# Nor'easters

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*These cyclonic storms batter the East Coast from October through April, yet their destructive potential remains among the most difficult to predict*

Robert E. Davis and Robert Dolan

Most of us are probably familiar with the parable of the man intently searching the sidewalk under a street lamp at night. As the story goes, a passerby stops to ask what he is looking for. When the man replies that he is trying to find a ring he lost down the street, the incredulous interloper asks why, if he lost the ring down the street, he is searching under the light. The answer, of course, is that he can see better there.

To no small extent, this parable applies to the study of storms. The most noticeable storms, and those that can be most clearly illuminated by atmospheric measurements, have been the most studied. Hurricanes and tornadoes, for example, are spatially confined, the forces that drive them are highly concentrated, and each has a distinctive form and readily quantifiable characteristics. As a result, data about them are abundant, and their behavior is relatively well understood, although still difficult to predict.

Hurricanes and tornadoes are also studied because they are highly destructive storms, and knowledge can help minimize injury to people and property.

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But other equally destructive storms are not so well studied. A primary example is the nor'easter, a type of extratropical coastal storm that causes significant damage along the eastern coast of North America. Hurricanes typically threaten a relatively small ribbon of coastline, roughly 100 to 150 kilometers. The high waves of strong nor'easters can cause damage comparable to, or even occasionally exceeding that of a hurricane, because they can affect stretches of coast over 1,500 kilometers long.

Nor'easters, so named for the direction from which their winds blow, are weaker low-pressure systems with winds that rarely acquire the strength of even the smallest hurricane. They have not been well studied because they are perceived to be less destructive than other storms and because their diffuse nature makes categorizing them and predicting their behavior very difficult. Recently we have been studying nor'easters to determine how they are formed, what factors contribute to their frequency and power, and how their destructive potential can be compared. We have developed a classification system that may help in the understanding of storm impacts, and we have found interesting seasonal patterns of storm strength and occurrence. Nor'easters are difficult to predict, but a systematic understanding of their development and behavior, combined with better measurement techniques, may eventually help in forecasting.

## Infamous Nor'easters

Although weather observations were not federally mandated in the United States until the mid-19th century, it is possible to piece together the history of great storms from newspaper reports and the journals of weather observers in the American Colonies. Nor'easters have had a prominent place in these forms of written history because they are often responsible for heavy snowfalls in New England and the Middle Atlantic states.

Massachusetts Bay Colony Governor John Winthrop, who kept a journal of weather events in the early 1600s, wrote that major New England snowstorms came out of the east: "When the weather sets in from the east, you can expect rain or snow in great abundance." The first person to recognize that cyclones are actually smaller systems embedded in a larger, steering flow was (as is often the case) Benjamin Franklin. Based on his observations of weather variations and wind direction, Franklin noted that northeast winds (usually associated with rain and snow) cause precipitation that begins in the south and spreads northward along the coast. A newspaper editor reported in 1802 that Franklin's theory was verified by that February's major nor'easter.

The most famous extratropical storm in U.S. history peaked on March 7, 1962 (Ash Wednesday). This storm produced open-ocean waves over 10 meters high and caused over $300 million in property damage along 1,000 kilometers of the Atlantic coast. The extensive damage and lack of warning associated with the Ash Wednesday storm contributed to a rapid expansion of development in research on coastal storms and coastal geomorphology.

In recent years, the U.S. coast has been struck by a series of very strong nor'easters. A March 1989 storm caused serious beach erosion and property

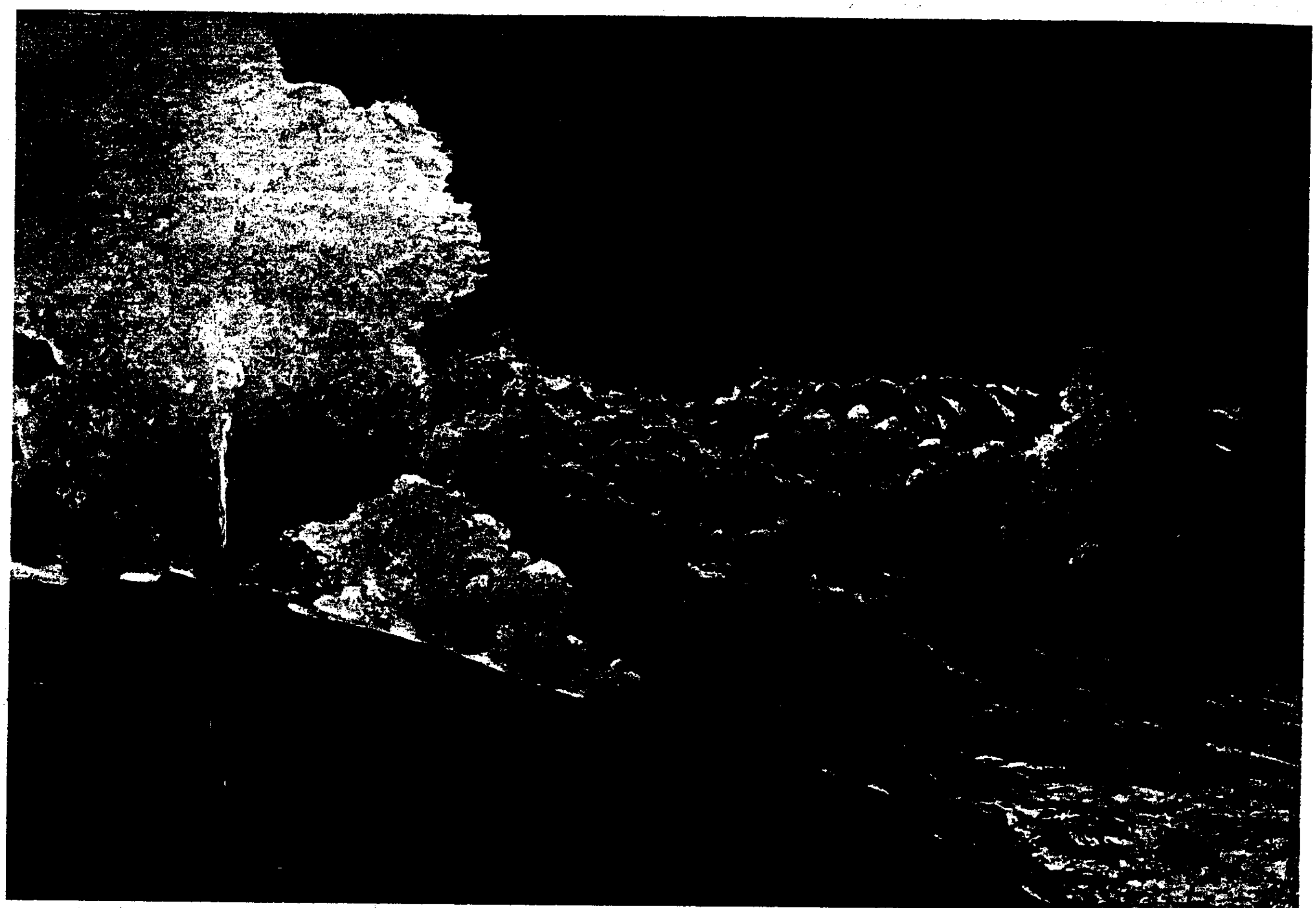


**Figure 1. Midlatitude cyclonic storms, called nor'easters, have been recognized for centuries as one of the most powerful influences on the weather of the East Coast of the United States. Yet the details of their genesis, their characteristics and their potential power have remained elusive, making their prediction difficult. Winslow Homer captured the destructive essence of the storms—their high waves—when he painted "Northeaster" in 1895. Copyright by the Metropolitan Museum of Art.**

damage to the mid-Atlantic coast. The strength of this single storm at North Carolina's Outer Banks accounted for two-thirds of the yearly average wave power and sediment transport along the coast. In October of that year, a small but locally powerful nor'easter drove an ocean-going hopper dredge through the Bonner Bridge spanning Oregon Inlet, North Carolina. The Halloween 1992 storm was noteworthy not only for its high waves but also for its unusually long fetch (the length of open ocean over which the wind blows from the same direction), which stretched 3,500 kilometers from Newfoundland to Miami. In December 1992 another major nor'easter struck the mid-Atlantic and New England coasts, generating waves over 6 meters high in some locations. This was followed in March 1993 by another significant storm, the so-called "storm of the century," which, in addition to heavy snowfalls, generated waves over 4.5 meters high along much of the East Coast.

**Storm Formation**

Like all storms, nor'easters arise in areas where the atmosphere is unstable and serve the purpose of reducing or eliminating those instabilities. These instabilities are the result of atmospheric systems at work on a global scale.

Atmospheric motion (wind) is generated from the unequal spatial distribution over the earth of energy from the sun. Large differences arise between the equator and the poles in the amount of energy received by the atmosphere and the surface of the earth. This differential heating causes air-pressure differences, which, in turn, cause the atmosphere to "slosh" back and forth like water in a tilted basin. Coupled with a rotating earth and an uneven distribution of land and water, a complex wind system develops that is constantly striving to achieve an atmospheric equilibrium.

The resulting general circulation of the atmosphere has six planetary-scale wind belts. In the tropics, the warm, moist air over the equator rises within thunderstorm clouds, travels poleward and sinks in the vicinity of 30 degrees north and 30 degrees south, where dry conditions prevail. One arm of this sinking air spreads poleward and turns to the east in the middle latitudes. This belt of predominantly westerly (west-to-east) winds is responsible for the familiar pattern of storm systems that move from west to east across the United States and Eurasia. The midlatitude westerlies are found not only at the surface but also 10 kilometers high in the atmosphere, where the polar-front jet stream is located. At that altitude, the core of wind is moving faster than at any other location. The jet stream circles the globe in a meandering pattern and is responsible for the formation of cyclones—counterclockwise-rotating storm systems that mix southern and northern air—at the surface.

Apart from their origins in atmospheric instabilities and their cyclonic winds, hurricanes and nor'easters bear little resemblance to each other. Hurri-

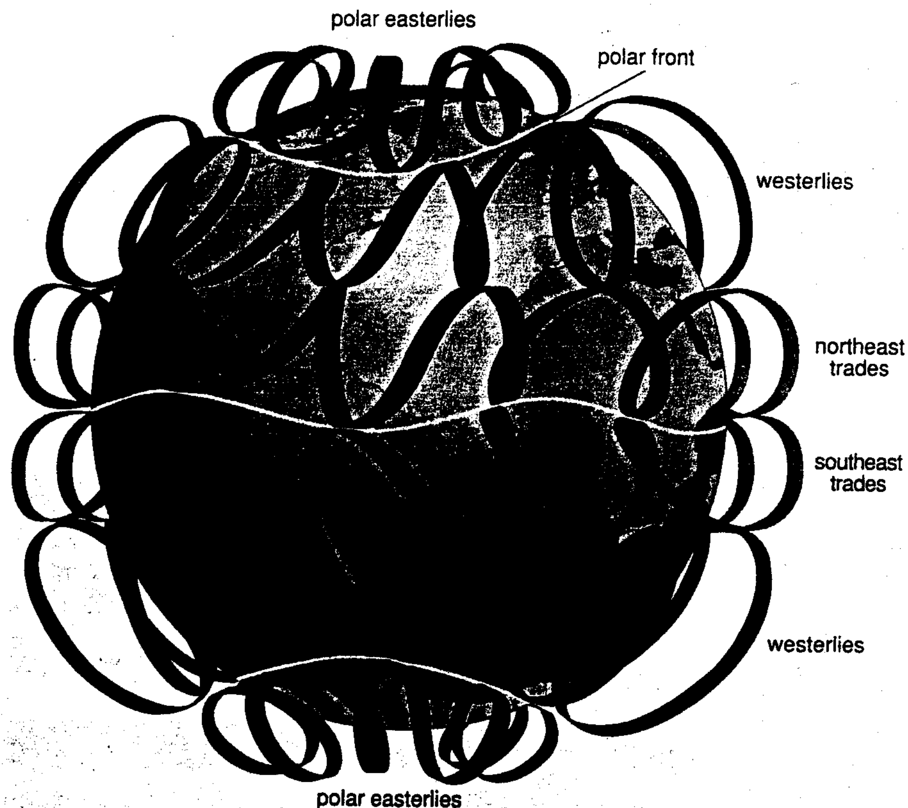



**Figure 2. Idealized planetary winds form six major belts, three in each hemisphere, which attempt to equalize the atmospheric energy imbalances that result from unequal distribution of solar radiation. Humid air over the equator rises, moves poleward and sinks at about 30 degrees north and south latitude, creating a subtropical belt of high-pressure air at the surface. Some of this air moves back toward the equator and forms the northeast and southeast trade winds. Other air moves poleward and forms the midlatitude westerlies at the surface. Over the poles, cold, sinking air moves toward the equator and forms the polar front when it encounters the midlatitude westerlies. At this junction is found the polar jet stream, a necessary component in the formation of nor'easters.**

canes are warm-core systems—the temperatures at their centers are higher than those in the surrounding regions—and are thus limited in height (or weakened at height) by the colder upper air. Hurricanes form over warm ocean waters and derive their energy from oceanic evaporation. Conversely, most extratropical cyclones are cold-core systems that do not lose intensity with height and that can be identified at the altitude of the jet stream. The fast winds of the jet stream move mass away from the center of the storm, allowing the surface pressure to become lower and the storm to become stronger. Thus a strong jet stream is necessary for the development and sustenance of nor'easters.

Cyclones often form along fronts—the boundaries between masses of air that have different temperatures. If one were to travel through a cool air mass toward a front, the temperature would be seen to rise only very gradually approaching the front. At the front, however, the horizontal temperature gradient would be large as one passed from one air mass into another. These areas of strong horizontal temperature gradation, referred to as baroclinic zones, are the spawning grounds for cyclones because the temperature difference creates instability. When a surface baroclinic zone coincides with a strong jet stream aloft, conditions are ideal for

AP/Wide World Photos

**Figure 3. Destruction from the Ash Wednesday (March 7, 1962) nor'easter amounted to more than $300 million. Brigantine, a suburb of Atlantic City, New Jersey, was battered by the storm for four days. Nor'easters, although capable of generating strong winds, inflict damage primarily as a result of high waves and storm surges. The Ash Wednesday storm may have generated deep-ocean waves 10 meters high.**

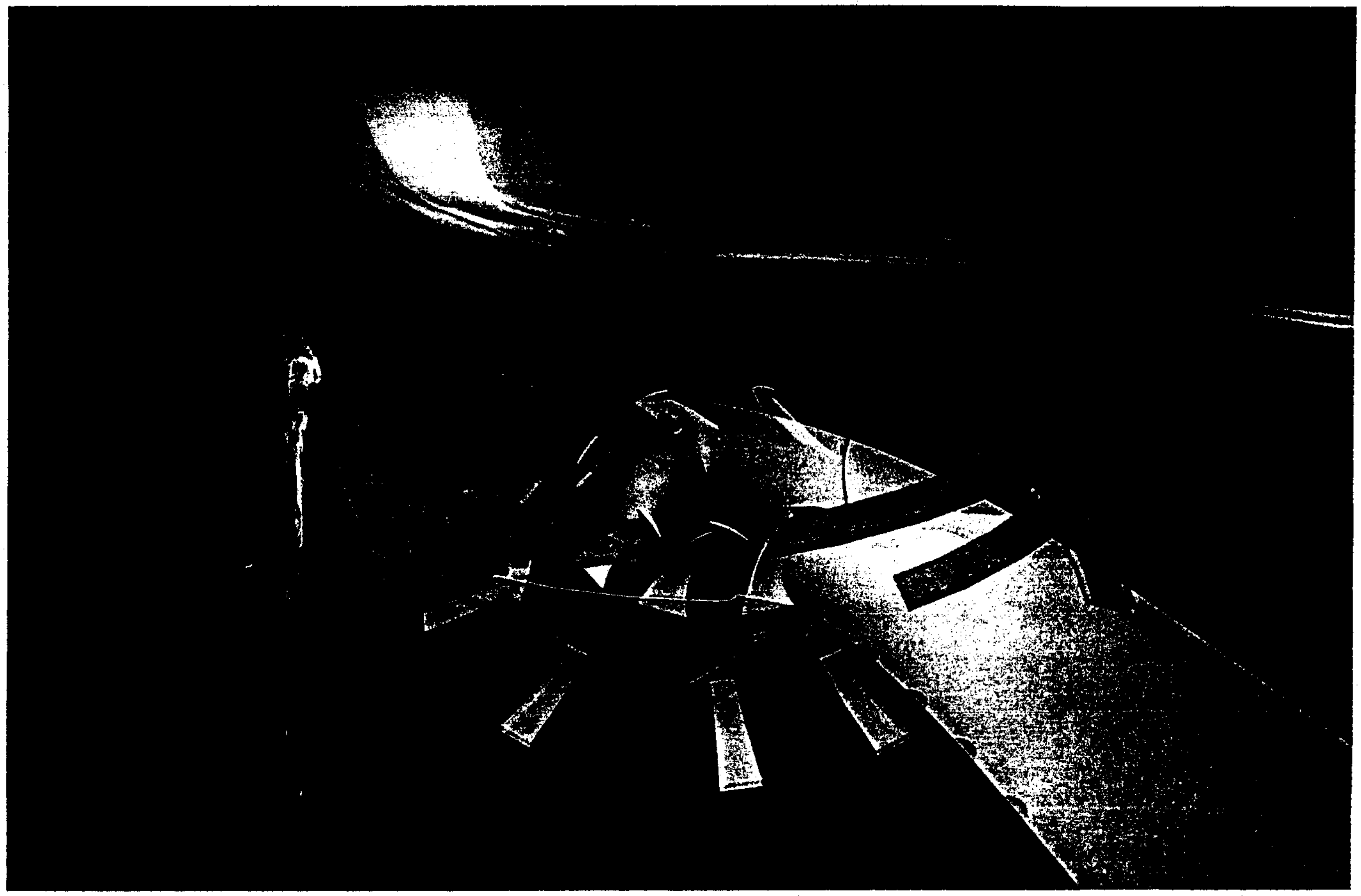


**Figure 4. Three-dimensional visualization of the wind flow around a midlatitude low-pressure area. Warm surface air flows up and over the cold front *(triangles)* and the warm front *(semicircles)*, causing clouds and precipitation to form. The polar jet stream shows how the strong winds of the jet draw mass from the low-pressure area *(at the junction of the fronts)*, intensifying the pressure depression and increasing the power of the storm. Nor'easters often form below the core of the jet's strongest winds and just downwind of the location where the jet's wave begins to turn back to the north. Because of the earth's rotation (Coriolis force) all low-pressure systems in the Northern Hemisphere are cyclonic; that is, they rotate counterclockwise.**

the development of a low-pressure system along the front.

### Climatology of Nor'easters

Unlike hurricanes, nor'easters do not necessarily form over the open ocean. In fact, many nor'easters form along baroclinic zones thousands of kilometers inland. Regions of marked temperature contrast are often to be found on the lee sides of mountain ranges and along coastlines. Over North America, preferred regions of cyclone formation are to the lee of the Rocky Mountains in Alberta and Colorado, in the Gulf of Mexico and off the East Coast in the vicinity of Cape Hatteras. Low-pressure systems form in these regions because of unstable conditions (cold air overlying warm air), the presence of moist air (which is more buoyant) and proximity to baroclinic zones. If the prevailing westerly winds cause these storms to move over the Atlantic Ocean while they retain their strength, and if the jet stream is in a proper position to support cyclone intensification, then a nor'easter can develop.

Because nor'easters require support from the jet stream to form, their prevalence is closely related to seasonal changes in the position and the strength of the jet. During the Northern Hemisphere's winter, large cold-air masses form over northern polar regions and migrate southeastward. As a result, both the jet stream and the primary baroclinic zone move to the south, fronts pass more frequently throughout the middle latitudes and temperature contrasts along fronts increase. This seasonal migration of the jet stream corresponds to a more southerly storm track and the formation of more and stronger cyclonic storms. Thus a strong correspondence exists between the position of the jet stream and the number of coastal storms. The primary nor'easter season is from October through April, and February is the stormiest month.

The strength and mean position of the jet stream also vary on an annual basis. Research based on 50 years of data suggests that the annual frequency of the strongest nor'easters is positively correlated with southerly jet-stream position over the eastern United States. From the mid-1940s through the mid-1960s, about 35 nor'easters per year had at least a minor impact on the mid-Atlantic coast. From the mid-1960s through the mid-1970s, the number of coastal storms declined to about 22 per year. Since then, the yearly number of nor'easters has varied but has not consistently reached pre-1965 levels.

### From Wind to Waves

Nor'easters can generate strong wind fields, but the winds from these storms do not present the most serious hazard to coastal residents. The waves and storm surge associated with the storm cause the major damage and loss of life. All waves produced by storms at

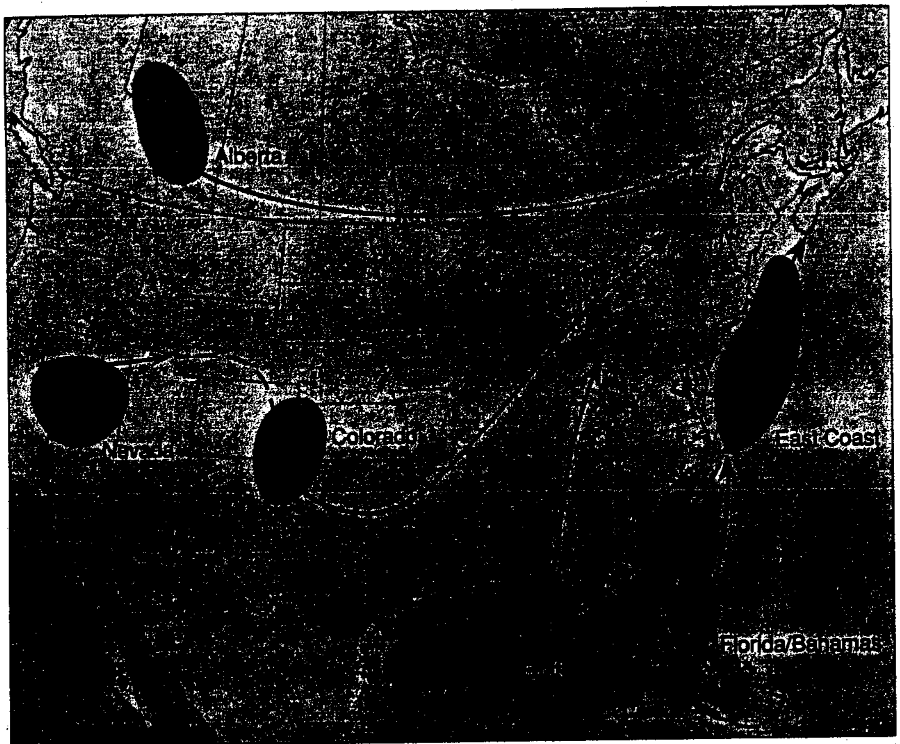


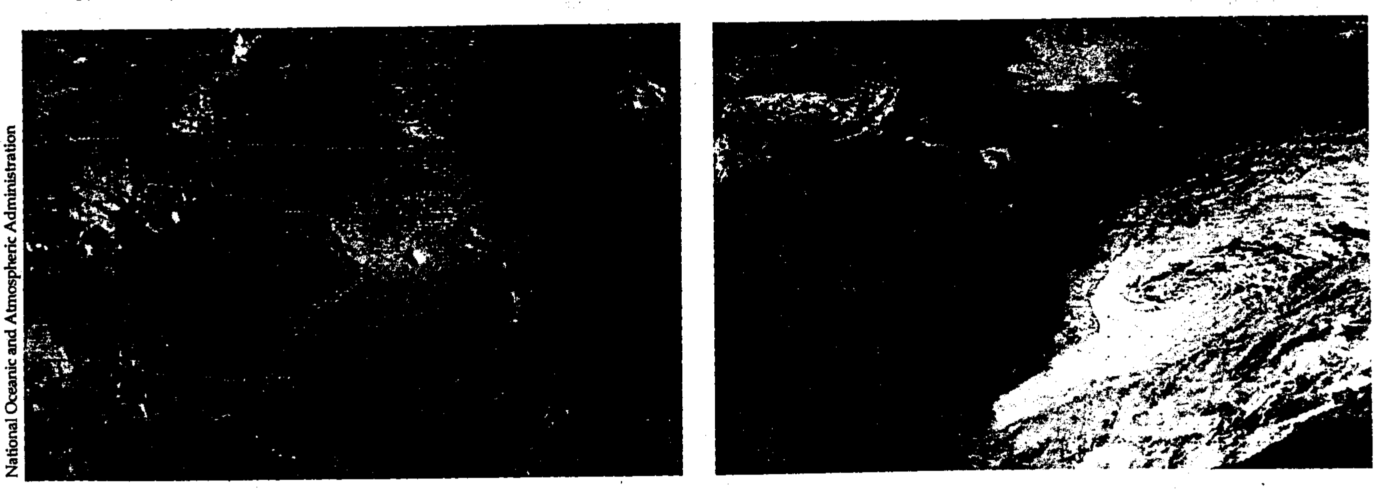

Figure 5. Unlike hurricanes, many nor'easters get their start as cyclones over land masses or along coastal margins. The primary regions for North American cyclone formation include the lee of mountain systems—in Nevada, Alberta and Colorado—and the Gulf of Mexico. Typical tracks for these cyclones, any of which can become nor'easters given favorable conditions, are shown. Other important areas for cyclone formation are off Florida or the Bahamas and off Cape Hatteras, North Carolina. Alhough less common, these cyclones produce the most powerful nor'easters.

sea end up releasing their energy in coastal zones, and that energy is surprisingly large. With waves about one meter high, the rate at which energy is expended by the waves as they break on the coast is the equivalent of 3 kilowatts per meter of shoreline. For the 400-kilometer open coast of North Carolina, this rate is roughly equal to the energy capacity of an average-size nuclear power plant. Extend this analogy to a severe nor'easter with waves higher than 5 meters, taking into consideration that the energy of waves is roughly proportional to the square of their height, and one obtains a comparative measure of the enormous power associated with these storms.

The growth of waves from the initial ripples and wavelets is governed by three factors: the wind's speed, its duration and the distance (fetch) of water surface over which it blows. With an increase in any of these factors, the height of the waves and the potential height of the storm surge increase. Ben Franklin described this process in 1774: "Air in motion, which is the wind, in passing over a surface of smooth water, may rub, as it were, upon that surface, and raise it into wrinkles, which, if the wind continues, are the elements of future waves." In other words, frictional stress develops along the boundary between the atmosphere and the ocean surface when the two fluids move at different speeds; thus there is a transfer of energy from the one moving faster (the air) to the one moving slower (the water). Wave-hindcasting methods, which we discuss in the next section, and predictions of storm-surge heights were developed by the extension of the basic physics Franklin described.

Nor'easters commonly produce wave heights of 1.5 to 10 meters. These waves can be very destructive to coastlines, but their effect is much stronger when accompanied by high storm surge.

Storm surge is a combined result of the shoreward transport of water from wind stress and a rise in the water's surface level caused by the storm's low air pressure. (Surface air pressure is actually a measure of the mass of air bearing down according to the force of gravity; therefore an area of lower surface air pressure has less atmosphere above it, permitting the water surface to rise.) Because there is a close relationship between water depth and the height of waves in shallow water, any



National Oceanic and Atmospheric Administration

Figure 6. Satellite images at visible wavelengths show significant differences between a hurricane *(left)* and a nor'easter *(right)*. The hurricane, Category 4 (severe) Diana of 1984, has a distinct, calm eye and extends over only a few hundred kilometers. (Hurricanes are classified in five categories by wind speed, Category 5 being the strongest.) The nor'easter, a Class V (extreme) storm photographed on October 24, 1982, has no central eye, and its cloud cover extends over most of the East Coast of the United States.

**Figure 7. Waves from nor'easters often breach coastal islands, washing away roadways and buildings. Here waves at the peak of the Halloween 1991 storm break on Pea Island, North Carolina. (Photograph by Carl Miller, U.S. Army Corps of Engineers.)**

increase in water depth at the coast contributes to conditions that permit higher wave action closer to the shoreline, thus increasing the potential for damage.

In quantitative terms, storm surge is the difference between the observed and the predicted water levels (tides) during the passage of a coastal storm. The most severe nor'easters can generate storm surges up to 5 meters high on open coasts. It should be noted that surges from severe nor'easters are sometimes especially destructive because they can span several tidal cycles (days).

### Hindcasting Waves

Because of their diffuse structure, nor'easters are difficult to characterize, categorize and predict. The wind speed of a nor'easter, for example, may or may not be related to the storm's wave height. A weak storm system that has stalled for several days with winds traversing a long fetch can produce much higher waves than a very strong, fast-moving storm with a wind direction that is constantly changing, resulting in a short fetch. Furthermore, the position of the storm's center is often not significant. Storms as far as 1,000 kilometers from the coast can result in high coastal waves given the appropriate wind-field orientation.

The key to determining the impact of nor'easters lies in studying how weather effects influence the waves produced by these storms, rather than solely what the storm's pressure or wind speed might be. However, wave records are discontinuous over both time and space and are not readily available for many locations for more than the past 10 or 15 years. Fortunately, it is possible, based on surface-pressure and wind-field records from the National Weather Service, to determine with fairly high accuracy past deep-water wave heights at

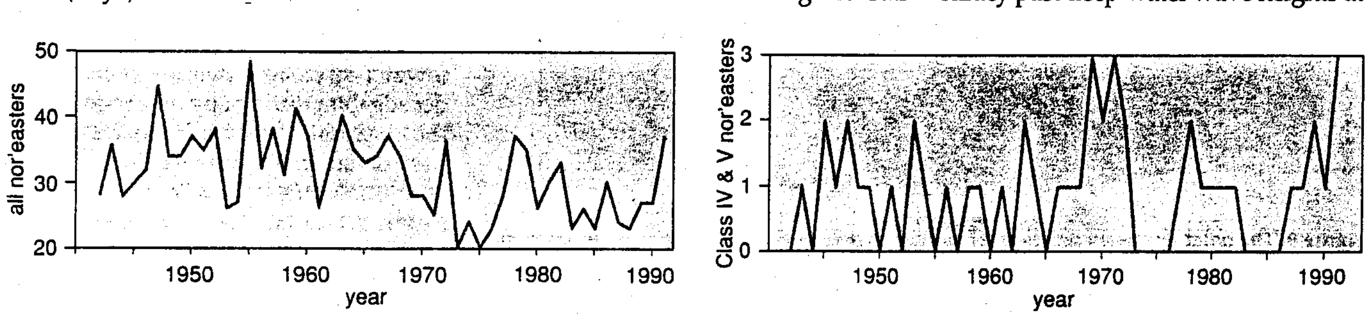



**Figure 8. Prevalence of all nor'easters declined about 22 percent from 1942 to the mid-1960s. Since then, prevalence has been erratic but has not reached pre-1965 levels *(left)*. The prevalence of the most powerful nor'easters, however, has been erratic but has increased overall. Seven of the eight extreme storms that have developed in the past 50 years have struck in the past 25 years *(right)*.**

any selected point along the coast. This procedure, referred to as wave hindcasting, is based on the physical relationships between surface wind stress and wave formation. Input variables include the duration of the storm, the length of the fetch and the surface wind speed and direction over the fetch region. Given the scarcity of wave data from buoys, hindcasting is the only means of obtaining regional-scale wave climatic data on storms.

Because of our interest in the geomorphology of mid-Atlantic barrier-island systems and the impact of winter storms, we have developed a nor'easter climatology for a representative location on the mid-Atlantic coast: Cape Hatteras, North Carolina. For each nor'easter from July 1942 through June 1992, the duration and maximum-significant-wave height (the average of the highest one-third of the waves) of each storm have been determined at Cape Hatteras. In our data set, only storms producing at least 1.5-meter-deep waves are included, since smaller waves have been determined to have little if any impact on mid-Atlantic barrier islands. This is, to the best of our knowledge, the most-complete extratropical-storm wave climatology that exists. Although this climatology was developed for Cape Hatteras, the results apply over much of the mid-Atlantic coastline, especially for the larger nor'easters.

## Dolan-Davis Nor'easter Scale

The lack of a direct relationship between a nor'easter's wind speed and its destructive power has also made classification and comparison of these storms difficult. Long-time coastal residents have had to rely on subjective judgments, usually based on local impacts, to assess the intensity of nor'easters. This approach is problematic because localized factors, such as the near-shore bottom profile and the degree of coastal development, make it difficult to find an appropriate baseline for comparison. Using wave hindcasting to analyze previous storms, however, we can make these comparisons in a more quantitative manner.

Using wave data, we have developed a five-group classification for nor'easters that is analogous to the Saffir-Simpson wind-speed-based system for classifying hurricanes. Specifically, for each storm from 1942 through 1984, a wave "power index" was calculated by multiplying the storm's duration by the square of the maximum significant wave height. The storms were then classified into five categories, from the very common Class I (weak) nor'easters to the very rare Class V (extreme) nor'easters. This data set was recently updated to include all storms through June 1992. Analysis of these data has revealed a number of surprising characteristics of different classes of nor'easters.

The different classes of nor'easters are not distributed throughout the nor'easter season in a uniform fashion. The weaker storms—Classes I, II and III—mirror the seasonality discussed previously. They are most common from December through April, peak in frequency in January or February and rarely arise between June and August. The Class IV and V nor'easters, however, are most prevalent in October, January and March. Of the 47 Class IV and V storms in the database, 53 percent took place within these three months.

The overall frequency of nor'easters—and particularly of different classes of nor'easters—has also changed significantly over the years. We have seen fewer nor'easters overall in the past decade than during any other decade in the past half-century. Yet each of the past six storm seasons has included at least one Class IV or Class V storm, a situation that has been duplicated only once in the past 50 years. Of the eight Class V storms in the data set, seven have taken place since 1960.

One possible cause for the prevalence of major nor'easters in recent years is an atmospheric circulation pat-

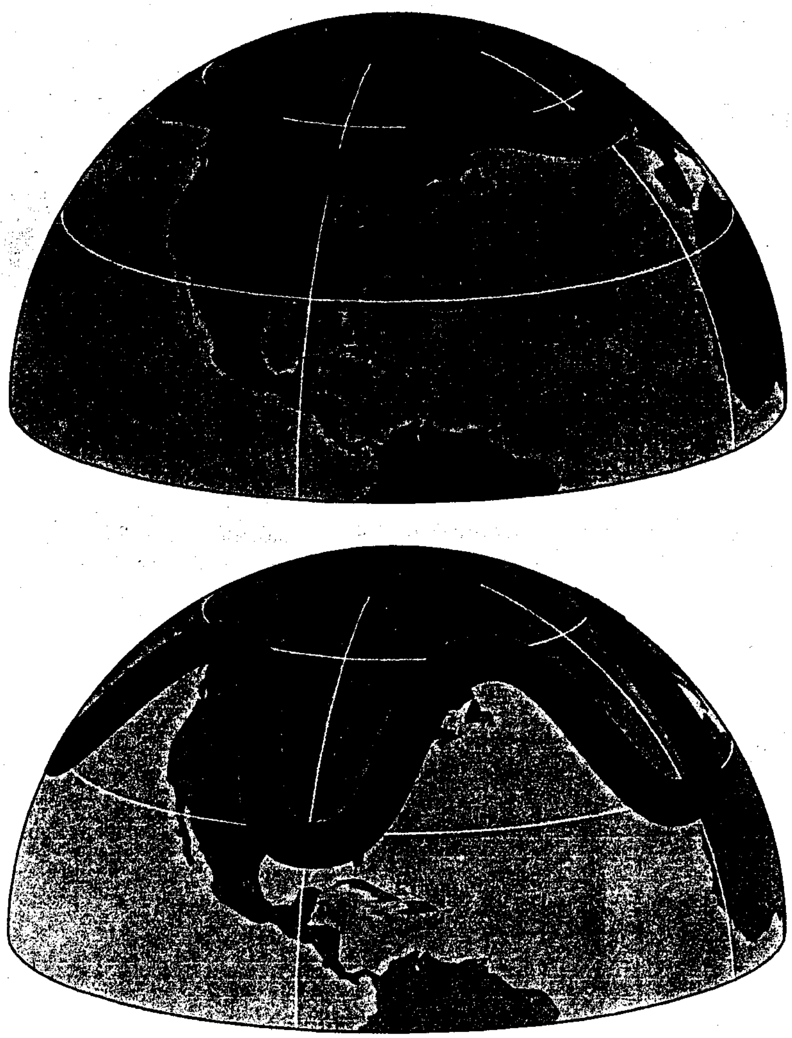


**Figure 9. The polar jet stream serves as a boundary between colder polar air and warmer subtropical air. During summer months, the jet is restricted to relatively high latitudes *(top)* as are the associated surface cyclones. In winter, however, the jet moves farther south and sometimes adopts a more meridional flow *(bottom)*. This pattern favors the formation of strong nor'easters on the downwind side of the jet's trough, off the East Coast of the United States. Evidence indicates that the jet stream has followed a more meridional path since 1965, during which time powerful nor'easters have been especially common.**

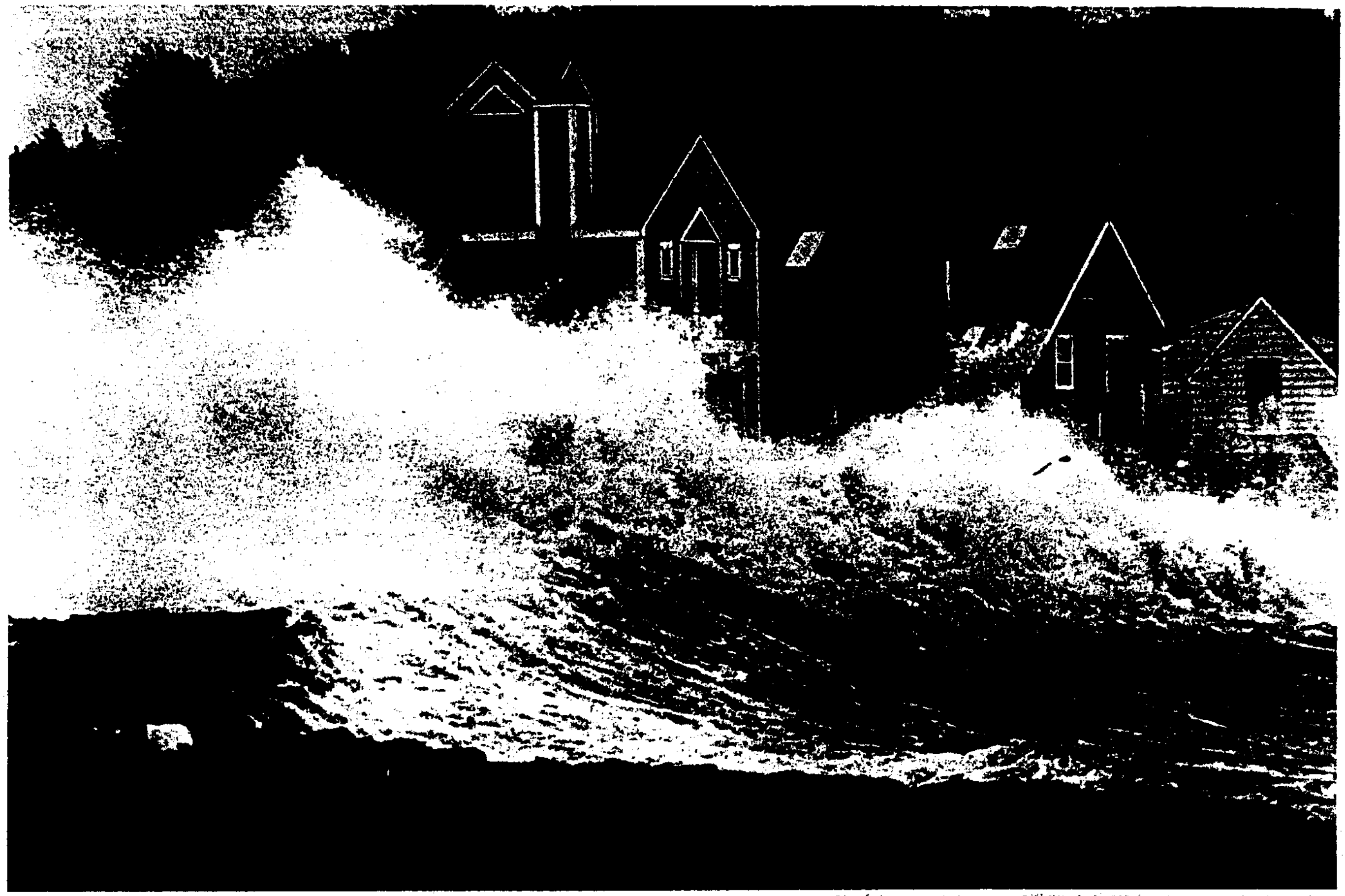


**Figure 10. Wave damage from the Halloween 1991 storm was extensive along the New England coast—here shown at Nantasket Beach, Hull, Massachusetts—although the storm's effects stretched 3,500 kilometers from Newfoundland to Miami. (Photograph by the Boston Globe.)**

tern conducive to the formation of polar-air masses over the Canadian prairies or the Arctic and the movement of these cold-air masses toward the southeast U. S. Large-amplitude north-south waves in the jet stream, where the flow more closely follows the meridians, bring polar air southward to the coastline, where an especially large temperature gradient forms between the colder land and the warmer ocean water—an effect that is enhanced near the Gulf Stream. The resulting baroclinic zone becomes a favorable region for coastal-storm development, especially for storms that form near Cape Hatteras and the Florida coast—some of the most destructive storms.

Current research indicates that meridional flow and the frequency of polar outbreaks over the eastern United States have increased in recent years, as have the number of citrus freezes in Florida. An abrupt shift in January circulation regimes was detected around 1965. Prior to 1965, zonal (west-to-east) flow predominated, whereas afterward the flow pattern became more meridional. Based on January nor'easters only, there is a significant difference in the mean Dolan-Davis storm intensity class between these two periods.

## Characteristic Tracks

Because cyclones form in a variety of regions and have different characteristic strengths, speeds and tracks as they move over the open ocean, we have also

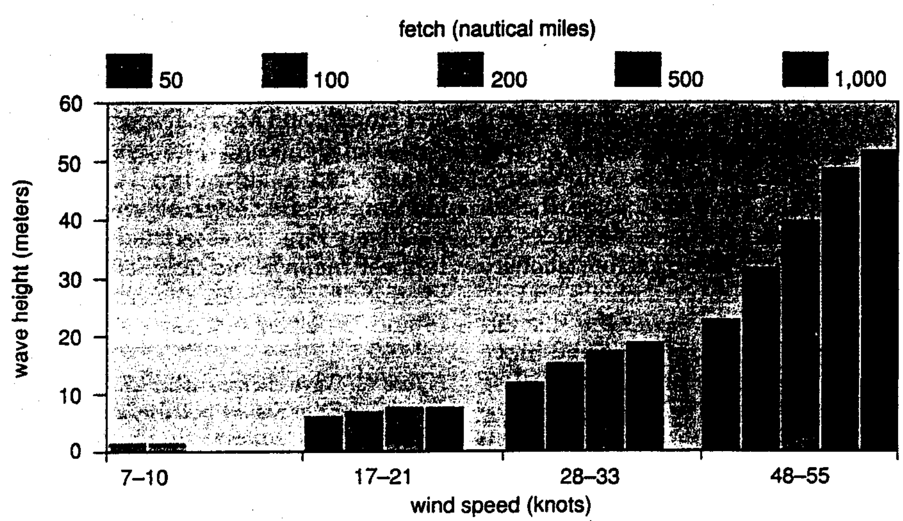



**Figure 11. Theoretical wave height is a function both of wind speed and of fetch, the distance wind blows from the same direction. Because the amount of energy transferred from fast-moving air to slower-moving water is controlled by the speed of the wind and the length of time the wind is in contact with the water, wind speed alone may not be a sufficient measure of a nor'easter's power. A long-lasting storm with moderate winds over a long fetch from a constant direction may generate waves as high as a short-lived storm with strong winds and a short fetch.**

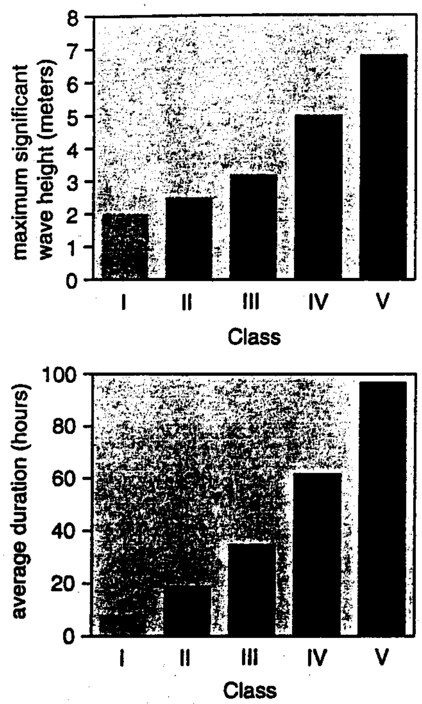



**Figure 12. Maximum significant wave heights (an average of the highest one-third of the waves) for all the storms in the authors' data set were calculated using wave hindcasting methods *(top)*. Durations were determined from weather records *(bottom)*. Because duration and wave height are related, storms were grouped into five classes based on their wave heights and durations.**

developed a classification system of nor'easters based on their genesis. Eight types of nor'easter have been identified.

Bahamas lows form in the open ocean near the Bahamas or north of Cuba and travel northward. Florida lows form over the Florida peninsula or near the coast and travel northward parallel to the East Coast. Gulf lows develop over the Gulf of Mexico, traverse the southeastern United States, intensify as they move over the Gulf Stream and continue moving quickly toward the northeast. Coastal-plains cyclogenesis includes cyclones that form along cold or stationary fronts east of the Appalachians and intensify as they move over the Atlantic. These storms are fairly rare and move quickly toward the east and northeast; thus they have little coastal impact.

Hatteras lows are secondary storm systems that form over the East Coast cyclogenetic region in the vicinity of Cape Hatteras. These systems often develop fairly quickly and travel northeastward along the coast. Many of the great East Coast snowstorms originated in this region. Continental lows are large, well-developed storm systems that typically form in Colorado and track through the Midwest and into the Ohio or the St. Lawrence river valleys. After the low moves over the Atlantic, the northerly winds behind the cold front can produce high waves, although the system must stall for high seas to develop along the mid-Atlantic coast. Coastal-front lows typically are weak systems that form along a stationary front oriented parallel to the East Coast.

Finally, anticyclones are high-pressure systems that have wind fields strong enough to produce high waves. Although not considered to be storms in the traditional sense, these high-pressure systems often move slowly enough to allow significant waves to develop. Thus they are sometimes called "dry nor'easters." Because the wind circulation around anticyclones is clockwise over the Northern Hemisphere, the center of the high may be over land when the waves are highest.

Seasonal analysis shows a clear predominance of certain storm tracks during specific months. Nor'easters are most prevalent from January through March, primarily because of Hatteras and Gulf lows. Winter is a preferred time for stationary fronts in the Gulf of Mexico, where cyclones frequently form and travel northeastward. The formation of Hatteras lows is encouraged not only by the southerly position of the jet stream but also by the presence of polar outbreaks. As a cold-air mass reaches the coastal margin, the temperature contrast between the ocean (especially the warm waters of the Gulf Stream) and the air mass results in the formation of a strong baroclinic zone. Bahamas lows and Florida lows are most common in October, and January and March, respectively.

Wave heights and durations are also closely tied to storm type. Bahamas lows and Florida lows, although comparatively rare, are associated with the highest mean wave heights and the longest durations—61 percent of Class IV and 75 percent of Class V storms are

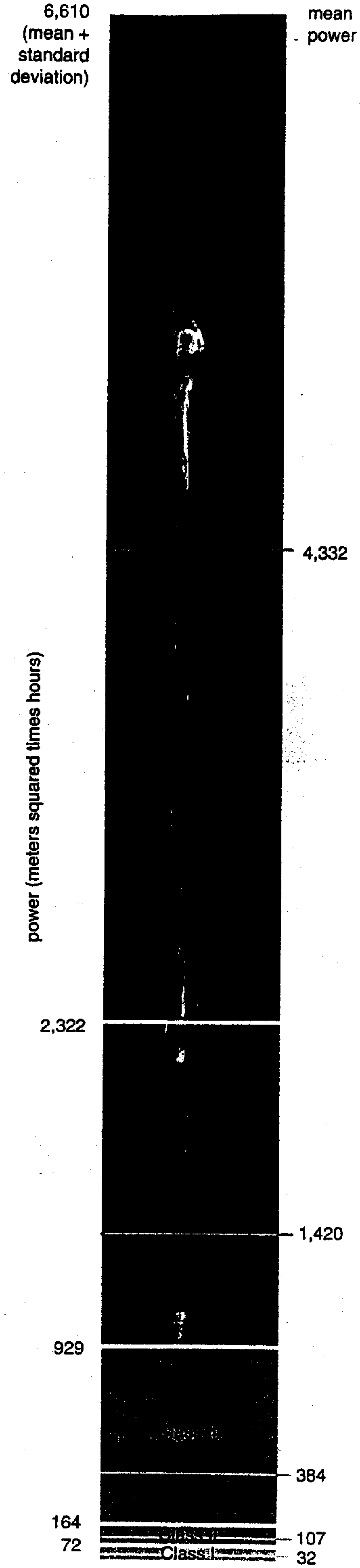



**Figure 13. Wave characteristics are preferred for ranking nor'easters because, as opposed to the case with hurricanes, wind speed alone is not sufficient to estimate their destructive potential. A wave-power index was calculated for each storm in the data set by multiplying the square of the maximum significant wave height in meters by the duration in hours. The storms were then divided into five classes. Although Class I storms are by far the most common, Class V storms are more powerful by several orders of magnitude.**

one of these two types. Because the principal ingredients necessary for the development of large waves are strong winds over the same long fetch for a substantial length of time, stalled or slow-moving storm systems tend to develop the most potent nor'easters.

One common characteristic of major extratropical coastal storms is the presence of a large, stationary high-pressure system over northeastern North American or the northwestern Atlantic. This blocks the progress of the cyclone as it moves to the north or northwest and enhances the wind speeds, as air attempts to move from the high-pressure zone to the low in response to the strong pressure gradient.

The famous Ash Wednesday storm provides a good example of this situation. The center of the storm remained nearly stationary for three days off the mid-Atlantic coast, because its northward progress was blocked by a strong anticyclone over southeastern Canada. The large gradient in pressure between the low and the high produced sustained 20- to 35-meter-per-second (45- to 78-mile-per-hour) winds over the open ocean, and the resulting waves caused unprecedented coastal erosion and structural damage.

The seasonality in the prevalence of severe and extreme nor'easters corresponds not only with the pattern of Bahamas and Florida lows but also with certain climatological aspects of North American atmospheric circulation. Bahamas lows, which are prevalent in October, coincide with frequent highs to the north that create blocking patterns. Similarly, Florida lows are most common in March, when blocking highs become common over the Atlantic. Thus, although strong nor'easters can be generated any time from October through April, they are somewhat more likely near the beginning and the end of the nor'easter season.

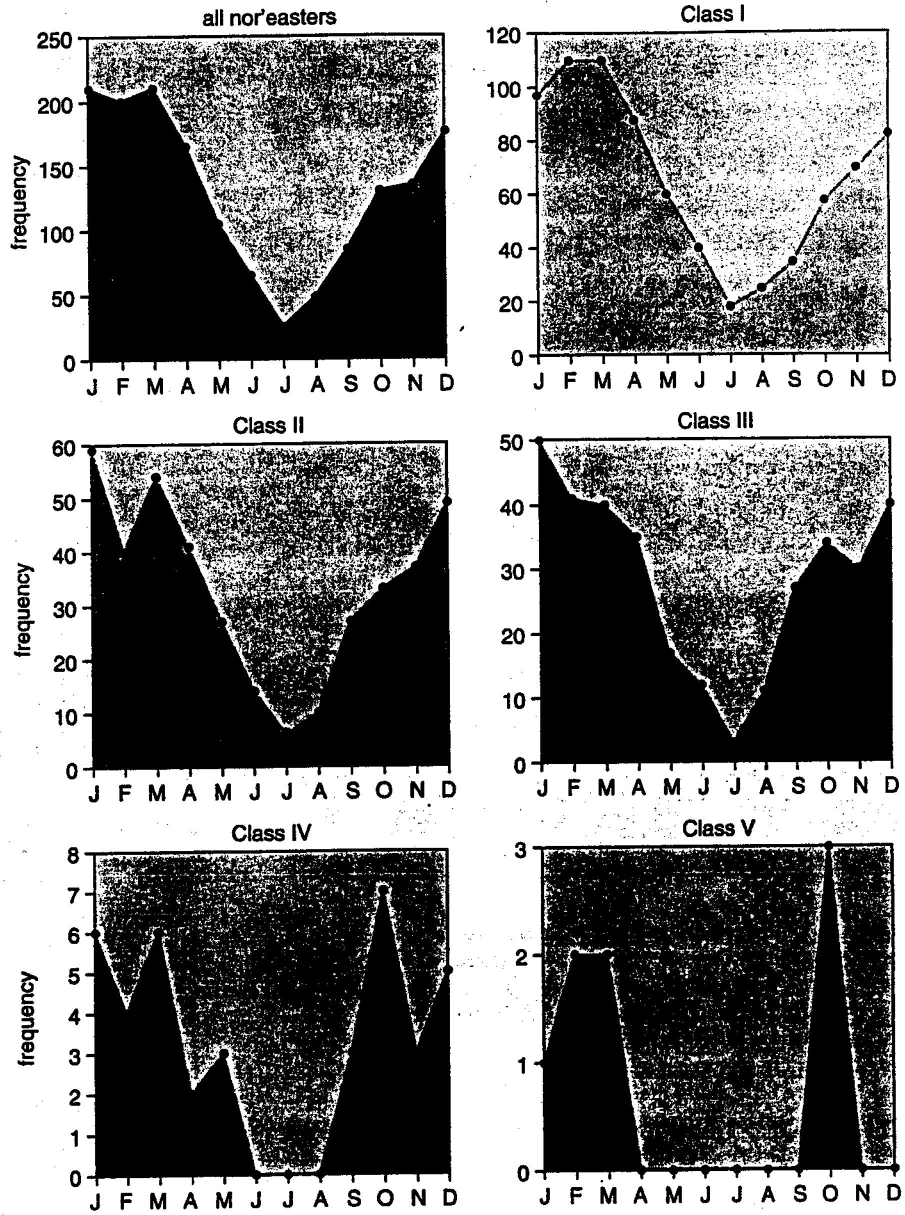



**Figure 14. Seasonality of nor'easters in the data set is not consistent throughout the classes. Less powerful storms—Classes I, II and III—make up the bulk of nor'easters and therefore control the overall seasonal distribution. These storms are most common in January, February and March. Class IV and V nor'easters account for fewer than 50 storms in the past 50 years, but they do not follow the pattern of other storms. These powerful storms are more common toward the beginning and end of the nor'easter season, in October and March.**

## Impacts

Because the characteristics of nor'easters differ considerably from those of hurricanes, the impacts of the two storm types cannot be directly compared. The local effects of a hurricane on the coast and the people living there can be great, but the likelihood of a hurricane striking a specific coastal location is relatively small. Nor'easters, on the other hand, affect much larger areas and are much more frequent, so their total destructive potential may exceed that of hurricanes. It also should be noted that when hurricane damage is assessed, much of the total impact is well inland from the coastal zone, whereas for nor'easters, the impact zone is usually concentrated along the coast.

We recently completed a preliminary assessment of the relationship between the wave and storm-surge heights associated with each class of nor'easter and the expected coastal response in terms of erosion, overwash and damage. The impact of a given storm depends, to a degree, on the physical characteristics of the coastal area involved. Areas with low relief, for example, overwash often, and other areas may have high erosion rates owing to factors other than storms, such as currents or lack of sedimentation. Thus the damage table was formulated based on direct experience along the mid-Atlantic coast. We are currently working to confirm these relationships and have only preliminary results available at this time. Bearing that in mind, a relative-damage index based on historic property losses within the mid-Atlantic region makes it appear that Class V nor'easters cause at least 10 times more damage than Class II storms.

The Ash Wednesday Storm of 1962 and the Halloween Storm of 1991 are

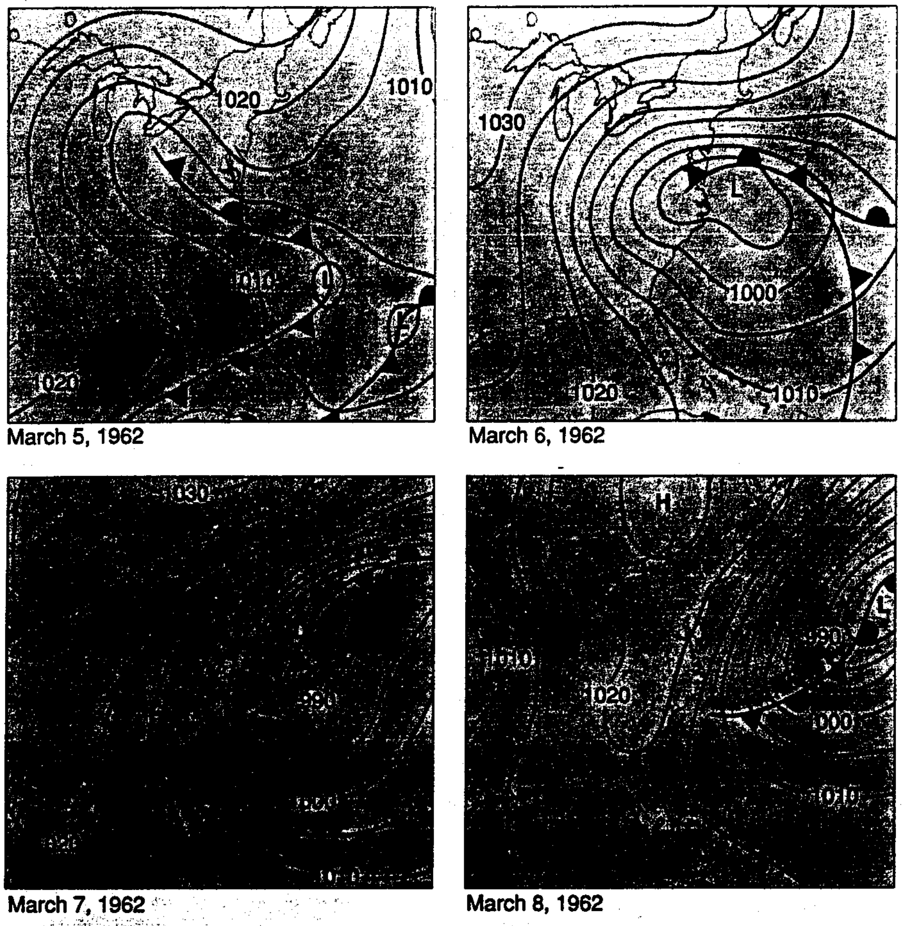



**Figure 15. High-pressure areas over eastern North America or the western North Atlantic are common accompaniments to especially destructive nor'easters. A high-pressure system can prevent a nor'easter from moving to the north, and the movement of air from high pressure to low pressure can feed its winds. The Ash Wednesday 1962 storm is a good example of a nor'easter whose effects were increased by being stalled by a high-pressure system over eastern Canada. On four consecutive days (March 5 through March 8) the storm center (*L*) can be seen to move little along the coast—creating a long fetch—and the air-pressure isobars (millibars at the surface) become closer together as the storm intensifies.**

examples of Class V nor'easters. The 1962 storm resulted in the formation of dozens of new tidal inlets, extensive island overwash, beach and dune erosion and major property losses. The Halloween Storm was one of the most severe Atlantic coast storms of the past 50 years. Hindcast results indicate 10.7-meter deep-water waves, and, at 114 hours duration, it was one of the longest nor'easters on record. The Halloween Storm generated unusually long wave periods for a nor'easter—ranging from 10 to 18 seconds from crest to crest. The typical wave period for nor'easters is from 6 to 10 seconds, and thus this storm's waves traveled faster, were more energetic and more easily moved sediment along the bottom in deeper water. The storm's destructive zone extended from Miami to Maine, but the hardest-hit areas were in New England, including $1.5 million in damage to President Bush's home in Kennebunkport, Maine.

Furthermore, a storm's coincidence with the annual and monthly tidal cycles can be crucial to its potential damage index. The Ash Wednesday storm struck during the perigean (when the moon is closest to earth) spring tides, and its duration spanned five tidal cycles. These high tides reduce wave attenuation in the normal shallow-water zone, increasing potential damage. In terms of damage potential, therefore, a Class IV nor'easter of long duration under certain oceanographic conditions can produce an impact equal to that of a Class V storm.

## The Future

As the population density along the Atlantic Coast continues to increase, nor'easters will have an even greater impact upon the lives and livelihoods of coastal residents. At present, long-range forecasting of nor'easters is difficult because of the lack of sufficient ocean-based observations and the difficulties in accounting for oceanic-moisture and heat fluxes in weather-forecasting models. Improvements in short- and medium-range forecasts have been made in the past decade. But current models often develop errors in predicting the intensity and position of coastal storms—errors that can strongly influence the predicted location and intensity of large waves and storm surges. Additionally, in many cases the highest waves develop at the coast when the storm is well offshore

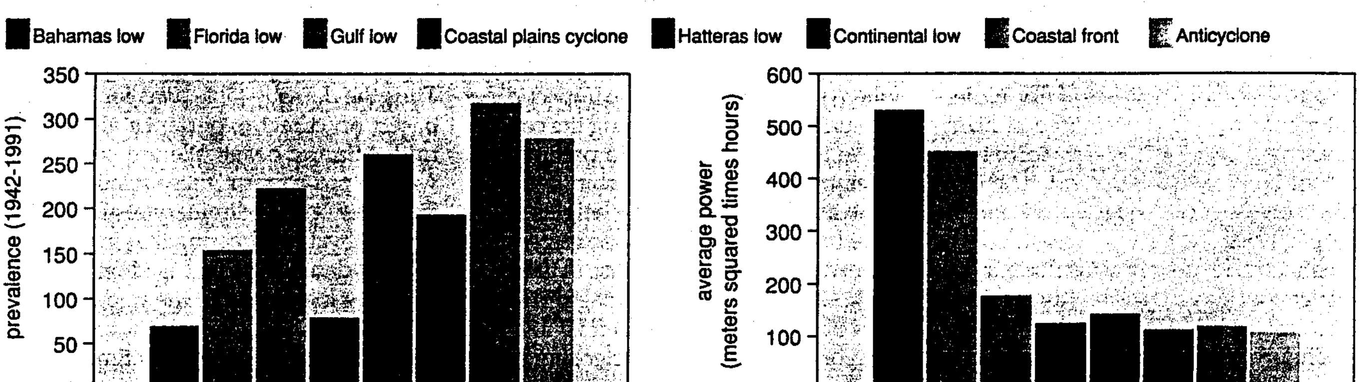



**Figure 16. When all nor'easters taking place from 1942 through 1991 are categorized according to their place of genesis, significant differences appear. Bahamas and Florida lows are far less frequent than the Gulf, Coastal and Continental lows *(left)*, but their power *(right)* is significantly greater.**

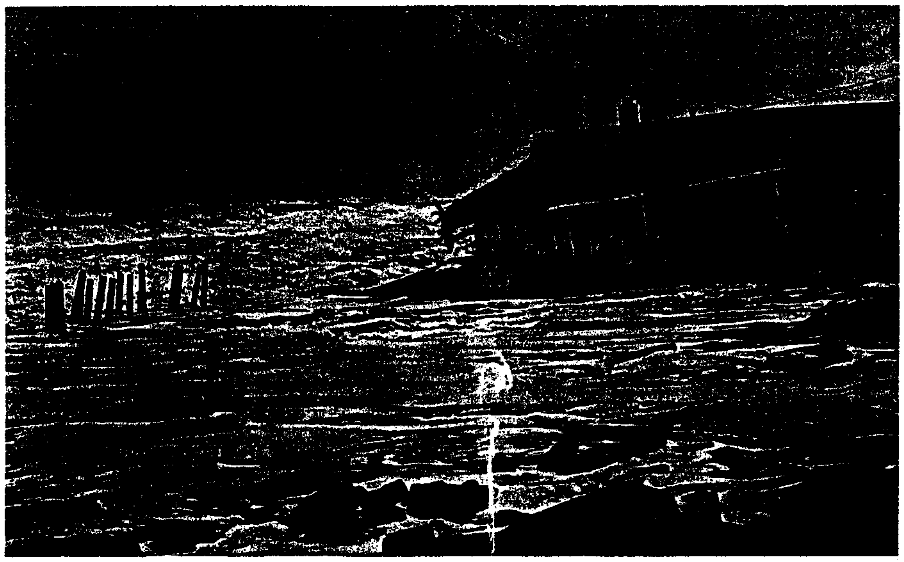


**Figure 17. The Lincoln's Birthday storm of 1972 caused extensive losses to structures along Cape Hatteras, North Carolina. High storm surges may bring large waves well up the beach, in some cases entirely overwashing barrier islands. (Photograph by Robert Dolan.)**

| storm class | beach erosion | dune erosion | overwash | property damage |
|---|---|---|---|---|
| I (weak) | minor | none | none | none |
| II (moderate) | moderate | minor | none | none |
| III (significant) | extending across beach | significant | none | moderate |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

**Figure 18. Hypothesized relationships between storm class and coastal damage are based on experience along the Outer Banks of North Carolina. Actual damage is influenced by numerous local factors such as ocean-bottom profile, the shoreline's orientation to the open ocean, tides, the presence of dunes and the degree of coastal development.**

and the precipitation and cloud cover have already passed. Thus it would be necessary for forecasters to track a storm carefully, even if the associated weather was no longer directly affecting the United States.

Another approach that would offer at least some advanced warning of a developing nor'easter would be to monitor the storm's effects and update its classification regularly. As more wave gauges are placed in continuous operation, it may become possible to alert coastal residents of impending high waves on a near-real-time basis using a nor'easter-classification system. The Dolan-Davis classification system is based on wave hindcasts rather than real-time observations and is specifically intended for storm assessment and comparison rather than for providing watches or warnings of forthcoming cyclones. However, given real-time wave-height observations, it would be simple to update the nor'easter class as storm intensities and waves continue to grow. Even short advanced warning could do much to reduce damage and loss of life from nor'easters.

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