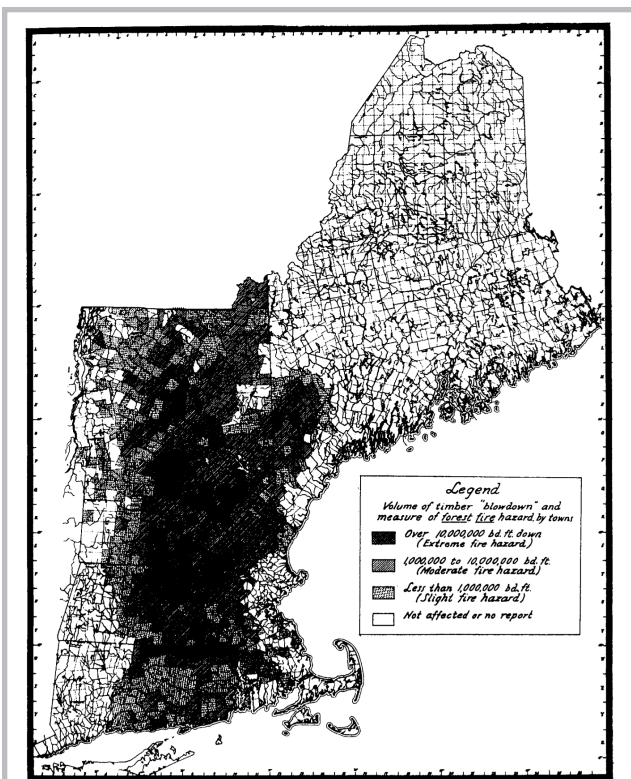
Severities of tree damage in each township as reported by the Northeastern Timber Salvage Administration following the 1938 Great New England Hurricane (Source: NETSA, 1943)

Closer to the coast, over 40% of the elm trees on Main Street in East Hampton, Long Island, were lost to windfall. In addition, many trees along the coastlines, affected by the high concentration of salt spray carried by the wind, died in the weeks following the hurricane. This phenomenon was repeated in Hurricane Bob in 1991, where USGS studies showed that 50% of the white pines along Buzzards Bay were killed by salt spray.

Approximately 20,000 miles (32,000 km) of electric power and telephone lines were inoperative due to the

Railway damage in Putnam, Connecticut as a result of the 1938 Great New England Hurricane (Source: New Haven Railroad, 1938)

Locations of track and bridge washouts along the New Haven Railroad as a result of the 1938 Great New England Hurricane (Source: New Haven Railroad, 1938)

tree damage, causing nearly everyone in the region to lose electric power and one-third of New England residents to lose telephone service. Even in the Boston suburbs, fallen trees downed power and telephone poles.

In addition to downed power and telephone lines, there was major infrastructure damage to the region's railway lines. The railway lines from New York to Boston, serviced primarily by the New Haven Railroad, were unserviceable for 7 to 14 days. Trains were derailed in East Hampton, New York and in Ashburnham, Massachusetts. Railway bridges were washed away in many locations, while some railway stations, such as the one in Norwich, Connecticut, were damaged by both wind and water. The tracks themselves were also washed away by the fast-moving flood waters, as seen in Putnam, Connecticut.

For many days after the storm, debris covered the tracks, such as in New London, Connecticut, where the "lightship tender Tulip" was lifted by the storm surge and dumped onto the tracks servicing the New York, New Haven, and Hartford railway (Minsinger, 1988). It took more than a week to reopen the line, as workers had to dredge a channel deep enough to refloat the ship.

The New Haven Railroad documented over 100 washouts along its lines, with over 30 reflecting lost bridges. The recovery following the storm was itself remarkable, with thousands of men "toiling 24 hours a day in 3 shifts," repairing the broken railway by replacing signal posts, straightening or replacing twisted tracks, and restoring washed-out roadbeds and bridges (New Haven Railroad, 1938). Within 2 days, partial service was restored between New York and Boston and within 6 days, key freight service lines were also restored. By the end of the second week of repair, the passenger service along the Shoreline track between New York and Boston was reinstated. ■

3 EXTRATROPICAL TRANSITION

By the time the 1938 Great New England Hurricane made landfall, it had started to undergo extratropical transition, the process by which a tropical cyclone transforms into an extratropical frontal system. The concept of a hurricane transitioning into a frontal storm was, in fact, discovered as a result of the meteorological analysis of the 1938 storm. In Charles H. Pierce's discussion of the event in the *Monthly Weather Review*, he stated that "…during the night of the 20th, the hurricane passed through a transitory stage. It changed from a tropical to an extratropical storm…" (Pierce, 1939). Seventy years later, in 2008, research into the structure and wind field of the 1938 storm continues, as evidenced by the reanalysis of the National Hurricane Center's North Atlantic hurricane database (HURDAT) (http://www.aoml.noaa.gov/hrd/data_ sub/re_anal.html; Landsea et al., 2008).

3.1 CHARACTERISTICS OF TRANSITIONING STORMS

Extratropical transition marks a change of the cyclone's primary energy source from the release of the latent heat of condensation to baroclinic processes associated with the boundary between air masses of different temperatures. During extratropical transition, a storm may tap into both energy sources simultaneously, explaining why tropical cyclones can sustain their strength above relatively cold ocean waters, retaining winds of hurricane or tropical storm force. RMS research indicates that it takes between 18 and 30 hours for a tropical cyclone to complete the transition to an extratropical cyclone.

Changes in the shape and size of the storm are also indications of a transition to an extratropical cyclone. During the transition, the approximately circularly symmetric cloud system typical of a tropical cyclone gradually changes into the asymmetric "comma-shaped" cloud geometry observed in extratropical cyclones. Moreover, extratropical cyclones are generally larger in extent than tropical cyclones and, for the most intense storms, the high forward speeds mean that the most damaging wind speeds are more pronounced to the right-hand side of the track. Satellite imagery of Hurricane Floyd in 1999 illustrates how the storm transitioned from a tropical cyclone on September 13 to a storm beginning its extratropical transition on September 15, to a storm near the end of extratropical transition on September 16, 1999.

Storms undergoing extratropical transition also derive energy from the jet stream and an interaction with the mid-latitude jet is a pre-determinant of transitioning. RMS employed computer simulations using a numerical weather prediction (NWP) model to understand the synoptic context of an event like the 1938 hurricane. In the computer simulation presented here, the simulated storm makes landfall in Rhode Island at a translational velocity of 45 mph (72 km/hr) with a minimum sea level pressure of 960 mb. The 1938 New England Hurricane moved faster at 70 mph (113 km/hr) with a lower minimum central pressure of approximately 946 mb.

Snapshots taken during the simulation illustrate how the surface wind speeds of the storm change as they interact with the upper level trough, the mid latitude perturbation that leads to the formation of extratropical storms. It is the interaction between the tropical cyclone (with its surface winds shown in shaded contours) and this trough (shown in red contour lines) that lead to the extratropical transition of the storm.

The jet stream tilts the vertical structure of a hurricane
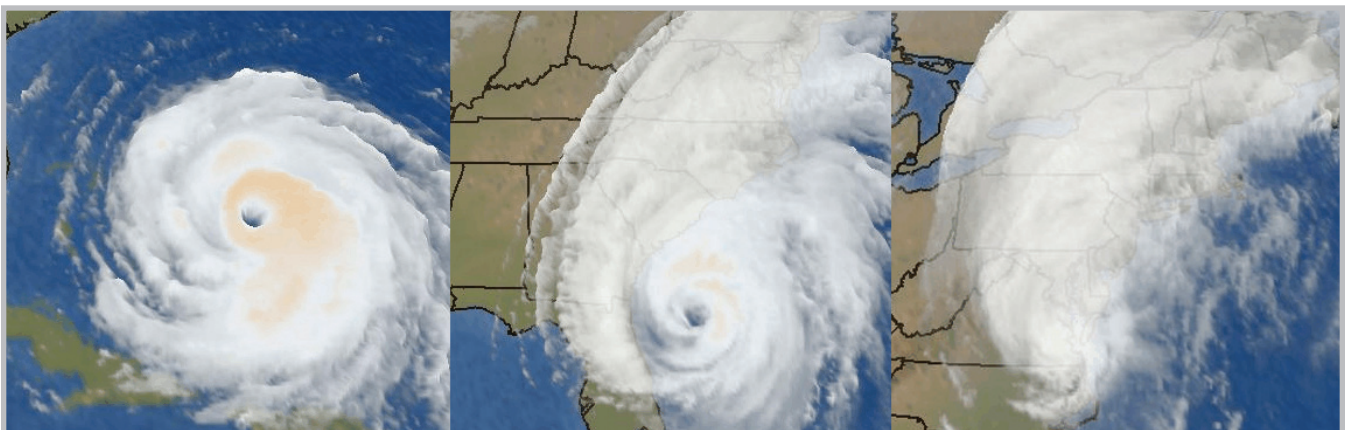
Comparison of 1999 Hurricane Floyd before transition on September 13, 1999 (left), beginning transition on September 15, 1999 (center) and toward the end of extratropical transition on September 16, 1999 (right) (Source: NOAA)
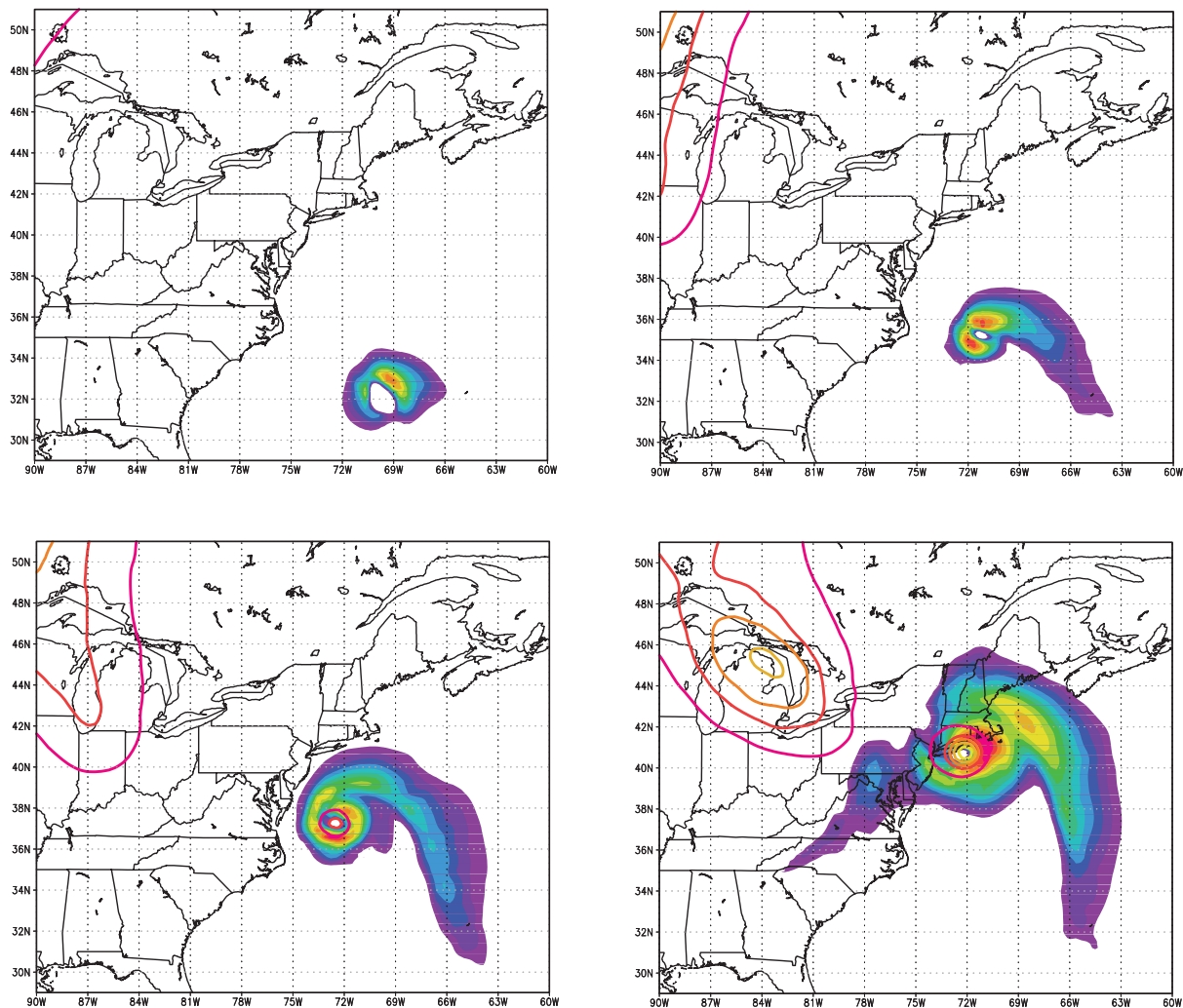
Synoptic context of a hurricane similar to the 1938 Great New England Hurricane: Red lines are the contours of the upper level trough with geopotential at 500 hPa and color contours illustrating surface wind speeds of the transitioning storm at 39 hours (upper left), 21 hours (upper right), 12 hours (lower left), and 0 hours (lower right) before landfall

toward the cold side of the jet stream, allowing cold, dry air to mix into the hurricane. This process turns the hurricane from a pure warm core system into a hybrid system. The increasing forward speed, combined with the ambient surface flow, shifts the damaging winds even more toward the right-hand side of the hurricane track. The baroclinic transition acts to broaden this wind field with time, weakening the peak wind gusts but producing winds over a larger area.

3.2 Transitioning Storms in the Atlantic Basin

Understanding extratropical transition, and in particular the interaction between tropical cyclones and mid-latitude troughs, is critical to assessing hurricane risk in the Northeast U.S. In particular, after landfall, wind fields are very sensitive to the transitioning stage, with transitioned systems not being constrained by the rates of inland filling found in pure tropical cyclones.

Other noteworthy cases of transitioning storms in the Atlantic Ocean include hurricanes Hazel (1954), Agnes (1972), Fran (1996), Luis (1996), Danny (1997), and Floyd (1999). More than 40% of all Atlantic tropical cyclones between 1899 and 1996 were classified by the National Hurricane Center (NHC) as undergoing extratropical transitioning and 50% of all landfalling storms ultimately underwent transition (Hart and Evans, 2000).

However, only a very fast-moving storm can preserve its deep intensity from the warm waters to the south of Cape Hatteras to make landfall along the southern coast of New England. In addition, forward speed strongly correlates with transitioning through the interaction with the jet stream. Therefore, deep storms are expected to transition with the highest forward speeds. The particular situation that led to the 1938 storm, characterized by a very high forward speed and intense damaging winds, appears to occur on average around once a century. ■

MODELING THE 1938 STORM

For the 70th anniversary of the 1938 Great New England Hurricane, RMS investigated the potential impacts of a repeat of the event in 2008 by analyzing the wind field, storm surge, and rainfall footprints across New England. Each peril was analyzed separately against the property at risk from wind and water damage.

For wind damage, property value estimates are based on the 2008 RMS® U.S. Industry Exposure Database (IED), which includes exposure for three primary insurance coverages: building/structure, contents, and time element (also known as business interruption or additional living expenses) for both residential and commercial lines. The U.S. IED incorporates assumptions of policy details (limits and deductibles) for wind coverage in these states, accounting for regional variability. Insurance coverage for water damage from storm surge and inland flooding is modeled in "excess" of the coverage provided by the National Flood Insurance Program (NFIP), as well as payments that "leak" into wind coverage. For example, if a residential structure's roof is torn off due to high winds but the contents are then damaged by rainfall, the loss will likely be covered by the homeowner's wind policy.

If the 1938 Great New England Hurricane occurred in 2008, it would be a major regional catastrophe leading to post disaster loss amplification, principally related to economic demand surge, raising the costs of insurance claims. In addition, as a large amount of tree damage is anticipated, some insurance coverage expansion is expected to cover losses due to fallen trees (e.g., debris or removal). For modeling purposes, RMS considers the expected contributions to loss amplification from these sources, as well as others. (For a complete description of the RMS loss amplification methodology, see RMS, 2006).
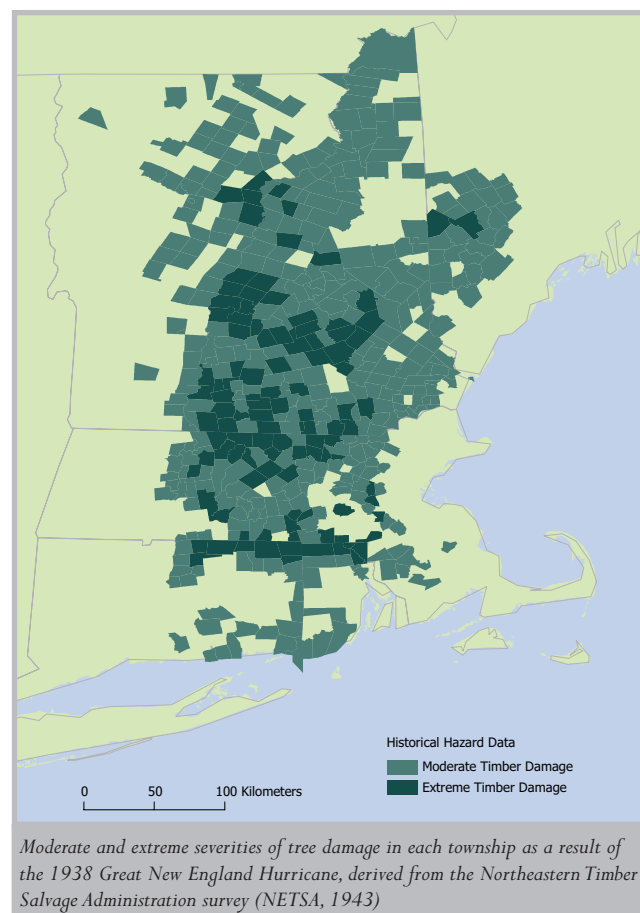
4.1 Wind Field Analysis

In attempting to reconstruct the wind field of the 1938 transitioning hurricane, in the absence of a detailed set of wind speed measurements, it becomes important to harness all of the available data describing the damage from the storm.
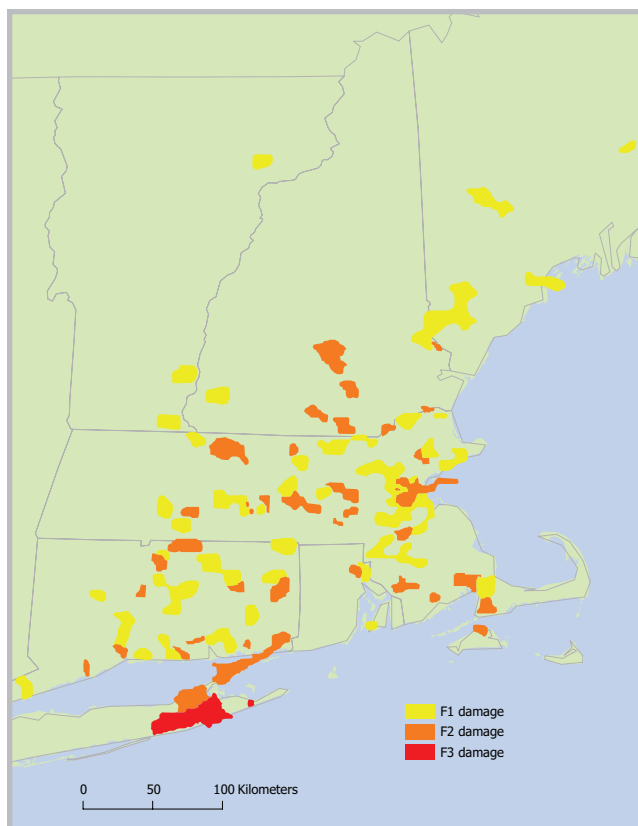
4.1.1 Wind Field Reconstruction

Two principal sources of damage data are available. The first source of information is a survey undertaken by the Northeastern Timber Salvage Administration that mapped the level of forest damage (in volume of timber felled) throughout the townships of New England (NETSA, 1943). In attempting to convert these damage estimates to wind speeds, it seems likely that extreme forest damage relates to wind speeds in excess of around 90 mph (145 km/hr), while the threshold for moderate levels of forest damage is around 75 mph (121 km/hr).

The second source of damage data comes from detailed accounts in local newspapers, which reported the most noteworthy incidents of wind damage and destruction. These newspaper accounts were compiled by Emery Boose in a study for the Harvard Forest Institute (Boose et al., 2001), and this data set was obtained and reinterpreted for the reconstruction of the 1938 wind field. In the work undertaken by Boose, the degree of wind damage was mapped into three levels that roughly correspond to F1, F2, and F3 damage on the Fujita Scale, which is used to classify tornado wind damage. For the revision of this work undertaken by RMS, a modified version of the Fujita Scale was employed, as the conversion of a damage level into an associated wind speed for a hurricane (with sustained winds lasting for a few hours) is at a much lower peak gust wind speed than would be the case for a tornado (with sustained winds lasting only a few seconds). Overall, where both sets of

Moderate and extreme severities of tree damage in each township as a result of the 1938 Great New England Hurricane, derived from the Northeastern Timber Salvage Administration survey (NETSA, 1943)

Degree of wind damage as a result of the 1938 Great New England Hurricane, as classified by the Fujita Scale (Source: Boose et al., 2001)

Both sets of damage data confirm the overall shape of the wind field of the 1938 storm, with the forestry data extending much farther north into more rural regions. Excluding damage along the coast and inland flooding damage, there was no significant wind damage away from the coast to the left-hand side of the storm's track. In addition, the overall structure of the storm's wind field appears more similar to an intense extratropical cyclone wind field, with a broad zone of damaging wind speeds to the right of and parallel to the track of the storm—as seen in the October 15-16, 1987 windstorm in the U.K. (For more information, see RMS, 2007).

The differences between a classic hurricane (with a very large radius of maximum winds) and a transitioning storm structure are illustrated here by modeling the 1938 track and central pressure, first as a hurricane wind field and comparing it to a transitioning storm wind field. In the case of the hurricane, even at these high forward speeds, damaging wind speeds are found on both sides of the storm's track. In contrast, the transitioning windfield has no damaging wind speeds to the left of the track and in passing inland, the zone of highest wind speeds moves farther away from the track.

4.1.2 Wind Field Losses

In order to estimate the potential damage and loss due to a repeat of the 1938 Great New England Hurricane in 2008, RMS modeled the hurricane as a transitioning storm, matching the overall wind field characteristics as reconstructed from the small number of wind speed
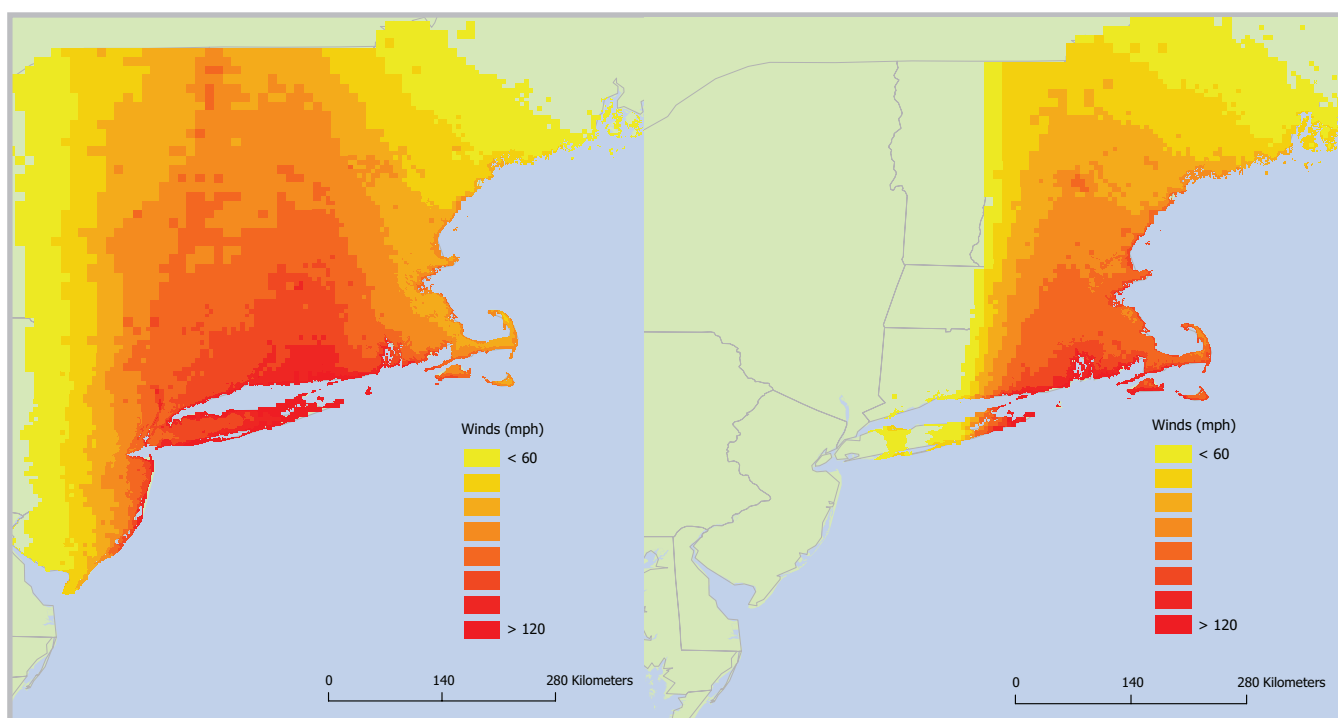
data are available and, in particular, where the area was primarily forested in 1938, the associated wind speeds for F1, F2, and F3 damage compare well with the wind speeds estimated from the forest damage at the same location.
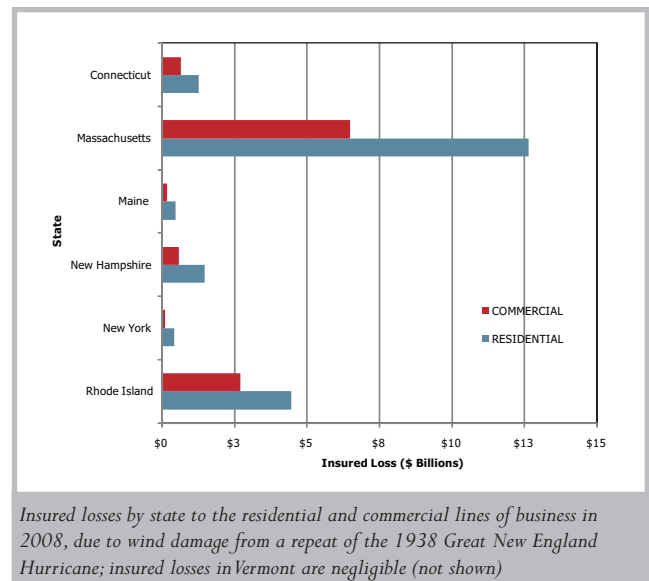

Modeled wind field of the 1938 Great New England Hurricane, assuming it has a classic hurricane structure (left) and a transitioning storm structure (right)
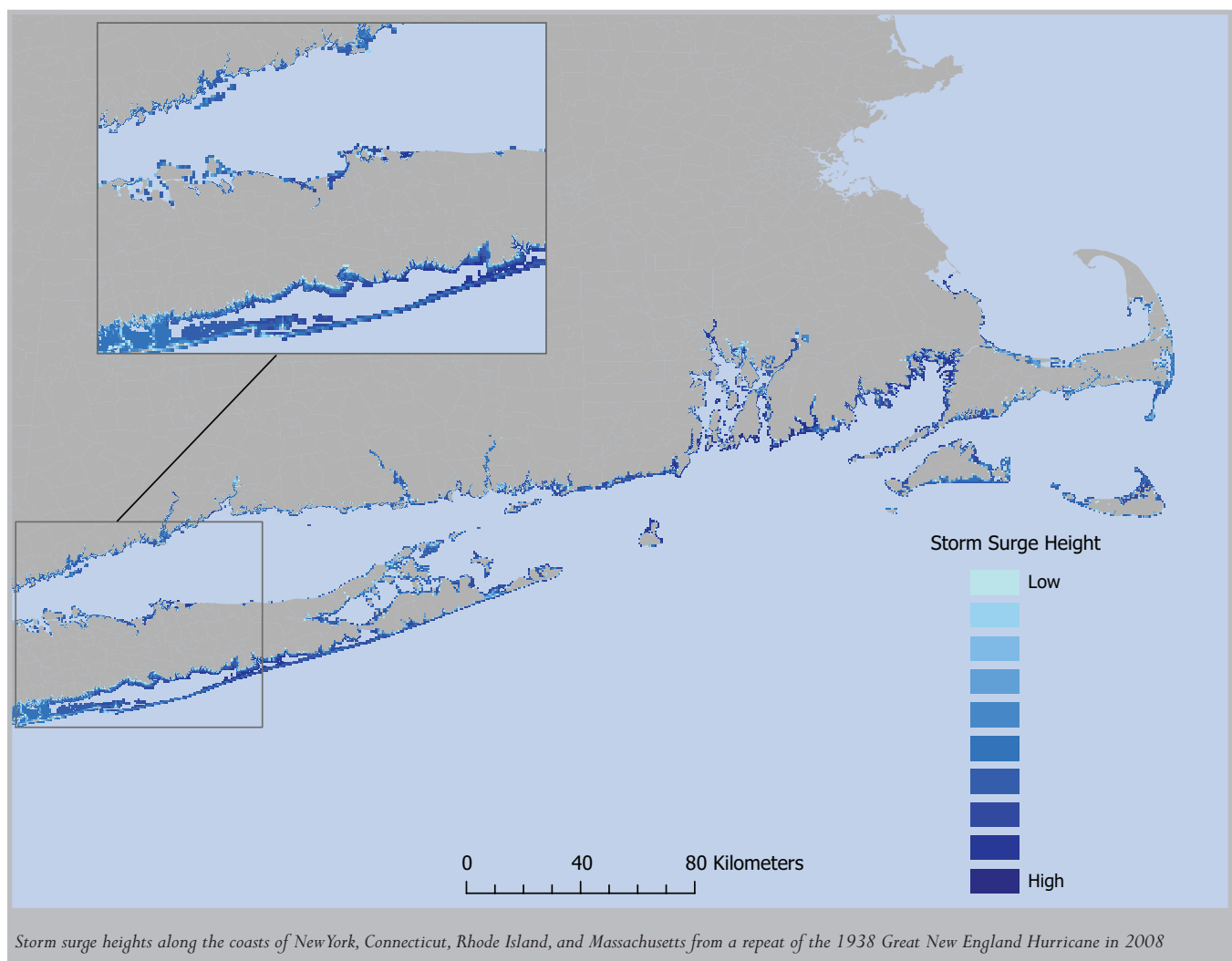
measurements and inferred from the distribution of damages. This reconstruction includes the broad area of damaging wind speeds found to the right-hand side of the storm's track and the span of damaging wind speeds extending almost all of the way to the Canadian border. Overall, the states of Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island and Vermont are impacted. Wind gusts along the southern coasts of Rhode Island and Massachusetts are modeled to exceed 120 mph (193 km/hr), while gusts along the eastern coast of Massachusetts exceed 100 mph (161 km/hr).

RMS estimates the 2008 insured property at risk from the damaging wind speeds within these seven states to be approximately $1.5 trillion for residential properties and $850 billion for commercial and industrial properties. Superimposing the modeled wind field on the residential and commercial exposure, insured losses due to wind damage from a repeat of the 1938 hurricane would total between $30 and $35 billion, with two-thirds of the loss sustained by the residential line of business and one-third of the loss sustained by the commercial line of business.

While some damage would occur across all of the states, there is negligible insured loss in Vermont, while the largest share of the loss is borne by property owners

Insured losses by state to the residential and commercial lines of business in 2008, due to wind damage from a repeat of the 1938 Great New England Hurricane; insured losses in Vermont are negligible (not shown)

in Massachusetts. In addition, losses are also very high along the Narragansett Bay in Rhode Island, including Newport at the mouth of the bay, and Warwick farther inland. Other high impact areas include New Bedford, Massachusetts along Buzzards Bay, as well as Plymouth and the greater Boston area.

Storm surge heights along the coasts of New York, Connecticut, Rhode Island, and Massachusetts from a repeat of the 1938 Great New England Hurricane in 2008

Fox Point Hurricane Barrier on the Providence River, which would protect Providence, Rhode Island from a storm surge if the 1938 Great New England Hurricane occurred in 2008

4.2 Storm Surge Analysis

In reconstructing the 1938 storm surge, RMS utilized the historic measurements of surge heights along the coast of Long Island, New York, as well as the southern coasts of Connecticut, Rhode Island, and Massachusetts. As estimated by Emmanuel (2005), water heights reached 5.9 feet (1.8 m) to 16.7 feet (5.1 m) above sea level across the southern coast of Long Island, as well as within the Long Island Sound and points eastward to the Nantucket Sound. Based on the strong onshore winds and swell, the storm surge was projected inland across a high resolution Digital Terrain Model (the 10-m or 33-ft USGS resolution National Elevation Dataset) to determine the high resolution flood depths in the coastal area, both along the southern coasts of Long Island and from the New York/Connecticut border to Cape Cod, Massachusetts. Flood barriers were taken into account, in particular the Fox Point Hurricane Barrier, completed in 1966 to protect downtown Providence, Rhode Island from surges arriving up Narragansett Bay. On the left-hand side of the track, winds from the northeast and north ensured there was no significant storm surge around Manhattan Island or along the Hudson River.

The values and types of property at risk at each location were then taken from the RMS detailed property exposure dataset employing the variable resolution grid (VRG) system. The VRG is a geographic indexing system developed by RMS, with cells varying in size from 0.001 degree (330 ft/100 m), to 1 degree (62 mi/100 km). The majority of the cell sizes in this analysis were at the 0.001 degree resolution, as these areas are highly populated with high hazard levels. For all those coastal VRG cells with water depths greater than zero, total insured property values sum to approximately $60 billion for the residential line of business and $20 billion for the commercial line of business.
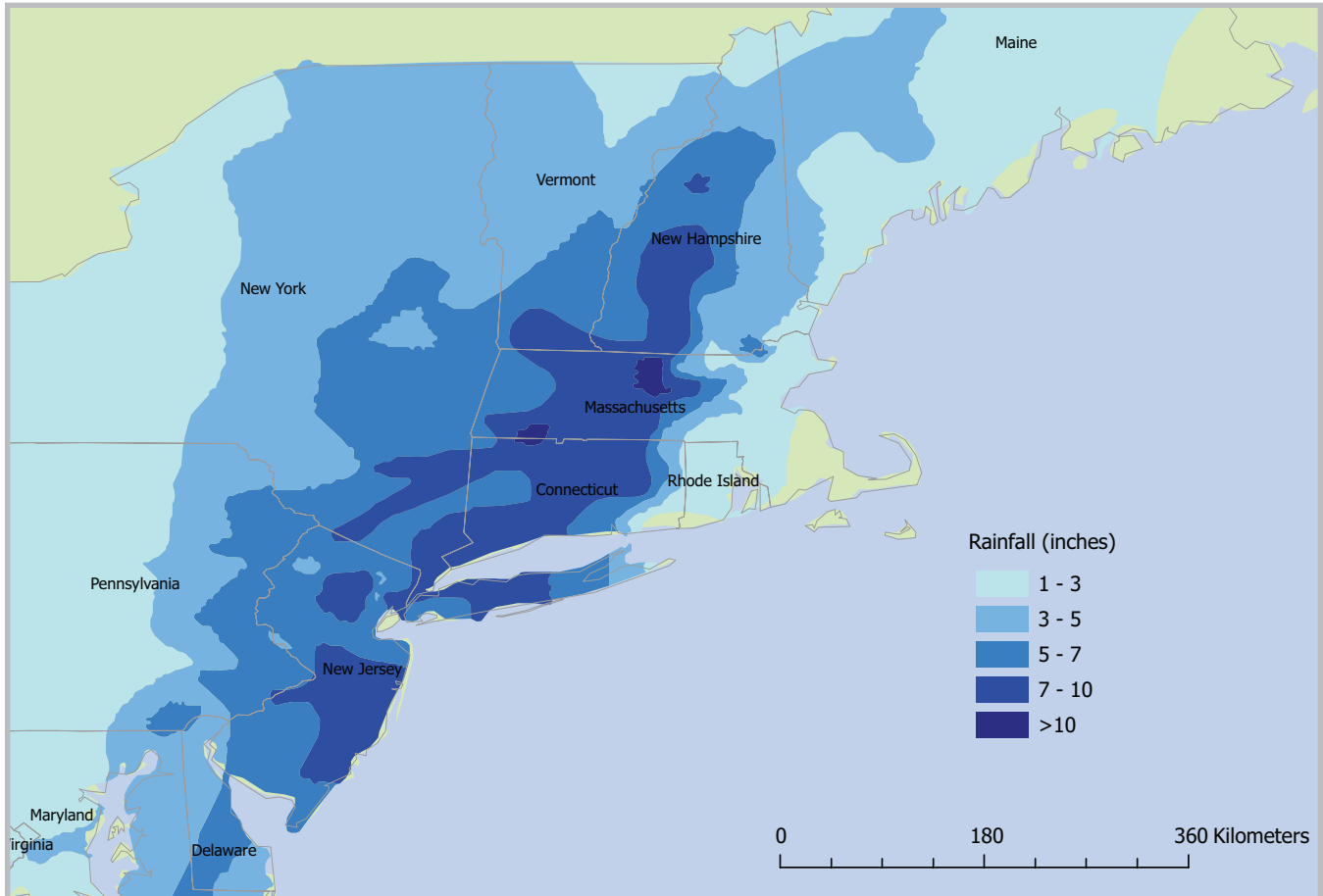
Rainfall from September 19-22, 1938, illustrating total accumulations before and during the 1938 Great New England Hurricane (Source: NOAA)

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Based on the above assumptions, the total insured loss associated with the storm surge flooding to all commercial and residential exposures is estimated to be between $6 billion and $10.5 billion. Of this loss, the loss borne by the National Flood Insurance Program (NFIP) is estimated between $3.0 billion and $4.5 billion. The privately insured losses resulting from the 1938 storm surge flooding are expected to range from $3 billion to $6 billion. The uncertainty in this range reflects the assumptions about the proportion of damage covered by private insurance in excess of NFIP policies, as well as commercial insurance penetration within the impacted region.

The property damage along Long Island's southern coastline and, in particular, on Fire Island, would be extensive. Thousands of tons of debris would be generated and coastlines would erode, as seen during the original 1938 hurricane. In addition, the property along the Narragansett Bay in Rhode Island, with the exception of downtown Providence, and along Buzzards Bay in Massachusetts would be impacted by the highest levels of coastal storm surges.

4.3 Inland Flooding Analysis

In order to reconstruct the extent of inland flooding in a repeat of the 1938 Great New England Hurricane, various sources of historical information were utilized, including rainfall estimates, measurements of flood crest levels at stations along the rivers across New England, and the locations of all the track and bridge washouts along the New Haven Railroad. In 2008, the extent of flooding would be significantly reduced in many places, as compared to 1938, due to the extensive flood mitigation measures put in place throughout the region since the historic hurricane. For example, the Army Corps of Engineers built and still operates various flood control dams, dikes, and pumping stations along the Connecticut River Valley in order to protect downstream areas from flooding. However, evaluating the extent of the inland flooding footprint at the time of the event is the first step in reconstructing its impact in 2008.

The inland flooding in the days following the 1938 hurricane was not solely a result of the rainfall associated with the hurricane, but also a consequence of the antecedent rainfall in the days leading up to September 21, 1938. Many rivers were already perilously close to flood stage before the storm. Along several rivers, the 1938 flood remains the peak flow seen during the 20th century, exceeding water levels during the Great Flood of 1936. In March of 1936, flooding was primarily due to warm and rainy weather melting the snow from an unusually snowy winter.

Estimates of rainfall throughout the mid-Atlantic and New England states from September 19 through September 22, 1938, have been compiled by NOAA's National Climatic Data Center (NCDC). The maximum rainfall over the days was close to 13 inches (33 cm) in Gardner, Massachusetts. The areas where flooding was widespread lie within the states of western Connecticut, western Massachusetts, New Hampshire, and Vermont, where rainfall exceeded 7 inches (18 cm) in the four-day span. The flooding in this area extended across much of the current 100-year flood plain, as defined by the National Flood Insurance Program (NFIP) maps.

Two sources of information were then utilized to confirm which rivers actually flooded during the 1938 event. First, the locations of the stations measuring crest levels above flood stage were identified, along with the river sections with maximum observed flows, in Connecticut, Massachusetts, New York, New Hampshire, and Vermont. These rivers were almost all located in the areas of highest rainfall levels. Second, the locations of

Power lines downed by fallen trees in Baton Rouge, Louisiana as a result of Hurricane Gustav, which made landfall along the Louisiana coast on September 1, 2008
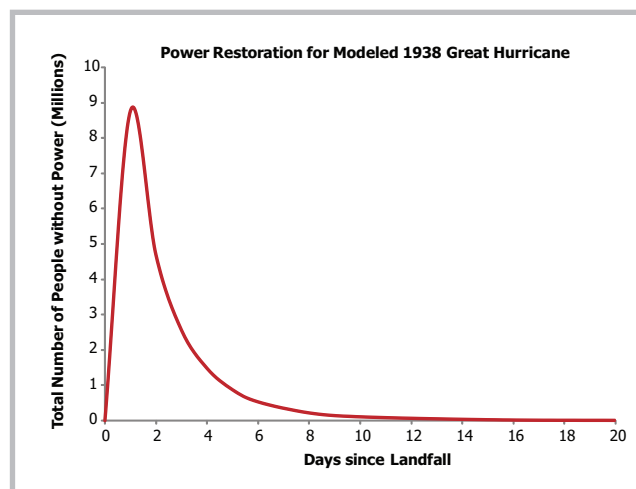
Power restoration curve utilized for modeling power outages from a repeat of the 1938 Great New England Hurricane in 2008

bridge and track washouts along the New Haven Railroad in Connecticut, Massachusetts, New York, and Rhode Island were mapped and compared to both rainfall and storm surge maps, also identifying those rivers in which river flows were beyond the design levels.

The total value of residential and commercial exposure in the 100-year flood plain of the affected areas and rivers is estimated to be $22.5 billion. Within this zone, assuming an average NFIP penetration rate of 22%, gives an NFIP loss of approximately $5 billion. In addition, the privately insured losses due to the inland flooding are estimated to be between $1 billion and $2.5 billion. These estimates, based on the extent of the flooding in 1938, would be further reduced by the network of river defenses that has now been constructed in the region.

4.4 INFRASTRUCTURE IMPACTS

During the 1938 Great New England Hurricane, the region's railroad network was damaged by the flood waters and power and telephone lines were downed by the falling trees. If a similar hurricane were to hit the region in 2008, most roads would be blocked by fallen trees, and extensive damage would occur to the power lines, telephone lines, and cell phone transmission towers across the affected region. In advance of the storm's landfall, the National Hurricane Center (NHC) would also issue storm warnings, prompting government officials to call for an evacuation of the residents in the areas with potential storm surge flooding.

4.4.1 Damage to a Power Distribution Network

In order to assess the scope of loss due to power outage and evacuation, RMS analyzed New England's power distribution network and the expected damage due to high winds, flooding, and falling trees. The duration and scope of a power outage increases as other factors increase, including the maximum wind speeds, the severity of the network's structural damage, the density of the population in the affected areas, and the density of the trees in the region. In addition, widespread flooding will increase the duration of outage, as workers are impeded from reaching damaged parts of the network.

Power outages occur as a result of damage to transmission lines, distribution lines, service lines, transformers, substations, and power plants. Typical damage involves broken transmission and distribution lines, as well as inoperative transformers or switching stations. Power outages due to hurricane damage start at wind speeds as low as 50 mph (80 km/hr), as above-ground distribution lines are damaged by falling trees. Power outages also occur when damage to one element

of the power distribution network leads to an electrical overload of other elements, such as transformers, which can then catch on fire. As more transformers are overloaded, they can fail in a cascade, amplifying the duration of a power outage.

4.4.2 Restoration of a Power Distribution Network

The speed of repairs to the lines of a power distribution network is a function of the number of available workers and the availability of materials and equipment. For example, after Hurricane Katrina in 2005, efforts to restore power in Louisiana involved 4,000 line workers at one utility company. However, after Hurricane Gustav in 2008, the same company brought over 15,000 workers from across the U.S. to assist in the power restoration efforts. In addition, special circumstances may delay the restoration of power, as when a critical part of the network, such as a nuclear power plant, has been shut down and requires certain regulatory procedures to restart its operations.
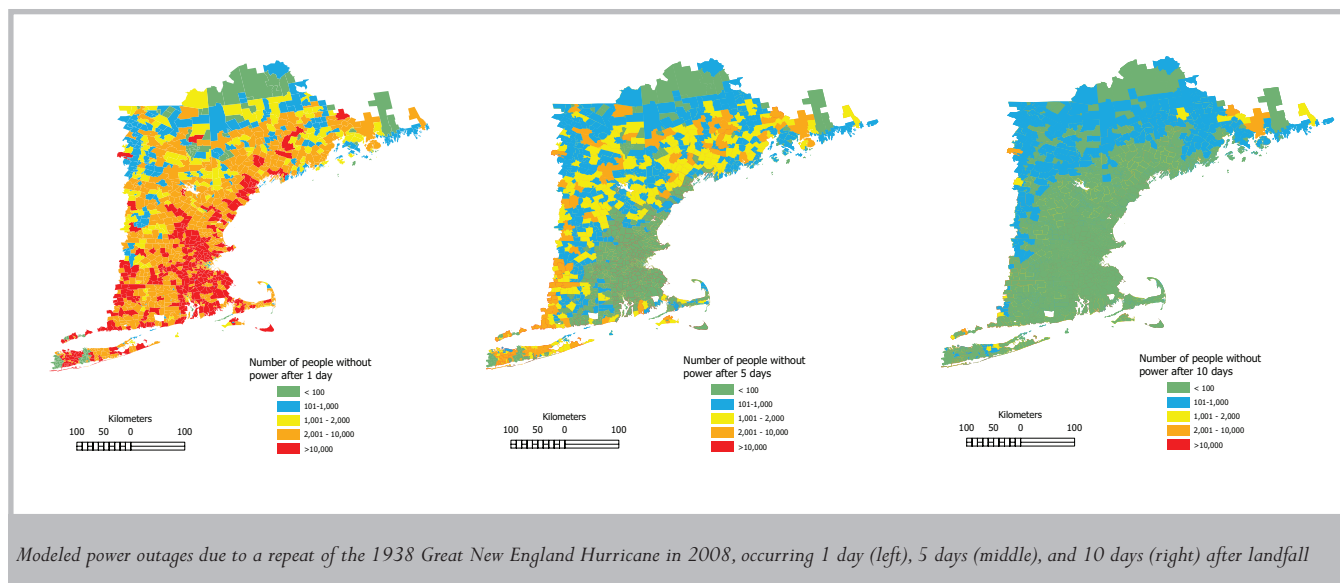
From a review of over 20 years of historical data, power outages typically do not last more than two to three weeks, with over 90% of customers recovering power within five to fourteen days. In addition, research has shown that utility companies generally assess the damaged parts of the network and the locations of damage within the first 24 to 48 hours after a hurricane's landfall. Restoration then proceeds based on safety and health, so hospitals, water treatment facilities and public service facilities, such as fire and police stations, are given first priority. Following the restoration of these critical facilities, large transmission lines are repaired, followed by substations and finally, the network's distribution and service lines.

4.4.3 Modeling Power Outages from a Repeat of the 1938 Storm

Based on the above assumptions on damage and restoration, as well as lessons learned from recent power outages during hurricanes Gustav and Ike in 2008, a model was developed for estimating the duration and scope of power outage in New England as a result of a repeat of the 1938 hurricane. The behavior of transmission lines and distribution lines are modeled separately, as the rate of repair to each set of lines is different, with transmission lines assumed to be repaired more quickly. In addition, the modeled power outage is based on the impacts of wind speed on the above ground portions of the power distribution network.

In the model, power restoration efforts for critical facilities are assumed to begin one day following the hurricane's landfall. Restoration efforts on downed

Modeled power outages due to a repeat of the 1938 Great New England Hurricane in 2008, occurring 1 day (left), 5 days (middle), and 10 days (right) after landfall

transmission towers and overloaded transformers then begin a few days after landfall. Assuming coastal areas are under evacuation order for a time following landfall, restoration efforts would first be concentrated on highly populated inland areas.

It is expected that there will be serious damage to transmission towers and substations. The initial number of customers without power on the first day after landfall is close to 9 million with less than one million without power on day 5 and close to full restoration of service across the region by day 10. As a result, indirect losses due to power outage could total between $2 and $3 billion, with the highest losses associated with business interruption.

4.5 Conclusions

Insured losses from wind, storm surge, and flooding from a repeat of the 1938 Great New England Hurricane total approximately $40 billion to $55 billion. This total estimate includes losses to both the private insurance market and those policies covered under the NFIP. In addition, those conditions that amplify insurance payments, in the context of a major regional catastrophe, are incorporated into the loss estimates, such as increased repair costs due to demand surge.

As the damaging wind speeds and flooding from the 1938 hurricane did not affect large areas of the populated cities of New York and Boston, widespread "Super Cat" secondary consequences of the event are not expected. Significant disruption would be limited to certain towns along the coast, and the scale of economic dislocation found in New Orleans after Hurricane Katrina in 2005 would not occur. While thousands of people would be displaced due to the destruction of their coastal homes, a large proportion of these individuals would have insurance and be able to find alternative temporary

accommodations. In addition, many coastal properties can be expected to be rebuilt, although the Base Flood Elevation (BFE) on the Flood Insurance Rate Maps (FIRMs) will most likely be raised for the construction of new properties along the affected coastlines. ■

NORTHEAST U.S. HURRICANE RISK

On the 70th anniversary of the 1938 Great New England Hurricane, the hurricane remains the costliest storm to impact the Northeast U.S. in the past century. Only one other storm over the past 300 years was comparable to the 1938 hurricane—the Great September Gale of 1815, which struck Long Island on September 23, 1815. The storm had a remarkably similar storm surge along the coastline, although the water levels in Providence, Rhode Island were slightly lower, as recorded on the wall of the city's Old Market Building. In addition, the 1815 storm's damage footprint was located a few tens of kilometers to the east. The most notable impact of the 1815 hurricane was the creation of the barrier beach of Long Island, leaving a permanent inlet that separates Long Beach from the rest of the island. One other major storm impacting the northeastern coastline of the U.S. occurred in the 17th century in 1635. However, the storm cannot be reconstructed with sufficient detail to determine the track or intensity of the storm.

Historically, a total of nine storms have had first landfalls in New England since 1900 with five storms of Category 3 strength over land, including the 1938 Great New England Hurricane, the 1944 Great Atlantic Hurricane, hurricanes Carol and Edna in 1954, and Hurricane Gloria in 1985. With the exception of Hurricane Edna, all of these storms made their landfall along New York's Long Island coastline. These historical storms illustrate the unique threat of hurricanes with first landfall in the Northeast U.S., which tend to travel faster than storms which impact the southeastern and Gulf Coast states. For example, the 1938 hurricane traveled over twice the distance as Hurricane Katrina during its final day before landfall. These storms are also driven by their interaction with the jet stream and have a tendency to undergo extratropical transition. Following transition, these storms are asymmetric with the heaviest rains often to the left-hand side of the hurricane's track and the strongest winds to the right-hand side of the track.

5.1 FUTURE HURRICANE RISK

In order to assess the future risk from hurricanes in the Northeast U.S., the RMS® U.S. Hurricane Model stochastic event set, which represents an exhaustive list of potential hurricanes to impact the U.S., was utilized. The storm events with first landfall in New York and of Category 3 or greater were modeled against the 2008 RMS® U.S. Industry Exposure Database (IED), noting the potential insured losses from the wind field alone.
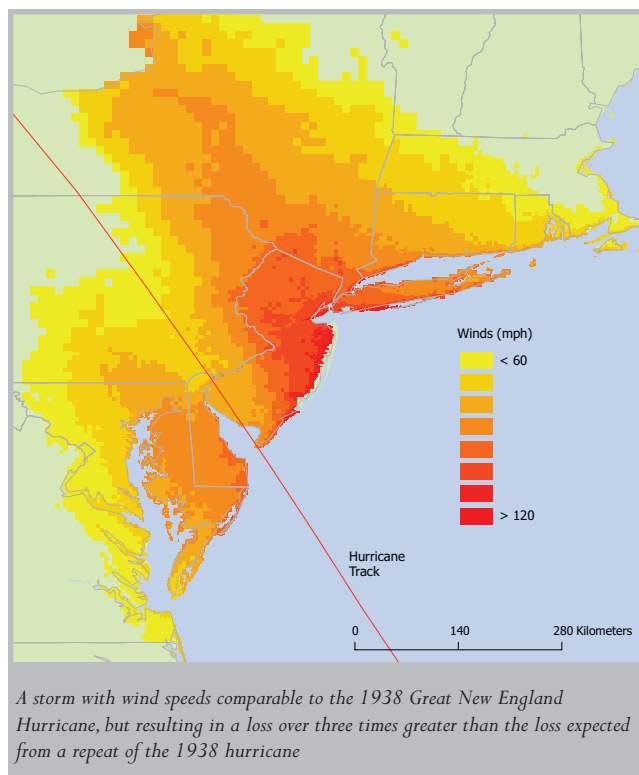
In the over 80 events to potentially impact the coastline of New York, the overwhelming majority of them are assumed to be transitioning storms. Losses range from between $1 billion and $150 billion with the 1938 Great New England Hurricane representing up to $35 billion in insured loss due to wind damage. So, while a repeat of the 1938 hurricane in 2008 would be a major regional catastrophe, events making landfall along New

Plaques on the Old Market Building in Providence, Rhode Island, denoting the water marks recorded during the 1815 Great September Gale (11 feet 9¼ inches) and the 1938 Great New England Hurricane (13 feet 8½ inches)
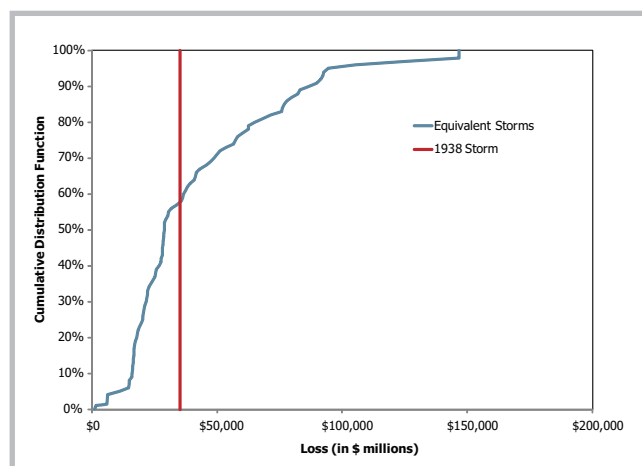
Northeast U.S. Hurricane Risk in 2008: Cumulative distribution function of potential insured losses from wind damage from storms of Category 3 or greater making landfall along New York's coastline, highlighting the loss from a repeat of the 1938 Great New England Hurricane

A storm with wind speeds comparable to the 1938 Great New England Hurricane, but resulting in a loss over three times greater than the loss expected from a repeat of the 1938 hurricane

York's coastline could potentially result in much greater damage. For example, the damaging winds from an event making landfall closer to the western end of Long Island would impact the high density of exposure in Manhattan, as well as create an overwhelming storm surge along the Hudson River.

In addition, a transitioning storm with wind speeds comparable to the 1938 storm but making landfall along another coastline could result in much greater damage. A Category 3 hurricane, making landfall along New Jersey's Delaware Bay coastline and proceeding on a more northwesterly track, would result in an estimated $115 billion in insured losses, over three times the expected loss from a repeat of the 1938 storm.

Climate change could potentially impact future hurricane risk in the Northeast U.S. as well. An increase in sea surface temperatures (SSTs) in the main area for storm development would increase the intensity of storms making landfall along these coastlines. However intense storms in New England are also very much dependent on the pattern of mid-latitude circulation and any changes in that circulation during the hurricane season will also affect the potential for intense storms to make a New England landfall. Global sea level rise would make coastal communities more vulnerable to damage from storm surge.

5.2 Mitigation of Hurricane Risk

As hurricanes are rarer in New England as compared to Florida or the Gulf Coast, it is imperative to educate the communities on the potential impacts of a Category 3 or greater storm and prepare well in advance of an impending storm. Preparations to minimize wind, storm surge, and inland flooding damage, as well as minimize the number of impacted individuals, can take various forms. For example, inland flooding damage from a severe hurricane would be greatly contained due to the extensive flood control projects currently in place along the Connecticut River Valley.

For property owners subject to hurricane risk in the Northeast U.S., proper disaster planning should include building assessment and insurance. Its imperative that a structure's ability to withstand wind and water damage be understood and mitigation techniques implemented as applicable. The right amount and type of insurance coverage, including flood coverage, should also be purchased to ensure financial security after an event.

To reduce the occurrence of power outages, the damage from falling trees on above ground distribution lines must be minimized. Utility companies are very active in removing debris around distribution lines, as well as pruning and removing overgrown trees. Alternatively, distribution lines can be buried. While this solution seems the best one to minimize wind damage, it is a very costly one. One study undertaken in North Carolina in 2003 reported that the burying of overhead power distribution lines would take 25 years to complete and increase the average electric bill by 125%. In addition, it takes longer and costs more to repair underground lines when they are damaged, and the susceptibility to corrosion from water inundation becomes a factor.

The evacuation of individuals living on Long Island, New York, is of particular concern, as the transportation infrastructure has not grown in proportion to the growth in the coastline's population. There are few evacuation routes off the island and a considerable area would be affected by the storm surge of a Category 3 or greater storm. In addition, a fast-moving storm would leave less time for compliance with an evacuation order.

In 2008, the coastline of the northeastern U.S. was spared the devastating effects of a major hurricane. However, this is not likely to continue indefinitely in the future. A major hurricane will strike New England again; only uncertainty in the size and timing of the event remains. ■

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