Marine Extension Bulletin

May 2012

Woods Hole Sea Grant Program
Cape Cod Cooperative Extension

Hurricane Vs. Nor'easter

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The Massachusetts shoreline is subject to erosion when wind, waves, and currents wear away the land along the water's edge. Occasional coastal storms can dramatically intensify the erosion process in the short term and have a significant impact on long-term erosion rates. Residents near the coast in Massachusetts often will hear about erosion caused by hurricanes (part of the Tropical Cyclone spectrum in Table 1) and by "nor'easters." While heavy winds, rain, large waves, and storm surge from both types of systems have potential for coastal damage, there are some significant differences between the two types of systems. This bulletin will cover the two types of storms, explain the differences, and discuss the potential coastal impacts.

Tropical cyclones and nor'easters have several similarities. They are both low-pressure systems characterized by the upward movement of air, counterclockwise (in the Northern Hemisphere) rotating winds, high wind speeds, and flooding of coastal areas by heavy rainfall, storm surge, and waves. However, fundamental differences exist between the two types of coastal storms. Hurricanes are "warm core" systems, which mean they thrive on warm temperatures, while nor'easters are "cold core" systems, thriving on cold air. They typically occur at different times of the year with different durations and size.

Tropical Cyclones

A tropical cyclone is classified as a warm core system because its center is warmer than the surrounding air and the wind speeds are greatest near the surface. The center of the storm, the eye, is cloud free and has relatively low surface pressure, warm temperature, and sinking air. Around the eye is an eye wall of intense thunderstorms where the strongest winds and heaviest rainfall typically occur. Bands of thunderstorms spiral out from the eye wall.

Tropical cyclones form over oceans that have a deep layer of warm tropical water. They get their energy from heat released as water vapor condenses into liquid water. In the North Atlantic ocean, tropical cyclones are also called hurricanes, tropical storms, and tropical depressions, depending upon intensity. Tropical oceans have their highest surface temperatures and evaporation rates in late summer and early fall. Thus, hurricane season in the Atlantic begins June 1 and ends November 30. However, August and September are the peak hurricane months. The number of hurricanes, and the resulting damage, in the Atlantic and Caribbean is typically reduced during El Niño years due to increased wind shear, which prevents tropical disturbances from developing into hurricanes. The opposite is true for La Niña (Pielke and Landsea, 1999). Tropical cyclones tend to travel quickly through New England. If not they typically

Wind Speed (mph)	
Tropical depression	0–38
Tropical storm	30–73
Hurricane	
Category 1	74–95
Category 2	96–110
Category 3	111–130
Category 4	131–155
Category 5	>155

Table 1. Tropical cyclone spectrum indicating the common names and corresponding intensities.

Tropical Cyclone	Nor'easter
Center of storm is warmer than surrounding air	Center of storm is cooler then surrounding air
Forms over a tropical ocean	Forms outside the tropics
Typically occurs June – November	Typically occurs October – April
No fronts	Has fronts
Strongest winds near surface	Strongest winds in the upper atmosphere
Typically 200–500 miles wide	Typically 700–1,000 miles wide
Name and category	No name or category*
Has an eye	Does not have an eye**

Table 2. The difference between a typical cyclone and a nor'easter.

* The media has a tendency to name events (Snowmageddon, Snowpocalypse, Groundhog Day Storm, Patriot's Day Storm) which is not the same as a National Hurricane Center official name. There is also Beaufort scale for wind speeds, that is primarily used in marine forecasts and warnings (small craft advisory, gale warning, storm warning, hurricane force wind warning) and associated warning flags. So while a nor'easter is not categorized, there is a corresponding wind scale similar to the Saffir-Simpson scale.

** Only tropical cyclones have structures officially called eyes, however other storms can exhibit eye-like structures apparent in radar and satellite imagery. While a nor'easter might have eye-like structures, it does not have an eye. An eye is a result of descending air that warms and contributes to the warm core of the tropical cyclone.

Figure 1. Satellite image of Hurricane Irene on August 25, 2011 (NOAA-NASA GOES Project).

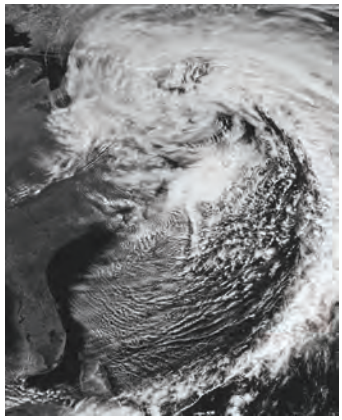


Figure 2. Satellite image of a nor'easter on April 16, 2007 (NOAA-NASA GOES Project).

weaken due to the cooler waters of southern New England and the north wall of the Gulf Stream. On the other hand, nor'easters do not weaken due to these conditions and can linger for days.

Nor'easters

A nor'easter is classified as a cold core system because its center is colder than the surrounding air and the wind speeds increase with altitude. A nor'easter (aka East Coast Winter Storm or ECWS) is a type of extratropical cyclone, which means that it forms outside of the tropics and is connected with warm and cold fronts and changes in temperature and humidity. It is called a nor'easter because the winds over coastal areas blow from a northeasterly direction. Unlike a tropical cyclone the location and intensity of the strongest winds coincide with the region in which the largest gradient between high and low pressure exist (which may be over 200 miles from the storm center).

Nor'easters obtain much of their energy from the temperature contrast between warm and cold air masses as gravity pulls cold heavy air under warm light air. Nor'easters that travel up the coast from the south are typically formed by the interaction of cold air over the coastal plain and the warm Gulf Stream waters. However, storms formed north of 35° N latitude almost exclusively are generated over the Plains or Midwest (Hirsch et al., 2001). An average of 12 nor'easters may impact Massachusetts any time of the year, but are most frequent and strongest between October and April. The seasons with the most nor'easters tend to occur in association with El Niño events, with some influence of the Pacific decadal oscillation (Hirsch et al. (2001). These drivers increase summer sea surface temperatures off the southeastern U.S. coast and in the Gulf of Mexico which indicates higher winter storm activity the following winter (DeGaetano, 2008).

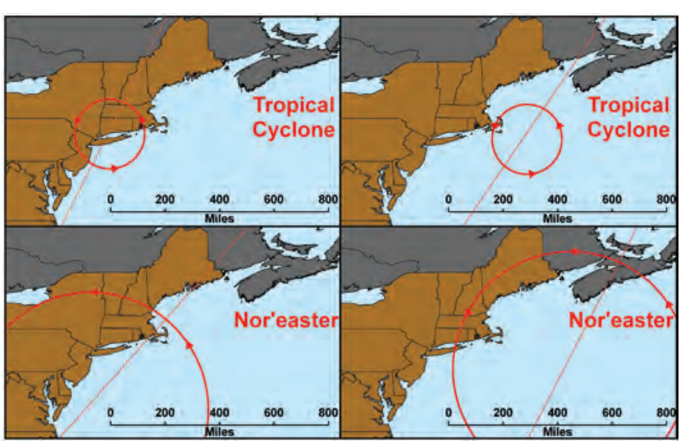


Figure 3. Illustration of the effect the size of the storm system will have on Massachusetts impacts. The sizes of these storms are near the maximum from Table 2.

Storm Impacts

A tropical cyclone may have significantly different effects on Massachusetts shoreline depending on the storm size. As shown in Figure 3, the top left scenario would have large surge potential for Buzzards Bay; however the top right scenario would have much less coastal flooding impacts. On the other hand, nor'easters (lower two panels on Figure 3) are so large regardless of exactly where the center of the storm is located all of coastal Massachusetts will feel the effects. The reason a nor'easter is called a nor'easter is because it produces winds from the northeast. This is due to the relatively large diameter of nor'easters. In order to have wind from the south affecting the Massachusetts coastline the center of the storm would have to be over land, which is not typical of nor'easters.

In the northwest Atlantic, a tropical cyclone's right side (relative to the direction it is travelling) has the strongest wind speed due to the hurricane wind speed being added to the speed at which the storm is traveling. The increased winds on the right side of the eye increase the storm surge. For example, in 1991 Hurricane Bob made landfall to the west of Buzzards Bay. If the storm trajectory had been farther to the east the surge would have been significantly reduced in Buzzards Bay. Although nor'easters have similar rotation to tropical cyclones the core is not as well formed and the strongest wind speeds are in the upper atmosphere, reducing the effect of where the center of the storm makes landfall. Nor'easters are typically larger with a poorly defined center than tropical cyclones. The geometry of Cape Cod is highly significant in determining the effect of each type of storm (Figure 3). The northeast winds of a nor'easter have great potential to affect the shorelines of the outer cape, Cape Cod Bay, and the north side of Martha's Vineyard and Nantucket. However, a tropical cyclone that makes landfall to the west would have significant winds from the south, which would have great potential to affect the shorelines of Buzzards Bay, Nantucket Sound, and the south side of the Islands.

Wave action can be a significant component to coastal inundation and coastal damage. The overwash at barrier beaches can contribute to the total inundation over land, and wave battery is responsible for much of the actual damage/destruction along the immediate open shoreline. The storm surge will typically be higher at the upper parts of bays and inlets because the water gets constricted. Along the open coastline near the mouths of bays, the surge may be not as high, but the wave action is more significant.

It is important to remember that hurricanes (and other tropical cyclones) can transform into nor'easters (aka extratropical cyclones) and maintain winds of hurricane or tropical storm force. During the transition, the storm's energy source changes from the release of heat due to condensation to the temperature contrast between warm and cold air masses. Also, the storm will lose its warm core and become a cold core system, forming or connecting with nearby fronts. The system will also increase in size and become less well-formed. Although less frequent, the opposite can occur, too. Tropical cyclones can form off the southeast United States from a cold core system. The October 1991 "Perfect Storm" transformed into a hurricane after the coastal damage had already taken place. While it was not named, it did take on an easily distinguishable eye, and existed for a short time as a Category 1 hurricane and prompted a Special Marine Warning for Georges Bank.

Adding Storms to Tides

The rhythmic rise and fall of the tides (the blue line in figure 4) due to the gravitational pull of the moon and sun can be accurately predicted by NOAA. Mean Higher High Water (MHHW) is defined as the average of the higher high water height of each tidal day, therefore when the blue line is above zero it indicates a day when the waterline would be further landward on a beach than normal. Evidence of these times is a wrack line further landward on the beach than typical tides; however waves can push this wrack line higher than just higher tides. The moon's orbit around the earth is elliptical rather than circular, which means that the distance between earth and moon is always changing. When the moon is closest to earth (called Perigee Moon), its effect on tides is greatest. At the perigee location the moon is about 30,000 miles closer to earth than at apogee. Perigee is reached once every time the moon circles the earth, which takes approximately one month (see figure 5). The blue line shows a rise above MHHW for both graphs due to the moon only being a day away from maximum Perigee conditions on April 17, 2007 and August 30, 2011 (see figure 4).

In addition to the Perigee moon, there is also a spring tide which, when combined, allow for the largest astronomically high tides of the year (Perigean Spring Tide) which happened to coincide with the Patriot's Day Storm on April 15-17, 2007. The predicted blue "spring tide" conditions are forced by the aligned gravitational pull of the moon and sun (see figure 6). The red tidal line is a plot of the data recorded at the Woods Hole Tide Gauge. The storms produced surge (a higher sea elevation) that were outside the scope of the NOAA tidal predictions (blue line). Storm surge varies widely by location because it depends on the shape of the coast, track and strength of the storm, slope of the sea floor, storm speed, and low barometer pressures. The storm surge is observed in the graph as the difference from the predicted tide and the storm tide (shown by the green line with the time period of >1' surge shaded in gray). The storm surge produced by both of these storms was up to three feet above the predicted blue line (figure 4).

For Hurricane Irene (which was downgraded to a tropical storm before it reached Massachusetts) the surge peaked at the Woods Hole, Mass. station on a falling tide on August 28, 2011 and the time period of 1' surge did not last until the next high tide (~15 hours). For the Patriot's Day Storm the surge peaked at the same location on a high tide on April 16, 2007 and the time period of 1' surge lasted more than four high tides (~47 hours). Major coastal flooding and storm damage resulted not only from the severity of the storm but also due to the timing of the Perigean spring tides. The 2007 nor'easter hit during highest predicted tide of the month which was also the top 0.2% of the year.

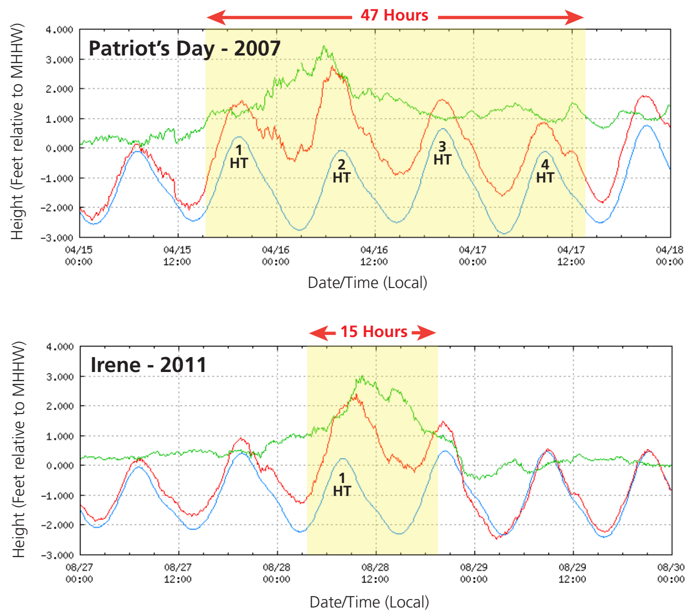


Figure 4. A water level graph for the three-day time period surrounding the intersection of Hurricane Irene (8/27-29/2011) and the Nor'easter from 4/15-17, 2007. The blue lines shows tidal conditions predicted by NOAA with the consideration of the gravitational pull of the moon and sun. The red line is a plot of the observed water level data recorded at the Woods Hole Tide Gauge. The green line indicates the difference from the predicted tide and the storm tide. The storm surge (time period shaded in yellow above 1') produced by these storms was up to three feet above the predicted blue line. (Adapted from NOAA's Center for Operational Oceanographic Products and Services Historic Tide Data available at: http://tidesandcurrents.noaa.gov/)

Figure 5.

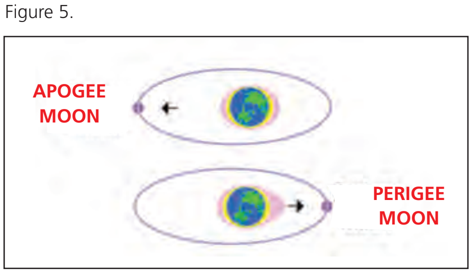
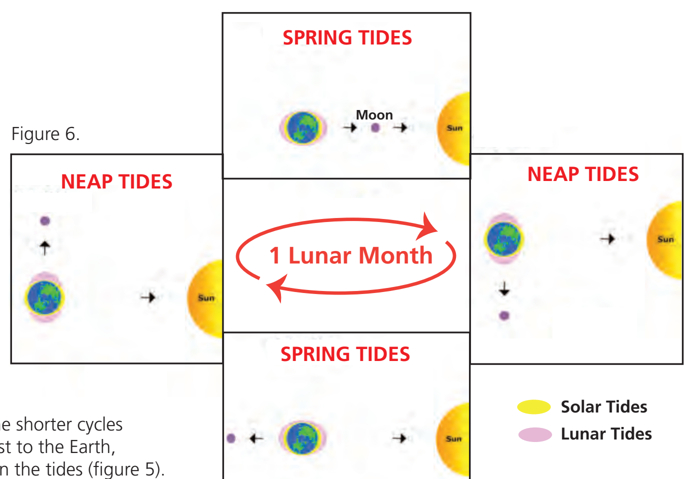


Figure 6.



In additional to the daily cycles of the tide there are longer cycles upon which the shorter cycles are superimposed. Once every lunar month, at perigee, when the moon is closest to the Earth, tide-generating forces are greater than usual, producing above average ranges in the tides (figure 5). Approximately two weeks later, at apogee, when the moon is farthest from the Earth, the lunar tide-raising force is smaller, and the tidal ranges are less than average. The gravitational pull of the moon and the sun affect the Earth's tides on a monthly basis (figure 6). When the sun, moon, and Earth are in alignment (at the time of the new or full moon), the solar tide (yellow) is added to the lunar tide (pink), creating higher high tides, and lower low tides (both are called spring tides). One week later, when the sun and moon are at right angles to each other, the solar tide partially cancels out the lunar tide and produces moderate tides known as neap tides. (Adapted from NOAA's National Ocean Service Tides and Waters Levels Tutorial available at: http://oceanservice.noaa.gov/education/tutorial_tides/)

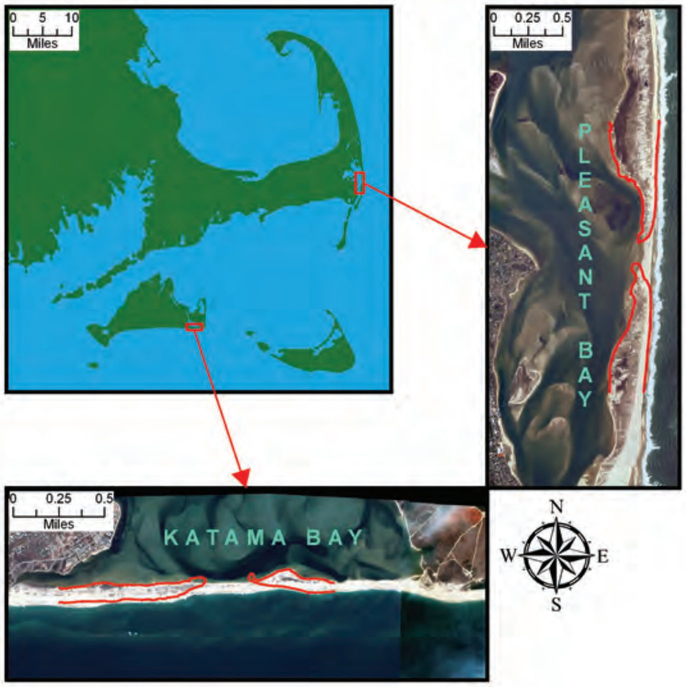


Figure 7. Locations of the barrier island breaches that occurred during the April 2007 storm. The Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) collected the aerial photograph shortly before the storm and the red lines were extracted from JALBTCX LIDAR flown shortly after the storm.

Nor'easters Break Barrier Beaches

Coastal storms (both extratropical and tropical) are major contributors to shoreline erosion, overwash processes, and the opening of tidal inlets on barrier systems (Leatherman, 1982). Nor'easters typically last longer than tropical cyclones (> tidal cycles) and so high winds, waves and increased water levels can extend over days instead of just hours (shown in Figure 4). In this way winds from nor'easters may decrease the amount of ebb tidal flow in embayments (e.g., within Pleasant Bay) allowing water in but not out over several tidal cycles. An average of 12 nor'easters impact Massachusetts from October to April with a maximum in January, however some coastal systems may be more vulnerable at the end of the season (April) after experiencing multiple nor'easters. This could be one reason why Pleasant Bay and Katama Bay were both primed to be breached during the April 2007 storm (in addition to the Perigean spring tide conditions).

The Patriot's Day Storm of April 15-17, 2007 breached the barrier beaches at both Pleasant Bay and Katama Bay (Figure 7). Nor'easters have been responsible for all of the significant openings at these two barrier beach systems in recent times (Pleasant Bay, Jan-1987; Apr-2007 and Katama Bay, Feb-1976; Apr-2007). While some breaches will close by themselves in a short amount of time (e.g. Hurricane Bob briefly opened Katama Bay in 1991), both of these 2007 breaches became new inlets for the bay. The location of a new breach is typically determined by the condition and elevation of the barrier beaches. The longevity of a new inlet is highly dependent on the local hydrodynamics and coastal processes of the system. The piling up of water from the north within the bay for multiple tide cycles likely added to the breach of the southern barrier beach of Katama Bay. There is a long history of new inlets forming, migrating, and closing for a time in Katama and as of 2012 this inlet has diminished from a 3,000' wide opening to only a few hundred feet separating Norton Pond from Chappaquiddick Island.

Nor'easters represent the greatest coastal flooding threat to Pleasant Bay. This threat is exacerbated by the orientation of the two inlets relative to the north east set of the storm waves, and due to the relatively slow rate of speed at which these systems move (Pleasant Bay Alliance, 2011). Pleasant Bay already had a relatively new inlet that had formed in 1987; however this 2007 inlet appears to have become the dominant inlet for the system. During the April 2007 storm, water was forced into the Pleasant Bay system from large storm driven waves, which increased water in the bay above normal tidal height. The duration of these waves restricted the discharge of water on outgoing tidal cycles, and greatly increased the low tide elevation over multiple tidal cycles.

Summary

Nor'easters have a major impact on coastal communities in Massachusetts. These storms cumulatively cause more damage than hurricanes due to their higher frequency of occurrence and more widespread impacts. While hurricanes may get more publicity (and cause more damage down south), it may be the nor'easters that cause more shoreline change over the long term to the Cape and Islands. This is not to say that hurricanes are not a threat, depending on the landfall location there is great potential for severe localized coastal damage due to tropical storms.

Additional Information

Hurricanes and Tropical Weather information available at: http://www.noaawatch.gov/themes/tropical.php

Storm Surge and Coastal Floods information available at: http://www.noaawatch.gov/themes/coastal_inundation.php

Acknowledgements

We'd like to thank Robert Thompson (MIC at NWS Taunton) for his valuable review and comments on this extension bulletin. His extensive knowledge of these coastal storms and how they act in New England was of great help.

Sources

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This document, a collaboration of the Woods Hole Sea Grant Program and Barnstable County's Cape Cod Cooperative Extension, should be cited as follows: Hurricane Vs. Nor'easter by Greg Berman and Kodi Nemunaitis-Monroe.

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